HANDBOOK

Telephone *and* Telegraph Engineers' Handbook

A CONVENIENT REFERENCE BOOK
For All Persons Interested In

Telephone and Telegraph Systems, Location of Faults, Electricity, Magnetism, Electrical Measurements, and Batteries

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BY

International Correspondence Schools
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PREFACE

The publishers have not attempted in this work to produce a condensed cyclopedia covering the subjects of telephony and telegraphy, but they have aimed to present to the public a handy reference book that is convenient to carry in the pocket and containing the rules, formulas, tables, and circuits that are most generally used and needed by linemen, wiremen, "troublemen," operators, foremen of construction, manufacturers of and dealers in telephone and telegraph apparatus and supplies, wire-chiefs, managers, and superintendents of telephone and telegraph companies.

The aim of the publishers has been to select from the vast amount of material at hand only that portion which is most likely to be used in connection with the daily work or which will be most frequently consulted. While the treatment of some subjects is of necessity brief, it is sufficient for the purpose. More important subjects have been covered in great detail; for instance, the treatment of electrical measurements and of the location of faults in line wires is very thorough and complete—more so, in fact, than in most textbooks. The tables selected are those most in demand, and the applications of the rules and formulas are shown, whenever possible, by practical examples and solutions, together with explanations. Special attention is called to the diagrams of circuits for representative magneto and central-energy systems; these have been fully explained. A very complete set of connections for the various wall and desk telephones has been given and also for intercommunicating systems suitable for private and apartment houses, factories, public buildings, and hotels. Descriptions of wireless telephone and telegraph systems and of methods for transmitting simultaneously telephone and telegraph messages over the same line wire are included.

This handbook was prepared under the supervision of Henry S. Webb, Principal of our School of Telephony and Telegraphy.

INTERNATIONAL CORRESPONDENCE SCHOOLS
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Telephone and Telegraph Engineers' Handbook

USEFUL TABLES

WEIGHTS AND MEASURES

LINEAR MEASURE

12	inches (in.)	= 1 foot	ft.
3	feet	= 1 yard	yd.
5½	yards	= 1 rod	rd.
40	rods	= 1 furlong	fur.
8	furlongs	= 1 mile	mi.

in.	*ft.*	*yd.*	*rd.*	*fur.*	*mi.*
36 =	3 =	1			
198 =	16.5 =	5.5 =	1		
7,920 =	660 =	220 =	40 =	1	
63,360 =	5,280 =	1,760 =	320 =	8 =	1

SQUARE MEASURE

144	square inches (sq. in.)	= 1 square foot	sq. ft.
9	square feet	= 1 square yard	sq. yd.
30¼	square yards	= 1 square rod	sq. rd.
160	square rods	= 1 acre	A.
640	acres	= 1 square mile	sq. mi.

sq. mi.	*A.*	*sq. rd.*	*sq. yd.*	*sq. ft.*	*sq. in.*
1 =	640 =	102,400 =	3,097,600 =	27,878,400 =	4,014,489,600

CUBIC MEASURE

1,728 cubic inches (cu. in.)	= 1 cubic foot	cu. ft.
27 cubic feet	= 1 cubic yard	cu. yd.
128 cubic feet	= 1 cord	cd.
24$\frac{3}{4}$ cubic feet	= 1 perch	P.

1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

MEASURE OF ANGLES OR ARCS

60 seconds (″)	= 1 minute	′
60 minutes	= 1 degree	°
90 degrees	= 1 rt. angle or quadrant	∟
360 degrees	= 1 circle	cir.

1 cir. = 360° = 21,600′ = 1,296,000″

AVOIRDUPOIS WEIGHT

437.5 grains (gr.)	= 1 ounce	oz.
16 ounces	= 1 pound	lb.
100 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,000 lb.	= 1 ton	T.
2,240 lb.	= 1 long ton	L. T.

1 T. = 20 cwt. = 2,000 lb. = 32,000 oz. = 14,000,000 gr.

The avoirdupois pound contains 7,000 gr.

TROY WEIGHT

24 grains (gr.)	= 1 pennyweight	pwt.
20 pennyweights	= 1 ounce	oz.
12 ounces	= 1 pound	lb.

1 lb. = 12 oz. = 240 pwt. = 5,760 gr.

DRY MEASURE

2 pints (pt.)	= 1 quart	qt.
8 quarts	= 1 peck	pk.
4 pecks	= 1 bushel	bu.

1 bu. = 4 pk. = 32 qt. = 64 pt.

The U. S. bushel contains 2,150.42 cu. in. = approximately 1$\frac{1}{4}$ cu. ft. The British bushel contains 2,218.19 cu. in.

LIQUID MEASURE

4 gills (gi.)	= 1 pint	pt.
2 pints	= 1 quart	qt.
4 quarts	= 1 gallon	gal.
31½ gallons	= 1 barrel	bbl.
2 barrels, or 63 gallons	= 1 hogshead	hhd.

1 hhd. = 2 bbl. = 63 gal. = 252 qt. = 504 pt. = 2,016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft., nearly, or 1 cu. ft. contains 7.481 gal.

When water is at its maximum density, 1 cu. ft. weighs 62.425 lb. and 1 gallon weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to 7½ gal., and 1 gal. as weighing 8⅓ lb.

THE METRIC SYSTEM

The metric system is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 in. The value commonly used is 39.37 in. and is authorized by the U. S. government.

There are three principal units—the *meter*, the *liter* (pronounced "lee-ter"), and the *gram*, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words *deca* (10), *hecto* (100), and *kilo* (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words *deci* ($\frac{1}{10}$), *centi* ($\frac{1}{100}$), and *milli* ($\frac{1}{1000}$). These prefixes form the key to the entire system. The abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter.

MEASURES OF LENGTH

10 millimeters (mm.)	= 1 centimeter	cm.
10 centimeters	= 1 decimeter	dm.
10 decimeters	= 1 meter	m.
10 meters	= 1 decameter	Dm.
10 decameters	= 1 hectometer	Hm.
10 hectometers	= 1 kilometer	Km.

MEASURES OF SURFACE (NOT LAND)

100 square millimeters (sq. mm.)	= 1 square centimeter	sq. cm.
100 square centimeters	= 1 square decimeter	sq. dm.
100 square decimeters	= 1 square meter	sq. m.

MEASURES OF VOLUME

1,000 cubic millimeters (cu. mm.)	= 1 cubic centimeter	cu. cm.
1,000 cubic centimeters	= 1 cubic decimeter	cu. dm.
1,000 cubic decimeters	= 1 cubic meter	cu. m.

MEASURES OF CAPACITY

10 milliliters (ml.)	= 1 centiliter	cl.
10 centiliters	= 1 deciliter	dl.
10 deciliters	= 1 liter	l.
10 liters	= 1 decaliter	Dl.
10 decaliters	= 1 hectoliter	Hl.
10 hectoliters	= 1 kiloliter	Kl.

The liter is equal to the volume occupied by 1 cu. dm.

MEASURES OF WEIGHT

10 milligrams (mg.)	= 1 centigram	cg.
10 centigrams	= 1 decigram	dg.
10 decigrams	= 1 gram	g.
10 grams	= 1 decagram	Dg.
10 decagrams	= 1 hectogram	Hg.
10 hectograms	= 1 kilogram	Kg.
1,000 kilograms	= 1 ton	T.

The gram is the weight of 1 cu. cm. of pure distilled water at a temperature of 39.2° F.; the kilogram is the weight of 1 liter of water; the ton is the weight of 1 cu. m. of water.

METRIC CONVERSION FACTORS

In order to use the following factors for converting from English to metric units, it is necessary to transform the equations; for example, 1,000 Km. × .621 = 621 mi., but 1,000 mi. ÷ .621 = 1,610 Km.

Km. × .621 = mi.
Km. ÷ 1.609 = mi.
Km. × 3,281 = ft.
m. × 39.37 = in.
m. × 3.281 = ft.
m. × 1.094 = yd.
cm. × .3937 = in.
cm. ÷ 2.54 = in.
mm. × .03937 = in.
mm. ÷ 25.4 = in.
sq. Km. × 247.1 = A.
sq. m. × 10.764 = sq. ft.
sq. cm. × .155 = sq. in.
sq. cm. ÷ 6.451 = sq. in.
sq. mm. × .00155 = sq. in.
sq. mm. ÷ 645.1 = sq. in.
cu. m. × 35.315 = cu. ft.
cu. m. × 1.308 = cu. yd.
cu. m. × 264.2 = gal. (U. S.)
cu. cm. ÷ 16.383 = cu. in.
l. × 61.022 = cu. in.
l. × .2642 = gal. (U. S.)
l. ÷ 3.78 = gal. (U. S.)
l. ÷ 28.316 = cu. ft.
g. × 15.432 = gr.
g. × 981 = dynes
g. ÷ 28.35 = oz. (avoir.)
grams per sq. cm. × 14.22 = lb. per sq. in.
Kg. × 2.205 = lb.
Kg. × 35.3 = oz. (avoir.)
Kg. × 1,102.3 = tons (2,000 lb.)
Kg. per sq. cm. × 14,223 = lb. per sq. in.
Kg.-m. × 7.233 = ft.-lb.
kilowatts (k. w.) × 1.34 = H. P.
watts ÷ 746 = H. P.
watts × .7373 = ft.-lb. per sec.
Joules × .7373 = ft.-lb.
Calorie (kilogram-degree) × 3.968 = B. T. U.
Calorie (kilogram-degree) ÷ .252 = B. T. U.
Joules × .24 = gram-calories
gram-calories × 4.19 = Joules
gravity (Paris) = 981 cm. per sec. per sec.
(Degrees centigrade × 1.8) + 32° = degrees F.

WEIGHT AND SPECIFIC GRAVITY OF VARIOUS SUBSTANCES

The specific gravity of a substance is the ratio of the weight of any volume of the substance to the weight of an equal volume of some standard substance (water, in the case of solids and liquids; and air, in the case of gases).

Metals	Weight per Cu. In. Pound	Specific Gravity
Aluminum	.096	2.660
Antimony	.242	6.712
Bismuth	.352	9.746
Brass, common	.307	8.500
Copper, cast	.314	8.700
Copper, rolled	.321	8.878
Gold, pure cast	.696	19.258
Iron, cast	.260	7.207
Iron, wrought	.281	7.780
Lead, pure	.409	11.330
Mercury, at 60° F	.491	13.580
Silver, pure	.378	10.474
Steel, hard	.286	7.919
Steel, soft	.283	7.833
Tin	.256	7.351
Zinc	.260	7.101

Stones and Earth	Weight per Cu. In. Pound	Specific Gravity
Asbestos	.1110	3 to 3.2
Brick	.0723	2.000
Chalk	.1006	2.784
Clay	.0686	1.900
Coal, anthracite	.0592 .0519	1.640 1.436
Coal, bituminous	.0488	1.350
Earth, loose	.0491	1.360
Emery	.1450	4.000
Glass, flint	.1260	3.500
Granite, Quincy	.0958	2.652
Gypsum, opaque	.0783	2.168
Limestone	.0980	2.700
Marble, common	.0970	2.686
Mica	.1012	2.800
Quartz	.0961	2.660
Salt, common	.0769	2.130
Sand	.0957	2.650
Slate	.1012	2.800
Soil, common	.0717	1.984
Stone, common	.0910	2.520
Sulphur, native	.0734	2.033

Dry Woods	Weight per Cu. In. Pound	Specific Gravity
Ash	.0305	.845
Beech	.0308	.852
Cedar, American	.0203	.561
Cork	.0090	.250
Ebony, American	.0441	1.220
Elm	.0202	.560
Lignum vitæ	.0481	1.330
Mahogany, Honduras	.0202	.560
Maple	.0285	.790
Oak	.0343	.950
Pine, Southern	.0260	.720
Pine, White	.0144	.400
Poplar	.0138	.383
Spruce	.0181	.500

Liquids	Weight per Cu. In. Pound	Specific Gravity
Acid, nitric	.0440	1.217
Acid, sulphuric	.0665	1.841
Acid, muriatic, or hydrochloric	.0434	1.200
Alcohol, commercial	.0301	.833
Alcohol, pure	.0286	.792
Oil, linseed	.0340	.940
Oil, turpentine	.0314	.870
Water, distilled (62.425 lb. per cu. ft.)	.0361	1.000

Gases and Vapors	Weight per Cu. Ft. Grains	Specific Gravity
At 32° and a tension of 1 atmosphere		
Atmospheric air	565.11	1.0000
Ammonia gas	333.1	.5894
Carbonic acid	859.0	1.5201
Carbonic oxide	546.6	.9673
Hydrogen	39.1	.0692
Oxygen	624.8	1.1056
Sulphureted hydrogen	663.8	1.1747
Nitrogen	548.9	.9713
Steam at 212° F	275.8	.4880

The weight of a cubic foot of any solid or liquid is found by multiplying its specific gravity by 62.425 lb. avoir. The weight of a cubic foot of any gas at atmospheric pressure and at 32° F. is found by multiplying its specific gravity by .08073 lb. avoir.

CHEMISTRY AND ELECTROCHEMISTRY

Divisions of Matter.—Science assumes three divisions of matter—*masses*, *molecules*, and *atoms*. A **mass** is any portion of matter appreciable by the senses. A **molecule** is the smallest particle of matter into which a body can be divided; it is the smallest particle that is capable of separate existence. An **atom** is the still smaller particle produced by the division of a molecule by chemical means, and is regarded by chemists as the unit quantity of chemical combination. A molecule is a group of two or more atoms that are united by their affinity, or mutual attraction. *Elemental* molecules are formed of like atoms, *compound* molecules are formed of unlike atoms. Matter composed of elemental molecules is called *simple*, or *elementary matter;* matter composed of compound molecules is called *compound matter.*

The **atomic weight** of an element is the relative proportion, by weight, with which it enters into combinations with other elements. Hydrogen combines with other elements in the smallest proportion, by weight, of any of the elements. The weight of oxygen entering into a combination is 15.88 times the corresponding weight of hydrogen; i. e., if the atomic weight of hydrogen is 1, that of oxygen is 15.88, and if the atomic weight of oxygen is 16, that of hydrogen is about 1.008.

Valence.—Atoms unite in molecules always in certain fixed proportions. For example, 2 atoms of hydrogen, H, unite with 1 atom of oxygen, O, to form 1 molecule of water, H_2O; 1 atom of hydrogen, H, unites with 1 atom of chlorine, Cl, to form 1 molecule of hydrochloric acid, HCl. The **valence** of an element is the measure of its power to hold other elements in combination, and is stated on the basis that the valence of hydrogen is I. An element is mono-, di-, tri-, tetra-, etc.

SYMBOLS, ATOMIC WEIGHTS, ETC. FOR A NUMBER OF THE MORE COMMON ELEMENTS

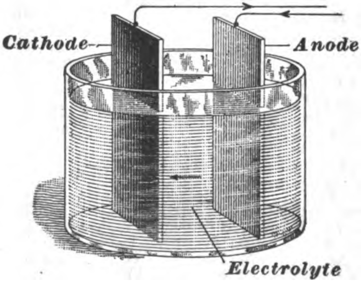
Element and Symbol	Atomic Weight	Common Valence	Chemical Equivalent
Aluminum, *Al*...	27.1	III	9.03
Antimony, *Sb*...	120.2	III–V	40.067— 24.04
Arsenic, As.	75.0	III–V	25. — 15.
Barium, *Ba*.....	137.4	II	68.7
Bismuth, *Bi*.....	208.5	III–V	69.5 — 41.7
Boron, B........	11.0	III	3.67
Bromine Br.....	79.96	I	79.96
Cadmium, *Cd* ...	112.4	II	56.2
Calcium, *Ca*.....	40.1	II	20.05
Carbon, C.......	12.0	IV	3.
Chlorine, Cl.....	35.45	I	35.45
Chromium, *Cr*...	52.1	II–VI	26.05 — 8.68
Cobalt, *Co*......	59.0	II–III	29.5 — 19.67
Copper, *Cu*......	63.6	I–II	63.6 — 31.8
Fluorine, F	19.0	I	19.
Gold, *Au*	197.2	III	65.73
Hydrogen, H	1.008	I	1.008
Iodine, I........	126.85	I	126.85
Iron, *Fe*........	55.9	II–III	27.95 — 18.63
Lead, *Pb*........	206.9	II–IV	103.45 — 51.73
Lithium, *Li*.....	7.03	I	7.03
Magnesium, *Mg*.	24.36	II	12.18
Manganese, *Mn*.	55.0	II–VII	27.5 — 7.86
Mercury, *Hg*	200.0	I–II	200.0 —100.0
Nickel, *Ni*.......	58.7	II–III	29.35 — 19.57
Nitrogen, N.....	14.04	III–V	4.68 — 2.81
Oxygen, O.......	16.0	II	8.0
Palladium, *Pd* ..	106.5	IV	26.63
Phosphorus, P...	31.0	III–V	10.33 — 6.2
Platinum, *Pt*....	194.8	IV	48.7
Potassium, *K* ..	39.15	I	39.15
Selenium Se	79.2	II	39.6
Silicon, Si.......	28.4	IV	7.1
Silver, *Ag*.......	107.93	I	107.93
Sodium, *Na*.....	23.05	I	23.05
Strontium, *Sr*...	87.6	II	43.8
Sulphur, S......	32.06	II	16.03
Tellurium, Te ..	127.6	II	63.8
Thallium, *Tl*....	204.1	I–III	204.1 — 68.03
Thorium, *Th*....	232.5	IV	58.13
Tin, *Sn*.........	119.0	II–IV	59.5 — 29.75
Tungsten, *W*....	184.0	IV–VI	46.0 — 30.67
Uranium, *U*.....	239.5	IV–VI	59.88 — 39.92
Vanadium, *V* ..	51.2	III–V	17.07 — 10.24
Zinc, *Zn*........	65.4	II	32.7

The names of non-metallic elements in the above table are printed in *Italics*. The atomic weights given are based on oxygen, O = 16.

valent according to whether its atoms hold the atoms of other elements in combination in the proportion of one, two, three, four, etc. Hydrogen is monovalent and oxygen bivalent because 1 atom of oxygen holds 2 atoms of hydrogen, as represented by the symbol H_2O. Some elements, for instance, copper, have two or more different valencies because they unite in different proportions with certain other elements to form different compounds. Thus there is cuprous chloride, $CuCl$, and cupric chloride, $CuCl_2$.

ELECTROLYTIC ACTION

A current of electricity in passing through an electrolyte decomposes it; e.g., an electrolyte consisting of zinc chloride (usually dissolved in water) is broken up into chlorine gas and metallic zinc. An electrolytic cell consists of a vessel



ELECTROLYTIC CELL

containing the electrolyte and the electrodes—the anode and the cathode; these are usually metal or carbon plates. The two parts into which the electrolyte is decomposed are called **ions**; those ions that appear at the anode are called *anions* and those at the cathode are called *cations*. In decomposing zinc chloride, zinc appears at the cathode and is thus a cation, and chlorine gas appears at the anode as an anion.

CHEMICAL AND ELECTROCHEMICAL EQUIVALENTS

BASED ON ATOMIC WEIGHT OF OXYGEN = 16 AND ELECTROCHEMICAL EQUIVALENT OF SILVER = .001118. THE NAMES OF NON-METALLIC ELEMENTS ARE PRINTED IN ITALICS.

Name of Element and Symbol	Common Valence	Electrochemical Equivalent Grams per Coulomb	Name of Element and Symbol	Common Valence	Electrochemical Equivalent Grams per Coulomb
Aluminum, *Al*	III	.00009354	Mercury, *Hg*	I–II	.00207172—.00103586
Antimony, *Sb*	III–V	.00041504—.00024902	Nickel, *Ni*	II–III	.00030402—.00020272
Arsenic, *As*	III–V	.00025997—.00015538	*Nitrogen*, *N*	III–V	.00004848—.00002911
Barium, *Ba*	II	.00071164	*Oxygen*, *O*	II	.00008287
Bismuth, *Bi*	III–V	.00071992—.00043195	Palladium, *Pd*	IV	.00027585
Boron, *B*	III	.00003802	*Phosphorus*, *P*	III–V	.00010700—.00006422
Bromine, *Br*	I	.00082827	Platinum, *Pt*	IV	.00050446
Cadmium, *Cd*	II	.00058216	Potassium, *K*	I	.00040554
Calcium, *Ca*	II	.00020768	*Selenium*, *Se*	II	.00041020
Carbon, *C*	IV	.00003108	*Silicon*, *Si*	IV	.00075346
Chlorine, *Cl*	I	.00036721	Silver, *Ag*	I	.00111800
Chromium, *Cr*	II–VI	.00026984—.00008991	Sodium, *Na*	I	.00023877
Cobalt, *Co*	II–III	.00030558—.00020375	Strontium, *Sr*	II	.00045371
Copper, *Cu*	I–II	.00065881—.00032940	*Sulphur*, *S*	II	.00016606
Fluorine, *F*	I	.00019681	*Tellurium*, *Te*	II	.00066088
Gold, *Au*	III	.00068087	Thallium, *Tl*	I–III	.00211419—.00070470
Hydrogen, *H*	I	.00001044	Thorium, *Th*	IV	.00060215
Iodine, *I*	I	.00131399	Tin, *Sn*	II–IV	.00061634—.00030817
Iron, *Fe*	II–III	.00028952—.00019298	Tungsten, *W*	IV–VI	.00047650—.00031769
Lead, *Pb*	II–IV	.00107160—.00053585	Uranium, *U*	IV–VI	.00062027—.00041352
Lithium, *Li*	I	.00007282	Vanadium, *V*	III–V	.00017682—.00010607
Magnesium, *Mg*	II	.00012617	Zinc, *Zn*	II	.00033873
Manganese, *Mn*	II–VII	.00028486—.00008142			

The **chemical equivalent** of an element is the quotient of the atomic weight divided by the valence. The **electrochemical equivalent** of an element is the weight in grams liberated electrolytically by 1 coulomb (1 ampere-second) of electricity. The electrochemical equivalent is proportional to the chemical equivalent. The electrochemical equivalent of silver has been accurately determined by experiment as .001118 gram, and that of each of the other elements can be calculated from this. For example, the electrochemical equivalent of aluminum is $\frac{9.03}{107.93} \times .001118 = .00009354$ gram.

HEAT

SPECIFIC HEATS OF METALS

The specific heat of a substance is the number of heat units required to raise a unit mass of the substance one degree in temperature. The specific heat of water is very nearly constant for all temperatures, but that at its temperature of maximum density (4° C. or 39.1° F.) is considered unity. The specific heats of most substances increase with increasing temperatures.

Substance	Specific Heat at		
	0° C. or 32° F.	50° C. or 122° F.	100° C. or 212° F.
Aluminum	.2070	.2185	.2300
Copper	.0901	.0923	.0966
German silver	.0941	.0947	.0952
Iron	.1060	.1130	.1200
Lead	.0300	.0315	.0331
Platinum	.0320	.0326	.0333
Platinum silver	.0473	.0487	.0581
Silver	.0547	.0569	.0591
Tin	.0523	.0568	.0595
Zinc	.0901	.0938	.0976

TEMPERATURE OF FUSION

Substance	Fusing Point, Degrees F.	Fusing Point, Degrees C.
Aluminum	1,160	627
Carbon	Infusible	Infusible
Copper	1,931	1,054
Gold	1,913	1,045
Iridium	3,542	1,950
Iron, cast	2,192	1,200
Iron, wrought	2,912	1,600
Lead	617	325
Mercury	−37.8	−38.8
Nickel	2,642	1,450
Osmium	3,900	2,200*
Platinum	3,225	1,774
Silver, pure	1,749	954
Steel	2,520	1,382
Sulphur	235	114.5
Tantalum	3,865	2,150*
Tin	551	233
Tungsten	above 3,420	above 1,900*

*J. Swinburne, F. R. S., Proc. British Institution of Electrical Engineers, Jan. 10, 1907.

HEAT UNITS

One *British thermal unit* (B. T. U.) is the quantity of heat required to raise the temperature of 1 lb. of pure water 1° F. at or near its maximum density, 39.1° F.

One *calorie* is the quantity of heat required to raise the temperature of 1 Kg. of water 1° C. at or near 4° C.

1 B. T. U. = .252 calorie and 1 calorie = 3.968 B. T. U.

One *small*, or *gram*, *calorie* (a heat unit also in some use) is the quantity of heat required to raise the temperature of 1 gram of water 1° C. at or near 4° C.

COEFFICIENTS OF LINEAR EXPANSION

The coefficient of expansion of a body is its expansion per degree rise of temperature. The coefficient of surface expansion is double, and that of cubical expansion three times, the coefficient of linear expansion.

Substance		Coefficient of Linear Expansion in Inches per Degree F.
Aluminum		.00001140
Brass		.00001040
Brick		.00000306
Cement and Concrete	from	.00000550
	to	.00000780
Copper		.00000961
Glass	from	.00000399
	to	.00000521
Gold		.00000841
Granite		.00000460
Iron, cast		.00000587
Iron, wrought		.00000677
Lead		.00001580
Marble		.00000400
Masonry	from	.00000206
	to	.00000490
Mercury		.00003334
Platinum		.00000494
Porcelain		.00000200
Sandstone	from	.00000400
	to	.00000670
Steel, untempered		.00000599
Steel, tempered		.00000702
Tin		.00001160
Wood (pine)		.00000276
Zinc		.00001634

For example, a 60-ft. steel rail in warming from 20° F. below zero to 100° F. will expand 120 × .00000599 × 60 × 12 = .5175 in.

THE MECHANICAL EQUIVALENT OF HEAT

1 B. T. U. = 778 ft.-lb.

1 ft.-lb. = $\frac{1}{778}$ = .001285 B. T. U.

1 H. P. = 33,000 ft.-lb. per min. = 42.416 B. T. U. per min.

CENTIGRADE AND FAHRENHEIT DEGREES

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
0	32.0	26	78.8	51	123.8	76	168.8
1	33.8	27	80.6	52	125.6	77	170.6
2	35.6	28	82.4	53	127.4	78	172.4
3	37.4	29	84.2	54	129.2	79	174.2
4	39.2	30	86.0	55	131.0	80	176.0
5	41.0	31	87.8	56	132.8	81	177.8
6	42.8	32	89.6	57	134.6	82	179.6
7	44.6	33	91.4	58	136.4	83	181.4
8	46.4	34	93.2	59	138.2	84	183.2
9	48.2	35	95.0	60	140.0	85	185.0
10	50.0	36	96.8	61	141.8	86	186.8
11	51.8	37	98.6	62	143.6	87	188.6
12	53.6	38	100.4	63	145.4	88	190.4
13	55.4	39	102.2	64	147.2	89	192.2
14	57.2	40	104.0	65	149.0	90	194.0
15	59.0	41	105.8	66	150.8	91	195.8
16	60.8	42	107.6	67	152.6	92	197.6
17	62.6	43	109.4	68	154.4	93	199.4
18	64.4	44	111.2	69	156.2	94	201.2
19	66.2	45	113.0	70	158.0	95	203.0
20	68.0	46	114.8	71	159.8	96	204.8
21	69.8	47	116.6	72	161.6	97	206.6
22	71.6	48	118.4	73	163.4	98	20[illegible].4
23	73.4	49	120.2	74	165.2	99	210.2
24	75.2	50	122.0	75	167.0	100	212.0
25	77.0						

TEMPERATURE

The temperature of a body is its degree of sensible heat. For the measurement of temperatures there are three kinds of thermometers: the Fahrenheit, abbreviated F. or Fahr., commonly used in America; the Centigrade, abbreviated C. or Cent., used in France and by scientists everywhere; and the Réaumur, abbreviated R. or Réau., used in Germany.

Standard Points	*Degrees F.*	*Degrees C.*	*Degrees R.*
Boiling point of water at sea level; i. e., pressure = 1 atmosphere.....	212	100	80
Melting point of ice.......	32	0	0
Absolute zero, i. e., the total absence of heat; theoretical only......	−460	−273	−219

Between boiling point and freezing point = 180° F. = 100° C. = 80° R.

$$\text{Temp. F.} = \frac{9}{5}(\text{Temp. C.} + 32°) = \frac{9}{4}\,\text{Temp. R.} + 32°.$$

$$\text{Temp. C.} = \frac{5}{9}(\text{Temp. F.} - 32°) = \frac{5}{4}\,\text{Temp. R.}$$

$$\text{Temp. R.} = \frac{4}{9}(\text{Temp. F.} - 32°) = \frac{4}{5}\,\text{Temp. C.}$$

MATHEMATICAL TABLES

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100

Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	.0491	.0002	4	12.5664	12.5664
1/32	.0982	.0008	4 1/8	12.9591	13.3641
1/16	.1963	.0031	4 1/4	13.3518	14.1863
1/8	.3927	.0123	4 3/8	13.7445	15.0330
3/16	.5890	.0276	4 1/2	14.1372	15.9043
1/4	.7854	.0491	4 5/8	14.5299	16.8002
5/16	.9817	.0767	4 3/4	14.9226	17.7206
3/8	1.1781	.1104	4 7/8	15.3153	18.6555
7/16	1.3744	.1503	5	15.7080	19.6350
1/2	1.5708	.1963	5 1/8	16.1007	20.6290
9/16	1.7671	.2485	5 1/4	16.4934	21.6476
5/8	1.9635	.3068	5 3/8	16.8861	22.6907
11/16	2.1598	.3712	5 1/2	17.2788	23.7583
3/4	2.3562	.4418	5 5/8	17.6715	24.8505
13/16	2.5525	.5185	5 3/4	18.0642	25.9673
7/8	2.7489	.6013	5 7/8	18.4569	27.1086
15/16	2.9452	.6903	6	18.8496	28.2744
1	3.1416	.7854	6 1/8	19.2423	29.4648
1 1/8	3.5343	.9940	6 1/4	19.6350	30.6797
1 1/4	3.9270	1.2272	6 3/8	20.0277	31.9191
1 3/8	4.3197	1.4849	6 1/2	20.4204	33.1831
1 1/2	4.7124	1.7671	6 5/8	20.8131	34.4717
1 5/8	5.1051	2.0739	6 3/4	21.2058	35.7848
1 3/4	5.4978	2.4053	6 7/8	21.5985	37.1224
1 7/8	5.8905	2.7612	7	21.9912	38.4846
2	6.2832	3.1416	7 1/8	22.3839	39.8713
2 1/8	6.6759	3.5466	7 1/4	22.7766	41.2826
2 1/4	7.0686	3.9761	7 3/8	23.1693	42.7184
2 3/8	7.4613	4.4301	7 1/2	23.5620	44.1787
2 1/2	7.8540	4.9087	7 5/8	23.9547	45.6636
2 5/8	8.2467	5.4119	7 3/4	24.3474	47.1731
2 3/4	8.6394	5.9396	7 7/8	24.7401	48.7071
2 7/8	9.0321	6.4918	8	25.1328	50.2656
3	9.4248	7.0686	8 1/8	25.5255	51.8487
3 1/8	9.8175	7.6699	8 1/4	25.9182	53.4563
3 1/4	10.2102	8.2958	8 3/8	26.3109	55.0884
3 3/8	10.6029	8.9462	8 1/2	26.7036	56.7451
3 1/2	10.9956	9.6211	8 5/8	27.0963	58.4264
3 5/8	11.3883	10.3206	8 3/4	27.4890	60.1322
3 3/4	11.7810	11.0447	8 7/8	27.8817	61.8625
3 7/8	12.1737	11.7933	9	28.2744	63.6174

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
9⅛	28.6671	65.3968	19½	61.2612	298.648
9¼	29.0598	67.2008	19¾	62.0466	306.355
9⅜	29.4525	69.0293	20	62.8320	314.160
9½	29.8452	70.8823	20¼	63.6174	322.063
9⅝	30.2379	72.7599	20½	64.4028	330.064
9¾	30.6306	74.6621	20¾	65.1882	338.164
9⅞	31.0233	76.589	21	65.9736	346.361
10	31.4160	78.540	21¼	66.7590	354.657
10¼	32.2014	82.516	21½	67.5444	363.051
10½	32.9868	86.590	21¾	68.3298	371.543
10¾	33.7722	90.763	22	69.1152	380.134
11	34.5576	95.033	22¼	69.9006	388.822
11¼	35.3430	99.402	22½	70.6860	397.609
11½	36.1284	103.869	22¾	71.4714	406.494
11¾	36.9138	108.434	23	72.2568	415.477
12	37.6992	113.098	23¼	73.0422	424.558
12¼	38.4846	117.859	23½	73.8276	433.737
12½	39.2700	122.719	23¾	74.6130	443.015
12¾	40.0554	127.677	24	75.3984	452.390
13	40.8408	132.733	24¼	76.1838	461.864
13¼	41.6262	137.887	24½	76.9692	471.436
13½	42.4116	143.139	24¾	77.7546	481.107
13¾	43.1970	148.490	25	78.5400	490.875
14	43.9824	153.938	25¼	79.3254	500.742
14¼	44.7678	159.485	25½	80.1108	510.706
14½	45.5532	165.130	25¾	80.8962	520.769
14¾	46.3386	170.874	26	81.6816	530.930
15	47.1240	176.715	26¼	82.4670	541.190
15¼	47.9094	182.655	26½	83.2524	551.547
15½	48.6948	188.692	26¾	84.0378	562.003
15¾	49.4802	194.828	27	84.8232	572.557
16	50.2656	201.062	27¼	85.6086	583.209
16¼	51.0510	207.395	27½	86.3940	593.959
16½	51.8364	213.825	27¾	87.1794	604.807
16¾	52.6218	220.354	28	87.9648	615.754
17	53.4072	226.981	28¼	88.7502	626.798
17¼	54.1926	233.706	28½	89.5356	637.941
17½	54.9780	240.529	28¾	90.3210	649.182
17¾	55.7634	247.450	29	91.1064	660.521
18	56.5488	254.470	29¼	91.8918	671.959
18¼	57.3342	261.587	29½	92.6772	683.494
18½	58.1196	268.803	29¾	93.4626	695.128
18¾	58.9050	276.117	30	94.2480	706.860
19	59.6904	283.529	30¼	95.0334	718.690
19¼	60.4758	291.040	30½	95.8188	730.618

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
30¾	96.6042	742.645	42	131.947	1,385.450
31	97.3896	754.769	42¼	132.733	1,401.990
31¼	98.1750	766.992	42½	133.518	1,418.630
31½	98.9604	779.313	42¾	134.303	1,435.370
31¾	99.7458	791.732	43	135.089	1,452.200
32	100.5312	804.250	43¼	135.874	1,469.140
32¼	101.3166	816.865	43½	136.660	1,486.170
32½	102.1020	829.579	43¾	137.445	1,503.300
32¾	102.8874	842.391	44	138.230	1,520.530
33	103.673	855.301	44¼	139.016	1,537.860
33¼	104.458	868.309	44½	139.801	1,555.29
33½	105.244	881.415	44¾	140.587	1,572.81
33¾	106.029	894.620	45	141.372	1,590.43
34	106.814	907.922	45¼	142.157	1,608.16
34¼	107.600	921.323	45½	142.943	1,625.97
34½	108.385	934.822	45¾	143.728	1,643.89
34¾	109.171	948.420	46	144.514	1,661.91
35	109.956	962.115	46¼	145.299	1,680.02
35¼	110.741	975.909	46½	146.084	1,698.23
35½	111.527	989.800	46¾	146.870	1,716.54
35¾	112.312	1,003.790	47	147.655	1,734.95
36	113.098	1,017.878	47¼	148.441	1,753.45
36¼	113.883	1,032.065	47½	149.226	1,772.06
36½	114.668	1,046.349	47¾	150.011	1,790.76
36¾	115.454	1,060.732	48	150.797	1,809.56
37	116.239	1,075.213	48¼	151.582	1,828.46
37¼	117.025	1,089.792	48½	152.368	1,847.46
37½	117.810	1,104.469	48¾	153.153	1,866.55
37¾	118.595	1,119.244	49	153.938	1,885.75
38	119.381	1,134.118	49¼	154.724	1,905.04
38¼	120.166	1,149.089	49½	155.509	1,924.43
38½	120.952	1,164.159	49¾	156.295	1,943.91
38¾	121.737	1,179.327	50	157.080	1,963.50
39	122.522	1,194.593	50½	158.651	2,002.97
39¼	123.308	1,209.958	51	160.222	2,042.83
39½	124.093	1,225.420	51½	161.792	2,083.08
39¾	124.879	1,240.981	52	163.363	2,123.72
40	125.664	1,256.640	52½	164.934	2,164.76
40¼	126.449	1,272.400	53	166.505	2,206.19
40½	127.235	1,288.250	53½	168.076	2,248.01
40¾	128.020	1,304.210	54	169.646	2,290.23
41	128.806	1,320.260	54½	171.217	2,332.83
41¼	129.591	1,336.410	55	172.788	2,375.83
41½	130.376	1,352.660	55½	174.359	2,419.23
41¾	131.162	1,369.000	56	175.930	2,463.01

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
56½	177.500	2,507.19	78½	246.616	4,839.83
57	179.071	2,551.76	79	248.186	4,901.68
57½	180.642	2,596.73	79½	249.757	4,963.92
58	182.213	2,642.09	80	251.328	5,026.56
58½	183.784	2,687.84	80½	252.899	5,089.59
59	185.354	2,733.98	81	254.470	5,153.01
59½	186.925	2,780.51	81½	256.040	5,216.82
60	188.496	2,827.44	82	257.611	5,281.03
60½	190.067	2,874.76	82½	259.182	5,345.63
61	191.638	2,922.47	83	260.753	5,410.62
61½	193.208	2,970.58	83½	262.324	5,476.01
62	194.779	3,019.08	84	263.894	5,541.78
62½	196.350	3,067.97	84½	265.465	5,607.95
63	197.921	3,117.25	85	267.036	5,674.51
63½	199.492	3,166.93	85½	268.607	5,741.47
64	201.062	3,217.00	86	270.178	5,808.82
64½	202.633	3,267.46	86½	271.748	5,876.56
65	204.204	3,318.31	87	273.319	5,944.69
65½	205.775	3,369.56	87½	274.890	6,013.22
66	207.346	3,421.20	88	276.461	6,082.14
66½	208.916	3,473.24	88½	278.032	6,151.45
67	210.487	3,525.66	89	279.602	6,221.15
67½	212.058	3,578.48	89½	281.173	6,291.25
68	213.629	3,631.69	90	282.744	6,361.74
68½	215.200	3,685.29	90½	284.315	6,432.62
69	216.770	3,739.29	91	285.886	6,503.90
69½	218.341	3,793.68	91½	287.456	6,575.56
70	219.912	3,848.46	92	289.027	6,647.63
70½	221.483	3,903.63	92½	290.598	6,720.08
71	223.054	3,959.20	93	292.169	6,792.92
71½	224.624	4,015.16	93½	293.740	6,866.16
72	226.195	4,071.51	94	295.310	6,939.79
72½	227.766	4,128.26	94½	296.881	7,013.82
73	229.337	4,185.40	95	298.452	7,088.24
73½	230.908	4,242.93	95½	300.023	7,163.04
74	232.478	4,300.85	96	301.594	7,238.25
71½	234.049	4,359.17	96½	303.164	7,313.84
75	235.620	4,417.87	97	304.735	7,389.83
75½	237.191	4,476.98	97½	306.306	7,466.21
76	238.762	4,536.47	98	307.877	7,542.98
76½	240.332	4,596.36	98½	309.448	7,620.15
77	241.903	4,656.64	99	311.018	7,697.71
77½	243.474	4,717.31	99½	312.589	7,775.66
78	245.045	4,778.37	100	314.160	7,854.00

DECIMAL EQUIVALENTS OF PARTS OF ONE INCH

1-64	.015625	17-64	.265625	33-64	.515625	49-64	.765625
1-32	.031250	9-32	.281250	17-32	.531250	25-32	.781250
3-64	.046875	19-64	.296875	35-64	.546875	51-64	.796875
1-16	.062500	5-16	.312500	9-16	.562500	13-16	.812500
5-64	.078125	21-64	.328125	37-64	.578125	53-64	.828125
3-32	093750	11-32	.343750	19-32	.593750	27-32	.843750
7-64	.109375	23-64	.359375	39-64	.609375	55-64	.859375
1-8	.125000	3-8	.375000	5-8	.625000	7-8	.875000
9-64	.140625	25-64	.390625	41-64	.640625	57-64	.890625
5-32	.156250	13-32	.406250	21-32	.656250	29-32	.906250
11-64	.171875	27-64	.421875	43-64	.671875	59-64	.921875
3-16	.187500	7-16	.437500	11-16	.687500	15-16	.937500
13-64	.203125	29-64	.453125	45-64	.703125	61-64	.953125
7-32	.218750	15-32	.468750	23-32	.718750	31-32	.968750
15-64	.234375	31-64	.484375	47-64	.734375	63-64	.984375
1-4	.250000	1-2	.500000	3-4	.750000	1	1

TRIGONOMETRIC FUNCTIONS

The table given on pages 26–27 contains the natural sines, cosines, tangents, and cotangents of angles from 0° to 90°. Angles less than 45° are given in the first column at the left-hand side of the page, and the names of the functions are given at the top of the page; angles greater than 45° appear at the right-hand side of the page, and the names of the functions are given at the bottom. Thus, the second column contains the sines of angles less than 45° and the cosines of angles greater than 45°; the sixth column contains the cotangents of angles less than 45° and the tangents of angles greater than 45°. To find the function of an angle less than 45°, look in the column of angles at the left of the page for the angle, and at the top of the page for the name of the function; to find a function of an angle greater than 45°, look in the column at the right of the page for the angle and at the bottom of the page for the name of the function. The successive angles differ by an interval of 10′; they increase downwards in the left-hand column and upwards in the right-hand column. Thus, for angles less than 45° read down from top of page, and for angles greater than 45° read up from bottom of page.

The third, fifth, seventh, and ninth columns, headed *d*, contain the differences between the successive functions; for example, the sine of 32° 10′ is .5324 and the sine of 32° 20′ is .5348, as given in the second column, page 26; the difference is .5348 − .5324 = .0024, and the 24 is written in the third column, just opposite the space between .5324 and .5348. In like manner, the differences between the successive tabular values of the tangents are given in the fifth column, those between the cotangents in the seventh column, and those for the cosines in the ninth column. These differences in the functions correspond to a difference of 10′ in the angle; thus, when the angle 32° 10′ is increased by 10′, that is, to 32° 20′, the increase of the sine is .0024, or, as given in the table, 24. In the tabular difference, no attention is paid to the decimal point, it being understood that the difference is merely the number obtained by subtracting the last two or three figures of the smaller function from those of the larger. These differences are used to obtain the sines, cosines, etc. of angles not given in the table; for example, to find the tangent of 27° 34′ find in the table the tangent of 27° 30′, .5206, and (in column 5) the difference for 10′, 37. Difference for 1′ is 37 ÷ 10 = 3.7, and difference for 4′ is 3.7 × 4 = 14.8. Adding this difference to the value of the tan 27° 30′, gives

tan 27° 30′ = .5206
difference for 4′ = 14.8

tan 27° 34′ = .52208, or .5221, to four places.

Since only four decimal places are retained, the 8 in the fifth place is dropped and the figure in the fourth place is increased by 1, because 8 is greater than 5.

To avoid multiplication, the column of proportional parts, headed P. P., at the extreme right of the page, is used. At the head of each table in this column is the difference for 10′, and below are the differences for any intermediate number of minutes from 1′ to 9′. In the above example, the difference at 27° 30′ for 10′ was 37; looking in the table with 37 at the head, the difference opposite 4 is 14.8; that opposite 7 is 25.9; and so on. For want of space, the differences for the cotangents for angles less than 45° (or the tangents of angles greater than 45°) have been omitted from the tables of proportional parts. The use of these functions should be

°	'	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	'	°
0	0	0.0000		0.0000		infinit.		1.0000		0	90
	10	0.0029	29	0.0029	29	343.7737		1.0000	0	50	
	20	0.0058	29	0.0058	29	171.8854		1.0000	0	40	
	30	0.0087	29	0.0087	29	114.5887		1.0000	0	30	
	40	0.0116	29	0.0116	29	85.9398		0.9999	1	20	
	50	0.0145	29	0.0145	29	68.7501		0.9999	0	10	
1	0	0.0175	30	0.0175	30	57.2900		0.9998	1	0	89
	10	0.0204	29	0.0204	29	49.1039	81861	0.9998	0	50	
	20	0.0233	29	0.0233	29	42.9641	61398	0.9997	1	40	
	30	0.0262	29	0.0262	29	38.1885	47756	0.9997	0	30	
	40	0.0291	29	0.0291	29	34.3678	38207	0.9996	1	20	
	50	0.0320	29	0.0320	29	31.2416	31262	0.9995	1	10	
2	0	0.0349	29	0.0349	29	28.6363	26053	0.9994	1	0	88
	10	0.0378	29	0.0378	29	26.4316	22047	0.9993	1	50	
	20	0.0407	29	0.0407	29	24.5418	18898	0.9992	1	40	
	30	0.0436	29	0.0437	30	22.9038	16380	0.9990	2	30	
	40	0.0465	29	0.0466	29	21.4704	14334	0.9989	1	20	
	50	0.0494	29	0.0495	29	20.2056	12648	0.9988	1	10	
3	0	0.0523	29	0.0524	29	19.0811	11245	0.9986	2	0	87
	10	0.0552	29	0.0553	29	18.0750	10061	0.9985	1	50	
	20	0.0581	29	0.0582	29	17.1693	9057	0.9983	2	40	
	30	0.0610	29	0.0612	30	16.3499	8194	0.9981	2	30	
	40	0.0640	30	0.0641	29	15.6048	7451	0.9980	1	20	
	50	0.0669	29	0.0670	29	14.9244	6804	0.9978	2	10	
4	0	0.0698	29	0.0699	29	14.3007	6237	0.9976	2	0	86
	10	0.0727	29	0.0729	30	13.7267	5740	0.9974	2	50	
	20	0.0756	29	0.0758	29	13.1969	5298	0.9971	3	40	
	30	0.0785	29	0.0787	29	12.7062	4907	0.9969	2	30	
	40	0.0814	29	0.0816	29	12.2505	4557	0.9967	2	20	
	50	0.0843	29	0.0846	30	11.8262	4243	0.9964	3	10	
5	0	0.0872	29	0.0875	29	11.4301	3961	0.9962	2	0	85
	10	0.0901	29	0.0904	29	11.0594	3707	0.9959	3	50	
	20	0.0929	28	0.0934	30	10.7119	3475	0.9957	2	40	
	30	0.0958	29	0.0963	29	10.3854	3265	0.9954	3	30	
	40	0.0987	29	0.0992	29	10.0780	3074	0.9951	3	20	
	50	0.1016	29	0.1022	30	9.7882	2898	0.9948	3	10	
6	0	0.1045	29	0.1051	29	9.5144	2738	0.9945	3	0	84
	10	0.1074	29	0.1080	29	9.2553	2591	0.9942	3	50	
	20	0.1103	29	0.1110	30	9.0098	2455	0.9939	3	40	
	30	0.1132	29	0.1139	29	8.7769	2329	0.9936	3	30	
	40	0.1161	29	0.1169	30	8.5555	2214	0.9932	4	20	
	50	0.1190	29	0.1198	29	8.34 0	2105	0.9929	3	10	
7	0	0.1219	29	0.1228	30	8.1443	2007	0.9925	4	0	83
	10	0.1248	29	0.1257	29	7.9530	1913	0.9922	3	50	
	20	0.1276	28	0.1287	30	7.7704	1826	0.9918	4	40	
	30	0.1305	29	0.1317	30	7.5958	1746	0.9914	4	30	
	40	0.1334	29	0.1346	29	7.4287	1671	0.9911	3	20	
	50	0.1363	29	0.1376	30	7.2687	1600	0.9907	4	10	
8	0	0.1392	29	0.1405	29	7.1154	1533	0.9903	4	0	82
	10	0.1421	29	0.1435	30	6.9682	1472	0.9899	4	50	
	20	0.1449	28	0.1465	30	6.8269	1413	0.9894	5	40	
	30	0.1478	29	0.1495	30	6.6912	1357	0.9890	4	30	
	40	0.1507	29	0.1524	29	6.5606	1306	0.9886	4	20	
	50	0.1536	29	0.1554	30	6.4348	1258	0.9881	5	10	
9	0	0.1564	28	0.1584	30	6.3138	1210	0.9877	4	0	81
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	'	°

P. P.

	30	29	28	5	4
1	3.0	2.9	2.8	0.5	0.4
2	6.0	5.8	5.6	1.0	0.8
3	9.0	8.7	8.4	1.5	1.2
4	12.0	11.6	11.2	2.0	1.6
5	15.0	14.5	14.0	2.5	2.0
6	18.0	17.4	16.8	3.0	2.4
7	21.0	20.3	19.6	3.5	2.8
8	24.0	23.2	22.4	4.0	3.2
9	27.0	26.1	25.2	4.5	3.6

P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	′	°
9	0	0.1564	29	0.1584	30	6.3138	1168	0.9877	5	0	81
	10	0.1593	29	0.1614	30	6.1970	1126	0.9872	4	50	
	20	0.1622	28	0.1644	29	6.0844	1086	0.9868	5	40	
	30	0.1650	29	0.1673	30	5.9758	1050	0.9863	5	30	
	40	0.1679	29	0.1703	30	5.8708	1014	0.9858	5	20	
	50	0.1708	28	0.1733	30	5.7694	981	0.9853	5	10	
10	0	0.1736	29	0.1763	30	5.6713	949	0.9848	5	0	80
	10	0.1765	29	0.1793	30	5.5764	919	0.9843	5	50	
	20	0.1794	28	0.1823	30	5.4845	890	0.9838	5	40	
	30	0.1822	29	0.1853	30	5.3955	862	0.9833	6	30	
	40	0.1851	29	0.1883	31	5.3093	836	0.9827	5	20	
	50	0.1880	28	0.1914	30	5.2257	811	0.9822	6	10	
11	0	0.1908	29	0.1944	30	5.1446	788	0.9816	5	0	79
	10	0.1937	28	0.1974	30	5.0658	764	0.9811	6	50	
	20	0.1965	29	0.2004	31	4.9894	742	0.9805	6	40	
	30	0.1994	28	0.2035	30	4.9152	722	0.9799	6	30	
	40	0.2022	29	0.2065	30	4.8430	701	0.9793	6	20	
	50	0.2051	28	0.2095	31	4.7729	683	0.9787	6	10	
12	0	0.2079	29	0.2126	30	4.7046	664	0.9781	6	0	78
	10	0.2108	28	0.2156	30	4.6382	646	0.9775	6	50	
	20	0.2136	28	0.2186	31	4.5736	629	0.9769	6	40	
	30	0.2164	29	0.2217	30	4.5107	613	0.9763	6	30	
	40	0.2193	28	0.2247	31	4.4494	597	0.9757	7	20	
	50	0.2221	29	0.2278	31	4.3897	582	0.9750	6	10	
13	0	0.2250	28	0.2309	30	4.3315	568	0.9744	7	0	77
	10	0.2278	28	0.2339	31	4.2747	554	0.9737	7	50	
	20	0.2306	28	0.2370	31	4.2193	540	0.9730	6	40	
	30	0.2334	29	0.2401	31	4.1653	527	0.9724	7	30	
	40	0.2363	28	0.2432	30	4.1126	515	0.9717	7	20	
	50	0.2391	28	0.2462	31	4.0611	503	0.9710	7	10	
14	0	0.2419	28	0.2493	31	4.0108	491	0.9703	7	0	76
	10	0.2447	29	0.2524	31	3.9617	481	0.9696	7	50	
	20	0.2476	28	0.2555	31	3.9136	469	0.9689	8	40	
	30	0.2504	28	0.2586	31	3.8667	459	0.9681	7	30	
	40	0.2532	28	0.2617	31	3.8208	448	0.9674	7	20	
	50	0.2560	28	0.2648	31	3.7760	439	0.9667	8	10	
15	0	0.2588	28	0.2679	32	3.7321	430	0.9659	7	0	75
	10	0.2616	28	0.2711	31	3.6891	421	0.9652	8	50	
	20	0.2644	28	0.2742	31	3.6470	411	0.9644	8	40	
	30	0.2672	28	0.2773	32	3.6059	403	0.9636	8	30	
	40	0.2700	28	0.2805	31	3.5656	395	0.9628	7	20	
	50	0.2728	28	0.2836	31	3.5261	387	0.9621	8	10	
16	0	0.2756	28	0.2867	32	3.4874	379	0.9613	8	0	74
	10	0.2784	28	0.2899	32	3.4495	371	0.9605	9	50	
	20	0.2812	28	0.2931	31	3.4124	365	0.9596	8	40	
	30	0.2840	28	0.2962	32	3.3759	357	0.9588	8	30	
	40	0.2868	28	0.2994	32	3.3402	350	0.9580	8	20	
	50	0.2896	28	0.3026	31	3.3052	343	0.9572	9	10	
17	0	0.2924	28	0.3057	32	3.2709	338	0.9563	8	0	73
	10	0.2952	27	0.3089	32	3.2371	330	0.9555	9	50	
	20	0.2979	28	0.3121	32	3.2041	325	0.9546	9	40	
	30	0.3007	28	0.3153	32	3.1716	319	0.9537	9	30	
	40	0.3035	27	0.3185	32	3.1397	313	0.9528	8	20	
	50	0.3062	28	0.3217	32	8.1084	307	0.9520	9	10	
18	0	0.3090		0.3249		3.0777		0.9511		0	72
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.

	32	31	30
1	3.2	3.1	3.0
2	6.4	6.2	6.0
3	9.6	9.3	9.0
4	12.8	12.4	12.0
5	16.0	15.5	15.0
6	19.2	18.6	18.0
7	22.4	21.7	21.0
8	25.6	24.8	24.0
9	28.8	27.9	27.0

	29	28	27
1	2.9	2.8	2.7
2	5.8	5.6	5.4
3	8.7	8.4	8.1
4	11.6	11.2	10.8
5	14.5	14.0	13.5
6	17.4	16.8	16.2
7	20.3	19.6	18.9
8	23.2	22.4	21.6
9	26.1	25.2	24.3

	9	8
1	0.9	0.8
2	1.8	1.6
3	2.7	2.4
4	3.6	3.2
5	4.5	4.0
6	5.4	4.8
7	6.3	5.6
8	7.2	6.4
9	8.1	7.2

	7	6
1	0.7	0.6
2	1.4	1.2
3	2.1	1.8
4	2.8	2.4
5	3.5	3.0
6	4.2	3.6
7	4.9	4.2
8	5.6	4.8
9	6.3	5.4

	5	4
1	0.5	0.4
2	1.0	0.8
3	1.5	1.2
4	2.0	1.6
5	2.5	2.0
6	3.0	2.4
7	3.5	2.8
8	4.0	3.2
9	4.5	3.6

P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	′	°
18	0	0.3090	28	0.3249	32	3.0777	302	0.9511	9	0	72
	10	0.3118	27	0.3281	33	3.0475	297	0.9502	10	50	
	20	0.3145	28	0.3314	32	3.0178	291	0.9492	9	40	
	30	0.3173	28	0.3346	32	2.9887	287	0.9483	9	30	
	40	0.3201	27	0.3378	33	2.9600	281	0.9474	9	20	
	50	0.3228	28	0.3411	32	2.9319	277	0.9465	10	10	
19	0	0.3256	27	0.3443	33	2.9042	272	0.9455	9	0	71
	10	0.3283	28	0.3476	32	2.8770	268	0.9446	10	50	
	20	0.3311	27	0.3508	33	2.8502	263	0.9436	10	40	
	30	0.3338	27	0.3541	33	2.8239	259	0.9426	9	30	
	40	0.3365	28	0.3574	33	2.7980	255	0.9417	10	20	
	50	0.3393	27	0.3607	33	2.7725	250	0.9407	10	10	
20	0	0.3420	28	0.3640	33	2.7475	247	0.9397	10	0	70
	10	0.3448	27	0.3673	33	2.7228	243	0.9387	10	50	
	20	0.3475	27	0.3706	33	2.6985	239	0.9377	10	40	
	30	0.3502	27	0.3739	33	2.6746	235	0.9367	11	30	
	40	0.3529	28	0.3772	33	2.6511	232	0.9356	10	20	
	50	0.3557	27	0.3805	34	2.6279	228	0.9346	10	10	
21	0	0.3584	27	0.3839	33	2.6051	225	0.9336	11	0	69
	10	0.3611	27	0.3872	34	2.5826	221	0.9325	10	50	
	20	0.3638	27	0.3906	33	2.5605	219	0.9315	11	40	
	30	0.3665	27	0.3939	34	2.5386	214	0.9304	11	30	
	40	0.3692	27	0.3973	33	2.5172	212	0.9293	10	20	
	50	0.3719	27	0.4006	34	2.4960	209	0.9283	11	10	
22	0	0.3746	27	0.4040	34	2.4751	206	0.9272	11	0	68
	10	0.3773	27	0.4074	34	2.4545	203	0.9261	11	50	
	20	0.3800	27	0.4108	34	2.4342	200	0.9250	11	40	
	30	0.3827	27	0.4142	34	2.4142	197	0.9239	11	30	
	40	0.3854	27	0.4176	34	2.3945	195	0.9228	12	20	
	50	0.3881	26	0.4210	35	2.3750	191	0.9216	11	10	
23	0	0.3907	27	0.4245	34	2.3559	190	0.9205	11	0	67
	10	0.3934	27	0.4279	35	2.3369	186	0.9194	12	50	
	20	0.3961	26	0.4314	34	2.3183	185	0.9182	11	40	
	30	0.3987	27	0.4348	35	2.2998	181	0.9171	12	30	
	40	0.4014	27	0.4383	34	2.2817	180	0.9159	12	20	
	50	0.4041	26	0.4417	35	2.2637	177	0.9147	12	10	
24	0	0.4067	27	0.4452	35	2.2460	174	0.9135	11	0	66
	10	0.4094	26	0.4487	35	2.2286	173	0.9124	12	50	
	20	0.4120	27	0.4522	35	2.2113	170	0.9112	12	40	
	30	0.4147	26	0.4557	35	2.1943	168	0.9100	12	30	
	40	0.4173	27	0.4592	36	2.1775	166	0.9088	13	20	
	50	0.4200	26	0.4628	35	2.1609	164	0.9075	12	10	
25	0	0.4226	27	0.4663	36	2.1445	162	0.9063	12	0	65
	10	0.4253	26	0.4699	35	2.1283	160	0.9051	13	50	
	20	0.4279	26	0.4734	36	2.1123	158	0.9038	12	40	
	30	0.4305	26	0.4770	36	2.0965	156	0.9026	13	30	
	40	0.4331	27	0.4806	35	2.0809	154	0.9013	12	20	
	50	0.4358	26	0.4841	36	2.0655	152	0.9001	13	10	
26	0	0.4384	26	0.4877	36	2.0503	150	0.8988	13	0	64
	10	0.4410	26	0.4913	37	2.0353	149	0.8975	13	50	
	20	0.4436	26	0.4950	36	2.0204	147	0.8962	13	40	
	30	0.4462	26	0.4986	36	2.0057	145	0.8949	13	30	
	40	0.4488	26	0.5022	37	1.9912	144	0.8936	13	20	
	50	0.4514	26	0.5059	36	1.9768	142	0.8923	13	10	
27	0	0.4540		0.5095		1.9626		0.8910		0	63
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.

	37	36	35
1	3.7	3.6	3.5
2	7.4	7.2	7.0
3	11.1	10.8	10.5
4	14.8	14.4	14.0
5	18.5	18.0	17.5
6	22.2	21.6	21.0
7	25.9	25.2	24.5
8	29.6	28.8	28.0
9	33.3	32.4	31.5

	34	33	32
1	3.4	3.3	3.2
2	6.8	6.6	6.4
3	10.2	9.9	9.6
4	13.6	13.2	12.8
5	17.0	16.5	16.0
6	20.4	19.8	19.2
7	23.8	23.1	22.4
8	27.2	26.4	25.6
9	30.6	29.7	28.8

	28	27	26
1	2.8	2.7	2.6
2	5.6	5.4	5.2
3	8.4	8.1	7.8
4	11.2	10.8	10.4
5	14.0	13.5	13.0
6	16.8	16.2	15.6
7	19.6	18.9	18.2
8	22.4	21.6	20.8
9	25.2	24.3	23.4

	13	12
1	1.3	1.2
2	2.6	2.4
3	3.9	3.6
4	5.2	4.8
5	6.5	6.0
6	7.8	7.2
7	9.1	8.4
8	10.4	9.6
9	11.7	10.8

	11	10	9
1	1.1	1.0	0.9
2	2.2	2.0	1.8
3	3.3	3.0	2.7
4	4.4	4.0	3.6
5	5.5	5.0	4.5
6	6.6	6.0	5.4
7	7.7	7.0	6.3
8	8.8	8.0	7.2
9	9.9	9.0	8.1

P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	′	°
27	0	0.4540	26	0.5095	37	1.9626	140	0.8910	13	0	63
	10	0.4566	26	0.5132	37	1.9486	139	0.8897	13	50	
	20	0.4592	25	0.5169	37	1.9347	137	0.8884	14	40	
	30	0.4617	26	0.5206	37	1.9210	136	0.8870	13	30	
	40	0.4643	26	0.5243	37	1.9074	134	0.8857	14	20	
	50	0.4669	26	0.5280	37	1.8940	133	0.8843	14	10	
28	0	0.4695	25	0.5317	37	1.8807	131	0.8829	13	0	62
	10	0.4720	26	0.5354	38	1.8676	130	0.8816	14	50	
	20	0.4746	26	0.5392	38	1.8546	128	0.8802	14	40	
	30	0.4772	25	0.5430	37	1.8418	127	0.8788	14	30	
	40	0.4797	26	0.5467	38	1.8291	126	0.8774	14	20	
	50	0.4823	25	0.5505	38	1.8165	125	0.8760	14	10	
29	0	0.4848	26	0.5543	38	1.8040	123	0.8746	14	0	61
	10	0.4874	25	0.5581	38	1.7917	121	0.8732	14	50	
	20	0.4899	25	0.5619	39	1.7796	121	0.8718	14	40	
	30	0.4924	26	0.5658	38	1.7675	119	0.8704	15	30	
	40	0.4950	25	0.5696	39	1.7556	119	0.8689	14	20	
	50	0.4975	25	0.5735	39	1.7437	116	0.8675	15	10	
30	0	0.5000	25	0.5774	38	1.7321	116	0.8660	14	0	60
	10	0.5025	25	0.5812	39	1.7205	115	0.8646	15	50	
	20	0.5050	25	0.5851	39	1.7090	113	0.8631	15	40	
	30	0.5075	25	0.5890	40	1.6977	113	0.8616	15	30	
	40	0.5100	25	0.5930	39	1.6864	111	0.8601	14	20	
	50	0.5125	25	0.5969	40	1.6753	110	0.8587	15	10	
31	0	0.5150	25	0.6009	39	1.6643	109	0.8572	15	0	59
	10	0.5175	25	0.6048	40	1.6534	108	0.8557	15	50	
	20	0.5200	25	0.6088	40	1.6426	107	0.8542	16	40	
	30	0.5225	25	0.6128	40	1.6319	107	0.8526	15	30	
	40	0.5250	25	0.6168	40	1.6212	105	0.8511	15	20	
	50	0.5275	24	0.6208	41	1.6107	104	0.8496	16	10	
32	0	0.5299	25	0.6249	40	1.6003	103	0.8480	15	0	58
	10	0.5324	24	0.6289	41	1.5900	102	0.8465	15	50	
	20	0.5348	25	0.6330	41	1.5798	101	0.8450	16	40	
	30	0.5373	25	0.6371	41	1.5697	100	0.8434	16	30	
	40	0.5398	24	0.6412	41	1.5597	100	0.8418	15	20	
	50	0.5422	24	0.6453	41	1.5497	98	0.8403	16	10	
33	0	0.5446	25	0.6494	42	1.5399	98	0.8387	16	0	57
	10	0.5471	24	0.6536	41	1.5301	97	0.8371	16	50	
	20	0.5495	24	0.6577	42	1.5204	96	0.8355	16	40	
	30	0.5519	25	0.6619	42	1.5108	95	0.8339	16	30	
	40	0.5544	24	0.6661	42	1.5013	94	0.8323	16	20	
	50	0.5568	24	0.6703	42	1.4919	93	0.8307	17	10	
34	0	0.5592	24	0.6745	42	1.4826	93	0.8290	16	0	56
	10	0.5616	24	0.6787	43	1.4733	92	0.8274	16	50	
	20	0.5640	24	0.6830	43	1.4641	91	0.8258	17	40	
	30	0.5664	24	0.6873	43	1.4550	90	0.8241	16	30	
	40	0.5688	24	0.6916	43	1.4460	90	0.8225	17	20	
	50	0.5712	24	0.6959	43	1.4370	89	0.8208	16	10	
35	0	0.5736	24	0.7002	44	1.4281	88	0.8192	17	0	55
	10	0.5760	23	0.7046	43	1.4193	87	0.8175	17	50	
	20	0.5783	24	0.7089	44	1.4106	87	0.8158	17	40	
	30	0.5807	24	0.7133	44	1.4019	85	0.8141	17	30	
	40	0.5831	23	0.7177	44	1.3934	86	0.8124	17	20	
	50	0.5854	24	0.7221	44	1.3848	84	0.8107	17	10	
36	0	0.5878		0.7265		1.3764		0.8090		0	54
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.

	44	43	42
1	4.4	4.3	4.2
2	8.8	8.6	8.4
3	13.2	12.9	12.6
4	17.6	17.2	16.8
5	22.0	21.5	21.0
6	26.4	25.8	25.2
7	30.8	30.1	29.4
8	35.2	34.4	33.6
9	39.6	38.7	37.8

	41	40	39
1	4.1	4.0	3.9
2	8.2	8.0	7.8
3	12.3	12.0	11.7
4	16.4	16.0	15.6
5	20.5	20.0	19.5
6	24.6	24.0	23.4
7	28.7	28.0	27.3
8	32.8	32.0	31.2
9	36.9	36.0	35.1

	38	37
1	3.8	3.7
2	7.6	7.4
3	11.4	11.1
4	15.2	14.8
5	19.0	18.5
6	22.8	22.2
7	26.6	25.9
8	30.4	29.6
9	34.2	33.3

	26	25	24
1	2.6	2.5	2.4
2	5.2	5.0	4.8
3	7.8	7.5	7.2
4	10.4	10.0	9.6
4	13.0	12.5	12.0
6	15.6	15.0	14.4
7	18.2	17.5	16.8
8	20.8	20.0	19.2
9	23.4	22.5	21.6

	23	17	16
1	2.3	1.7	1.6
2	4.6	3.4	3.2
3	6.9	5.1	4.8
4	9.2	6.8	6.4
5	11.5	8.5	8.0
6	13.8	10.2	9.6
7	16.1	11.9	11.2
8	18.4	13.6	12.8
9	20.7	15.3	14.4

	15	14	13
1	1.5	1.4	1.3
2	3.0	2.8	2.6
3	4.5	4.2	3.9
4	6.0	5.6	5.2
5	7.5	7.0	6.5
6	9.0	8.4	7.8
7	10.5	9.8	9.1
8	12.0	11.2	10.4
9	13.5	12.6	11.7

P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.	′	°
36	0	0.5878	23	0.7265	45	1.3764	84	0.8090	17	0	54
	10	0.5901	24	0.7310	45	1.3680	83	0.8073	17	50	
	20	0.5925	23	0.7355	45	1.3597	83	0.8056	17	40	
	30	0.5948	24	0.7400	45	1.3514	82	0.8039	18	30	
	40	0.5972	23	0.7445	45	1.3432	81	0.8021	17	20	
	50	0.5995	23	0.7490	46	1.3351	81	0.8004	18	10	
37	0	0.6018	23	0.7536	45	1.3270	80	0.7986	17	0	53
	10	0.6041	24	0.7581	46	1.3190	79	0.7969	18	50	
	20	0.6065	23	0.7627	46	1.3111	79	0.7951	17	40	
	30	0.6088	23	0.7673	47	1.3032	78	0.7934	18	30	
	40	0.6111	23	0.7720	46	1.2954	78	0.7916	18	20	
	50	0.6134	23	0.7766	47	1.2876	77	0.7898	18	10	
38	0	0.6157	23	0.7813	47	1.2799	76	0.7880	18	0	52
	10	0.6180	22	0.7860	47	1.2723	76	0.7862	18	50	
	20	0.6202	23	0.7907	47	1.2647	75	0.7844	18	40	
	30	0.6225	23	0.7954	48	1.2572	75	0.7826	18	30	
	40	0.6248	23	0.8002	48	1.2497	74	0.7808	18	20	
	50	0.6271	22	0.8050	48	1.2423	74	0.7790	19	10	
39	0	0.6293	23	0.8098	48	1.2349	73	0.7771	18	0	51
	10	0.6316	22	0.8146	49	1.2276	73	0.7753	18	50	
	20	0.6338	23	0.8195	48	1.2203	72	0.7735	19	40	
	30	0.6361	22	0.8243	49	1.2131	72	0.7716	18	30	
	40	0.6383	23	0.8292	50	1.2059	71	0.7698	19	20	
	50	0.6406	22	0.8342	49	1.1988	70	0.7679	19	10	
40	0	0.6428	22	0.8391	50	1.1918	71	0.7660	18	0	50
	10	0.6450	22	0.8441	50	1.1847	69	0.7642	19	50	
	20	0.6472	22	0.8491	50	1.1778	70	0.7623	19	40	
	30	0.6494	23	0.8541	50	1.1708	68	0.7604	19	30	
	40	0.6517	22	0.8591	51	1.1640	69	0.7585	19	20	
	50	0.6539	22	0.8642	51	1.1571	67	0.7566	19	10	
41	0	0.6561	22	0.8693	51	1.1504	68	0.7547	19	0	49
	10	0.6583	21	0.8744	52	1.1436	67	0.7528	19	50	
	20	0.6604	22	0.8796	51	1.1369	66	0.7509	19	40	
	30	0.6626	22	0.8847	52	1.1303	66	0.7490	20	30	
	40	0.6648	22	0.8899	53	1.1237	66	0.7470	19	20	
	50	0.6670	21	0.8952	52	1.1171	65	0.7451	20	10	
42	0	0.6691	22	0.9004	53	1.1106	65	0.7431	19	0	48
	10	0.6713	21	0.9057	53	1.1041	64	0.7412	20	50	
	20	0.6734	22	0.9110	53	1.0977	64	0.7392	19	40	
	30	0.6756	21	0.9163	54	1.0913	63	0.7373	20	30	
	40	0.6777	22	0.9217	54	1.0850	64	0.7353	20	20	
	50	0.6799	21	0.9271	54	1.0786	62	0.7333	19	10	
43	0	0.6820	21	0.9325	55	1.0724	63	0.7314	20	0	47
	10	0.6841	21	0.9380	55	1.0661	62	0.7294	20	50	
	20	0.6862	22	0.9435	55	1.0599	61	0.7274	20	40	
	30	0.6884	21	0.9490	55	1.0538	61	0.7254	20	30	
	40	0.6905	21	0.9545	56	1.0477	61	0.7234	20	20	
	50	0.6926	21	0.9601	56	1.0416	61	0.7214	21	10	
44	0	0.6947	20	0.9657	56	1.0355	60	0.7193	20	0	46
	10	0.6967	21	0.9713	57	1.0295	60	0.7173	20	50	
	20	0.6988	21	0.9770	57	1.0235	59	0.7153	20	40	
	30	0.7009	21	0.9827	57	1.0176	59	0.7133	21	30	
	40	0.7030	20	0.9884	58	1.0117	59	0.7112	20	20	
	50	0.7050	21	0.9942	58	1.0058	58	0.7092	21	10	
45	0	0.7071		1.0000		1.0000		0.7071		0	45
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.

	58	57	56	55
1	5.8	5.7	5.6	5.5
2	11.6	11.4	11.2	11.0
3	17.4	17.1	16.8	16.5
4	23.2	22.8	22.4	22.0
5	29.0	28.5	28.0	27.5
6	34.8	34.2	33.6	33.0
7	40.6	39.9	39.2	38.5
8	46.4	45.6	44.8	44.0
9	52.2	51.3	50.4	49.5
	54	**53**	**52**	**51**
1	5.4	5.3	5.2	5.1
2	10.8	10.6	10.4	10.2
3	16.2	15.9	15.6	15.3
4	21.6	21.2	20.8	20.4
5	27.0	26.5	26.0	25.5
6	32.4	31.8	31.2	30.6
7	37.8	37.1	36.4	35.7
8	43.2	42.4	41.6	40.8
9	48.6	47.7	46.8	45.9
	50	**49**	**48**	
1	5.0	4.9	4.8	
2	10.0	9.8	9.6	
3	15.0	14.7	14.4	
4	20.0	19.6	19.2	
5	25.0	24.5	24.0	
6	30.0	29.4	28.8	
7	35.0	34.3	33.6	
8	40.0	39.2	38.4	
9	45.0	44.1	43.2	
	47	**46**	**45**	
1	4.7	4.6	4.5	
2	9.4	9.2	9.0	
3	14.1	13.8	13.5	
4	18.8	18.4	18.0	
5	23.5	23.0	22.5	
6	28.2	27.6	27.0	
7	32.9	32.2	31.5	
8	37.6	36.8	36.0	
9	42.3	41.4	40.5	
	24	**23**	**22**	**21**
1	2.4	2.3	2.2	2.1
2	4.8	4.6	4.4	4.2
3	7.2	6.9	6.6	6.3
4	9.6	9.2	8.8	8.4
5	12.0	11.5	11.0	10.5
6	14.4	13.8	13.2	12.6
7	16.8	16.1	15.4	14.7
8	19.2	18.4	17.6	16.8
9	21.6	20.7	19.8	18.9
	20	**19**	**18**	**17**
1	2.0	1.9	1.8	1.7
2	4.0	3.8	3.6	3.4
3	6.0	5.7	5.4	5.1
4	8.0	7.6	7.2	6.8
5	10.0	9.5	9.0	8.5
6	12.0	11.4	10.8	10.2
7	14.0	13.3	12.6	11.9
8	16.0	15.2	14.4	13.6
9	18.0	17.1	16.2	15.3

P. P.

avoided, if possible, since the differences change very rapidly, and the computation is therefore likely to be inexact.

In finding the functions of an angle, note carefully whether the difference obtained from the table of proportional parts is to be added or subtracted, by observing whether the function is increasing or decreasing as the angle increases. For example, the sine of 21° is .3584, and the following sines, reading downwards, are .3611, .3638, etc. The sine of 21° 6′ is greater than that of 21°, and the difference for 6′ must be added. On the other hand, the cosine of 21° is .9336, and the following cosines, reading downwards, are .9325, .9315, etc.; that is, as the angle grows larger the cosine decreases, and the difference obtained for any angle between 21° and 21° 10′, say 21° 6′, must be subtracted from the cosine of 21°.

Suppose the function, i. e., the sine, cosine, tangent, or cotangent is given and the corresponding angle is to be found; for example, find the angle whose sine is .4943. First find in the second column the sine next *smaller* than .4943, which is .4924, and the difference for 10′ is 26. The angle corresponding to .4924 is 29° 30′. Subtracting the .4924 from .4943, the first remainder is 19; in the table of proportional parts under 26, the part next lower than this difference, is 18.2, opposite which is 7′. Subtracting 18.2 from 19 leaves .8 as the second remainder. In the table under 26 is found 7.8, which with its decimal point moved one place to the left is nearest to the second remainder, and opposite 7.8 is 3, which indicates .3′ or 18″. Hence, the angle is 29° 30′ + 7′ + 18″ = 29° 37′ 18″.

INVOLUTION AND EVOLUTION

By means of the following table, the square, cube, square root, cube root, and reciprocal of any number may be obtained correct always to five significant figures, and in the majority of cases correct to six significant figures.

In any number, the figures beginning with the first digit* at the left and ending with the last digit at the right, are

*Ciphers (used merely to locate the decimal point) are not digits.

called the *significant figures* of the number. Thus, the number 405,800 has the four significant figures 4, 0, 5, 8; and the *significant part* of the number is 4058. The number .000090067 has five significant figures, 9, 0, 0, 6, 7, and the significant part is 90067. *All numbers that differ only in the position of the decimal point have the same significant figures and the same significant part.* For example, .002103, 21.03, 21,030, and 210,300 have the same significant figures 2, 1, 0, and 3, and the same significant part 2103.

The *integral part* of a number is the part to the left of the decimal point.

Square and Cube Roots.—If the given number contains less than four significant figures, the required root can be found in the table, the square root under $\sqrt{n}$, or $\sqrt{10n}$, and the cube root under $\sqrt[3]{n}$, $\sqrt[3]{10n}$, or $\sqrt[3]{100n}$, according to the number of significant figures in the integral part of the number. Thus, $\sqrt{3.14} = 1.772$; $\sqrt{31.4} = \sqrt{10 \times 3.14} = 5.60357$; $\sqrt[3]{3.14} = 1.46434$; $\sqrt[3]{31.4} = \sqrt[3]{10 \times 3.14} = 3.15484$; $\sqrt[3]{314} = \sqrt[3]{100 \times 3.14} = 6.79688$.

In order to locate the decimal point, the given number must be pointed off into periods of two figures each for square root and three figures each for cube root, beginning always at the decimal point. Thus, for square root: 12703, 1'27'03; 12.703, 12.70'30; 220000, 22'00'00; .000442, .00'04'42; and for cube root: 3141.6, 3'141.6; 67296428, 67'296'428; .0000000217, .000'000'021'700, etc.

There are as many figures in the root preceding the decimal point as there are periods preceding the decimal point in the given number; if the number is entirely decimal, the root is entirely decimal, and there are as many ciphers following the decimal point in the root as there are cipher periods following the decimal point in the given number.

Applying this rule, $\sqrt{220000} = 469.04$, $\sqrt{.000442} = .021024$, $\sqrt[3]{518000} = 80.3113$, and $\sqrt[3]{.000073} = .0418$.

If the number has more than three significant figures, point off the number into periods, place a decimal point between the first and second periods of the significant part of the number, and proceed as in the following examples:

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.01	1.0201	1.03030	1.00499	3.17805	1.00332	2.16159	4.65701	.990099
1.02	1.0404	1.06121	1.00995	3.19374	1.00662	2.16870	4.67233	.980392
1.03	1.0609	1.09273	1.01489	3.20936	1.00990	2.17577	4.68755	.970874
1.04	1.0816	1.12486	1.01980	3.22490	1.01316	2.18278	4.70267	.961538
1.05	1.1025	1.15763	1.02470	3.24037	1.01640	2.18976	4.71769	.952381
1.06	1.1236	1.19102	1.02956	3.25576	1.01961	2.19669	4.73262	.943396
1.07	1.1449	1.22504	1.03441	3.27109	1.02281	2.20358	4.74746	.934579
1.08	1.1664	1.25971	1.03923	3.28634	1.02599	2.21042	4.76220	.925926
1.09	1.1881	1.29503	1.04403	3.30151	1.02914	2.21722	4.77686	.917431
1.10	1.2100	1.33100	1.04881	3.31662	1.03228	2.22398	4.79142	.909091
1.11	1.2321	1.36763	1.05357	3.33167	1.03540	2.23070	4.80590	.900901
1.12	1.2544	1.40493	1.05830	3.34664	1.03850	2.23738	4.82028	.892857
1.13	1.2769	1.44290	1.06301	3.36155	1.04158	2.24402	4.83459	.884956
1.14	1.2996	1.48154	1.06771	3.37639	1.04464	2.25062	4.84881	.877193
1.15	1.3225	1.52088	1.07238	3.39116	1.04769	2.25718	4.86294	.869565
1.16	1.3456	1.56090	1.07703	3.40588	1.05072	2.26370	4.87700	.862069
1.17	1.3689	1.60161	1.08167	3.42053	1.05373	2.27019	4.89097	.854701
1.18	1.3924	1.64303	1.08628	3.43511	1.05672	2.27664	4.90487	.847458
1.19	1.4161	1.68516	1.09087	3.44964	1.05970	2.28305	4.91868	.840336
1.20	1.4400	1.72800	1.09545	3.46410	1.06266	2.28943	4.93242	.833333
1.21	1.4641	1.77156	1.10000	3.47851	1.06560	2.29577	4.94609	.826446
1.22	1.4884	1.81585	1.10454	3.49285	1.06853	2.30208	4.95968	.819672
1.23	1.5129	1.86087	1.10905	3.50714	1.07144	2.30835	4.97319	.813008
1.24	1.5376	1.90662	1.11355	3.52136	1.07434	2.31459	4.98663	.806452
1.25	1.5625	1.95313	1.11803	3.53553	1.07722	2.32080	5.00000	.800000
1.26	1.5876	2.00038	1.12250	3.54965	1.08008	2.32697	5.01330	.793651
1.27	1.6129	2.04838	1.12694	3.56371	1.08293	2.33310	5.02653	.787402
1.28	1.6384	2.09715	1.13137	3.57771	1.08577	2.33921	5.03968	.781250
1.29	1.6641	2.14669	1.13578	3.59166	1.08859	2.34529	5.05277	.775194
1.30	1.6900	2.19700	1.14018	3.60555	1.09139	2.35134	5.06580	.769231
1.31	1.7161	2.24809	1.14455	3.61939	1.09418	2.35735	5.07875	.763359
1.32	1.7424	2.29997	1.14891	3.63318	1.09696	2.36333	5.09164	.757576
1.33	1.7689	2.35264	1.15326	3.64692	1.09972	2.36928	5.10447	.751880
1.34	1.7956	2.40610	1.15758	3.66060	1.10247	2.37521	5.11723	.746269
1.35	1.8225	2.46038	1.16190	3.67423	1.10521	2.38110	5.12993	.740741
1.36	1.8496	2.51546	1.16619	3.68782	1.10793	2.38696	5.14256	.735294
1.37	1.8769	2.57135	1.17047	3.70135	1.11064	2.39280	5.15514	.729927
1.38	1.9044	2.62807	1.17473	3.71484	1.11334	2.39861	5.16765	.724638
1.39	1.9321	2.68562	1.17898	3.72827	1.11602	2.40439	5.18010	.719425
1.40	1.9600	2.74400	1.18322	3.74166	1.11869	2.41014	5.19249	.714286
1.41	1.9881	2.80322	1.18743	3.75500	1.12135	2.41587	5.20483	.709220
1.42	2.0164	2.86329	1.19164	3.76829	1.12399	2.42156	5.21710	.704225
1.43	2.0449	2.92421	1.19583	3.78153	1.12662	2.42724	5.22932	.699301
1.44	2.0736	2.98598	1.20000	3.79473	1.12924	2.43288	5.24148	.694444
1.45	2.1025	3.04863	1.20416	3.80789	1.13185	2.43850	5.25359	.689655
1.46	2.1316	3.11214	1.20830	3.82099	1.13445	2.44409	5.26564	.684932
1.47	2.1609	3.17652	1.21244	3.83406	1.13703	2.44966	5.27763	.680272
1.48	2.1904	3.24179	1.21655	3.84708	1.13960	2.45520	5.28957	.675676
1.49	2.2201	3.30795	1.22066	3.86005	1.14216	2.46072	5.30146	.671141
1.50	2.2500	3.37500	1.22474	3.87298	1.14471	2.46621	5.31329	.666667

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10\,n}$	$\sqrt[3]{n}$	$\sqrt[3]{10\,n}$	$\sqrt[3]{100\,n}$	$\frac{1}{n}$
1.51	2.2801	3.44295	1.22882	3.88587	1.14725	2.47168	5.32507	.662252
1.52	2.3104	3.51181	1.23288	3.89872	1.14978	2.47718	5.33680	.657895
1.53	2.3409	3.58158	1.23693	3.91152	1.15230	2.48255	5.34848	.653595
1.54	2.3716	3.65226	1.24097	3.92428	1.15480	2.48794	5.36011	.649351
1.55	2.4025	3.72388	1.24499	3.93700	1.15729	2.49332	5.37169	.645161
1.56	2.4336	3.79642	1.24900	3.94968	1.15978	2.49866	5.38321	.641026
1.57	2.4649	3.86989	1.25300	3.96232	1.16225	2.50399	5.39469	.636943
1.58	2.4964	3.94431	1.25698	3.97492	1.16471	2.50930	5.40612	.632911
1.59	2.5281	4.01968	1.26095	3.98748	1.16717	2.51458	5.41750	.628931
1.60	2.5600	4.09600	1.26491	4.00000	1.16961	2.51984	5.42884	.625000
1.61	2.5921	4.17328	1.26886	4.01248	1.17204	2.52508	5.44012	.621118
1.62	2.6244	4.25153	1.27279	4.02492	1.17446	2.53030	5.45136	.617284
1.63	2.6569	4.33075	1.27671	4.03733	1.17687	2.53549	5.46256	.613497
1.64	2.6896	4.41094	1.28062	4.04969	1.17927	2.54067	5.47370	.609756
1.65	2.7225	4.49213	1.28452	4.06202	1.18167	2.54582	5.48481	.606061
1.66	2.7556	4.57430	1.28841	4.07431	1.18405	2.55095	5.49586	.602410
1.67	2.7889	4.65746	1.29228	4.08656	1.18642	2.55607	5.50688	.598802
1.68	2.8224	4.74163	1.29615	4.09878	1.18878	2.56116	5.51785	.595238
1.69	2.8561	4.82681	1.30000	4.11096	1.19114	2.56623	5.52877	.591716
1.70	2.8900	4.91300	1.30384	4.12311	1.19348	2.57128	5.53966	.588235
1.71	2.9241	5.00021	1.30767	4.13521	1.19582	2.57631	5.55050	.584795
1.72	2.9584	5.08845	1.31149	4.14729	1.19815	2.58133	5.56130	.581395
1.73	2.9929	5.17772	1.31529	4.15933	1.20046	2.58632	5.57205	.578035
1.74	3.0276	5.26802	1.31909	4.17133	1.20277	2.59129	5,58277	.574713
1.75	3.0625	5.35938	1.32288	4.18330	1.20507	2.59625	5.59344	.571429
1.76	3.0976	5.45178	1.32665	4.19524	1.20736	2.60118	5.60408	.568182
1.77	3.1329	5.54523	1.33041	4.20714	1.20964	2.60610	5.61467	.564972
1.78	3.1684	5.63975	1.33417	4.21900	1.21192	2.61100	5.62523	.561798
1.79	3.2041	5.73534	1.33791	4.23084	1.21418	2.61588	5.63574	.558659
1.80	3.2400	5.83200	1.34164	4.24264	1.21644	2.62074	5.64622	.555556
1.81	3.2761	5.92974	1.34536	4.25441	1.21869	2.62558	5.65665	.552486
1.82	3.3124	6.02857	1.34907	4.26615	1.22093	2.63041	5.66705	.549451
1.83	3.3489	6.12849	1.35277	4.27785	1.22316	2.63522	5.67741	.546448
1.84	3.3856	6.22950	1.35647	4.28952	1.22539	2.64001	5.68773	.543478
1.85	3.4225	6.33163	1.36015	4.30116	1.22760	2.64479	5.69802	.540541
1.86	3.4596	6.43486	1.36382	4.31277	1.22981	2.64954	5.70827	.537634
1.87	3.4969	6.53920	1.36748	4.32435	1.23201	2.65428	5.71848	.534759
1.88	3.5344	6.64467	1.37113	4.33590	1.23420	2.65900	5.72865	.531915
1.89	3.5721	6.75127	1.37477	4.34741	1.23639	2.66371	5.73879	.529101
1.90	3.6100	6.85900	1.37840	4.35890	1.23856	2.66840	5.74890	.526316
1.91	3.6481	6.96787	1.38203	4.37035	1.24073	2.67307	5.75897	.523560
1.92	3.6864	7.07789	1.38564	4.38178	1.24289	2.67773	5.76900	.520833
1.93	3.7249	7.18906	1.38924	4.39318	1.24505	2.68237	5.77900	.518135
1.94	3.7636	7.30138	1.39284	4.40454	1.24719	2.68700	5.78896	.515464
1.95	3.8025	7.41488	1.39642	4.41588	1.24933	2.69161	5.79889	.512821
1.96	3.8416	7.52954	1.40000	4.42719	1.25146	2.69620	5.80879	.510204
1.97	3.8809	7.64537	1.40357	4.43847	1.25359	2.70078	5.81865	.507614
1.98	3.9204	7.76239	1.40712	4.44972	1.25571	2.70534	5.82848	.505051
1.99	3.9601	7.88060	1.41067	4.46094	1.25782	2.70989	5.83827	.502513
2.00	4.0000	8.00000	1.41421	4.47214	1.25992	2.71442	5.84804	.500000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
2.01	4.0401	8.12060	1.41774	4.48330	1.26202	2.71893	5.85777	.497512
2.02	4.0804	8.24241	1.42127	4.49444	1.26411	2.72343	5.86746	.495050
2.03	4.1209	8.36543	1.42478	4.50555	1.26619	2.72792	5.87713	.492611
2.04	4.1616	8.48966	1.42829	4.51664	1.26827	2.73239	5.88677	.490196
2.05	4.2025	8.61513	1.43178	4.52769	1.27033	2.73685	5.89637	.487805
2.06	4.2436	8.74182	1.43527	4.53872	1.27240	2.74129	5.90594	.485437
2.07	4.2849	8.86974	1.43875	4.54973	1.27445	2.74572	5.91548	.483092
2.08	4.3264	8.99891	1.44222	4.56070	1.27650	2.75014	5.92499	.480769
2.09	4.3681	9.12933	1.44568	4.57165	1.27854	2.75454	5.93447	.478469
2.10	4.4100	9.26100	1.44914	4.58258	1.28058	2.75893	5.94392	.476191
2.11	4.4521	9.39393	1.45258	4.59347	1.28261	2.76330	5.95334	.473934
2.12	4.4944	9.52813	1.45602	4.60435	1.28463	2.76766	5.96273	.471698
2.13	4.5369	9.66360	1.45945	4.61519	1.28665	2.77200	5.97209	.469484
2.14	4.5796	9.80034	1.46287	4.62601	1.28866	2.77633	5.98142	.467290
2.15	4.6225	9.93838	1.46629	4.63681	1.29066	2.78065	5.99073	.465116
2.16	4.6656	10.0777	1.46969	4.64758	1.29266	2.78495	6.00000	.462963
2.17	4.7089	10.2183	1.47309	4.65833	1.29465	2.78924	6.00925	.460829
2.18	4.7524	10.3602	1.47648	4.66905	1.29664	2.79352	6.01846	.458716
2.19	4.7961	10.5035	1.47986	4.67974	1.29862	2.79779	6.02765	.456621
2.20	4.8400	10.6480	1.48324	4.69042	1.30059	2.80204	6.03681	.454545
2.21	4.8841	10.7939	1.48661	4.70106	1.30256	2.80628	6.04594	.452489
2.22	4.9284	10.9410	1.48997	4.71169	1.30452	2.81051	6.05505	.450451
2.23	4.9729	11.0896	1.49332	4.72229	1.30648	2.81472	6.06413	.448431
2.24	5.0176	11.2394	1.49666	4.73286	1.30843	2.81892	6.07318	.446429
2.25	5.0625	11.3906	1.50000	4.74342	1.31037	2.82311	6.08220	.444444
2.26	5.1076	11.5432	1.50333	4.75395	1.31231	2.82728	6.09120	.442478
2.27	5.1529	11.6971	1.50665	4.76445	1.31424	2.83145	6.10017	.440529
2.28	5.1984	11.8524	1.50997	4.77493	1.31617	2.83560	6.10911	.438597
2.29	5.2441	12.0090	1.51327	4.78539	1.31809	2.83974	6.11803	.436681
2.30	5.2900	12.1670	1.51658	4.79583	1.32001	2.84387	6.12693	.434783
2.31	5.3361	12.3264	1.51987	4.80625	1.32192	2.84798	6.13579	.432900
2.32	5.3824	12.4872	1.52315	4.81664	1.32382	2.85209	6.14463	.431035
2.33	5.4289	12.6493	1.52643	4.82701	1.32572	2.85618	6.15345	.429185
2.34	5.4756	12.8129	1.52971	4.83735	1.32761	2.86026	6.16224	.427350
2.35	5.5225	12.9779	1.53297	4.84768	1.32950	2.86433	6.17101	.425532
2.36	5.5696	13.1443	1.53623	4.85798	1.33139	2.86838	6.17975	.423729
2.37	5.6169	13.3121	1.53948	4.86826	1.33326	2.87243	6.18846	.421941
2.38	5.6644	13.4813	1.54272	4.87852	1.33514	2.87646	6.19715	.420168
2.39	5.7121	13.6519	1.54596	4.88876	1.33700	2.88049	6.20582	.418410
2.40	5.7600	13.8240	1.54919	4.89898	1.33887	2.88450	6.21447	.416667
2.41	5.8081	13.9975	1.55242	4.90918	1.34072	2.88850	6.22308	.414938
2.42	5.8564	14.1725	1.55563	4.91935	1.34257	2.89249	6.23168	.413223
2.43	5.9049	14.3489	1.55885	4.92950	1.34442	2.89647	6.24025	.411523
2.44	5.9536	14.5268	1.56205	4.93964	1.34626	2.90044	6.24880	.409836
2.45	6.0025	14.7061	1.56525	4.94975	1.34810	2.90439	6.25732	.408163
2.46	6.0516	14.8869	1.56844	4.95984	1.34993	2.90834	6.26583	.406504
2.47	6.1009	15.0692	1.57162	4.96991	1.35176	2.91227	6.27431	.404858
2.48	6.1504	15.2530	1.57480	4.97996	1.35358	2.91620	6.28276	.403226
2.49	6.2001	15.4382	1.57797	4.98999	1.35540	2.92011	6.29119	.401606
2.50	6.2500	15.6250	1.58114	5.00000	1.35721	2.92402	6.29961	.400000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
2.51	6.3001	15.8133	1.58430	5.00999	1.35902	2.92791	6.30799	.398406
2.52	6.3504	16.0030	1.58745	5.01996	1.36082	2.93179	6.31636	.396825
2.53	6.4009	16.1943	1.59060	5.02991	1.36262	2.93567	6.32470	.395257
2.54	6.4516	16.3871	1.59374	5.03984	1.36441	2.93953	6.33303	.393701
2.55	6.5025	16.5814	1.59687	5.04975	1.36620	2.94338	6.34133	.392157
2.56	6.5536	16.7772	1.60000	5.05964	1.36798	2.94723	6.34960	.390625
2.57	6.6049	16.9746	1.60312	5.06952	1.36976	2.95106	6.35786	.389105
2.58	6.6564	17.1735	1.60624	5.07937	1.37153	2.95488	6.36610	.387597
2.59	6.7081	17.3740	1.60935	5.08920	1.37330	2.95869	6.37431	.386100
2.60	6.7600	17.5760	1.61245	5.09902	1.37507	2.96250	6.38250	.384615
2.61	6.8121	17.7796	1.61555	5.10882	1.37683	2.96629	6.39068	.383142
2.62	6.8644	17.9847	1.61864	5.11859	1.37859	2.97007	6.39883	.381679
2.63	6.9169	18.1914	1.62173	5.12835	1.38034	2.97385	6.40696	.380228
2.64	6.9696	18.3997	1.62481	5.13809	1.38208	2.97761	6.41507	.378788
2.65	7.0225	18.6096	1.62788	5.14782	1.38383	2.98137	6.42316	.377358
2.66	7.0756	18.8211	1.63095	5.15752	1.38557	2.98511	6.43123	.375940
2.67	7.1289	19.0342	1.63401	5.16720	1.38730	2.98885	6.43928	.374532
2.68	7.1824	19.2488	1.63707	5.17687	1.38903	2.99257	6.44731	.373134
2.69	7.2361	19.4651	1.64012	5.18652	1.39076	2.99629	6.45531	.371747
2.70	7.2900	19.6830	1.64317	5.19615	1.39248	3.00000	6.46330	.370370
2.71	7.3441	19.9025	1.64621	5.20577	1.39419	3.00370	6.47127	.369004
2.72	7.3984	20.1236	1.64924	5.21536	1.39591	3.00739	6.47922	.367647
2.73	7.4529	20.3464	1.65227	5.22494	1.39761	3.01107	6.48715	.366300
2.74	7.5076	20.5708	1.65529	5.23450	1.39932	3.01474	6.49507	.364964
2.75	7.5625	20.7969	1.65831	5.24404	1.40102	3.01841	6.50296	.363636
2.76	7.6176	21.0246	1.66132	5.25357	1.40272	3.02206	6.51083	.362319
2.77	7.6729	21.2539	1.66433	5.26308	1.40441	3.02571	6.51868	.361011
2.78	7.7284	21.4850	1.66733	5.27257	1.40610	3.02934	6.52652	.359712
2.79	7.7841	21.7176	1.67033	5.28205	1.40778	3.03297	6.53434	.358423
2.80	7.8400	21.9520	1.67332	5.29150	1.40946	3.03659	6.54213	.357143
2.81	7.8961	22.1880	1.67631	5.30094	1.41114	3.04020	6.54991	.355872
2.82	7.9524	22.4258	1.67929	5.31037	1.41281	3.04380	6.55767	.354610
2.83	8.0089	22.6652	1.68226	5.31977	1.41448	3.04740	6.56541	.353357
2.84	8.0656	22.9063	1.68523	5.32917	1.41614	3.05098	6.57314	.352113
2.85	8.1225	23.1491	1.68819	5.33854	1.41780	3.05456	6.58084	.350877
2.86	8.1796	23.3937	1.69115	5.34790	1.41946	3.05813	6.58853	.349650
2.87	8.2369	23.6399	1.69411	5.35724	1.42111	3.06169	6.59620	.348432
2.88	8.2944	23.8879	1.69706	5.36656	1.42276	3.06524	6.60385	.347222
2.89	8.3521	24.1376	1.70000	5.37587	1.42440	3.06878	6.61149	.346021
2.90	8.4100	24.3890	1.70294	5.38516	1.42604	3.07232	6.61911	.344828
2.91	8.4681	24.6422	1.70587	5.39444	1.42768	3.07585	6.62671	.343643
2.92	8.5264	24.8971	1.70880	5.40370	1.42931	3.07936	6.63429	.342466
2.93	8.5849	25.1538	1.71172	5.41295	1.43094	3.08287	6.64185	.341297
2.94	8.6436	25.4122	1.71464	5.42218	1.43257	3.08638	6.64940	.340136
2.95	8.7025	25.6724	1.71756	5.43139	1.43419	3.08987	6.65693	.338983
2.96	8.7616	25.9343	1.72047	5.44059	1.43581	3.09336	6.66444	.337838
2.97	8.8209	26.1981	1.72337	5.44977	1.43743	3.09684	6.67194	.336700
2.98	8.8804	26.4636	1.72627	5.45894	1.43904	3.10031	6.67942	.335571
2.99	8.9401	26.7309	1.72916	5.46809	1.44065	3.10378	6.68688	.334448
3.00	9.0000	27.0000	1.73205	5.47723	1.44225	3.10723	6.69433	.333333

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
3.01	9.0601	27.2709	1.73494	5.48635	1.44385	3.11068	6.70176	.332226
3.02	9.1204	27.5436	1.73781	5.49545	1.44545	3.11412	6.70917	.331126
3.03	9.1809	27.8181	1.74069	5.50454	1.44704	3.11755	6.71657	.330033
3.04	9.2416	28.0945	1.74356	5.51362	1.44863	3.12098	6.72395	.328947
3.05	9.3025	28.3726	1.74642	5.52268	1.45022	3.12440	6.73132	.327869
3.06	9.3636	28.6526	1.74929	5.53173	1.45180	3.12781	6.73866	.326797
3.07	9.4249	28.9344	1.75214	5.54076	1.45338	3.13121	6.74600	.325733
3.08	9.4864	29.2181	1.75499	5.54977	1.45496	3.13461	6.75331	.324675
3.09	9.5481	29.5036	1.75784	5.55878	1.45653	3.13800	6.76061	.323625
3.10	9.6100	29.7910	1.76068	5.56776	1.45810	3.14138	6.76790	.322581
3.11	9.6721	30.0802	1.76352	5.57674	1.45967	3.14475	6.77517	.321543
3.12	9.7344	30.3713	1.76635	5.58570	1.46123	3.14812	6.78242	.320513
3.13	9.7969	30.6643	1.76918	5.59464	1.46279	3.15148	6.78966	.319489
3.14	9.8596	30.9591	1.77200	5.60357	1.46434	3.15484	6.79688	.318471
3.15	9.9225	31.2559	1.77482	5.61249	1.46590	3.15818	6.80409	.317460
3.16	9.9856	31.5545	1.77764	5.62139	1.46745	3.16152	6.81128	.316456
3.17	10.0489	31.8550	1.78045	5.63028	1.46899	3.16485	6.81846	.315457
3.18	10.1124	32.1574	1.78326	5.63915	1.47054	3.16817	6.82562	.314465
3.19	10.1761	32.4618	1.78606	5.64801	1.47208	3.17149	6.83277	.313480
3.20	10.2400	32.7680	1.78885	5.65685	1.47361	3.17480	6.83990	.312500
3.21	10.3041	33.0762	1.79165	5.66569	1.47515	3.17811	6.84702	.311527
3.22	10.3684	33.3862	1.79444	5.67450	1.47668	3.18140	6.85412	.310559
3.23	10.4329	33.6983	1.79722	5.68331	1.47820	3.18469	6.86121	.309598
3.24	10.4976	34.0122	1.80000	5.69210	1.47973	3.18798	6.86829	.308642
3.25	10.5625	34.3281	1.80278	5.70088	1.48125	3.19125	6.87534	.307692
3.26	10.6276	34.6460	1.80555	5.70964	1.48277	3.19452	6.88239	.306749
3.27	10.6929	34.9658	1.80831	5.71839	1.48428	3.19779	6.88942	.305810
3.28	10.7584	35.2876	1.81108	5.72713	1.48579	3.20104	6.89643	.304878
3.29	10.8241	35.6129	1.81384	5.73585	1.48730	3.20429	6.90344	.303951
3.30	10.8900	35.9370	1.81659	5.74456	1.48881	3.20753	6.91042	.303030
3.31	10.9561	36.2647	1.81934	5.75326	1.49031	3.21077	6.91740	.302115
3.32	11.0224	36.5944	1.82209	5.76194	1.49181	3.21400	6.92436	.301205
3.33	11.0889	36.9260	1.82483	5.77062	1.49330	3.21723	6.93130	.300300
3.34	11.1556	37.2597	1.82757	5.77927	1.49480	3.22044	6.93823	.299401
3.35	11.2225	37.5954	1.83030	5.78792	1.49629	3.22365	6.94515	.298508
3.36	11.2896	37.9331	1.83303	5.79655	1.49777	3.22686	6.95205	.297619
3.37	11.3569	38.2728	1.83576	5.80517	1.49926	3.23005	6.95894	.296736
3.38	11.4244	38.6145	1.83848	5.81378	1.50074	3.23325	6.96582	.295858
3.39	11.4921	38.9582	1.84120	5.82237	1.50222	3.23643	6.97268	.294985
3.40	11.5600	39.3040	1.84391	5.83095	1.50369	3.23961	6.97953	.294118
3.41	11.6281	39.6518	1.84662	5.83952	1.50517	3.24278	6.98637	.293255
3.42	11.6964	40.0017	1.84932	5.84808	1.50664	3.24595	6.99319	.292398
3.43	11.7649	40.3536	1.85203	5.85662	1.50810	3.24911	7.00000	.291545
3.44	11.8336	40.7076	1.85472	5.86515	1.50957	3.25227	7.00680	.290698
3.45	11.9025	41.0636	1.85742	5.87367	1.51103	3.25542	7.01358	.289855
3.46	11.9716	41.4217	1.86011	5.88218	1.51249	3.25856	7.02035	.289017
3.47	12.0409	41.7819	1.86279	5.89067	1.51394	3.26169	7.02711	.288184
3.48	12.1104	42.1442	1.86548	5.89915	1.51540	3.26482	7.03385	.287356
3.49	12.1801	42.5085	1.86815	5.90762	1.51685	3.26795	7.04058	.286533
3.50	12.2500	42.8750	1.87083	5.91608	1.51829	3.27107	7.04730	.285714

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
3.51	12.3201	43.2436	1.87350	5.92453	1.51974	3.27418	7.05400	.284900
3.52	12.3904	43.6142	1.87617	5.93296	1.52118	3.27729	7.06070	.284091
3.53	12.4609	43.9870	1.87883	5.94138	1.52262	3.28039	7.06738	.283286
3.54	12.5316	44.3619	1.88149	5.94979	1.52406	3.28348	7.07404	.282486
3.55	12.6025	44.7389	1.88414	5.95819	1.52549	3.28657	7.08070	.281690
3.56	12.6736	45.1180	1.88680	5.96657	1.52692	3.28965	7.08734	.280899
3.57	12.7449	45.4993	1.88944	5.97495	1.52835	3.29273	7.09397	.280112
3.58	12.8164	45.8827	1.89209	5.98331	1.52978	3.29580	7.10059	.279330
3.59	12.8881	46.2683	1.89473	5.99166	1.53120	3.29887	7.10719	.278552
3.60	12.9600	46.6560	1.89737	6.00000	1.53262	3.30193	7.11379	.277778
3.61	13.0321	47.0459	1.90000	6.00833	1.53404	3.30498	7.12037	.277008
3.62	13.1044	47.4379	1.90263	6.01664	1.53545	3.30803	7.12694	.276243
3.63	13.1769	47.8321	1.90526	6.02495	1.53686	3.31107	7.13349	.275482
3.64	13.2496	48.2285	1.90788	6.03324	1.53827	3.31411	7.14004	.274725
3.65	13.3225	48.6271	1.91050	6.04152	1.53968	3.31714	7.14657	.273973
3.66	13.3956	49.0279	1.91311	6.04979	1.54109	3.32017	7.15309	.273224
3.67	13.4689	49.4309	1.91572	6.05805	1.54249	3.32319	7.15960	.272480
3.68	13.5424	49.8360	1.91833	6.06630	1.54389	3.32621	7.16610	.271739
3.69	13.6161	50.2434	1.92094	6.07454	1.54529	3.32922	7.17258	.271003
3.70	13.6900	50.6530	1.92354	6.08276	1.54668	3.33222	7.17905	.270270
3.71	13.7641	51.0648	1.92614	6.09098	1.54807	3.33522	7.18552	.269542
3.72	13.8384	51.4788	1.92873	6.09918	1.54946	3.33822	7.19197	.268817
3.73	13.9129	51.8951	1.93132	6.10737	1.55085	3.34120	7.19841	.268097
3.74	13.9876	52.3136	1.93391	6.11555	1.55223	3.34419	7.20483	.267380
3.75	14.0625	52.7344	1.93649	6.12372	1.55362	3.34716	7.21125	.266667
3.76	14.1376	53.1574	1.93907	6.13188	1.55500	3.35014	7.21765	.265957
3.77	14.2129	53.5826	1.94165	6.14003	1.55637	3.35310	7.22405	.265252
3.78	14.2884	54.0102	1.94422	6.14817	1.55775	3.35607	7.23043	.264550
3.79	14.3641	54.4399	1.94679	6.15630	1.55912	3.35902	7.23680	.263852
3.80	14.4400	54.8720	1.94936	6.16441	1.56049	3.36198	7.24316	.263158
3.81	14.5161	55.3063	1.95192	6.17252	1.56186	3.36492	7.24950	.262467
3.82	14.5924	55.7430	1.95448	6.18061	1.56322	3.36786	7.25584	.261780
3.83	14.6689	56.1819	1.95704	6.18870	1.56459	3.37080	7.26217	.261097
3.84	14.7456	56.6231	1.95959	6.19677	1.56595	3.37373	7.26848	.260417
3.85	14.8225	57.0666	1.96214	6.20484	1.56731	3.37666	7.27479	.259740
3.86	14.8996	57.5125	1.96469	6.21289	1.56866	3.37958	7.28108	.259067
3.87	14.9769	57.9606	1.96723	6.22093	1.57001	3.38249	7.28736	.258398
3.88	15.0544	58.4111	1.96977	6.22896	1.57137	3.38540	7.29363	.257732
3.89	15.1321	58.8639	1.97231	6.23699	1.57271	3.38831	7.29989	.257069
3.90	15.2100	59.3190	1.97484	6.24500	1.57406	3.39121	7.30614	.256410
3.91	15.2881	59.7765	1.97737	6.25300	1.57541	3.39411	7.31238	.255755
3.92	15.3664	60.2363	1.97990	6.26099	1.57675	3.39700	7.31861	.255102
3.93	15.4449	60.6985	1.98242	6.26897	1.57809	3.39988	7.32483	.254453
3.94	15.5236	61.1630	1.98494	6.27694	1.57942	3.40277	7.33104	.253807
3.95	15.6025	61.6299	1.98746	6.28490	1.58076	3.40564	7.33723	.253165
3.96	15.6816	62.0991	1.98997	6.29285	1.58209	3.40851	7.34342	.252525
3.97	15.7609	62.5706	1.99249	6.30079	1.58342	3.41138	7.34960	.251889
3.98	15.8404	63.0448	1.99499	6.30872	1.58475	3.41424	7.35576	.251256
3.99	15.9201	63.5212	1.99750	6.31664	1.58608	3.41710	7.36192	.250627
4.00	16.0000	64.0000	2.00000	6.32456	1.58740	3.41995	7.36806	.250000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
4.01	16.0801	64.4812	2.00250	6.33246	1.58872	3.42280	7.37420	.249377
4.02	16.1604	64.9648	2.00499	6.34035	1.59004	3.42564	7.38032	.248756
4.03	16.2409	65.4508	2.00749	6.34823	1.59136	3.42848	7.38644	.248139
4.04	16.3216	65.9393	2.00998	6.35610	1.59267	3.43131	7.39254	.247525
4.05	16.4025	66.4301	2.01246	6.36396	1.59399	3.43414	7.39864	.246914
4.06	16.4836	66.9234	2.01494	6.37181	1.59530	3.43697	7.40472	.246305
4.07	16.5649	67.4191	2.01742	6.37966	1.59661	3.43979	7.41080	.245700
4.08	16.6464	67.9173	2.01990	6.38749	1.59791	3.44260	7.41686	.245098
4.09	16.7281	68.4179	2.02237	6.39531	1.59922	3.44541	7.42291	.244499
4.10	16.8100	68.9210	2.02485	6.40312	1.60052	3.44822	7.42896	.243902
4.11	16.8921	69.4265	2.02731	6.41093	1.60182	3.45102	7.43499	.243309
4.12	16.9744	69.9345	2.02978	6.41872	1.60312	3.45382	7.44102	.242718
4.13	17.0569	70.4450	2.03224	6.42651	1.60441	3.45661	7.44703	.242131
4.14	17.1396	70.9579	2.03470	6.43428	1.60571	3.45939	7.45304	.241546
4.15	17.2225	71.4734	2.03715	6.44205	1.60700	3.46218	7.45904	.240964
4.16	17.3056	71.9913	2.03961	6.44981	1.60829	3.46496	7.46502	.240385
4.17	17.3889	72.5117	2.04206	6.45755	1.60958	3.46773	7.47100	.239808
4.18	17.4724	73.0346	2.04450	6.46529	1.61086	3.47050	7.47697	.239234
4.19	17.5561	73.5601	2.04695	6.47302	1.61215	3.47327	7.48292	.238664
4.20	17.6400	74.0880	2.04939	6.48074	1.61343	3.47603	7.48887	.238095
4.21	17.7241	74.6185	2.05183	6.48845	1.61471	3.47878	7.49481	.237530
4.22	17.8084	75.1514	2.05426	6.49615	1.61599	3.48154	7.50074	.236967
4.23	17.8929	75.6870	2.05670	6.50385	1.61726	3.48428	7.50666	.236407
4.24	17.9776	76.2250	2.05913	6.51153	1.61853	3.48703	7.51257	.235849
4.25	18.0625	76.7656	2.06155	6.51920	1.61981	3.48977	7.51847	.235294
4.26	18.1476	77.3088	2.06398	6.52687	1.62108	3.49250	7.52437	.234742
4.27	18.2329	77.8545	2.06640	6.53452	1.62234	3.49523	7.53025	.234192
4.28	18.3184	78.4028	2.06882	6.54217	1.62361	3.49796	7.53612	.233645
4.29	18.4041	78.9536	2.07123	6.54981	1.62487	3.50068	7.54199	.233100
4.30	18.4900	79.5070	2.07364	6.55744	1.62613	3.50340	7.54784	.232558
4.31	18.5761	80.0630	2.07605	6.56506	1.62739	3.50611	7.55369	.232019
4.32	18.6624	80.6216	2.07846	6.57267	1.62865	3.50882	7.55953	.231482
4.33	18.7489	81.1827	2.08087	6.58027	1.62991	3.51153	7.56535	.230947
4.34	18.8356	81.7465	2.08327	6.58787	1.63116	3.51423	7.57117	.230415
4.35	18.9225	82.3129	2.08567	6.59545	1.63241	3.51692	7.57698	.229885
4.36	19.0096	82.8819	2.08806	6.60303	1.63366	3.51962	7.58279	.229358
4.37	19.0969	83.4535	2.09045	6.61060	1.63491	3.52231	7.58858	.228833
4.38	19.1844	84.0277	2.09284	6.61816	1.63616	3.52499	7.59436	.228311
4.39	19.2721	84.6045	2.09523	6.62571	1.63740	3.52767	7.60014	.227790
4.40	19.3600	85.1840	2.09762	6.63325	1.63864	3.53035	7.60590	.227273
4.41	19.4481	85.7661	2.10000	6.64078	1.63988	3.53302	7.61166	.226757
4.42	19.5364	86.3509	2.10238	6.64831	1.64112	3.53569	7.61741	.226244
4.43	19.6249	86.9383	2.10476	6.65582	1.64236	3.53835	7.62315	.225734
4.44	19.7136	87.5284	2.10713	6.66333	1.64359	3.54101	7.62888	.225225
4.45	19.8025	88.1211	2.10950	6.67083	1.64483	3.54367	7.63461	.224719
4.46	19.8916	88.7165	2.11187	6.67832	1.64606	3.54632	7.64032	.224215
4.47	19.9809	89.3146	2.11424	6.68581	1.64729	3.54897	7.64603	.223714
4.48	20.0704	89.9154	2.11660	6.69328	1.64851	3.55162	7.65172	.223214
4.49	20.1601	90.5188	2.11896	6.70075	1.64974	3.55426	7.65741	.222717
4.50	20.2500	91.1250	2.12132	6.70820	1.65096	3.55689	7.66309	.222222

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
4.51	20.3401	91.7339	2.12368	6.71565	1.65219	3.55953	7.66877	.221730
4.52	20.4304	92.3454	2.12603	6.72309	1.65341	3.56215	7.67443	.221239
4.53	20.5209	92.9597	2.12838	6.73053	1.65462	3.56478	7.68009	.220751
4.54	20.6116	93.5767	2.13073	6.73795	1.65584	3.56740	7.68573	.220264
4.55	20.7025	94.1964	2.13307	6.74537	1.65706	3.57002	7.69137	.219780
4.56	20.7936	94.8188	2.13542	6.75278	1.65827	3.57263	7.69700	.219298
4.57	20.8849	95.4440	2.13776	6.76018	1.65948	3.57524	7.70262	.218818
4.58	20.9764	96.0719	2.14009	6.76757	1.66069	3.57785	7.70824	.218341
4.59	21.0681	96.7026	2.14243	6.77495	1.66190	3.58045	7.71384	.217865
4.60	21.1600	97.3360	2.14476	6.78233	1.66310	3.58305	7.71944	.217391
4.61	21.2521	97.9722	2.14709	6.78970	1.66431	3.58564	7.72503	.216920
4.62	21.3444	98.6111	2.14942	6.79706	1.66551	3.58823	7.73061	.216450
4.63	21.4369	99.2528	2.15174	6.80441	1.66671	3.59082	7.73619	.215983
4.64	21.5296	99.8973	2.15407	6.81175	1.66791	3.59340	7.74175	.215517
4.65	21.6225	100.545	2.15639	6.81909	1.66911	3.59598	7.74731	.215054
4.66	21.7156	101.195	2.15870	6.82642	1.67030	3.59856	7.75286	.214592
4.67	21.8089	101.848	2.16102	6.83374	1.67150	3.60113	7.75840	.214133
4.68	21.9024	102.503	2.16333	6.84105	1.67269	3.60370	7.76394	.213675
4.69	21.9961	103.162	2.16564	6.84836	1.67388	3.60626	7.76946	.213220
4.70	22.0900	103.823	2.16795	6.85565	1.67507	3.60883	7.77498	.212766
4.71	22.1841	104.487	2.17025	6.86294	1.67626	3.61138	7.78049	.212314
4.72	22.2784	105.154	2.17256	6.87023	1.67744	3.61394	7.78599	.211864
4.73	22.3729	105.824	2.17486	6.87750	1.67863	3.61649	7.79149	.211417
4.74	22.4676	106.496	2.17715	6.88477	1.67981	3.61904	7.79697	.210971
4.75	22.5625	107.172	2.17945	6.89202	1.68099	3.62158	7.80245	.210526
4.76	22.6576	107.850	2.18174	6.89928	1.68217	3.62412	7.80793	.210084
4.77	22.7529	108.531	2.18403	6.90652	1.68334	3.62665	7.81339	.209644
4.78	22.8484	109.215	2.18632	6.91375	1.68452	3.62919	7.81885	.209205
4.79	22.9441	109.902	2.18861	6.92098	1.68569	3.63171	7.82429	.208768
4.80	23.0400	110.592	2.19089	6.92820	1.68687	3.63424	7.82974	.208333
4.81	23.1361	111.285	2.19317	6.93542	1.68804	3.63676	7.83517	.207900
4.82	23.2324	111.980	2.19545	6.94262	1.68920	3.63928	7.84059	.207469
4.83	23.3289	112.679	2.19773	6.94982	1.69037	3.64180	7.84601	.207039
4.84	23.4256	113.380	2.20000	6.95701	1.69154	3.64431	7.85142	.206612
4.85	23.5225	114.084	2.20227	6.96419	1.69270	3.64682	7.85683	.206186
4.86	23.6196	114.791	2.20454	6.97137	1.69386	3.64932	7.86222	.205761
4.87	23.7169	115.501	2.20681	6.97854	1.69503	3.65182	7.86761	.205339
4.88	23.8144	116.214	2.20907	6.98570	1.69619	3.65432	7.87299	.204918
4.89	23.9121	116.930	2.21133	6.99285	1.69734	3.65682	7.87837	.204499
4.90	24.0100	117.649	2.21359	7.00000	1.69850	3.65931	7.88374	.204082
4.91	24.1081	118.371	2.21585	7.00714	1.69965	3.66179	7.88909	.203666
4.92	24.2064	119.095	2.21811	7.01427	1.70081	3.66428	7.89445	.203252
4.93	24.3049	119.823	2.22036	7.02140	1.70196	3.66676	7.89979	.202840
4.94	24.4036	120.554	2.22261	7.02851	1.70311	3.66924	7.90513	.202429
4.95	24.5025	121.287	2.22486	7.03562	1.70426	3.67171	7.91046	.202020
4.96	24.6016	122.024	2.22711	7.04273	1.70540	3.67418	7.91578	.201613
4.97	24.7009	122.763	2.22935	7.04982	1.70655	3.67665	7.92110	.201207
4.98	24.8004	123.506	2.23159	7.05691	1.70769	3.67911	7.92641	.200803
4.99	24.9001	124.251	2.23383	7.06399	1.70884	3.68157	7.93171	.200401
5.00	25.0000	125.000	2.23607	7.07107	1.70998	3.68403	7.93701	.200000

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
5.01	25.1001	125.752	2.23830	7.07814	1.71112	3.68649	7.94229	.199601
5.02	25.2004	126.506	2.24054	7.08520	1.71225	3.68894	7.94757	.199203
5.03	25.3009	127.264	2.24277	7.09225	1.71339	3.69138	7.95285	.198807
5.04	25.4016	128.024	2.24499	7.09930	1.71452	3.69383	7.95811	.198413
5.05	25.5025	128.788	2.24722	7.10634	1.71566	3.69627	7.96337	.198020
5.06	25.6036	129.554	2.24944	7.11337	1.71679	3.69871	7.96863	.197628
5.07	25.7049	130.324	2.25167	7.12039	1.71792	3.70114	7.97387	.197239
5.08	25.8064	131.097	2.25389	7.12741	1.71905	3.70358	7.97911	.196850
5.09	25.9081	131.872	2.25610	7.13442	1.72017	3.70600	7.98434	.196464
5.10	26.0100	132.651	2.25832	7.14143	1.72130	3.70843	7.98957	.196078
5.11	26.1121	133.433	2.26053	7.14843	1.72242	3.71085	7.99479	.195695
5.12	26.2144	134.218	2.26274	7.15542	1.72355	3.71327	8.00000	.195313
5.13	26.3169	135.006	2.26495	7.16240	1.72467	3.71566	8.00520	.194932
5.14	26.4196	135.797	2.26716	7.16938	1.72579	3.71810	8.01040	.194553
5.15	26.5225	136.591	2.26936	7.17635	1.72691	3.72051	8.01559	.194175
5.16	26.6256	137.388	2.27156	7.18331	1.72802	3.72292	8.02078	.193798
5.17	26.7289	138.188	2.27376	7.19027	1.72914	3.72532	8.02596	.193424
5.18	26.8324	138.992	2.27596	7.19722	1.73025	3.72772	8.03113	.193050
5.19	26.9361	139.798	2.27816	7.20417	1.73137	3.73012	8.03629	.192678
5.20	27.0400	140.608	2.28035	7.21110	1.73248	3.73251	8.04145	.192308
5.21	27.1441	141.421	2.28254	7.21803	1.73359	3.73490	8.04660	.191939
5.22	27.2484	142.237	2.28473	7.22496	1.73470	3.73729	8.05175	.191571
5.23	27.3529	143.056	2.28692	7.23187	1.73580	3.73968	8.05689	.191205
5.24	27.4576	143.878	2.28910	7.23878	1.73691	3.74206	8.06202	.190840
5.25	27.5625	144.703	2.29129	7.24569	1.73801	3.74443	8.06714	.190476
5.26	27.6676	145.532	2.29347	7.25259	1.73912	3.74681	8.07226	.190114
5.27	27.7729	146.363	2.29565	7.25948	1.74022	3.74918	8.07737	.189753
5.28	27.8784	147.198	2.29783	7.26636	1.74132	3.75158	8.08248	.189394
5.29	27.9841	148.036	2.30000	7.27324	1.74242	3.75392	8.08758	.189036
5.30	28.0900	148.877	2.30217	7.28011	1.74351	3.75629	8.09267	.188679
5.31	28.1961	149.721	2.30434	7.28697	1.74461	3.75865	8.09776	.188324
5.32	28.3024	150.569	2.30651	7.29383	1.74570	3.76100	8.10284	.187970
5.33	28.4089	151.419	2.30868	7.30068	1.74680	3.76336	8.10791	.187617
5.34	28.5156	152.273	2.31084	7.30753	1.74789	3.76571	8.11298	.187266
5.35	28.6225	153.130	2.31301	7.31437	1.74898	3.76806	8.11804	.186916
5.36	28.7296	153.991	2.31517	7.32120	1.75007	3.77041	8.12310	.186567
5.37	28.8369	154.854	2.31733	7.32803	1.75116	3.77275	8.12814	.186220
5.38	28.9444	155.721	2.31948	7.33485	1.75224	3.77509	8.13319	.185874
5.39	29.0521	156.591	2.32164	7.34166	1.75333	3.77740	8.13822	.185529
5.40	29.1600	157.464	2.32379	7.34847	1.75441	3.77976	8.14325	.185185
5.41	29.2681	158.340	2.32594	7.35527	1.75549	3.78210	8.14828	.184843
5.42	29.3764	159.220	2.32809	7.36206	1.75657	3.78442	8.15329	.184502
5.43	29.4849	160.103	2.33024	7.36885	1.75765	3.78675	8.15831	.184162
5.44	29.5936	160.989	2.33238	7.37564	1.75873	3.78907	8.16331	.183824
5.45	29.7025	161.879	2.33452	7.38241	1.75981	3.79139	8.16831	.183486
5.46	29.8116	162.771	2.33666	7.38918	1.76088	3.79371	8.17330	.183150
5.47	29.9209	163.667	2.33880	7.39594	1.76196	3.79603	8.17829	.182815
5.48	30.0304	164.567	2.34094	7.40270	1.76303	3.79834	8.18327	.182482
5.49	30.1401	165.469	2.34307	7.40945	1.76410	3.80065	8.18824	.182149
5.50	30.2500	166.375	2.34521	7.41620	1.76517	3.80295	8.19321	.181818

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
5.51	30.3601	167.284	2.34734	7.42294	1.76624	3.80526	8.19818	.181488
5.52	30.4704	168.197	2.34947	7.42967	1.76731	3.80756	8.20313	.181159
5.53	30.5809	169.112	2.35160	7.43640	1.76838	3.80986	8.20808	.180832
5.54	30.6916	170.031	2.35372	7.44312	1.76944	3.80115	8.21303	.180505
5.55	30.8025	170.954	2.35584	7.44983	1.77051	3.81444	8.21797	.180180
5.56	30.9136	171.880	2.35797	7.45654	1.77157	3.81673	8.22290	.179856
5.57	31.0249	172.809	2.36008	7.46324	1.77263	3.81902	8.22783	.179533
5.58	31.1364	173.741	2.36220	7.46994	1.77369	3.82130	8.23275	.179212
5.59	31.2481	174.677	2.36432	7.47663	1.77475	3.82358	8.23766	.178891
5.60	31.3600	175.616	2.36643	7.48331	1.77581	3.82586	8.24257	.178571
5.61	31.4721	176.558	2.36854	7.48999	1.77686	3.82814	8.24747	.178253
5.62	31.5844	177.504	2.37065	7.49667	1.77792	3.83041	8.25237	.177936
5.63	31.6969	178.454	2.37276	7.50333	1.77897	3.83268	8.25726	.177620
5.64	31.8096	179.406	2.37487	7.50999	1.78003	3.83495	8.26215	.177305
5.65	31.9225	180.362	2.37697	7.51665	1.78108	3.83721	8.26703	.176991
5.66	32.0356	181.321	2.37908	7.52330	1.78213	3.83948	8.27190	.176678
5.67	32.1489	182.284	2.38118	7.52994	1.78318	3.84174	8.27677	.176367
5.68	32.2624	183.250	2.38328	7.53658	1.78422	3.84400	8.28164	.176056
5.69	32.3761	184.220	2.38537	7.54321	1.78527	3.84625	8.28649	.175747
5.70	32.4900	185.193	2.38747	7.54983	1.78632	3.84850	8.29134	.175439
5.71	32.6041	186.169	2.38956	7.55645	1.78736	3.85075	8.29619	.175131
5.72	32.7184	187.149	2.39165	7.56307	1.78840	3.85300	8.30103	.174825
5.73	32.8329	188.133	2.39374	7.56968	1.78944	3.85524	8.30587	.174520
5.74	32.9476	189.119	2.39583	7.57628	1.79048	3.85748	8.31069	.174216
5.75	33.0625	190.109	2.39792	7.58288	1.79152	3.85972	8.31552	.173913
5.76	33.1776	191.103	2.40000	7.58947	1.79256	3.86196	8.32034	.173611
5.77	33.2929	192.100	2.40208	7.59605	1.79360	3.86419	8.32515	.173310
5.78	33.4084	193.101	2.40416	7.60263	1.79463	3.86642	8.32995	.173010
5.79	33.5241	194.105	2.40624	7.60920	1.79567	3.86865	8.33476	.172712
5.80	33.6400	195.112	2.40832	7.61577	1.79670	3.87088	8.33955	.172414
5.81	33.7561	196.123	2.41039	7.62234	1.79773	3.87310	8.34434	.172117
5.82	33.8724	197.137	2.41247	7.62889	1.79876	3.87532	8.34913	.171821
5.83	33.9889	198.155	2.41454	7.63544	1.79979	3.87754	8.35390	.171527
5.84	34.1056	199.177	2.41661	7.64199	1.80082	3.87975	8.35868	.171233
5.85	34.2225	200.202	2.41868	7.64853	1.80185	3.88197	8.36345	.170940
5.86	34.3396	201.230	2.42074	7.65506	1.80288	3.88418	8.36821	.170649
5.87	34.4569	202.262	2.42281	7.66159	1.80390	3.88639	8.37297	.170358
5.88	34.5744	203.297	2.42487	7.66812	1.80492	3.88859	8.37772	.170068
5.89	34.6921	204.336	2.42693	7.67463	1.80595	3.89082	8.38247	.169779
5.90	34.8100	205.379	2.42899	7.68115	1.80697	3.89300	8.38721	.169492
5.91	34.9281	206.425	2.43105	7.68765	1.80799	3.89520	8.39194	.169205
5.92	35.0464	207.475	2.43311	7.69415	1.80901	3.89739	8.39667	.168919
5.93	35.1649	208.528	2.43516	7.70065	1.81003	3.89958	8.40140	.168634
5.94	35.2836	209.585	2.43721	7.70714	1.81104	3.90177	8.40612	.168350
5.95	35.4025	210.645	2.43926	7.71362	1.81206	3.90396	8.41083	.168067
5.96	35.5216	211.709	2.44131	7.72010	1.81307	3.90615	8.41554	.167785
5.97	35.6409	212.776	2.44336	7.72658	1.81409	3.90833	8.42025	.167504
5.98	35.7604	213.847	2.44540	7.73305	1.81510	3.91051	8.42494	.167224
5.99	35.8801	214.922	2.44745	7.73951	1.81611	3.91269	8.42964	.166945
6.00	36.0000	216.000	2.44949	7.74597	1.81712	3.91487	8.43433	.166667

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
6.01	36.1201	217.082	2.45153	7.75242	1.81813	3.91704	8.43901	.166389
6.02	36.2404	218.167	2.45357	7.75887	1.81914	3.91921	8.44369	.166113
6.03	36.3609	219.256	2.45561	7.76531	1.82014	3.92138	8.44836	.165837
6.04	36.4816	220.349	2.45764	7.77174	1.82115	3.92355	8.45303	.165563
6.05	36.6025	221.445	2.45967	7.77817	1.82215	3.92571	8.45769	.165289
6.06	36.7236	222.545	2.46171	7.78460	1.82316	3.92787	8.46235	.165017
6.07	36.8449	223.649	2.46374	7.79102	1.82416	3.93003	8.46700	.164745
6.08	36.9664	224.756	2.46577	7.79744	1.82516	3.93219	8.47165	.164474
6.09	37.0881	225.867	2.46779	7.80385	1.82616	3.93434	8.47629	.164204
6.10	37.2100	226.981	2.46982	7.81025	1.82716	3.93650	8.48093	.163934
6.11	37.3321	228.099	2.47184	7.81665	1.82816	3.93865	8.48556	.163666
6.12	37.4544	229.221	2.47386	7.82304	1.82915	3.94079	8.49018	.163399
6.13	37.5769	230.346	2.47588	7.82943	1.83015	3.94294	8.49481	.163132
6.14	37.6996	231.476	2.47790	7.83582	1.83115	3.94508	8.49942	.162866
6.15	37.8225	232.608	2.47992	7.84219	1.83214	3.94722	8.50404	.162602
6.16	37.9456	233.745	2.48193	7.84857	1.83313	3.94936	8.50864	.162338
6.17	38.0689	234.885	2.48395	7.85493	1.83412	3.95150	8.51324	.162075
6.18	38.1924	236.029	2.48596	7.86130	1.83511	3.95363	8.51784	.161812
6.19	38.3161	237.177	2.48797	7.86766	1.83610	3.95576	8.52243	.161551
6.20	38.4400	238.328	2.48998	7.87401	1.83709	3.95789	8.52702	.161290
6.21	38.5641	239.483	2.49199	7.88036	1.83808	3.96002	8.53160	.161031
6.22	38.6884	240.642	2.49399	7.88670	1.83906	3.96214	8.53618	.160772
6.23	38.8129	241.804	2.49600	7.89303	1.84005	3.96426	8.54075	.160514
6.24	38.9376	242.971	2.49800	7.89937	1.84103	3.96638	8.54532	.160256
6.25	39.0625	244.141	2.50000	7.90569	1.84202	3.96850	8.54988	.160000
6.26	39.1876	245.314	2.50200	7.91202	1.84300	3.97062	8.55444	.159744
6.27	39.3129	246.492	2.50400	7.91833	1.84398	3.97273	8.55899	.159490
6.28	39.4384	247.673	2.50599	7.92465	1.84496	3.97484	8.56354	.159236
6.29	39.5641	248.858	2.50799	7.93095	1.84594	3.97695	8.56808	.158983
6.30	39.6900	250.047	2.50998	7.93725	1.84691	3.97906	8.57262	.158730
6.31	39.8161	251.240	2.51197	7.94355	1.84789	3.98116	8.57715	.158479
6.32	39.9424	252.436	2.51396	7.94984	1.84887	3.98326	8.58168	.158228
6.33	40.0689	253.636	2.51595	7.95613	1.84984	3.98536	8.58620	.157978
6.34	40.1956	254.840	2.51794	7.96241	1.85082	3.98746	8.59072	.157729
6.35	40.3225	256.048	2.51992	7.96869	1.85179	3.98956	8.59524	.157480
6.36	40.4496	257.259	2.52190	7.97496	1.85276	3.99165	8.59975	.157233
6.37	40.5769	258.475	2.52389	7.98123	1.85373	3.99374	8.60425	.156986
6.38	40.7044	259.694	2.52587	7.98749	1.85470	3.99583	8.60875	.156740
6.39	40.8321	260.917	2.52784	7.99375	1.85567	3.99792	8.61325	.156495
6.40	40.9600	262.144	2.52982	8.00000	1.85664	4.00000	8.61774	.156250
6.41	41.0881	263.375	2.53180	8.00625	1.85760	4.00208	8.62222	.156006
6.42	41.2164	264.609	2.53377	8.01249	1.85857	4.00416	8.62671	.155763
6.43	41.3449	265.848	2.53574	8.01873	1.85953	4.00624	8.63118	.155521
6.44	41.4736	267.090	2.53772	8.02496	1.86050	4.00832	8.63566	.155280
6.45	41.6025	268.336	2.53969	8.03119	1.86146	4.01039	8.64012	.155039
6.46	41.7316	269.586	2.54165	8.03741	1.86242	4.01246	8.64459	.154799
6.47	41.8609	270.840	2.54362	8.04363	1.86338	4.01453	8.64904	.154560
6.48	41.9904	272.098	2.54558	8.04984	1.86434	4.01660	8.65350	.154321
6.49	42.1201	273.359	2.54755	8.05605	1.86530	4.01866	8.65795	.154083
6.50	42.2500	274.625	2.54951	8.06226	1.86626	4.02073	8.66239	.153846

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
6.51	42.3801	275.894	2.55147	8.06846	1.86721	4.02279	8.66683	.153610
6.52	42.5104	277.168	2.55343	8.07465	1.86817	4.02485	8.67127	.153374
6.53	42.6409	278.445	2.55539	8.08084	1.86912	4.02690	8.67570	.153139
6.54	42.7716	279.726	2.55734	8.08703	1.87008	4.02896	8.68012	.152905
6.55	42.9025	281.011	2.55930	8.09321	1.87103	4.03101	8.68455	.152672
6.56	43.0336	282.300	2.56125	8.09938	1.87198	4.03306	8.68896	.152439
6.57	43.1649	283.593	2.56320	8.10555	1.87293	4.03511	8.69338	.152207
6.58	43.2964	284.890	2.56515	8.11172	1.87388	4.03715	8.69778	.151976
6.59	43.4281	286.191	2.56710	8.11788	1.87483	4.03920	8.70219	.151745
6.60	43.5600	287.496	2.56905	8.12404	1.87578	4.04124	8.70659	.151515
6.61	43.6921	288.805	2.57099	8.13019	1.87672	4.04328	8.71098	.151286
6.62	43.8244	290.118	2.57294	8.13634	1.87767	4.04532	8.71537	.151057
6.63	43.9569	291.434	2.57488	8.14248	1.87862	4.04735	8.71976	.150830
6.64	44.0896	292.755	2.57682	8.14862	1.87956	4.04939	8.72414	.150602
6.65	44.2225	294.080	2.57876	8.15475	1.88050	4.05142	8.72852	.150376
6.66	44.3556	295.408	2.58070	8.16088	1.88144	4.05345	8.73289	.150150
6.67	44.4889	296.741	2.58263	8.16701	1.88239	4.05548	8.73726	.149925
6.68	44.6224	298.078	2.58457	8.17313	1.88333	4.05750	8.74162	.149701
6.69	44.7561	299.418	2.58650	8.17924	1.88427	4.05953	8.74598	.149477
6.70	44.8900	300.763	2.58844	8.18535	1.88520	4.06155	8.75034	.149254
6.71	45.0241	302.112	2.59037	8.19146	1.88614	4.06357	8.75469	.149031
6.72	45.1584	303.464	2.59230	8.19756	1.88708	4.06558	8.75904	.148810
6.73	45.2929	304.821	2.59422	8.20366	1.88801	4.06760	8.76338	.148588
6.74	45.4276	306.182	2.59615	8.20975	1.88895	4.06961	8.76772	.148368
6.75	45.5625	307.547	2.59808	8.21584	1.88988	4.07163	8.77205	.148148
6.76	45.6976	308.916	2.60000	8.22192	1.89081	4.07364	8.77638	.147929
6.77	45.8329	310.289	2.60192	8.22800	1.89175	4.07564	8.78071	.147711
6.78	45.9684	311.666	2.60384	8.23408	1.89268	4.07765	8.78503	.147493
6.79	46.1041	313.047	2.60576	8.24015	1.89361	4.07965	8.78935	.147275
6.80	46.2400	314.432	2.60768	8.24621	1.89454	4.08166	8.79366	.147059
6.81	46.3761	315.821	2.60960	8.25227	1.89546	4.08365	8.79797	.146843
6.82	46.5124	317.215	2.61151	8.25833	1.89639	4.08565	8.80227	.146628
6.83	46.6489	318.612	2.61343	8.26438	1.89732	4.08765	8.80657	.146413
6.84	46.7856	320.014	2.61534	8.27043	1.89824	4.08964	8.81087	.146199
6.85	46.9225	321.419	2.61725	8.27647	1.89917	4.09164	8.81516	.145985
6.86	47.0596	322.829	2.61916	8.28251	1.90009	4.09362	8.81945	.145773
6.87	47.1969	324.243	2.62107	8.28855	1.90102	4.09561	8.82373	.145560
6.88	47.3344	325.661	2.62298	8.29458	1.90194	4.09760	8.82801	.145349
6.89	47.4721	327.083	2.62488	8.30060	1.90286	4.09958	8.83229	.145138
6.90	47.6100	328.509	2.62679	8.30662	1.90378	4.10157	8.83656	.144928
6.91	47.7481	329.939	2.62869	8.31264	1.90470	4.10355	8.84082	.144718
6.92	47.8864	331.374	2.63059	8.31865	1.90562	4.10552	8.84509	.144509
6.93	48.0249	332.813	2.63249	8.32466	1.90653	4.10750	8.84934	.144300
6.94	48.1636	334.255	2.63439	8.33067	1.90745	4.10948	8.85360	.144092
6.95	48.3025	335.702	2.63629	8.33667	1.90837	4.11145	8.85785	.143885
6.96	48.4416	337.154	2.63818	8.34266	1.90928	4.11342	8.86210	.143678
6.97	48.5809	338.609	2.64008	8.34865	1.91019	4.11539	8.86634	.143472
6.98	48.7204	340.068	2.64197	8.35464	1.91111	4.11736	8.87058	.143267
6.99	48.8601	341.532	2.64386	8.36062	1.91202	4.11932	8.87481	.143062
7.00	49.0000	343.000	2.64575	8.36660	1.91293	4.12129	8.87904	.142857

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
7.01	49.1401	344.472	2.64764	8.37257	1.91384	4.12325	8.88327	.142653
7.02	49.2804	345.948	2.64953	8.37854	1.91475	4.12521	8.88749	.142450
7.03	49.4209	347.429	2.65141	8.38451	1.91566	4.12716	8.89171	.142248
7.04	49.5616	348.914	2.65330	8.39047	1.91657	4.12912	8.89592	.142046
7.05	49.7025	350.403	2.65518	8.39643	1.91747	4.13107	8.90013	.141844
7.06	49.8436	351.896	2.65707	8.40238	1.91838	4.13303	8.90434	.141643
7.07	49.9849	353.393	2.65895	8.40833	1.91929	4.13498	8.90854	.141443
7.08	50.1264	354.895	2.66083	8.41427	1.92019	4.13695	8.91274	.141243
7.09	50.2681	356.401	2.66271	8.42021	1.92109	4.13887	8.91693	.141044
7.10	50.4100	357.911	2.66458	8.42615	1.92200	4.14082	8.92112	.140845
7.11	50.5521	359.425	2.66646	8.43208	1.92290	4.14276	8.92531	.140647
7.12	50.6944	360.944	2.66833	8.43801	1.92380	4.14470	8.92949	.140449
7.13	50.8369	362.467	2.67021	8.44393	1.92470	4.14664	8.93367	.140253
7.14	50.9796	363.994	2.67208	8.44985	1.92560	4.14858	8.93784	.140056
7.15	51.1225	365.526	2.67395	8.45577	1.92650	4.15051	8.94201	.139860
7.16	51.2656	367.062	2.67582	8.46168	1.92740	4.15245	8.94618	.139665
7.17	51.4089	368.602	2.67769	8.46759	1.92829	4.15438	8.95034	.139470
7.18	51.5524	370.146	2.67955	8.47349	1.92919	4.15631	8.95450	.139276
7.19	51.6961	371.695	2.68142	8.47939	1.93008	4.15824	8.95866	.139082
7.20	51.8400	373.248	2.68328	8.48528	1.93098	4.16017	8.96281	.138889
7.21	51.9841	374.805	2.68514	8.49117	1.93187	4.16209	8.96696	.138696
7.22	52.1284	376.367	2.68701	8.49706	1.93277	4.16402	8.97110	.138504
7.23	52.2729	377.933	2.68887	8.50294	1.93366	4.16594	8.97524	.138313
7.24	52.4176	379.503	2.69072	8.50882	1.93455	4.16786	8.97938	.138122
7.25	52.5625	381.078	2.69258	8.51469	1.93544	4.16978	8.98351	.137931
7.26	52.7076	382.657	2.69444	8.52056	1.93633	4.17169	8.98764	.137741
7.27	52.8529	384.241	2.69629	8.52643	1.93722	4.17361	8.99176	.137552
7.28	52.9984	385.828	2.69815	8.53229	1.93810	4.17552	8.99588	.137363
7.29	53.1441	387.420	2.70000	8.53815	1.93899	4.17743	9.00000	.137174
7.30	53.2900	389.017	2.70185	8.54400	1.93988	4.17934	9.00411	.136986
7.31	53.4361	390.618	2.70370	8.54985	1.94076	4.18125	9.00822	.136799
7.32	53.5824	392.223	2.70555	8.55570	1.94165	4.18315	9.01233	.136612
7.33	53.7289	393.833	2.70740	8.56154	1.94253	4.18506	9.01643	.136426
7.34	53.8756	395.447	2.70924	8.56738	1.94341	4.18696	9.02053	.136240
7.35	54.0225	397.065	2.71109	8.57321	1.94430	4.18886	9.02462	.136054
7.36	54.1696	398.688	2.71293	8.57904	1.94518	4.19076	9.02871	.135870
7.37	54.3169	400.316	2.71477	8.58487	1.94606	4.19266	9.03280	.135685
7.38	54.4644	401.947	2.71662	8.59069	1.94694	4.19455	9.03689	.135501
7.39	54.6121	403.583	2.71846	8.59651	1.94782	4.19644	9.04097	.135318
7.40	54.7600	405.224	2.72029	8.60233	1.94870	4.19834	9.04504	.135135
7.41	54.9081	406.869	2.72213	8.60814	1.94957	4.20023	9.04911	.134953
7.42	55.0564	408.518	2.72397	8.61394	1.95045	4.20212	9.05318	.134771
7.43	55.2049	410.172	2.72580	8.61974	1.95132	4.20400	9.05725	.134590
7.44	55.3536	411.831	2.72764	8.62554	1.95220	4.20589	9.06131	.134409
7.45	55.5025	413.494	2.72947	8.63134	1.95307	4.20777	9.06537	.134228
7.46	55.6516	415.161	2.73130	8.63713	1.95395	4.20965	9.06942	.134048
7.47	55.8009	416.833	2.73313	8.64292	1.95482	4.21153	9.07347	.133869
7.48	55.9504	418.509	2.73496	8.64870	1.95569	4.21341	9.07752	.133690
7.49	56.1001	420.190	2.73679	8.65448	1.95656	4.21529	9.08156	.133511
7.50	56.2500	421.875	2.73861	8.66025	1.95743	4.21716	9.08560	.133333

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
7.51	56.4001	423.565	2.74044	8.66603	1.95830	4.21904	9.08964	.133156
7.52	56.5504	425.259	2.74226	8.67179	1.95917	4.22091	9.09367	.132979
7.53	56.7009	426.958	2.74408	8.67756	1.96004	4.22278	9.09770	.132802
7.54	56.8516	428.661	2.74591	8.68332	1.96091	4.22465	9.10173	.132626
7.55	57.0025	430.369	2.74773	8.68907	1.96177	4.22651	9.10575	.132450
7.56	57.1536	432.081	2.74955	8.69483	1.96264	4.22838	9.10977	.132275
7.57	57.3049	433.798	2.75136	8.70057	1.96350	4.23024	9.11378	.132100
7.58	57.4564	435.520	2.75318	8.70632	1.96437	4.23210	9.11779	.131926
7.59	57.6081	437.245	2.75500	8.71206	1.96523	4.23396	9.12180	.131752
7.60	57.7600	438.976	2.75681	8.71780	1.96610	4.23582	9.12581	.131579
7.61	57.9121	440.711	2.75862	8.72353	1.96696	4.23768	9.12981	.131406
7.62	58.0644	442.451	2.76043	8.72926	1.96782	4.23954	9.13380	.131234
7.63	58.2169	444.195	2.76225	8.73499	1.96868	4.24139	9.13780	.131062
7.64	58.3696	445.944	2.76405	8.74071	1.96954	4.24324	9.14179	.130890
7.65	58.5225	447.697	2.76586	8.74643	1.97040	4.24509	9.14577	.130719
7.66	58.6756	449.455	2.76767	8.75214	1.97126	4.24694	9.14976	.130548
7.67	58.8289	451.218	2.76948	8.75785	1.97211	4.24879	9.15374	.130378
7.68	58.9824	452.985	2.77128	8.76356	1.97297	4.25063	9.15771	.130208
7.69	59.1361	454.757	2.77308	8.76926	1.97383	4.25248	9.16169	.130039
7.70	59.2900	456.533	2.77489	8.77496	1.97468	4.25432	9.16566	.129870
7.71	59.4441	458.314	2.77669	8.78066	1.97554	4.25616	9.16962	.129702
7.72	59.5984	460.100	2.77849	8.78635	1.97639	4.25800	9.17359	.129534
7.73	59.7529	461.890	2.78029	8.79204	1.97724	4.25984	9.17754	.129366
7.74	59.9076	463.685	2.78209	8.79773	1.97809	4.26168	9.18150	.129199
7.75	60.0625	465.484	2.78388	8.80341	1.97895	4.26351	9.18545	.129032
7.76	60.2176	467.289	2.78568	8.80909	1.97980	4.26534	9.18940	.128866
7.77	60.3729	469.097	2.78747	8.81476	1.98065	4.26717	9.19335	.128700
7.78	60.5284	470.911	2.78927	8.82043	1.98150	4.26900	9.19729	.128535
7.79	60.6841	472.729	2.79106	8.82610	1.98234	4.27083	9.20123	.128370
7.80	60.8400	474.552	2.79285	8.83176	1.98319	4.27266	9.20516	.128205
7.81	60.9961	476.380	2.79464	8.83742	1.98404	4.27448	9.20910	.128041
7.82	61.1524	478.212	2.79643	8.84308	1.98489	4.27631	9.21303	.127877
7.83	61.3089	480.049	2.79821	8.84873	1.98573	4.27813	9.21695	.127714
7.84	61.4656	481.890	2.80000	8.85438	1.98658	4.27995	9.22087	.127551
7.85	61.6225	483.737	2.80179	8.86002	1.98742	4.28177	9.22479	.127389
7.86	61.7796	485.588	2.80357	8.86566	1.98826	4.28359	9.22871	.127227
7.87	61.9369	487.443	2.80535	8.87130	1.98911	4.28540	9.23262	.127065
7.88	62.0944	489.304	2.80713	8.87694	1.98995	4.28722	9.23653	.126904
7.89	62.2521	491.169	2.80891	8.88257	1.99079	4.28903	9.24043	.126743
7.90	62.4100	493.039	2.81069	8.88819	1.99163	4.29084	9.24433	.126582
7.91	62.5681	494.914	2.81247	8.89382	1.99247	4.29265	9.24823	.126422
7.92	62.7264	496.793	2.81425	8.89944	1.99331	4.29446	9.25213	.126263
7.93	62.8849	498.677	2.81603	8.90505	1.99415	4.29627	9.25602	.126103
7.94	63.0436	500.566	2.81780	8.91067	1.99499	4.29807	9.25991	.125945
7.95	63.2025	502.460	2.81957	8.91628	1.99582	4.29987	9.26380	.125786
7.96	63.3616	504.358	2.82135	8.92188	1.99666	4.30168	9.26768	.125628
7.97	63.5209	506.262	2.82312	8.92749	1.99750	4.30348	9.27156	.125471
7.98	63.6804	508.170	2.82489	8.93308	1.99833	4.30528	9.27544	.125313
7.99	63.8401	510.082	2.82666	8.93868	1.99917	4.30707	9.27931	.125156
8.00	64.0000	512.000	2.82843	8.94427	2.00000	4.30887	9.28318	.125000

°	'	Sin.	d.	Tan.	d.	Cot.	d.	[illegible]
9	0	0.1564	29	0.1584	30	6.3138	1168	[illegible]
	10	0.1593	29	0.1614	30	6.1970	1126	[illegible]
	20	0.1622	28	0.1644	30	6.0844	1086	[illegible]
	30	0.1650	29	0.1673	30	5.9758	1050	[illegible]
	40	0.1679	29	0.1703	30	5.8708	1014	[illegible]
	50	0.1708	28	0.1733	30	5.7694	981	[illegible]
10	0	0.1736	29	0.1763	30	5.6713	949	[illegible]
	10	0.1765	29	0.1793	30	5.5764	919	[illegible]
	20	0.1794	28	0.1823	30	5.4845	890	[illegible]
	30	0.1822	29	0.1853	30	5.3955	862	[illegible]
	40	0.1851	29	0.1883	31	5.3093	836	[illegible]
	50	0.1880	28	0.1914	30	5.2257	811	[illegible]
11	0	0.1908	29	0.1944	30	5.1446	788	[illegible]
	10	0.1937	28	0.1974	30	5.0658	764	[illegible]
	20	0.1965	29	0.2004	31	4.9894	742	[illegible]
	30	0.1994	28	0.2035	30	4.9152	722	[illegible]
	40	0.2022	29	0.2065	30	4.8430	701	[illegible]
	50	0.2051	28	0.2095	31	4.7729	683	[illegible]
12	0	0.2079	29	0.2126	30	4.7046	664	[illegible]
	10	0.2108	28	0.2156	30	4.6382	646	[illegible]
	20	0.2136	28	0.2186	31	4.5736	629	[illegible]
	30	0.2164	29	0.2217	30	4.5107	613	[illegible]
	40	0.2193	28	0.2247	31	4.4494	597	[illegible]
	50	0.2221	29	0.2278	31	4.3897	582	[illegible]
13	0	0.2250	28	0.2309	30	4.3315	568	[illegible]
	10	0.2278	28	0.2339	31	4.2747	554	[illegible]
	20	0.2306	28	0.2370	31	4.2193	540	[illegible]
	30	0.2334	29	0.2401	31	4.1653	527	[illegible]
	40	0.2363	28	0.2432	30	4.1126	515	[illegible]
	50	0.2391	28	0.2462	31	4.0611	503	[illegible]
14	0	0.2419	28	0.2493	31	4.0108	491	[illegible]
	10	0.2447	29	0.2524	31	3.9617	481	[illegible]
	20	0.2476	28	0.2555	31	3.9136	469	[illegible]
	30	0.2504	28	0.2586	31	3.8667	459	[illegible]
	40	0.2532	28	0.2617	31	3.8208	448	[illegible]
	50	0.2560	28	0.2648	31	3.7760	439	[illegible]
15	0	0.2588	28	0.2679	32	3.7321	430	[illegible]
	10	0.2616	28	0.2711	31	3.6891	421	[illegible]
	20	0.2644	28	0.2742	31	3.6470	411	[illegible]
	30	0.2672	28	0.2773	32	3.6059	403	[illegible]
	40	0.2700	28	0.2805	31	3.5656	395	[illegible]
	50	0.2728	28	0.2836	31	3.5261	387	[illegible]
16	0	0.2756	28	0.2867	32	3.4874	379	[illegible]
	10	0.2784	28	0.2899	32	3.4495	371	[illegible]
	20	0.2812	28	0.2931	31	3.4124	365	[illegible]
	30	0.2840	28	0.2962	32	3.3759	357	[illegible]
	40	0.2868	28	0.2994	32	3.3402	350	[illegible]
	50	0.2896	28	0.3026	31	3.3052	343	[illegible]
17	0	0.2924	28	0.3057	32	3.2709	338	[illegible]
	10	0.2952	27	0.3089	32	3.2371	330	[illegible]
	20	0.2979	28	0.3121	32	3.2041	325	0.9546
	30	0.3007	28	0.3153	32	3.1716	319	0.9537
	40	0.3035	27	0.3185	32	3.1397	313	[illegible]
	50	0.3062	28	0.3217	32	3.1084	307	[illegible]
18	0	0.3090		0.3249		3.0777		0.9511
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.

n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
72.4201	616.295	2.91719	9.22497	2.04163	4.39855	9.47640	.117509
72.5904	618.470	2.91890	9.23038	2.04243	4.40028	9.48011	.117371
72.7609	620.650	2.92062	9.23580	2.04323	4.40200	9.48381	.117233
72.9316	622.836	2.92233	9.24121	2.04402	4.40372	9.48752	.117096
73.1025	625.026	2.92404	9.24662	2.04482	4.40543	9.49122	.116959
73.2736	627.222	2.92575	9.25203	2.04562	4.40715	9.49492	.116822
73.4449	629.423	2.92746	9.25743	2.04641	4.40887	9.49861	.116686
73.6164	631.629	2.92916	9.26283	2.04721	4.41058	9.50231	.116550
73.7881	633.840	2.93087	9.26823	2.04801	4.41229	9.50600	.116414
73.9600	636.056	2.93258	9.27362	2.04880	4.41400	9.50969	.116279
74.1321	638.277	2.93428	9.27901	2.04959	4.41571	9.51337	.116144
74.3044	640.504	2.93598	9.28440	2.05039	4.41742	9.51705	.116009
74.4769	642.736	2.93769	9.28978	2.05118	4.41913	9.52073	.115875
74.6496	644.973	2.93939	9.29516	2.05197	4.42084	9.52441	.115741
74.8225	647.215	2.94109	9.30054	2.05276	4.42254	9.52808	.115607
74.9956	649.462	2.94279	9.30591	2.05355	4.42425	9.53175	.115473
75.1689	651.714	2.94449	9.31128	2.05434	4.42595	9.53542	.115340
75.3424	653.972	2.94618	9.31665	2.05513	4.42765	9.53908	.115207
75.5161	656.235	2.94788	9.32202	2.05592	4.42935	9.54274	.115075
75.6900	658.503	2.94958	9.32738	2.05671	4.43105	9.54640	.114943
75.8641	660.776	2.95127	9.33274	2.05750	4.43274	9.55006	.114811
76.0384	663.055	2.95296	9.33809	2.05828	4.43444	9.55371	.114679
76.2129	665.339	2.95466	9.34345	2.05907	4.43614	9.55736	.114548
76.3876	667.628	2.95635	9.34880	2.05986	4.43783	9.56101	.114417
76.5625	669.922	2.95804	9.35414	2.06064	4.43952	9.56466	.114286
76.7376	672.221	2.95973	9.35949	2.06143	4.44121	9.56830	.114155
76.9129	674.526	2.96142	9.36483	2.06221	4.44290	9.57194	.114025
77.0884	676.836	2.96311	9.37017	2.06299	4.44459	9.57557	.113895
77.2641	679.151	2.96479	9.37550	2.06378	4.44627	9.57921	.113766
77.4400	681.472	2.96648	9.38083	2.06456	4.44796	9.58284	.113636
77.6161	683.798	2.96816	9.38616	2.06534	4.44964	9.58647	.113507
77.7924	686.129	2.96985	9.39149	2.06612	4.45133	9.59009	.113379
77.9689	688.465	2.97153	9.39681	2.06690	4.45301	9.59372	.113250
78.1456	690.807	2.97321	9.40213	2.06768	4.45469	9.59734	.113122
78.3225	693.154	2.97489	9.40744	2.06846	4.45637	9.60095	.112994
78.4996	695.506	2.97658	9.41276	2.06924	4.45805	9.60457	.112867
78.6769	697.864	2.97825	9.41807	2.07002	4.45972	9.60818	.112740
78.8544	700.227	2.97993	9.42338	2.07080	4.46140	9.61179	.112613
79.0321	702.595	2.98161	9.42868	2.07157	4.46307	9.61540	.112486
79.2100	704.969	2.98329	9.43398	2.07235	4.46474	9.61900	.112360
79.3881	707.348	2.98496	9.43928	2.07313	4.46642	9.62260	.112233
79.5664	709.732	2.98664	9.44458	2.07390	4.46809	9 62620	.112108
79.7449	712.122	2.98831	9.44987	2.07468	4.46976	9.62980	.111982
79.9236	714.517	2.98998	9.45516	2.07545	4.47142	9.63339	.111857
80.1025	716.917	2.99166	9.46044	2.07622	4.47309	9.63698	.111732
80.2816	719.323	2.99333	9.46573	2.07700	4.47476	9.64057	.111607
80.4609	721.734	2.99500	9.47101	2.07777	4.47642	9.64415	.111483
80.6404	724.151	2.99666	9.47629	2.07854	4.47808	9.64774	.111359
80.8201	726.573	2.99833	9.48156	2.07931	4.47974	9.65132	.111235
81.0000	729.000	3.00000	9.48683	2.08008	4.48140	9.65489	.111111

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
9.01	81.1801	731.433	3.00167	9.49210	2.08085	4.48306	9.65847	.110988
9.02	81.3604	733.871	3.00333	9.49737	2.08162	4.48472	9.66204	.110865
9.03	81.5409	736.314	3.00500	9.50263	2.08239	4.48638	9.66561	.110742
9.04	81.7216	738.763	3.00666	9.50789	2.08316	4.48803	9.66918	.110620
9.05	81.9025	741.218	3.00832	9.51315	2.08393	4.48969	9.67274	.110497
9.06	82.0836	743.677	3.00998	9.51840	2.08470	4.49134	9.67630	.110375
9.07	82.2649	746.143	3.01164	9.52365	2.08546	4.49299	9.67986	.110254
9.08	82.4464	748.613	3.01330	9.52890	2.08623	4.49464	9.68342	.110132
9.09	82.6281	751.089	3.01496	9.53415	2.08699	4.49629	9.68697	.110011
9.10	82.8100	753.571	3.01662	9.53939	2.08776	4.49794	9.69052	.109890
9.11	82.9921	756.058	3.01828	9.54463	2.08852	4.49959	9.69407	.109770
9.12	83.1744	758.551	3.01993	9.54987	2.08929	4.50123	9.69762	.109649
9.13	83.3569	761.048	3.02159	9.55510	2.09005	4.50288	9.70116	.109529
9.14	83.5396	763.552	3.02324	9.56033	2.09081	4.50452	9.70470	.109409
9.15	83.7225	766.061	3.02490	9.56556	2.09158	4.50616	9.70824	.109290
9.16	83.9056	768.575	3.02655	9.57079	2.09234	4.50780	9.71177	.109170
9.17	84.0889	771.095	3.02820	9.57601	2.09310	4.50945	9.71531	.109051
9.18	84.2724	773.621	3.02985	9.58123	2.09386	4.51108	9.71884	.108932
9.19	84.4561	776.152	3.03150	9.58645	2.09462	4.51272	9.72236	.108814
9.20	84.6400	778.688	3.03315	9.59166	2.09538	4.51436	9.72589	.108696
9.21	84.8241	781.230	3.03480	9.59687	2.09614	4.51599	9.72941	.108578
9.22	85.0084	783.777	3.03645	9.60208	2.09690	4.51763	9.73293	.108460
9.23	85.1929	786.330	3.03809	9.60729	2.09765	4.51926	9.73645	.108342
9.24	85.3776	788.889	3.03974	9.61249	2.09841	4.52089	9.73996	.108225
9.25	85.5625	791.453	3.04138	9.61769	2.09917	4.52252	9.74348	.108108
9.26	85.7476	794.023	3.04302	9.62289	2.09992	4.52415	9.74699	.107991
9.27	85.9329	796.598	3.04467	9.62808	2.10068	4.52578	9.75049	.107875
9.28	86.1184	799.179	3.04631	9.63328	2.10144	4.52740	9.75400	.107759
9.29	86.3041	801.765	3.04795	9.63846	2.10219	4.52903	9.75750	.107643
9.30	86.4900	804.357	3.04959	9.64365	2.10294	4.53065	9.76100	.107527
9.31	86.6761	806.954	3.05123	9.64883	2.10370	4.53228	9.76450	.107411
9.32	86.8624	809.558	3.05287	9.65401	2.10445	4.53390	9.76799	.107296
9.33	87.0489	812.166	3.05450	9.65919	2.10520	4.53552	9.77148	.107181
9.34	87.2356	814.781	3.05614	9.66437	2.10595	4.53714	9.77497	.107066
9.35	87.4225	817.400	3.05778	9.66954	2.10671	4.53876	9.77846	.106952
9.36	87.6096	820.026	3.05941	9.67471	2.10746	4.54038	9.78195	.106838
9.37	87.7969	822.657	3.06105	9.67988	2.10821	4.54199	9.78543	.106724
9.38	87.9844	825.294	3.06268	9.68504	2.10896	4.54361	9.78891	.106610
9.39	88.1721	827.936	3.06431	9.69020	2.10971	4.54522	9.79239	.106496
9.40	88.3600	830.584	3.06594	9.69536	2.11045	4.54684	9.79586	.106383
9.41	88.5481	833.238	3.06757	9.70052	2.11120	4.54845	9.79933	.106270
9.42	88.7364	835.897	3.06920	9.70567	2.11195	4.55006	9.80280	.106157
9.43	88.9249	838.562	3.07083	9.71082	2.11270	4.55167	9.80627	.106045
9.44	89.1136	841.232	3.07246	9.71597	2.11344	4.55328	9.80974	.105932
9.45	89.3025	843.909	3.07409	9.72111	2.11419	4.55488	9.81320	.105820
9.46	89.4916	846.591	3.07571	9.72625	2.11494	4.55649	9.81666	.105708
9.47	89.6809	849.278	3.07734	9.73139	2.11568	4.55809	9.82012	.105597
9.48	89.8704	851.971	3.07896	9.73653	2.11642	4.55970	9.82357	.105485
9.49	90.0601	854.670	3.08058	9.74166	2.11717	4.56130	9.82703	.105374
9.50	90.2500	857.375	3.08221	9.74679	2.11791	4.56290	9.83048	.105263

n	n^2	n^3	$\sqrt{n}$	$\sqrt{10n}$	$\sqrt[3]{n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
9.51	90.4401	860.085	3.08383	9.75192	2.11865	4.56450	9.83392	.105152
9.52	90.6304	862.801	3.08545	9.75705	2.11940	4.56610	9.83737	.105042
9.53	90.8209	865.523	3.08707	9.76217	2.12014	4.56770	9.84081	.104932
9.54	91.0116	868.251	3.08869	9.76729	2.12088	4.56930	9.84425	.104822
9.55	91.2025	870.984	3.09031	9.77241	2.12162	4.57089	9.84769	.104712
9.56	91.3936	873.723	3.09192	9.77753	2.12236	4.57249	9.85113	.104603
9.57	91.5849	876.467	3.09354	9.78264	2.12310	4.57408	9.85456	.104493
9.58	91.7764	879.218	3.09516	9.78775	2.12384	4.57568	9.85799	.104384
9.59	91.9681	881.974	3.09677	9.79285	2.12458	4.57727	9.86142	.104275
9.60	92.1600	884.736	3.09839	9.79796	2.12532	4.57886	9.86485	.104167
9.61	92.3521	887.504	3.10000	9.80306	2.12605	4.58045	9.86827	.104058
9.62	92.5444	890.277	3.10161	9.80816	2.12679	4.58203	9.87169	.103950
9.63	92.7369	893.056	3.10322	9.81326	2.12753	4.58362	9.87511	.103842
9.64	92.9296	895.841	3.10483	9.81835	2.12826	4.58521	9.87853	.103734
9.65	93.1225	898.632	3.10644	9.82344	2.12900	4.58679	9.88195	.103627
9.66	93.3156	901.429	3.10805	9.82853	2.12974	4.58838	9.88536	.103520
9.67	93.5089	904.231	3.10966	9.83362	2.13047	4.58996	9.88877	.103413
9.68	93.7024	907.039	3.11127	9.83870	2.13120	4.59154	9.89217	.103306
9.69	93.8961	909.853	3.11288	9.84378	2.13194	4.59312	9.89558	.103199
9.70	94.0900	912.673	3.11448	9.84886	2.13267	4.59470	9.89898	.103093
9.71	94.2841	915.499	3.11609	9.85393	2.13340	4.59628	9.90238	.102987
9.72	94.4784	918.330	3.11769	9.85901	2.13414	4.59786	9.90578	.102881
9.73	94.6729	921.167	3.11929	9.86408	2.13487	4.59943	9.90918	.102775
9.74	94.8676	924.010	3.12090	9.86914	2.13560	4.60101	9.91257	.102669
9.75	95.0625	926.859	3.12250	9.87421	2.13633	4.60258	9.91596	.102564
9.76	95.2576	929.714	3.12410	9.87927	2.13706	4.60416	9.91935	.102459
9.77	95.4529	932.575	3.12570	9.88433	2.13779	4.60573	9.92274	.102354
9.78	95.6484	935.441	3.12730	9.88939	2.13852	4.60730	9.92612	.102250
9.79	95.8441	938.314	3.12890	9.89444	2.13925	4.60887	9.92950	.102145
9.80	96.0400	941.192	3.13050	9.89949	2.13997	4.61044	9.93288	.102041
9.81	96.2361	944.076	3.13209	9.90454	2.14070	4.61200	9.93626	.101937
9.82	96.4324	946.966	3.13369	9.90959	2.14143	4.61357	9.93964	.101833
9.83	96.6289	949.862	3.13528	9.91464	2.14216	4.61513	9.94301	.101729
9.84	96.8256	952.764	3.13688	9.91968	2.14288	4.61670	9.94638	.101626
9.85	97.0225	955.672	3.13847	9.92472	2.14361	4.61826	9.94975	.101523
9.86	97.2196	958.585	3.14006	9.92975	2.14433	4.61983	9.95311	.101420
9.87	97.4169	961.505	3.14166	9.93479	2.14506	4.62139	9.95648	.101317
9.88	97.6144	964.430	3.14325	9.93982	2.14578	4.62295	9.95984	.101215
9.89	97.8121	967.362	3.14484	9.94485	2.14651	4.62451	9.96320	.101112
9.90	98.0100	970.299	3.14643	9.94987	2.14723	4.62607	9.96655	.101010
9.91	98.2081	973.242	3.14802	9.95490	2.14795	4.62762	9.96991	.100908
9.92	98.4064	976.191	3.14960	9.95992	2.14867	4.62918	9.97326	.100807
9.93	98.6049	979.147	3.15119	9.96494	2.14940	4.63073	9.97661	.100705
9.94	98.8036	982.108	3.15278	9.96995	2.15012	4.63229	9.97996	.100604
9.95	99.0025	985.075	3.15436	9.97497	2.15084	4.63384	9.98331	.100503
9.96	99.2016	988.048	3.15595	9.97998	2.15156	4.63539	9.98665	.100402
9.97	99.4009	991.027	3.15753	9.98499	2.15228	4.63694	9.98999	.100301
9.98	99.6004	994.012	3.15911	9.98999	2.15300	4.63849	9.99333	.100200
9.99	99.8001	997.003	3.16070	9.99500	2.15372	4.64004	9.99667	.100100
10.00	100.000	1000.00	3.16228	10.0000	2.15443	4.64159	10.0000	.100000

Square Root.—EXAMPLE.— (*a*) $\sqrt{3.1416}=?$ (*b*) $\sqrt{2342.9}=?$

SOLUTION.—(*a*) In this case, the decimal point need not be moved. In the table under n^2 find $3.1329=1.77^2$ and $3.1684=1.78^2$, one of these numbers being a little less and the other a little greater than the given number 3.1416. The first three figures of the required root are 177. 31,684 − 31,329 = 355 is the first difference; 31,416 (the number itself) − 31,329 = 87 is the second difference. 87 ÷ 355 = .245, or .25, which gives the fourth and fifth figures of the root. Hence, $\sqrt{3.1416}=1.7725$.

(*b*) Pointing off and placing the decimal point between the first and second periods, the number appears 23.4290. Under n^2 find $23.4256=4.84^2$ and $23.5225=4.85^2$. The first three figures of the root are 484. The first difference is 235,225 − 234,256 = 969; the second difference is 234,290 − 234,256 = 34; 34 ÷ 969 = .035, or .04, which gives the fourth and fifth figures of the root. Since the integral part of the number 23′42.9 contains two periods, the integral part of the root contains two figures, or $\sqrt{2342.9}=48.404$.

Cube Root.—EXAMPLE.—(*a*) $\sqrt[3]{.0000062417}=?$
(*b*) $\sqrt[3]{50932676}=?$

SOLUTION.—(*a*) Pointed off, the number appears .000′006′241′700, and with the decimal point placed between the first and second periods of the significant part, gives 6.2417. Under n^3 find $6.22950=1.84^3$ and $6.33163=1.85^3$. The first three figures of the root are 1.84. The first difference is 10,213, and the second difference is 1,220; 1,220 ÷ 10,213 = .119, or .12, which gives the fourth and fifth figures. There is one cipher period after the decimal point in the number; hence, $\sqrt[3]{.0000062417}=.018412$.

(*b*) Replace all after the sixth figure with ciphers, making the sixth figure 1 greater when the seventh figure is 5 or greater; that is, $\sqrt[3]{50932700}$ and $\sqrt[3]{50932676}$ will be the same. Placing the decimal point between the first and second periods gives 50.9327. Under n^3 find $50.6530=3.70^3$ and $51.0648=3.71^3$. The first three figures of the root are 370.

The second difference 2,797 ÷ the first difference, 4,118 = .679 or .68. Hence, $\sqrt[3]{50932676} = 370.68$.

Squares.—If the given number contains less than four significant figures, the significant figures of the square or cube can be found under n^2 or n^3 opposite the given number under n. The decimal point can be located by the fact that if the column headed $\sqrt{10n}$ is used, the square will contain twice as many figures as the number to be squared, while if the column headed $\sqrt{n}$ is used, the square will contain twice as many figures as the number to be squared, less 1. If the number contains an integral part, the principle is applied to the integral part only; if the number is wholly decimal, the square will have twice as many ciphers, or twice as many plus 1, following the decimal point as in the number itself, depending on whether $\sqrt{10n}$ or $\sqrt{n}$ column is used.

To square a number containing more than three significant figures, place the decimal point between the first and second significant figures and find in the column headed $\sqrt{n}$ or $\sqrt{10n}$ two consecutive numbers, one a little greater and the other a little less than the given number. The remainder of the work is exactly as described for extracting roots. The square will contain twice as many figures as the number itself, or twice as many less 1, according to whether the column headed $\sqrt{10n}$ or $\sqrt{n}$ is used. The number of ciphers following the decimal point in the square of a number wholly decimal is indicated in the same way.

EXAMPLE 1.—(*a*) $273.42^2 = ?$ (*b*) $.052436^2 = ?$

SOLUTION.—(*a*) Placing the decimal point between the first and second significant figures, the number is 2.7342, which occurs between $2.73313 = \sqrt{7.47}$ and $2.73496 = \sqrt{7.48}$, found under $\sqrt{n}$. The first three figures of the square are 747. The second difference 107 ÷ the first difference 183 = .584, or .58. Hence, $273.42^2 = 74{,}758$.

(*b*) With the position of the decimal point changed, the number is 5.2436, which is between $5.23450 = \sqrt{2.74}$ and $5.24404 = \sqrt{2.75}$, both under $\sqrt{10n}$. The first three significant figures of the root are 2.74 and the second difference

910 + the first difference 954 = .953, or .95, the next two figures. The number has one cipher following the decimal point, and the column headed $\sqrt{10n}$ is used; hence, $.052436^2 = .0027495$.

Cubes.—To cube a number, proceed in the same way, but use a column headed $\sqrt[3]{n}$, $\sqrt[3]{10n}$, or $\sqrt[3]{100n}$. If the number contains an integral part, the number of figures in the integral part of the cube will be three times as many as in the given number if the column headed $\sqrt[3]{100n}$ is used; it will be three times as many less 1 if the column headed $\sqrt[3]{10n}$ is used; and it will be three times as many less 2 if the column headed $\sqrt[3]{n}$ is used. If the number is wholly decimal, the number of ciphers following the decimal point in the cube will be three times, three times plus 1, or three times plus 2, as many as in the given number, depending on whether $\sqrt[3]{100n}$, $\sqrt[3]{10n}$, or $\sqrt[3]{n}$ column is used.

EXAMPLE 2.—(*a*) $129.684^3 = ?$ (*b*) $7.6442^3 = ?$ (*c*) $.032425^3 = ?$

SOLUTION.—(*a*) With the position of the decimal point changed, the number 1.29684 is between $1.29664 = \sqrt[3]{2.18}$ and $1.29862 = \sqrt[3]{2.19}$, found under $\sqrt[3]{n}$. The second difference 20 + the first difference 198 = .101+, or .10. Hence, the first five significant figures are 21810; the number of figures in the integral part of the cube is $3 \times 3 - 2 = 7$; and $129.684^3 = 2,181,000$, correct to five significant figures.

(*b*) 7.64420 occurs between $7.64032 = \sqrt[3]{446}$ and $7.64603 = \sqrt[3]{447}$. The first difference is 571; the second difference is 388; and $388 + 571 = .679+$, or .68. Hence, the first five significant figures are 44668; the number of ciphers following the decimal point is $3 \times 0 = 0$; and $7.6442^3 = 446.68$, correct to five significant figures.

(*c*) 3.2425 falls between $3.24278 = \sqrt[3]{10 \times 3.41}$ and $3.23961 = \sqrt[3]{10 \times 3.40}$. The first difference is 317; the second difference is 289; $289 + 317 = .911+$, or .91. Hence, the first five significant figures are 34091; the number of ciphers following the decimal point is $3 \times 1 + 1 = 4$; and $.032425^3 = .000034091$, correct to five significant figures.

Reciprocals.—The table gives the reciprocals of all numbers expressed by three significant figures correct to six significant figures. The number of ciphers following the decimal point in the reciprocal of a number is 1 less than the number of figures in the integral parts of the number; and if the number is entirely decimal, the number of figures in the integral part of the reciprocal is 1 greater than the number of ciphers following the decimal point in the number. For example, the reciprocal of 3370 = .000296736 and of .00348 = 287.356.

The following examples show the process when the number contains more than three significant figures:

EXAMPLE.—The reciprocal (*a*) of 379.426 = ? (*b*) of .0004692 = ?

SOLUTION.—(*a*) .379426 falls between $.378788 = \frac{1}{2.64}$ and $.380228 = \frac{1}{2.63}$. The first difference is 380,228 − 378,788 = 1,440; the second difference is 380,228 − 379,426 = 802; 802 ÷ 1,440 = .557, or .56. Hence, the first five significant figures are 26356, and the reciprocal of 379.426 is .0026356, to five significant figures.

(*b*) .469200 falls between $.469484 = \frac{1}{2.13}$ and $.467290 = \frac{1}{2.14}$. The first difference is 2,194; the second difference is 284; 284 ÷ 2,194 = .129 +, or .13. Hence, $\frac{1}{.0004692} = 2,131.3$, correct to five significant figures.

MENSURATION

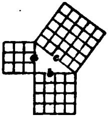
In the following formulas, unless otherwise stated, the letters have the meanings here given:

A = area of a plane figure;
d = diameter;
r = radius;
p = perimeter, or circumference;
π = ratio of any circumference to its diameter.

POLYGONS

Rectangle and parallelogram

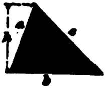
$A = ab$



Right-angled triangle

$c^2 = a^2 + b^2$

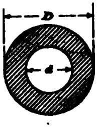
$A = \frac{1}{2}\, ab$



Any triangle

$A = \frac{1}{2}\, bh$

CIRCLES



The circle: $p = \pi d = 2\pi r$

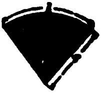
$$A = \pi r^2 = \frac{\pi d^2}{4}$$

The ring: $A = \frac{\pi}{4}(D^2 - d^2)$

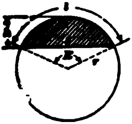
The sector:

$$A = \tfrac{1}{2}lr = \frac{E}{360}\pi r^2 = .008727r^2E$$

E = angle; l = length of arc



The segment:



$$A = \tfrac{1}{2}[lr - c(r-h)] = \frac{E}{360}\pi r^2 - \frac{c}{2}(r-h)$$

$$l = \frac{\pi r E}{180} = .0175rE$$

$$c = \text{chord} = 2\sqrt{2hr - h^2}$$

ELLIPSE

$$p = \pi\sqrt{\frac{D^2 + d^2}{2} - \frac{(D-d)^2}{8.8}}$$

$$A = \frac{\pi}{4}Dd$$

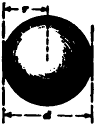
SOLIDS

The cylinder: Convex surface $= \pi dh$

Both end surfaces $= \frac{\pi d^2}{2}$

Volume $= \frac{\pi d^2}{4}\, h$

The sphere:



$$\text{Surface} = \pi d^2 = 4\pi r^2$$

$$\text{Volume} = \frac{1}{6}\pi d^3 = \frac{4}{3}\pi r^3$$

USEFUL NUMBERS

$\frac{1}{\pi} = .3183$	$\pi^2 = 9.8696$	$\frac{1}{\pi^2} = .1013$
$\sqrt{\pi} = 1.7725$	$\frac{1}{\sqrt{\pi}} = .5642$	

MECHANICS

FALLING BODIES

Let g = 32.16 = constant acceleration due to the attraction of the earth;

t = number of seconds that the body falls;

v = velocity in feet per second at the end of the time t;

h = distance, in feet, that the body falls during the time t.

Then,

$$v = gt = \frac{2h}{t} = \sqrt{2gh} = 8.02\sqrt{h};$$

$$h = \frac{vt}{2} = \frac{gt^2}{2} = \frac{v^2}{2g} = .015547v^2;$$

$$t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}} = .24938\sqrt{h}.$$

If h is in centimeters and v in centimeters per second, then $g = 981$ at Paris.

CENTRIFUGAL FORCE

F = centrifugal force, in pounds;

W = weight of revolving body, in pounds;

m = mass of body = $\frac{W}{g}$;

r = distance from axis of motion to center of gravity of body, in feet;

N = number of revolutions per minute;
v = velocity, in feet per second.

$$F=\frac{Wv^2}{gr}=\frac{Mv^2}{r}=.00034WrN^2.$$

In calculating the centrifugal force of flywheels, it is customary to neglect the arms and take r equal to the mean radius of the rim; in such cases, W is taken as one-half the weight of the rim. The result thus obtained, divided by π, is approximately the force tending to burst the flywheel rim.

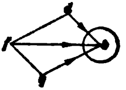
EXAMPLE.—What is the force tending to burst a flywheel rim weighing 7 tons, making 150 rev. per min., and having a mean radius of 5 ft.?

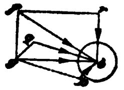
SOLUTION.—

$$F=\frac{.00034\times(\tfrac{1}{2}\times7\times2{,}000)5\times150^2}{3.1416}=85{,}227 \text{ lb.}$$

PARALLELOGRAM OF FORCES

Let db and qb represent the magnitudes and directions of two forces that act to move the body b. By completing the parallelogram, there will be obtained a diagonal force fb, whose magnitude and direction are equal to the effect produced by db and qb. fb is called the resultant of db and qb. If three or more forces act in different directions to move a body b, find the resultant of any two of them, and consider it as a single force. Between this and the next force find a second resultant. Thus, pb, qb, and rb are magnitudes and directions of the forces. $pb+qb+rb=gb+rb=fb$, which is the resultant in the magnitude and direction of the three forces pb, qb, and rb.





WORK AND POWER

Work is the overcoming of resistance through a distance. The unit of work is the *foot-pound;* that is, it equals 1 lb. raised vertically 1 ft. The amount of work done is equal to the resistance in pounds multiplied by the distance in feet through which it is overcome. If a body is lifted, the resistance is the weight or the overcoming of the attraction of gravity, the work done being the weight in pounds multiplied by the height of the lift in feet. If a body moves in a horizontal direction, the work done is the friction overcome, or the force needed to move a resistant body or combination of bodies, multiplied by the distance moved through.

Power is the rate of doing work, or the quantity of work done in unit time. The ordinary unit of mechanical power is the horsepower, which is equivalent to 33,000 ft.-lb. per min., or 550 ft.-lb. per sec.

The work necessary to be done in raising a body weighing W lb. through a height of h ft. equals $W\,h$ ft.-lb. The total work that any moving body is capable of doing in being brought to rest equals its kinetic energy, or $\frac{Wv^2}{2g} = \frac{1}{2}mv^2$.

The kinetic energy of a 200,000-lb. train running at 40 mi. per hr. (58.7 ft. per sec.) is $200{,}000 \times 58.7^2 \div (2 \times 32.16) = 10{,}714{,}220$ ft.-lb.; the retarding force necessary to stop the train within 2,000 ft. is $10{,}714{,}220 \div 2{,}000 = 5357.1$ lb., and the average power required to stop the train in $\frac{1}{2}$ min. is $10{,}714{,}220 \div \frac{1}{2} = 21{,}428{,}440$ ft.-lb. per min. or $21{,}428{,}440 \div 33{,}000 = 649.3$ H. P.

BELTS, SHAFTING, ETC.

To find the angle of contact of a belt on each pulley:

Let D = diameter of the larger pulley, in inches;
d = diameter of the smaller pulley, in inches;
l = distance between the pulley centers, in inches;
a = $\frac{1}{2}$ the arc of contact on the smaller pulley.

Then,
$$\cos a = \frac{D - d}{2\,l}.$$

From a table of natural cosines the angle a can be found and $2\,a$ = the arc of contact on the smaller pulley; $360° - 2a$ = the arc of contact on the larger pulley. In calculating belts, only the arc of contact on the smaller pulley need be considered.

To find the length L of a belt,

$$L = \frac{D+d}{2} \times 3\tfrac{1}{4} + 2l, \text{ approximately.}$$

NOTE.—These formulas apply only to ordinary open belts and not to crossed belts.

EXAMPLE.—A 12-in. pulley and a 60-in. pulley with centers 15 ft. apart are connected by an open belt. (*a*) Find the arc of contact of the belt on each pulley. (*b*) Find the length of the belt.

SOLUTION.—(*a*) 15 ft. = 180 in. (60 − 12) ÷ (2 × 180) = .1333 = cos 82° 20′.

Arc of contact on smaller pulley = 2 × 82° 20′ = 164° 40′.

Arc of contact on larger pulley = 360 − 164° 40′ = 195° 20′.

(*b*) $\frac{60+12}{2} \times 3\tfrac{1}{4} + 2 \times 180 = 477$ in. = 39 ft. 9 in.

The following formulas give conservative results:

Let C = allowable effective pull, in pounds per inch, width of belt (see table);

H = horsepower to be transmitted;

W = width of belt, in inches;

V = belt speed, in feet per minute.

Then, $$W = \frac{33{,}000H}{VC}; \qquad H = \frac{VCW}{33{,}000}$$

ALLOWABLE BELT PULL

Arc Covered by Belt		Allowable Pull per Inch Width in Pounds	
Degrees	Fraction of Circumference	Single belt	Double belt
90	.250	23	32.9
112½	.312	27.4	39.2
120	.333	28.8	41.2
135	.375	31.3	44.7
150	.417	33.8	48.3
157½	.437	34.9	49.9
180	.500	38.1	54.5

Single belting is $\frac{3}{16}$ in. thick; four-ply cotton belting is generally considered equivalent to single belting. To install one pulley directly over the other, so that the belt runs vertical should be avoided if possible; it is better that the angle between the belt and the floor does not exceed 45°, and the bottom side of the belt should be the driving side. The distance between pulley centers depends on the size of the pulleys and of the belt; it should be great enough so that the belt will run with a slight sag and a gently undulating motion, but not great enough to cause excessive sag and an unsteady flapping motion of the belt. In general, the centers of small pulleys carrying light narrow belts should be about 15 ft. apart and the belt sag 1½ to 2 in.; for large pulleys and heavy belts the distance should be 20 to 30 ft. and the sag 2½ to 5 in.

Loose-running belts will last much longer than tight ones, and will be less likely to cause heating and wear of pulley bearings. High-speed belts are less likely to slip than low-speed belts; hence, pulleys should be selected so as to make the belt speeds high, provided they do not exceed 3,500 ft. per min. for laced belts and 5,000 ft. per min. for endless belts. Leather belts should be run with the grain, or hair, side next to the pulley; they should be kept clean, dry, and free from grease and lubricating oil. A dry, husky, leather belt can be made soft and pliable by the application of a coat of melted tallow and beeswax; this should be done only when the belt becomes dry and hard.

SHAFTING

The diameter of a shaft may be found by the following formulas. The first is used when great stiffness is required and the shafts are very long; the second when strength only is required to be considered; and the third for calculating the diameters of steel shafts for dynamos.

d = diameter of shaft, in inches;
H = horsepower transmitted;
W = kilowatts output;
N = number of revolutions per minute,
c = constant in formula (1);

c' = constant in formula (2);
k = constant in formula (3).

$$d = c\sqrt[4]{\frac{H}{N}} \quad (1) \qquad d = c'\sqrt[4]{\frac{H}{N}} \quad (2) \qquad d = k\sqrt[4]{\frac{W}{N}} \quad (3)$$

c = 5.26 for cast iron; 4.75 for wrought iron; 3.96 for steel;
c' = 4.02 for cast iron; 3.63 for wrought iron; 3.03 for steel.
k = .9 to 1 for 1- to 10-kilowatt dynamos;
k = 1.1 to 1.4 for 50- to 500-kilowatt dynamos.

NOTE.—To extract the fourth root, extract the square root twice.

ROPES AND CHAINS

D = diameter of the rope in inches = diameter of iron from which the link in chain is made;
W = safe load in tons of 2,000 lb.
For common hemp rope, $W = \frac{1}{3} D^2$.
For iron-wire rope, $W = \frac{8}{3} D^2$.
For steel-wire rope, $W = \frac{14}{3} D^2$.
For close-link wrought-iron chain, $W = 6 D^2$.
For stud-link wrought-iron chain, $W = 9 D^2$.

ELECTRICITY AND MAGNETISM

ELECTRICAL UNITS, SYMBOLS, AND QUANTITIES

The fundamental units, from which are derived the units used in electricity and magnetism, are the *centimeter* as the unit of length, the *gram* as the unit of mass, and the *second* as the unit of time. A system of units derived from these fundamental units is called the *centimeter-gram-second*, or *C. G. S., system*. The C. G. S. unit of velocity, sometimes called the *kine* is 1 centimeter per second; the C. G. S. unit of force, called the *dyne*, is the force required to produce an acceleration of 1 kine per second in a body having a mass of 1 gram; the C. G. S. unit of work or energy, called the *erg*, is the work done by a force of 1 dyne working through a distance of 1 centimeter.

Two systems of units are derived from the fundamental units: the *electrostatic units*, based on the force exerted between two quantities of electricity; and the *electromagnetic units*, based on the force exerted between two magnetic poles or between a current and a magnetic pole. The ratio of the electrostatic to the electromagnetic units is some multiple or submultiple of the velocity v of light in air, which is 3×10^{10} cm. per sec.

The electrostatic units are those of quantity, current, electromotive force, resistance, capacity, and inductivity. These units have not been named.

The electromagnetic units may be considered in two classes, electric units and magnetic units. The C. G. S. electromagnetic units have not been named and, as they are inconvenient in magnitude for practical purposes, a so-called practical system of units has been adopted. Practical electromagnetic units are equal to the C. G. S. electromagnetic units multiplied or divided by some power of 10. The practical units are used to express quantity of electricity, strength of electric current, electromotive force, resistance, work, power, inductance, and capacity.

The magnetic units that would correspond to the practical electric units are not used and have not been definitely named on account of their inconvenient magnitudes. The names of all the practical electromagnetic units, except the mho, have been adopted by some international conventions and their use legalized by most of the important nations.

Numerical Expression of Electrical Units.—The expression of electrical units often requires large numbers, and it is customary to use the multiple 10 with an index to indicate the power to which it is raised. The sign of the index indicates whether the designated power of 10 is to be used as a multiplier or as a divisor. For example, $7\times10^{2}=700$, but $7\times10^{-2}=.07$; $v\times10^{-1}=\frac{v}{10}$; $v^2\times10^{-9}=\frac{v^2}{1{,}000{,}000{,}000}$; $723\times10^{-4}=\frac{723}{10{,}000}=.0723$; etc.

LIST OF IMPORTANT SYMBOLS

In the two tables following, l represents a length or distance, F a force, v a velocity, T the number of turns in a coil or circuit, t time, W work, and A an area.

In this work, the following meanings will be understood unless otherwise specified:

A = area in square centimeters;
$\mathbf{A}$ = area in square inches;
$\mathcal{B}$ = magnetic density per square centimeter;
$\mathbf{B}$ = magnetic density per square inch;
C = capacity in farads or microfarads;
D, d = diameters;
E, e = electromotive force, in volts;
F = force, usually in dynes;
$\mathfrak{F}$ = magnetomotive force;
G = conductance;
$\mathcal{H}$ = intensity of magnetic field per square centimeter,
$\mathbf{H}$ = intensity of magnetic field per square inch,
H. P. = horsepower;
I = current, in amperes;
$\mathfrak{J}$ = intensity of magnetization;
J = work, in joules;

MAGNETIC UNITS

Magnetic Quantities	Symbol	Defining Equation	Names of C. G. S. Units
Strength of pole	m	$m=\sqrt{Fl^2}$	Has no name
Magnetic moment	$\mathfrak{M}$	$\mathfrak{M}=ml$	Has no name
Intensity of magnetization	$\mathfrak{J}$	$\mathfrak{J}=\frac{m}{A}$	Has no name
Magnetizing force or field density	$\mathcal{H}$	$\mathcal{H}=\frac{F}{m}=\frac{m}{l^2}$	Gauss, or 1 line of force per sq. cm.
Susceptibility	κ	$\kappa=\frac{\mathfrak{J}}{\mathcal{H}}$	Has no name
Magnetomotive force	$\mathfrak{F}$	$\mathfrak{F}=\mathcal{H}l$ or $\mathfrak{F}=\frac{W}{m}$	Gilbert (Not internationally accepted)
Magnetic density or magnetic induction	$\mathcal{B}$	$\mathcal{B}=4\pi\mathfrak{J}+\mathcal{H}$	Gauss, or 1 line of force per sq. cm.
Magnetic flux	Φ	$\Phi=\mathcal{B}A$	Maxwell, or 1 line of force
Permeability	μ	$\mu=\frac{\mathcal{B}}{\mathcal{H}}$	Has no name
Reluctance	$\mathcal{R}$	$\mathcal{R}=\frac{\mathfrak{F}}{\Phi}$ or $\mathcal{R}=\frac{l}{A\mu}$	Oersted (Not internationally accepted)

ELECTRICAL UNITS

Electrical Quantities	Symbol	Defining Equation	Names of Practical Electromagnetic Units	Quantities by Which to Multiply Practical Electromagnetic Units to Reduce to	
				C. G. S. Electromagnetic Units	C. G. S. Electrostatic Units $v=3\times10^{10}$
Current.......	I or i	$I=\frac{F}{l\mathcal{H}}$	Ampere	10^{-1}	$v\times10^{-1}=3\times10^{9}$
Quantity of electricity...	Q or q	$Q=It$ or $Q=\sqrt{Fl^2}$	Coulomb	10^{-1}	$v\times10^{-1}=3\times10^{9}$
Electromotive force.......	E or e	$E=\mathcal{H}lv=\frac{\Phi}{t}$ or $E=\frac{W}{Q}$	Volt	10^{8}	$10^{8}+v=\frac{1}{3}\times10^{-2}$
Resistance....	R	$R=\frac{E}{I}$ or $R=\frac{W}{I^2t}$	Ohm	10^{9}	$10^{9}+v^{2}=\frac{1}{9}\times10^{-11}$
Resistivity....	ρ	$\rho=\frac{RA}{l}$	Ohm		

ELECTRICAL UNITS—*(Continued)*

Electrical Quantities	Symbol	Defining Equation	Names of Practical Electromagnetic Units	Quantities by Which to Multiply Practical Electromagnetic Units to Reduce to	
				C. G. S. Electromagnetic Units	C. G. S. Electrostatic Units $v=3\times10^{10}$
Conductance...	G	$G=\frac{1}{R}$	Mho (Not internationally accepted)		
Conductivity..	γ	$\gamma=\frac{1}{\rho}$	Mho (Not internationally accepted)		
Work or energy	W or J	$J=EIt$	Joule	10^7 ergs	
Power........	P	$P=EI$	Watt	10^7 ergs per sec.	
Capacity......	C	$C=\frac{Q}{E}$	Farad	10^{-9}	$v^2\times10^{-9}=9\times10^{11}$
Inductivity....	K	$K=\frac{Q}{Q'}$ (air as dielectric) (other dielectric) or $K=\frac{4\pi Cl}{A}$	A number		
Inductance (self).......	L	$L=\frac{\Phi T}{I}$	Henry	10^9	$10^9\div v^2=\frac{1}{9}\times10^{-11}$
Inductance (mutual)....	M	$M=\frac{\Phi T}{I}$	Henry	10^9	$10^9\div v^2=\frac{1}{9}\times10^{-11}$

K. W. = power, in kilowatts;
l = length, in centimeters;
$\mathbf{l}$ = length, in inches;
L = inductance or coefficient of self-induction, in henrys:
$\mathcal{M}$ = magnetic moment;
M = mutual inductance;
m = strength of pole;
P = power, in watts;
Q = quantity of electricity, in coulombs;
$\mathcal{R}$ = reluctance;
R = resistance, in ohms;
ρ = resistivity;
t = time, in seconds;
v = volume, in cubic centimeters, or velocity, in centimeters per second;
$\mathbf{V}$ = volume, in cubic inches;
W = work;
Φ = total magnetic flux;
μ = permeability.

PRACTICAL ELECTROMAGNETIC UNITS

Current (I).—The strength of current I is the rate at which electricity is flowing through a conductor, and is analogous to the rate of flow of water through a pipe in gallons per second.

The unit strength of current, called the *ampere*, is represented sufficiently well for practical use by the unvarying current that, when passed through a specified solution of nitrate of silver in water, deposits silver at the rate of .001118 gram per sec.

A *milliampere* is equal to $\frac{1}{1,000}$ or .001 ampere.

Quantity of Electricity (Q).—The quantity of electricity that passes through a circuit is comparable to the quantity of water that flows through a pipe, and equals the product of the rate of flow and the time; that is,

$$Q = It$$

If I is 1 ampere and t is 1 second, Q is 1 ***coulomb***, which is the practical unit quantity of electricity. If 5 amperes is flowing through a wire, then, in 30 seconds, $5 \times 30 = 150$ coulombs of electricity will pass. One coulomb will deposit

.001118 gram of silver out of a neutral solution of silver nitrate consisting of 15 parts by weight of silver nitrate and 85 parts of water.

Electromotive Force (*E. M. F.*, or *E*).—Electromotive force, or electric pressure, is that which causes electricity to flow in a closed circuit. The practical unit of E. M. F is the *volt*, which is the E. M. F. that will cause a current of 1 ampere to flow through a resistance of 1 ohm. The volt is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the E. M. F. between the electrodes of a Carhart-Clarke standard cell at a temperature of 15° C. A *kilovolt* = 1,000 volts, a *millivolt* = .001 volt, and a *microvolt* = .000001 volt.

Resistance (*R*.)—All substances offer resistance to the passage of electricity through them, the amount of the resistance depending on the substance and on its shape; that is, on the length and cross-section. The resistance of all metals increases with an increase in the temperature; while the resistance of carbon, insulating materials, and electrolytic solutions decreases with an increase in their temperatures.

The practical *unit of resistance* is the *ohm*. A conductor has a resistance of 1 ohm when the pressure required to send 1 ampere through it is 1 volt. In other words, the drop, or fall, in pressure through a resistance of 1 ohm, when a current of 1 ampere is flowing, is 1 volt. The *microhm* = .000001 ohm. The *megohm* = 1,000,000 ohms. The ohm is one of the few electrical units for which a material standard can be used. Different standards have been used, all based on the resistance of a column of mercury at 0° C., having a cross-sectional area of 1 sq. mm. and a different length for each standard, as follows:

1. The *international ohm*, now universally recognized as the standard, has a column of mercury 106.3 cm. in length.

2. The *legal ohm*, in use previous to 1893, but now superseded by the international ohm, has a column of mercury 106 cm. in length.

3. The *British Association unit* (B. A. U.). which preceded the legal ohm but which is no longer in use, has a column of mercury 104.8 cm. in length.

RESISTANCES AND TEMPERATURE COEFFICIENTS OF METALS*

Metal	Specific Resistance ρ† (Microhms per Centimeter Cube)	Resistance of 1 Mil-Foot in Ohms		Temperature Coefficient per Degree C. Between 0° and 100° C.	Temperature Coefficient per Degree F. Between 32° and 212° F.	Percentage Conductivity	Relative Resistance
	At 0° C. or 32° F.	0° C. or 32° F.	23.8° C. or 75° F.				
Silver,[2] pure annealed..	1.468	8.831	9.674	.004000	.002220	108.60	.925
Copper,[2] pure annealed.	1.561	9.390		.004280	.002380	102.10	.980
Copper,[1] annealed	1.594	9.590	10.505	.004020	.002230	100.00	1.000
Silver, hard-drawn.....	1.629	9.799				97.80	1.022
Copper,[1] hard-drawn...	1.631	9.810	10.745	.004020	.002230	97.80	1.022
Gold[2] (99.9% pure)....	2.197	13.216		.003770	.002090	72.55	1.378
Aluminum (99.5% pure)	2.530	15.219				63.00	
Aluminum[2] (commer-							1.587
cial—97.5% pure)...	2.665	16.031		.004350	.002420	59.80	1.672
Magnesium[2]...........	4.355	26.197		.003810	.002120	36.60	2.732
Zinc[2] (very pure)......	5.751	34.595		.004060	.002260	27.72	3.608
Iron [2] approximately							
pure...............	9.065	54.529		.006250	.003470	17.50	5.714
Iron "E. B. B." iron wire	9.759	58.702	65.190	.004630	.002570	16.20	6.173

Cadmium[3] (pure)	10.023	60.292		.004190	.002320	15.90	6.289
Palladium[3] (pure)	10.219	61.471		.003540	.001970	15.60	6.410
Platinum[3] (pure)	10.917	65.670		.003669	.002038	14.60	6.845
Iron, "B. B." iron wire	11.085	68.680	76.270	.004630	.002570	13.50	7.407
Nickel[3]	12.323	74.128		.006220	.003460	12.94	7.726
Tin[3] (pure)	13.048	78.489		.004400	.002450	12.22	8.184
Steel (wire)	13.495	81.179	90.150	.004630	.002570	11.60	8.621
Thallium[3] (pure)	17.633	106.070		.003980	.002210	9.04	11.060
Lead[2] (pure)	20.380	122.590	134.610	.004110	.002280	7.82	12.790
Antimony (pressed)	35.400	212.950		.004100		4.50	22.220
Mercury[2] (pure)	94.070	565.870	610.370	.000720	.000400	1.69	59.170
Bismuth (pressed)	130.800	786.810		.003540		1.22	81.970

* The resistances are given in international ohms † This is the resistance of a piece 1 cm. long and 1 sq. cm. in sectional area, at 0° C., in microhms. [1]Determined by Matthiessen and taken as the standard. [2]Determined by Fleming and Dewar. According to the American Institute of Electrical Engineers, the temperature coefficient of pure commercial copper should be .0042 per degree C

RESISTANCES AND TEMPERATURE COEFFICIENTS OF ALLOYS†

Substance	Specific Resistance ρ‡ (Microhms per Centimeter Cube) At 0° C. or 32° F.	Resistance of 1 Mil-Foot in Ohms at 0° C. or 32° F.	Temperature Coefficient per Degree Centigrade	Temperature Coefficient per Degree Fahrenheit	Percentage Conductivity	Relative Resistance
Brass	7.200	43.310			22.15	4.515
Phosphor-bronze, commercial—*Cu*, *Sn*, *P*	8.479	51.005	.000640	.000356	18.80	5.319
Aluminum bronze	12.300	73.989	.001000	.000556	12.96	7.714
Platinum rhodium,[2] *Pt* 90, *Rh* 10	21.142	127.180	.001430*	.000795*	7.54	13.260
German silver,[3] *Cu* 50, *Zn* 35, *Ni* 15	21.250	127.800	.000400	.000220	7.50	17.300
Platinum silver,[3] *Pt* 66⅔, *Ag* 33⅓	24.900	149.800	.000310	.000170	6.40	15.600
German silver,[2] *Cu* 60, *Zn* 25, *Ni* 15	29.982	180.350	.000273*	.000152*	5.32	18.800
Platinum iridium,[2] *Pt* 80, *Ir* 20	30.896	185.850	.000822*	.000457*	5.16	19.380

Platinum silver,[3] *Pt* 33⅓, *Ag* 66⅔	31.582	189.980	.000243*	.000135*	5.05	19.800
Platinoid,[3] *Cu* 59, *Zn* 25.5, *Ni* 14, *W* (tungsten) 55.	41.731	251.030	.000310*	.000172*	3.82	26.180
German silver,[3] *Cu* 55, *Zn* 20, *Ni* 35	45.540	271.100	.000330	.000180	3.50	28.600
Manganin,[3] *Cu* 84, *Ni* 4, *Mn* 12	46.678	280.790	.000000*		3.41	29.330
Constantan, *Cu* 58, *Ni* 41, *Mn* 1	{50, 52}	{300.77, 312.80}	±.000010	.000005	{3.19, 3.07}	{31.35, 32.57}
Reostene	76.468	459.990	.001100*	.000610*	2.08	48.080
Gray cast iron, *C* 3.46; graphite, 2.06; *Mn* .173; *S* .042; *Si* 2.04; *P* .151	114.000	684.000				
Carbon, arc light	{4400, 8600}	{26500, 51700}	.000520*	.000289*	{.0360, .0186}	{2778, 5376}

*These are the temperature coefficients at 15° C. or 59° F.; the others are mean temperature coefficients between the freezing and boiling temperatures of water. †Where the proportions are not given, the experimenters merely stated that they were made of the usual proportions. As this is not very definite, we cannot give the proportions. ‡This is the resistance of a piece 1 cm. long and 1 sq. cm. in sectional area at 0° C. in microhms. [2]Determined by Fleming and Dewar. [3]Given by Jackson. *Pt*=platinum; *Ag*=silver; etc.

The relative values of these units, as accepted by United States Bureau of Standards, are as follows:

1 international ohm = 1.01348 B. A. U.
1 international ohm = 1.00283 legal ohms
1 legal ohm = .997178 international ohm
1 legal ohm = 1.0106 B. A U.
1 B. A. U. = .986699 international ohm
1 B. A. U. = .98949 legal ohm

The legal ohm has been extensively used, and many resistance coils still in use were calibrated in legal ohms; but nearly all instruments containing resistance coils that were made since about 1893 have been calibrated in international ohms.

The *resistivity*, or *specific resistance*, of a substance is usually defined as the resistance, at 32° F. or 0° C., of a piece of the substance 1 cm. long and 1 sq. cm. in sectional area. If l is the length and a is the sectional area of a piece of a substance whose resistivity is ρ, at a given temperature, then the resistance R of the piece at the same temperature may be determined by the formula

$$R = \frac{\rho \times l}{a}$$

SPECIFIC RESISTANCE OF INSULATORS

Substance	Specific Resistance ρ
Mica	84 tregohms
Gutta percha	449 tregohms
Hard rubber	28 quegohms
Paraffin (solid)	34 quegohms
Paraffin oil	8 tregohms
Porcelain	540 quegohms
Flint glass	16,700 quegohms
Olive oil	1 tregohm
Lard oil	350 begohms
Benzine	14 tregohms
Wood tar	1,670 tregohms
Ozokerite (crude)	450 tregohms

The *resistivity per meter-gram* means the resistance of a piece of a substance 1 meter long (uniform in sectional area) and having a mass of 1 gram; this is the resistivity expressed in terms of the length and mass. If k represents the length-mass resistivity, then, a conductor l meters in length and having a mass of m grams will have a resistance of

$$R = \frac{k \times l^2}{m}$$

The *mile-ohm* is a circular wire 1 mi. long having a resistance of 1 ohm. The *weight per mile-ohm* is a convenient standard for expressing the conducting quality of wires; the higher the conductivity of a metal, the less its weight per mile-ohm. The mile-ohm = weight per mile × resistance per mile. The expression that the weight per mile-ohm of a certain grade of copper is 888 lb. at 60° F. means that a wire 1 mi. long made of this copper and having a resistance of 1 ohm at 60° F. weighs 888 lb.

The weight per mile-ohm of pure copper is 859 lb. Calling the conductivity of pure copper 100, the percentage conductivity x of copper weighing 888 lb. per mile-ohm may be determined as follows:

$$x : 100 = 859 : 888$$

or

$$x = \frac{859}{888} \times 100 = 96.73$$

in which x = percentage conductivity.

The following formulas are useful:

$$\text{Weight of a given wire per mile} = \frac{\text{weight per mile-ohm}}{\text{resistance per mile}}$$

$$\text{Resistance per mile} = \frac{\text{weight per mile-ohm}}{\text{weight per mile}}$$

PHYSICAL AND ELECTRICAL PROPERTIES OF METALS AND ALLOYS

(By H. F. Parshall, M. Inst. C. E., and H. M. Hobart, S. B., in "Engineering.")

The following table gives some physical and electrical properties of various metals and alloys. In nearly every case the name of the observer is stated. No attempt has been made to reconcile divergent measurements. The merit

PHYSICAL AND ELECTRICAL PROPERTIES OF METALS AND ALLOYS

Material	Specific Resistance at 0° C. (Microhms per Cent. Cube)	Microhms per Cubic Inch at 0° C.	Resistance of Wire 1 Ft. Long and .001 In. Dia. Ohms at 0° C.	Per Cent. Increase of Resistance per Deg. Cent.	Melting Point Deg. Cent.	Specific Heat Mean	Ultimate Tensile Strength. Pounds per Square Inch	Specific Gravity	Weight of 1 Cu. In. Pound
Aluminum (Neuhausen), 99% *Al*. Dewar and Fleming	2.56	1.01	15.4	.423	600	.21		2.6	.094
Aluminum (commercial), 97.5% *Al.* Dewar and Fleming	2.67	1.05	16.0	.435	600	.21		2.6	.094
Aluminum (annealed). Matthiessen	2.89	1.14	17.4	.139	600	.21		2.6	.094
Aluminum, 94%; copper, 6%. Dewar and Fleming	2.90	1.14	17.4	.381					
Aluminum, 94%; copper, 6% (annealed). Charpentier	3.11	1.23	18.7					2.95	.107
Aluminum, 94%; copper, 6% (hard). Charpentier	3.33	1.31	20.0					2.95	.107
Aluminum, 94%; silver, 6%. Dewar and Fleming	4.64	1.83	27.8	.238					

Aluminum Bronze, *Cu* (90%) *Al* (10%). C. Limb	12.6	4.96	75.5	.105				7.7	.278
Antimony (compressed). Matthiessen	35.2	13.9	211	.389	440	.049		6.7	.242
Bessemer soft steel, *C* (.045); *Mn* (.200); *S* (.030); *Si* (0); *P* (.040). Hopkinson	10.5	4.14	63.0			.117		7.8	.282
Bismuth (compressed). Matthiessen	130	51.2	780	.354	260	.030		9.8	.354
Cadmium (pure). Dewar and Fleming	10.0	3.93	60.0	.419				8.60	.310
Chrome bronze, copper, tin, and chromium. Hospitalier	1.64	.645	9.84				64,000	8.9	.321
Chrome bronze, copper, tin, and chromium	4.71	1.85	28.3				107,000		
Chrome bronze, copper, tin, and chromium. Hospitalier	7.80	3.07	46.8				150,000	8.9	.321
Chrome steel (annealed), *C*, 687; *Mn*, .28; *S*, .02; *Si*, .134; *P*, .043; *Cr*, 1.195. Hopkinson	17.9	7.05	108						
Chrome steel (annealed), *C*, .532; *Mn*, .393; *S*, .02; *Si*, .22; *P*, .04; *Cr*, .621. Hopkinson	19.4	7.65	117						
Electrolytic copper (annealed). Lagarde	1.54	.605	9.25	.445	1050	.093		9.05	.327
Electrolytic copper (annealed). Dewar and Fleming	1.56	.614	9.35	.428	1050	.093		8.91	.322
Copper (annealed). Matthiessen	1.59	.625	9.54	.388	1050	.093		8.9	.321

PHYSICAL AND ELECTRICAL PROPERTIES OF METALS AND ALLOYS—(*Continued*)

Copper, 50%; silver, 50% Abbott	1.84	.725	11.1						
Copper, 96%; silicon, 4% Abbott	2.11	.830	12.7						
Copper, 88%; silicon, 12% Abbott	2.94	1.16	17.7						
Copper, 99.29%; zinc, 71% R. Haas	1.83	.720	11.0	.373					
Copper, 90.9%; zinc, 9.1% R. Haas	3.64	1.43	21.8	.204					
Zinc, 99.5%; copper, 5% R. Haas	5.88	2.31	35.3	.385		.095		7.1	.256
Copper, 65.8%; zinc, 34.2% R. Haas	6.30	2.48	37.8	.158					
Cast copper	4.65	1.83	27.9						
Copper, 90%; lead, 10% Abbott	5.28	2.08	31.7						
Copper, 97%; aluminium, 3%. Dewar and Fleming	8.84	3.48	53.0	.090					
Copper, 87%; *Ni*, 6.5%; *Al*, 6.5%. Dewar and Fleming	14.9	5.87	89.5	.0645					
Copper, 90%; arsenic, 10% Abbott	17.6	6.94	106						
Copper, 75%; nickel, 25% Feussner and Lindeck	34.2	13.5	205	.019					
German silver. *Cu* (60); *Zn* (25); *Ni* (15). Feussner and Lindeck	30.0	11.8	180	.036					
Gold (annealed), Matthiessen	2.04	.803	12.3	.365	1100	.032		19.3	.695

Gold, 99.9% (pure). Dewar and Fleming	2.20	.865	13.2	.377	1200	.032		19.3	.695
Gold, 90%; silver, 10%. Dewar and Fleming	6.28	2.47	37.7	.124					
Gold, 67%; silver, 33% (alloy). Matthiessen	10.8	4.25	64.8	.065					
Iron (very pure). Dewar and Fleming	9.07	3.57	54.5	.625		.113		7.8	.282
Iron with .25% *Mn* and .01% *S*. Dewar and Fleming	10.5	4.14	63.0	.544		.113		7.8	.282
White cast iron, *C*, 2.04; graphite, *O*, *Mn*, .386; *S*, .467; *Si*, .764; *P*, .458. Hopkinson	56.6	22.3	340		1130			7.20	.260
Spiegeleisen—*C*, 4.5%; *Mn*, 7.97%; *S* traces, *Si*, .502% *P*, .128%. Hopkinson	105	41.4	630						
Grey cast iron—*C*, 3.46; graphite, 2.06; *Mn*, .173; *S*, .042; *Si*, 2.04; *P*, .151. Hopkinson	114	44.9	684		1220			7.20	.260
Wrought iron (annealed). Hopkinson	13.8	5.44	82.8					7.8	.282
Lead (compressed) Matthiessen	19.5	7.68	117	.387	330	.032		11.4	.410
Lead (pure). Dewar and Fleming	20.4	8.04	123	.411	330	.032		11.4	.410
Magnesium. Dewar and Fleming	4.36	1.72	26.2	.381		.25		1.74	.063
Manganese steel (annealed), *C*, .674; *Mn*, 4.73; *S*, .023; *Si*, .608; *P*, .078. Hopkinson	39.3	15.5	236		1260			7.8	.282

PHYSICAL AND ELECTRICAL PROPERTIES OF METALS AND ALLOYS—(*Continued*)

Copper, 84%; manganese, 12%; *Ni*, 4% (manganine). Dewar and Fleming	46.7	18.4	281	.00				8.9	.321
Copper, 73%; manganese, 24%; nickel, 3%. Feussner and Lindeck.........	47.7	18.8	287	.003				8.9	.321
Copper, 80.5%; manganese, 16.5%; nickel, 3% (manganine). Tests by G. E. Co.	49.0	19.3	294	.0				8.9	.321
Copper, 83.4%; *Mn*, 15.2%; *Fe*, 1.4%. Tests by G. E. Co..................	50.0	19.7	300	.0				8.9	.321
Copper, 79.5%; *Mn*, 19.7%; *Fe*, .8%. Tests by G. E. Co..................	65.5	25.8	393	.0					
Manganese steel (annealed), *C*, 1.298; *Mn*, 8.74; *S*, .024; *Si*, .094; *P*, .072. Hopkinson..............	63.2	24.9	380		1260			7.8	.282
Manganese steel (Hadfield), *C*, 1.005; *Mn*, 12.36; *S*, .038; *Si*, .204; *P*, .070. Hopkinson.............	65.5	25.8	393		1260			7.8	.282
Manganese steel (Hadfield), 12% *Mn*. Dewar and Fleming................	67.1	26.4	401	.127	1260			7.8	.282
Manganese steel (Hadfield's Hecla Foundry), *C*, 1.001; *Mn*, 11.40; *P*, .059. Tests by G. E. Co............	69.0	27.1	414	.135	1260			7.8	.282

Manganese steel. Hospitalier	75.0	29.5	450	.136	1260		230,000	7.8	.282
Copper, 70%; manganese, 30%. Feussner and Lindeck	101.0	39.8	605	.004					
Mercury. Matthiessen	94.3	37.1	566	.072		.032		13.6	.490
Nickel. Dewar and Fleming	12.3	4.85	73.7	.62	1500	.109		8.9	.321
Nickel (annealed). Matthiessen	12.4	4.89	74.4	.50	1500	.109		8.9	.321
Nickel steel (Hadfield), 4.35%; nickel. Dewar and Fleming	29.5	11.6	177	.201					
Nickeline. Lange & Co., Berlin	40.0	15.8	240						
Palladium (pure). Dewar and Fleming	10.2	4.02	61.1	.354					
Platinum, 67%; silver, 33% (alloy). Matthiessen	24.2	9.54	145	.133					
Platinum, 80%; iridium, 20%. Dewar and Fleming	30.9	12.2	186	.082					
Platinoid. Dewar and Fleming	41.7	16.4	251	.031				8.8	.318
Platinoid-martino. Dewar and Fleming	43.6	17.2	262					8.8	.318
Platinoid-martino	33.0	13.0	198	.024					
Platinum (soft annealed, pure)	8.25	3.24	49.5		1775	.032		21.2	.765
Platinum (annealed). Matthiessen	8.98	3.53	53.9	.247	1775	.032		21.2	.765

PHYSICAL AND ELECTRICAL PROPERTIES OF METALS AND ALLOYS—(*Continued*)

Platinum (pure) wire .0259 cm. in diam. Dewar and Fleming	11.0	4.34	66.0	.35	1775	.032		21.2	.765
Platinum, 90%; rhodium, 10%. Dewar and Fleming	21.1	8.30	127	.143					
Platinum, 90%; iridium, 10% (alloy). Matthiessen	21.6	8.50	130	.133					
Phosphor-bronze, with 9% phosphorus. Abbott	32.5	12.8	195						
Phosphor-bronze (copper, tin, and phosphorus). Hospitalier	1.6	.630	9.6	.394			64,000	8.9	.321
Phosphor-bronze (copper, tin, and phosphorus). Hospitalier	5.6	2.20	33.6	.394			117,000	8.9	.321
Phosphor-bronze, with 10% of tin. Abbott	24.6	9.69	148						
Pure electrolytic (annealed) silver. Dewar and Fleming	1.47	.579	8.82	.400	950	.056		10.5	.379
Silver (annealed). Matthiessen	1.49	.586	8.94	.377	950	.056		10.5	.379
Silverine, *Cu* (77), *Ni* (17), *Fe* (2), *Zn* (2), *CO* (2). Dewar and Fleming	2.06	.810	12.4	.285					
Silver, 80%; palladium 20% Dewar and Fleming	15.0	5.90	90.0						
Silver, 66%; platinum, 33% Dewar and Fleming	31.6	12.4	190	.0213					

Silicon-bronze (copper, tin, and silicon). Hospitalier	1.67	.657	10.0	.152			64,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	2.69	1.06	16.2				93,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	5.76	2.27	31.6				107,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	7.80	3.07	46.8				143,000	8.9	.321
Silicon steel (annealed), *C*, .685; *Mn*, .694; *S*, .024; *Si*, 3.44; *P*, .133. Hopkinson	61.9	24.3	372						
Thallium (pure). Dewar and Fleming	17.6	6.94	106	.398					
Tin (pure). Dewar and Fleming	13.1	5.16	78.5	.440	230	.056		7.3	.264
Tin (compressed). Matthiessen	13.1	5.16	78.5	.365	230	.056		7.3	.264
Tungsten steel (annealed), *C*, 1.36; *Mn*, .36; *S*, 0; *Si*, .043; *P*, .047; tungsten, 4.65. Hopkinson	22.5	8.86	135.0						
Whitworth soft steel (annealed), *C*, .090; *Mn*, .153; *S*, .016; *Si*, .0; *P*, .042. Hopkinson	10.8	4.25	64.8			.117		7.8	.282
Zinc (very pure). Dewar and Fleming	5.75	2.26	34.5	.406	415	.095		7.1	.256
Zinc (compressed) Matthiessen	5.80	2.28	34.8	.365	415	.095		7.1	.256

RESISTANCES AND TEMPERATURE COEFFICIENTS OF ELECTROLYTES

(*Kohlrausch, Wiedemann's Annalen*)

Composition	Per Cent.	5	10	15	20	25	30	35	40	50	60	70	80
Nitric Acid HNO_3	Ohms	3.90	2.18	1.64	1.41	1.31	*1.28*	1.31	1.37	1.59	1.96	2.54	3.76
	Temp.Coef.	1.50	1.40	1.40	1.40	1.40	1.40	1.40	1.50	1.6	1.6	1.5	1.3
Hydrochloric Acid HCl	Ohms	2.55	1.59	1.35	*1.32*	1.39	1.52	1.70	1.95				
	Temp.Coef.	1.60	1.60	1.60	1.50	1.50	1.50	1.50	1.50				
Sulphuric Acid H_2SO_4	Ohms	4.82	2.57	1.85	1.54	1.40	*1.36*	1.39	1.48	1.87	2.70	4.66	9.13
	Temp.Coef.	1.20	1.30	1.40	1.50	1.50	1.60	1.70	1.80	1.90	2.10	2.60	3.53
Silver Nitrate $AgNO_3$	Ohms	39.30	21.40	14.70	11.60	9.50	8.11	7.18	6.44	5.44	4.80		
	Temp.Coef.	2.20	2.20	2.20	2.10	2.10	2.10	2.10	2.10	2.10	2.10		
Caustic Potash KOH	Ohms	5.84	3.19	2.36	2.01	1.86	*1.85*	1.97	2.23				
	Temp.Coef.	1.90	1.90	1.90	2.00	2.10	2.30	2.40	2.70				
Zinc Sulphate $ZnSO_4$	Ohms	52.30	31.40	24.10	21.90	*21.40*	22.90	28.50					
	Temp.Coef.	2.20	2.30	2.30	2.40	2.60	3.00	4.00					

Copper Sulphate $CuSO_4$	Ohms	52.30	31.40	24.10									
	Temp.Coef.	2.20	2.30	2.30									
Magnesium Sulphate $MgSO_4$	Ohms	39.30	24.10	20.90	20.90	24.10							
	Temp.Coef.	2.30	2.40	2.50	2.70	2.90							
Sodium Sulphate Na_2SO_4	Ohms	24.80	14.70	11.30									
	Temp.Coef.	2.40	2.50	2.60									
Alum $KAl(SO_4)_2$	Ohms	39.30											
	Temp.Coef.	2.00											
Sodium Chloride $NaCl$	Ohms	14.90	8.33	6.15	5.14	4.70							
	Temp.Coef.	2.20	2.10	2.10	2.20	2.30							
Sal Ammoniac NH_4Cl	Ohms	10.90	5.67	3.89	2.98	2.50							
	Temp.Coef.	2.00	1.00	1.70	1.60	1.50							

of the table is that it presents in compact form recent information previously scattered through a large number of publications and technical journals.

In the last table the first horizontal line gives the per cent. by weight of the substance dissolved in water. The *specific resistance* of each substance (opposite the word "Ohms") is given in ohms at 18° C. between opposite parallel faces of a cube of the electrolyte 1 centimeter on a side. Opposite *temperature coefficient* is given the per cent. decrease of resistance per ohm for each degree increase of temperature. The resistance also varies with the density of the solution. The resistance of the best conducting sulphuric-acid solution is about 1,000,000 times that of copper.

Conductance (G).—Conductance is that property of a substance in virtue of which it conducts an electric current. The conductance of a piece of any material 1 cm. long and 1 sq. cm. in cross-section is called its *specific conductance*, or *conductivity*, and is represented by the Greek letter γ (gamma). The word *mho*, which is ohm spelled backwards, has been proposed as the name of the unit of conductance and conductivity, but it has not been generally accepted. Conductance is the reciprocal of resistance, and conductivity is the reciprocal of resistivity. Thus, if the resistance of 2 cm. of a piece of any material having a uniform sectional area of 1 sq. cm. is 4 ohms, its resistivity is 2 ohms, its conductance ¼ mho, and its conductivity ½ mho. Percentage conductivity of a substance is the ratio of its conductivity to that of the standard at the same temperature. The conductivity of Matthiessen's pure copper at 0° C. is usually taken as the standard, i. e., 100%.

RESISTANCE OF CIRCUITS

Resistances in Series.—When a number of resistances are connected in series, the total resistance is equal to their sum.

Resistances in Parallel.—The joint resistance R of any number of resistances r_1, r_2, etc., in parallel, may be determined by the following formula, in the denominator of which there should be as many terms as there are resistances in parallel:

$$R=\frac{1}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4}+\text{ etc.}}$$

TEMPERATURE COEFFICIENT

The change in the resistance of a substance per ohm per degree change of temperature is known as the *temperature coefficient*. If R_0 is the resistance of a piece of wire at 0° C. and a is the temperature coefficient of the substance, its resistance R_t at t^0 may be calculated by the formula

$$R_t=R_0\,(1+at)$$

If the resistance R_0 is not known, but the resistance R_1 at a temperature t_1 is known, and it is desired to determine the resistance R_2 at a temperature t_2, the following formula may be used:

$$R_2=\frac{R_1(1+at_2)}{(1+at_1)}.$$

The value of the temperature coefficient a taken from any table must be for Fahrenheit or centigrade scales, according to which is used in expressing t_1 and t_2. The American Institute of Electrical Engineers considers .0042 as the best value of a for commercial copper; for ordinary work it is quite customary to use the approximate value .004.

TEMPERATURE COEFFICIENTS FOR COPPER WIRE

The following table gives factors by which the known resistance of good commercial copper at any temperature from 31.5° F to 85° F., inclusive, may be multiplied to give its resistance at 75° F.; or, if the resistance at 75° F. is known, the resistance at any other temperature can be found by dividing the resistance at 75° by the factor corresponding to the other temperature. Also, if the resistance at any temperature is known, the resistance at any other temperature can be found by means of the factors; for example, multiplying a known resistance at 32° F. by the corresponding factor 1.1026 and dividing the product by the factor for 55° F. 1.0454, gives the resistance at 55° F.

TEMPERATURE FACTORS FOR COPPER WIRE

Temperature Degrees F.	Factor	Temperature Degrees F.	Factor	Temperature Degrees F.	Factor	Temperature Degrees F.	Factor
85.0	.9787	71.5	1.0077	58.0	1.0384	44.5	1.0708
84.5	.9797	71.0	1.0088	57.5	1.0395	44.0	1.0720
84.0	.9808	70.5	1.0099	57.0	1.0407	43.5	1.0733
83.5	.9818	70.0	1.0110	56.5	1.0419	43.0	1.0745
83.0	.9820	69.5	1.0121	56.0	1.0430	42.5	1.0757
82.5	.9839	69.0	1.0132	55.5	1.0442	42.0	1.0770
82.0	.9850	68.5	1.0144	55.0	1.0454	41.5	1.0783
81.5	.9861	68.0	1.0155	54.5	1.0466	41.0	1.0795
81.0	.9871	67.5	1.0166	54.0	1.0478	40.5	1.0808
80.5	.9882	67.0	1.0177	53.5	1.0490	40.0	1.0821
80.0	.9892	66.5	1.0188	53.0	1.0501	39.5	1.0833
79.5	.9903	66.0	1.0200	52.5	1.0513	39.0	1.0846
79.0	.9914	65.5	1.0211	52.0	1.0525	38.5	1.0858
78.5	.9924	65.0	1.0222	51.5	1.0537	38.0	1.0871
78.0	.9935	64.5	1.0233	51.0	1.0549	37.5	1.0884
77.5	.9046	64.0	1.0245	50.5	1.0561	37.0	1.0897
77.0	.9950	63.5	1.0257	50.0	1.0573	36.5	1.0910
76.5	.9967	63.0	1.0268	49.5	1.0585	36.0	1.0922
76.0	.9978	62.5	1.0279	49.0	1.0598	35.5	1.0935
75.5	.9989	62.0	1.0291	48.5	1.0610	35.0	1.0948
75.0	1.0000	61.5	1.0302	48.0	1.0622	34.5	1.0961
74.5	1.0011	61.0	1.0314	47.5	1.0634	34.0	1.0974
74.0	1.0022	60.5	1.0325	47.0	1.0646	33.5	1.0987
73.5	1.0033	60.0	1.0337	46.5	1.0659	33.0	1.1000
73.0	1.0044	59.5	1.0349	46.0	1.0671	32.5	1.1013
72.5	1.0055	59.0	1.0360	45.5	1.0683	32.0	1.1026
72.0	1.0066	58.5	1.0372	45.0	1.0695	31.5	1.1039

NOTE.—This table, which is given by Kempe in his "Handbook of Electrical Testing," is calculated from the exact formula $R_t = R_{32}\ [1 + .0023708\ (t - 32°) + .0000034548\ (t - 32°)^2]$, for pure, or good commercial, copper, as determined by Clark, Ford, and Taylor, in which t is expressed in degrees Fahrenheit.

Crocker's Method.—Dr. F. B. Crocker gives, for finding resistance of copper at any temperature $t°$ C the formula

$$R_t = R_0(1 + .004t + .0000024t^2)$$

This formula is easy to apply and gives very accurate results up to 100° C., being only .1% above those given by Matthiessen's formula for conductance G, which is as follows:

$$G_t = G_0(1 - .0038901t + .000009009t^2)$$

Kennelly's Method.—In applying the formula for resistance, it is usually necessary to work to or from R_0; to avoid this when changing from one temperature $t°$ to another $t° + u°$, Kennelly's method, which is as follows, may be used:

$$R_{t+u} = R_t(1 + au)$$

R_t is the resistance at $t°$ C., and a is the temperature coefficient at $t°$; the temperature coefficient varies with the initial temperature $t°$, and is given in the accompanying table. For example, if the resistance R_t, when $t = 25°$ C., is known, and the resistance at 30° is desired, then $u = 5°$ C., and

$t°C$.	a
0	.0042
12	.0040
25	.0038
40	.0036

$$R_{30} = R_{25}\ (1 + .0038 \times 5) = 1.019\ R_{25}$$

In North America, the table and formulas given on page 88 are considered the best.

SIZES AND RESISTANCES OF WIRES

In expressing diameters of wires, .001 in. is called 1 *mil* and the square of the diameter of a wire in mils is called its area in *circular mils*. A wire 1 ft. long and 1 mil in diameter is 1 *mil-foot*. Resistance per mil-foot is a unit much used.

The resistance R of any conductor varies directly as the length of the conductor, and inversely as the sectional area. For a cylindrical wire

$$R = \frac{m \times l}{d^2}$$

in which m is the resistance per mil-foot, l is the length in feet, and d is the diameter in mils, d^2 being the sectional area in circular mils.

WIRE GAUGES

The Brown and Sharpe (B. & S.) gauge or American wire gauge (A. W. G.), as it is sometimes called, is generally used in the United States. Other gauges and their comparative diameters are also given in the following table, dimensions of wires being given in decimal parts of an inch.

VARIOUS WIRE GAUGES

Number of Wire Gauge	American, or Brown & Sharpe (B. & S.)	Birmingham, or Stubs (B. W. G.)	Washburn & Moen Mfg. Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	G. W. Prentiss, Holyoke, Mass.	Old English, From Brass Mfrs' List	British Standard (S. W. G.)	Number of Wire Gauge
0000000							.500	0000000
000000			.460				.464	000000
00000			.430	.450			.432	00000
0000	.46000	.454	.393	.400			.400	0000
000	.40964	.425	.362	.360	.3586		.372	000
00	.36480	.380	.331	.330	.3282		.348	00
0	.32486	.340	.307	.305	.2994		.324	0
1	.28930	.300	.283	.285	.2777		.300	1
2	.25763	.284	.263	.265	.2591		.276	2
3	.22942	.259	.244	.245	.2401		.252	3
4	.20431	.238	.225	.225	.2230		.232	4
5	.18194	.220	.207	.205	.2047		.212	5
6	.16202	.203	.192	.190	.1885		.192	6
7	.14428	.180	.177	.175	.1758		.176	7
8	.12849	.165	.162	.160	.1605		.160	8
9	.11443	.148	.148	.145	.1471		.144	9
10	.10189	.134	.135	.130	.1351		.128	10
11	.090742	.120	.120	.1175	.1205		.116	11
12	.080808	.109	.105	.1050	.1065		.104	12
13	.071961	.095	.0920	.0925	.0928		.0920	13
14	.064084	.083	.0800	.0800	.0816	.08300	.0800	14
15	.057068	.072	.0720	.0700	.0726	.07200	.0720	15

16	.050820	.065	.0630	.0610	.0627	.06500	.0640	16
17	.045257	.058	.0540	.0525	.0546	.05800	.0560	17
18	.040303	.049	.0470	.0450	.0478	.04900	.0480	18
19	.035890	.042	.0410	.0400	.0411	.04000	.0400	19
20	.031961	.035	.0350	.0350	.0351	.03500	.0360	20
21	.028462	.032	.0320	.0310	.0321	.03150	.0320	21
22	.025347	.028	.0280	.0280	.0290	.02950	.0280	22
23	.022571	.025	.0250	.0250	.0261	.02700	.0240	23
24	.020100	.022	.0230	.0225	.0231	.02500	.0220	24
25	.017900	.020	.0200	.0200	.0212	.02300	.0200	25
26	.015940	.018	.0180	.0180	.0194	.02050	.0180	26
27	.014195	.016	.0170	.0170	.0182	.01875	.0164	27
28	.012641	.014	.0160	.0160	.0170	.01650	.0148	28
29	.011257	.013	.0150	.0150	.0163	.01550	.0136	29
30	.010025	.012	.0140	.0140	.0156	.01375	.0124	30
31	.008928	.010	.0130	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0120	.0120	.0136	.01125	.0108	32
33	.007080	.008	.0110	.0110	.0130	.01025	.0100	33
34	.006305	.007	.0100	.0100	.0118	.00950	.0092	34
35	.005615	.005	.0095	.0095	.0109	.00900	.0084	35
36	.005000	.004	.0090	.0090	.0100	.00750	.0076	36
37	.004453		.0085	.0085	.0095	.00650	.0068	37
38	.003965		.0080	.0080	.0090	.00575	.0066	38
39	.003531		.0075	.0075	.0083	.00500	.0052	39
40	.003145		.0070	.0070	.0078	.00450	.0048	40
41							.0044	41
42							.0040	42

TEMPERATURE COEFFICIENTS FOR COPPER

(i is the initial temperature in degrees C; a, the temperature coefficient in per cent. per ohm per degree C.)

i	a	i	a	i	a
0	.4200	17	.3920	34	.3675
1	.4182	18	.3905	35	.3662
2	.4165	19	.3890	36	.3648
3	.4148	20	.3875	37	.3635
4	.4131	21	.3860	38	.3622
5	.4114	22	.3845	39	.3609
6	.4097	23	.3830	40	.3596
7	.4080	24	.3815	41	.3583
8	.4063	25	.3805	42	.3570
9	.4047	26	.3786	43	.3557
10	.4031	27	.3772	44	.3545
11	.4015	28	.3758	45	.3532
12	.3999	29	.3744	46	.3520
13	.3983	30	.3730	47	.3508
14	.3967	31	.3716	48	.3495
15	.3951	32	.3702	49	.3483
16	.3936	33	.3689	50	.3471

The American Institute of Electrical Engineers gives this table and following formulas for calculating resistance of copper wire at a temperature $u°$ C. above an initial temperature $i°$ C. and the rise in degrees C. above an initial temperature $i°$ C.:

$$R_{i+u} = R_i\left(1+\frac{au}{100}\right)$$

$$u = (238.1+i)\left(\frac{R_{i+u}}{R_i} - 1\right)$$

in which a is the temperature coefficient given in the table corresponding to the initial temperature $i°$ C., and u is the rise in temperature above the initial temperature $i°$ C.

COPPER WIRE

The specific gravity of pure annealed copper at 60° F. is 8.89 to 8.91. One cubic inch of it weighs .32 lb., and its melting point is about 2,100° F. By the process of hard drawing, the tensile strength of copper is greatly increased without greatly decreasing its conductivity. Since the conductivity varies, even with a variation of less than .02 of 1% of impurity, scarcely two samples can be obtained with exactly the same conductivity. Authorities very seldom agree on the specific resistance or temperature coefficient of copper.

Matthiessen's Standards.—Copper-wire tables are usually based on the grade of copper used by Matthiessen in determining the resistance of copper. The following are based on his measurements on copper with a specific gravity of 8.89.

Dimensions	Resistance at 0° C. International Ohms
Mil-foot soft copper	9.590
Meter-gram soft copper	.141729
Meter-millimeter soft copper	.02030
Centimeter cube soft copper	.000001594
Meter-gram hard-drawn copper	.1449
Ratio hard- to soft-drawn copper	1.0226

COPPER-WIRE TABLES

In the copper-wire tables to follow, the values in the columns marked † at the top are taken from the table prepared by the American Institute of Electrical Engineers and are correct to one part in two thousand. These values were computed for Matthiessen's standard copper from the data in the preceding table, and from temperature coefficients of resistance for 20° C. = 1.07968, for 50° C. = 1.20625, and for 80° C = 1.33681; 1 ft. = .3048028 m.; 1 lb. = 453.59256 g.

Matthiessen's standard of resistivity may be permanently recognized, but the temperature coefficient that he introduced, and which is here used, may in future undergo slight revision. The values in the columns marked with a * were computed especially for this pocketbook from data given in other parts of the table and the ratio of resistivity of hard to soft copper.

The average of a number of the most reliable determinations gives the resistance of a meter-gram of pure annealed

SIZE AND WEIGHT OF ANNEALED COPPER WIRE

(B. & S. Gauge, Specific Gravity, 8.89)

B. & S. Gauge	Diameter in Mils d †	Area in Circular Mils d^2 †	Area in Sq. In. $\frac{d^2 \times .7854}{1,000,000}$ *	Pounds per 1,000 Feet †	Pounds per Mile *	Feet per Pound †
0000	460.00	211,600	.16619	640.5	3,381.4	1.561
000	409.64	167,805	.13179	508.0	2,682.2	1.969
00	364.80	133,079	.10452	402.8	2,126.8	2.482
0	324.86	105,534	.082887	319.5	1,686.9	3.130
1	289.30	83,694	.065732	253.3	1,337.2	3.947
2	257.63	66,373	.052128	200.9	1,060.6	4.977
3	229.42	52,634	.041339	159.3	841.09	6.276
4	204.31	41,742	.032784	126.4	667.39	7.914
5	181.94	33,102	.025999	100.2	529.06	9.980
6	162.02	26,250	.020618	79.46	419.55	12.58
7	144.28	20,816	.016351	63.02	332.75	15.87
8	128.49	16,509	.012967	49.98	263.89	20.01
9	114.43	13,094	.010283	39.63	209.24	25.23
10	101.89	10,381	.0081548	31.43	165.95	31.82
11	90.742	8,234.0	.0064656	24.93	131.63	40.12
12	80.808	6,529.9	.0051287	19.77	104.39	50.59
13	71.961	5,178.4	.0040672	15.68	82.791	63.79
14	64.084	4,106.8	.0032254	12.43	76.191	80.44
15	57.068	3,256.7	.0025579	9.858	52.050	101.4

16	50.820	2,582.9	.0020285	7.818	41.277	127.9
17	45.257	2,048.2	.0010087	6.200	32.736	161.3
18	40.303	1,624.3	.0012757	4.917	25.960	203.4
19	35.890	1,288.1	.0010117	3.899	20.595	256.5
20	31.961	1,021.5	.00080231	3.092	16.324	323.4
21	28.462	810.10	.00063626	2.452	12.946	407.8
22	25.347	642.40	.00050457	1.945	10.268	514.2
23	22.571	509.45	.00040015	1.542	8.142	684.4
24	20.100	404.01	.00031733	1.223	6.457	817.6
25	17.900	320.40	.00025166	.9699	5.121	1020
26	15.940	254.10	.00019958	.7692	4.061	1300
27	14.195	201.50	.00015827	.6100	3.221	1639
28	12.641	159.79	.00012551	.4837	2.554	2067
29	11.257	126.72	.000099536	.3836	2.025	2607
30	10.025	100.50	.000078936	.3042	1.606	3287
31	8.928	79.70	.000062599	.2413	1.274	4145
32	7.950	63.21	.000049643	.1913	1.010	5227
33	7.080	50.13	.000039368	.1517	.801	6591
34	6.305	39.75	.000031221	.1203	.635	8311
35	5.615	31.52	.000024759	.09543	.504	10480
36	5.000	25.00	.000019635	.07568	.400	13210
37	4.453	19.82	.000015574	.06001	.317	16660
38	3.965	15.72	.000012345	.04759	.251	21010
39	3.531	12.47	.0000097923	.03774	.199	26500
40	3.145	9.89	.0000077634	.02993	.158	33410

RESISTANCE OF ANNEALED COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Pounds per Ohm			Fect per Ohm		
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F †
0000	13,090	11,720	10,570	20,440	18,290	16,510
000	8,232	7,369	6,647	16,210	14,510	13,090
00	5,177	4,634	4,182	12,850	11,500	10,380
0	3,256	2,914	2,630	10,190	9,123	8,232
1	2,048	1,833	1,654	8,083	7,235	6,528
2	1,288	1,153	1,040	6,410	5,738	5,177
3	810.0	725.0	654.2	5,084	4,550	4,106
4	509.4	455.9	411.4	4,031	3,608	3,256
5	320.4	286.7	258.7	3,197	2,862	2,582
6	201.5	180.3	162.7	2,535	2,269	2,048
7	126.7	113.4	102.3	2,011	1,800	1,624
8	79.69	71.33	64.36	1,595	1,427	1,288
9	50.12	44.86	40.48	1,265	1,132	1,021
10	31.52	28.21	25.46	1,003	897.6	809.9
11	19.82	17.74	16.01	795.3	711.8	642.3
12	12.47	11.16	10.07	630.7	564.5	509.4
13	7.840	7.017	6.332	500.1	447.7	404.0
14	4.931	4.413	3.982	396.6	355.0	320.3

15	3.101	2.776	2.504	314.5	281.5	254.0
16	1.950	1.746	1.575	249.4	223.3	201.5
17	1.226	1.098	.9906	197.8	177.1	159.8
18	.7713	.6904	.6230	156.9	140.4	126.7
19	.4851	.4342	.3918	124.4	111.4	100.5
20	.3051	.2731	.2464	98.66	88.31	79.68
21	.1919	.1717	.1550	78.24	70.03	63.19
22	.1207	.1080	.09746	62.05	55.54	50.11
23	.07589	.06793	.06129	49.21	44.04	39.74
24	.04773	.04272	.03855	39.02	34.93	31.52
25	.03002	.02687	.02424	31.29	28.01	24.99
26	.01888	.01690	.01525	24.54	21.97	19.82
27	.01187	.01063	.009588	19.46	17.42	15.72
28	.007466	.006683	.006030	15.43	13.82	12.47
29	.004696	.004203	.003792	12.24	10.96	9.886
30	.002953	.002643	.002385	9.707	8.688	7.840
31	.001857	.001662	.001500	7.698	6.890	6.217
32	.001168	.001045	.0009436	6.105	5.464	4.930
33	.0007346	.0006575	.0005933	4.841	4.333	3.910
34	.0004620	.0004135	.0003731	3.839	3.436	3.101
35	.0002905	.0002601	.0002347	3.045	2.725	2.459
36	.0001827	.0001636	.0001476	2.414	2.161	1.950
37	.0001149	.0001029	.00009281	1.915	1.714	1.547
38	.00007210	.00006454	.00005824	1.519	1.359	1.226
39	.00004545	.00004068	.00003671	1.204	1.078	.9726
40	.00002858	.00002559	.00002309	.9550	.8548	.7713

RESISTANCE OF ANNEALED COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Ohms per Pound			Ohms per 1,000 Feet		
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	.00007639	.00008535	.00009459	.04893	.05467	.06058
000	.0001215	.0001357	.0001504	.06170	.06404	.07640
00	.0001931	.0002158	.0002391	.07780	.08692	.09633
0	.0003071	.0003431	.0003803	.09811	.1096	.1215
1	.0004883	.0005456	.0006046	.1237	.1382	.1532
2	.0007765	.0008675	.0009614	.1560	.1743	.1932
3	.001235	.001379	.001529	.1967	.2198	.2435
4	.001963	.002193	.002431	.2480	.2771	.3071
5	.003122	.003487	.003865	.3128	.3495	.3873
6	.004963	.005545	.006145	.3944	.4406	.4883
7	.007892	.008817	.009772	.4973	.5556	.6158
8	.01255	.01402	.01554	.6271	.7007	.7765
9	.01995	.02229	.02471	.7908	.8835	.9791
10	.03173	.03545	.03928	.9972	1.114	1.235
11	.05045	.05636	.06246	1.257	1.405	1.557
12	.08022	.08962	.09932	1.586	1.771	1.963
13	.1276	.1425	.1579	1.999	2.234	2.476
14	.2028	.2266	.2511	2.521	2.817	3.122

15	.3225	.3603	.3993	3.179	3.552	3.936
16	.5128	.5729	.6349	4.009	4.479	4.964
17	.8153	.9109	1.010	5.055	5.648	6.259
18	1.296	1.448	1.605	6.374	7.122	7.892
19	2.061	2.303	2.552	8.038	8.980	9.952
20	3.278	3.662	4.058	10.14	11.32	12.55
21	5.212	5.823	6.453	12.78	14.28	15.83
22	8.287	9.259	10.26	16.12	18.01	19.96
23	13.18	14.72	16.32	20.32	22.71	25.16
24	20.95	23.41	25.94	25.63	28.63	31.73
25	33.32	37.22	41.25	32.31	36.10	40.01
26	52.97	59.18	65.59	40.75	45.52	50.45
27	84.23	94.11	104.3	51.38	57.40	63.62
28	133.9	149.6	165.8	64.79	72.39	80.22
29	213.0	237.9	263.7	81.70	91.28	101.2
30	338.6	378.3	419.3	103.0	115.1	127.6
31	538.4	601.6	666.7	129.9	145.1	160.8
32	856.2	956.5	1060	163.8	183.0	202.8
33	1361	1521	1685	206.6	230.8	255.8
34	2165	2418	2680	260.5	291.0	322.5
35	3441	3845	4262	328.4	366.9	406.7
36	5473	6114	6776	414.2	462.7	512.9
37	8702	9722	10770	522.2	583.5	646.6
38	13870	15490	17170	658.5	735.7	815.4
39	22000	24580	27240	830.4	927.7	1,028
40	34980	39080	43320	1,047	1,170	1,296

RESISTANCE OF ANNEALED AND HARD-DRAWN COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Annealed Ohms per Mile	Hard-Drawn. At 20° C. or 68° F.		
	At 20° C. or 68° F.	Ohms per Pound *	Ohms per 1,000 Feet *	Ohms per Mile *
0000	.25835	.00007812	.050036	.26419
000	.32577	.0001242	.063094	.33314
00	.41079	.0001975	.079558	.42007
0	.51802	.0003140	.10033	.52973
1	.65314	.0004993	.12649	.66790
2	.82368	.0007940	.15953	.84230
3	1.0386	.001263	.20114	1.0621
4	1.3094	.002007	.25361	1.3392
5	1.6516	.003193	.31987	1.6889
6	2.0825	.005075	.40332	2.1295
7	2.6258	.008070	.50854	2.6850
8	3.3111	.01283	.64127	3.3859
9	4.1753	.02040	.80876	4.2769
10	5.2657	.03245	1.0199	5.3848
11	6.6369	.05159	1.2854	6.7869
12	8.3741	.08203	1.6218	8.5633

13	10.555	.1305	2.0443	10.794
14	13.311	.2074	2.5779	13.612
15	16.785	.3298	3.2508	17.165
16	21.168	.5244	4.0996	21.646
17	26.691	.8337	5.1692	27.294
18	33.655	1.325	6.5183	34.416
19	42.441	2.108	8.2196	43.400
20	53.539	3.352	10.372	54.749
21	67.479	5.330	13.069	78.004
22	85.114	8.444	16.484	87.038
23	107.29			
24	135.53			
25	170.59			
26	215.16			
27	271.29			
28	342.09			
29	431.37			
30	543.84			
31	685.87			
32	864.87			
33	1,090.8			
34	1,375.5			
35	1,734.0			
36	2,187.0			
37	2,757.3			
38	3,476.8			
39	4,384.5			
40	5,528.2			

NOTE.—In these tables, the resistances are all based on Matthiessen's Standard.

SIZE AND WEIGHT OF ANNEALED COPPER WIRE

(B. W. G. or Stubbs Gauge; Specific Gravity, 8.89)

Gauge No. (B. W. G.)	Diameter in Mils d	Area in Circular Mils d^2 †	Pounds per 1,000 Feet †	Pounds per Mile *	Pounds per Ohm		
					At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	454	206,116	623.9	3,294	12,420	11,120	10,570
000	425	180,625	546.8	2,887	9,538	8,537	7,702
00	380	144,400	437.1	2,308	6,096	5,456	4,924
0	340	115,600	349.9	1,847	3,907	3,497	3,155
1	300	90,000	272.4	1,438	2,368	2,120	1,913
2	284	80,656	244.1	1,289	1,902	1,702	1,536
3	259	67,081	203.1	1,072	1,316	1,178	1,063
4	238	56,644	171.5	905	938.0	839.6	757.6
5	220	48,400	146.5	773	684.9	613.0	553.1
6	203	41,209	124.7	659	496.5	444.4	401.0
7	180	32,400	98.08	518	306.9	274.7	247.9
8	165	27,225	82.41	435	216.7	194.0	175.0
9	148	21,904	66.30	350	140.3	125.6	113.3
10	134	17,956	54.35	287	94.26	84.37	76.13
11	120	14,400	43.59	230	60.62	54.26	48.96
12	109	11,881	35.96	190	41.27	36.94	33.33
13	95	9,025	27.32	144	23.81	21.31	19.23

14	83	6,889	20.85	110	13.87	12.42	11.21
15	72	5,184	15.69	83.0	7.857	7.032	6.346
16	65	4,225	12.79	68.0	5.219	4.671	4.215
17	58	3,364	10.18	54.0	3.308	2.961	2.672
18	49	2,401	7.268	38.4	1.658	1.509	1.361
19	42	1,764	5.340	28.2	.9097	.8143	.7347
20	35	1,225	3.708	19.6	.4387	.3927	.3543
21	32	1,024	3.100	16.4	.3066	.2744	.2476
22	28	784	2.373	12.5	.1797	.1608	.1451
23	25	625	1.892	10.0	.1142	.1022	.09224
24	22	484	1.465	7.70	.06849	.06130	.05531
25	20	400	1.211	6.40	.04678	.04187	.03778
26	18	324	9.808	5.20	.03069	.02747	.02479
27	16	256	.7749	4.10	.01916	.01715	.01548
28	14	196	.5933	3.10	.01123	.01005	.009071
29	13	169	.5116	2.70	.008350	.007474	.006744
30	12	144	.4359	2.30	.006062	.005426	.004896
31	10	100	.3027	1.60	.002924	.002617	.002361
32	9	81	.2452	1.30	.001918	.001717	.001549
33	8	64	.1937	1.02	.001197	.001072	.0009672
34	7	49	.1483	.780	.0007019	.0006283	.0005669
35	5	25	.07568	.400	.0001827	.0001636	.0001476
36	4	16	.04843	.256	.00007484	.00006699	.00006045

LENGTH AND RESISTANCE OF ANNEALED COPPER WIRE

(*B. W. G. or Stubbs Gauge*)

Gauge No. (B. W. G.)	Feet per Pound †	Feet per Ohm			Ohms per Pound		
		At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	1.603	19,910	17,820	16,080	.00008051	.00008996	.00009969
000	1.829	17,450	15,620	14,090	.0001048	.0001171	.0001298
00	2.288	13,950	12,480	11,260	.0001640	.0001833	.0002031
0	2.858	11,160	9,993	9,017	.0002560	.0002860	.0003169
1	3.671	8,692	7,780	7,020	.0004223	.0004718	.0005228
2	4.096	7,790	6,973	6,292	.0005258	.0005874	.0006510
3	4.925	6,479	5,799	5,233	.0007601	.0008492	.0009412
4	5.832	5,471	4,897	4,419	.001066	.001191	.001320
5	6.826	4,675	4,184	3,775	.001460	.001631	.001808
6	8.017	3,980	3,562	3,215	.002014	.002250	.002494
7	10.20	3,129	2,801	2,527	.003258	.003640	.004034
8	12.13	2,629	2,354	2,124	.004615	.005156	.005714
9	15.08	2,116	1,894	1,709	.007129	.007965	.008827
10	18.40	1,734	1,552	1,401	.01061	.01185	.01314
11	22.94	1,391	1,245	1,123	.01650	.01843	.02042
12	27.81	1,147	1,027	926.9	.02423	.02707	.03000
13	36.60	871.7	780.2	704.0	.04199	.04692	.05200
14	47.95	665.4	595.5	537.4	.07207	.08052	.08924

15	63.73	500.7	448.1	404.4	.1273	.1422	.1576
16	78.19	408.1	365.2	329.6	.1916	.2141	.2373
17	98.23	324.9	290.8	262.4	.3023	.3377	.3742
18	137.6	231.9	207.6	187.3	.5933	.6629	.7346
19	187.3	170.4	152.5	137.6	1.099	1.228	1.361
20	269.7	118.3	105.9	95.56	2.279	2.547	2.822
21	322.6	98.10	88.52	79.88	3.262	3.644	4.039
22	421.4	75.72	67.78	61.16	5.565	6.217	6.890
23	528.6	60.36	54.03	48.75	8.756	9.783	10.84
24	682.6	46.75	41.84	37.75	14.60	16.31	18.08
25	825.9	38.63	34.58	31.20	21.38	23.88	26.47
26	1,020	31.29	28.01	25.27	32.58	36.40	40.34
27	1,290	24.73	22.13	19.97	52.19	58.31	64.62
28	1,685	18.93	16.94	15.29	89.04	99.48	110.2
29	1,955	16.32	14.61	13.18	119.8	133.8	148.3
30	2,294	13.91	12.45	11.23	165.0	184.3	204.2
31	3,304	9.658	8.645	7.800	342.0	382.1	423.5
32	4,078	7.823	7.002	6.318	521.3	582.5	645.5
33	5,162	6.181	5.533	4.992	835.1	933.0	1,034
34	6,742	4.733	4.236	3.822	1,425	1,792	1,764
35	13,210	2.414	2.161	1.950	5,473	6,114	6,776
36	20,650	1.545	1.383	1.248	13,360	14,930	16,540

RESISTANCE OF ANNEALED AND HARD-DRAWN COPPER WIRE

(B. W. G. or Stubbs Gauge)

Gauge No. (B. W. G.)	Annealed				Hard-Drawn. At 20° C. or 68° F.		
	Ohms per 1,000 Ft.			Ohms per Mile At 20° C. or 68° F. *	Ohms per Pound *	Ohms per 1,000 Feet *	Ohms per Mile *
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †				
0000	.05023	.05612	.06220	.2652	.00008233	.05137	.2712
000	.05732	.06404	.07097	.3026	.0001072	.05862	.3095
00	07170	.08011	.08878	.3786	.0001677	.07332	.3871
0	.08957	.1001	.1109	.4729	.0002618	.09159	.4836
1	.1150	.1285	.1424	.6072	.0004318	.1176	.6209
2	.1284	.1434	.1589	.6780	.0005377	.1313	.6833
3	.1543	.1724	.1911	.8147	.0007773	.1578	.8332
4	.1828	.2042	.2263	.9652	.001090	.1869	.9868
5	.2139	.2390	.2649	1.129	.001493	.2187	1.155
6	.2513	.2807	.3111	1.327	.002060	.2570	1.357
7	.3196	.3570	.3957	1.687	.003331	.3268	1.726
8	.3803	.4249	.4709	2.008	.004719	.3889	2.053
9	.4727	.5281	.5853	2.496	.007290	.4834	2.552
10	.5766	.6442	.7140	3.044	.01085	.5896	3.113

11	.7190	.8033	.8903	3.796	.01687	.7352	3.882
12	.8715	.9736	1.079	4.602	.02479	.8912	4.706
13	1.147	1.282	1.420	6.056	.04294	1.173	6.193
14	1.503	1.679	1.861	7.936	.07370	1.537	8.115
15	1.997	2.231	2.473	10.54	.1302	2.042	10.78
16	2.451	2.738	3.034	12.94	.1959	2.506	13.23
17	3.078	3.439	3.811	16.52	.3101	3.148	16.62
18	4.312	4.818	5.339	22.77	.6067	4.409	23.28
19	5.870	6.558	7.267	30.99	1.124	6.003	31.70
20	8.452	9.443	10.47	44.63	2.331	8.643	45.64
21	10.11	11.30	12.52	53.38	3.336	10.34	54.60
22	13.21	14.75	16.35	69.75	5.691	13.51	71.33
23	16.57	18.51	20.51	87.49	8.954	16.94	89.44
24	21.39	23.90	26.49	112.9	14.93	21.87	115.5
25	25.88	28.92	32.05	136.6	21.86		
26	31.96	35.70	39.57	168.7	33.32		
27	40.45	45.19	50.08	213.6	53.37		
28	52.83	59.02	65.41	278.9	91.05		
29	61.27	68.45	75.86	323.5	122.5		
30	71.90	80.33	89.03	379.6	168.7		
31	103.5	115.7	128.2	546.5	349.7		
32	127.8	144.8	158.3	674.8	533.1		
33	161.8	130.7	200.3	854.3	854.0		
34	211.3	236.1	261.6	1,116	1,457		
35	414.2	462.7	512.9	2,187	5,597		
36	647.1	723.0	801.1	3,417	13,660		

APPROXIMATE WEIGHTS OF WEATHER-PROOF WIRE

(*American Electrical Works*)

TRIPLE-BRAIDED INSULATION

Size	Feet per Pound	Pounds per 1,000 Ft.	Pounds per Mile	Ampere Capacity Allowed by Fire Under-writers
0000	1.34	742	3,920	312
000	1.64	609	3,215	262
00	2.05	487	2,570	220
0	2.59	386	2,040	185
1	3.25	308	1,625	156
2	4.10	244	1,289	131
3	5.15	194	1,025	110
4	6.26	160	845	92
5	7.46	134	710	77
6	9.00	111	585	65
8	13.00	73	385	46
10	20.00	50	265	32
12	29.00	35	182	23
14	38.00	26	137	16
16	48.00	21	113	8
18	67.00	15	81	5

DOUBLE-BRAIDED INSULATION

Size	Feet per Pound	Pounds per 1,000 Ft.	Pounds per Mile	Ampere Capacity Allowed by Fire Under-writers
0000	1.40	711	3,754	312
000	1.75	570	3,010	262
00	2.29	436	2,300	220
0	2.81	355	1,875	185
1	3.56	281	1,482	156
2	4.49	223	1,175	131
3	5.45	184	969	110
4	6.82	147	774	92
5	9.10	110	580	77
6	10.35	97	510	65
8	15.52	64	340	46
10	22.00	45	237	32
12	40.00	25	132	23
14	56.00	18	95	16
16	76.00	13	69	8
18	100.00	10	53	5

commercial copper as .1486 ohm at 60° F. In England, Matthiessen's values, .150822 ohm for a meter-gram of annealed high-conductivity commercial copper and .153858 ohm for a meter-gram of hard-drawn high-conductivity commercial copper, both at 60° F. and having a temperature coefficient of .00238 per degree F., are considered as standards.

STANDARD WEATHER-PROOF FEED-WIRE

(Roebling's)

Circular Mils	Outside Diameters Inches	Weights Pounds		Approximate Length on Reels Feet	Carrying Capacity, National Board Fire Underwriters
		1,000 Ft.	Mile		
1,000,000	1 1/2	3,550	18,744	800	1,000
900,000	1 13/32	3,215	16,975	800	920
800,000	1 11/32	2,880	15,206	850	840
750,000	1 5/16	2,713	14,325	850	
700,000	1 9/32	2,545	13,438	900	760
650,000	1 1/4	2,378	12,556	900	
600,000	1 7/32	2,210	11,668	1,000	680
550,000	1 3/16	2,043	10,787	1,200	
500,000	1 1/8	1,875	9,900	1,320	590
450,000	1 3/32	1,703	8,992	1,400	
400,000	1 1/16	1,530	8,078	1,450	500
350,000	1	1,358	7,170	1,500	
300,000	15/16	1,185	6,257	1,600	400
250,000	29/32	1,012	5,343	1,600	

Carl Herring advocates the following values: resistance of 1 mil-foot at 15° C., 10.0275 international ohms, as given by Prof. Lindeck for pure copper, and 10.1478 international ohms for Matthiessen's standard copper; resistivity (per centimeter cube) at 15° C., 1.667 microhms, as given by Prof. Lindeck for pure copper, and 1.687 microhms for Matthiessen's standard copper.

Joints in aluminum and hard-drawn copper telephone and telegraph line wires should always be made with McIntire or similar sleeves made of the same metal as the wire. When making a McIntire sleeve joint, pass each end of the wire through the sleeve until it extends ½ inch beyond the end of the sleeve, then place a steel tie-wrench or connector on each end of the sleeve, the outside of the tool to be ½ inch from

HARD-DRAWN COPPER WIRE

Diameter in Mils	Gauge and Number	Weight per Mile in Pounds	Resistance per Mile in Ohms at 60° F.
165	8 B. W. G.	435	1.9742
162	6 B. & S. G.	419	2.0481
160	8 N. B. S. G.	409	2.0998
148	9 B. W. G.	350	2.4541
144.3	7 B. & S. G.	331	2.5925
144	9 N. B. S. G.	331	2.5925
134	10 B. W. G.	287	2.9835
128.5	8 B. & S. G.	262	3.2810
128	10 N. B. S. G.	262	3.2810
120	11 B. W. G.	230	3.7330
116	11 N. B. S. G.	215	3.9948
114.4	9 B. & S. G.	208	4.1363
109	12 B. W. G.	190	4.5244
104	12 N. B. S. G.	173	4.9701
101.9	10 B. & S. G.	166	5.1665
95	13 B. W. G.	144	5.9558
92	13 N. B. S. G.	135	6.3518
90.74	11 B. & S. G.	132	6.4891
83	14 B. W. G.	110	7.8038
80.81	12 B. & S. G.	105	8.1946
80	14 N. B. S. G.	102	8.4005

N. B. S. stands for the New British Standard wire gauge.

the end of the sleeve, after which 3 to 4½ complete turns, depending on the size of the wire, should be made, using great care to keep the sleeve absolutely straight. For No. 8 B. W. G. wire give 4½ turns, for sizes more extensively used give 3 turns and use sleeves of proper size to fit the wire. Full-length and half-length sleeves are made, the former for through line joints and the latter for branch joints.

HARD-DRAWN COPPER WIRE

Number and Gauge	Diameters in Mils			Weights per Mile			Breaking Weights		Weights of Coils		Conductivity		Twist in 6 In.	Per Cent. Elongation in 5 Ft.
	Required	Maximum	Minimum	Required	Maximum	Minimum	Actual Required	Per Square Inch	Maximum	Minimum	Required	Minimum		
8 B.W.G.	165.0	166.0	164.0	436.4	441.7	431.1	1,328	62,108	218	152	97	96	30	1.14
12 N.B.S. *	104.0	104.7	103.3	173.4	175.7	171.1	549	64,600	219	151	97	96	40	1.00
10 B. & S.	101.9	102.8	101.0	165.0	168.0	162.0	540	64,800	218	152	97	96	40	.99
12 B. & S.	80.8	81.3	80.3	104.7	106.0	103.4	336	65,500	72	52	97	96	44	.95
14 B. & S.	64.0	65.0	63.0	65.0	67.5	63.0	220	68,200			97	96	47	.91
16 B.W.G.	65.0	65.5	64.5		68.8	66.7	220	66,200				96		.91
14 N.B.S.	80.0	80.5	79.5		103.9	101.3	330	65,600				96		.94
13 N.B.S.	92.0	92.6	91.4		137.5	133.9	433	65,100				96		.97
10 N.B.S.	128.0	128.8	127.2		265.9	259.4	820	63,700				96		1.06
10 B.W.G.	134.0	134.9	133.1		291.7	284.0	894	63,400				96		1.07

*N. B. S. stands for the New British Standard wire gauge for which S. W. G. is sometimes used.

TENSILE STRENGTH OF COPPER WIRE

Nos. B. & S. Gauge	Breaking Weight in Pounds		Nos. B. & S. Gauge	Breaking Weight in Pounds	
	Hard-Drawn	Annealed		Hard-Drawn	Annealed
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

DATA ON DOUBLE SILK-COVERED COPPER WIRE

B. & S. Gauge No.	σ = Ohms per Cubic Inch	u	Pounds per Cubic Inch
20	.76	.79	.24
22	2.0	.69	.23
24	5.0	.62	.21
26	12.0	.55	.19
28	25.0	.49	.17
30	54.0	.43	.14
32	105.0	.37	.12
34	195.0	.31	.08
36	355.0	.25	.075
38	630.0	.19	.06
40	1,050.0	.13	.05

NOTE.—u is the portion of the total volume that is occupied by the copper alone, the difference $1-u$ being the portion occupied by the insulation.

IRON WIRE

There are three grades of iron wire; namely, Extra Best Best (E. B. B.), which has the highest conductivity and is the most uniform in quantity, being both tough and pliable; Best Best (B. B.), which is less uniform and tough, lower in conductivity, frequently sold as E. B. B.; and Best, which is the poorest grade made, being still less uniform, more brittle, and lowest in conductivity.

MECHANICAL AND ELECTRICAL TESTS OF IRON WIRE OF AMERICAN MANUFACTURE

The column headed "Percentage Conductivity" in the following table gives the percentages that the conductivities of the various samples bear to the conductivity of pure copper. "Percentage of Elongation" means the percentage of the length the wire elongated before breaking. The column headed "Relative Breaking Stress" gives the number of feet of its own length that each sample was able to sustain.

Specifications.—Iron wire for use on telegraph and telephone lines should conform to the following specifications of the Western Union Telegraph Company:

1. The wire must be soft and pliable, and be capable of elongating 15%, without breaking, after being galvanized.

2. Great tensile strength is not required, but the wire must not break under a less strain than 2½ times its weight, in pounds per mile.

3 Tests for ductility should be made as follows: The piece of wire will be gripped by two vises, 6 in. apart, and twisted; the full number of twists must be distinctly visible on the 6-in. piece between the vises, and the number of twists must not be less than 15.

4. The weight per mile for the different gauge wires must be: for No. 4 B. W. G., 730 lb.; No. 6, 540 lb.; No. 8, 380 lb.; No. 9, 320 lb.; No. 10, 250 lb.; or as near these figures as practicable.

5. The electrical resistance of the wire, in ohms per mile, at a temperature of 68° F., must not exceed the quotient arising from dividing the constant number 4,800 by the

MECHANICAL AND ELECTRICAL TESTS OF IRON WIRE OF AMERICAN MANUFACTURE

Sample Mark and B. W. G. No.		Mechanical					Electrical	
		Weight per Mile Pounds	Percentage of Elongation	Number of Twists That 6 In. Will Stand	Actual Breaking Stress Pounds	Relative Breaking Stress	Percentage Conductivity	Resistance per Mile in Ohms, at 60° F.
E. B. B.	12	190.83	11.50	15.00	417.50	11,552.20	14.40	30.50
E. B. B.	8	381.66	17.70	26.50	937.50	12,930.50	17.30	12.67
E. B. B.	11	222.64	17.20	21.50	577.50	13,639.40	15.60	24.20
151	9½	282.80	10.00	26.50	770.00	14,375.90	21.90	16.10
E. B. B.	10	254.44	17.70	28.50	697.50	14,478.10	17.80	18.42
146	9½	287.50	16.00	29.00	832.50	15,288.86	21.90	16.10
E. B. B.	6	508.88	11.40	21.50	1,587.50	16,462.40	17.70	9.21
E. B. B.	9	318.05	19.30	17.50	1,007.50	16,725.10	16.90	15.54
Nashua	8	381.66	15.10	26.50	1,535.00	21,183.00	14.70	15.00
M. S. plain	6	528.00	10.40	19.50	2,137.50	21,375.00	13.50	11.78
443	8	378.10	10.00	31.00	1,635.00	22,301.40	16.50	16.10
A. H.	9½	293.50	16.00	27.50	1,257.50	22,635.00	15.10	22:70

DIMENSIONS AND RESISTANCE OF IRON WIRE

No. B. W. G.	Diameter in Mils = d	Area in Circular Mils = d^2	Weight in Pounds		Breaking Strength in Pounds		Resistance per Mile at 68° F.		
			1,000 Ft.	1 Mi.	Iron	Steel	E. B. B.	B. B.	Steel
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.70	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	4.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120.40	139.00
18	49	2,401	6.3	33	99	189	140.80	164.80	194.80

IRON AND STEEL WIRE

(*Weight per Mile-Ohm*)

Name of Wire	Weight per Mile-Ohm	
	Roebling's Sons Co.	Washburn & Moen
Extra Best Best	4,700	5,000
Best Best	5,500	6,200
Best	6,000	
Steel	6,500	6,500

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM

Properties	Aluminum	Copper
Conductivity (for equal sizes)	.54 to .63	1
Weight (for equal sizes)	.33	1
Weight (for equal length and resistance)	.48	1
Price—aluminum, 29c.; copper, 16c.; (bare line wire)	1.81	1
Price—(Equal resistance and length, bare line wire)	.868	1
Temperature coefficient per degree F.	.002138	.002155
Resistance of mil-foot (20° C.)	18.73	10.5
Specific gravity	2.5 to 2.68	8 89 to 8.93
Tensile strength (hard-drawn) per square inch	40,000	60,000
Tensile strength (for equal weight and resistance)	58,000	60,000
Coefficient of expansion per degree F.	.0000231	.0000093

COMPARATIVE DATA—ALUMINUM AND COPPER

Property	Pure Copper	Aluminum		
		A 0	A 75	A 2
Conductivity	100	62	58	54
Comparative section of equal conductivity	100	156.4	167.0	180.0
Comparative weights of same lengths of equal conductivity	100	47	50.2	54.0

weight of the wire, in pounds per mile. The coefficient .003 will be allowed for each degree F. in reducing to standard temperature.

6. The wire must be well galvanized, and be capable of withstanding the following tests: Several samples to be selected at random and immersed in a saturated solution of copper sulphate for 70 sec., then removed and wiped dry and clean; this operation to be repeated three more times and if, then, the wire remains black as after the first immersion, there being no appearance of a copper deposit, the samples are well galvanized. Any appearance of a copper deposit shows that the film of zinc forming the galvanizing covering was too thin and has been removed by combining with the sulphuric acid of the solution and forming zinc sulphate.

ALLOYED WIRE

Phono-electric wire is made by the Bridgeport Brass Company of an alloy containing 98.55% copper, 1.4% tin, and .5% silicon. In its manufacture, the silicon is nearly all slagged off, only .05% remaining. It is claimed to have a tensile strength from 40 to 45% greater than that of hard-drawn copper. Its conductivity is only 40% of pure copper. It is exceedingly tough, as a 6-in. piece of No. 8 will stand 50 complete turns, instead of 30 for hard-drawn copper. It is used for trolley wire and for long telephone-line spans.

RESISTANCE OF PURE ALUMINUM WIRE AT 75° F.*

B. & S. Gauge No.	Ohms per 1,000 Ft.	Ohms per Mile	Feet per Ohm	Ohms per Pound
0000	.08177	.43172	12,229.8	.00042714
000	.10310	.54440	9,699.0	.00067022
00	.13001	.68645	7,692.0	.0010812
0	.16385	.86515	6,245.4	.0016739
1	.20672	1.09150	4,637.35	.0027272
2	.26077	1.37637	3,836.22	.0043441
3	.32872	1.7357	3,036.12	.0069057
4	.41448	2.1885	2,412.60	.010977
5	.52268	2.7597	1,913.22	.017456
6	.65910	3.4802	1,517.22	.027758
7	.83118	4.3885	1,203.12	.044138
8	1.06802	5.5355	964.180	.070179
9	1.32135	6.9767	756.780	.11156
10	1.66667	8.8000	600.000	.17467
11	2.1012	11.0947	475.908	.28211
12	2.6497	13.990	377.412	.44856
13	3.3412	17.642	299.298	.71478
14	4.3180	22.800	231.582	1.1623
15	5.1917	27.462	192.612	1.7600
16	6.6985	35.368	149.286	2.8667
17	8.4472	44.602	118.380	4.5588
18	10.6518	56.242	93.8820	7.2490

19	13.8148	72.942	72.3840	12.192
20	16.938	89.430	59.0406	18.328
21	21.358	112.767	46.8222	29.142
22	26.920	142.138	37.1466	46.316
23	33.962	179.32	29.4522	73.686
24	42.825	226.12	23.3508	117.17
25	54.000	285.12	18.5184	186.28
26	68.113	359.65	14.6814	296.32
27	85.865	453.37	11.6460	485.56
28	108.277	571.70	9.2358	749.02
29	136.535	720.90	7.3242	1,191.0
30	172.17	908.98	5.8087	1,893.9
31	212.12	1,119.98	4.7144	2,941.5
32	273.97	1,445.45	3.6528	4,788.9
33	345.13	1,822.3	2.8974	7,610.7
34	435.38	2,298.8	2.2969	12,109.
35	548.92	2,898.2	1.8218	19,251.
36	692.07	3,654.2	1.4449	30,600
37	872.93	4,609.2	1.1456	48,661.
38	1,100.62	5,811.2	.9086	76,658.
39	1,387.47	7,325.8	.7207	121,881.
40	1,749.50	9,236.8	.5716	193,835.

*Calculated on the basis of Matthiessen's standard, viz.: 1 mi. of pure copper wire of 1/16 in. diameter equals 13.59 ohms at 15.5° C. or 59.9° F.

RESISTANCE, TENSILE STRENGTH, AND WEIGHT OF ALUMINUM LINE WIRE

No. in B. & S. Gauge	Diameter in Mils d	Circular Mils d^2	Area in Square Inches $\frac{d^2 \times .7854}{100,000,000}$	Grade A 0		Grade A 75		Grade A 2		Pounds per Mile Sp. Gr. 2.68 Water, 62,355 lb. per Cu. Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given. Grade A 75
				Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch	Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch	Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch		
4	204.31	41,742	.032784	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	33,102	.025998	.5058	27,500	.5408	34,000	.5818	42,000	159.30	266.4
6	162.02	26,250	.020617	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	20,816	.016349	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	16,509	.012966	1.634	30,000	1.105	37,000	1.187	48,000	79.46	133.2
9	114.43	13,094	.010284	1.278	32,000	1.367	39,000	1.468	50,000	62.99	105.4
10	101.89	10,381	.0081532	1.613	33,000	1.724	40,000	1.852	51,000	48.71	83.6
11	90.74	8,234.0	.0064670	2.033	35,000	2.173	41,000	2.335	53,000	39.63	66.3
12	80.81	6,529.9	.0051286	2.565	39,000	2.741	42,000	3.084	55,000	31.43	52.6
13	71.96	5,178.4	.0040671	3.233		3.456		3.712		24.83	
14	64.08	4,106.8	.0031469	4.179		4.467		4.798		19.76	

Silicon- and *aluminum-bronze wires* have high tensile strength and are free from corrosion, thus rendering them especially suitable for guy wires; they resist corrosion fully as well as hard-drawn copper. Some silicon-bronze wires have a tensile strength of 80,000 lb. per sq. in. and are capable of standing 80 twists in a length of 6 in. before breaking. An aluminum-bronze wire showed a strength of 110,000 lb. per sq. in., but its ductility was less than that of the silicon-bronze wire. The low conductivity of bronze wires (not much over 35% that of pure copper, and much lower for some of the alloys) excludes them from use for line wires.

Bronze wires cost about six times as much as either iron or steel. On account of their cost, they are used but very little, if at all, in the United States; on some long lines in Europe, it is quite customary to use bronze wires of some kind.

GERMAN-SILVER WIRE

German silver is an alloy consisting of 18% to 30% nickel and the balance about 4 parts copper to 1 part zinc. Weight of the alloy per cubic foot about 530 lb.; specific gravity, 8.5. Resistance of the 18% alloy at 25° C. 18 times that of copper, and of the 30% alloy about 28 times that of copper. Temperature coefficient from 0° to 100° C. .044% increase of resistance for 1° C. increased temperature. The maximum safe carrying capacity of German-silver wire in spirals in open air for continuous duty is such that the circular mils per ampere varies from about 1,500 in No. 10 wire to about 475 in No. 30. For intermittent duty, the capacity is twice as great.

SIZES OF WIRE FOR TELEPHONE AND TELEGRAPH LINES

Telephone Lines.—No definite rules can be given for choosing the proper wire to be used for overhead telephone lines, but the following wires and sizes will ordinarily answer for the purposes mentioned. For telephone lines in the country and small towns for distances not exceeding 8 mi., No. 14 B. W. G., B. B. galvanized-iron wire may be used; for distances not to exceed 25 mi., No. 12 B. W. G., B. B.

RESISTANCE OF GERMAN-SILVER WIRE

B. & S. G. No.	Resistance per 1,000 Feet International Ohms		B. & S. G. No.	Resistance per 1,000 Feet International Ohms	
	18% Wire	30% Wire		18% Wire	30% Wire
6	7.20	11.21	21	232.92	362.32
7	9.12	14.18	22	295.38	459.48
8	11.54	17.95	23	370.26	575.96
9	14.55	22.63	24	468.18	728.28
10	18.18	28.28	25	590.22	918.12
11	22.84	35.53	26	748.08	1,163.68
12	28.81	44.82	27	937.98	1,459.08
13	36.48	56.75	28	1,191.24	1,853.04
14	46.17	71.82	29	1,481.22	2,304.12
15	58.21	90.55	30	1,891.8	2,942.8
16	72.72	113.12	31	2,388.6	3,715.6
17	93.40	145.29	32	2,955.6	4,597.6
18	118.20	183.87	33	3,751.2	5,835.2
19	145.94	227.02	34	4,764.6	7,411.6
20	184.68	287.28	35	6,031.8	9,382.8

galvanized-iron wire may be used; for distances from 25 to 100 mi., No. 10 B. W. G., B. B. galvanized-iron wire may be used; for distances of 100 mi. and over, hard-drawn copper wire should be used, not smaller than No. 10 B. & S. for 150 mi. and over. The size most generally used on farmers' lines is No. 12 B. B. galvanized-iron wire, weighing about 165 lb. per mi. although No 14 will answer up to about 8 mi.

For small city or town lines, No. 14 B. W. G., B. B. galvanized-iron wire is extensively used; although in towns where cable forms part of the line, steel wire may be used. For lines connected with large city exchanges, hard-drawn copper wire (usually No. 12 B. & S.) is almost always used.

For toll lines not exceeding 75 mi., B. B. galvanized-iron wire, generally No. 10 B. W. G. (but in a few cases No. 8 B. W. G.) is used; from 75 to 150 mi., the E. B. B. grade or hard-drawn copper should be used. For good toll lines of any length, the best practice calls for complete metallic circuits of hard-drawn copper, No. 10 B. & S. up to about 500 mi., and No. 8 B. & S. up to about 1,000 mi.

For interior wiring for telephones, No. 16 or No. 18 B. & S. copper wire should be used—in dry places weather-proof office wire, and in damp places rubber-covered wire.

Telegraph Lines.—The following sizes are those in use for telegraph lines:

No. 10 B. & S. hard-drawn copper and No. 4 B. W. G. galvanized-iron wires are now used on important quadruplex circuits. Formerly, No. 6 B. W. G. galvanized-iron wire was used for this purpose.

No. 6 B. W. G. galvanized-iron wire is used for important circuits between cities.

No. 8 B. W. G. galvanized-iron wire, or No. 12 B. & S. hard-drawn copper wire, is much used for circuits of 400 mi., or less, in length. No. 9 B. W. G. galvanized-iron wire was formerly used for this purpose.

No. 9 B. W. G. galvanized-iron wire was, until recently, the size generally used in the United States. It is now used on short circuits where No. 8 is not considered necessary.

Nos. 10 and 11 B. W. G. galvanized-iron wires are used for still shorter circuits and for railway telegraph, police, fire-alarm, and private lines. No. 12 B. W. G. galvanized-iron wire is also used for these purposes.

Nos. 13 and 14 B. W. G. steel wires are used for short private lines and where strength is especially necessary.

No. 8 B. & S. copper wire should be used for permanent ground wires in terminal telegraph offices

OHM'S LAW

The law governing the flow of current in an electric circuit is known as *Ohm's law*, and may be stated as follows: *The strength of the continuous current in any circuit is directly proportional to the electromotive force in the circuit, and inversely proportional to the resistance of the circuit;* that is, $I=\frac{E}{R}$, from which $R=\frac{E}{I}$, and $E=IR$, where I = current in amperes, E = E. M. F. in volts, and R = resistance in ohms. If there is in the circuit more than one source of electromotive force, the value of the resultant electromotive force must be used in these formulas. Furthermore, if the circuit contains inductance or capacity, the formulas are not applicable to variable- or alternating-currents.

CAPACITY

Capacity (C) is comparable to the capacity of a bottle containing air. The addition of a given amount of air will raise the pressure more or less, and the amount of air required to produce a certain pressure in the bottle may be taken as the measure of the capacity of the bottle. This capacity is analogous to the electrostatic capacity of a condenser, which is measured by the quantity of electricity with which it must be charged in order to raise its electrical potential from zero to unity. The *unit of capacity* is the *farad*. A condenser has a capacity of 1 farad when 1 coulomb is required to raise its potential from zero to 1 volt. Since the farad is very large, its millionth part, or the *microfarad*, is generally used as the practical unit. The microfarad $=\frac{1}{1,000,000}$, or 10^{-6} farads. Condensers from $\frac{1}{10}$ to 6 micro farads capacity are the sizes most commonly used in the United States.

CAPACITY OF CONDENSERS

If a difference of potential of E volts exists across the terminals of a condenser of C farads capacity, then the charge of Q coulombs in the condenser may be calculated from the formula

$$Q = CE$$

from which

$$C = \frac{Q}{E}$$

and

$$E = \frac{Q}{C}$$

The capacity of a condenser is given by the formula

$$C \text{ (microfarads)} = \frac{885\ Ka}{d10^{10}},$$

in which K is the inductivity of the dielectric between the tin-foil or metal plates; a is the area in square centimeters of all the dielectric sheets actually between and separating the condenser plates; and d is the average thickness in centimeters of the dielectric sheets. If there are n insulating sheets, each of area s, then $a = ns$.

When a and d are given in square inches and inches, respectively, the formula becomes

$$C \text{ (microfarads)} = \frac{2{,}248\ Ka}{d \times 10^{10}}.$$

Condensers in Parallel.—When two or more condensers are connected in parallel, the joint capacity C is equal to the sum of their capacities, that is, $C = C_1 + C_2 + C_3 + \text{etc.}$

Condensers in Series.—When two or more condensers C_1, C_2, C_3, etc. are joined in series, their joint capacity C is equal to the reciprocal of the sum of their reciprocals, that is,

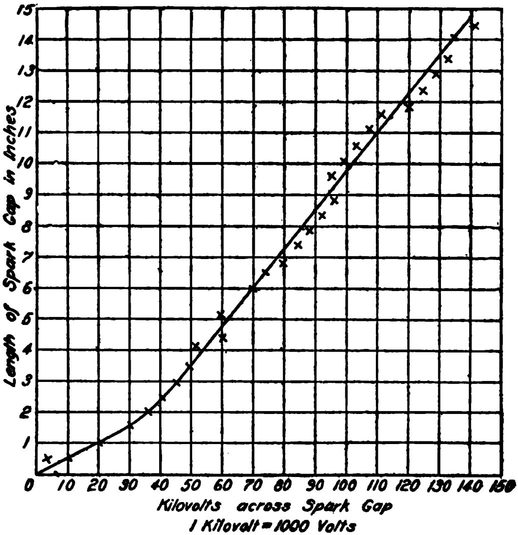
$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}}$$

There are as many terms in the denominator as there are condensers connected in series. For example, the capacity of four condensers of 2, 4, 5, and 8 microfarads capacity connected in series is calculated as follows: $\frac{1}{2} + \frac{1}{4} + \frac{1}{5} + \frac{1}{8} = 1.075$, and $\frac{1}{1.075} = .93$ microfarad.

INDUCTIVITY

The *inductivity*, or *specific inductive capacity*, of a substance is its *dielectric power*, or ability to convey the influence of an electrified body. Calling the inductivity of dry air at standard atmospheric pressure 1, the inductivity of any other substance is measured by the ratio of the capacity

DIELECTRIC STRENGTH OF AIR



of a condenser when its plates are separated by that substance to the capacity of the same condenser when its plates are separated by the same thickness of dry air. Various methods are used to determine the inductivities of substances and the capacities of condensers, and these methods do not all give the same results. Values obtained by the so-

INDUCTIVITIES OF VARIOUS SUBSTANCES

Material	Inductivity K
Air, vacuum at about .001 mm. pressure	.9400
Air, vacuum at about 5 mm. pressure	.9990
Hydrogen, at ordinary pressure	.9997 to 1.00026
Air, at ordinary pressure, standard	1.0000
Carbon dioxide, at ordinary pressure	1.00036 to 1.00095
Olefiant gas, at ordinary pressure	1.0007
Methane	1.0009
Sulphur dioxide, at ordinary pressure	1.0037
Manila paper	1.50
Carbon bisulphide	1.60 to 1.81
Paraffin, clear	1.68 to 2.32
Beeswax	1.86
Paraffin, solid	1.9936* to 2.32
Resin	1.77 to 2.55
Ozokerite	2.00
Petroleum	2.03 to 2.42
Ebonite	2.05* to 3.15
Turpentine	2.15 to 2.43
India rubber, pure	2.22 to 2.497
Sulphur	2.24 to 3.84
Gutta percha	2.46* to 4.20
Shellac	2.74* to 3.60
Olive and neat's-foot oils	3.00 to 3.16
Sperm oil	3.02 to 3.09
Glass	3.013* to 3.258*
Mica	4.00 to 8
Porcelain	4.38
Quartz	4.50
Flint glass, very light	6.57
Flint glass, light	6.85
Flint glass, very dense	7.40
Flint glass, double extra dense	10.10

*Results obtained by instantaneous methods.

called instantaneous methods are invariably lower than values obtained by the slower charge and discharge methods.

DIELECTRIC STRENGTH

The *dielectric strength* of an insulating substance is the maximum difference of potential that it will stand without being punctured. It is determined by placing a thin layer of the substance between two metal electrodes, and increasing the difference of potential between the electrodes by small steps until a spark passes through the dielectric; the difference of potential in volts preceding that which punctures the insulation is the maximum strength of the dielectric.

The curve on page 122 shows the dielectric strength of air, as determined by C. P. Steinmetz, with a frequency of 125 cycles per sec., using needle points 2½ in. long.

INDUCTANCE

Inductance, or the *coefficient of self-induction* L, is the ratio between the total induction through a circuit to the current producing it. The unit of inductance is the *henry*. An inductance of 1 henry exists in a circuit when a current changing at a rate of 1 ampere per sec. induces an electromotive force of 1 volt in the circuit. As the henry is quite large, the one-thousandth part of it, or the millihenry, is frequently used. The millihenry $= \frac{1}{1000}$ or 10^{-3} henry.

WORK AND POWER

Work, or *energy*, is expended in a circuit or conductor when a current of electricity flows through it. The unit of electrical work or energy is called the *joule*, after an eminent English scientist. If E is the electromotive force, or difference of potential, in volts that causes Q coulombs of electricity to flow through a circuit, the work expended in joules is

$$J = E \times Q$$

If an electromotive force, or difference of potential, of E volts causes a current of I amperes to flow for t seconds through a resistance of R ohms, then

$$J = EIt$$
$$J = \frac{E^2t}{R}$$
$$J = I^2Rt$$

The joule may be defined as the work done when 1 ampere flows for 1 second through a resistance of 1 ohm.

The energy used in forcing current through a resistance is converted into heat as follows:

4.2 joules = 1 small calorie
1 joule = .24 small calorie

The *watt-hour* is an extensively used unit of work. Watt-hours equal the product of the average number of watts and the number of hours during which they are expended. One *kilowatt-hour* = 1,000 watt-hours, or the product of the average number of kilowatts and the number of hours. Although five figures are given in most of the values in the accompanying table, it is rarely necessary to use more than three figures, and in very many cases two figures are sufficient. For instance, it is usually sufficient to use 1 calorie (gram-degree-C.) = 4.2 joules, or, to be a little more exact, 1 calorie = 4.19 joules. This table was calculated on the basis of 1 B. T. U. being equal to 778 ft.-lb., and the acceleration of gravity g was taken as equal to 981 cm. per sec. per sec.

Power (P), which is the rate at which work is done, is equal to the work divided by the time, and may be calculated by any one of the following formulas.

$$P = IE = I^2R = \frac{E^2}{R} = \frac{J}{t}$$

If I is in amperes, R in ohms, E in volts, J in joules, and t in seconds, P is in watts.

The *watt*, or unit of electric power, is equal to 1 joule per sec. It is the rate at which work is expended when 1 ampere flows through a resistance of 1 ohm. The watt is too small a unit for convenient use in many cases, so that the kilowatt (K. W.), or 1,000 watts, is frequently used. 1 H. P. equals 746 watts; therefore, $\text{H. P.} = \frac{P \text{ (in watts)}}{746}$,

or
$$\text{H. P.} = \frac{P \text{ (in kilowatts)}}{.746}$$

NUMBER OF VOLTS REQUIRED TO PRODUCE A SPARK BETWEEN BALLS IN AIR

Length of Spark Gap in		Diameter of the Balls		
		1 Cm. =.3937 In.	2 Cm. =.787 In.	6 Cm. =2.36 In.
Centimeters	Inches	Volts	Volts	Volts
.02	.0079	1,560	1,530	
.04	.0157	2,460	2,430	
.06	.0236	3,300	3,240	
.08	.0315	4,050	3,990	
.10	.0394	4,800	4,800	4,500
.20	.0787	8,400	8,400	7,800
.30	.1181	11,400	11,400	10,800
.40	.1575	14,400	14,400	13,500
.50	.1969	17,100	17,100	16,500
.60	.2362	19,500	19,800	19,500
.70	.2756	21,600	22,500	22,500
.80	.3150	23,400	24,900	26,100
.90	.3543	24,600	27,300	29,000
1.00	.3937	25,500	29,100	32,700

DIELECTRIC STRENGTH OF VARIOUS SUBSTANCES

(Macfarlane and Pierce)

Substance	Strength in Volts per Centimeter
Oil of turpentine	94,000
Paraffin oil	87,000
Olive oil	82,000
Paraffin (melted)	56,000
Kerosene oil	50,000
Paraffin (solid)	130,000
Beeswaxed paper	540,000
Air (thickness 5 cm.)	23,800
CO^2 (thickness 5 cm.)	22,700
Oxygen (thickness 5 cm.)	22,200
Hydrogen (thickness 5 cm.)	15,100
Coal gas (thickness 5 cm.)	22,300

DIELECTRIC STRENGTH OF VARIOUS SUBSTANCES

(Parshall and Hobart)

Substance	Thickness in Inches	Puncturing Voltage	Volts per $\frac{1}{1000}$ In
Composite sheets of mica and paper prepared so as to be moisture-proof	.005	3,600 to 5,860	
	.007	7,800 to 10,800	
	.009	8,800 to 11,400	
	.011	11,600 to 14,600	
Leatheroid	$\frac{1}{64}$ or .0156	5,000	320
	$\frac{1}{32}$ or .0313	8,000	256
	$\frac{3}{64}$ or .0469	12,000	256
	$\frac{1}{16}$ or .0625	15,000	240
	$\frac{1}{8}$ or .125	15,000	120
	$\frac{3}{16}$ or .188	6,000	32
	$\frac{1}{4}$ or .25	6,000	24
Vulcanized fiber	$\frac{1}{8}$ or .125 to 1	about 10,000	
Hard rubber			500
Kiln-dried maple and other similar woods	1	10,000 to 20,000	
Vulcabeston	$\frac{1}{2}$	10,000	
Red pressboard	.03	10,000	
Red rope paper	.01	1,000	
Manila paper	.003	400	
Oiled cambric	.007	2,500 to 4,500	
Oiled cotton	.003	6,300 to 7,000	
Oiled paper	{ .004	{ 3,400 to 4,800	
	.010	5,000	
Mica		1 to 2.1×10^6 per mm.	

RELATION BETWEEN UNITS OF WORK

Name of Unit	Ergs	Joules	Kilowatt-Hours	Calories	Foot-Pounds	B. T. U.
1 erg..................	1	$\frac{1}{10^7}$	$\frac{2,778}{10^{17}}$	$\frac{23,882}{10^{12}}$	$\frac{73,734}{10^{12}}$	$\frac{94,774}{10^{15}}$
1 joule..................	10^7	1	$\frac{2,778}{10^{10}}$	.23882	.73734	$\frac{94,774}{10^8}$
1 kilowatt-hour..........	36×10^{12}	36×10^5	1	859,770	2,654,400	3,411.8
1 calorie (gram-deg. C.)...	41,872,000	4.1872	$\frac{11,631}{10^{10}}$	1	3.0873	$\frac{39,683}{10^7}$
1 foot-pound............	13,562,000	1.3562	$\frac{37,673}{10^{11}}$	.32390	1	.001285
1 British thermal unit (lb.-deg. F.)..........	$10,551 \times 10^6$	1,055.1	$\frac{29,310}{10^8}$	252.00	778	1

MAGNETISM

MAGNETIC QUANTITIES

Strength of Pole (m).—A magnetic pole of unit strength is one that repels with a force of 1 dyne another similar and equal pole when placed 1 cm. from it.

Magnetic Moment ($\mathfrak{M}$).—The magnetic moment of a magnet is equal to the product of the strength m of one of its poles and the distance l between the poles. That is $\mathfrak{M} = m \times l$.

Intensity of Magnetization ($\mathfrak{J}$).—The intensity of magnetization is equal to the strength m of a magnetic pole divided by its area A; that is, $\mathfrak{J} = \frac{m}{A}$.

The *intensity of magnetic field, field density,* or *magnetizing force* $\mathcal{H}$ at any point is measured by the force with which the field acts on a unit pole placed at that point. A unit field, called a *gauss*, acts with a force of 1 dyne on a unit pole, and is represented by 1 line of force, or 1 *maxwell*, per sq. cm. A field having an intensity of 5 lines of force per sq. cm. may be called a field of 5 maxwells per sq. cm., or simply a field of 5 gausses. The number of lines of force, or maxwells per unit area of a magnetic substance is variously called its *magnetic induction, flux density, magnetic density,* or simply *magnetism*, and is represented by $\mathcal{B}$ when the unit area is 1 sq. cm. or by **B** when the unit area is 1 sq. in.

Magnetic flux, or *total induction*, usually designated by the Greek letter Φ (phi), is the total number of lines of force threading a magnetic circuit, and is equal to the product of the magnetic density and the cross-sectional area; that is,

$$\Phi = \mathcal{B}A$$

If $\mathcal{B}$ is expressed in lines of force per square centimeter, or gausses, then A must be in square centimeters; and if **B** is in lines of force per square inch, A must be in square inches.

Magnetic Permeability (μ).—Magnetic permeability is the ratio between the flux density $\mathcal{B}$ and the field intensity $\mathcal{H}$; that is, if the flux density through a solenoid is $\mathcal{H}$

MAGNETIC QUALITIES OF ANNEALED SHEET IRON

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch **B**	Square Centimeter $\mathcal{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	2.480	16	1.973	5.011	625.0
3,100	20,000	3.565	23	2.836	7.204	869.6
4.650	30,000	4.340	28	3.452	8.770	1,071.4
6,200	40,000	5.115	33	4.069	10.34	1,212.1
7,750	50,000	6.510	42	5.179	13.15	1,190.4
9.300	60.000	8.215	53	6.535	16.60	1,132.0
10.075	65,000					
10.850	70,000	10.54	68	8.384	21.30	1,029.4
12.400	80,000	14.57	94	11.59	29.44	851.0
13,950	90,000	21.39	138	17.02	43.22	652.2
15.500	100,000	33.17	214	26.39	67.02	467.3
16,275	105,000					
17,050	110,000	57.97	374	46.11	117.14	294.1
17,825	115,000					
18,600	120,000	112.38	725	89.39	227.07	165.5
19,375	125,000	166.63	1,057	132.55	346.69	116.3

MAGNETIC QUALITIES OF UNANNEALED CAST STEEL

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathcal{B}$	Square Inch **B**	Square Centimeter $\mathcal{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	2.790	18	2.219	5.638	555.5
3,100	20,000	4.340	28	3.452	8.770	714.3
4,650	30,000	5.425	35	4.312	10.96	857.1
6,200	40,000	6.665	43	5.302	13.47	930.2
7,750	50,000	8.370	54	6.658	16.91	925.9
9,300	60,000	11.16	72	8.878	22.55	833.3
10,075	65,000					
10,850	70,000	15.35	99	10.85	31.01	707.1
12,400	80,000	22.63	146	18.00	45.73	547.3
13,950	90,000	34.88	225	27.74	70.47	400.0
15,500	100,000	58.13	375	46.24	117.45	266.6
16,275	105,000					
17,050	110,000	113.15	730	90.01	228.64	150.7
17,825	115,000	157.33	1,015	125.15	317.90	113.3

MAGNETIC QUALITIES OF WROUGHT-IRON FORGINGS

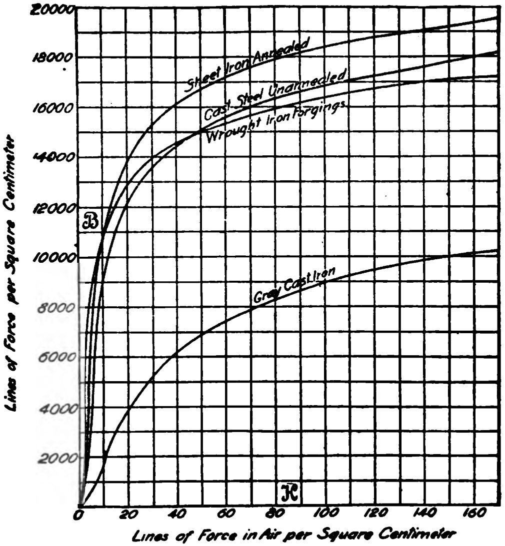
Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathcal{B}$	Square Inch **B**	Square Centimeter $\mathcal{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	1.860	12	1.480	3.758	833.3
3,100	20,000	2.325	15	1.850	4.698	1,333.3
4,650	30,000	2.790	18	2.219	5.638	1,595.7
6,200	40,000	3.565	23	2.836	7.204	1,739.1
7,750	50,000	4.650	30	3.699	9.396	1,666.6
9,300	60,000	6.820	44	5.425	13.78	1,363.6
10,075	65,000					
10,850	70,000	10.08	65	8.015	20.36	1,076.9
12,400	80,000	16.12	104	12.82	32.57	769.2
13,950	90,000	31.00	200	24.66	62.64	450.0
15,500	100,000	66.05	430	53.02	134.68	232.6
16,275	105,000	97.65	630	77.68	197.32	166.6
17,050	110,000	160.43	1,035	127.62	324.16	106.3

MAGNETIC QUALITIES OF GRAY CAST IRON

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathcal{B}$	Square Inch **B**	Square Centimeter $\mathcal{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	9.92	64	7.891	20.04	156.3
3,100	20,000	16.28	105	12.95	32.89	190.5
4,650	30,000	25.42	164	20.22	51.36	182.9
6,200	40.000	40.61	262	32.30	82.06	152.9
7,750	50.000	66.65	430	53.02	134.68	116.3
9,300	60.000	112.29	718	88.53	224.49	83.6
10,075	65,000	159.65	1,030	127.0	322.60	63.1

when the core consists of air, and is $\mathcal{B}$ when the core consists of iron, the permeability of the iron is

$$\mu = \frac{\mathcal{B}}{\mathcal{H}} = \frac{\mathbf{B}}{\mathbf{H}}$$

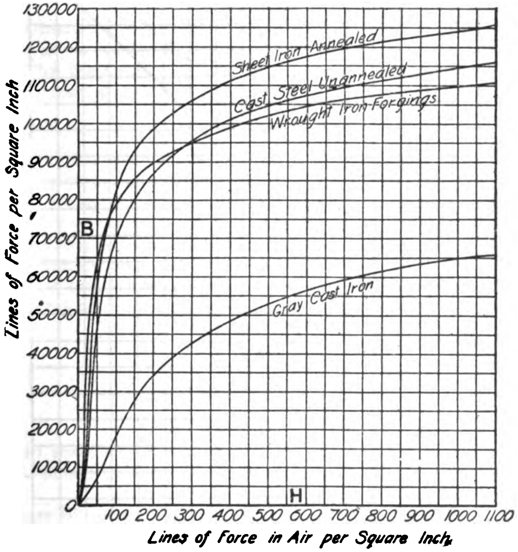


$\mathcal{B}$–$\mathcal{H}$ CURVES

Magnetomotive force $\mathfrak{F}$ (sometimes written M. M. F.), for the unit of which the name *Gilbert* has been proposed, is the total magnetizing force produced by a coil of T turns through which a current of I amperes is flowing. The magnetomotive force

$$\mathfrak{F} = \frac{4\pi I T}{10} = 1.257\, IT$$

Reluctance $\mathcal{R}$, for the unit of which the name *oersted* has been proposed, is the magnetic resistance, or opposition, offered by a substance to the passage of magnetic flux. Unit magnetomotive force will produce unit flux through



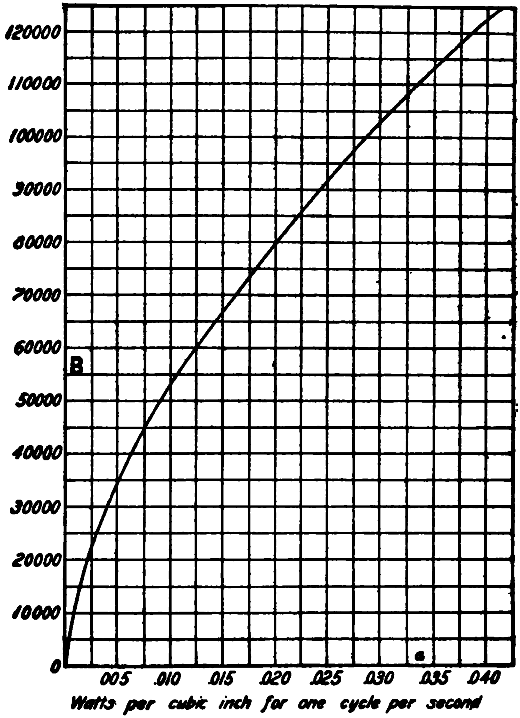
B-H CURVES

unit reluctance. A cubic centimeter of a perfectly non-magnetic substance, such as air, has unit reluctance.

HYSTERESIS

Hysteresis may be defined as the tendency of a magnetic substance to persist in any magnetic state that it may have acquired. When an alternating or variable current flows

HYSTERESIS LOSS AT ONE CYCLE PER SECOND AT VARIOUS FREQUENCIES



in a coil around iron, some work is expended due to the hysteresis of the iron; this work appears as heat in the iron.

If a is the power in watts expended in 1 cu. in. of iron for 1 cycle per sec.; **V**, the volume of iron in cubic inches; n, the number of cycles per second; and P, the total watts expended in hysteresis; then,

$$P = a\mathbf{V}n$$

Obtain the value of a from the curve given on page 136 for any given density **B**.

The Steinmetz formula for the power in watts lost in hysteresis is

$$P = \frac{kV\mathfrak{B}^{1.6}n}{10^7}$$

where V is the volume in cubic centimeters and $\mathfrak{B}$ is the induction per square centimeter.

The constant k will vary a great deal, depending on the quality of the iron. A fair value for k for annealed sheet iron and steel, such as used in dynamo and motor armatures, is .0035; for gray cast iron .013; and for cast steel, .003.

The total hysteresis loss in watts in iron, where the dimensions are given in inches, is very nearly

$$P = \frac{.83k\mathbf{B}^{1.6}\mathbf{V}n}{10^7}$$

EDDY-CURRENT LOSS

(From Parshall and Hobart)

In sheet iron not over .025 in. thick, the eddy-current loss should theoretically conform to the formula

$$W = 1.5t^2n^2\mathbf{B}^2 \times 10^{-10}$$

where W = watts per pound of iron at 0° C.;
t = thickness of iron, in inches;
n = number of cycles per second;
B = number of lines of force per square inch.

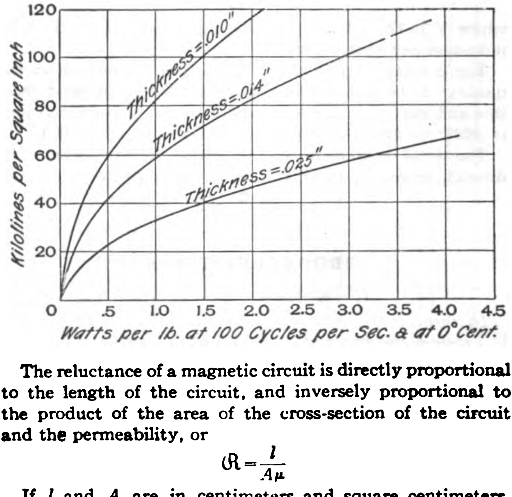
The loss decreases .5% per degree C. increase of temperature. The formula holds for iron whose specific resistance is 10 microhms per cm. cube at 0° C. and whose specific weight is .282 lb. per cu. in. For thicknesses greater than .025 in., the results given by the above formula are greatly modified. The curves in the accompanying figure show eddy-current losses in various thicknesses of sheet iron.

LAWS OF MAGNETIC CIRCUIT

The total magnetic flux in a circuit is directly proportional to the magnetomotive force acting in the circuit and inversely proportional to the reluctance of the circuit; or

$$\Phi = \frac{\mathcal{F}}{\mathcal{R}}$$

If Φ is the flux in maxwells, then $\mathcal{F}$ will be the magnetomotive force in C. G. S. units, or gilberts, and $\mathcal{R}$ will be the reluctance in C. G. S. units, or oersteds.



The reluctance of a magnetic circuit is directly proportional to the length of the circuit, and inversely proportional to the product of the area of the cross-section of the circuit and the permeability, or

$$\mathcal{R} = \frac{l}{A\mu}$$

If l and A are in centimeters and square centimeters, respectively, $\mathcal{R}$ will be in C. G. S units; if in inches and square inches, the reluctance will be in units to which no name has been given. Since for air and all other non-magnetic substances $\mu = 1$, the reluctance $\mathcal{R} = \frac{1}{A}$. In a complex magnetic circuit, the total reluctance is equal to the sum of the reluctances of all the parts.

The magnetomotive force due to an electromagnetic solenoid is directly proportional to the current and to the number of turns in the solenoid; that is,

$$\mathcal{F} = \mathcal{H}l = 1.257IT$$

$$\mathbf{H}\mathrm{l} = 3.192IT$$

in which l must be expressed in centimeters and l in inches. The field density (in air) produced inside a long solenoid, and approximately inside any coil, whose length is large compared with its diameter, can be determined by the preceding formulas. From the same formulas can be determined the ampere-turns IT required to produce a given field density $\mathcal{H}$ or $\mathbf{H}$ inside a coil whose length is known. The field density multiplied by the average area of the coil gives the total number of lines threading the coil when it contains no iron. If iron is introduced, it is necessary to multiply the field density by the permeability of the iron for that particular field density, and then by the sectional area of the iron, in order to get the total flux threading the iron.

Since $\mathcal{H}l = 1.257IT.$, $IT = .796\mathcal{H}l$, where l is in centimeters; and for a given magnetizing force in a complex magnetic circuit, the number of ampere-turns is

$$IT = .796\mathcal{H}_1l_1 + .796\mathcal{H}_2l_2 + .796\mathcal{H}_3l_3 + \text{etc.},$$

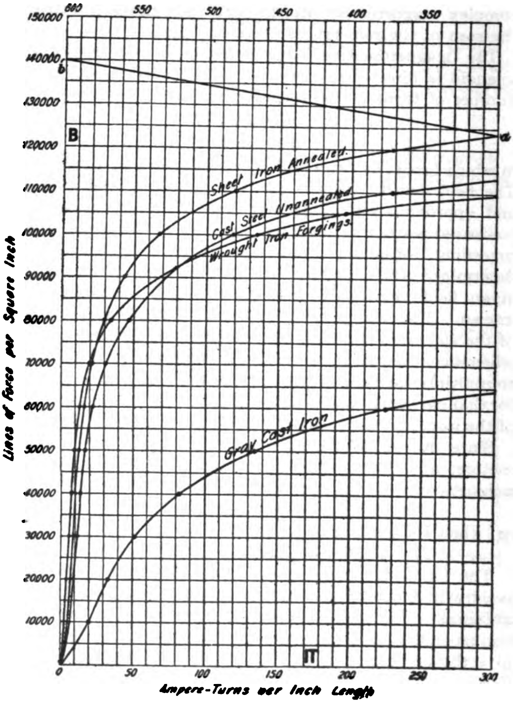
or, when the dimensions are in inches,

$$IT = .313\mathbf{H}_1\mathrm{l}_1 + .313\mathbf{H}_2\mathrm{l}_2 + .313\mathbf{H}_3\mathrm{l}_3 + \text{etc.}$$

The following ampere-turn curves are plotted respectively with $\mathcal{B}$ and $\mathbf{B}$ as ordinates and $.796\mathcal{H}$ and $.313\mathbf{H}$ as abscissas. For a given density, find from the curve the corresponding abscissa which multiplied by the length will give the ampere-turns required for that part of the circuit. The sum of the ampere-turns for each part will give the total number of ampere-turns required.

AMPERE-TURN CURVE—ENGLISH MEASURES

To reduce the length of the curve for sheet iron, the portion *a b* for densities greater than 123,000 per sq. in. is plotted backwards; for example, a density of 125,000 lines per sq. in. requires 325 ampere-turns per in.



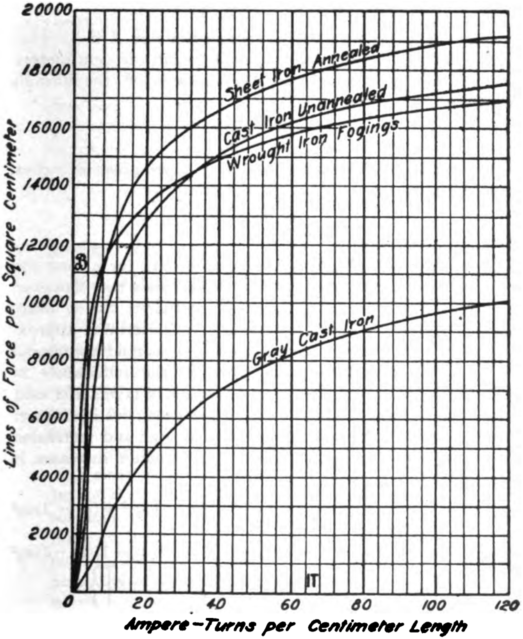
INDUCTION

The electromotive force E in volts generated in a conductor cutting Φ lines of force in t seconds may be computed by the formula

$$E = \frac{\Phi}{10^8 t}$$

Self-Induction.—A coil has 1 C G. S. unit of inductance when 1 C G. S. unit of current flowing through 1 turn pro-

AMPERE-TURN CURVE—METRIC MEASURES



duces 1 line of force. If I is the current in amperes, T the number of turns in a coil, Φ the number of lines of force due to the coil, then the inductance of the coil in henrys is

$$L = \frac{\Phi T}{10^8 I}$$

The inductance in henrys of a coil containing no iron may be computed by the formula

$$L = \frac{4\pi T^2 A}{10^9 l}$$

in which T is the number of turns in the coil, A is its mean area in square centimeters. and l is its length in centimeters. For a cylindrical coil whose mean area is πr^2, the formula reduces to

$$L = \frac{3{,}948 r^2 T^2}{10^{11} l}$$

If the radius and the length of the coil are given in inches, then the inductance in henrys is similar to r

$$L = \frac{10{,}028 r^2 T^2}{10^{11} l}$$

These two formulas are strictly true only for a long coil in which the length is twenty or more times the diameter, and the depth of winding is small compared to the mean radius. However, they may be used to determine approximately the inductance of any ordinary solenoid containing no magnetic material. A formula for the inductance in C. G. S. units of coils having any number of layers and said by L. Cohen to be exact to $\frac{1}{2}$ of 1 per cent., even for short solenoids whose length is twice the diameter and increasing in accuracy as the ratio of length to diameter increases, is as follows:

$$L = 4\pi^2 n^2 m \left\{ \frac{2a_0^4 + a_0^2 l^2}{\sqrt{a_0^2 + l^2}} \right\} + 8\pi^2 n^2 \left\{ [(m-1)a_1^2 + (m-2)a_2^2 + \cdots][\sqrt{a_1^2 + l^2} - \tfrac{4}{3}a_1] + \tfrac{1}{2}[m(m-1)a_1^2 + (m-1)(m-2)a_2^2 + (m-2)(m-3)a_3^2 + \cdots]\left[\frac{a_1 r_1}{\sqrt{a_1^2 + l^2}} - r\right] \right\}$$

in which m is the number of layers; a_0, the mean radius of the solenoid; a_1, a_2, a_3, etc., the mean radii of the various layers; l, the length of solenoid; r, the radial distance between two consecutive layers; n, the number of turns per unit length; all dimensions are in centimeters. For a solenoid whose length is at least four times its diameter, the **last** formula reduces to

$$L = 4\pi^2 n^2 m^2 \left[\frac{2a_0^4 + a_0^2 l^2}{\sqrt{4a_0^2 + l^2}} - \frac{8a_0^3}{3\pi}\right] + 8\pi^2 n^2 \Big\{[(m-1)a_1^2$$
$$+ (m-2)a_2^2 + \cdots][\sqrt{a_1^2 + l^2} - \tfrac{7}{8}a_1]\Big\}$$

For a single layer the first formula reduces to

$$L = 4\pi^2 n^2 \left[\frac{2a^4 + a^2 l^2}{\sqrt{4a^2 + l^2}} - \frac{8a^3}{3\pi}\right]$$

If the solenoid contains magnetic material the inductance given by these formulas must be multiplied by the permeability μ of the magnetic material at the density to which the coil magnetizes the iron.

The mutual inductance between two coils in henrys is

$$M = \frac{\Phi T}{10^8 I}$$

RULES FOR DIRECTION OF CURRENT AND MOTION

Rule.—*If the current in a conductor is flowing from south to north, and a compass is placed under the conductor, the north end of the needle will be deflected to the west; if the compass is placed over the conductor, the north end of the needle will be deflected to the east.*

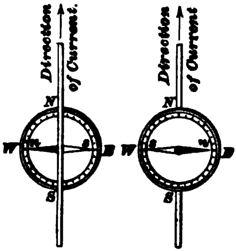


FIG. 1

To determine the polarity of an electromagnetic solenoid: In looking at the end of a solenoid, if an electric current flows in it clockwise, the end next to the observer is a south pole and the other end is a north pole; if counter-clockwise, the position of the poles is reversed.

To determine the direction of the lines of force set up around a conductor: If the current in a conductor is flowing away from the observer, then the direction of the lines of force will be clockwise around the conductor.

To determine the direction of motion of a conductor carrying a current when placed in a magnetic field: Place

INDUCTION-COIL DATA SUITABLE FOR WIRELESS TELEGRAPHY AND ROENTGEN-RAY WORK

(From "Scientific American Supplement")

Length of Spark Gap Inches	Length of Core Inches	Diameter of Core Inches	Primary Wire B. & S. Gauge	Number of Layers in Primary Coil	Secondary Wire B. & S. Gauge	Secondary Wire Pounds	Condenser		Voltage of Battery
							Number of Sheet	Area of Each Sheet Square Inches	
[illegible]	3	[illegible]	23	2	36	[illegible]	25	2×1	2
[illegible]	3[illegible]	[illegible]	23	2	36	[illegible]	40	2×1[illegible]	2
[illegible]	4[illegible]	[illegible]	22	2	36	[illegible]	45	4×2	4
[illegible]	6	[illegible]	19	2	36	[illegible]	50	4×2	4
[illegible]	7	[illegible]	16	2	36	[illegible]	60	4×4	6
1	8	1	16	2	34	1	100	7×5	12
2	10	1[illegible]	14	2	34	3	100	9×7	12
3	11[illegible]	1[illegible]	14	2	33	5	150	9×7	12
6	14[illegible]	1[illegible]	12	2	33	10	200	9×9	16
12	19	1[illegible]	10	3	33	12	60	12×8	10

thumb, forefinger, and middle finger of the *left hand* each at right angles to the other two; if the forefinger shows the direction of the lines of force and the middle finger shows the direction of the

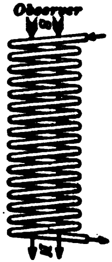


FIG. 2

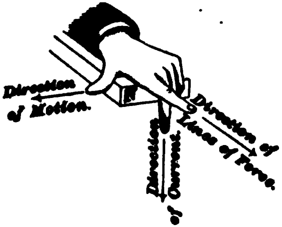


FIG. 3

current, then the thumb will show the direction of the motion given to the conductor.

To determine the direction of an induced current in a conductor that is moving in a magnetic field: Place thumb, forefinger, and middle finger of the *right hand* each at right angles to the other two; if the forefinger shows the direction of the lines of force and the thumb shows the direction of motion of the conductor, then the middle finger will show the direction of the induced current.

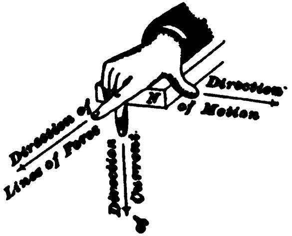


FIG. 4

A rule that is sometimes useful is the following: If the effect of the movement of a closed coil is to diminish the number of lines of force that pass through it, the current will flow in the conductor in a clockwise direction, when viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase

COTTON-COVERED ANNEALED COPPER WIRE

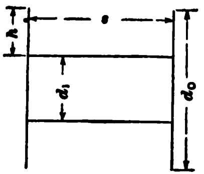
B. & S. Gauge	Bare		Single Cotton-Covered		
	Dia. Mils d	Area Cir. Mils d^2	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
0000	460	212,000			
000	410	168,000			
00	365	133,000			
0	325	106,000			
1	289	83,700			
2	258	66,400			
3	229	52,600			
4	204	41,700	211	4.73	22.3
5	182	33,100	189	5.29	27.9
6	162	26,300	169	5.91	34.9
7	144	20,800	151	6.62	43.8
8	128	16,500	136	7.35	54.0
9	114	13,100	121	8.26	68.2
10	102	10,400	108	9.25	85.5
11	90.7	8,230	97	10.3	106
12	80.8	6,530	87	11.4	129
13	71.9	5,180	78	12.8	163
14	64.1	4,110	70	14.2	201
15	57.1	3,260	63	15.8	249
16	50.8	2,580	56	17.8	316
17	45.3	2,050	50	20.0	400
18	40.3	1,620	45	22.2	492
19	35.9	1,290	39	25.6	655
20	32.0	1,020	36	27.7	767
21	28.5	810	32.5	30.7	942
22	25.3	642	29.0	34.4	1,180
23	22.6	510	26.6	37.5	1,400
24	20.1	404	24.1	41.4	1,710

TABLE—(*Continued*)

B. & S. Gauge	Bare		Single Cotton-Covered		
	Dia. Mils d	Area Cir. Mils d^2	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
25	17.9	320	21.9	45.6	2,070
26	15.9	254	19.9	50.2	2,520
27	14.2	202	18.2	54.9	3,010
28	12.6	160	16.6	60.2	3,620
29	11.3	127	15.3	65.3	4,260
30	10.0	101	14.0	71.4	5,090
31	8.93	79.7	12.9	77.5	6,000
32	7.95	63.2	11.9	84.0	7,050
33	7.08	50.1	11.1	90.0	8,100
34	6.31	39.8	10.3	97.0	9,400
35	5.62	31.5	9.6	104	10,800
36	5.00	25.0	8.5	117	13,600
37	4.45	19.8			
38	3.97	15.7			
39	3.53	12.5			
40	3.15	9.89			

the number of lines of force that pass through the coil, the current will flow in the opposite direction.

MAGNET-WINDING CALCULATIONS



Suppose a winding space, having the length s and the depth $h=\frac{d_0-d_1}{2}$, is to be filled with wire wound in layers as closely as possible. The diameter of the bare wire is d, and over the insulation d_x. The space will hold $\frac{s}{d_x}$ turns per layer and

COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Double Cotton-Covered Wire			Triple Cotton-Covered Wire		
	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
0000				478	2.09	4.36
000				428	2.33	5.42
00				383	2.61	6.81
0	339	2.94	8.64	343	2.91	8.46
1	303	3.30	10.8	307	3.25	10.5
2	272	3.67	13.4	276	3.62	13.1
3	242	4.13	17.0	247	4.04	16.3
4	216	4.62	21.3	220	4.54	20.6
5	194	5.15	26.5	198	5.05	25.5
6	174	5.74	32.9	178	5.61	31.4
7	156	6.41	41.0	160	6.25	39.0
8	141	7.09	50.2	145	6.89	47.4
9	126	7.93	62.8	130	7.69	59.1
10	112	8.92	79.5	116	8.02	64.3
11	101	9.90	98.0	105	9.52	90.6
12	91	10.9	118	95	10.5	110
13	82	12.1	146	86	11.6	134
14	74	13.5	182	78	12.8	163
15	67	14.9	222	71	14.0	196
16	59	16.9	285	63	15.8	249
17	53	18.8	353	57	17.5	306
18	48	20.8	432	52	19.2	368
19	43	23.2	538	47	21.2	449
20	40	25.0	625	44	22.7	515
21	36.5	27.3	745	40.5	24.6	605
22	33.0	30.3	918	37	27.0	729
23	30.6	32.6	1,060	34.6	28.9	835
24	28.1	35.5	1.260	32.1	31.1	967

TABLE—(*Continued*)

B. & S. Gauge	Double Cotton-Covered Wire			Triple Cotton-Covered Wire		
	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
25	25.9	38.6	1,480			
26	23.9	41.8	1,740			
27	22.2	45.0	2,020			
28	20.6	48.5	2,350			
29	19.3	51.8	2,680	These small-size wires are seldom, if ever, covered with three layers of cotton.		
30	18.0	55.5	3,080			
31	16.9	59.1	3,490			
32	15.9	62.8	3,940			
33	15.1	66.2	4,380			
34	14.3	69.9	4,880			
35	13.6	73.5	5,400			
36	12.0	83.3	6,930			

$\frac{h}{d_x}$ layers, and the total turns

$$T=\frac{sh}{(d_x)^2}=\frac{s(d_0-d_1)}{(d_x)^2} \qquad (1)$$

The mean diameter of all the turns is

$$d_0-h=d_0-\frac{d_0-d_1}{2}=\frac{d_0+d_1}{2},$$

the length l of a mean turn is

$$\frac{\pi(d_0+d_1)}{2},$$

and the total length of wire is

$$L=\frac{\pi T(d_0+d_1)}{2}=\frac{\pi sh(d_0+d_1)}{(d_x)^2}. \qquad (2)$$

The resistance is

$$R=\frac{\pi\rho sh(d_0+d_1)}{2(d_x)^2} \qquad (3)$$

where ρ is the resistance per unit length of wire. Since $\frac{\pi sh(d_0+d_1)}{2}=V$, the total volume of winding space, then

$$R=\frac{\rho V}{(d_x)^2} \qquad (4)$$

In general, if m is the resistance per mil-foot, a the circular mils cross-section of the wire, l the mean length in inches of one turn, and T the total number of turns, the resistance is

$$R=\frac{mlT}{12a} \qquad (5)$$

If the coil is to be used on a fixed voltage E, the current $I=\frac{E}{R}=\frac{12Ea}{mlT}$, and the ampere-turns $IT = \frac{12Ea}{ml}$ from which the circular mils

$$a=\frac{mlIT}{12E} \qquad (6)$$

For copper wire at 75° F. $m=10.5$ ohms, but if the wire is heated until the resistance is increased about 14%, the constant becomes 12 ohms, a value frequently used. If $m=12$, the formula becomes

$$a=\frac{lIT}{E} \qquad (7)$$

which gives the cross-section of wire needed for a given number of ampere-turns when the temperature of the wire is about 135° F.

By making no allowance for the thickness of insulation, except that each wire occupies a space of $d_x{}^2$ square inches, the diameter of a wire required to fill a winding space of outside diameter d_0, inside diameter d_1, and length s all in inches, and offer a given resistance of R ohms, is given approximately by the formula

$$d=.0288\sqrt[4]{\frac{s(d_0{}^2-d_1{}^2)}{R}} \qquad (8)$$

where d is the diameter of the bare wire in inches.

A more exact formula for determining the size of insulated wire to fill a given space is

$$d=\sqrt{i^2+\sqrt{\frac{.7854ms(d_0{}^2-d_1{}^2)}{R}}}-i \qquad (9)$$

where i is the radial thickness of the insulation.

The bare diameter d of a wire for a coil that will produce IT ampere-turns with a given voltage E may be determined from the formula

$$d=\sqrt{\frac{.000001374(d_0+d_1)IT}{E}} \qquad (10)$$

The length of insulated wire on a spool or bobbin is given by the formula

$$L=\frac{.7854s(d_0^2-d_1^2)}{(2i+d)^2} \qquad (11)$$

When the volume V of the winding space in cubic inches and the ohms per cubic inch o of the sized wire used is known, the resistance of a coil can be determined from the formula

$$R=Vo=.7854so(d_0^2-d_1^2) \qquad (12)$$

The heating effect of the energy lost in a magnet coil depends on the shape of the coil and on the conditions of ventilation. If d_0 is the outside diameter of a coil and s is its length, both in inches, and W is the total watts lost in the coil, the watts per square inch of cylindrical surface is

$$w=\frac{W}{\pi d_0 s}$$

The safe value for w varies generally from .25 to 1.5, a fair value, if the ventilating conditions are good, being .75 to 1 for coils at 75° F. above the temperature of the surrounding air. Higher values of w can be used only for exceptionally good ventilating conditions or for intermittent-service conditions.

Since $W=I^2R=\frac{E^2}{R}$, $R=\frac{E^2}{W}=\frac{E^2}{\pi d_0 sw}$, which gives the resistance of a coil when dissipating w watts per square inch.

The following formula gives the diameter d of a wire that will produce the greatest number of ampere-turns with a rise in temperature of $t°$ F..

$$d=\sqrt{\sqrt{.000002159\times(1+.00223t°)\times d_0\times s^2\times(d_0^2-d_1^2)\,W_s}+i^2}-i$$

in which i is the radial thickness of the insulation on the wire, and W_s is the watts radiated per square inch of cylindrical surface of the coil.

The greatest number of ampere-turns IT that can be obtained in a coil of given size for a given voltage E, a given rise in temperature $t°$F., and W_s watts radiated per square inch of cylindrical surface, can be calculated from the formula

$$IT = \frac{E\left[\sqrt{\sqrt{\frac{.000002159\times(1+.00223\,t^{\circ})\times d_0\times s^2\times(d_0^2-d_1^2)\times W_s}{E^2}}+i^2}-i\right]^2}{.000001374\times(d_0+d_1)}$$

DRY-CORE PAPER-INSULATED TELEPHONE CABLES

No. of Pairs	No. 19 B. & S. Wire			No. 20 B. & S. Wire	No. 22 B. & S. Wire		
	Diameter of Cable Inches	Splicing Sleeve		Diameter of Cable	Diameter of Cable Inches	Splicing Sleeve	
		Diameter Inches	Length Inches			Diameter Inches	Length Inches
15		2	20			1¼	18
20	1.134	2	20	1.032	.860	1½	18
25	1.169	2	25	1.100	.928	2	20
50	1.534	2	28	1.427	1.251	2	20
75	1.822	2¼	28	1.648	1.461	2¼	22
100	2.063	2½	28	1.907	1.632	2½	24
125	2.268	3	28	2.102	1.805	2¾	28
150	2.457	3	30	2.269	1.943	3	28
175	2.630	3¼	30	2.423	2.080	3	28
200	2.784	3½	32	2.578	2.200	3	28
300		4	36		2.630	3¼	28
400		4	40			4	28

Each conductor has a capacity of .08 microfarad per mile. The 20-pair No. 20 B. & S. conductor cable and the 25-pair No. 22 B. & S. conductor cable have lead sheaths $\frac{3}{32}$ in. thick, the 20-pair No. 22 B. & S. conductor cable has a lead sheath $\frac{7}{64}$ in. thick; all others have lead sheaths $\frac{1}{8}$ in. thick. For Y and loop splices, use a sleeve one size larger than given for straight splices in this table.

Concrete.—For manholes and around conduits good concrete may be made of 1 part of Portland cement or 2 parts of Rosendale or native cement, 3 parts of sand, and 5 or 6 parts of broken stone, or good cinders or furnace slag, that will pass through a ring 1½ inches in diameter, but not through a ring ½ inch in diameter. For good results, concrete should be mixed as follows First, mix the sand and cement, turning them together at least three times dry, then add the stone, which should previously have been thoroughly wetted, and turn the mixture at least once over, finally add enough water to make the concrete tamp nicely, but not so moist as to have water run from it, and turn over at least three times. The water should not be supplied from a hose giving a strong stream that will cause the finely divided cement to be washed away; use buckets or a weak stream of water.

Poles.—Telephone and telegraph poles 25-ft. long should be set in 5-ft. holes; 30-ft. poles in 5½-ft. holes; 35- and 40-ft. poles in 6-ft. holes; 45-ft. poles in 6½-ft. holes; 50-ft. poles in 7-ft. holes; 55-ft. poles in 7½-ft. holes; 60-ft. poles in 8-ft. holes; 65-ft. poles in 8½-ft. holes; 70-ft. poles in 9-ft. holes; 75-ft. poles in 9½-ft. holes; 80-ft. poles in 10-ft. holes; 85-ft. poles in 10½-ft. holes, 90-ft. poles in 11-ft. holes. Poles on corners should be set about ½ ft. deeper.

Cross-arms should be placed at such a height on poles that the lowest wire will be, in hot weather, at least 27 ft. and preferably 30 ft. above railroad rails over which the wire crosses. Double cross-arms should be used on each side of a railroad track. Poles along a railroad should be at least 7 feet from the nearest rail with lowest cross-arm at least 22 ft. above rail. Lowest wire crossing a public road should be at least 19 ft. above crown of road. Standard telephone and telegraph cross-arms are 3¼ in.×4¼ in., and so-called telephone cross-arms are 2¾in.×3¾ in.

For telephone drop lines, extending from line or cable to the house, many companies use a rubber-covered and braided copper, and occasionally iron, wire of No. 14 or 16 B. & S. gauge. Usually this wire comes twisted in pairs, but occasionally two single wires are used.

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

(*S. G. McMeen in "Telephony"*)

B. & S. Gauge	Diameter in Mils					Ohms per Cubic Inch		
	Bare	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk
20	31.961	37.861	42.161	34.261	36.161	.646	.533	.801
21	28.462	34.362	38.662	30.762	32.662	.981	.795	1.261
22	25.347	31.247	35.547	27.647	29.547	1.502	1.188	1.956
23	22.571	28.471	32.771	24.871	26.771	2.359	1.772	3.049
24	20.100	26.000	30.300	22.401	24.300	3.582	2.595	4.739
25	17.900	23.800	28.100	20.200	22.100	5.831	3.802	7.489
26	15.940	21.840	26.140	18.240	20.140	6.941	5.552	9.031
27	14.195	20.095	24.395	16.495	18.395	10.814	8.078	13.92
28	12.641	18.541	22.841	14.941	16.841	17.617	11.54	26.86
29	11.257	17.157	21.457	13.557	15.457	25.500	16.47	41.29
30	10.025	15.925	20.225	12.325	14.225	34.800	23.43	62.98
31	8.928	14.828	19.128	11.228	13.128	48.5	32.83	95.70
32	7.950	13.850	18.150	10.250	12.150	73.8	46.19	144.70
33	7.080	12.980	17.280	9.380	11.280	104.5	64.30	217.8
34	6.304	12.204	16.504	8.504	10.504	151.4	70.38	342.1
35	5.614	11.514	15.841	7.914	9.814	202.0	125.9	489.0
36	5.000	10.900	15.200	7.300	9.200	298.8	166.3	721.1
37	4.453	10.353	14.653	6.753	8.653	418	225.6	1062
38	3.965	9.865	14.165	6.265	8.165	567	305.5	1557
39	3.531	9.431	13.731	5.831	7.731	811	409.8	2266
40	3.144	9.044	13.344	5.344	7.344	1113	545.5	3400

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Turns per Linear Inch				Turns per Square Inch			
	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk	Double Silk
20	25.7	22.5	27.70	26.22	660.5	506.3	767.3	687.5
21	28.3	24.5	30.97	29.07	800.9	600.2	959.1	845.0
22	31.0	26.7	34.39	32.11	961.0	712.9	1,182.7	1,031.0
23	34.4	28.97	38.19	35.53	1,183.0	839.2	1,458.5	1,262.4
24	36.9	31.35	42.37	39.14	1,321.6	982.8	1,795.2	1,532.0
25	38.0	33.92	47.02	42.94	1,444.0	1150.8	2,210.9	1,843.8
26	42.0	36.29	52.06	46.81	1,764.0	1317.0	2,710.3	2,191.2
27	48.0	38.95	57.67	51.59	2,304.0	1517.2	3,326.0	2,661.6
28	53.0	41.61	63.36	56.43	2,809.0	1731.0	4,014.5	3,184.5
29	56.5	44.27	70.11	61.56	3,192.3	1959.9	4,915.5	3,789.8
30	59.66	46.93	77.14	66.79	3,559.2	2202.5	5,950.2	4,461.0
31	64.12	49.78	84.64	72.39	4,112.2	2478.0	7,164.0	5,240.0
32	68.60	52.34	92.72	78.19	4,692.5	2739.5	8,597.5	6,114.0
33	73.05	55.10	101.65	84.17	5,333.5	3036.1	10,332	7,085.0
34	77.90	57.57	112.11	90.44	6,068.5	3314.2	12,570	8,179.5
35	82.60	60.04	119.7	96.90	6,773.3	3605.0	14,328	9,389.5
36	87.10	62.51	130.15	103.55	7,586.5	3907.5	16,940	10,722
37	91.87	64.70	140.60	110.20	8,440.0	4186.1	19,770	12,145
38	95.0	66.80	151.05	116.85	9,025.0	4462.2	22,820	13,655
39	100.7	68.80	163.04	122.55	10,140.5	4733.6	26,700	15,018
40	106.0	71.20	177.65	129.20	11,236.0	5069.8	31,559	16,692

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

(*S. G. McMeen in "Telephony"*)

B. & S. Gauge	Diameter in Mils					Ohms per Cubic Inch		
	Bare	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk
20	31.961	37.861	42.161	34.261	36.161	.646	.533	.801
21	28.462	34.362	38.662	30.762	32.662	.981	.795	1.261
22	25.347	31.247	35.547	27.647	29.547	1.502	1.188	1.956
23	22.571	28.471	32.771	24.871	26.771	2.359	1.772	3.049
24	20.100	26.000	30.300	22.401	24.300	3.582	2.595	4.739
25	17.900	23.800	28.100	20.200	22.100	5.831	3.802	7.489
26	15.940	21.840	26.140	18.240	20.140	6.941	5.552	9.031
27	14.195	20.095	24.395	16.495	18.395	10.814	8.078	13.92
28	12.641	18.541	22.841	14.941	16.841	17.617	11.54	26.86
29	11.257	17.157	21.457	13.557	15.457	25.500	16.47	41.29
30	10.025	15.925	20.225	12.325	14.225	34.800	23.43	62.98
31	8.928	14.828	19.128	11.228	13.128	48.5	32.83	95.70
32	7.950	13.850	18.150	10.250	12.150	73.8	46.19	144.70
33	7.080	12.980	17.280	9.380	11.280	104.5	64.30	217.8
34	6.304	12.204	16.504	8.504	10.504	151.4	70.38	342.1
35	5.614	11.514	15.841	7.914	9.814	202.0	125.9	489.0
36	5.000	10.900	15.200	7.300	9.200	298.8	166.3	721.1
37	4.453	10.353	14.653	6.753	8.653	418	225.6	1062
38	3.965	9.865	14.165	6.265	8.165	567	305.5	1557
39	3.531	9.431	13.731	5.831	7.731	811	409.8	2266
40	3.144	9.044	13.344	5.344	7.344	1113	545.5	3400

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Turns per Linear Inch				Turns per Square Inch			
	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk	Double Silk
20	25.7	22.5	27.70	26.22	660.5	506.3	767.3	687.5
21	28.3	24.5	30.97	29.07	800.9	600.2	959.1	845.0
22	31.0	26.7	34.39	32.11	961.0	712.9	1,182.7	1,031.0
23	34.4	28.97	38.19	35.53	1,183.0	839.2	1,458.5	1,262.4
24	36.9	31.35	42.37	39.14	1,321.6	982.8	1,795.2	1,532.0
25	38.0	33.92	47.02	42.94	1,444.0	1150.8	2,210.9	1,843.8
26	42.0	36.29	52.06	46.81	1,764.0	1317.0	2,710.3	2,191.2
27	48.0	38.95	57.67	51.59	2,304.0	1517.2	3,326.0	2,661.6
28	53.0	41.61	63.36	56.43	2,809.0	1731.0	4,014.5	3,184.5
29	56.5	44.27	70.11	61.56	3,192.3	1959.9	4,915.5	3,789.8
30	59.66	46.93	77.14	66.79	3,559.2	2202.5	5,950.2	4,461.0
31	64.12	49.78	84.64	72.39	4,112.2	2478.0	7,164.0	5,240.0
32	68.60	52.34	92.72	78.19	4,692.5	2739.5	8,597.5	6,114.0
33	73.05	55.10	101.65	84.17	5,333.5	3036.1	10,332	7,085.0
34	77.90	57.57	112.11	90.44	6,068.5	3314.2	12,570	8,179.5
35	82.60	60.04	119.7	96.90	6,773.3	3605.0	14,328	9,389.5
36	87.10	62.51	130.15	103.55	7,586.5	3907.5	16,940	10,722
37	91.87	64.70	140.60	110.20	8,440.0	4186.1	19,770	12,145
38	95.0	66.80	151.05	116.85	9,025.0	4462.2	22,820	13,655
39	100.7	68.80	163.04	122.55	10,140.5	4733.6	26,700	15,018
40	106.0	71.20	177.65	129.20	11,236.0	5069.8	31,559	16,692

DIAMETERS OF WIRES OF VARIOUS MATERIALS THAT WILL BE FUSED BY A CURRENT OF GIVEN STRENGTH

(*W. H. Preece, F. R. S.*)

Current Amperes	Diameters in Inches								
	Copper	Aluminum	Platinum	German Silver	Platinoid	Iron	Tin	Tin-Lead Alloy	Lead
1	.0021	.0026	.0033	.0033	.0035	.0047	.0072	.0083	.0081
2	.0034	.0041	.0053	.0053	.0056	.0074	.0113	.0132	.0128
3	.0044	.0054	.007	.0069	.0074	.0097	.0149	.0173	.0168
4	.0053	.0065	.0084	.0084	.0089	.0117	.0181	.021	.0203
5	.0062	.0076	.0098	.0097	.0104	.0136	.021	.0243	.0236
10	.0098	.012	.0155	.0154	.0164	.0216	.0334	.0386	.0375
15	.0129	.0158	.0203	.0202	.0215	.0283	.0437	.0506	.0491
20	.0156	.0191	.0246	.0245	.0261	.0343	.0529	.0613	.0595
25	.0181	.0222	.0286	.0284	.0303	.0398	.0614	.0711	.069
30	.0205	.025	.0323	.032	.0342	.045	.0694	.0803	.0779

35	.0227	.0277	.0358	.0356	.0379	.0498	.0769	.089	.0864
40	.0248	.0303	.0391	.0388	.0414	.0545	.084	.0973	.0944
45	.0268	.0328	.0423	.042	.0448	.0589	.0909	.1052	.1021
50	.0288	.0352	.0454	.045	.048	.0632	.0975	.1129	.1095
60	.0325	.0397	.0513	.0509	.0542	.0714	.1101	.1275	.1237
70	.036	.044	.0568	.0564	.0601	.0791	.122	.1413	.1371
80	.0394	.0481	.0621	.0616	.0657	.0864	.1334	.1544	.1499
90	.0426	.052	.0672	.0667	.0711	.0935	.1443	.1671	.1621
100	.0457	.0558	.072	.0715	.0762	.1003	.1548	.1792	.1739
120	.0516	.063	.0814	.0808	.0861	.1133	.1748	.2024	.1964
140	.0572	.0698	.0902	.0895	.0954	.1255	.1937	.2243	.2176
160	.0625	.0763	.0986	.0978	.1043	.1372	.2118	.2452	.2379
180	.0676	.0826	.1066	.1058	.1128	.1484	.2291	.2652	.2573
200	.0725	.0886	.1144	.1135	.121	.1592	.2457	.2845	.276
225	.0784	.0958	.1237	.1228	.1309	.1722	.2658	.3077	.2986
250	.0841	.1028	.1327	.1317	.1404	.1848	.2851	.3301	.3203
275	.0897	.1095	.1414	.1404	.1497	.1969	.3038	.3518	.3417
300	.095	.1161	.1498	.1487	.1586	.2086	.322	.3728	.3617

PRIMARY BATTERIES

The primary, voltaic, or galvanic cell, as it is variously called, is an apparatus for converting chemical energy directly into electrical energy. A primary cell consists of two conducting elements immersed in a solution that acts chemically on one element only, or on one more than on the other. One of the elements, usually zinc, is called the *anode* and the other, for which various substances may be used, is called the *cathode*. The chemical action incident to the generation of the current consumes the zinc and in the simplest cell liberates hydrogen at the cathode, which tends to adhere to the surface and reduces the E. M. F. of the cell. To overcome this effect of polarization, a depolarizer is often used, which will dispose of the hydrogen as fast as it is formed. Depolarizers may be solid or liquid. When solid, the material is usually placed around the cathode, as in the case of the Leclanché cell. When the depolarizer is liquid, it is sometimes prevented from mixing with the electrolyte by a porous partition; or, if their specific gravities differ sufficiently, they may be kept separate by placing the lighter over the heavier one in the same jar. A battery is generally considered to be a combination of a number of separate voltaic cells properly joined together; the two terms, battery and cell, are, however, used rather indiscriminately. The table on page 160 gives the elements, depolarizers, and the E. M. F. in volts for various cells.

Care of Leclanché Cells.—The amount of sal ammoniac required to charge a Leclanché cell will depend on the amount of water required to fill the jar to the proper height; usually from 4 to 6 oz. is sufficient. It is best never to put in more than will dissolve; 3 oz. of sal ammoniac to a pint of pure water is the best proportion. When the solution is extra dense at the bottom, the top portion of the zinc is eaten away more rapidly than the bottom. There should never be crystals or undissolved salts of any kind in the bottom or around the lower ends of either electrode; all the crystals should be removed by dissolving them in water or scraping them off. The jars usually have printed directions (which should be followed) pasted upon them for setting up the cells and marks upon the jar to show how much water is required. Where porous cups are used, the liquid should come to within about 1½ in. of the top of the porous cup. Cells with porous cups are not usually in good condition for use until 10 or 12 hr. after setting up, because time is required for the solution to soak through the porous cup. Where there are one or more vent holes at the top, the action may be hastened by pouring some of the sal-ammoniac solution into the porous cup through the vent holes; but the top of the cup should be thoroughly wiped dry to prevent the corrosion and formation of salts around the binding post. If the solution evaporates, pure water should be added from time to time to keep the level up to the proper height.

Directions for Setting up the Crowfoot Gravity Cell. Proceed as follows: Unfold the copper strip so as to form a star and place it in the bottom of the jar. The point where the copper connecting wire is riveted to the copper electrode should be near the bottom of the cell, and the insulated covering on the wire should come close to the riveted joint. Suspend the zinc about 4 in. above the copper by hooking the lug on the side of the jar. The method of suspending other forms of zincs will be evident from their construction. Pour sufficient clean water into the jar to cover the zinc and drop about 3 lb. of copper sulphate in a cell to be used for heavy, continuous work—for instance, for the local-circuit batteries that run telegraph sounders; for the batteries in a main-line telegraph circuit, a smaller charge will be sufficient, and, in quadruplex-telegraph circuits, the so-called "long" end of the battery will need less bluestone than the "short" end, because the former is not worked as continuously as the latter. The internal resistance may be reduced and the battery made immediately available by drawing about ½ pt. of solution of sulphate of zinc from a battery already in use, and pouring it gently into the jar; or, when this cannot be done, by pouring carefully on top of the solution in the jar 4 or 5 oz. of pulverized sulphate of zinc previously dissolved in a cup of water.

PRIMARY CELLS

Name	Anode	Electrolyte	Cathode	Depolarizer	E. M. F. Volts	Remarks
Bichromate Grenet, or Poggendorff	Zinc	Sulphuric acid, 4 parts; potassium, or sodium bichromate, 3 parts; water, 18 parts; *or* Chromic acid, 6 oz.; water, 5½ pt.; sulphuric acid, ½ pt.	Carbon	Potassium bichromate; *or* sodium bichromate; *or* chromic acid	1.9 to 2.1	Suitable for closed-circuit work. Electrodes should be removed from solution when not in use
Fuller	Zinc; in porous cup containing 6 oz. of zinc sulphate to 1 pint of water and a few drops of mercury	Sulphuric acid, 17 oz.; water, 56 oz.; sodium bichromate, 6 oz.; placed in jar containing carbon element	Carbon; placed in jar containing electrolyte	Sodium bichromate	2.14	Suitable for closed- or open-circuit work. Will furnish current up to .6 ampere. Elements need not be removed from solution when cell is not in use

Bunsen	Zinc; in jar containing sulphuric-acid solution	Sulphuric acid, 1 part; water, 20 parts; specific gravity of solution should be about 1.09	Carbon; placed in porous cup containing depolarizer	Nitric acid, specific gravity about 1.33 to 1.4	1.89	Suitable for closed-circuit work. Gives off disagreeable fumes. Elements should be removed from solution when not in use
Partz	Zinc; hung from the lid of the cell	Sodium chloride; *or* Magnesium sulphate (being lighter, this solution floats on top of the depolarizer)	Carbon; plate slightly raised from bottom of jar	Bichromate solution; *or* sulpho-chromic salt solution	1.9 to 2	Solutions kept apart by the different specific gravities. Resistance: with sodium chloride about .5 ohm; with magnesium sulphate, about 1 ohm

TABLE—(*Continued*)

Name	Anode	Electrolyte	Cathode	Depolarizer	E. M. F. Volts	Remarks
Pabst	Wrought Iron	Ferric chloride	Carbon		.78	Non-polarizing electrolyte
Daniell	Zinc; in porous cup containing electrolyte	Zinc sulphate	Copper; surrounded by depolarizer	Saturated copper-sulphate solution and crystals	1.07	For closed-circuit work. Electrolyte and depolarizer kept apart by porous cup
Daniell, gravity, or Crowfoot	Zinc; held in top part of jar	Zinc sulphate; specific gravity not to exceed 1.15; being lighter, floats on top of copper-sulphate solution	Copper; sheet star-shaped, placed in bottom of jar surrounded by depolarizer	Saturated copper-sulphate solution and crystals. 3 pounds of copper-sulphate crystals for 1 cell	1.07	Solutions kept apart by their different specific gravities. For closed-circuit work only. Most economic output is $\frac{1}{4}$ ampere. Average resistance, about 3 ohms

Leclanché and some dry cells.	Zinc	Ammonium chloride (sal ammoniac) 3 oz. to 1 pt. water	Carbon; usually placed with depolarizer in porous cup; *or* Carbon forms porous cup containing depolarizer	Dioxide of manganese, sometimes mixed with broken coke	1.3 to 1.7	Suitable only for open-circuit work. Internal resistance, from .4 to 4 ohms
Edison-Lalande	Zinc; plate held between two cathode plates	Caustic potash. 15 per cent. of silicate of soda said to nearly double capacity of cell.	Molded plates of cupric oxide; held in copper frames	Cupric oxide	.7	Electrolyte must be covered with mineral oil. Suitable for closed-circuit work. Internal resistance very low

TABLE—(*Continued*)

Name	Anode	Electrolyte	Cathode	Depolarizer	E. M. F. Volts	Remarks
Harrison	Zinc; must be amalgamated	Dilute sulphuric acid, or bisulphate of potassium, or sodium; must be pure to avoid local action	Lead	Peroxide of lead; compressed around a conductor of hard lead	2.5	Local action is very likely to cause trouble
Latimer Clark	Zinc	Zinc sulphate, 2 parts; water, 1 part. Saturated at 30° C.	Mercury	Paste of mercurous sulphate and zinc sulphate	1.4333 at 15° C., or as furnished with cell	E. M. F. at $t°$ C given by formula: $E_t = E_{15} - .00119\,(t-15°) - .000007\,(t-15°)^2$

Carhart-Clark	Zinc	Zinc-sulphate solution saturated at 0° C.	Mercury	Paste of mercurous sulphate and sodium sulphate	1.440 at 15° C., or as furnished with cell	E. M. F. at t° C given by formula: $E_t = E_{15} - .00056 \times (t - 15°)$.
Weston	Cadmium; amalgam of cadmium and mercury	Cadmium sulphate saturated, at all temperatures, by presence of excess of cadmium-sulphate	Mercury	Mercurous sulphate	1.0187 at 20° C., or as furnished with cell	E. M. F. at t° C given by formula: $E_t = E_{20} - .000038(t - 20°) - .00000065 \times (t - 20°)^2$ Temperature coefficient is practically negligible

TABLE—(*Continued*)

Name	Anode	Electrolyte	Cathode	Depolarizer	E. M. F. Volts	Remarks
Gordon	Zinc; in form of hollow cylinder surrounding cathode	Caustic soda	Perforated tinned-iron cylinder	Flaky cupric oxide; held in perforated tinned-iron cylinder	.7	Suitable for open- or closed-circuit work. Very low internal resistance, gives a relatively large current continuously. Solution covered with mineral oil
Chloride of silver	Zinc	Ammonium chloride .8 oz. (avoir.) to 1 qt. water *or* Zinc chloride or sodium chloride	Silver wire or plate	Chloride of silver covering cathode	1.03; zinc chloride, 1.02; sodium chloride, .97	Cells may be made very small, and are used mostly with portable testing sets

If there is no hurry for the cells, do not put in the zincs until the solutions have had time to settle to their normal conditions, which will require at least 24 hr. This prevents or reduces the formation of a black deposit on the zinc. When there is much of this black deposit, remove the zinc and brush or scrape it off. If no zinc sulphate is added in setting up the cell, it will be necessary to short-circuit the cell for some time (24 hr. will not be too long) before it will be in good condition.

Open- and Closed-Circuit Cells.—For practical purposes, primary cells may be roughly divided into two general classes: First, those capable of furnishing, in a circuit of moderate resistance, a reasonably uniform current for quite a long time; and, second, those capable of supplying a current only intermittently, and then only for a few seconds each time, but able to stand for long intervals on open circuit without consumption of materials due to local action. The former are called *closed-circuit cells*, and the latter *open-circuit cells*. Some closed-circuit cells may be used to supply intermittent currents—that is, they may be used on circuits that are open the greater part of the time—but open-circuit cells should never be used where a continuous current is required—that is, on circuits that are closed the greater part of the time. Some closed-circuit cells deteriorate if left on open circuit too much of the time, and hence they are not suitable for intermittent work, where only small currents are required and the inactive periods are long. Leclanché and dry cells are the best examples of open-circuit cells;. and Edison-Lalande, Gordon, gravity Daniell, and bichromate cells are the most extensively used closed-circuit cells. For intermittent work—for instance, for electric bells, and some types of telephones that are not in constant use, or else are not in use for long periods at any one time—good open-circuit cells, such as the Leclanché and dry cells, are the most satisfactory. They are not, however, suitable where a continuous current is required, nor even for intermittent work, unless the idle periods are sufficiently long and frequent to allow the cells time to recuperate.

INTERNAL RESISTANCE AND CURRENT CALCULATIONS

If a number s of similar cells, each having an internal resistance of b ohms, are connected in series, the total internal resistance B of the battery thus formed is equal to $s \times b$. The total electromotive force of a number of cells connected in series is equal to the sum of the electromotive forces of all the cells. If a number p of similar cells, each having an internal resistance of b ohms, are arranged in parallel, the total internal resistance B of the battery thus formed is equal to $\frac{b}{p}$. If a number of similar cells are connected in parallel, the electromotive force of the battery is equal to that of one cell. If a number $p \times s$ of similar cells are arranged in p parallel rows, with s cells in series in each row, the total internal resistance B of the battery thus formed is equal to $\frac{s \times b}{p}$, and the total electromotive force is equal to $s \times e$; b is the internal resistance and e the electromotive force of one cell. If $p \times s$ similar cells are arranged in p parallel rows, with s cells in each row, each cell having an electromotive force of e volts and an internal resistance of b ohms, the current C that the battery will produce through an external resistance of R ohms is

$$C = \frac{s \times e}{\frac{s \times b}{p} + R}$$

Whenever the external resistance R is very small and negligible compared with the internal resistance of the battery, the number of cells in parallel must be increased in order to increase the current. Whenever the external resistance is very large compared with the internal resistance of the battery, the number of cells in series must be increased in order to increase the current.

The maximum current is obtained through a given external resistance R from a given number of cells, when the grouping of the cells is such that the internal resistance of the battery can be made equal to the external resistance.

That is, so choose s and p that $R = \frac{s \times b}{p}$. The efficiency of such an arrangement is only 50%, because half the energy is expended in the internal and half in the external circuit.

To determine the least number of cells N that will give a certain (maximum) current C through an external resistance R, when each cell has an internal resistance of b ohms and electromotive force of e volts, use the formula

$$N = \frac{4 \times C^2 \times R \times b}{e^2}$$

The number of parallel rows $= p = \sqrt{\frac{N \times b}{R}}$, and the number of cells in series in each row $= s = \sqrt{\frac{N \times R}{b}}$.

The most economical arrangement, so far as the consumption of battery material is concerned, is that in which the internal resistance of the battery is very small compared with the external resistance This would generally require such a large number of cells that their cost and the space occupied by them would be unnecessarily large.

In telegraph circuits, it has been quite customary to consider the best arrangement as that in which the total resistance of all relays never exceeded the total resistance of the line and internal resistance of the battery. When cells, each having an internal resistance of b ohms and an electromotive force of e volts, are arranged in series, the number of cells s required to produce a current C through a given external resistance R is given by the formula

$$s = \frac{C \times R}{e - b \times C}$$

STORAGE BATTERIES

Storage batteries or accumulators are composed of specially prepared lead plates, placed side by side, in glass or rubber jars or wooden boxes lined with hard rubber or lead, alternate plates being connected together, thus forming two sets, which constitute the positive and negative elements. The plates are entirely submerged (½ in. below the surface) in a solution of pure sulphuric acid made from sulphur or brimstone and pure water, both free especially from such impurities as iron, arsenic, nitric acid, or hydrochloric acid. The proper proportion is 1 of acid to 5 of water by volume, which should give at 60° F. a specific gravity of 1.20 to 1.24, as indicated by an ordinary hydrometer or 25° on a hydrometer having a Baumé scale, when the cells are fully charged. Cells should never be allowed to stand over 2 hr. after the electrolyte has been put in before they are charged. The charging E. M. F. is about 2.5 volts per cell, and a cell should never be discharged below 1.7 volts. To make up for the evaporation of water, add pure water occasionally, and to make up for the acid lost in the spray, acid may have to be added every 1 or 2 yr.

The proper rate of charging is usually the same as the 8 hr. rate of discharge specified by the manufacturers. Be sure that the direction of current through the cell in charging is from the positive, or brown, plate to the negative, or gray, one. The charging should be continued until complete according to the signs to be given presently. While it is uneconomical and detrimental to the life of the plates to repeatedly overcharge the cells, nevertheless it is advisable to overcharge the batteries slightly, about once a week in order to thoroughly stir up the electrolyte and also to correct any inequality in the voltage of the cells that may have developed. At the end of the first charge, it is advisable to discharge the battery about one-half, and then immediately recharge it. Repeat this operation two or three times to put the battery in condition for regular use.

Indications of a Complete Charge.—A complete charge should exceed the previous discharge, in ampere-hours, from 12 to 15%. The principal indications of a complete charge are: (1) The voltage and specific gravity reach a maximum value that is not necessarily fixed; for example, the voltage at the end of a charge may be from 2.4 to 2.7. (2) The amount of gas given off at the plates also increases. (3) The positive plates become a dark brown, and the negatives a light gray. (4) With all the cells in normal condition, with pure electrolyte, and no material lodged between the plates or sediment touching them at the bottom, the maximum voltage and specific gravity are reached when, with the charging current constant at the normal rate, there is no further increase in either during a period from $\frac{1}{4}$ to $\frac{1}{2}$ hr. The voltage at the end of a charge depends on the age of the plates and on the temperature of the electrolyte. As the age increases, the full-charge voltage may drop from 2.5, when new, to 2.4 volts. With charging rates lower than normal, the full-charge voltage will be approximately .05 volt less for each 25% decrease in the rate. If the temperature is increased above normal, the final charging voltage is noticeably lowered, and vice versa, irrespective of the age of the plates. The final voltage per cell when charged at the maximum rate, which should be done only in cases of emergency, will be about .05 volt higher than if charged at normal rate. It is understood that all voltage readings mentioned are taken with the current flowing; readings taken with the battery on open circuit are of little value and are frequently misleading.

After the completion of a charge and when the current is off, the voltage per cell will drop to about 2.15 volts and then to 2 volts or slightly less, when the discharge is started. Repeated heavy overdischarges are almost sure to injure the cells if maintained for a considerable time. Batteries should be discharged at about the normal rate. A battery should never be discharged below 1.7 volts per cell; and in ordinary service it is advisable not to ever discharge below 1.75 volts per cell. The change in specific gravity, which is even a more satisfactory guide, depends on the quantity of solution compared with the bulk of the plates in a cell. If a cell contains the full number of plates, the change in specific gravity is about 35 points; with fewer plates in the same-sized vessel, the range will be lessened. Also, at higher rates of discharge than normal, the drop in specific gravity will be less because of the smaller number of ampere-hours discharged. As the discharging progresses, the positive plates become somewhat lighter and the negatives darker, so that the color of the plates is a rough indication of the amount of discharge. A battery should never be allowed to stand discharged for a long time.

Each cell should be examined regularly at least once a month for voltage and, by looking between all the plates, for material lodged there; and near the end of each charge to see that all cells are gassing equally. If any cell gives a voltage reading lower than normal and does not gas freely at the end of the charge, examine it for material lodged between the plates or for an accumulation in the bottom of mud that reaches the plates. Readings of voltage and specific gravity should be noted for each cell at the end of a prolonged charge, while the current is still flowing. Recording voltmeters and wattmeters are very useful in a storage-battery circuit, as they show just what the battery has been doing.

A cell that is lower than normal will require more than the usual charge to restore it to a proper condition after the cause of the trouble has been removed. Care must be taken to remove sediment in cells before it reaches the bottom of any plate. When a battery is used occasionally only, it should be given a weekly freshening charge. If the use of a battery is to be discontinued for a considerable time, give it a complete charge, draw off the electrolyte, refill immediately with water, discharge at normal rate to 1 volt per cell, and draw off all the water. To use again, put in the electrolyte, charge at normal rate, taking care that the current flows through the battery in the proper direction, as the polarity of the charging source may have changed in the meantime, until completely charged, which usually requires 25 to 30 hr. In case white, insoluble sulphate appears on the plates, give the battery a long-continued charge at a rate somewhat below the normal 8-hr. rate until the cells give all signs of a full charge and the plates have resumed their normal color. In badly sulphated cells, the color of the positive plates becomes lighter than normal and the negatives considerably darker. The most frequent causes of sulphating are overdischarging (below 1.7 volts) frequently, too strong an electrolyte, and allowing the battery to stand discharged for too long a time.

Charging Connections.—A storage battery may be charged from a 110-volt, direct-current circuit as shown at (*a*) in

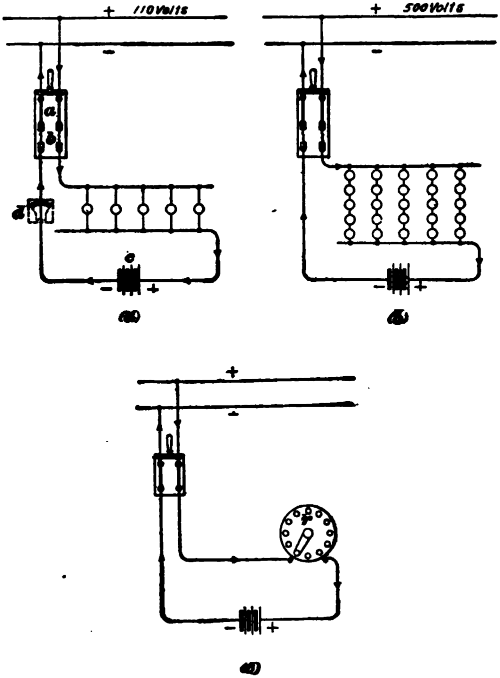


FIG. 1

Fig. 1, in which *d* represents an ammeter, *c* the storage battery, and the circles 110-volt incandescent lamps. Use as many 32-candlepower or twice as many 16-candlepower carbon-filament lamps as there are amperes in the normal charging rate. Fig. 1 (*b*) shows a similar arrangement for charging the same battery from a 500-volt circuit. There are five 110-volt lamps in series in each row, there being as many rows of 32-candlepower, or twice as many rows of 16-candlepower, carbon-filament lamps as amperes are required. Fig. 1 (*c*) shows an arrangement for charging where an adjustable rheostat *r* is used. The resistance required in the rheostat is $R = \frac{E-2N}{I}$, in which E is the line E. M. F., N is the number of cells in series, and I is the charging current.

Fig. 2 shows about the simplest arrangement for charging from a dynamo A, having a rheostat *f* in series with its shunt field. It is desirable to have an automatic underload- and overload-circuit breaker at K, where the battery is not watched constantly. Fig. 3 shows a simple switchboard where the battery or charging mains may be used separately or in parallel to supply the current required. The voltmeter V may be connected by switch *p* across either the dynamo or battery *b*; *r* is the handle of the rheostat in series with the shunt field of the dynamo. When the battery is being charged, the switch *k* is open and *s* closed. When the battery alone is furnishing current to the lines, *s* is open

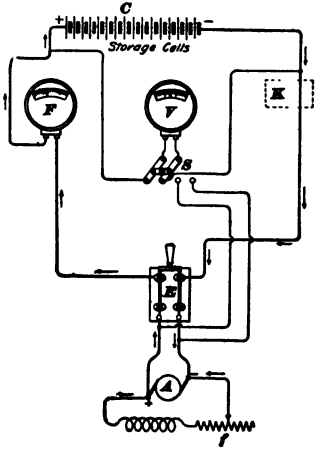


FIG. 2

and *k* closed. If both dynamo and battery are to furnish current to the lines at the same time, both switches are closed.

The intensity of the hum sometimes produced in telephones when the battery is being charged while supplying current to the circuits in central-energy telephone exchanges may be eliminated or at least reduced by connecting choke coils *R*, *R'* and a condenser *C*, as shown in Fig. 4. Each coil may consist of 20 turns of No. 4 B. & S. copper wire wound on a straight core of iron wire 8 or 10 in. long.

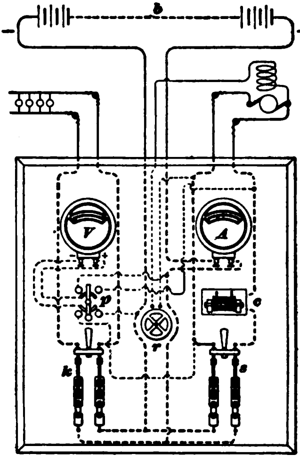


Fig. 3

It is most economical to have only one storage battery in a telephone exchange and to charge it sufficiently during the busiest part of the day to carry the night load alone. It is advisable, especially in smaller exchanges, to install a

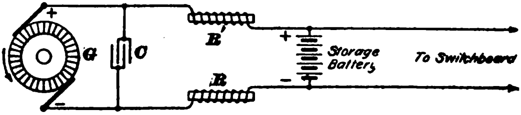


Fig. 4

battery large enough to carry the load for 36 and even 48 hr. If two batteries are used, each should be kept between three-fourths and full charge for best efficiency. The average efficiency is between 75 and 80% in telephone systems.

Ampere-Hour Capacity.—The number of cells required in a battery is usually considered to be one-half the voltage required; more accurately, the number required is the voltage required divided by 1.75. The ampere-hour capacity may be determined with the aid of the following data: The current required for each subscriber's transmitter is from .05 to .1 ampere, the average length of conversation 3 min., and the average number of connections per subscriber per day is from 5 to 15. The current required by each operator's transmitter is about .12 ampere throughout the day. Line and supervisory lamps require about .06 ampere for 6 sec. for each call. Cut-off relays require about .05 ampere for 3 min. for each call. Pilot lamps require about .06 ampere for 7 hr. each day. The current required for each conversation varies from .08 to .04 ampere in the different systems.

GENERAL DATA ON STORAGE CELLS

In order to give an idea as to the size capacity, weight, etc. of storage cells, the following three tables are given. In each table, the first cell of a given type is the smallest size made in that type, and the last given is the largest. The number of plates per cell is always an odd number, because there is always one less plate in the group of positives than in the group of negatives. For example, a 13-plate cell would be made up of 6 positives and 7 negatives. The capacities of cells with a number of plates different from that shown in the tables can be easily calculated. For example, in the first table, the 9-plate, type F, cell has an 8-hr. capacity of 40 amperes and a 15-plate cell of the same type has a capacity of 70 amperes. The addition of 6 plates or 3 pair of plates increases the capacity 30 amperes; hence, the capacity per pair of plates is 10 amperes. A 27-plate cell has 13 pair; hence, its capacity is $13 \times 10 = 130$ amperes for 8 hr. In making estimates of the room occupied by a given battery, about 1¼ in. clearance should be allowed between glass jars, 2½ in. between metal tanks, and 2 in. between wooden tanks.

GENERAL DATA ON CHLORIDE ACCUMULATORS

Type of Cell	Size of Plates Inches	Number of Plates	Normal Charge Rate Amperes	8-Hr. Discharge Rate	Weight of Cell Complete With Acid, Glass Jar Pounds	Weight of Cell Complete With Acid, Metal Tank Pounds	Weight of Cell Complete, Lead-Lined Tank Pounds	Outside Dimensions of Glass Jars Inches			Outside Dimensions of Lead-Lined Tanks Inches		
								Width	Length	Height	Width	Length	Height
C	4[illegible] × 4	3	1[illegible]	1[illegible]	11			3[illegible]	5[illegible]	7[illegible]			
C	4[illegible] × 4	5	2[illegible]	2[illegible]	15.1			4[illegible]	5[illegible]	7[illegible]			
C	4[illegible] × 4	7	3[illegible]	3[illegible]	19.2			5[illegible]	5[illegible]	7[illegible]			
D	6 × 6	3	2½	2½	20			3[illegible]	7[illegible]	9[illegible]			
D	6 × 6	5	5	5	28			4[illegible]	7[illegible]	9[illegible]			
D	6 × 6	7	7½	7½	38			6[illegible]	7[illegible]	9[illegible]			
D	6 × 6	13	15	15	63			11	8[illegible]	9[illegible]			
E	7[illegible] × 7[illegible]	5	10	10	49	85		5[illegible]	9[illegible]	11[illegible]			
E	7[illegible] × 7[illegible]	9	20	20	74	124		8	9[illegible]	11[illegible]			
E	7[illegible] × 7[illegible]	15	35	35	112	180		11	9[illegible]	11[illegible]			
F	11 × 10[illegible]	9	40	40	174.5	256	250	9	12[illegible]	17	13[illegible]	15	20[illegible]
F	11 × 10[illegible]	15	70	70	260	377	372	12	12[illegible]	17	18[illegible]	15	20[illegible]
F	11 × 10[illegible]	27	130	130		618	615				28[illegible]	15	20[illegible]
G	15[illegible] × 15[illegible]	11	100	100			568				15[illegible]	19[illegible]	26
G	15[illegible] × 15[illegible]	25	240	240			1,165				27[illegible]	20[illegible]	26[illegible]
G	15[illegible] × 15[illegible]	55	540	540			2,475				53[illegible]	21[illegible]	27[illegible]
G	15[illegible] × 15[illegible]	75	740	740			3,300				69[illegible]	21[illegible]	27[illegible]
H	30[illegible] × 15[illegible]	21	400	400			1,967				25[illegible]	21[illegible]	48[illegible]
H	30[illegible] × 15[illegible]	41	800	800			3,538				41[illegible]	21[illegible]	49[illegible]
H	30[illegible] × 15[illegible]	75	1,480	1,480			6,215				69[illegible]	21[illegible]	49[illegible]

Weights of type C cells complete with electrolyte in rubber jars are: C–3, 6[illegible] lb.; C–5, 10 lb.; C–7, 13

GENERAL DATA ON GOULD STORAGE CELLS

Type of Cell	Size of Plates Inches	Number of Plates	Normal Charge Rate Amperes	8-Hr. Discharge Rate Amperes	Weight of Cell Complete With Acid, Rubber Jar Pounds	Weight of Cell Complete With Acid, Lead-Lined Tank Pounds	Outside Dimensions of Rubber Jar Inches			Outside Dimensions of Glass Jar Inches			Outside Dimensions of Lead-Lined Tank Inches		
							Width	Length	Height	Width	Length	Height	Width	Length	Height
K	3 × 3	3	.75	.63	4.		2¼	3¾	5½	3	4	6½			
K	3 × 3	5	1.5	1.25	7.		3⅞	3¾	5½	5¼	4½	6½			
L	4 × 4	3	1.5	1.25	6.5		2¼	4¾	6½	2½	5	7			
L	4 × 4	7	4.5	3.75	16.5		5½	4¾	6½	7½	5½	7			
M	6 × 6	3	3	2.5	14.0		2¾	6¾	8¾	3¾	8	9½			
M	6 × 6	7	9	7.5	35.0		5¾	6¾	8¾	7¾	7¾	9½			
M	6 × 6	11	15	12.5	55.5		8⅞	6¾	8¾	11⅛	8¾	9½			
N	7¾ × 7¾	5	10	10	39.		4	8½	10½	5¾	9½	12½			
N	7¾ × 7¾	9	20	20	73.		7½	8½	10½	9⅞	9¾	12½			
N	7¾ × 7¾	13	30	30	107.		12¾	8½	10½	15½	10	12½			
O	10½ × 10½	5	20	20	112.5					6½	12¾	15½			
O	10½ × 10½	11	50	50	208.	285							12¾	14¾	20¾
O	10½ × 10½	17	80	80		420							18 1/16	14¾	20¾
S	15½ × 15½	7	60	60		370							9	20¾	28¾
S	15½ × 15½	19	180	180		934							21¼	20¾	29
S	15½ × 15½	35	340	340		1,654							36¾	20¾	29
S	15½ × 15½	67	660	660		3,178							68¾	21¾	29¾
T	15½ × 31	11	400	400		1,950							23 1/16	21¾	28½
T	15½ × 31	53	1,040	1,040		4,850							55 1/16	22¾	49
T	15½ × 31	83	1,640	1,640		7,475							84	22¾	49

GENERAL DATA ON ELECTRIC VEHICLE CELLS

Type of Cell	Size of *Plates* Inches	Number of Plates	Discharge for 4-Hr. Amperes	Weight of Cell Complete With Acid Pounds	Outside Dimensions of Hard-Rubber Jar Inches		
					Width	Length	Height
Exide M V	$5\frac{3}{4} \times 8\frac{5}{8}$	7	21	22	$2\frac{3}{4}$	$6\frac{1}{8}$	$12\frac{3}{8}$
Exide M V	$5\frac{3}{4} \times 8\frac{5}{8}$	9	28	$28\frac{3}{4}$	$3\frac{1}{2}$	$6\frac{1}{8}$	$12\frac{3}{8}$
Exide M V	$5\frac{3}{4} \times 8\frac{5}{8}$	11	35	$35\frac{1}{4}$	$4\frac{1}{4}$	$6\frac{1}{8}$	$12\frac{3}{8}$
Exide M V	$5\frac{3}{4} \times 8\frac{5}{8}$	15	49	$46\frac{3}{4}$	$5\frac{3}{4}$	$6\frac{1}{8}$	$12\frac{3}{8}$
Exide M V	$5\frac{3}{4} \times 8\frac{5}{8}$	19	63	$60\frac{1}{4}$	$7\frac{1}{4}$	$6\frac{1}{8}$	$12\frac{3}{8}$
Exide P V	$4\frac{11}{16} \times 8\frac{5}{8}$	5	12	$14\frac{1}{4}$	2	$5\frac{5}{16}$	$11\frac{7}{8}$
Exide P V	$4\frac{11}{16} \times 8\frac{5}{8}$	7	18	$19\frac{1}{2}$	$2\frac{3}{4}$	$5\frac{5}{16}$	$11\frac{7}{8}$
Exide P V	$4\frac{11}{16} \times 8\frac{5}{8}$	11	30	$29\frac{3}{4}$	$4\frac{1}{4}$	$5\frac{5}{16}$	$11\frac{7}{8}$
Gould T P	$5\frac{3}{4} \times 8\frac{3}{4}$	7	21	$24\frac{1}{2}$	$6\frac{1}{8}$	$2\frac{3}{4}$	12
Gould T P	$5\frac{3}{4} \times 8\frac{3}{4}$	9	28	$31\frac{1}{2}$	$6\frac{1}{8}$	$3\frac{1}{2}$	12
Gould T P	$5\frac{3}{4} \times 8\frac{3}{4}$	11	35	$38\frac{1}{2}$	$6\frac{1}{8}$	$4\frac{1}{4}$	12
Gould T P	$5\frac{3}{4} \times 8\frac{3}{4}$	13	42	$45\frac{1}{2}$	$6\frac{1}{8}$	5	12

ELECTRICAL MEASUREMENTS

MEASUREMENT OF RESISTANCE

WHEATSTONE BRIDGE

The *Wheatstone bridge* is used more than any other one method for the measurement of resistance, and is suitable for the measurement of all resistances except those very large or very small. In Fig. 1 is shown the theoretical diagram of the Wheatstone bridge. It can be shown that if the resistance *ac* : resistance *ad* = the resistance *cb* : resistance *db*, then there is no difference of potential between the points *c*, *d*, and consequently no current will flow through the galvanometer *G*. By arranging four resistances in a circuit of this kind, and varying the resistance of the three arms *ac*, *ad*, and *db* until the galvanometer gives no deflection, the unknown resistance

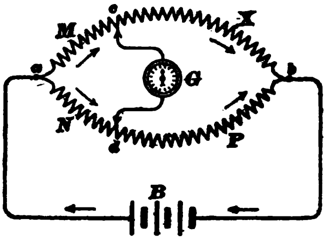


FIG. 1

$$X = \frac{M \times P}{N}$$

In Fig. 2 is shown a form of portable testing set, including a Wheatstone bridge, four dry cells, a galvanometer *G*, a battery key *Ba*, a galvanometer key *Ga*, and an arrangement of brass block *A*, *R*, *B*, *X* for reversing the position of the balance arms *aA* and *aB*, with reference to the rheostat arm *dikb* and the resistance *X* that is to be measured. Being connected together by a short, heavy wire *f*, the two blocks *a*, *a* are really one and the same point. With one plug between A and X and another between R and B, which is the arrangement for measuring a resistance X not over 6,100 ohms, $A : B = X : R$. With one plug between A and R and another between B and X, which is the arrangement for measuring a resistance X not under 6,100 ohms,

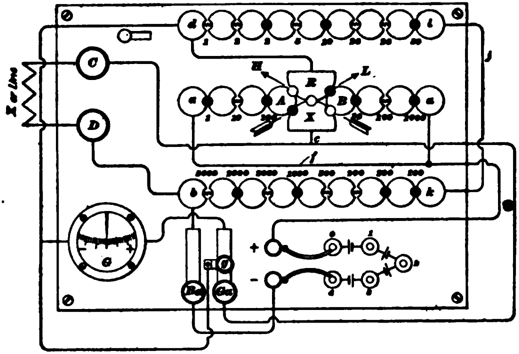


FIG. 2

$A : B = R : X$. A stands for the resistance in the arm aA, B for the resistance in the arm aB, and R for the resistance in the arm *dikb*.

In using a Wheatstone bridge, the battery circuit is first closed by pressing the battery key *Ba* and then the galvanometer key *Ga*, which, in this case, first opens a short circuit around the galvanometer, and almost immediately connects the galvanometer from d to C. If the galvanometer deflects, both keys are released, the known resistances are readjusted, and the keys again closed in the same order as before. This operation is repeated until no deflection can be detected; then the unknown resistance can be calculated from the known resistances in the three arms of the bridge.

RATIO ARM VALUES FOR WHEATSTONE BRIDGE

Resistance	Make A Equal to	Make B Equal to	Place Plugs Between
Below 1.5 ohms	1	100	A,X and R B
Between 1.5 and 11 ohms	1	100	A,X and $R.B$
Between 11 and 78 ohms	10	100	A,X and R B
Between 78 and 1.100 ohms	100	1,000	A,X and $R.B$
Between 1,100 and 6.100 ohms	100	100	A,X and R B or A,R and B,X
Between 6,100 and 110,000 ohms	100	1,000	$A.R$ and B X
Between 110.000 and 1,110,000 ohms	10	100	A,R and $B.X$
Between 1,110,000 and 11.110,000 ohms	1	1,000	A,R and B,X

The table on page 182 shows the values of A and B to be chosen when measuring any resistance within the range of the set, and is applicable to almost any Wheatstone bridge having the same resistances in the rheostat and balance arms.

SLIDE-WIRE BRIDGE

For measuring low resistances, a modification of the Wheatstone bridge, known as the *slide-wire bridge*, is used; a diagram of it is shown in Fig. 3. The pointer n is moved along a German-silver wire ab of uniform resistance until a point is found where the galvanometer gives no deflection. The unknown resistance X can then be calculated from the formula

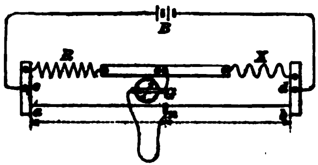


FIG. 3

$$X = R\frac{\text{distance } nb}{\text{distance } an}$$

The *resistance of electrolytes* may be measured with the slide-wire bridge by using a telephone receiver in place of the galvanometer G, and some source of alternating or rapidly interrupted current in place of the battery B.

MEASUREMENT OF HIGH, OR INSULATION, RESISTANCE

Wheatstone-Bridge Method.—A *high*, or *insulation*, *resistance* may be measured in the ordinary manner by the Wheatstone bridge, if it does not exceed about 2,000,000 ohms. Another way is to measure a resistance, as high as can be accurately determined with the bridge and call it y ohms. Then, connect this resistance y in parallel with the high, or insulation, resistance and measure the joint resistance of the two in parallel, and call this z ohms. Then, if x is the unknown high, or insulation, resistance.

$$x = \frac{y \times z}{y - z}$$

Direct-Deflection Method.—Complete connections for measuring insulation resistance by the direct-deflection method are shown in Fig. 4. In this figure, *G* represents a galvanometer sufficiently sensitive for the purpose; *S*, an Ayrton, or universal, shunt; *A* and *D*, reversing switches; and *R*, a known high resistance, at least $\frac{1}{10}$ megohm, but sometimes as high as 1 megohm is required. Enough cells must be used at *B* to give a deflection of the galvanometer when connected with the insulation resistance to be measured. The plug is first placed at *n*, so as to connect the battery and galvanometer in series with the known resistance *R*,

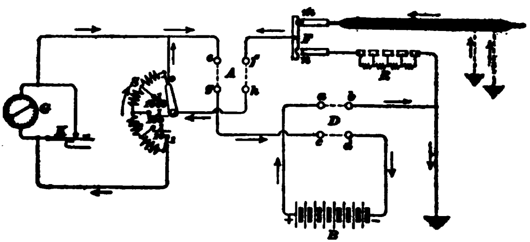


Fig. 4

the reversing switches *A* and *D* being closed and the shunt *S* adjusted so that a readable deflection of the galvanometer will probably be obtained. The key *K* is cautiously depressed. If the galvanometer gives a readable deflection, the deflection is noted; otherwise, the shunt is readjusted and the observation repeated until a good deflection is obtained. The plug is then removed from *n* and placed at *m*, and the deflection of the galvanometer obtained as before. Where the insulation resistance of long cables is measured in this manner, the deflection is likely to be large at first and then decrease in value. As it is impracticable to wait in many cases until a steady deflection is obtained, the usual custom is to observe the deflection at exactly 1 minute after the circuit is closed. This is usually stated thus: insulation resistance after 1 minute's electrification, 400 megohms.

The unknown resistance X, expressed in megohms, is given with sufficient accuracy for most purposes by the formula

$$X = \frac{Rmd}{m'd'},$$

in which R is the known resistance expressed in megohms; m, the multiplying power of the shunt used when the deflection d is obtained; and, similarly, m' the multiplying power of the shunt when the deflection d' is obtained.

The multiplying powers of a galvanometer shunt are usually marked on the shunt box. In order to determine the insulation resistance per mile of a cable or a line wire, multiply the insulation resistance obtained by the measurement by the length of the cable or the line expressed in miles or a fraction thereof. Rmd is called the constant of the testing set.

Leakage Method.—The direct-deflection method is not suitable for measuring resistances over 1,000 megohms with E. M. F. less than several hundred volts. There are, however, the variously called *loss-of-charge*, *fall-of-charge*, or *leakage methods* for measuring higher resistances. These methods require some capacity as well as a very high resistance in the insulation to be measured. At least as accurate results can be obtained by the following leakage method, and, moreover, the calculations required are less complicated than for other leakage methods.

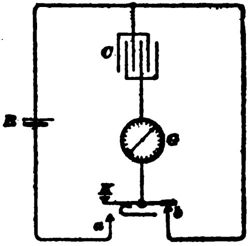


Fig. 5

The method consists in charging the cable as a condenser, then allowing it, while insulated, to leak for an observed number of seconds, and, finally, again charging it to the same potential as before through the galvanometer. The ballistic galvanometer required may be calibrated by any method, but the most convenient way is probably by means of a condenser connected as shown in Fig. 5. All apparatus and connections must be very highly insulated throughout this test, and the condenser must be thoroughly discharged. By pressing the key K the condenser is charged, producing a throw of the galvanometer; on letting up the key so that it touches b, the condenser discharges, producing another deflection.

Let d' be the mean of the two deflections, E_1 the E. M. F. of the cell B, and C_1 the capacity of the condenser; then, the quantity of electricity per unit deflection, that is, the constant of the ballistic galvanometer, is

$$K = \frac{C_1 E_1}{d_1}$$

The cable to be tested is then connected as shown in Fig. 6. If the cable is on a reel, it should be immersed in a tank of water, and particular care should be taken to insulate the ends of the cable so as to avoid surface leakage. With the switch N and key K closed, charge the cable. For a

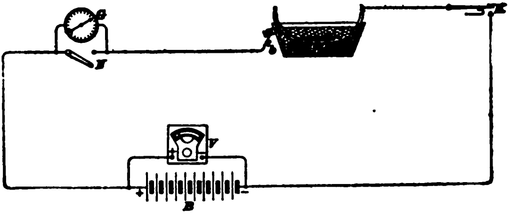


FIG. 6

preliminary test, a charge lasting 1 min. is sufficient, as poor insulation may render a longer charge useless. Then, open the circuit at K for a carefully observed number of seconds, say 30, in the meantime opening the switch N and noting the zero reading of the galvanometer. At the end of the 30 sec., close the key K and note the throw d_2 of the galvanometer G. This throw, corrected for the zero reading, indicates the quantity of electricity passing through the galvanometer, and hence the quantity required to replace that part of the charge lost by leakage or absorption during the observed time that the cable was disconnected.

In order to obtain a series of values that will show the condition of the insulation and the amount of absorption, repeat the foregoing observation after equal periods of charge of at least 1 min., and for equal periods of discharge, say 30 sec. The insulation resistance may then be calculated by the formula

$$R=\frac{E_2}{E_1}\times\frac{d_1}{d_2}\times\frac{t}{C_1},$$

in which E_2 is the E. M. F. of the battery, which may be most conveniently measured by the voltmeter V; d_2, the deflection observed with the connections used in Fig. 6; and t, the number of seconds (in this case 30) during which the cable is disconnected and the charge allowed to escape.

If C_1 is expressed in farads, R will be in ohms, but it is usually more convenient to express C_1 in microfarads, in which case R will be in megohms. Constant results may not be obtained unless the insulation is very high, and not even then, unless the cable is charged until absorption ceases, requiring in many cases at least ½ hr. If the deflections decrease as the time the cable is allowed to remain on open circuit is lengthened, it indicates absorption; the greater the decrease, the greater is the absorption. The higher the insulation resistance, the easier is the application of this method. In any one cable, the discharge intervals or the E. M. F. or both should be regulated to give desirable deflections.

PUNCTURE TEST

A *puncture*, or *breakdown*, *test* of insulating materials is now considered fully as important as an insulation test. The connections for this test are shown in Fig. 7, in which V represents the electrostatic voltmeter, and V' an electromagnetic voltmeter connected to the circuit through its own transformer. One voltmeter is desirable, although not really necessary; either one may be used. *A* is called a spark-gap gauge, means being provided for accurately determining the distance across the air between the points of the two steel needles. The transformer *T* is so constructed that any ordinary alternating-current potential of about 125 volts acting on the primary winding *p* will produce an E. M. F. in the secondary winding *s* sufficiently high for the test. The spark gap *A* and the insulator *W*, or other insulating material to be tested, are connected in parallel.

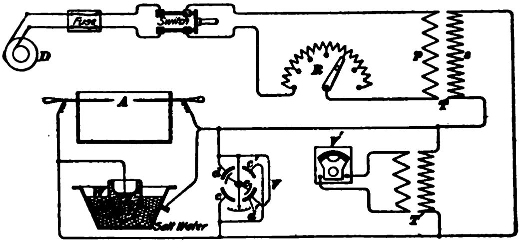


FIG. 7

The spark gap prevents the application of a greater potential to the insulator than will produce a spark across its points at the particular distance to which they may have been separated. A spark will jump across the spark gap, provided the insulators have not already given away, when the voltage has been raised to the highest value at which it is desired to test the insulators.

This distance *A* between the needle points for the maximum voltage desired may be determined by the curve given in Fig. 8. The test is started with all the resistance in *R*; then gradually reduce *R*, leaving it remain in each position 1 min., thus slowly increasing the potential between the inside and outside of the insulator until the insulator either punctures, or an arc is formed over its surface, or until the desired test potential is reached, thereby causing a spark to pass across the air gap *A*. New needles should be used at the gap after each discharge crosses it, otherwise the potential necessary to produce a spark across the gap may not follow the curve given. The difference of potential

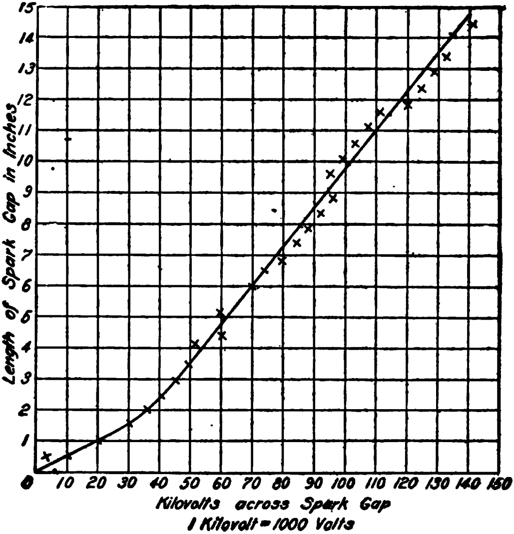


FIG. 8

applied to the insulator may be determined either by the distance between the points of the needles at *A*, in connection with the accompanying curve, or by the reading of the voltmeter *V* or *V′*, whichever is used. To test insulators under such conditions as prevail during a rainstorm, a stream of water through a sprinkler under a pressure of at least 50 lb. per sq. in. should be played on the insulator at an angle of about 30° from the horizontal. The insulator should not arc over from the wire to the pin at less than the potential that will exist in service between any two conductors.

ELECTROSTATIC CAPACITY

The *electrostatic capacity* of well-insulated condensers may be measured by any one of a number of methods, but the various methods fail to a greater or less extent with leaky condensers, submarine and underground cables, and overhead lines. The direct-deflection method is the simplest and probably the most generally used, except perhaps for submarine cables and for alternating-current apparatus; for the latter the alternating-current method is usually preferred. The results obtained by the direct-deflection method are hardly correct, even under favorable conditions, to within 1%.

DIRECT-DEFLECTION METHOD FOR MEASURING ELECTROSTATIC CAPACITY

In the *direct-deflection method*, the capacity is measured by comparing the extreme swing of the galvanometer produced by discharging the cable to be measured through the galvanometer with that produced by the discharging through the same galvanometer a condenser of known capacity charged to the same potential. If no shunt is used with the galvanometer, or if the same shunt is used in each case, the two capacities will vary in proportion to the respective swings of the galvanometer. Thus, calling d the deflection obtained with the known condenser whose capacity is C, and d' the deflection produced by the cable whose capacity is C',

$$C' = \frac{Cd'}{d}$$

The capacity of the cable per mile is found by dividing its total capacity by the length of the cable in miles. If a shunt is used with the galvanometer, the deflections d

and d' must each be multiplied by the multiplying power of the shunt used in each case. Shunts are liable to introduce errors, hence their use should be avoided as much as possible. Fig. 9 shows a diagram of connections for determining the electrostatic capacity of a cable by the direct-deflection method. *A* and *D* represent reversing switches, *C* the condenser whose capacity is known, *C'* the cable whose capacity is to be measured, and *K* a charge-and-discharge key. First, thoroughly discharge the cable *C'* by connecting it to ground. With *p* upon a suitable point

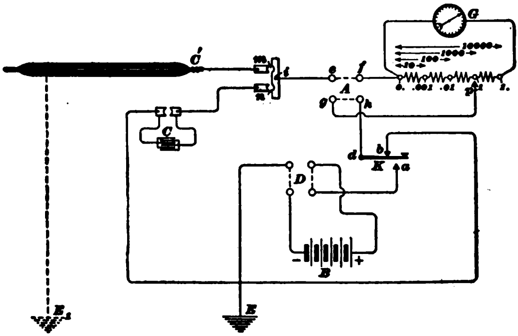


FIG. 9

of the galvanometer shunt, a plug in hole *m*, the reversing switches *A*, *D* closed, and the galvanometer perfectly at rest—its position of rest being noted—depress the key *K* and note the extreme first swing of the galvanometer. Reverse the switch *A* so as to obtain the next deflection on the same side of the scale, and when the galvanometer comes to rest, let up the key *K* and observe the discharge deflection. Thoroughly discharge the cable and repeat the same observations with the plug in hole *n*. The average of both charge and discharge deflections will give the best results. For this test, a ballistic galvanometer is preferable, although a Thomson or D'Arsonval galvanometer may be used, if the system is arranged to make one-half a complete vibration in from 10 to 15 sec., that is, one swing in one direction and back to zero. Thus, a charge of several seconds' duration may act on the moving system before it is moved from its position of rest.

GOTT'S METHOD FOR MEASURING CAPACITY

Gott's method for measuring electrostatic capacity is probably more accurate than the direct-deflection method, and, moreover, any kind of a sufficiently sensitive galvanometer may be used. The connections for this test are shown in Fig. 10, in which C is the known capacity of a condenser, C' the unknown capacity of a condenser or cable.

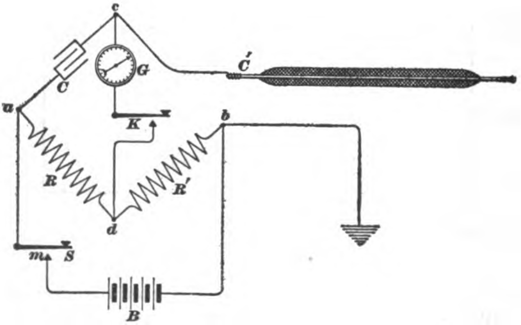


FIG. 10

and R, R' two adjustable resistances. R and R' may have any suitable values, but $R+R'$ should be as large as possible or convenient. Close the switch S, and after 5 or 10 sec. close the key K and note the deflection of the galvanometer G. The battery circuit must remain closed until after the galvanometer deflection is observed. Then, open S, and thoroughly discharge both C and C' by holding K

closed at least several times as long as the battery circuit previously remained closed. After readjusting R or R', always keeping $R+R'$ large, the foregoing operation is repeated until, on closing K with S resting on m, no deflection of the galvanometer is produced. The capacity of the unknown condenser C' can be computed from the formula

$$C' = C\frac{R}{R'}$$

If the insulation of the cable is less than several megohms to the microfarad, the capacity obtained by Gott's method will be appreciably greater than the actual capacity. Both leakage and absorption tend to increase the apparent capacity of the cable as obtained by this method. The best conditions are to have the known and unknown capacities about equal and the total resistance $R+R'$ high; also, the battery should supply as large a current as $R+R'$ will safely carry. In order to obtain uniform results in the final adjustments, it is necessary to make the duration of charge the same for each observation. With long submarine cables, the duration of charge should be at least 15 sec. For electric-light, telephone, and telegraph cables, which have much less absorption, about 5 sec. is sufficient.

MEASUREMENT OF CAPACITY WITH ALTERNATING CURRENTS

Method No. 1.—Connect the condenser C, Fig. 11, in series with the alternating-current ammeter A and the generator

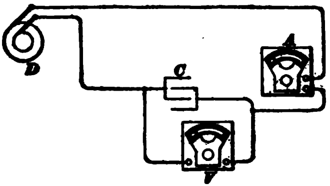


FIG. 11

of alternating currents D; also, connect the alternating-current voltmeter V across the terminals of the condenser.

If the resistance and inductance of the whole circuit are negligible compared to $\frac{1}{2\pi nC}$, then the capacity of the condenser is given by the formula,

$$C=\frac{I}{2\pi nE},$$

in which I is the current measured by A; E, the difference of potential measured by V; and n, the frequency or number of cycles per second made by the alternating current.

If the generator D has p pairs of poles and makes s revolutions per second, then $n=ps$. If I is expressed in amperes and E in volts, C will be in farads.

If a non-inductive resistance R is included in series with the condenser, and the voltmeter is connected so as to measure the drop of potential through both R and C, then, the inductance being negligible,

$$C=\frac{I}{2\pi n\sqrt{E^2-I^2R^2}}$$

R should be measured by a Wheatstone bridge or with direct current if a voltmeter and ammeter are used.

Method No. 2.—Connect a non-inductive resistance (an incandescent lamp or graphite resistance) in series with the condenser. Also, measure, as nearly simultaneous as possible, the difference of potential E' across the non-inductive resistance and the difference of potential E across the condenser terminal; then,

$$C=\frac{E'}{ER2\pi n}$$

In this method a known resistance R is required, but no ammeter.

MEASUREMENT OF INDUCTANCE

The *self-inductance of a coil* is a quantity that is strictly constant only when no magnetic material, or mass of metal, or closed coils are near it. Constant values cannot be expected from measurements of the inductance of coils unless great care is taken to remove all iron, metal, or closed coils from the neighborhood of the coil. Moreover, if the inductance itself is variable, there is little use in striving for great accuracy in its measurement. If possible, the inductance of a coil, especially when it contains iron, should be determined with exactly the same current flowing through it as when in use.

MAXWELL-REMINGTON METHOD

In Fig. 12 is shown a diagram of connections of the Maxwell-Remington method. M, N, and P represent three non-inductive resistances, while R is the coil whose inductance L is to be determined. Some form of adjustable resistance must be used for the arm ad, so that the position of e can be adjusted without in any way alternating the total resistance N from a to d after the proper value for this total resistance has been once determined. First, balance the bridge in the usual manner by closing K_1 for 1 or 2 sec., and then K, adjusting M, N, and P until the galvanometer G gives no deflection. From the values of M, N, and P so obtained, R can be computed. If the resistance of the arm cb containing the coil R is low, it is well to add enough non-inductive resistance, so that M may be made equal to N. In any case, R in the formula to be given, will be the total resistance of the arm cb. A point e should be located along ad where no kick of the galvanometer is produced by first closing K and then K_1. Let n be the resistance from d to e after this balance is obtained. The inductance of the coil R may then be calculated by the formula

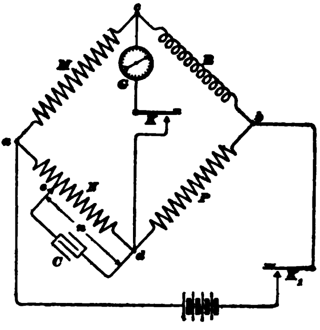


FIG. 12

$$L = \frac{Cn^2R}{N}$$

L will be in henrys if the capacity C is expressed in farads, and the resistances n, R, and N in ohms. An ordinary Thomson or D'Arsonval galvanometer may be used, provided the rate of change of the current in the condenser C does not vary so much from the rate of change of the current in the coil R as to make G deflect in spite of C and L being otherwise balanced. Otherwise, a ballistic galvanometer, which, however, requires more time and is more troublesome, should be used.

ALTERNATING-CURRENT METHOD

To determine the self-inductance L, Fig. 13, of a coil whose resistance is R with alternating current, connect the coil in series with an alternating-current ammeter A and an alternating-current dynamo D, using, if possible, an adjustable resistance S to regulate the strength of the current. Across the terminals of the coil connect an alternating-current voltmeter V, preferably an electrostatic voltmeter,

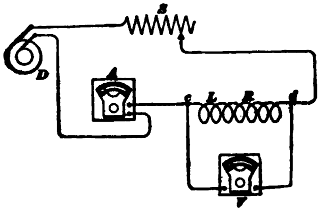


FIG. 13

and read both instruments A and V as nearly simultaneously as possible. Then, the inductance, in henrys, may be calculated from the formula

$$L = \frac{\sqrt{E^2 - I^2R^2}}{2\pi n I},$$

in which E is the difference of potential from c to d; I, the current in the coil; R, the resistance of the coil; and n, the frequency, or number of cycles per sec., made by the alternating current. If E is expressed in volts, I in amperes, and R in ohms, then L will be in henrys. R can be measured by a Wheatstone bridge or with direct current and a voltmeter and ammeter. There must be no appreciable electrostatic capacity between the points c, d.

POTENTIOMETER

The principles of a *potentiometer*, which is an instrument suitable for measuring E. M. F., current, very low resistances, and for calibrating ammeters and voltmeters, can be explained by the aid of Fig. 14, in which *R* is an adjustable resistance whose value need not be known, and *D* a steady source of E. M. F. for which a storage battery of one or two cells answers admirably. The E. M. F. of *D* must be at least a trifle greater than that of *B*. Like poles or terminals of *D* and *B* must be joined together at the same end of a very uniform wire *ab* stretched over a divided scale.

The distance *ab* is usually divided into 1,000 or 1,500 equal parts. At *B* is first placed a standard cell whose E. M. F. is known, and the slider *d* is set at the division of the scale corresponding to this known E. M. F. Suppose that *ab* is divided into 1,500 equal divisions and that the E. M. F. of the standard cell *B* is 1.431 volts; then, set *d* at a point 1,431 divisions from *a*, and adjust *R* until the galvanometer gives no deflection when both circuits are closed, first at *T* and then at *K*, in which case the E. M. F. of *B* must just balance the fall of potential from *a* to *d*, due to the current supplied by *D*. The length *ad* then represents 1.431 volts, and hence each division represents .001 volt. An E. M. F. not exceeding 1.5 volts may now be measured by substituting it for the cell *B*. Without disturbing any part of the circuit containing *D*, and with *T* closed, adjust *d* along the slide wire *ab* until no deflection of the galvanometer is produced on closing *K*. Suppose that the scale reads 1,324 at the point where the balance is obtained, then the E. M. F. measured is 1.324 volts. Instead of having all the resistance in one slide wire, it is now very customary to use

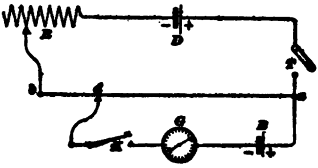


FIG. 14

a number of equal resistance coils for part or even for all of *ab*.

Measurement of Current.—To measure a current or to calibrate an ammeter, it is necessary to have a known low resistance through which the current to be measured may be allowed to flow. By then measuring the drop of potential through this known resistance by the potentiometer, the current in the circuit including the ammeter may be calculated by Ohm's law.

Measurement of Low Resistance.—Two low resistances—a standard whose value is known, and the one to be measured—are connected in series, preferably, with an adjustable resistance and a source of very constant current. The resistance is adjusted, or the number of cells varied, until the fall of potential across each one of the resistances will fall within the range of potential that can be measured on the potentiometer. The current through the resistances must remain steady long enough to determine the drop in potential across each resistance. Then, the unknown resistance is to the known resistance as the potentiometer reading across the unknown resistance is to the potentiometer reading across the known resistance, from which the unknown resistance can be calculated.

CALIBRATION OF VOLTMETERS

A voltmeter may be calibrated by connecting it in parallel with a voltmeter of suitable range whose readings are known to be correct, or by connecting it across a suitable known resistance that is connected in series with a standard ammeter and a battery or other suitable source of current, or the drop across this known resistance may be determined with a potentiometer.

Franklin's Method.—To calibrate a voltmeter by Prof. W. S. Franklin's method, connect as shown in Fig. 15, in which *R* is an adjustable resistance; *D*, a steady source of E. M. F.; *B*, one or more standard cells connected in series;

V, the voltmeter to be calibrated; *H*, a high resistance whose value need not be known; and *G*, a sufficiently sensitive galvanometer with a shunt. Adjust *R* until no deflection of the galvanometer is observed when the key *K* is closed. Then, the E. M. F. of the standard cells corrected for temperature gives the E. M. F. at the terminals of the galvanometer. By varying the number of standard cells at *B*, as many points as desirable may be calibrated on the voltmeter scale. The high resistance *H* may be short-circuited, and the shunt resistance *S* cut out for the final adjustment. The E. M. F. of *D* must exceed that of *B*.

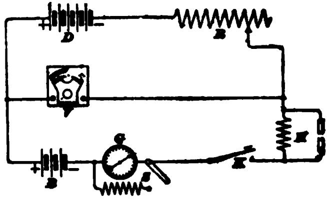


Fig. 15

Carhart's method for calibrating a voltmeter is shown in Fig. 16, in which *D* is a storage battery having a sufficient number of cells to give the desired reading on the voltmeter *V*, and *R*, *R'* are adjustable resistances For a high-reading voltmeter, *R'* should be at least as high as 100,000 ohms, while the range of *R* will depend on the number of standard cells used at *B* and the reading desired on the voltmeter Adjust the resistances *R*, *R'* until no deflection of the galvanometer *G* is produced when the key *K* is closed, the high resistance *H*

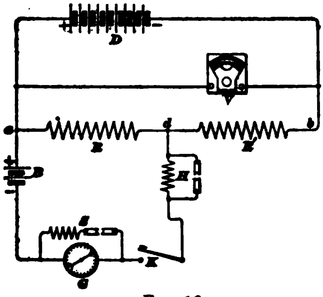


Fig. 16

being short-circuited and S opened for the final balance. Then, the reading of the voltmeter should be

$$V = nE\frac{R+R'}{R},$$

in which E is the E. M. F. of one standard cell corrected for its temperature during the test; n the number of standard cells used; and R, R', the resistances inserted at R, R', respectively.

For a voltmeter not reading over 3 or 4 volts, a slide wire can be used instead of the resistance boxes R, R', and the point d moved along the slide wire until no deflection of the galvanometer is obtained. Since $\frac{R+R'}{R}$ is merely a ratio, the distance along the slide wire from a to d can be used in place of R, and the distance a to b in place of $R+R'$.

CALIBRATION OF AMMETERS

An ammeter may be calibrated by connecting it in series with an ammeter of similar range whose readings are known to be correct. Another way is to connect the ammeter in series with a copper or silver voltmeter, by which the current may be determined for one reading of the ammeter. This is one of the most accurate methods, but in most cases is too slow. A third method, which is very satisfactory, requires the use of a potentiometer and a low resistance whose value is accurately known.

Calibration of Ammeter by Potentiometer.—Connect the ammeter in series with a battery or direct-current dynamo, the current from which may be regulated, and a suitable known resistance, the fall of potential across which may be determined with a potentiometer. Having measured the fall of potential and knowing the resistance, the current that flows through both the known resistance and the ammeter may be calculated.

Calibration of Ammeter by Franklin's Method.—Franklin's method for calibrating an ammeter is shown in Fig. 17, in which D is a steady source of E. M. F., preferably a storage battery; *A*, the ammeter to be calibrated; and *R* a standard known resistance. With a suitable number of standard cells at *B*, adjust the resistance *P* until the galvanometer *G* gives no deflection when *K* is closed; then, the E. M. F. between the terminals of the standard resistance *R* is equal to the E. M. F. of the battery *B*. The E. M. F. of the

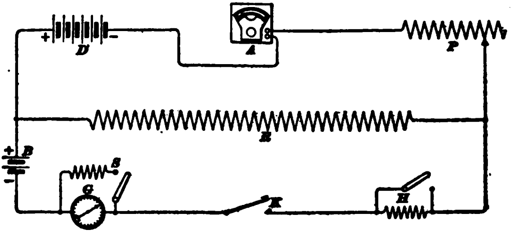


FIG. 17

standard cells divided by *R* will give the current through the ammeter *A*. The high resistance *H*, equivalent to about 10,000 ohms or more per cell at *B*, may be short-circuited and the shunt *S* open-circuited when making the final adjustment. By the use of a different number of standard cells, various points on the ammeter scale may be calibrated. The E. M. F. of *D* must always exceed that of *B*.

OHMMETERS

Ohmmeters are instruments from whose scale may be directly read the value, in ohms, of a resistance that is being measured. The principle of the slide-wire ohmmeter may be explained by means of Fig. 18 (*b*). When the plug *P* is inserted in a hole, say the brown hole, the corresponding coil constitutes the known resistance arm *CD*, while the two long wires *CB* and *BA*, joined by a bar *B* of negligible resistance, constitute two adjustable arms of a Wheatstone bridge. The manufacturers mark along the wire in colors

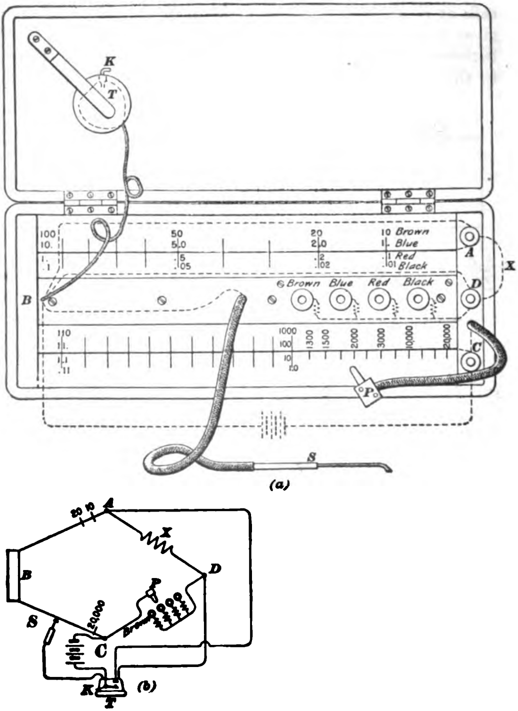

K
T
100
10.
50
5.0
20
2.0
10 Brown
1. Blue
.1 Red
.01 Black
A
X
D
B
Brown
Blue
Red
Black
C
P
S
1000
100
10
1.0
1300
1500
2000
3000
10,000
20,000
(a)
20
10
A
X
D
B
S
20,000
Brown
C
K
T
(b)

FIG. 18

scales that read directly in ohms; the color of the scale to be used corresponds to the color of the hole in which the plug P is inserted. The divisions per ohm are not equal in length but gradually decrease in length as the resistance at X increases. The red coil has exactly 10, the blue 100, and the brown 1,000 times the resistance of the black coil.

Having once calibrated the bridge wire with known resistances at X, any unknown resistance at X that would bring the balance point S somewhere on the bridge wire may be measured and its resistance read directly from the point of balance found on the scale.

Using a Sage Ohmmeter.—To measure the unknown resistance, usually designated as X, connect it between posts A and D, as indicated in Fig. 18 (a). Put plug P in the brown hole, place telephone T to the ear, being certain to press circuit-closing key K, and tap the stylus S along slide wire ABC until the click of the telephone ceases or is a minimum. The brown number under the balance point gives the value of X in ohms. If the approximate value of X is very low, the balance point, using the brown hole, will be so close to the A end of the slide wire that an accurate reading cannot be made. In such a case, change the plug successively to the blue, red, and black holes, if necessary, remembering that the scale to be used, when a balance is obtained, must be of the same color as that marked on the hole in which the plug is placed.

When the telephone will emit no sound between certain limits on the slide wire, a more accurate result may be obtained as follows: Suppose that the brown hole and scale are in use and that on starting from A the telephone becomes silent at the 695 mark and remains silent until mark 705 is reached, when it begins to click again; by taking the 700 mark, half way between the two, the result is more nearly accurate than if either limit is taken. It is not absolutely accurate, because the intervening divisions are not of the same length.

Two *inductances* may be compared, provided the resistance of each coil is negligible compared with its reactance ($2\pi nL$), by connecting the coils X, Y as shown in Fig. 19. I represents an ordinary induction coil or other arrangement by which alternating current may be obtained at the terminals AC. Obtain a balance by first closing K and adjusting S until

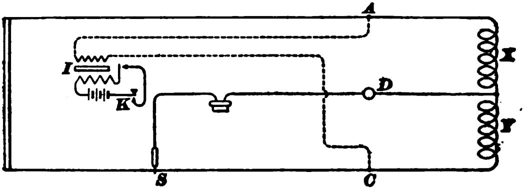


Fig. 19

a point giving a minimum sound is found. If only a battery can be obtained for use across AC, the balance point is that which gives a minimum sound when the slide wire is tapped. Then, the inductance of X is to the inductance of Y as the length AS is to the length SC.

Two *capacities* may be compared in a similar manner, but in this case the capacities are inversely proportional to the resistances; that is, the capacity at X is to the capacity at Y, as the length SC is to the length AS. In either case,

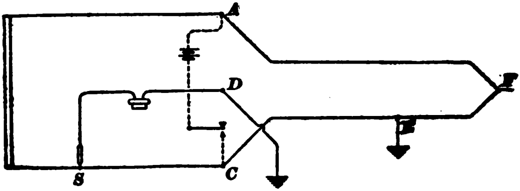


Fig. 20

when one inductance or one capacity is known, the other can be calculated.

A *ground* on one of a pair of line wires may be located by using the ohmmeter as indicated in Fig. 20. In order to use this method, a good wire AF of the same material and size as the line wire CF should be joined to the faulty wire at some point F beyond the fault E. Then, if S is the point of balance,

$$\text{distance } CE = \frac{\text{length } SC \times \text{distance } AFC}{\text{length } ASC}$$

The *resistance of electrolytes* may also be measured with the ohmmeter by connecting the electrolytic resistance in the unknown arm of the bridge and using an alternating current from an ordinary induction coil or other source in place of a battery.

MEASUREMENTS WITH COMMERCIAL INSTRUMENTS

AMMETERS AND VOLTMETERS

An *ammeter* is an instrument for measuring the current flowing in a circuit. The ammeter, or its shunt, is connected directly in series with the circuit through which the current is flowing.

A *voltmeter* is an instrument for measuring the difference of potential between two points; this is done by connecting the voltmeter across the two points.

The *range of an ammeter* may be increased by connecting a shunt across its terminals. Let R be the resistance of the ammeter and S the resistance of the shunt connected around the ammeter terminals; I the highest reading, that is, the present range of the ammeter; and I' the range desired. Then the resistance of the shunt required is

$$S = \frac{RI}{I' - I}$$

When thus shunted, the indicated reading must be multiplied by $\frac{I'}{I}$ to obtain the total current flowing in the main circuit.

The *range of a voltmeter* may be increased by connecting a resistance in series with the voltmeter. Let R be the resistance of the voltmeter; R' the resistance connected in series with it; V, the highest reading of the voltmeter; and V' the highest reading desired. Then,

$$R' = R\left(\frac{V' - V}{V}\right)$$

When the resistance R is connected in series with the voltmeter, the scale readings must be multiplied by $\frac{V'}{V}$ to give the difference of potential across the circuit.

Double, or *two-scale*, *voltmeters* are usually connected internally, as shown in Fig. 21. The resistance of the non-inductive coil ab, together with that of the movable coil, that is, the resistance from a to p', may be 15,000 ohms for a 15-volt scale, and the total resistance from p to p'' 150,000 ohms for a 150-volt scale. When using a double-scale voltmeter, care must be taken not to apply too high a voltage to the terminals of the lower resistance coil that is associated with the lower reading scale.

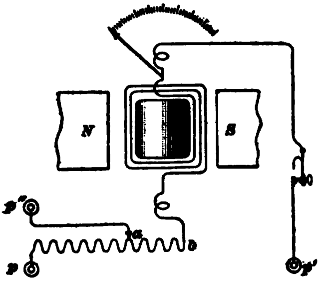


FIG. 21

Measurement of Resistance by Voltmeter and Ammeter. A resistance R may be measured by connecting an ammeter A in series with the resistance R and a battery B or other source of current, and connecting a voltmeter VM around the resistance, as shown in Fig. 22. Then, by Ohm's law, $R = \frac{E}{I}$. It is quite customary and sometimes necessary to connect the voltmeter across the terminals t, t' of the resistance to be measured, instead of including, as shown in this figure, the ammeter A between the voltmeter terminals. Usually, either method of connecting the voltmeter will give sufficiently accurate results, but it generally introduces less of an error to connect the voltmeter as shown in this figure. By using instruments of the proper range, resistances from quite low to quite high values may be measured.

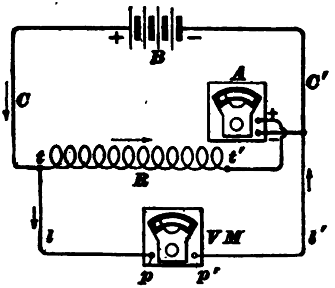


FIG. 22

Resistance Measurement With Voltmeter and Known Resistance.—A resistance may be measured by connecting it in series with a dynamo or battery *B* and with a known resistance *R'*, as shown in Fig. 23. With the voltmeter

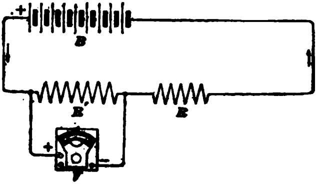


FIG. 23

first connected across the ends of *R'*, let the reading be *E'* volts; with the voltmeter connected across the ends of the unknown resistance *R*, let the reading be *E* volts. If *R'* is very different from *R* it is sometimes very convenient to measure one on the higher-reading scale and the other on the lower-reading scale of a double-scale voltmeter.

High-Resistance Measurement With Voltmeter.—High-resistance voltmeters may be used to measure very high resistances, such as insulation resistances, by connecting as shown in Fig. 24, in which R is the insulation or high resistance to be measured; BC the battery or other source of E. M. F., which should be as high as the range of the voltmeter VM will allow; and K a switch for short-circuiting the resistance R. Then,

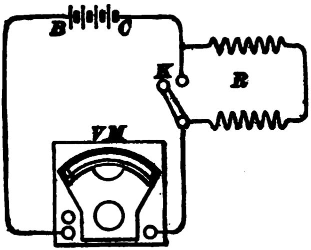


FIG. 24

$$R = r\left(\frac{d}{d'} - 1\right)$$

in which d is the reading of the voltmeter with the key K closed; d' the reading of the voltmeter with the key K open; and r the resistance of the voltmeter, which is usually marked upon the instrument or the case.

Insulation Resistance With Voltmeter.—The method just described may be used to measure the insulation resistance of telephone, telegraph, and electric-light and power circuits, and also of dynamos and motors while the system is in operation, no shutting down being necessary. In Fig. 25 is shown the connections for measuring the insulation resistance of a line while the dynamo D is supplying current to the lamps l. Let R_a represent the joint resistance of all leakage paths between the main line AA and the ground, and R_b the same between BB and the ground. First, connect a suitable voltmeter Vm between the mains ef, and let the reading be V_m volts. Then, connect the same voltmeter between the ground G and the main AA by closing switch S on contact a, and let this reading be V_a volts. Finally, connect the voltmeter between the ground G and the main BB by closing S on b and let the reading be Vb volts. To obtain the last reading with most voltmeters, it will be necessary to reverse the connections at the voltmeter in

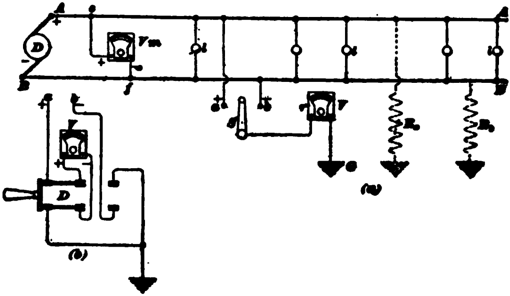


FIG. 25

order to make the needle deflect in the right direction. If r is the resistance of the voltmeter, and R the joint resistance of all possible paths between both mains and the ground, the insulation of the whole system will be

$$R = r\left(\frac{V_m}{V_a + V_b} - 1\right) \qquad (1)$$

If the insulation resistance of one side, for instance BB, is extremely high, and the other side AA is poorly insulated or partially grounded, the voltmeter reading V_a between the partially grounded side and the ground will be practically zero, because there is no path for any current back to the well-insulated main. The formula for the insulation resistance of the side AA then reduces to

$$R = r\left(\frac{V_m}{V_b} - 1\right) \qquad (2)$$

Hence, to measure the insulation resistance of one side of a system only, take two readings—one between the two mains and the other between the other or good side and the ground.

If the ratio $\frac{V_m}{V_b}$ in formula 2 is very much greater than 1, the formula reduces to

$$R = r\left(\frac{V_m}{V_b}\right). \qquad (3)$$

This is an approximate formula that is often used for ordinary measurements.

If the voltmeter has two scales and the reading V_a or V_b is less than the largest reading on the lower reading scale, a more accurate result may be obtained by using the lower reading scale for determining V_a or V_b. In the formula, r will be the resistance of the voltmeter coil used in obtaining the reading V_a or V_b; the resistance of the coil used in obtaining the reading V_m will not enter into the result.

When this insulation-resistance test is to be made repeatedly, a convenient arrangement is shown in Fig. 25 (*b*), in which the double-throw switch *D* is so connected as to make the voltmeter deflect in the proper direction, whether connected to *a* or to *b*. The switches and connections should be very much better insulated than the system to be tested, and the voltmeter readings should be taken as quickly as possible, one after the other, as the formula assumes that all readings are observed simultaneously. Slight variations in the E. M. F. of the source of supply do not affect the results very materially. The insulation resistance of a dynamo may be measured in the same way as that of a line circuit.

ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE OF BATTERIES

The *internal resistance* of a battery or cell is a very variable quantity; hence, it is somewhat difficult to measure, and very exact results should not be expected. The voltmeter-and-ammeter method is about the most satisfactory, as it enables both the electromotive force and the internal resistance of the battery to be measured under actual working conditions.

Wheatstone's Method.—Wheatstone's method for comparing the E. M. F. of voltaic cells by means of a voltmeter is as follows: First, connect one of the cells so as to be in series with the voltmeter V and the resistance R, as shown in Fig. 26, and note the reading d when the key K is closed. Then, increase the external resistance by opening the key K with r_1 ohms and note the deflection d'. Repeat these two observations with the second cell connected at E in place of the first cell; but, with the key K closed, first make the resistance R of such a value as to give exactly the same deflection d as with the first cell. Then, open the

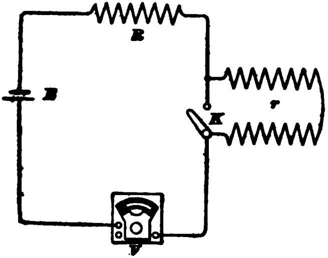


Fig. 26

switch K and make the additional resistance r_2 of such a value as to get exactly the same deflection d' as under similar connections for the first cell. Then, $E_1 : E_2 = r_1 : r_2$. If E_1 is smaller than E_2, the resistance of the voltmeter itself may be taken for R_1 when E_1 is connected in the circuit. It is preferable to make r_1 about twice as large as the combined resistance of E_1 and R_1. With a suitable voltmeter, this method is correct to about 1%.

Voltmeter-and-Ammeter Method.—By the voltmeter-and-ammeter method, both the internal resistance and the E.M.F. of a cell may be determined from the same observations; and, moreover, the measurements may be made when the cell or battery is generating current at its normal or desired rate. Connections for this method are shown in Fig. 27, in which R is a resistance of such value that the battery B to be tested will furnish its normal amount of current.

With the key K open, read the voltmeter V, which will give E, the E. M. F. of the battery when practically no current is flowing, that is, when the battery is practically on open circuit; then close the key, and read as nearly simultaneously as possible both the ammeter A and voltmeter V. These two readings give the difference of potential E' at the

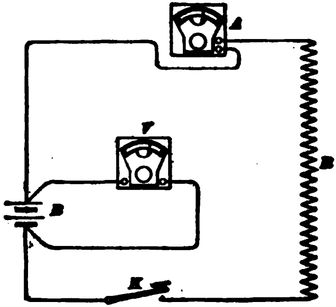


FIG. 27

battery terminals and the current I which is flowing through the circuit. Then, the internal resistance $B = \frac{E - E'}{I}$. If the total resistance R external to the battery is known, the ammeter will not be necessary, for the current I is equal to $\frac{E'}{R}$ and can therefore be calculated.

MEASUREMENT OF POWER

The *power* expended in a direct-current circuit may be determined by measuring the current and the difference of potential, the product of these two measurements giving the power expended. Such measurements can be readily made with a voltmeter and an ammeter. Voltmeters and ammeters, however, cannot generally be used in this manner to determine the power consumed in alternating-current circuits.

MEASUREMENT OF POWER WITH VOLTMETER AND AMMETER

Fig. 28 shows the method of connecting voltmeters and ammeters to determine the power expended in direct-current circuits. The product of the simultaneous readings of V_3 and A_3 gives the power in watts expended by the

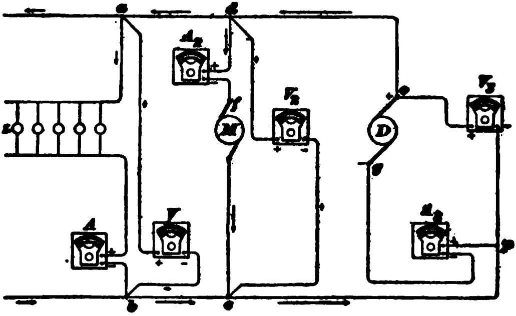


FIG. 28

dynamo D in the whole circuit; that of the simultaneous readings of V_2 and A_2 gives the power consumed by the motor M; and that of the simultaneous readings of V and A gives the power expended in the group of lamps L.

DYNAMOMETERS

The *dynamometer* is an instrument that may be used to measure currents, E. M. F., and power in both direct- and alternating-current circuits. Instruments of this type consist of two coils, one fixed and the other arranged to revolve a limited amount inside the fixed coil. The movable coil, which is usually suspended by a helical spring that tends to keep it at right angles to the fixed coil, has a pointer attached to it.

In the Siemen's dynamometer, the helical spring is secured to a nut, called the torsion head, to which is also fastened a pointer that moves over a circular scale. When a current passes through both coils the swinging coil is deflected, but is brought back to its zero position by turning the torsion head. The number of degrees through which it is necessary to turn the torsion head is the reading of the instrument, and is proportional to the product of the currents in the two coils.

Commercial, portable, and switchboard instruments of the dynamometer type are constructed on the same principle, except that the scale is calibrated by the makers, so that the position of a pointer attached to the movable coil indicates directly the current, voltage, or power, depending on how the two coils are connected.

Measuring Current.—If the two coils of a dynamometer are connected in series so that the same current flows through each coil, the rotating force is proportional to the square of the current, and the scale may be calibrated to indicate the strength of the current.

Measuring Difference of Potential.—When the dynamometer is used to measure the difference of potential, the fixed and movable coils and a sufficiently high non-inductive resistance are connected in series across the two points in a circuit between which the difference of potential is to be measured. Then the deflections are proportional to the square of the currents as before, but the currents, since the resistance remains constant, are proportional to the potential differences; hence, the deflections are proportional to the squares of the potential differences, and the scale may be calibrated to indicate directly the difference of potential across the instrument.

Measuring Power.—If the swinging-coil circuit has a constant and high resistance and is connected between two points, the currents through it will be proportional to the difference of potential between those two points. If the fixed coil is connected in series with a circuit joined to the same two points, practically the whole current in the circuit will pass through the fixed coil; consequently, the torsion will be proportional to the product of potential difference and current, that is, to the power being expended in the circuit.

The earth's field may produce an error in the dynamometer reading, but it may be eliminated if the average of two readings is taken for one in which the current through both coils is reversed in direction. In such cases, the earth's field increases the torsion for one reading as much as it diminishes it for the other. The dynamometer type of instrument is even more suitable for measuring alternating currents, E. M. F.'s, and power than for direct current, for then the earth's field has no effect on it. Commercial wattmeters have their scales calibrated to read amperes, volts, or watts directly. So-called multipliers, that is, non-inductive resistances, are made for use with wattmeters; the multipliers increase the capacity of the instrument, usually in volts, with the maximum current capacity remaining unchanged.

Weston Compensated Wattmeter.—In measuring power with a voltmeter and an ammeter, the product of the two readings includes not only the power consumed in the lamps or other devices, but also the power consumed in one of the instruments. The same error occurs in the results obtained by the use of a non-compensated wattmeter. This error is eliminated in the Weston compensated wattmeter by winding the wire running to the potential coil alongside of each turn in the current coil, the current circulating in the two turns in opposite directions. So far as the magnetic action of the current in the current coil is concerned, the result is the same as if the current in the potential coil were subtracted from the current in the current coil.

Fig. 29 shows the connections of the Weston instrument. *A* and *B* are the current terminals connected to the current coils *c*, *c′*. The compensating coil *e* is connected in series with the swinging coil *D*, and the protective resistance *R*. The potential binding posts that are ordinarily used for measuring the power supplied to a given load are *ab*. When a reading is taken, the button *k* is pressed, thus allowing current to pass through the swinging coil. A third binding post *I* is provided for use when the field and pressure terminals are connected to independent circuits. Such connections are required when the instrument is being checked by

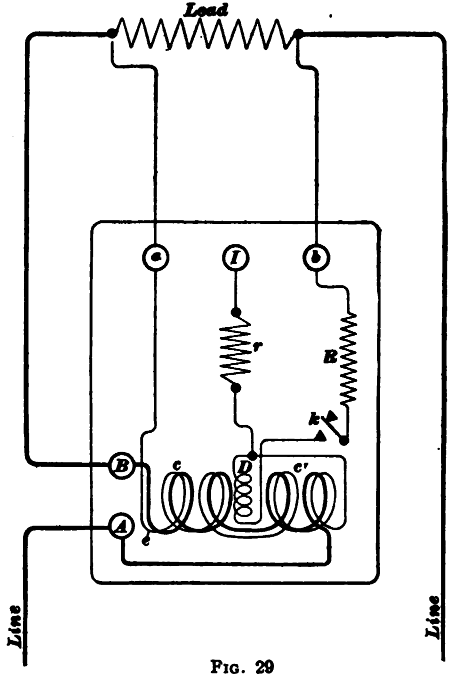


FIG. 29

passing a current through the current coils and applying a variable pressure to the potential coil; also, in cases where a test is being made with a constant current and varying pressure. If an independent potential circuit is used in this way, the potential terminals are connected to posts *Ib*, thus cutting out the compensating coil. The small resistance *r* takes the place of coil *e*, so that the resistance of the potential circuit remains unaltered.

Recording Wattmeters.—Instruments that show the value of the watts expended at any instant are frequently called *indicating wattmeters* to distinguish them from *recording wattmeters*, which measure the total work done during the given time. The recording wattmeter indicates the product of watts and time, usually in watt-hours or kilowatt-hours. Strictly speaking, these recording instruments are work-meters, not wattmeters, because they record work, not power. Large numbers of recording wattmeters are used for measuring the electrical energy supplied to customers on electric-light and power circuits; the watt-hours or kilowatt-hours are read about once a month from a dial similar to that of a gas meter.

LOCATION OF FAULTS

Faults on a line may be of three kinds: (1) The line may be broken; (2) an unbroken line may be grounded at one or more points; and (3) an unbroken line may be in contact with another line. The first fault is called a *break*, or an *open;* the second, a *ground;* and the third, a *cross*. A break may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired, so as to form also a cross or a ground. A ground or a cross may be of such low resistance as to form a dead ground or a short circuit, respectively, or may possess high resistance, thus forming what is termed a *leak*. The existence of a wire whose insulation and continuity are known to be good is termed a *good wire*.

Line Resistance When Three Conductors Are Available. The best method for measuring the resistance of a line wire, where there are three or more line wires or two line wires and a ground-return circuit between the same two offices, is as follows: Let the resistance of the three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together; then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and call it a ohms. Then, have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined and measure the resistance of this loop, calling it c ohms. Then, $x+y=a$; $x+z=b$; $y+z=c$. Solving these equations for x, y, and z gives:

$$x=\frac{a+b-c}{2} \qquad (1)$$

$$y=\frac{a+c-b}{2} \qquad (2)$$

$$z=\frac{b+c-a}{2} \qquad (3)$$

Elimination of Earth Currents.—Where the ground is used as a part of the circuit, *earth currents* will often render measurements very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may be usually eliminated by making a measurement and then reversing the battery and making another measurement. The average of the two measurements should be taken as the correct result. For good results, the earth current should not only be steady but it should also be small compared with the testing current.

TESTS FOR LOCATING A BREAK

NO GOOD WIRES AVAILABLE

Measurements From One End Only, Using a Condenser. When there is not a single good wire available, but the total capacity and length or capacity per mile of the conductor is known, or can be measured, the distance to a break may be determined as follows: Let d be the deflection, or throw, of a ballistic galvanometer obtained by charging or discharging through it a condenser of known electrostatic capacity C, and let d' be the throw when charging or discharging the broken line wire whose capacity is C', using the same battery in each case. Then,

$$C' = \frac{Cd'}{d}$$

The electrostatic capacity per mile of the broken line must be known; then, by dividing C' by this electrostatic capacity per mile, the number of miles to the break is obtained. By using the foregoing method, this electrostatic capacity per mile may be determined by measuring the total electrostatic capacity of the line when it is in good condition—that is, free from breaks, grounds, and crosses—and dividing this total electrostatic capacity by the total length of the line. The electrostatic capacity per mile may be obtained approximately from the following table:

ELECTROSTATIC CAPACITY PER MILE

Number and Gauge	Diameter In.	Capacity in Microfarads per Mile, 30 Ft. Above Ground: Between One Wire and Ground (Grounded at Both Ends)	Capacity in Microfarads per Mile, 30 Ft. Above Ground: Wire to Wire 12 In. Apart
1	2	3	4
8 B. & S.	.128	.00958	.00854
9 B. & S.	.114	.00946	.00835
10 B. & S.	.102	.00935	.00818
12 B. & S.	.0808	.00913	.00785
14 B. & S.	.0641	.00892	.00754
16 B. & S.	.0508	.00871	.00726
12 B. W. G.	.109	.00942	.00828
14 B. W. G.	.0830	.00915	.00788

The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially whether any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. It will also vary with the number of insulator supports per mile and the moisture on them. When one overhead wire is grounded at one end and insulated at the other end, the capacity is twice as great as when both ends are grounded; that is, twice as great as the capacity given in column 3 in the table. When a high inductance, such as a high-resistance (1,200-ohm) bridging bell, is connected between one end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is open and insulated.

The capacity C, in microfarads, per mile of one wire .104 in. in diameter, grounded at both ends and suspended at a height of h ft. above the ground, is given in the accompanying

ELECTROSTATIC CAPACITY OF SINGLE LINE WIRES
(Grounded at both ends)

h Ft. Above Ground	C Microfarads per Mile
10	.010600
20	.009796
30	.009379
40	.009105

table. If there are two such wires .104 in. in diameter, 1 ft. apart, and grounded at both ends, the capacity between either wire and the ground is .01171 microfarad per mile when both wires are 20 ft. above the ground, and .0115 microfarad when both wires are 30 ft. above the ground. The capacity, in microfarads per mile, between two wires .104 in. in diameter, and forming one metallic circuit is .008503 when the two wires are 10 in. apart, .008218 when 12 in. apart, .007992 when 14 in. apart, .007806 when 16 in. apart, and .007649 when 18 in. apart.

Measurements From Each End, Using a Condenser.—Another method of locating a break when no good wire is available is as follows: Determine the discharge deflection d from the broken wire at one end of the cable, also the discharge deflection D from a condenser of known capacity C. Then, determine the discharge deflection d' from the other end of the broken wire, and the discharge deflection D' from a condenser of the same capacity, or preferably from the same condenser. The same amount of battery must be used for both tests at one end, but the same amount of battery need not be used at one end as at the other. This method gives very satisfactory results. Let L be the length of the cable; then, the distance x to the break is given by the formula

$$x = \frac{Ld}{d + \frac{D}{D'}d'}$$

ONE OR MORE GOOD WIRES AVAILABLE

Three Good Wires Available.—A method that has been successfully used for the location of breaks in telephone-cable conductors is shown in Fig. 30, in which V and B represent any suitable means for supplying a reversible, interrupted, or alternating current—in this case a rotating device—for reversing rapidly the current from the battery B.

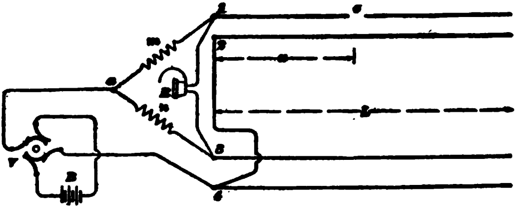


FIG. 30

The conductor *1* is open at o, while its mate *2* and the pair *3*, *4* are supposed to be good wires; m and n represent two adjustable arms of a Wheatstone, or slide-wire, bridge. The resistance in the arms m, n is adjusted until no sound, or a minimum sound, is produced in the receiver R. Then, the distance to the fault o is given by the formula

$$x = \frac{n}{m}L$$

The wires *1*, *2*, *3*, *4* should be well insulated at tne distant end. For cables 1,000 ft. long, the battery B should give 60 to 120 volts, and the resistance in the arm n may have to be 100 or 1,000 ohms. The larger the capacity between the wires, the less need be the number of cells at B and the less the resistance in the arm n.

One Good Wire Available.—When one good wire having the same capacity to ground per mile as the broken wire is accessible, deflections may be taken on the broken wire and on the good wire with the distant end open.

Let d' = throw on the broken wire;
d = throw on good wire;
x = distance to break;
L = total length of good wire.

Then,
$$x = \frac{d'L}{d}$$

In a telephone cable, it is best to use the mate of the broken wire as the good wire, and to ground to the lead sheath all the conductors except the one from which the deflection is being obtained. At least the mate of the faulty wire should be grounded at the testing end when the discharge deflection of the faulty wire is observed, and both ends of the faulty wire should be grounded when the discharge deflection of its mate is being observed.

The method for locating a break in a line wire by comparing the capacity of the broken wire with that of a similar good wire is reliable, provided the insulation resistance is high and the break is so complete that no current passes through the point of rupture. In using these methods, therefore, it is best to first measure the insulation resistance of the broken wire and also of the good wire. If the insulation resistance of the good wire is near 1 megohm, capacity methods are not very reliable. The insulation resistance of the good wire should preferably be about 20 megohms in order to obtain reliable results. Breaks in cables cannot be as accurately located as grounds or crosses under favorable conditions, because the electrostatic capacity is much less uniform than the resistance of the wire; in fact, the electrostatic capacity of a conductor in a telephone cable may vary as much as 5%.

TESTS FOR LOCATING A GROUND

Accidental connections with the ground occur much more frequently than breaks, and are often difficult to locate, especially if more than one ground occurs on the same line wire. Various methods for locating grounds will be given, as no one method is always applicable.

Ground on a Line of Known Resistance.—Where there is a dead ground on a line whose length and resistance are known, let f be the known resistance of the line and L the length of the line, in miles. Then, if the line wire is uniform in size and material, $\frac{f}{L}$ is the normal resistance of the line per mile. To locate the distance to a dead ground in such a case, measure the resistance between the home end of the line and the ground and call it a ohms. Then, the number of miles x from the testing station to the dead ground is given by the formula

$$x=\frac{aL}{f}$$

TESTS FROM BOTH ENDS WITHOUT A GOOD WIRE

Earth Overlap Method.—Where there is no available good wire and tests can be made from each end of a grounded wire, the *earth overlap method* may be used. This method is especially valuable for the location of high-resistance faults,

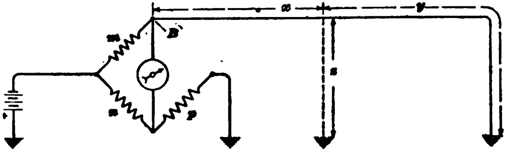


FIG. 31

and experience seems to show that it is the best practical method for locating grounds in submarine cables, provided there is only one ground and no good wire is available. Let x represent the resistance from one end of the conductor to the fault; y the resistance from the other end of the conductor to the fault itself; and f the normal resistance of the faulty wire. Then, $f=x+y$.

First, measure, with a Wheatstone bridge, the resistance from the x end with the other end grounded, the connections being made as shown in Fig. 31; call the resistance thus measured a ohms. Second, measure, in the same manner, the resistance of the grounded wire from the other, or y, end with the distant end grounded; call the resistance so determined b ohms. Then,

$$x=\frac{a(f-b)}{a-b}\left[1-\sqrt{\frac{b(f-a)}{a(f-b)}}\right] \qquad (1)$$

$$y=\frac{b(f-a)}{b-a}\left[1-\sqrt{\frac{a(f-b)}{b(f-a)}}\right] \qquad (2)$$

The zinc, or negative, terminal of the battery should be connected toward the line, and the tests in the earth overlap method should be made alternately and as rapidly as possible from each end, so that pairs of readings may be secured while the fault undergoes as little change as possible.

When one end of a good line is grounded and its resistance measured, the result, called its *apparent resistance*, will be less than the true resistance of the conductor when perfectly insulated. Better results will be obtained in the earth overlap method if the apparent resistance of the wire measured under normal conditions, that is, free from faults, is used for f, rather than its true resistance, which is usually determined from a wire table. The shorter the line or the better its insulation, the less is the error due to using the true resistance.

TEST FROM ONE END WITHOUT A GOOD WIRE

Blavier Test.—The *Blavier method* for locating a partial ground or an escape is about the only one that can be used where there is no available good wire and when the test must be made from one end only. However, this method is rather unreliable in practice, because, if the resistance of the partial ground changes between the two measurements, the result cannot be depended on; and, moreover, the normal, or total, resistance of the line must be known from some previous measurement, obtained from a wire table, or calculated from the length, size, and conductivity of the line wire. Let the total resistance of the line wire be f. First, measure the resistance of the line with the distant end open, and call the resistance so obtained b; also, measure the resistance of the line with the distant end grounded, and call this resistance c. Then, the resistance x to the partial ground from the testing station is given by the formula

$$x = c - \sqrt{(b-c)(f-c)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurement, obtained from a wire table or calculated by the length, size, and conductivity of the line wire, the distance to the partial ground is obtained. If L is the length of a cable and f the total resistance of the bad wire to the distant end of the cable, the distance to the fault equals $\frac{xL}{f}$.

The accuracy of the result obtained by this test depends on the resistance of the fault remaining the same during both measurements. The farther the fault lies from the testing station, the more accurate will be the result. Therefore, the more reliable result will be that obtained by making the test from the end farthest from the fault. However, if two faults exist, the best result is obtained by making the test at the end nearest to the one to be located. Where a series of observations are taken, the most accurate result is secured by using the lowest of all the readings taken with the distant end open and the lowest with the distant end grounded; but if the resistance of the fault is very unsteady, the means of each series may be used.

LOOP TESTS WITH ONE OR MORE GOOD WIRES

Varley Loop Test.—Where there is one available good wire, the *Varley loop method* is probably the most convenient and best for locating a ground or a cross on a line. The distant ends of the good and bad wires are joined together, and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown in Fig. 32. Balance the bridge, and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then,

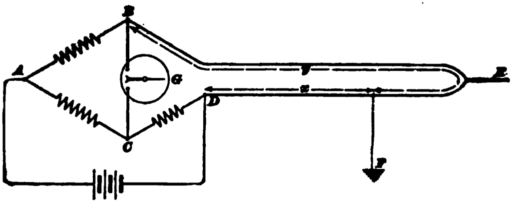


FIG. 32

connect one end of the battery to the ground instead of to D, as shown in Fig. 33. Call y the resistance from B through E to F and x, the resistance from D to F. R, the

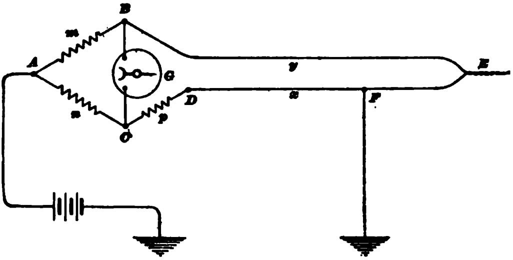


FIG. 33

total resistance of the loop, is equal to $x+y$. Then, when the bridge is balanced, $\frac{m}{n}=\frac{y}{p+x}$. Hence, the resistance,

$$x=\frac{nR-mp}{m+n}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the wire per foot, the distance to the fault is readily calculated.

Murray Loop Test.—The *Murray loop test* is quite similar to the Varley loop test. Under favorable and suitable conditions, the Varley test gives more correct results, but the great simplicity of the Murray test recommends it, especially for underground-cable work, where it is generally only necessary to locate the fault between manholes. First, have the distant ends of the available good and bad wires joined together. Then, connect the loop so formed to the bridge, as shown in Fig. 32 for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Evidently

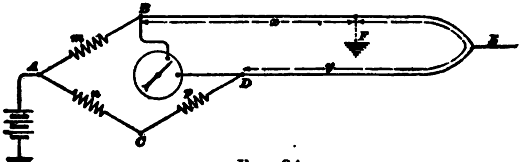


FIG. 34

$R=x+y$. Then connect the loop and battery as in Fig. 34, thus having really only two adjustable arms, because AC and CD now form only one arm. F is now the junction between the arms x and y. When the bridge is balanced,

$$\frac{m}{n+p}=\frac{x}{y}$$

Solving the two equations for x, the resistance of the line wire to the fault is

$$x=\frac{mR}{m+n+p} \qquad (1)$$

A test made by this method gives a result that is independent of the resistance at the fault. If the good and bad wires constitute a pair of wires in a cable or at least two wires of equal length, size, and material, x may be called the distance to the fault, while twice the length L of the cable may be used for R. The formula may then be written,

$$\text{Distance to fault}=\frac{2mL}{m+n+p} \qquad (2)$$

A check on the result obtained by the Murray loop test may be secured by reversing the connections of the good and bad wires with the bridge, obtaining another balance and result, and taking the mean of the two.

For reliable results with the Murray loop test, the good wire should have an insulation resistance of at least ten times that of the bad wire. Some good wire should be selected and the insulation resistance of the good and bad wires measured or compared by some suitable and convenient method to determine if this condition is fulfilled.

It is best to connect the good and bad wires directly to the bridge; but if lead wires must be used, R in the formula

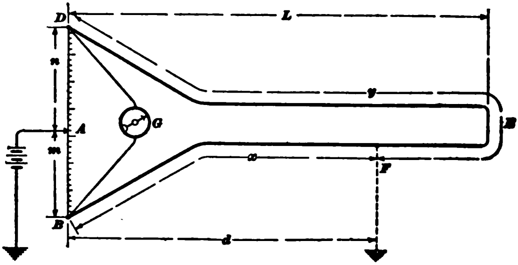


FIG. 35

for this test must be increased by the resistance of the two lead wires, and later the resistance of the lead wire in series with the bad wire must be subtracted from the calculated resistance to the fault to get the correct result. If the leading wires are short and differ from the cable wires by one or two sizes only, the error introduced does not amount to more than a few feet, which is usually negligible if the length of one of the two equal lead wires is added to the length L of the cable in formula 2, and this same length is then subtracted from the final result.

Murray Loop Test With Slide-Wire Bridge.—A very simple and sometimes a very convenient way of locating a ground on a line wire consists in using a slide-wire bridge, as shown in Fig. 35, in place of the two adjustable arms of a Wheatstone bridge in the Murray loop method. If A is a point on the slide wire that can be touched without producing a deflection of the galvanometer, then $\frac{n}{m}=\frac{y}{x}$, and $y+x=R$. Hence,

$$\text{resistance } x=\frac{mR}{n+m}, \qquad (1)$$

in which x will be the resistance along the bad wire to the ground and R the resistance of the loop, which, if not already known, must be determined by another measurement or calculated by means of a wire table.

This method is especially useful, however, when both x and R are considered as distances in miles or feet. If the two line wires are of the same size, length, and material, their resistances are proportional to their lengths; hence, the distance to the fault is

$$d=\frac{2mL}{n+m}, \qquad (2)$$

in which L is the length of one line wire, or the length of the cable containing the line wires, and d, the distance from B to the fault F.

The length $2L$ will usually be twice the length of one line wire plus the length of any lead wires (preferably of the same size and material as the line wire) that may be used to connect the two line wires to the points B, D.

If all the conductors in a cable have become defective, but some are much more heavily grounded than others, the Murray loop test may still be used with fair success, provided there is no disturbing difference of potential from an outside source between the two wires selected for the test. Even if all the conductors in a cable are heavily or equally grounded, the Murray loop test may still be successfully applied, provided there is available a good aerial wire or conductor in another cable that can be joined to the faulty conductor at the distant end.

Murray Loop Test Requiring Two Good Wires.—Where a good wire of the same size as the faulty conductor is not available, but where two good wires of any size and material either inside or outside the cable, are available, the following modification of the Murray loop test, made by H. W. Fisher, may be used. It must be possible to connect together the distant end of the faulty conductor BE and the two good available wires i, j, as shown in Fig. 36. These conductors are connected together at E and to the bridge as shown in (a). The arms m and n are adjusted until the galvanometer gives no deflection, and their values are recorded. The wire h running from the battery to the lead sheath of the cable is

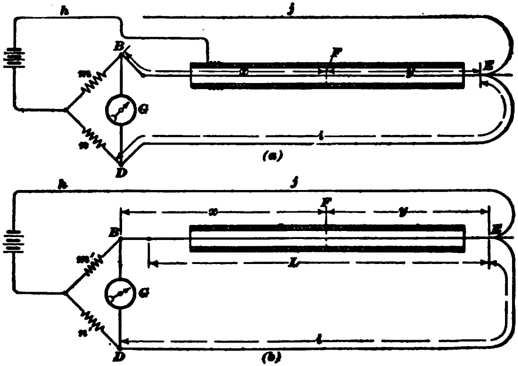


FIG. 36

then connected to the conductor j, as shown in (b), after which the bridge arms are adjusted until values m' and n' are obtained that again produce no deflection of the galvanometer. If L is the total length of the faulty conductor and x the distance to the fault, then

$$x = \frac{m(m'+n')L}{m'(m+n)}$$

In the application of this method, the resistance of conductors i, j may be quite different without affecting the result; hence, before the test is made, lead wires of the proper length may be used at either end for making the connections with the conductors *i*, *j*. Usually, the same values for *m* and *m'* can be used, thereby reducing the calculations. If the faulty wire cannot be conveniently connected to the Wheatstone bridge, a wire of the same size and material as the cable conductor may be used to make the connections; then it will be necessary to add the length of this wire to the length of the bad wire or cable, using this total length for *L* in the formula, and subtract the length of this lead wire from the calculated distance *x* to the fault.

Goodrum Slide-Wire Bridge Method.—One of the best and simplest loop methods for locating grounds and crosses

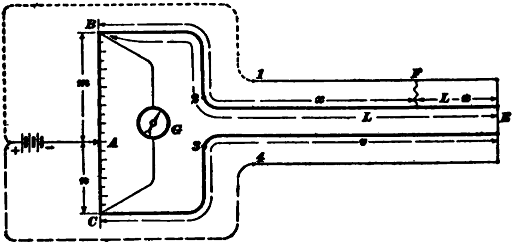


FIG. 37

where two good wires are available is that proposed by C. L. Goodrum. Theoretically, it is the same as the method just explained, but a slide-wire bridge is used instead of a regular Wheatstone bridge, thereby simplifying the test. In Fig. 37, *BC* represents a slide wire, which may be a piece of No. 24 B. & S. German-silver or iron wire stretched between posts *B* and *C*, so as to be over a scale divided into exactly 1,000 equal divisions, preferably millimeters. The smoother and more uniform the diameter and material of the wire *BC*, the more accurate will be the results. This method may be used to determine the distance *x* to a fault at *F*, which may be either a ground on wire *2* or a cross between wires *1* and *2*. Have all the wires joined together at the distant end, and at the testing end join B to *2*, C to *3*, and the battery to *4*; the dotted-line connection from the battery to line *1* is not made at this time. G represents a galvanometer or a sufficiently sensitive millivoltmeter. Adjust the pointer along the slide wire until a point A is found where G gives no deflection. The connecting wire from B to *2* should be sufficiently short or large in diameter, or both, so that its resistance may be neglected. Then,

$$\frac{L}{v}=\frac{m}{n}$$

in which L = length of cable;
v = length of wire *3*;
m = distance BA, that is, the scale reading from the end B to the point of balance A;
n = distance AC, that is, the length $BC-m$.

If line *2* is crossed at F with line *1*, then connect the positive terminal of the battery to this wire *1*, as represented by the light dotted line, instead of to line *4*, as represented by the dash line. If line *2* is grounded at F, connect the positive terminal of the battery to ground instead of to line *1*. In either case, the procedure is as follows: Again, balance the bridge and let m' be the new reading on the slide-wire scale from B to the new point of balance. Then,

$$\frac{x}{L-x+v}=\frac{m'}{n'}$$

Solving these equations for x gives

$$x=\frac{m'L}{m}$$

Although two good wires *3* and *4* are required, they may be of any reasonable size, material, or length, and they may be wires inside or outside the cable. The distance x to the ground or cross is merely a certain ratio $\frac{m'}{m}$ of the total length L of the cable, and this distance is independent of the length of the good wires. The only requisite necessary for extreme accuracy is that the faulty wire *2* shall twist in the same uniform manner throughout the entire length of the cable. If it starts as an inside wire, it must continue as such. Most loop tests not only assume this to be the case, but also assume that the good and faulty wires are of exactly the same length, which is not true when one is an inside wire and the other an outside wire in a telephone or telegraph cable, because the latter twists around the inner wires and is therefore somewhat longer than any wire inside of it. This method requires only two balances, and only one connection has to be changed. An apparatus, called the *lineman's faultfinder*, has been placed on the market for locating faults by practically this method.

For the location of grounds, some form of loop test is usually superior to all others. When the leakage along the lines is great, the loop tests may be seriously vitiated thereby, in common with other methods. The next best method is the earth overlap, which is more suitable than the Blavier method for a fault that has a varying resistance or much polarization. Since the earth overlap method requires tests from both ends of the line, it is not always applicable, in which case the best alternative method is the Blavier.

OTHER METHODS OF LOCATING GROUNDS

Receiver Method.—The following method is said by A. B. Dungan to be very simple and reliable for locating grounds on aerial cable conductors, provided the cable is free from dead grounds against other cables and guy wires. In Fig. 38

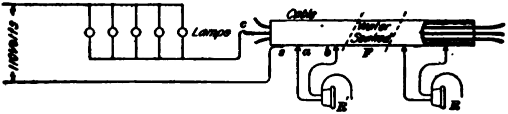


FIG. 38

is shown the necessary connections, consisting of a lead-covered cable with its sheath connected to one side of a 110-volt lighting circuit. The conductor or conductors grounded at some point *F* are connected through a suitable resistance, such as five 110-volt, 16-c.-p. lamps in parallel, to the other side of the 110-volt lighting circuit; either direct or alternating current may be used. If a portion of the cable is water-soaked or the cable is injured so that one or more conductors are more or less grounded on the lead sheath. then some current will pass from the conductors at the fault to the sheath, through which it returns to the office. If an ordinary head-telephone receiver wound to a very low resistance, about $\frac{1}{100}$ ohm, has its two terminals touched to two points *a*, *b*, as far apart as convenient on the lead sheath of the cable and at any place between the exchange and the point *F*, a noticeable click will be heard in the receiver, due to a part of the current passing through it. If the same connection is made beyond the point *F*, no sound whatever will be heard in the receiver. The points *a*, *b* should be kept the same distance apart for all comparative tests. In this way, the most inexperienced lineman is said to be able to locate within a few inches such a ground in a cable. A similar test may be made with a millivoltmeter, the terminals of which are touched to the lead sheath a few feet apart. On the home end of the fault, the deflection will always be in the same direction; beyond the fault, there will be no deflection.

Location of Ground by Voltmeter.—The distance to a ground on a line can be determined only approximately by means of a voltmeter, and then only when the resistance at the ground is negligible compared with the resistance of the bad wire from the testing end to the ground. To estimate the distance to the ground, connect the voltmeter across the terminals of a suitable battery and call the reading *d*. Then connect the same battery and voltmeter in series with the line to be tested and the ground, thus forming a circuit through the battery, voltmeter, line, and ground. Let the voltmeter reading be *d'*. Then, if *r* is the resistance of the voltmeter, the resistance of the circuit is

$$R=r\left(\frac{d}{d'}-1\right) \qquad (1)$$

This is the same formula used in determining the insulation resistance of a line. Since the line is grounded at some point, *R* is only larger than *r* by the resistance of the line, earth return, and ground contacts. Hence, the resistance *x* to the ground is $R-r$ and is given by the formula

$$x=r\left(\frac{d}{d'}-2\right) \qquad (2)$$

Locating a Bad Escape.—A method of locating a *bad escape* on a telegraph or telephone line wire is to insert, at the testing office, between the line and the ground, a voltmeter and a battery in series. Then have the intermediate offices open the line wire in turn, beginning at an office beyond the escape. A voltmeter needle will indicate the amount of escape until the first office between the escape and the testing office opens the wire, then the needle will show practically no deflection if the insulation of the line is in proper condition.

LOCATING CROSSES

Where the two crossed wires run parallel and have the same resistance per mile, it is a rather simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered. As a rule, the loop methods given for locating grounds can also be employed for locating crosses, in which case one of the crossed wires is used instead of the ground.

RESISTANCE AT CROSS NEGLIGIBLE

To Determine the Resistance of Cross.—It is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines with a Wheat-

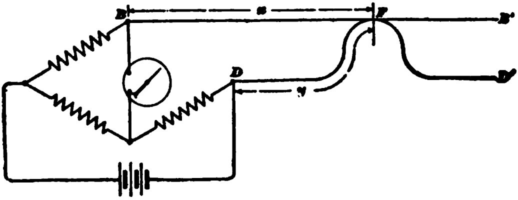


FIG. 39

stone bridge, as shown in Fig. 39, so as to measure the resistance from *B* to *D* through the cross *F*; call this *a*. Then, $x+y=a$.

Now have the wires connected together at the nearest station beyond the cross and again measure the resistance; call this b. If b is only a little less than a, the resistance of the cross is probably negligible, but not necessarily perfectly so; for if the cross is near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible.

Cross Between Two Wires of Same Size and Material.—If the resistance of the cross is negligible, and if the two wires are of the same size and material and run along parallel the whole distance from the testing station to the cross, the distance x to the fault, in miles, is given by the following formula:

$$x=\frac{a}{2s}$$

in which s is the resistance per mile along one wire, and a, the resistance of the loop through the cross.

Resistance of Two Line Wires per Unit Length Not Equal. If the wires are still parallel with each other, but the resistance of one is w ohms per mile and of the other v ohms per mile, the formula just given becomes

$$x=\frac{a}{w+v}$$

RESISTANCE OF CROSS NOT NEGLIGIBLE BUT CONSTANT

Where the resistance of the cross is constant, but not negligible, either the Varley or the Murray loop method explained for locating grounds may be used; in this case, one of the crossed wires is used instead of the ground.

Method Requiring Three Measurements.—First, measure the resistance of the line as connected in Fig. 40. Let this resistance be a ohms; hence,

$$x+u=a$$

Then, measure the resistance of the loop from B to D through the cross whose resistance will be called s ohms.

with the distant ends of the two crossed wires open. Let the resistance so measured be b; hence,

$$x+z+y=b$$

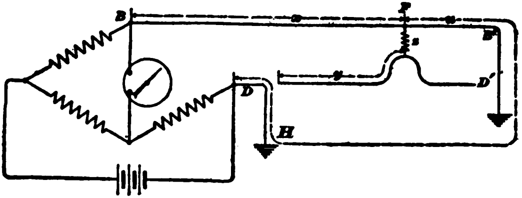


FIG. 40

Finally, measure the resistance through y, z, and u, as connected in Fig. 41. Let this resistance be c; hence,

$$y+z+u=c$$

Then, the resistance along BB' to the cross is

$$x=\frac{a+b-c}{2}$$

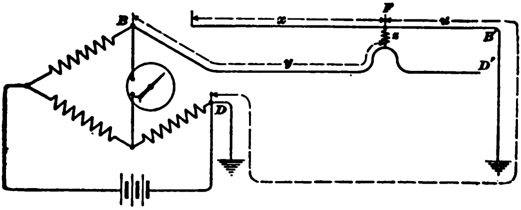


FIG. 41

It will be noticed that the resistance of the cross z is eliminated, so that if z remains constant during the second and third measurements, the formula is accurate and independent of the value of z. This method has the disadvantage of requiring three measurements, during two of which the resistance of the fault is supposed to remain constant.

RESISTANCE OF CROSS NEITHER NEGLIGIBLE NOR CONSTANT

A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. First, connect up as shown in Fig. 40, and measure the resistance of the line BB', including the ground return path Let this be a; hence,

$$x+u=a$$

Then, connect the bridges as shown in Fig. 42, using only two arms p and n of the bridge. The resistance of the cross z and that portion y of the line DD' is included in the galvanometer circuit, and, therefore, this resistance z and y will not

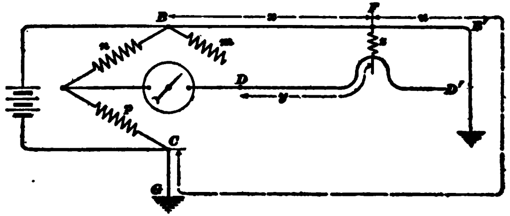


FIG. 42

enter into the result; also, the final formula is entirely independent of the resistance of the cross whether it is constant or not. After adjusting the bridge until there is no deflection,

$$nu=px$$

Solving these equations for x, the following formula for the resistance along the wire BB' to the cross is obtained:

$$x=\frac{na}{p+n} \qquad (1)$$

Finally, by dividing x by the resistance of the line BB' per mile, the distance in miles from B to the cross F is obtained.

If more convenient to do so, the end B of the wire may be joined to the end of the arm m. In this case, x in the second equation must be changed to $m+x$, which results in the following formula:

$$x = \frac{na - pm}{p + n} \qquad (2)$$

Slide-Wire Bridge Method.—To locate a cross between two wires of equal size by means of a slide-wire bridge, connect as shown in Fig. 43. A good wire, which is necessary in addition to the two crossed wires, is connected to either of the crossed wires at some point beyond the cross. The

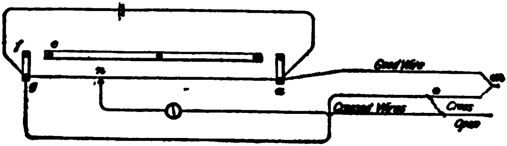


FIG. 43

home end of the crossed wire, to which the good wire is connected, is joined to the bridge at g; and one terminal of the galvanometer is connected to the other crossed wire, which must be open at the distant end. Then, find a point n on the slide wire that produces no deflection of the galvanometer. Then, the

$$\text{distance } go = \text{distance } goma \times \frac{\text{length } gn}{\text{length } ga}$$

For the distance *goma*, twice the length of one line wire or twice the length of a cable being tested may be used. This result is independent of the resistance of the fault, even if it varies during the test. This is practically the Murray loop test made with a slide-wire bridge.

One Wire in Use.—The method about to be described may be used to determine the resistance of one wire or the distance to a cross between that wire and another wire while the latter is in regular use as a telegraph line. The result is not, however, independent of the resistance of the cross. By this method, low-resistance crosses and grounds may be located, and if a balance can be secured while the fault exists, swinging crosses and grounds may be approximately located.

The connections for this test are shown in Fig. 44, in which BC represents a slide-wire bridge; R, a known resistance; G, a sensitive galvanometer with its usual shunt r and short-circuiting key k; CFg', the wire in use; and HF, the line wire, which is crossed at F with the other line wire and is open beyond the cross.

To make the test, set the slide about midway along the slide wire BC, short-circuit or remove all the resistance at R, open the galvanometer short-circuit key k, and adjust the position of A along the slide wire until the galvanometer returns to its normal position of rest. The telegraph relays may be in service all the time the test is made, although the test is more readily made with this relay circuit permanently closed. Remove or open the galvanometer shunt, adjust

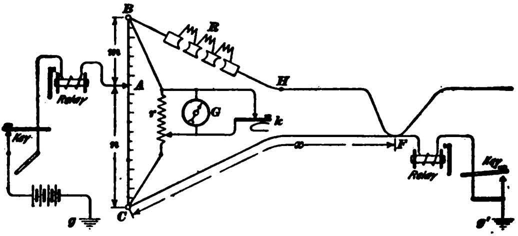


FIG. 44

the position of A until the galvanometer gives no deflection, and note the lengths m and n. Then, insert the resistance R between B and the crossed wire HF, move the pointer A until the bridge is balanced again, and note the lengths m' and n'. The resistance x of the working wire from C to the cross F may then be calculated by the formula

$$x = \frac{n \times n' \times R}{(m' - m)(m + n)}$$

$m + n$ is the total length of the slide wire and is usually 1,000 or 100. The resistance used at R should be enough to make the two points of balance quite different. The greater the resistance of CF, that is, the greater the distance to the cross, the greater must be R.

ROUGH TESTS

It is frequently necessary to make *rough tests* to show whether circuits are continuous or broken, whether crossed, grounded, or properly insulated. These tests do not require accurate measurements, as they are made merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

TESTS WITH MAGNETO-GENERATOR AND BELL

Magneto Testing Set.—A very common and useful testing instrument consists of a magneto-generator and polarized ringer, together with a simple telephone, all mounted compactly in a box provided with a strap for convenience in carrying. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt.

Continuity Tests.—In testing wires for continuity, the terminals of the magneto-set should be connected to the terminals of the wire and the generator operated, the switch, if one is provided on the testing set, being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be relied on with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current to flow through the bell to operate it, even though the line or lines are open at some distant point.

Testing for Crosses.—In testing a line for crosses, one terminal of the magneto-set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto-set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. Under these conditions, a ringing of the bell will indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross. As in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists, if the line under test is very long. The insulation may be perfect and yet a sufficient current may pass to and from the line, due to its static capacity, and through the bell to cause it to ring.

Telephone Testing Set.—In many forms of testing sets, microphone transmitters and batteries for operating them are also included. A portable telephone testing set, shown in Fig. 45, contains a standard three- or four-bar generator, a 1,000-ohm bell, and other telephone devices. The receiver and transmitter are secured to one handle, the granular-carbon transmitter *t* being provided with a metal mouthpiece that prevents the breaking of the same. In the handle of the *microtelephone*, as it is termed, is a push button that, when closed, connects the batteries *b*, *b* in the transmitter circuit. This prevents the exhaustion of the batteries when not actually in use for talking purposes. The door of the testing set may be closed when the microtelephone is outside. When the full voltage of the generator is desired for ringing on a line, the bell can be cut out of the circuit by means of a push button. The generator is provided with collecting devices by means of which either alternating or direct pulsating currents may be obtained; a switch *s* through

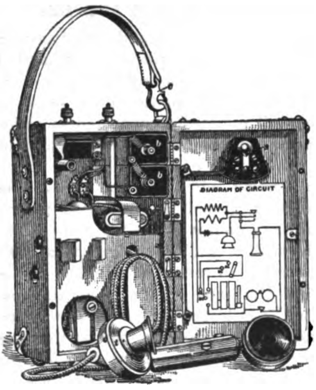


FIG. 45

which the desired current may be obtained is placed on the inside of the cover, where a diagram of the wiring of the set is shown.

TESTS WITH VOLTMETER OR CURRENT-DETECTOR GALVANOMETER

In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto-set, a cheap galvanometer for detecting currents, a voltmeter, or millivoltmeter may be used. In testing for grounds or crosses, the voltmeter or galvanometer should be connected in series with several cells of battery, and one terminal of this circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the needle may take place whenever the circuit is first closed, due to the rush of current that is necessary to charge the wire. If the insulation is good, the needle will soon return to zero; but if a leak exists from a line to ground or to the other wire with which it is being tested, the needle will remain permanently deflected. Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about fifty cells is used, but if a very high insulation resistance must be measured with more accuracy, more sensitive methods should be employed.

In testing for continuity, the distant end of the line should be grounded and the voltmeter, or galvanometer, and battery applied between the wire under test and ground or the distant end of the line should be connected with another wire, known to be good, and the voltmeter, or galvanometer, and battery applied between the wire under test and the good wire. In this case, a permanent deflection of the needle will denote that the wire is continuous; while if the needle returns to zero, it is an indication of a broken wire. If the needle is very unsteady, there is probably a loose connection somewhere.

TESTS WITH TELEPHONE RECEIVER

A good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than a magneto testing set or a detector galvanometer. The ordinary watch-case receiver with a head-band for attaching it to the ear of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminal may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

Tests for Grounds and Crosses With a Receiver.—In using the receiver for making rough tests for grounds or crosses on conductors in a lead-covered cable, one terminal of the testing circuit, including the receiver and battery, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at both ends. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must be carefully separated from each other and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire, even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire; but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, hold the terminal of the testing set against the wire several seconds, and then break and quickly remake the connection. If no sound is heard at the instant the connection is again made, the insulation is good, while a continuance of the clicks each time the circuit is remade will indicate that the wire is grounded. The loudness of the click depends on the sensitiveness of the telephone used, the number and voltage of the cells used, the electrostatic capacity of the conductor, the resistance of the insulation, and the interval of time between the break and make. Under ordinary conditions, with a telephone cable from 1,000 ft. to a few miles in length, 1 sec. between a break and the next make, and a battery of 1 volt, no click usually means at least 50 megohms resistance between the conductor and the ground. This number increases about in proportion to the increase in electromotive force used.

Tests for Continuity With a Receiver.—In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires in succession at the near end of the cable, all the wires at this end being carefully separated from each other. In this case, a continuation of the clicks, on tapping, will indicate that the wire being tested is continuous, while the cessation, after a few taps, will indicate that it is broken. It is probably better in making this test, to use an ordinary vibrating bell or buzzer instead of a receiver, for then, if the wire is ruptured in such a manner as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it might allow enough to pass to produce a decided click in the receiver.

When the conductors in a cable are to be tested and their ends numbered and connected to terminals, the first thing to do is to test out a pair that may be used for communication during the rest of the test. A common method of locating this talking pair is to have the man at the distant end *M*, Fig. 46 (*a*), connect his head-receiver between one conductor and the lead sheath, all conductors at that end being preferably fanned out and at least insulated from the conductor that is being tested. The man at the office end *O* then connects one terminal of his head-receiver to the sheath, and the other terminal to two or three dry cells *B*, while with the free end *d* he taps all the conductor terminals, one at a time, until both men get a decided click in their receivers, which indicates to them that the wire to which the pole man *M* has his receiver connected has been found by the office man *O*.

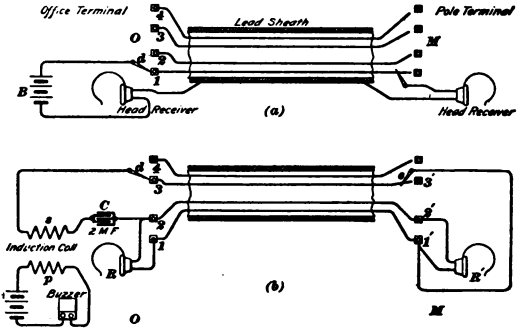


FIG. 46

The other wire *2* of this pair can be readily found, and, if necessary, tested in a similar manner.

The connections shown at both ends of Fig. 46 (*b*) are then made, and the pair *1–2* used to talk over. The pole man *M* then connects his terminal *e* to any wire whose location and number he desires, and the office man *O* feels for this wire by touching, with *d*, all his terminals until a loud hum indicates to both of them that the desired wire has been picked up by the office man *O*. The buzzer makes and breaks the circuit containing the primary winding *p* of an induction coil, thereby inducing an alternating electromotive force in the secondary winding *s*. This may, at all times, produce a slight hum in the receivers, due to the slight charging and discharging of the 2-microfarads condenser *C*, but the hum will be very much louder when the circuit of *s* is completed through a conductor.

The office man *O* then removes his needle *d* from the conductor just found and tells the pole man *M* its number, so that the latter can connect it to the terminal of the same number at his end. Should the loud hum be also obtained if the office man *O* touches his needle to *4* while the pole man *M* keeps his needle against *3'*, conductors *3* and *4* are probably crossed; and if the loud hum should be obtained if the office man *O* touches the sheath, the conductor touching *e* is probably grounded. In this way, each conductor may be tested for a cross or ground. When testing cables while in use on central-energy systems, the source of current should be at the office end in any case. As the charging and discharging of an open cable line, especially a long one, may cause a click or hum in a receiver, many prefer to use a buzzer instead of a receiver for such tests.

WIRE CHIEF'S TESTING CIRCUIT FOR A MAGNETO-EXCHANGE

A wire chief's testing circuit suitable for use in medium-sized magneto exchanges is shown in Fig. 47. Jacks *1* to *11* may be mounted in a position to suit the testing apparatus. Jacks *1* and *4* connect to the line side and jacks *2* and *3* to the switchboard side of the test clip adapted to fit in the arrester springs at the terminal rack. Any circuit can thus be tested toward the switchboard or line. To jacks *5*, *6*, and *7* are connected two batteries of any suitable voltage, and by means of the resistance *r* the strength of the current may be regulated, provided jack *7* is used. Jack *8* is connected to a good ground. Jacks *9* and *10* are connected to a two-conductor plug at the switchboard, where it may be inserted in any line to be tested from that point for grounds, crosses, short-circuits, etc. Jack *11* and its drop are connected with a jack and drop at the switchboard, so that inspectors may be connected to the wire chief when they c ll up the exchange from any subscriber's station. The wire chief may also ring up

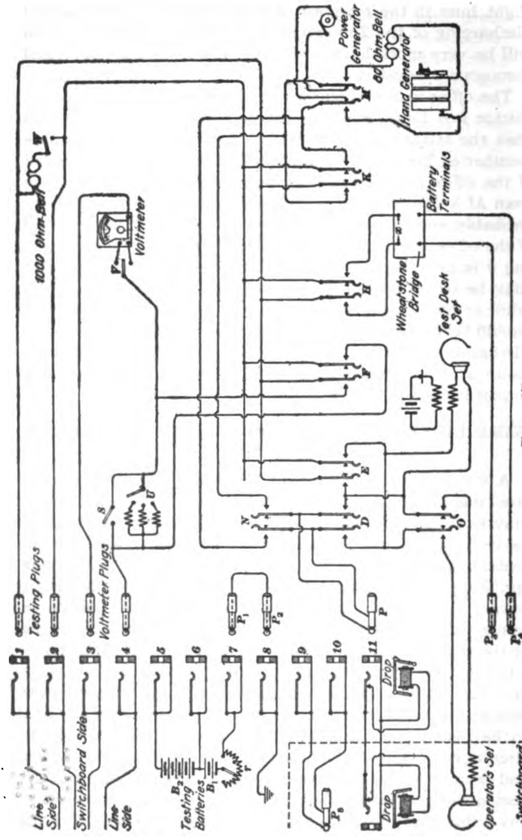

Power Generator
80 Ohm Bell
Hand Generator
1000 Ohm Bell
Voltmeter
Battery Terminals
Wheatstone Bridge
Test Desk Set
Testing Plugs
Voltmeter Plugs
Line Side
Switchboard Side
Line Side
Testing Batteries
Drop
Drop
Operator's Set
Switchboard

FIG 47

the operator over the same circuit by inserting the plug *P* in jack *11* and closing key *N*.

The testing plugs are connected to a number of keys that are normally open. If it is desired to test a subscriber's instrument, the testing plugs may be inserted in jacks *1* and *4* or in *9* and *10*. Then, closing *K* should ring the subscriber's bell with current from the power generator; if it is desired to use a hand generator and an ordinary 80-ohm bell, close key *M* in addition to key *K*. A cross or open circuit in local apparatus or on short lines, where the electrostatic capacity is not large, may be determined by using the hand generator and bell. By closing switch *W*, the ability of a subscriber's generator to ring a 1,000-ohm, or other suitable bell, may be tested. By closing the key *H*, the Wheatstone bridge may be connected to the testing plugs for a resistance or loop test on any line or either side of any line. The battery terminals of the bridge are connected to plugs so that the testing battery terminating at jacks *5*, *6*, and *7* may be used to facilitate the making of loop tests. To measure the loop resistance through the two sides of a crossed or grounded line, insert, for instance, the testing plugs in jacks *1* and *4*, close key *H*, and insert plugs P_3 and P_4 in jacks *6* and *7*. To obtain the second balance, which requires one side of battery to be grounded, remove the proper plug P_3 or P_4 from jack *6* or *7*, and ground that side of the battery by connecting jack *6* or *7* to jack *8* with the plugs P_1 and P_2. Where the testing set has its own battery, it will simply be necessary to have one side of its own battery connected to one plug for insertion in the grounded jack *8* for the second balance. If the ground seems to be on the wrong side of the line, reverse the position of the test plugs in the jacks. A voltmeter will readily determine which side of the line is grounded. These connections are very convenient for making loop tests.

To test for insulation resistance or crosses with the voltmeter, insert the voltmeter plugs in the jacks of the testing battery—one of the testing plugs in the jack of the line to be tested, and the other testing plug in jack *8*, and close key *F*. Switch *V* allows either scale of the voltmeter to be used, switch S allows the voltmeter to be connected directly across the testing battery, and switch U enables readings of the voltmeter to be taken across any one of three known resistances. This is convenient for estimating the resistance, by voltmeter readings, to a ground or cross, for with the same battery the reading of the voltmeter will be inversely proportional to the total resistance of the circuit. Closing key E connects the test-desk set across the testing plugs; closing D connects it across the calling plug F, which may be used to call up an operator or to converse with an inspector. Closing key O connects the test-desk set through an order wire to a switchboard operator's set. O, D, E, F, H, and M should be keys, or cams, that will remain in either position, but keys K and N should return to their normal positions, as indicated in the figure, when released.

WIRE CHIEF'S TESTING CIRCUIT FOR A CENTRAL-ENERGY EXCHANGE

In Fig. 48 are shown the circuits of a wire chief's testing table used in connection with a central-energy exchange. With this arrangement, the wire chief may make tests with a voltmeter or a Wheatstone bridge and ring or talk over a line metallic or from either side to ground. By using a four-point plug or test clip suitable for insertion in the terminal head where the heat coils are located, tests can be made on a circuit either out on the line or through the exchange. The wire chief's telephone may be used independent of the test circuits as an ordinary instrument. The generator has an 80-ohm ringer in series with it, so as to obtain the same results as when testing with a magneto. An extra key could be readily connected so that either a power or hand generator could be used.

The operation of the set is as follows: After inserting the test plug between heat-coil springs on the cable terminal, key *5* is thrown. This puts the voltmeter VM and test battery across the line. To test one side to ground, key *6* is thrown; and by throwing both keys *6* and *7* the other side is tested to ground. To listen on the line, key *3* is thrown. This cuts out the voltmeter, and if it is desired to talk,

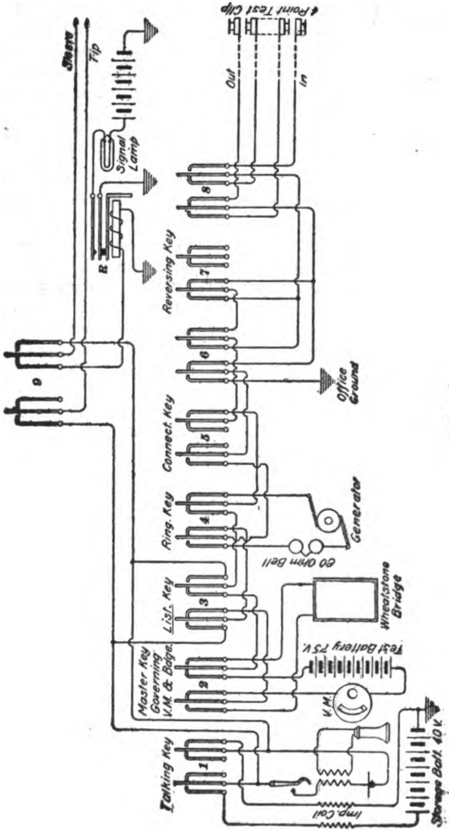

Sleeve
Tip
Signal Lamp
B
4 Point Test Clip
Out
In
9
8
Reversing Key
7
6
Office Ground
Connect Key
5
Ring. Key
4
Generator
60 Ohm Bell
List. Key
3
Wheatstone Bridge
Master Key Governing V.M. & Bdge.
2
Test Battery 75 V.
V.M.
Talking Key
1
Imp. Coil
Storage Batt. 40 V.

Fig. 48

close key *1*, which supplies both wire chief's and subscriber's telephone with battery. Ringing is done with key *4*. Key *2* places the Wheatstone bridge in circuit instead of the voltmeter and battery, and by using key *8*, the wire chief can talk, ring, or test back toward the exchange.

The test telephone may be used as a regular instrument by throwing key *9*. This places the wire chief's telephone across a line running to the switchboard, and the operator receives a signal in the same manner as from a subscriber. An operator may signal the wire chief by inserting a plug in the jack corresponding to this telephone number. In doing this, the positive battery is put on the sleeve of the jack, which connects with the relay *R* controlling the signal lamp on the testing table. When the wire chief answers by throwing key *9*, the relay circuit is opened, putting out the lamp. It is not necessary to use key *1* in talking through the switchboard.

TELEPHONY

Telephony is the art of transmitting articulate speech and other sounds between distant points by means of fluctuations in an electric current flowing between those points. The successive vibrations of the human voice that form distinguishable and intelligible sounds constitute *articulate speech*. These vibrations are probably the most complex in the whole realm of sound.

TELEPHONE APPARATUS

TELEPHONE TRANSMITTERS

A *telephone transmitter* is an instrument that serves to produce variations in the current flowing in the circuit in unison with the sound waves that reach the transmitter. Practically all telephone transmitters now used depend on the fact that the electrical resistance between two or more bodies either in light or in loose contact is varied greatly by slight changes in the pressure between them. Such transmitters are frequently called *microphones*, or *battery transmitters*.

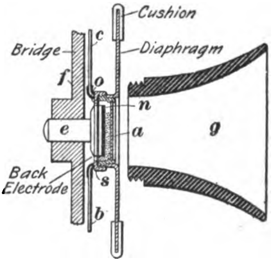


FIG. 1

A view of the working parts of a Dean transmitter is shown in Fig. 1. A metal cup *a*, plated or lined on the inside with platinum, forms the front electrode, and is held in an opening in the center of an aluminum diaphragm. The rear electrode *e* is held rigidly in a metal bridge piece *f*, which is fastened to the frame that supports the mouthpiece *g* and the whole transmitter. This rear electrode consists of a hard, polished carbon button *n* secured to a brass button, between two parts of which is clamped a mica ring, or diaphragm, *o*, the outer edge of which is clamped against the front electrode *a* by means of an annular metal ring *s* that screws over *a*. The space between the rear carbon button and the platinum-faced surface inside the cup is partly filled with hard, granular carbon of uniform size. Two light dampening springs *b*, *c*, having tips covered with rubber or felt, press lightly against the cup system and prevent the diaphragm from vibrating at its natural rate when the air waves have ceased, which would cause indistinctness. To adapt the transmitter for local-battery or common-battery systems, the cup and the rear electrode, which form an easily changed unit, are the only parts that have to be changed.

The current from a battery passes from one terminal through *e*–carbon electrode–granular carbon–metal cup to the other electrode. When talking close to the transmitter, the aluminum diaphragm and the cup are forced to vibrate in unison with the sound waves produced in the air, thus causing the pressure of the front and rear electrodes on the granular carbon to vary and, consequently, the resistance of the transmitter, to vary in a similar manner. Therefore, with a constant E. M. F. supplied by a battery, the variation in resistance causes a variation of current that is in unison with the original voice vibrations. In the Dean transmitter, the entire granular carbon chamber is well shaken up, which probably decreases the liability of the granules becoming packed. The thin mica ring *o* is flexible enough to allow the diaphragm and its cup to vibrate sufficiently to produce good articulation and volume of sound.

The variation in resistance of any transmitter of similar construction is undoubtedly due to the variation in area of the surfaces of granules and electrodes that are in contact at any instant, and not to any compression within the carbon itself. The greater the area of the surfaces in contact, the less the resistance, and vice versa. While transmitters of different makes vary more or less in construction, all those in practical use in the United States depend on the principle just mentioned. Practically all transmitters have rear and front electrodes of carbon, or one may be a gold-plated or platinum-plated metal, granular carbon being placed between them. The front electrode is attached to the diaphragm in various ways, while the rear one is rigidly supported.

TELEPHONE RECEIVER

A *telephone receiver* of modern construction is shown in Fig. 2. It consists of a U-shaped permanent magnet *a*, to the ends of which are fastened soft-iron pole pieces *c*, *c'*; over each pole piece is placed a coil of fine wire. The two coils are connected in series, so as to tend to make the front end of one a north pole and the front end of the other a south pole when a current flows through both coils in a certain direction. The coils are usually wound to a resistance of about 70, 100, or 125 ohms, although they have been wound

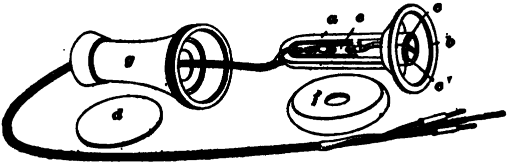


FIG. 2

as low as 10 ohms and as high as 5,000 ohms. The pole pieces pass through the bottom of a metal cup *b*, which is thus secured firmly in place. On the rim of this cup rests a tinned sheet-iron diaphragm *d*, which is about 2 in. in diameter. The receiver cords are connected to the terminals of the coils at *e*, being secured at the rear in such a manner that if the receiver is dropped the strain comes upon the cord and the rear end of the permanent magnet and not upon any connections nor upon the hard-rubber or composition shell *g*. This shell slips over the working parts of the receiver and is held in place by the ear piece *f* that screws on the shell. When all parts are in place, the diaphragm is held as close to the pole pieces as is possible without allowing it, even while vibrating, to touch either of them. The distinguishing feature of this particular receiver is the nearly semicircular shape of the pole pieces; this shape, it is claimed, gives a more uniform distribution of the lines of force through the diaphragm than the rectangular-shaped pole pieces which are more extensively used. The permanent magnet of many double-pole receivers consists of two permanent bar magnets, held the proper distance apart by means of a piece of soft iron, and a bolt at the rear end. A receiver having a U-shaped permanent magnet is called a *double-pole receiver*, because both poles are presented to the diaphragm. Formerly, straight-bar magnets with one pole only presented to the diaphragm were almost exclusively used in the United States; they were called *single-pole receivers*.

Operation of Receivers.—If a current flows through the coils in such a direction that the lines of force due to it coincide with those due to the permanent magnet, the diaphragm will be pulled closer toward the pole pieces; whereas, if the current flows through the coils in such a direction that the lines of force due to it oppose those due to the permanent magnet, the strength of the magnetic field will be reduced and the diaphragm will spring farther from the poles. If an undulating current always flowing in the same direction is sent through the coils, the lines of force due to it and, hence, the pull on the diaphragm, will increase while the current is increasing and decrease while the current is decreasing. Thus, whether the lines of force due to the current in the coils assist or oppose those due to the permanent magnet, a varying pull is produced on the diaphragm that causes vibrations in the latter that are in unison with the changes in the current. Thus, either an undulating or an alternating current may cause the receiver to produce sounds.

INDUCTION COIL

One more step will explain the principles involved wherever an *induction*, or *repeating*, *coil* is used in telephone systems. In Fig. 3, *T* represents a transmitter, *B* a battery, *P* the primary, and S the secondary winding of an induction coil, and R a receiver. By speaking toward the transmitter, its resistance varies, causing a variable current to flow through the primary winding. This induces in the secondary winding an alternating current that flows through the receiver and causes the receiver diaphragm to vibrate in exactly the same manner, though somewhat less vigorously,

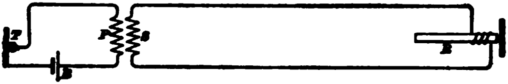


Fig. 3

than the transmitter diaphragm. Hence, sounds produced at the transmitter are reproduced by the receiver. The primary winding is usually composed of a small number of turns of about No. 22 B. & S. copper wire, and the secondary winding of a large number of turns of about No. 34 B. & S. copper wire wound over the primary. Hence, the E. M. F. produced in the secondary is many times greater than that in the primary.

Repeating coils are wound with an equal number of turns in each coil, so that they will repeat equally well in both directions. They are used in central-energy systems and also where it is desirable to have communication between

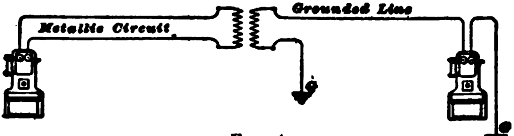


Fig. 4

a complete metallic circuit and a ground-return, or common-return, system, without making a metallic connection between the two circuits. This is shown in Fig. 4. The metallic circuit is thus kept free from grounds, and induction from outside disturbing circuits is limited to that which ordinarily affects the grounded line.

CALLING APPARATUS

For attracting the attention of a party at a distant station, the magneto generator and the polarized bell have been extensively used.

Magneto Generators.—A *magneto generator* is a very simple form of dynamo. It consists usually of an armature of iron, wound with a large number of turns of fine insulated copper wire, and is adapted to be readily revolved between the poles of a powerful permanent magnet. In Fig. 5, *A* represents the armature, around the shank of which is wound a coil of wire. *S* and *N* are the south and north poles of one

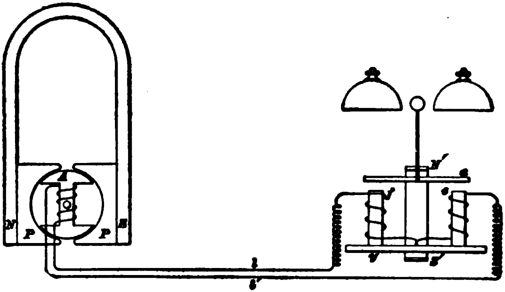


FIG. 5

of 3 to 6 permanent magnets placed in a row, and *P*, *P* are the pole pieces, usually of soft cast iron, fastened to the magnets and bored out so as to afford a space in which the armature may revolve. When the armature revolves, the coil cuts the lines of force produced by the permanent magnets and an E. M. F. is developed in the winding. In a complete revolution of the armature, the number of lines passing through the coil will vary from a maximum in one direction through zero to a maximum in the other direction, and then through zero again to the first maximum. It therefore follows that for one revolution two impulses of current will flow in the coil, first in one direction and then in the opposite direction. The current is therefore an alternating one.

A very important adjunct to the magneto generator is an automatic device that either short-circuits the armature or opens the armature circuit when the armature is at rest. It is found desirable in series telephones, while the generator is not in use, to remove the resistance of the armature from the circuit by means of such an automatic device, called a *shunt*, which forms a path of practically no resistance around the armature. In a bridging telephone, however, it is desirable to have the automatic device open the armature circuit when the latter is at rest. This short-circuiting or opening of the armature circuit is accomplished automatically in a variety of ways. At the usual rate of turning by hand, the voltage given by a telephone generator is from 65 to 75 volts, at a frequency of about 15 complete cycles per second.

Polarized Bells.—A *polarized bell*, or *ringer*, as it is often called, is shown at the right-hand side of Fig. 5, in which *f* and *e* represent soft-iron cores, upon which are wound coils of wire connected in series with the line wires *l*, *l'*. *N'*, *S'* is a permanent magnet, and *a* is a soft-iron armature pivoted at the middle. To the center of the armature is fastened a slender rod, terminating at the top end in a small ball. When no current is flowing through the coils, the permanent magnet causes both of the upper ends of the soft-iron cores *e*, *f* to be south poles and the both ends of the armature *a* opposite the cores to be north poles. Consequently, the armature will be attracted by both cores and will rest against the core to which it happens to be nearest. If a current passes through the coils in such a direction as to increase the stength of the south pole at *f* and to make *e* a north pole or a weaker south pole, then *f* will attract the end of the armature opposite it, while *e* will repel its end of the armature or attract it with a much smaller force. If the current is now reversed in direction so that *f* becomes a north pole or a weaker south pole and *e* a stronger south pole, the action will be reversed, and *e* will attract its end of the armature and *f* will repel its end or attract it with a much smaller force. By thus reversing the direction of the current about fifteen times per second, the ball at the top of the rod fastened to the armature will vibrate between the two gongs and produce a continuous ringing sound. For series telephones, the ringer coils are wound to a resistance of from 80 to 120 ohms. For bridging telephones, the ringer coils are usually wound to a resistance of 1,000, 1,200, 1,600 and even as high as 5,000 ohms.

Magneto-Bells.—The term *magneto-bell* is usually applied to the combination of a magneto generator and a ringer mounted in the same box. A fairly good generator will ring its own bell through a resistance of 10,000 ohms, which is an ordinary test applied to them. Thus, a 10,000-ohm magneto-bell or magneto generator does not mean that either the bell or the generator has a resistance of 10,000 ohms, but that the generator should be able to ring its own bell through a circuit whose total resistance is 10,000 ohms.

Hook Switches.—As the apparatus for sending and receiving both articulate speech and signals performs entirely different functions, it has been found necessary to provide means for cutting one set out of the circuit while

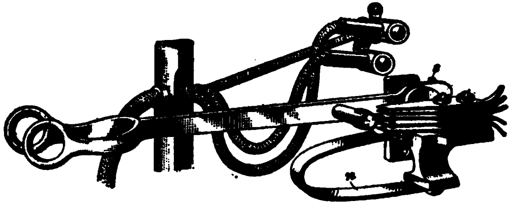


FIG. 6

the other is in use. During the idle periods of the instrument the ringer must be left in the circuit, but as soon as the call is received or sent, it is necessary to cut the calling apparatus out of the circuit and the talking apparatus into the circuit. For this purpose *automatic hook switches* are used.

The Kellogg hook switch is shown in Fig. 6. The hook is held down by the weight of the receiver, which causes the lower contact springs to be electrically connected together. When the receiver is removed from the hook, the spring *n* lifts the hook, thus separating the lower contact springs from one another and causing the upper contact springs to be electrically connected together. Evidently the number of spring contacts above or below the middle spring may be diminished or increased, or some of the springs may be left unused, or the middle spring may have an insulating piece on the top or bottom of the movable end, so that it will make connection only with the springs below or above; thus, this hook switch may be made suitable for almost any system. By removing the screw *s*, the hook lever may be slipped out, which is desirable for shipment. This is a good example of modern hook switches.

BATTERIES FOR TELEPHONES

With the various forms of solid-back transmitters, a battery of any two good Leclanché or dry cells will give good results. Dry cells are now being used extensively. The adoption of central-energy systems is doing away with primary cells at the subscriber's instrument for local city service and even for quite long distances. In long-distance work, two and even three Fuller bicromate cells have been used a great deal. For central-energy systems, storage batteries at the central office are nearly always used, and no magneto generator is required at the subscriber's instrument; consequently, the energy for all telephones connected with the switchboard, both for talking and for signaling purposes, is supplied by the central office.

CONNECTIONS OF TELEPHONE INSTRUMENTS

Series Instruments.—*Series telephones* are designed so that they may be connected in series with each other in the line circuit. Fig. 7 shows the Post method, and Fig. 8 the Western Electric No. 2 method—two ways of wiring a series wall telephone that accomplishes the same purpose. *G* is the magneto generator, *C* the bell, *R* the receiver, *T* the

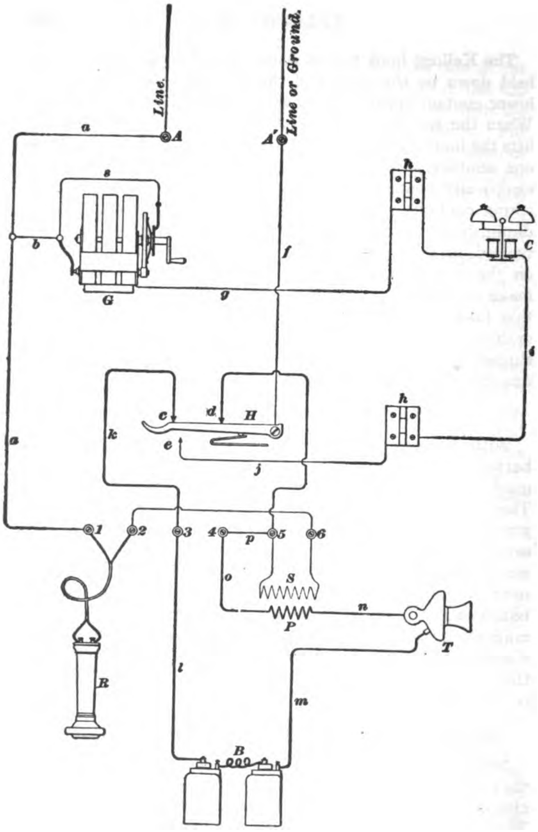


FIG. 7

transmitter, *H* the hook switch, *B* the battery, and *S* and *P* the secondary and primary windings, respectively, of the induction coil. While supporting the receiver, the hook is depressed and thus connects the bell *C* and the generator

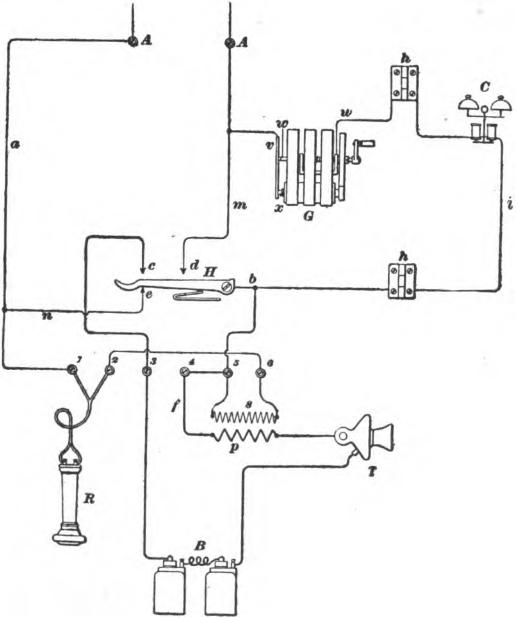


FIG. 8

G in series across the two line wires. In Fig. 7, the circuit containing the receiver and secondary coil is open at *d*, while it is short-circuited by *n-e-b* in Fig. 8. When the generator is at rest, its armature is short-circuited; when the hand of the generator is turned, the short circuit around the armature is opened; and when the receiver is removed from the hook, the transmitter, battery, and primary winding of the induction coil are connected in a local circuit, and the receiver is also connected in series with the secondary winding of the induction coil and across the two line wires. The generator and bell circuit is open at *e*, Fig. 7, and short-

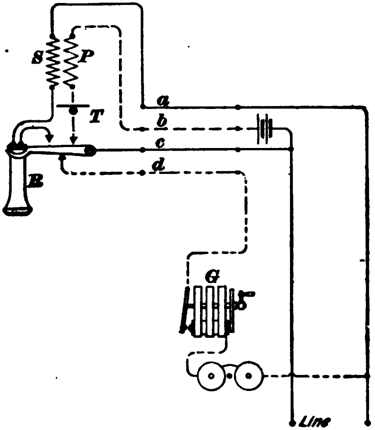


FIG. 9

circuited by *m-d-b*, Fig. 8. The same principles are employed in wiring series desk instruments.

A *series desk telephone*, with the induction coil in the base of the stand, is wired as shown in Fig. 9, *a*, *b*, *c*, *d* being the flexible conductors in the desk-stand cord. The generator and bell are usually placed in a separate case or box. The wiring of a series desk telephone, with the induction coil in the base of the desk stand, the generator in one box, the bell in another box, and the necessary binding posts on a terminal block, is shown in Fig. 10. Generally, the ends of the flexible cord running from the desk stand to the binding

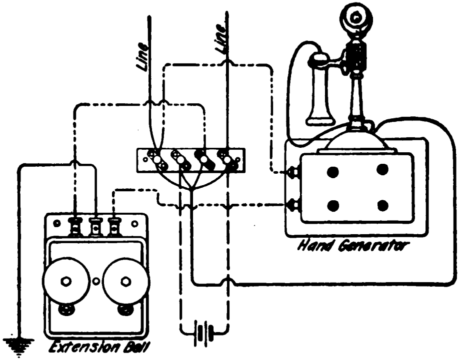


FIG. 10

posts on the terminal block are numbered or lettered, so that it is only necessary to connect each flexible conductor in the desk-stand cord to a similarly numbered or lettered binding post on the terminal block. Sometimes, the induction coil is mounted on the terminal block.

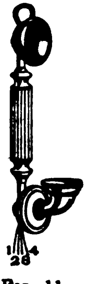


FIG. 11

Hand Microtelephone.—In Fig. 11 is shown a *hand microtelephone*, which consists of a transmitter, watch-case receiver, and switch, all mounted in one handle. The switch can easily be held closed by the same hand that holds the microtelephone. The connections in Fig. 12 show how this instrument may be used as an ordinary series telephone; it may also be wired as a bridging telephone by connecting wire *d* to line *L* and omitting the wire *d–1–a*.

Bridging Instruments.—In Fig. 13 is shown the arrangement and connection of apparatus forming a complete *bridging wall telephone.* The bell and the generator circuits are permanently connected across the line binding posts A, A', but the generator circuit is normally open between q and r, being closed only while the crank is being turned. When the switch is up, the receiver R and the secondary winding S are connected in series and across the binding posts A, A' through *a–1–R–2–6–S–5–d–H–f*, and the transmitter-battery circuit is closed through *B–l–3–k–H–d–5–4–o–P–n–T–m–B*. The bell is wound so as to have a large number of turns and

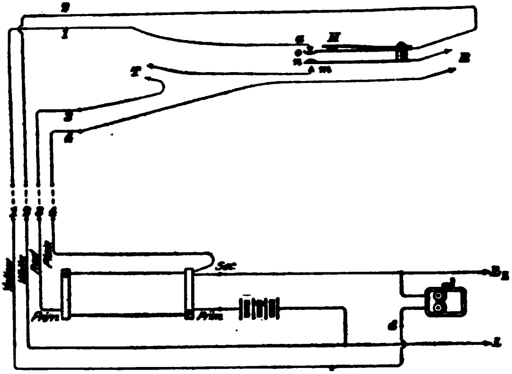


FIG. 12

a high resistance (1,000, 1,200, 1,600, or 2,500 ohms), and, consequently, may be left permanently connected across the line, because its inductance, together with its resistance, is so high that the very rapidly fluctuating voice currents do not pass through the bell to an appreciable extent, but pass into the line or receiver circuit, which offers much less opposition to them.

The wiring for an ordinary *bridging desk telephone set* is shown in Fig. 14. The binding posts *e, f, g, h, i* are located in the base of the desk stand. The binding post *h* and

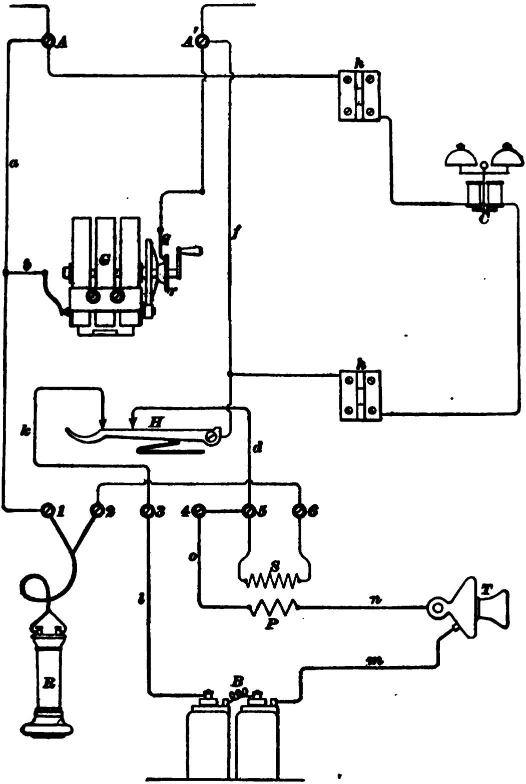


Fig. 13

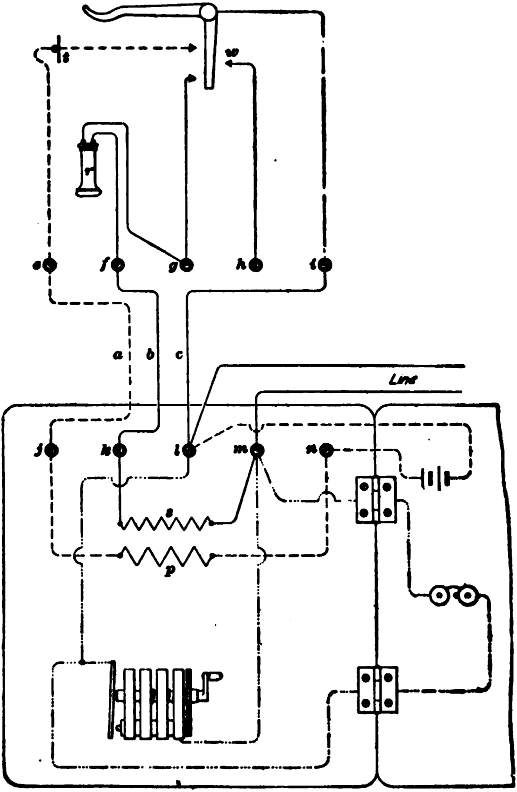


FIG. 14

contact *w* are not used for this bridging circuit, but are provided because they are required in an arrangement to be shown presently, as well as in series sets. Flexible conductors *a, b, c* connect the desk stand with the box containing the bell, generator, and induction coil. On the top or bottom of this box are placed the binding posts *j, k, l, m, n*. The induction coil may be placed in the base of the desk stand without increasing the number of flexible conductors; *a* will then connect *e* to *n* and *b* will connect *f* to *m*, *p* being between *t* and *e*, and *s* between *r* and *f*. The binding posts *j, k* will not then be required.

Bell Desk Set.—The connections of a bridging *desk set* used by the Bell Telephone Companies on local-battery system is shown in Fig. 15. The induction coil is mounted on a wooden base having five binding posts *n, j, l, k, m*. One of the cords *b* is connected to an insulated terminal *w* in

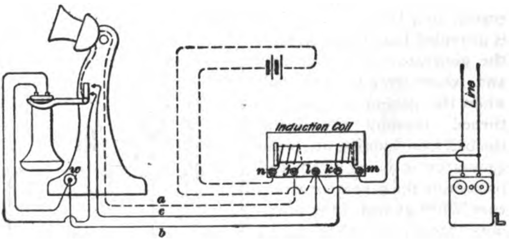


FIG. 15

the foot of the stand, to which is also attached one terminal of the receiver cord; *c* is connected to one contact of the hook switch, and *a* to the transmitter. The other terminal of the transmitter is connected through the metal work of the stand to the hook switch.

Other Methods of Connecting Instruments.—Another way of connecting bridging generators and bells, shown in Fig. 17, is to arrange them so that both the bell and the generator will be cut out when the hook switch rises. This is especially desirable but only necessary for party-line circuits having a number of instruments bridged across the same circuit. The same object is also accomplished by connecting the generator terminal q directly to binding post A' instead of to contact w, the bell still being left connected between contact w and binding post A.

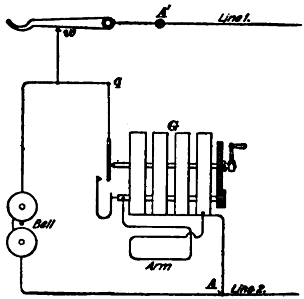


FIG. 16

Fig. 17 illustrates another way of connecting bells and generators in a bridging telephone. A platinum-pointed spring is provided that short-circuits the generator when at rest and short-circuits the bell when the generator crank is turned, thereby preventing the bell from ringing when the generator is being used and protecting the generator armature, when at rest, from burn-outs through the entrance of foreign currents. This arrangement reduces, by one, the number of bells on a party line that the generator must ring. Moreover, the home bell in the ordinary arrangement takes somewhat more current than any of the other bells, because it has no line resistance in series with it; hence, cutting it out is quite desirable, especially on long party lines.

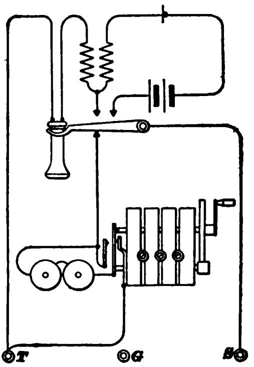


FIG. 17

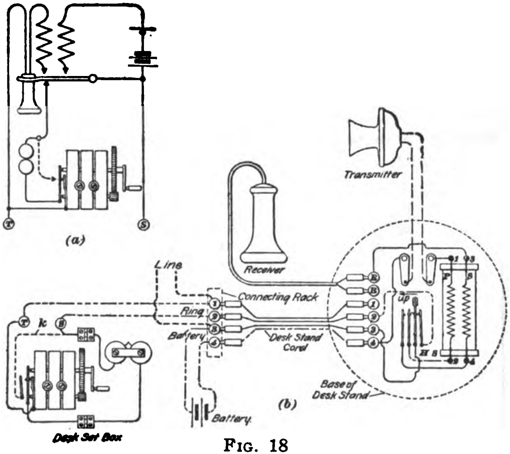

(a)
Transmitter
Receiver
Line
Connecting Rack
Ring
Battery
Desk Stand Cord
Base of Desk Stand
(b)
Battery
Desk Set Box

FIG. 18

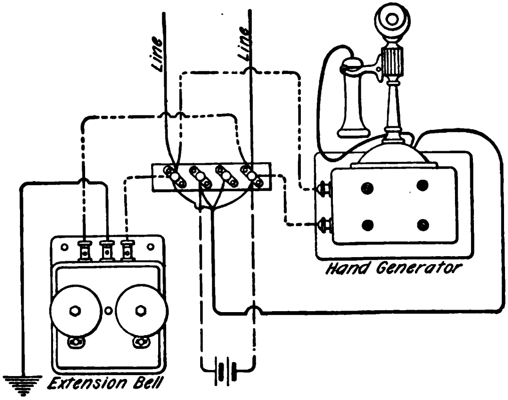

Line
Line
Hand Generator
Extension Bell

FIG. 19

The connections of the Dean desk set, in which the receiver, transmitter, hook switch, and induction coil are mounted in the desk stand, the bell and generator in one box, and four binding posts on a connecting rack, are shown in Fig. 18. At (*a*) is shown a simplified diagram of the connections.

Separate Bridging Generator and Bell Box.—The wiring for a bridging desk set using separate generator and bell boxes and a terminal block is shown in Fig. 19.

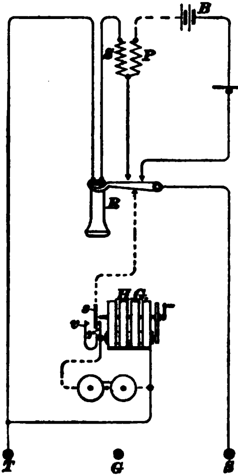


FIG. 20

Kellogg Bridging Wall Telephone.—Still another slight modification suitable for use on party lines is shown in connection with Fig. 20. When the generator handle is turned, the spring *s* is pushed away from *r* and into contact with *v*. Since the armature winding is connected between the frame of the generator and through an insulated pin in the end of the shaft with the spring *v*, the generator is cut in and the bell is cut out when the generator handle is turned. Thus the bell and generator are not only cut out by the rising of the hook switch, but the bell is also cut out when the generator handle is turned.

Kellogg Bridging Desk Telephone.—The connections for a desk set, when the induction coil is mounted on a separate connecting rack along with the necessary binding posts, is shown in Fig. 21. Four flexible conductors *a*, *b*, *d*, *c* connect the terminals *e*, *f*, *h*, *i* with binding posts, *1*, *4*, *3*, *2*, respectively, on the connecting rack. The bell and generator are cut out when the hook switch rises and the bell is cut out when the generator handle is turned.

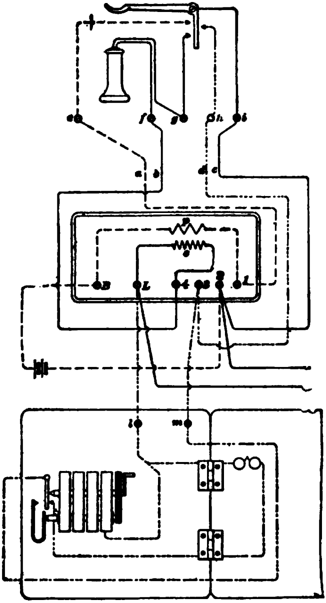

a
f
g
h
i
a
b
d
c
B
L
4
3
2
1
l
m

FIG. 21

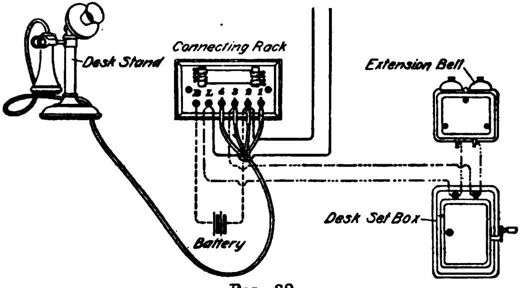

Desk Stand
Connecting Rack
B L 4 3 2 1
Extension Bell
Desk Set Box
Battery

FIG. 22

Fig. 22 shows the wiring when the generator and bell are mounted in separate boxes and the induction coil on a connecting rack. The battery in Figs. 20 and 21 is placed on the floor or wherever convenient.

EXTENSION BELLS

All bells used in connection with a telephone, except the bell in the telephone instrument or generator box, are termed *extension bells*. They are used so that signals may be received in places where it is not desired to locate the telephone. The extension bell rings whenever

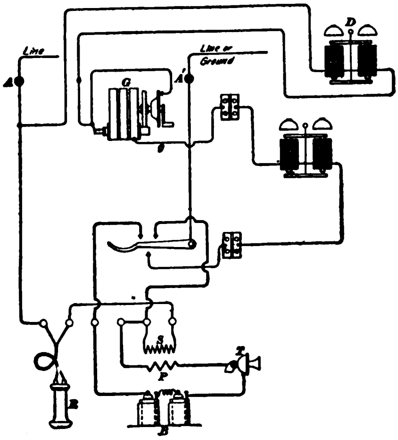


Fig. 23

the telephone bell rings. Ordinary extension bells can be used in connection with either series or bridging telephones, but, in either case, the extension bell should have exactly the same resistance (which implies also the same number of turns) as the telephone bell with which it is to be used.

Series Extension Bell.—Fig. 23 shows the proper way to connect an extension bell *D* to a series telephone in

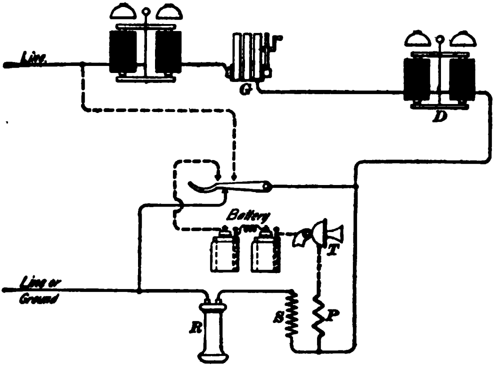


Fig. 24

which the Post circuit is used, while Fig. 24 shows the same thing when the Western Electric No. 2 circuit is used.

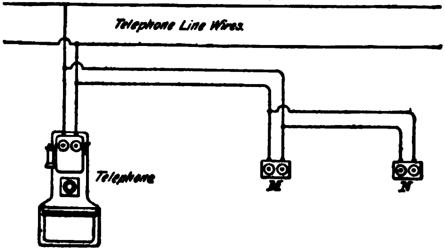


Fig. 25

Bridging Extension Bells.—The extension bell, which should be of the same resistance as the bridging telephone bell, may be bridged across the line circuit of a bridging telephone at the most convenient point. Two *bridging extension bells* M, N are shown in Fig. 25 properly connected across a bridging-telephone circuit. When bridging telephones are connected on the ground return circuits, the extension bells are connected between the one line wire and the most convenient ground connection.

CENTRAL-ENERGY INSTRUMENTS

Instruments for use on central-energy, or common-battery, systems can hardly be classified as series or bridging instruments. No generators are used, the central office being signaled by merely removing the receiver from the hook. These instruments usually have an ordinary polarized bell, varying in resistance from 80 to 2,500 ohms (usually in series with a condenser of about 2 microfarads capacity), connected across the line circuit, or between one line wire and the ground when the receiver is on the hook. The transmitters and receivers are arranged in various ways. In the simplest arrangement, the transmitter and receiver are connected in series across the line circuit when the receiver is removed from the hook. With this arrangement, satisfactory results can undoubtedly be obtained for short distances if the transmitter and the receiver are suitably designed; but the use of induction or impedance coils and condensers in connection with a subscriber's telephone instrument seems to give better results.

Transmitter and Receiver in Series.—The simplest arrangement of a subscriber's instrument for use on central-energy circuits is shown in Fig. 26. When the receiver rests on the hook, the ringing current flows from one line wire through the bell, condenser, and contact a, to the other line wire. The bell usually has a resistance of 500 to 1,000 ohms and the condenser a capacity of ½ to 2 microfarads. When the receiver is not resting on the hook, it is in series with the transmitter across the line circuit, and the bell and condenser are on open circuit. The bell circuit may be connected from contact a to the ground, instead of to line L, the ground then being used as a common return for all ringing currents, but it is cut out when the receiver is off the hook. For an arrangement of this kind, the receiver should have a low resistance and the transmitter a high resistance, a large proportion of which is variable. From 20 to 25 ohms has been found to be about the lowest resistance for an

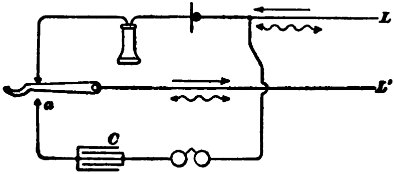


FIG. 26

efficient receiver for such an arrangement. The one main drawback to this arrangement is that the battery current flows through the receiver; this is all right if the current passes in the direction to increase the magnetism, but the current may at some time be reversed on the line, in which case the receiver becomes demagnetized. Another fault is

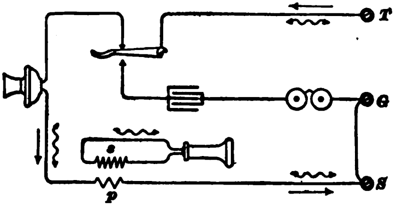


FIG. 27

that this arrangement lacks the proper quality that many other combinations possess.

Receiver in Closed Local Circuit.—In Fig. 27, the receiver is in a permanently closed local circuit containing the secondary winding *s* of an induction coil. Both battery and voice currents pass through the primary winding *p* and the transmitter, but the latter current, being fluctuating in character, induces a similar current in the secondary *s*, thereby operating the receiver. When the receiver rests on the hook, the transmitter circuit is open and the bell and a condenser are connected in series across the signaling circuit.

Impedance-Coil Circuit.—In Fig. 28 is shown a subscriber's conversation circuit in which a receiver and 2-microfarad condenser are connected in series and shunted by a 25-ohm impedance coil. The direct current from the exchange battery passes through the impedance coil and

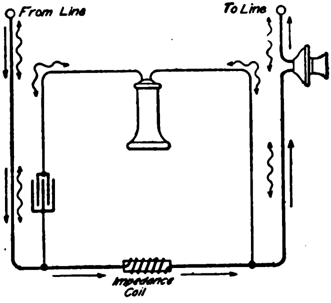


FIG. 28

the transmitter, but is prevented from flowing through the receiver by the condenser, which is opaque to direct currents. The incoming voice currents, however, are practically prevented from flowing through the impedance coil, on account of its high reactance to such high frequency currents, but find a comparatively low-impedance path through the condenser and receiver, as indicated by the double-headed wavy arrows.

Dean Central-Energy Subscriber's Circuit.—The subscriber's talking circuit used in telephones made by the Dean Electric Company is shown in Fig. 29. The coils *A*, *B*, *C*, *D* are arranged in the form of a Wheatstone bridge, the usual position of the galvanometer being occupied by the receiver. *B* and *C* are non-inductively wound, while *A* and *D* are wound so as to have a high inductance. The bridge is balanced for direct currents, as indicated by the straight single-pointed arrows, by making the resistance of the four arms so that *A* is to *B* as *C* is to *D*. No direct current will then flow between the points *2* and *3*, as their potential is the same; hence, the receiver will be free from direct-current action. However, the bridge is entirely out of balance for the high-frequency voice currents, which cannot readily penetrate the inductively wound coils *A* and *D*

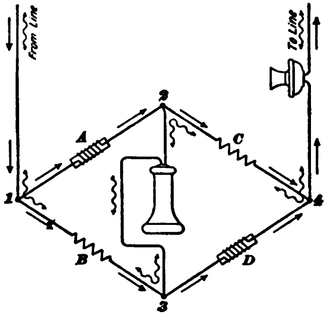


FIG. 29

and are thus forced through the receiver and non-inductive resistances *B* and *C* in the path indicated by the wavy arrows. The resistances of the four windings, which are wound on one iron-wire core with four terminals *1*, *2*, *3*, *4*, are approximately 20 ohms for *A* and *B* and 30 ohms for *C* and *D*. The direct current from the exchange battery passes through the two 50-ohm halves of the bridge, as indicated by the straight single-headed arrows, and thence through the transmitter.

The method of wiring a complete wall instrument, using the Dean circuit, is shown in Fig. 30 (*a*). When the hook is down, the coil and receiver are shunted by the wire *e*, thus

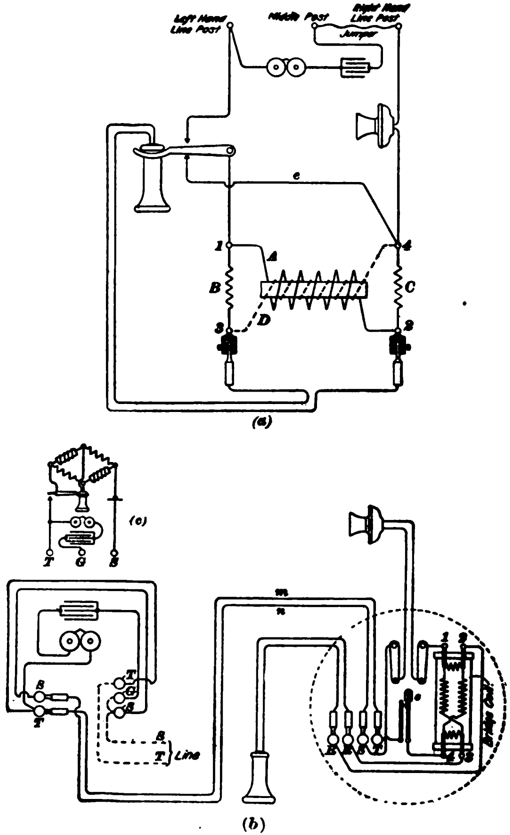

Left Hand Line Post
Middle Post
Right Hand Line Post
Jumper
e
1
A
4
B
C
3
D
2
(a)
(c)
T
G
S
m
n
S
T
T
G
S
S
T
Line
1
2
Bridge Coil
(b)

FIG. 30

preventing any damage from lightning discharges or high-tension currents, which are liable to jump the gap between the springs of a hook switch. The Dean central-energy desk set is wired as shown in Fig. 30 (*b*), while (*c*) shows a simplified diagram of the same circuit.

COMMON FAULTS AND THEIR REMEDIES

The most common troubles in telephone instruments are due generally to one of three causes: (1) Loose or dirty connections at the binding posts of the instrument, at the binding posts of the batteries, or in joints in the line wires; (2) exhausted, poor, or weak batteries; (3) crossed, open, or defective wires. These troubles, of course, do not include those arising from inferior or defective instruments, which it is impossible to enumerate on account of the large number of different makes of instruments now in use.

In the case of a defective instrument, the best thing to do is to return it to the dealer for repairs. If the connections are dirty, corroded, or greasy, scrape the wires and clean out the binding posts; then, screw the wires firmly in place. If the telephone does not then work properly, examine the batteries and see whether they are run down, or whether the zincs are eaten away. With wet batteries, it may be possible that the water has evaporated; in dry batteries, the zinc may be eaten through, or the batteries may be otherwise defective. The simplest way to test the battery is to try a new battery, and see whether it will make the telephone work properly; if it does, the trouble was with the old battery. If the trouble is present after changing the battery, examine the line connections and the line outside; if any loose connections are found, correct them at once. When inspecting the line outside see that it does not touch anything except the insulators, and that it is neither crossed nor broken. On grounded lines, examine the ground connection the first thing and see whether it is in good condition; and if a plate is used, see that it is in moist ground.

A frequent trouble with transmitters is a frying noise; this is usually caused by too much current or by loose connections.

If any coils in the instrument have been damaged by lightning, the smell of the charred insulation can frequently be detected when the door of the telephone is opened. If this is the trouble, the only thing to do is to replace the coil that has been burned out. One thing that should be carefully avoided is the placing of nails, screws, screwdrivers, scissors, or metallic instruments on the top of the telephone box. In a series telephone, this might cut out the instrument; on the bridging line, it might result in all the instruments on the line being thrown out of service. A very short list of only the most common faults that occur in ordinary series and bridging instruments, with suggestions as to their cause, will now be given.

Cannot Ring nor Receive a Ring.—The line or generator circuit may be open in a series instrument or short-circuited in a bridging instrument. If a series bell, connect the two main binding posts together; if the bell will not then ring when the generator is operated, the trouble is probably a broken wire inside the box. For a bridging instrument, remove the two line wires at the top of the instrument; then if the bell will ring, when the generator is turned, the trouble was due to a short circuit outside the instrument, probably between the line wires.

Can be Called, but Cannot Call Others.—This trouble may be due to weak or defective generators, or to bell coils of different resistance on the same line. If a call from another station rings the bell loudly but the home generator rings its own and other bells weakly, the trouble is probably due to a weak generator, poor connection in the generator circuit, or partial short circuit of the generator armature. On a grounded, bridging, party-line system, the trouble may be due to a high resistance in the ground connection at the home station only; for this high resistance may cause such a decrease in the current sent out by the home generator that when it subdivides through all the other bells, each part is too feeble to ring any of them, whereas the small incoming current may still be large enough to ring the bell.

Cannot be Called, but Can Call Others.—This trouble may be due to imperfect adjustment of the bell, armature, or gongs, or to bell coils of different resistance on the same line. In a bridging instrument, it may be due to a defect in the automatic cut-in device of the generator; in a series instrument, it may be due to a short circuit around the bell.

Can Hear, but Cannot be Heard.—In such cases, the trouble is usually with the battery or transmitter circuit. A careful examination of all connections therein should be made. It may be due to a defective, packed, or improperly adjusted transmitter, an exhausted battery, cells improperly connected, or a broken wire or short circuit in the battery circuit, or a short circuit in the secondary or primary winding of the induction coil. The person talking into the instrument may stand too far away; the proper way is to stand so that the lips are about 1 in. from the transmitter. The trouble may also be due to a defective receiver at the distant telephone, such as weak magnets, improperly adjusted receiver, dented diaphragm, or short circuit in receiver or its cords.

Weak Receiver.—This trouble may be due to poor connections in the receiver circuit, partial short circuit, bent or dirty diaphragm, diaphragm too close or too far from pole pieces (should usually be .015 in. from face of pole pieces), or permanent magnet may be weak (should usually support an 8-oz. iron weight or hold diaphragm on edge).

Cannot Hear, but Can be Heard.—In such cases, the trouble is usually in the receiver circuit, and is probably due to a defective or improperly adjusted receiver, dented diaphragm, or to a short circuit in receiver coil or in receiver cords. However, it may be due to a defective transmitter or a weak or improperly connected battery at the transmitting station; or, possibly, in a bridging instrument with a ground return, to an imperfect ground connection, the ground connections at the several other instruments on the same line being good.

Weak Ringing of Bells.—This may be due to loose connections, bad joints in the line, or imperfect ground connection at terminals, in case a ground return is used; a cross on the line if a bridged-metallic circuit is used; to a ground, if a bridged-grounded circuit is used. The bell adjustment may also be defective.

Instrument Receives and Transmits Rings, but Nothing Can be Heard at Either Station.—This trouble may be due to loose connections or a broken wire in either receiver, in either receiver cord, in either secondary winding of the induction coil, or to poor or loose contacts in the switch hook, or to weak batteries, improperly connected cells, open or short circuits in primary circuits at both stations, or short circuits in both receivers, or in the secondary windings of both induction coils. With a series-instrument, the following test may be made to determine whether the trouble is in the receiver or cord: Disconnect the cord from the box, but allow the receiver to remain on the hook. Remove the line wire from the binding posts, and place the two ends of the receiver cord in the line binding posts and turn the generator handle; if the receiver or cord circuit is not broken, the bell will ring. The wires in a cord may be broken, and yet the break may not be apparent if the cord is held in a certain position; hence, move the cords while making the test. If either conductor is broken, a scraping sound is produced in the telephone, or it may interrupt the speech so that a word is only audible occasionally.

Clapper Clings to One Gong.—If the clapper clings to one gong, move that gong toward the other gong and against the clapper. A slight adjustment of this kind will usually remedy the difficulty.

Rasping, Grating, or Sizzling Noises in Receiver.—This trouble may be caused by loose connections or excessive current in the battery circuit, by a buckled diaphragm in the receiver, or by particles of foreign substance lodged between the diaphragm and the pole piece of the receiver; or, the position of the diaphragm may not be correct. In modern receivers, no provision is usually made for adjusting the distance of the diaphragm from the magnet. Where such adjustment is possible, the diaphragm should be .015 in. from the magnet. This trouble may also be due to a weak magnet; the magnet should be strong enough at least to hold the diaphragm by its edge. It may also be due to a live wire of a power, electric-light, or other circuit lying across the telephone line.

Bell Rings Frequently Without Apparent Cause.—The line wire swings across telegraph or other live wires. On some selective-ringing party-line systems, a bell will often give one or more taps when another bell on the same line is being rung, especially if some receiver at another instrument on the opposite side of the line is off the hook. When the ground is used as one side of the ringing circuit, bells will sometimes give a few taps when the line side of its circuit forms a better return to the exchange than the ground between some other instrument that is being rung and the exchange. This may sometimes be remedied by putting an extra bell (removing the moving parts and gongs) or an impedance coil in the circuit between the bell and the ground.

Poor Hook-Switch Contacts.—Dirty contacts or weak springs of hook switches are generally the cause of troubles that can be very easily remedied by cleaning or retempering the springs. The latter may be done by bringing the spring to a red heat and then dipping it into water. Oil may be used instead of water if it makes the spring too hard.

TESTING MAGNETO GENERATORS

One way to test a magneto generator consists in placing the fingers across the terminals and turning the crank; if the generator is in proper working order, a shock will be felt. This method of testing is preferred by some, because if the magneto is bridged, the ringer might be open and the generator O. K.

To test a series-bell and generator, place a piece of metal across the binding posts of the telephone, and turn the crank; if the bell rings, it is O. K., if not, trouble is inside. This is not specific, however, and both this and the former test should be made. Assume that the latter test has been made and that the bells did not ring clear and strong, but when another generator was used to send current through the defective magneto, the bell in the latter rang all right; then the wires were taken off the terminals and it tested clear, that is, the bell did not ring. If taken apart and examined closely, it will probably be found that the trouble is due to the automatic cut-out on the armature not working properly. If no shock can be felt, the fault will be due to a short circuit (crossed wires) or to a broken wire; if, however, a shock is received, but the bell does not respond, then the fault is in the ringer and may be due to bad adjustment or to broken or crossed wires. If the shock is weak, the fault may be due to defective or weak magnets or to a partial short circuit in the generator armature. All contacts in generators should be made and kept tight; also, the springs should be examined often, as holes are frequently worn in them and cause trouble. Very little oil should be used, as it is liable to cause trouble.

INSPECTOR'S OUTFIT

The following list of tools and materials for setting up and repairing instruments will be found very useful. Although not complete for all and too complete for some work, it can be added to or subtracted from as may be found necessary. One pair of long-nosed 5-in. pliers; one small hammer; three 6-in. screwdrivers, with blades of different sizes; one keyhole saw; one set of drills; one pair of tweezers; three small files; one pair of side-cutting pliers; one box of fuses; one box each of screws, tacks, washers, staples, etc.; one racket brace; one set of bits, ½, ⅝, ¾ in.; one small can of oil; emery paper or cloth, size 0000; crocus cloth; cloth and polishing paste; black insulating tape; 8-oz. weight for testing strength of receiver magnets; soldering lamp, iron, solder, and flux; small dusting brush; receiver and transmitter diaphragms and granular carbon; insulated and bare wire; candle or small lamp; battery material and battery gauge (for local-battery instruments only); satchel for carrying the tools and material mentioned.

Telephone installers should have an angle or ratchet brace, a long bit of proper size to take circular loom conduit, a Syracuse drill, a long gimlet bit, a pair of side cutting pliers, long-nosed pliers, a hammer, a small keyhole saw, two sizes of screwdrivers, an alcohol torch, a small gimlet, a coarse, flat file, some screws, washers, tacks, staples, etc.

DISTURBANCES IN TELEPHONE LINES

CAUSES OF NOISES IN TELEPHONE CIRCUITS

Strange noises are frequently heard in instruments connected with grounded telephone lines of considerable length. These noises may be due to one or more of several causes. The sudden shifting of the earth's magnetic field may induce currents in the line, which will cause sounds in the receiver; earth currents, due to differences in potential between the ground plates at the ends of the line, may also pass through the telephone instruments, producing the same result; there may be leakage from other lines; a neighboring wire carrying fluctuating currents will have set up about itself a varying magnetic field of force, which field may embrace the telephone line under consideration and by its fluctuations cause corresponding alternating currents to flow in the telephone line; and there may be a condenser action between the telephone wire and the neighboring wire, by which the latter may induce fluctuating charges on the former, and these charges will produce currents capable of affecting the receivers.

GROUNDED AND METALLIC CIRCUITS

Grounded telephone systems are those in which one line wire is used, the ground forming one side of the circuit, or, as it is commonly designated, the *return circuit*. Such telephone lines frequently form part of the return circuit for electric street-railway systems and, moreover, induction from neighboring parallel lines may be considerable; in either case, the result may be what is commonly termed a *noisy line*. The first source of trouble just mentioned may be eliminated by the use of a common return wire in place of the earth, constituting what is called a *common-return system*.

To eliminate noises due to induction as well as those due to leakage, two separate wires must be used for each circuit. The two wires must be placed on adjacent insulators and transposed about every ¼ mile, care being taken that no two adjacent pairs are transposed in exactly the same manner.

In case the circuit runs through a cable containing other similar telephone circuits, the two wires constituting each circuit are invariably insulated with dry paper and twisted spirally about each other. Where two conductors are used for each circuit, it is said to be a *complete metallic*, or merely a *metallic, circuit system.*

TRANSPOSITIONS

The proper way to make a *transposition*, where McIntire sleeves are used, is shown in Fig. 31. In Fig. 32 is shown

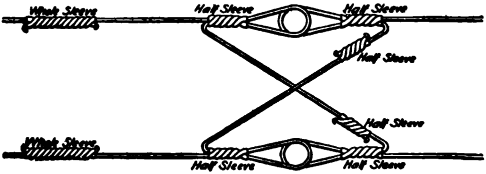


FIG. 31

the transposition insulator used where these transpositions are made.

The *single-pin*, or *Murphy, transposition* is shown in Fig. 33. Suppose that pole *b* is the one on which the transposition is to be made between the wires *l*, *k*, which take at the pole *a*, the pins *2* and *1*, respectively. A transposition insulator is placed on pin *1* at the pole *b* and the conductor *k* is tied in the lower groove, while the conductor *l* is tied in the upper groove. On the next pole *c*, the conductor *k* will be tied in the usual manner to pin *2*, while the conductor *l* will be tied to pin *1*. Their mutual positions are thus reversed.

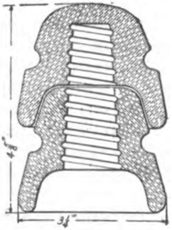


FIG. 32

To make this transposition, all that is necessary is to take up slack enough in the conductors to enable them to be shifted one pin to the right or left as the case may be. The single-pin transposition is said to have the comparative advantage of less first cost and simpler construction. It can be cut in at

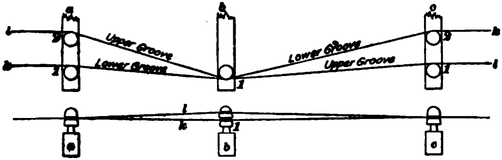


FIG. 33

any time, cut out, or moved several poles, at less cost and with much less work than in the case of a square, or ordinary, transposition.

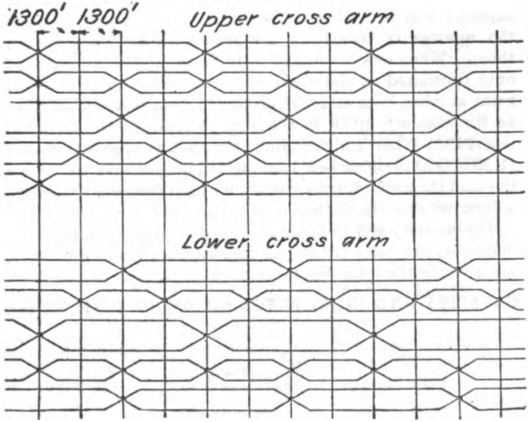


FIG. 34

The scheme of transpositions used on the New York-Chicago telephone lines, is shown in Fig. 34. The poles on which the transpositions are made are 1,300 feet apart.

CAPACITY AND INDUCTANCE OF LINE WIRES

The length of time necessary for an impulse to rise to an appreciable strength at the distant end of a line depends on the distributed electrostatic capacity and the resistance of the line; in fact, it seems to be proportional to the product of these two quantities. For good transmission, both clear and loud, over telephone circuits, this product should be kept as low as practicable.

The electrostatic capacity of overhead wires, suspended at a height of about 30 feet above the ground, is approximately as shown in the table on page 219. The electrostatic capacity of an overhead wire will depend on the number and proximity of other wires, and especially if any of the neighboring wires are grounded. Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be higher. The capacity will also vary with the number of insulators per mile and the moisture on them. When one overhead wire is grounded at one end only (insulated at the other end), the capacity is twice as great as when both ends are grounded, that is, twice as great as the capacity given in the third column of the table on page 219. When a high inductance, such as a high-resistance (1,200-ohm) bridging bell, is connected between the end of the line and the ground, the capacity for high-frequency currents will be very nearly as great as when the end is insulated.

The capacity and inductance of one copper wire, .104 in. in diameter, weighing 173 lb. per mi., with both ends grounded, are given in the following table:

CAPACITY AND INDUCTANCE OF SINGLE LINE WIRES

Height of Wire Above Ground Feet	Capacity Microfarads per Mile	Inductance Henrys per Mile
10	.01060	.002796
20	.009796	.003019
30	.009379	.003149
40	.009105	.003242

The capacity and inductance, when two copper wires, .104 in. in diameter, are suspended at the same height and 1 ft. apart, are given in the following table:

CAPACITY AND INDUCTANCE OF LINE WIRES

Height Above Ground Feet	Capacity Between Wire Grounded at Both Ends and the Ground Microfarads per Mile	Capacity Between Two Wires (Distant Ends Open) Microfarads per Mile	Inductance of One Wire Grounded at Both Ends Henrys per Mile	Mutual Inductance of Two Wires Connected Together at Distant End Henrys per Mile
20	.01171	.004732	.003019	.001187
30	.01150	.004936	.003149	.001318

The increase of capacity between one wire and ground due to the adjacent grounded circuit is .01171 − .009796 = .001914, or 19.6% at a height of 20 ft. and .0115 − .009379 = .002121, or 22.6% at a height of 30 ft.

The capacity and inductance of metallic circuits of copper wire.,.104 in. in diameter, for various separations, are given in the following table:

CAPACITY AND INDUCTANCE OF METALLIC-CIRCUIT LINES

Separation Inches	Capacity Microfarads per Mile	Inductance Henrys per Mile
10	.008503	.003546
12	.008218	.003663
14	.007992	.003762
16	.007806	.003848
18	.007649	.003924

Formulas for Capacity.—The electrostatic capacity of a single wire of length l and diameter d at a height h in the air above the ground when grounded at both ends may be theoretically calculated by the formula

$$C = \frac{.0388l}{\log_{10}\left(\frac{4h}{d}\right)} \text{ microfarads} \qquad (1)$$

The electrostatic capacity of two parallel wires each of length l and diameter d at a distance h from each other may be theoretically calculated by the formula

$$C = \frac{.0194lK}{\log_{10}\left(\frac{2h}{d}\right)} \text{ microfarads} \qquad (2)$$

In these two formulas, l must be expressed in miles, but h and d may be expressed in any units of length, provided both are expressed in the same units. K is the inductivity of the dielectric filling the space between the two wires. For a bare overhead line, $K=1$. Values calculated by these formulas agree closely enough with results obtained for bare overhead wires by actual measurement. The effect of adjacent circuits is to increase the effective capacity of a line as determined by the foregoing formulas.

If the two parallel wires of a metallic circuit have an insulating covering, in addition to being suspended a distance apart in air, the capacity is slightly increased by the greater inductivity of the insulating covering. If the wires have a diameter d, an insulating covering of diameter d_1, the distance between them being h, the inductivity of the insulating covering K, and their length in miles l, then the capacity, in microforads, is given by the formula

$$C = \frac{.0194l}{\log_{10}\frac{2h}{d_1} + \frac{1}{K}\log\frac{d_1}{d}} \qquad (3)$$

The mutual capacity C, in microfarads, between two two-wire metallic aerial circuits, of length in miles l, one circuit consisting of wire of diameter d_a and the other of wire of diameter d_b, is given by the formula

$$C = \frac{.15536 \log_{10}\frac{r_1 r_2}{r_3 r_4} l}{16 \log_{10}\frac{2r_5}{d_a}\log_{10}\frac{2r_6}{d_b} - \left(2 \log_{10}\frac{r_1 r_2}{r_3 r_4}\right)^2} \qquad (4)$$

The distances r_1, r_2, r_3, r_4, r_5, and r_6 are shown in Fig. 35.

These formulas are correct for wires of magnetic or non-magnetic material. The presence of the earth beneath an aerial metallic circuit increases the capacity very slightly—less than a fraction of 1 per cent. if the wires are above the earth a distance at least several times the distance between them. The assumption made in the deduction of the formulas for electrostatic capacity is that there are no other wires in the immediate vicinity of those being considered. The effect of adjacent circuits is to increase the effective capacity of a line. For a pair of conductors in a telephone cable, the formula would be too complicated to be of any practical value (even if one could be derived), on account of the influence of neighboring conductors and the grounded lead sheath.

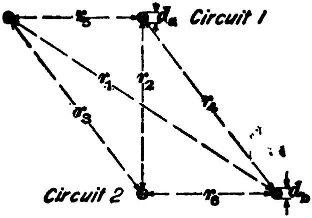


FIG. 35

Formulas for Inductance.—The formula for the inductance of a single aerial wire, composing a grounded circuit, is

$$L = \left(\frac{.08047 + .7411 \log_{10}\frac{2h}{r}}{10^3}\right), \qquad (5)$$

in which L = inductance per mile, in henrys;
h = height of wire above earth;
r = radius of wire.

h and r should be expressed in the same units. The inductance of a two-wire aerial metallic line may be expressed by the formula

$$L = \left(\frac{.1609 + 1.482 \log_{10}\frac{d}{r}}{10^3}\right). \qquad (6)$$

in which L = inductance per mile of the line circuit, in henrys;
d = distance between centers of two wires;
r = radius of wire (both same size).

d and r should be expressed in the same units. Formulas 5 and 6 are for wires made of non-magnetic material. The inductance of iron or steel wires is greater than that of copper wires of the same size. The effect of the earth on the inductance of a metallic circuit is less than a fraction of 1 per cent. if the wires are above the earth a distance greater than two or three times the distance between them. The inductance is decreased by the presence of the earth. These formulas assume that there are no magnetizable substances within a distance of the circuits less than several times the distance between the wires forming the pair, or the height of a wire above the earth.

The mutual inductance M between two two-wire metallic aerial circuits is given in henrys per mile by the formula

$$M = \frac{.7411 \log_{10} \frac{r_1 r_2}{r_3 r_4}}{10^3}, \qquad (7)$$

in which the distances r_1, r_2, r_3, and r_4 are the same as in Fig. 35.

If, in formulas 4 and 7, the distances are such that $r_1 \times r_2 = r_3 \times r_4$, C and M become equal to zero. Therefore, it is possible to arrange two two-wire metallic circuits so that there will be no electrostatic or electromagnetic interference between the two circuits; in other words, so that there will be no cross-talk between two circuits so arranged. This is practically accomplished by twisting the wires in pairs as in ordinary telephone cables.

PUPIN LOAD COIL SYSTEM

An articulate voice current consists of a fundamental wave and a large number of overtone waves of different frequency. Also, the greater the frequency of an overtone wave, the more does inductance tend to make it lag behind the fundamental; whereas, capacity has the opposite effect, so that the greater the frequency of an overtone wave, the more does it tend to lead the fundamental wave. Furthermore, the proper amount of inductance inserted in a circuit will neutralize a given capacity for one particular frequency. The difficulty with telephone circuits is the fact that the capacity between the line and the ground or other conductors is distributed throughout its length, and the frequency varies from about 32 to 40,000 periods per second. Prof. M. I. Pupin was the first to mathematically demonstrate and then practically prove that the distributed capacity of a line can be neutralized by inductance by connecting properly designed inductance coils in series with the line and at definitely calculated distances apart. He showed that, by neutralizing the capacity by inductance for the highest frequency commonly occurring in conversation, namely, about 750 periods per second, the neutralization was sufficient for all frequencies. The coils must have a definite inductance and be located definite distances apart along the line, so that there are at least several within the length of a half electric wave. The calculations, however, are too complex to be given here. When the neutralization is properly done, the overtone waves are so little displaced from each other and from the fundamental wave that distinct conversation can be held not only over much greater distances but also over smaller-sized wires.

The coils, known as the *Pupin load coils*, are now used on the New York-St. Louis, New York-Chicago, and other long circuits. On the New York-Chicago line, it is claimed that the use of the load coils has improved the transmission 100%. This circuit consists of No. 8 B. W. G. hard-drawn copper line wires, with load coils in series with the line every 2½ mi. In the underground cables between New York and Hartford, extra-large manholes are located every 6,600 ft. apart, in which Pupin load coils are placed. The use of load coils seems more beneficial and profitable in underground cable circuits than in bare overhead line circuits. Professor Pupin is confident that a conversation between New York and San Francisco may be held without difficulty over a circuit properly equipped with these inductance coils. A more complete discussion of this theory and the use of load coils is given in the International Correspondence Schools' Telephone Engineering Course.

ATTENUATION AND DISTORTION

Attenuation.—By *attenuation* is meant the decrease in intensity, strength, or amplitude of an electrical wave between the transmitting and receiving ends. Contrary to the conception frequently held, the maximum, or mean, value of an alternating or variable current may not be the same in all parts of a line wire, even at any given instant, but may decrease gradually as the distance from the transmitting end increases; this is not necessarily true for a steady direct current, however. This reduction is due to the resistance of the conductors, insulation resistance, and improper relative values of distributed capacity and inductance of the line circuit.

Distortion.—The *distortion* of an electrical wave is due to the fact that some electrical property (usually, distributed capacity) of the line acts unequally on the component waves of different frequencies that together make up a complex current wave representing articulate speech, the result being that the change in the phase relations and intensity of the various overtones and the fundamental tone produces a change in the shape of the current waves that renders the articulation more or less defective. Increased distance interferes with the transmission over a uniform conductor, not only on account of the diminished volume of the sound transmitted, but also on account of the rapid deterioration of the articulation.

PARTY LINES

Each telephone may be connected to a line circuit terminating in an exchange, where the proper switching devices are provided for connecting together any two lines. Such circuits are termed private, or, better, individual telephone lines. Frequently, several telephone instruments are connected to the same line circuit, such a circuit being called a *party line*. On party lines, the instruments may be connected in various ways.

In the method shown in Fig. 36, which represents a ground-return circuit, the instruments are connected in series, and such a party line is called a ***grounded, series*** *party line*. A line wire may be used in place of the ground return, and it is then called a *metallic, series party line*. Each bell is wound to a low resistance (from 60 to 120 ohms), and is so connected through the switch hook that the removal of the receiver from its hook cuts out the bell. Evidently, the ringing current encounters the impedance of all the bells

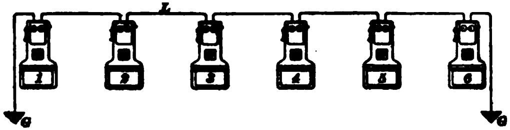


FIG. 36

in the same circuit in addition to the line resistance, and the talking current also encounters the resistance of the line and the impedance of all the bells, except at the stations where the receivers are removed from the hooks. As the frequency of the voice current is very high (average about 300 periods per sec.), while that of the ringing current is low (15 periods per sec.), the former is considerably reduced in strength, and the articulation becomes weak and indistinct if too many

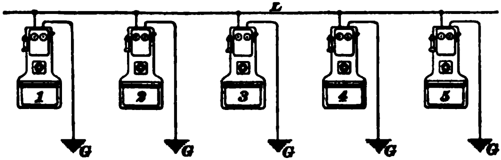


FIG. 37

telephones are connected in the same line. The bells in series telephones must not be too high in resistance, and the generators must develop sufficient E. M. F. to send a current of proper strength through the line and all the bells that are in series. The generator must be provided with an automatic device that short-circuits its armature when the battery is at rest and opens this short circuit when the generator is in use.

A better method, now extensively used, consists in connecting the telephone instruments in parallel across the line circuit, as shown in Fig. 37, which represents a *grounded, bridged party-line circuit*, so called because the telephones are said to be bridged across the circuit from the line wire to the ground. A *metallic, bridged party-line circuit* is shown in Fig. 38.

In bridging instruments, bells wound to a high resistance must be used, in order that the bells at telephones not in

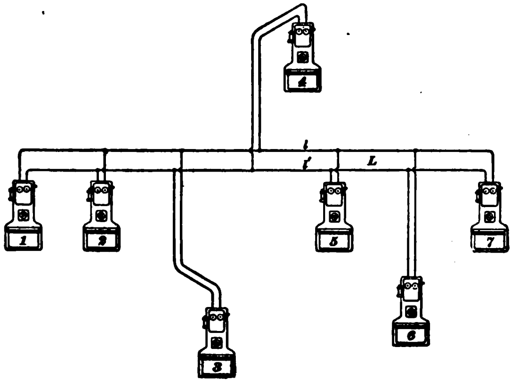


FIG. 38

use may not short-circuit or form serious leaks for the voice currents flowing between two stations in use. The higher the resistance of the line and the greater the number of telephones bridged across one line, the greater should be the resistance of the bells. The ringing current divides through all the bells connected across the line. The generator is usually provided with an automatic device that leaves the armature on open circuit when at rest and connects it directly across the line binding posts of the instrument while the generator is in use. Usually, the bells are connected permanently across the line binding posts, but in many instruments the bell is cut out when the receiver is removed from the hook. The bells are usually wound to 1,000, 1,200, 1,600, 2,500 and even as high as 5,000 ohms. The impedance of such bells to the high-frequency voice currents is so great that the voice currents are practically confined to the line and instruments at which the receivers are removed from the hooks.

Party-Line Signals.—On the party-line systems so far described, it is necessary to use a code of audible signals to enable the parties at the various stations to distinguish their calls from those of other stations on the same line circuit. These codes are usually made up of a various number of rings or various combinations of long and short rings, so that, by sound, a party may at once tell whether his attention is desired at the telephone.

There are other systems in which means are provided for ringing the bell of any one subscriber without disturbing any of the other bells on the same party line. They are termed *selective-signaling systems*, and may be divided into three classes:

1. Those employing step-by-step mechanisms operated by impulses of current sent from the central exchange in such a manner as to close the bell circuits at the subscribers' stations successively. This method has been used but little in actual practice because it is difficult to secure proper electrical contacts between the stationary and movable parts; also, the devices have been too complicated.

2. The second system applies to the harmonic, or reed, method of selecting, wherein currents of various frequencies are employed for actuating the different bells. The four-party selective-signaling systems devised by W. W. Dean come under this class. The four bell hammers on the same circuit are made so as to have different periods in which they will readily vibrate, and four different frequency currents and, in one case, slightly different voltages also, are used for ringing. In the system made by the American Electric

Telephone Company, alternating currents of two frequencies are used (20 and 60 cycles per sec.), while the capacity and inductance of the two bell circuits connected between the same two line wires are so proportioned that the lower frequency current will ring only one of the bells and the higher frequency only the other bell. By connecting two such bell circuits between each side of a complete metallic circuit and the ground, as is customary, any one of the four bells may be rung by connecting the proper frequency ringing machine between the proper line and the ground. A condenser is connected between each bell and the ground, so that neither line is actually grounded. When the receiver is removed from the hook, the telephone is connected across the two line wires; thus, a complete metallic circuit is used when conversing.

3. There is another system in which selective signaling is accomplished by changes in the direction of the current. A polarized relay or an ordinary polarized bell can be readily arranged to respond to current impulses in one direction only. Obviously, this in itself affords means for signaling either one of two stations on the same line circuit without disturbing the other. By attaching a spring to one end of the armature of an ordinary polarized bell, the hammer may be held normally against one gong. If direct but pulsating current flows through the bell coils in such a direction as to move the hammer against the other gong, the bell will ring, because the current impulses cause the hammer to hit one gong and the spring draws it back against the other gong between each impulse and while no current is flowing through the coils. A pulsating current in the opposite direction will not ring the bell, because the magnetism developed in the cores merely tends to pull the armature in the same direction as the spring and there is no tendency to move the hammer against the other gong. Another similarly polarized and wound bell may be rung by putting the spring on the opposite end of the armature and sending pulsating currents through the coils in the opposite direction. By connecting two such bells, wound to a high resistance, in parallel across a line, either bell may be rung. By

connecting two such bells between one wire of a metallic circuit and the ground and two similar bells between the other wire and the ground, any one of the four bells may be rung by connecting between the ground and the proper line wire one of two generators that will send pulsating currents in the proper direction. The circuits are arranged so that all conversations are carried on over the two line wires.

TELEPHONE-EXCHANGE SYSTEMS

The ordinary form of telephone exchange for handling a large number of subscribers comprises a central office, from which the lines to the subscribers' stations radiate. The lines terminate at the central office in what is called a *switchboard*, which must contain apparatus for attracting the attention of the operator when one subscriber desires to talk to another; means for the operator to connect her telephone with the subscriber's line, in order to ascertain his wants; means for connecting his line with that of any other subscriber; means for calling the subscriber desired; and, finally, means for enabling either subscriber to notify the operator that their conversation is ended.

Line Signals.—The apparatus for attracting the operator's attention may be an electromagnetic annunciator, or a very small incandescent lamp whose circuit is controlled by a relay in the line circuit. Annunciators, or *drops*, as they are commonly called, are used on switchboards where the subscriber's set is equipped with a magneto generator, and relays controlling lamps are used in large central-energy, or common-battery, systems.

SIMPLE MAGNETO SWITCHBOARD

The circuits of a *simple magneto switchboard* are illustrated in Fig. 39. The binding posts L L' are connected through line wires with the tip spring t', t'' and the sleeve contacts s', s'' of the spring jacks J', J'', while the drops D', D'' are connected between the contact spring p', p'' and the sleeve side of the line circuit.

If subscriber *A* operates his generator *G′*, current flows through the line and drop *D′*, causing the shutter of the latter to fall, thereby attracting the operator's attention. The operator inserts the answering plug *P′* in the jack *J′*, thereby cutting out the drop and extending the line circuit to a flexible cord circuit, and restores the shutter of *D′* to its normal position. The tip *t* and sleeve *s* of the plugs are insulated from each other, but connect with wires *1*, *2*, and to the tip and sleeve of a jack when inserted therein. The

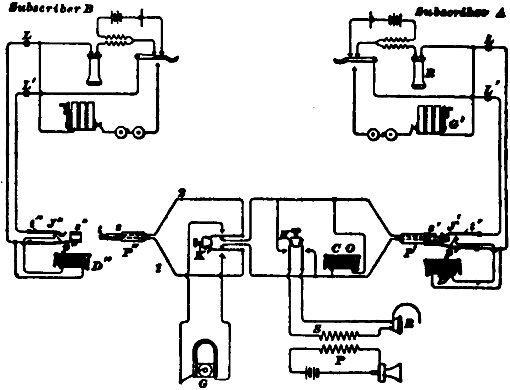


Fig. 39

operator depresses the listening key *K*, which connects the secondary circuit containing the head-receiver *R* and secondary *S* of the induction coil across the cord circuit. This enables the operator to converse with subscriber *A*, who has in the meantime taken down his receiver *R* and from whom is obtained the information that connection is desired with another subscriber, say *B*. The operator then inserts the calling plug *P″* in the jack *J″*, thereby cutting out the drop *D″* and establishing connection with the line wires of subscriber *B*. The operator then depresses the ringing key *K'*, thereby connecting the ringing generator *G* across the strands *1*, *2* of the calling side of the cord circuit leading to the calling plug *P''*, thus ringing the bell at station *B*. The ringing current cannot pass to station *A* because the depression of the ringing key *K'* disconnects the two cord conductors leading to the answering plug *P'*. When the operator releases the key *K'* and subscriber *B* removes his receiver from its hook, the talking circuit between the two subscribers is complete. After the conversation is finished, one or both of the subscribers should operate their generators, or "ring-off," as it is usually termed. This will send a current over the lines of the two connected subscribers, a part of which will find a path through the clearing-out drop *CO* and cause its shutter to fall. The operator, seeing the signal, should close the listening key, restore the shutter of *CO* to its normal position and inquire whether any further service is desired; if no response is received, the two lines should be disconnected by removing the two plugs from the jacks.

The line drop in a system of this kind should have about the same resistance as the subscriber's bell. In order that the clearing-out drop *CO*, which is connected across the circuit during the conversation, shall not form too low a leakage path between the two sides of the circuit, it is wound with a large number of turns to a high resistance (from 500 to 1,000 ohms). The inductance of the drop is increased by enclosing the core and coil in a tube of soft iron, which makes its impedance to the high-frequency voice currents very great, and, furthermore prevents cross-talk and other inductive disturbance between neighboring drops.

CENTRAL-ENERGY, OR COMMON-BATTERY, SYSTEMS

Replacing all the transmitter batteries and the signaling generators at the subscribers' stations by a single source of current located at the central office has proved so successful that most of the new large exchanges are now operated on this plan. While there are many different systems in use, nearly all of them involve one of the following principles:

1. In the *Stone system*, the lines during a conversation, are connected through impedance coils with a common battery; that is, between one terminal of the common battery and one side of each circuit is connected an impedance coil, and between the other terminal of the battery and the other side of each circuit is connected another impedance coil. Thus, for each pair of lines connected together, there is a separate pair of impedance coils through which the battery supplies current for those lines. Therefore, each subscriber's station receives current from the central battery through a pair of impedance coils, which allows the battery current to flow, but confines the high-frequency voice currents to the line wires. These impedance coils may be made to serve as relays to give clearing-out or supervisory signals.

2. The *Hayes common-battery system* consists in connecting each side of two circuits in use through a repeating coil to the terminals of the common battery. The repeating coil is usually divided into at least four coils, constituting really two separate repeating coils. One coil connects one side of one circuit with one terminal of the battery, another coil connects the other side of the same circuit to the other terminal of the battery, and, similarly, the other half of the repeating coil connects the two sides of another circuit with the opposite terminals of the battery. This method of operation will be understood from the description to be given of the Bell central-energy exchange.

LARGE SWITCHBOARD SYSTEMS

Transfer Switchboards.—When the number of subscribers connected with an exchange is larger than can be attended to by three operators, any one of whom can reach all the jacks, either transfer or multiple switchboards must be used. In the transfer system, auxiliary circuits, termed *trunk*, or *transfer lines*, run between the various sections into which the switchboard is divided, and means are provided by which the operator may connect one end of any one of these trunk lines with the line of a subscriber, while the operator at the other end, when instructed to do so by the first operator, can complete the action between her end of the trunk line and the line of the subscriber called for. Trunk lines thus serve as auxiliary connecting circuits between two subscribers' lines that cannot be connected together at any one section of the switchboard. A switchboard arranged to operate in this general manner is termed a *transfer*, or *express*, *switchboard*.

Multiple Switchboards.—The primary object of the *multiple-switchboard system* is to so arrange the apparatus that any operator can connect the line of a calling subscriber with that of any other subscriber in the entire system without the assistance of another operator. The entire board is divided into sections, each usually containing the necessary apparatus and room for three operators. In each section are placed as many multiple jacks as there are lines in the exchange in addition to the line signals and answering jacks of the lines the calls from which are to be attended to at that section. Each operator can reach over one operator's position on each side of her. On some common-battery multiple switchboards, each operator attends to as many as 200 lines.

It is evident that the operator at one section will, unless special means are provided, have no way of knowing whether a line called for by a subscriber at her section is already connected with another line at some other section of the board. Should she make connections between one subscriber's line and another line already in use, three subscribers would be connected together and much confusion would result. In order to prevent an operator from making connection with a line that is already in use at another section of the board, there is provided a so-called *busy test*, which forms an essential feature of every multiple switchboard. The operator usually performs the test for a busy line by applying the tip of the calling plug to the sleeve or ring of the jack of the subscriber called for. If the line is busy, the operator will hear a click in her head telephone, while if it is free or not in use, silence will inform her of that fact. The details of the busy test will be explained in connection with the circuit of a central-energy multiple switchboard.

Central-Energy Multiple Switchboard.—The principal features of the *central-energy multiple-switchboard system* used by the licensees of the American Bell Telephone Company are shown in Fig. 40. The Hayes principle of utilizing repeating coils and one battery for all line circuits is employed. Two operator cords and three subscriber circuits are shown. Normally, the circuit between the line wires is closed only through the subscriber's bell and condenser. The alternating current from the ringing generator at the exchange can ring the bell through this circuit, but no battery current can pass through it on account of the condenser. In each cord circuit there is one repeating coil, which has four windings w, x, y, and z. In the answering, or left-hand, side of the cord circuit, there is one supervisory relay AR, controlling the answering supervisory lamp AL; and there is a similar arrangement in the calling, or right, side. So as not to impede the voice currents too much, the relays AR and CR are shunted by non-inductive resistances Ar and Cr, which do not, however, interfere with the proper operation of the relays. When the resistance coil u and lamp AL are in series across the 24-volt battery B, the lamp will light, but it will go out when the 40-ohm resistance v is connected in parallel with the lamp by the operation of the relay AR. For the sake of clearness several batteries are shown, but there is really only one battery. Normally, no current flows through the cut-off relay CO_1, and hence, the line circuit is closed between a, b and between m, i.

When the subscriber at station *1* removes the receiver R_1 from the hook, the transmitter T_1 and one winding P_1 of the induction coil form a circuit across the two line wires of sufficiently low resistance to allow enough battery current to flow from B_1 to energize the line relay LR_1, thereby closing its local circuit and lighting the line lamp LL_1, which notifies the operator that her attention is desired on that line. The operator responds by inserting the answering plug (belonging to any one of the ten- or fifteen-cord circuits

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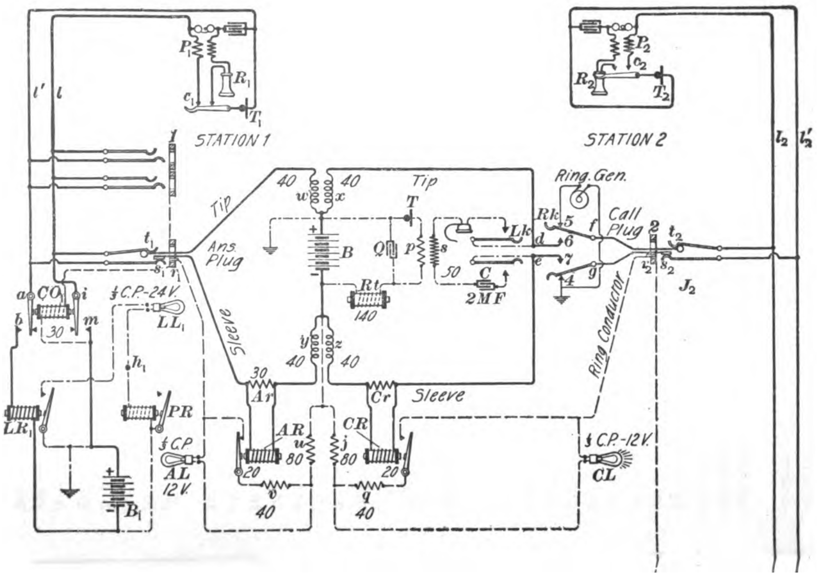
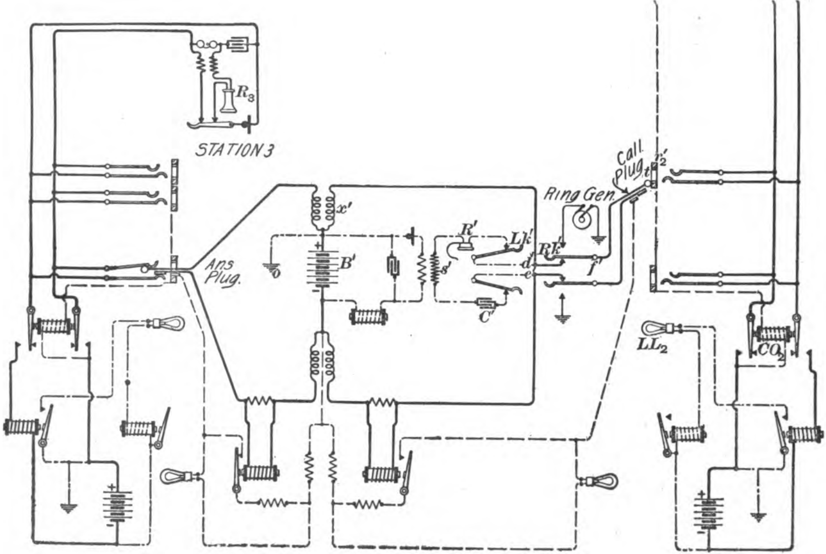

STATION 1
STATION 2
Tip
Ans. Plug
Sleeve
Call Plug
Ring. Gen.
Ring Conductor
1/4 C.P.-24 V.
LL1
PR
1/4 C.P.
AL
12 V.
1/4 C.P.-12 V.
CL
LR1
B1
CO1
AR
Ar
CR
Cr
Rt
140
2MF
Rk
Lk
J2



STATION 3
R_3
Ans Plug.
x'
B'
R'
Lk'
s'
C'
d'
e'
Rk'
f'
Ring Gen.
Call Plug
t
r'2
LL_2
CO_2

FIG. 40

73807

that she has before her) into the answering jack belonging to line *1*, as shown. Enough current flows through *AR* to close it, which prevents the lighting of *AL*. Current also flows through CO_1, thereby breaking the circuit at *b* through the line relay LR_1, which causes the line lamp LL_1 to go out. The operator closes the listening key *Lk*, thereby connecting the receiver, secondary winding *s* of her induction coil, and the condenser *C* across the cord circuit. The operator's transmitter *T*, primary to winding *p*, and retarding coil *Rt* are connected to the terminals of the battery *B*. The retarding coil not only limits the current through any one transmitter, but also enables current to be supplied to all the operators' transmitters from one battery without causing cross-talk. The condenser *Q* improves the transmitting qualities, probably because it compensates more or less for the inductance of the retarding coil *Rt*.

If the subscriber at station *2* is wanted, the operator will make the usual busy test on that line, and if the line is not busy, she inserts the calling plug into the multiple jack J_2 opens the listening key, and closes the ringing key *Rk*. Current from the ringing generator flows through and rings the bell at station *2*. Current now flows through B–CO_2-r_2-CL–j, thereby lighting the supervisory lamp *CL* and closing the relay CO_2, which prevents the lighting of the line lamp LL_2. When the subscriber removes his receiver R_2 from its hook, current flows from *B* through the subscriber's circuit and the relay *CR*, thereby connecting *q* in parallel with *CL*, which causes the latter to go out.

When the subscriber talks into the transmitter T_1, its resistance changes sufficiently to produce a variable current through the windings *w*, *y*, which induces an alternating current in the windings *x*, *z*. This alternating current, combined with the direct battery current, produces a current of variable strength in the line circuit of station *2*. This variable current in the winding P_2 of the induction coil induces an alternating E. M. F. in the other winding of the induction coil, thus producing an alternating current in the local circuit containing the receiver, transmitter, and condenser. It is also probable that the effect produced by this current is reinforced by some of the variable current, which may flow through the hook switch, receiver, and induction coil and assist in charging and discharging the condenser. When the conversation is finished, the lamp *CL* will light as soon as R_2 is hung up, and *AL* will light as soon as R_1 is hung up.

To explain the "busy" test, assume that the circuits are exactly as shown in Fig. 40; that is, that stations *1* and *2* are connected together, subscriber *2* not having removed his receiver from its hook, and that the call of subscriber *3* for connection with subscriber *2*, whose line is now busy, has just been answered by an operator at another section of the switchboard where the lower cord circuit is located. The latter operator makes the busy test as follows: Her listening key is already closed, so she merely touches the tip *t* of her calling plug to the ring contact r_2' of the multiple jack in her section belonging to subscriber *2*. Current flowing from $+B$ through CO_2–r_2–CL–j makes the potential of the ring contacts of all jacks belonging to this line different from that of the ground, and produces a click in the operator's receiver R', for current then flows through B–ground–o–x'–d'–f'–t–r_2' where it unites with current flowing through B–CO_2–r_2', and the whole current flows through r_2–CL–j. Before touching t to r_2', the points d', e', and hence the terminals of condenser C', had exactly the same potential difference as the terminals of battery B'; but now the current through B–ground–o–x'–d'–f'–t–r_2'–r_2–CL–j has suddenly lowered the potential of d', and hence the charge on condenser C' has suddenly decreased, thereby producing a momentary current and click in the receiver R', which notifies the operator that the line is already in use, or busy, as it is called.

If the line is not in use, that is, if there is no plug in any jack of this line, the tip t of the calling plug and the sleeve r_2' of the jack will be at the same potential—the potential of the positive terminal of the common battery—and hence no click will be produced.

The circuits of all the line lamps at any one position are connected together at h_1, between which point and the battery is connected a line-pilot relay *PR*. This relay controls the circuit of a line-pilot lamp, which is not shown in this figure, but which lights every time any line lamp at that operator's position lights, and goes out when the line lamp goes out; that is, when the call is attended to by inserting a plug in the jack. A similar supervisory-pilot relay and supervisory-pilot lamp is associated with all the cord circuits at one operator's position. The supervisory-pilot relay is energized and the supervisory-pilot lamp lights when any answering supervisory lamp at the same operator's position is illuminated.

AUTOMATIC TELEPHONE SYSTEMS

An *automatic telephone system* is one designed to supplant the telephone-exchange operator by automatic appliances. Switches located at a central office automatically connect two lines for a conversation and also disconnect them, this result being produced as a result of certain operations performed by the subscribers themselves. An automatic system usually consists of a telephone and selecting device at the subscribers' stations, the selecting device being used by the subscriber to select the line desired by sending a certain number of impulses over one or both line wires. At the exchange, a switch automatically connects the calling line to the line selected by the subscriber. Therefore, to establish connections between any two lines running to the same automatic exchange, no operators are required. Thus a large item of expense—operators' salaries—is saved in the cost of operation. Those favoring manually operated systems claim that more expert troublemen and switchboard men are required, which more or less offsets the saving in operators' salaries. Operators are generally employed, however, for toll service and trunking between different exchanges, even if both exchanges are automatic. The use and popularity of automatic systems are increasing and a large number of exchanges, both large and small, are now equipped with such systems. Automatic telephone systems are rather complicated, and, every new installation is likely to contain improvements over preceding systems; even a general description that would apply to one installation would require more space than can be devoted to it here. Such systems are fully described in the International Correspondence Schools' Telephone Engineering Course.

TELEPHONE-PROTECTING DEVICES

A complete protector for telephone lines includes three forms of protective apparatus: (1) an open-space cut-out, designed to act as a spark gap and relieve the circuit from high-potential discharges by forming a non-inductive path to ground; (2) a thermal apparatus so designed that when an abnormal current of relatively low voltage appears, the thermal apparatus under the effect of the heat created by the extra current will operate in such a manner as to open or ground the side of the circuit toward the apparatus to be protected and ground the other, or line, side; and (3) a fusible cut-out of relatively large current-carrying capacity and extended across a long gap.

These three pieces of apparatus are known by the names *open-space cut-out lightning arrester* or *static arrester*, *heat coil* or *sneak-current protector*, and *fuse*. For the complete protection of a telephone line, it is usually considered desirable to place an open-space cut-out and heat coil on the distributing board to protect the central-station apparatus; to place a fuse wire on underground lines where the cable to the central office joins open wire; and to place a second fuse and open-space cut-out and sometimes a heat coil at the subscriber's telephone substation.

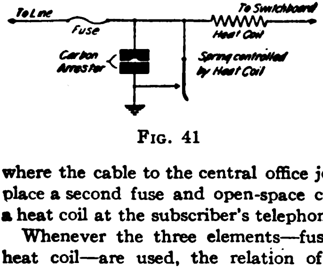


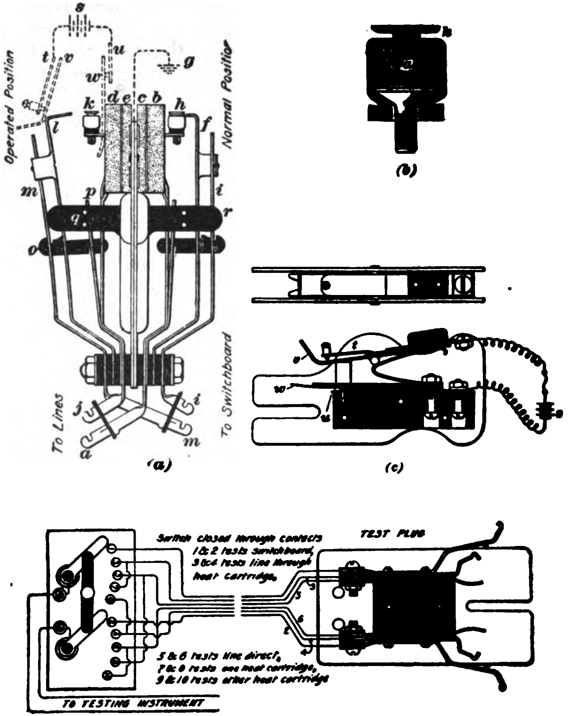
FIG. 41

Whenever the three elements—fuse static arrester, and heat coil—are used, the relation of the elements should be as shown in Fig. 41, the heat coil being connected on the switchboard side or, if at a subscriber's station, on the telephone side of the circuit. The first duty of protective apparatus is to prevent foreign currents from damaging central-office equipments; hence, the proper position for the fuse is between that part of the line circuit which can come into contact with a source of dangerous current and the office equipment. The term *exposed wiring* may be applied to such parts of the line as may ever come in contact with a source of dangerous current, while *unexposed wiring* may be applied to all parts of the line that are secure from such contact. Unexposed wiring includes underground cables cables formed of wires insulated with rubber, and wiring wholly within buildings. All other wiring may be considered as exposed to accidental contact with high-potential circuits. In this class, aerial cables having lead sheaths are included, because contact between such a cable and a high-potential wire very frequently causes an arc that destroys the sheath and allows current to enter the conductors.

Lightning Arresters.—Lightning arresters used on telephone lines usually consist of two blocks of carbon separated by silk, paper, perforated mica, or celluloid. At central stations, the separation is usually .005 in., and the same or a trifle greater (.008 in.) at the subscribers' stations. Where fuses are used, they are generally enclosed in long and nearly air-tight wooden or fiber tubes.

Fig. 42 (*a*) shows Cook's No. 10 protector for use on the terminal frame of an exchange. The carbons *c*, *e* of the lightning arrester rest on a grounded strip and are separated from the line carbons *b*, *d* by perforated or U-shaped pieces of celluloid .005 in. thick. The many small perforations in the celluloid are said to break up the discharge, thereby forcing it to pass through the arrester at many points and thus prevent particles of carbon from breaking off and short-circuiting the arrester. If an arc continues across *bc* or *de*, due to a cross with a high-voltage circuit, the celluloid will melt and allow the springs to press the carbon blocks together and form a dead ground; this will stop the arc, and if the current increases sufficiently, the fuses at the outer end of the line will melt and cut off the line circuit from the switchboard.

A low-voltage current that is large enough—if it persisted—to damage a switchboard, coil, or other device


Operated Position
Normal Position
To Lines
To Switchboard
(a)
(b)
(c)
Switch closed through contacts
1 & 2 tests switchboard,
3 & 4 tests line through
heat cartridge,
TEST PLUG
5 & 6 tests line direct,
7 & 8 tests one heat cartridge,
9 & 10 tests other heat cartridge
TO TESTING INSTRUMENT

(d)

FIG. 42

will pass from line *a* through the heat cartridge *h*–springs *f*, *i*–switchboard–springs *m*, *l*–heat cartridge *k*–springs *j*, to line. An unusually large current will heat the graphite *a* packed in the cartridge [see Fig. 42 (*b*)], and, by the conduction of heat, a low-temperature-melting solder on the brass shell at *k* will become soft enough to allow the spring *m*, Fig. 42 (*a*), to pull the hard-rubber piece *o* and with it the spring *l* out of *k*. This also causes spring *p*, which is forked, to touch both metal pins *q* and thus close a circuit (not shown) containing a battery and an alarm bell. The cartridge, Fig. 42 (*b*), consists of a metal shell, enclosing a graphite composition that is insulated from the metal casing except on the upper and lower ends. Hard-rubber strips *r*, Fig. 42 (*a*), pass through the central grounded strip and keep the springs belonging to one line circuit alined and separated from adjacent springs.

To reset the heat cartridge, the resetting plug shown in Fig. 42 (*c*) is pushed between the springs, thereby connecting a battery *s*, Fig. 42 (*a*), between the springs *v*, *w* and pressing the springs *m*, *l* back toward their normal position. When *l* touches *k*, current flows through *k*, softens the solder, allows *l* to slip into place, and breaks contact between springs *t*, *v*, thereby stopping the current, which allows the solder to harden and hold the springs *l*, *m* in position. Should the cartridge be defective, the operation of resetting automatically indicates the fact, because the spring *l* cannot be reset properly. By inserting the test plug, Fig. 42 (*d*), between the springs of one protector, Fig. 42 (*a*), it is possible to test the various circuits, by the aid of the switch shown and the proper testing instruments.

Combination Protector.—The *D and W combination protector*, shown in Fig. 43, well represents the complete protection frequently used at subscribers' stations. Sometimes the heat coil is omitted and sometimes the fuse, depending on conditions and the opinion of the telephone man in charge of the system. The arresters almost invariably consist of two carbons similar to *a*, *b*, one of which is in contact with each line wire and separated from a grounded brass plate *e*, usually by means of a piece of silk, paper, or perforated mica, .008 in. thick. This thickness of mica will permit 350 or more volts to arc across the air gap, and thus allow the line to discharge to ground. Long, enclosed fuses, the center portion of which in this particular make runs through an air-tight capsule of gelatine *vu*, are used, and

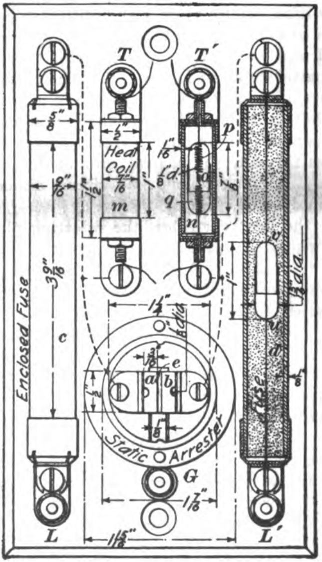


FIG. 43

the heat coils consist of spirals *p*, *q* of German-silver wire pulling away from each other. These spirals are held together, however, by a little solder at *o*, which melts when more than about .3 ampere flows through the line and the heat coil for 15 sec.

INTERIOR SYSTEMS

In many factories, large houses, and institutions, telephonic communication between various departments without the aid of a central switchboard and operator is frequently desired. Intercommunication may be obtained by running at least one more wire than there are stations through all the stations, at each of which is provided a simple switch whereby the telephone instrument at that station may be connected with any other station. Such a system is variously known as an *intercommunicating*, *house*, or *speaking-tube*, *system*. There is practically no end to the various arrangements of apparatus and circuits used in house systems. In order to illustrate as many as possible, the description of each system will be very brief.

For systems requiring more than 20 or 30 stations, a private branch switchboard seems better. Plugs and spring jacks and, frequently, push buttons may be used, but the circuits can be most clearly shown in the figures by using strap switches. On each switch, the button bearing the same number as the station at which that switch is located is usually placed at the left-hand end, and is called the home button. All the switch levers normally rest on this home button. In practically all systems to be shown, the wiring is arranged so that the bells at any station can be rung from any other station, no matter on what button the switch lever may have been left, but before a conversation can be carried on, the switch at the station called should be returned to the home contact if not already there. This is usually the best arrangement, except for vestibule or apartment houses, because it cultivates the desirable habit of returning the switch to its home position.

A *complete metallic-circuit, intercommunicating, telephone system* is here intended to mean one that has a pair of wires for each station and, if necessary, one or more wires that may be used for signaling purposes in common by all the stations. All these wires run through all the stations. The object of using two wires, usually twisted to form a pair, for each station is to eliminate cross-talk. Where cross-talk to a moderate degree is not objectionable, systems using only one wire for each station, in addition to one or more common wires, are cheaper to install, simpler, and give good satisfaction. However, where the wires are run in cables, as is usually the case in first-class installations, and all cross-talk must be eliminated, it is almost imperative to use a complete metallic-circuit system—as here defined—of some kind. In systems having only one wire for each station, there is likely to be more or less cross-talk, due either to induction between line wires running parallel and close together or to the use of one common wire as a common return by all stations as a part of their talking circuits.

MAGNETO-BELL SYSTEMS

A system using ordinary magneto generators, polarized bells, the necessary talking apparatus, and strap switches is shown in Fig. 44. To call station *1* from station *2*, turn S_2 to contact *1*, as shown, close the ringing key K_2 and turn the

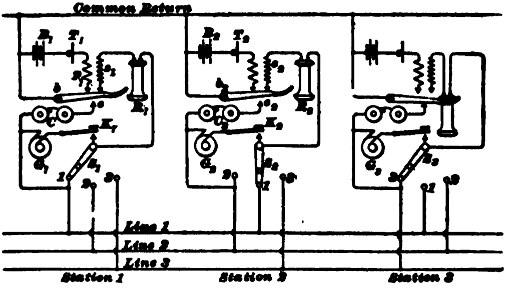


FIG. 44

ringing generator G_2, which will send a current through the bells C and C_2. The generator may be so constructed as to automatically close its circuit when its handle is turned. When both receivers are removed from their hooks, the two parties may converse over line *1* and the common return wire.

If station *2* should desire to hold a consultation with both stations *1* and *3*, station *2* would first call up station *3*, request that the switch there be turned to button *1*, and then station *2* would call up station *1*. The three parties could then converse.

Complete Metallic-Circuit System.—To eliminate all trouble from cross-talk and interference from ringing currents, the wiring shown in Fig. 45 may be used. Two radial switch arms *c*, *d* are mechanically connected by

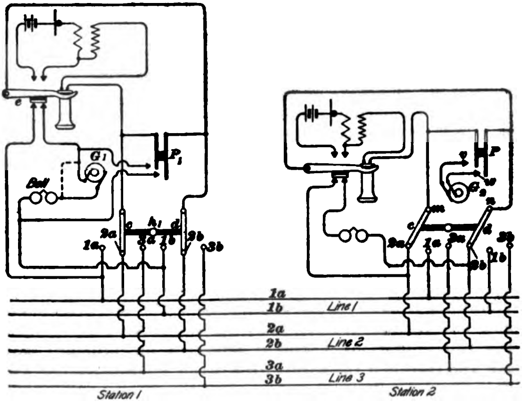


Fig. 45

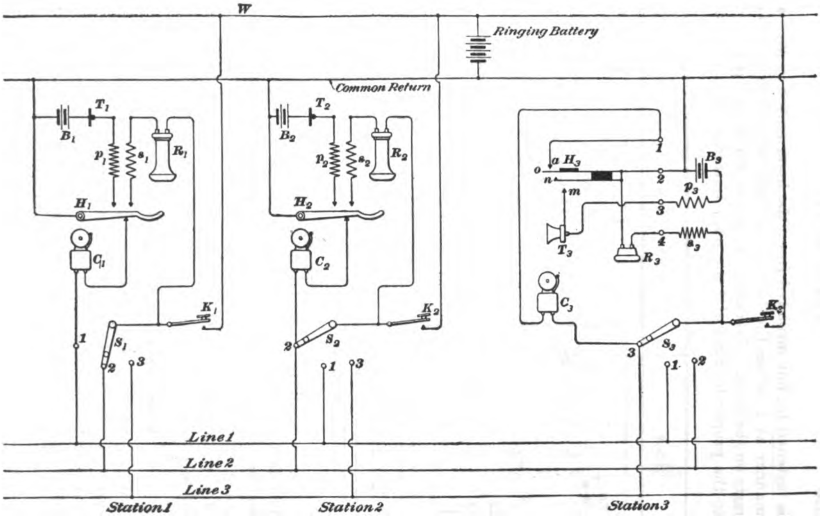
an insulating piece, to which one handle h_1 for controlling both arms is fastened. Of course, any other form of switch that will accomplish the same result may be used. To call a station, turn the switch to the number of the station desired, holding the double-contact push button P_1 closed while the handle of the magneto generator G_1 is turned. The piece *e* is insulated from the hook switch so that the ringing currents cannot interfere with other telephones in use, should the switch arm be left off its home position.

The bell can be rung no matter in what position the switch is left, but it must be on the home position at the station called before a conversation can be carried on. A series bell and generator are required with the wiring shown at station *1*, and the usual automatic shunt used in series telephones is necessary, as indicated by the dotted line around the generator G_1. However, the generator may be connected as shown at station *2*, that is, across the contacts *v*, *w*. In this arrangement, any suitable generator may be used and no automatic shunt or cut-in device is necessary; in fact, one terminal of the generator could then be permanently connected to *m* and a single-point push button used to connect the other generator terminal to *n* when using the generator. A generator having an automatic cut-in device could be connected across *m*, *n*, no push button being required. Either series or bridging bells may be used with the wiring shown at station *2*.

COMMON RINGING-BATTERY SYSTEMS

Common-Return Circuit.—The *common ringing-battery system* is one in which one battery is used in common by all stations for signaling purposes only. Fig. 46 shows such a system. The means for signaling consists of an ordinary vibrating, or battery, bell and a push button at each station and one ringing battery conveniently located for ringing the bells. Stations *1* and *2* represent an ordinary wall set, and station *3* the wiring for a hand microtelephone set. The latter consists of a receiver and transmitter mounted in one handle, which contains a switch that can be readily held closed by the pressure of the hand that holds it to the mouth and ear. The bell at the station making the call does not ring.

Complete Metallic Circuit.—A good way to wire common-ringing battery telephone instruments for a system having two wires for each station is shown in Fig. 47. The wiring is shown more clearly at station *1*, but the practical arrangement of the hook-switch contacts is more accurately shown at station *2*. A centrally located battery *RB* is used for ringing ordinary battery bells V_1, V_2. At station *1*, a contact piece *e*



W
Ringing Battery
Common Return
Line 1
Line 2
Line 3
Station 1
Station 2
Station 3

FIG. 46

is fastened to, but insulated from, the hook switch in such a manner as to close the bell circuit only when the receiver rests on the hook. To call up a station, the switch is turned to the proper buttons and the push button is then pressed.

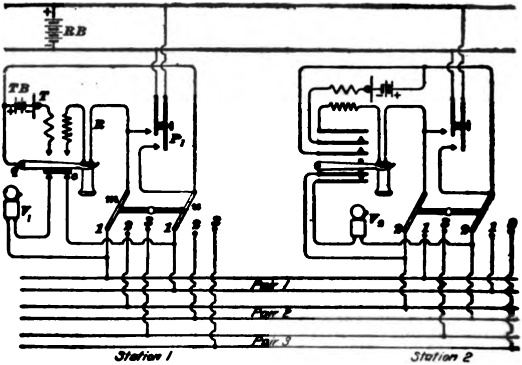


Fig. 47

The fact that the switch at the station desired may not rest on the home position does not prevent that station from being called from any other station. However, the switch at the station called must rest on, or be returned to, the home position before any conversation can be carried on.

CENTRAL-ENERGY HOUSE SYSTEMS

Where batteries are not desired at each station, a *central-energy system*, one of which is shown in Fig. 48, may be used. The objection to most all central-energy intercommunicating systems is the liability to cross-talk. Cross-talk may be reduced by inserting a 25- to 50-ohm impedance coil *I* in series with each transmitter, as shown at station *3*. Current is supplied to the various transmitters, when in use, by the set of cells *ab*, and the cells *cd* are used for ringing the bells.

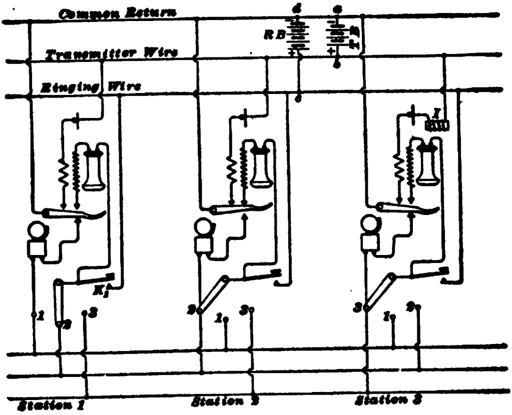

Common Return
Transmitter Wire
Ringing Wire
RB
B
Station 1
Station 2
Station 3

FIG. 48

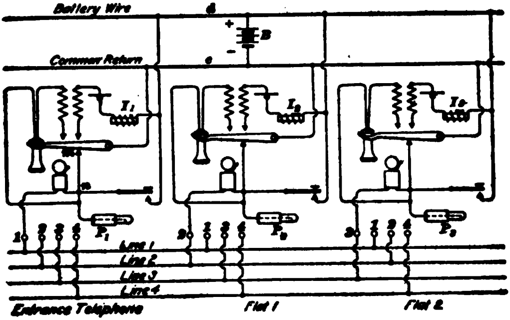

Battery Wire
Common Return
B
Line 1
Line 2
Line 3
Line 4
Entrance Telephone
Flat 1
Flat 2

FIG. 49

On a small system, where the same number of cells may answer for both transmitters and bells, one wire less may be used by connecting each transmitter to the ringing wire, the transmitter wire and battery *TB* being omitted.

Apartment-House System.—In Fig. 49 is shown a more suitable arrangement for communication between the vestibule and the various flats in a modern apartment house, as the plug does not have to be returned to its home jack or be removed from any jack in order that the parties may converse. Any station may be rung, regardless of the position of its plug. At each station there is an impedance coil I_1, I_2, I_3 to reduce the cross-talk and a plug P_1, P_2, P_3 to make connections through one of the jacks *1*, *2*, *3*, *4* with the desired telephone. This arrangement may be used to provide communication between the tenants, between the tenants and callers, and between the tenants and the janitor, in whose quarters a telephone set may be located. The common battery *B* may also be placed in the janitor's quarters. An objection to this system is that, if any two stations are connected, and a third station calls either one of the first two, the bells of the first two stations will both ring if the receivers are on their hooks. In many cases, no bell would be required in the entrance telephone and the circuit *m–n–1* would be omitted.

Simple Plug-Switch System.—In Fig. 50 is shown a very simple central-energy intercommunicating system, described in the Telephone Magazine by James V. Crecelius, who says that he has found it more satisfactory, where the longest line does not exceed 1,000 ft., than many other more complicated systems. Provided the receivers are hung up when not in use, no bell except the one desired will ring even though the plugs are accidentally left in any jack. To call station *2* from station *1*, insert the plug P_1 in jack *2* at station *1* and press the push button K_1. Very little of the ringing current passes through the transmitter T_2, because the bell W_2 has very much less resistance. Although it has not been found necessary, the arrangement shown only at station *3*, in which the transmitter circuit is normally open and therefore not in parallel with the bell, could be

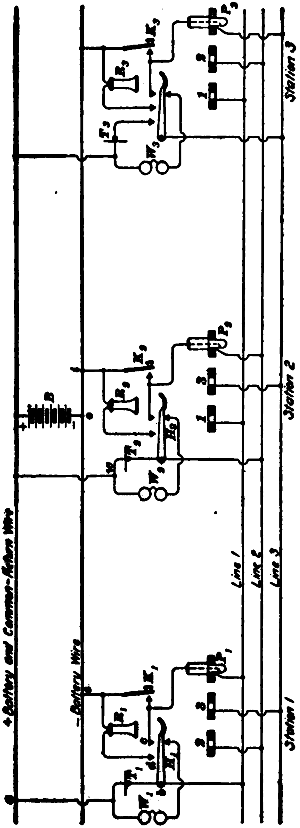

+ Battery and Common-Return Wire
– Battery Wire
Line 1
Line 2
Line 3
Station 1
Station 2
Station 3

FIG. 50

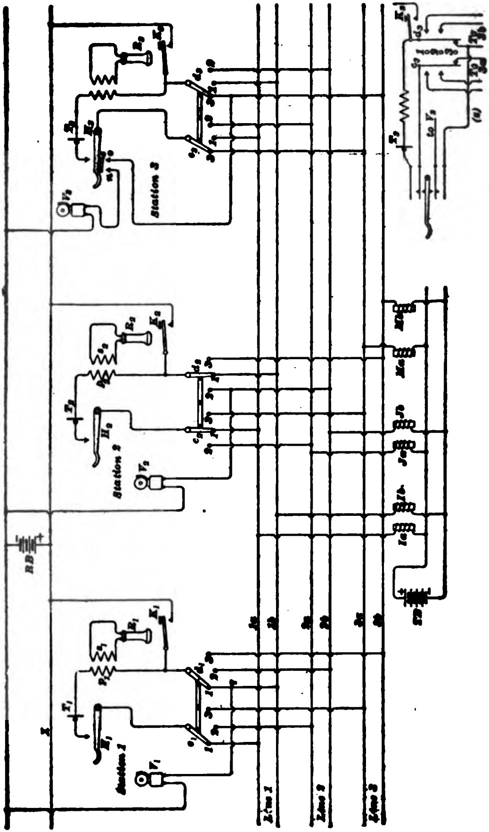


FIG. 51

used at all stations. The receiver must be connected in the proper direction in the circuit and the plugs should always be withdrawn at the end of a conversation, because otherwise there is a chance for cross-talk should four or more people be talking at the same time. For the battery *B*, use enough dry cells to give from 6 to 9 volts.

Complete Metallic Circuit.—A central-energy intercommunicating circuit that is suitable for a large system because it is free from cross-talk, is shown in Fig. 51. There is one battery *RB* for signaling purposes and another *TB* for supplying current to all the transmitters. Each pair of line wires is connected through two coils of high inductance to the talking battery *TB*. The transmitter is connected in series with the primary of an induction coil, and the receiver in series with the secondary and in a permanently closed local circuit. At station *S*, the bell V_3 is disconnected from the circuit at the hook switch while conversing; this prevents the possibility of interference while talking, due to charging and discharging currents and to leakage through the bell and the wire. However, it is very doubtful whether this would usually be serious enough to warrant the use of the extra contacts *n*, *o*, *e* thereby required. The bell at any station can be rung from any other station, even if the switch has not been returned to its home position, but the conversation cannot be held until the switch at the station called is returned to its home position.

CONNECTION BETWEEN INTERCOMMUNICATING AND EXCHANGE TELEPHONES

It is often very desirable to be able to connect a telephone belonging to a city exchange with an intercommunicating system. Intercommunicating systems are being used for this purpose in place of small private branch switchboards. Whether such connections can be made, depends on whether the local exchange company will allow it, and, furthermore, intercommunicating telephones should be so arranged as not to interfere with the proper operation of the exchange telephone and the switchboard signals.

Kellogg System.—In Fig. 52 is shown the central-energy intercommunicating system made by the Kellogg Switchboard and Supply Company. It is a complete metallic-circuit system. The battery bell has two gongs, which give it the appearance on the outside of a polarized bell. Two sets of dry batteries are required, one *TB* for talking and another *RB* for ringing the bells. For five to ten stations with 1,000 ft. of cable, the talking battery should contain three cells and the ringing battery six cells; with 2,000 ft. of cable, the talking battery should contain four cells and the ringing battery seven cells; for eleven to twenty stations with 1,000 ft. of cable, the talking battery should contain six cells and the ringing battery six cells; with 2,000 ft. of cable, the talking battery should contain eight cells and the ringing battery seven cells.

Two classes of telephone instruments—one called the major and the other the minor—are made for the Kellogg system. The major has a receiver and condenser in series, the two being connected in parallel with an impedance coil, as shown at station *2*. The minor instruments have the same apparatus, but the condensers and impedance coils are omitted, the transmitters being connected simply in series with the receiver, as shown at station *1*. The impedance coil in a major instrument forms a path of low resistance for the battery-transmitter current, which the condenser excludes from the receiver, while the fluctuating currents, since they pass through a condenser more easily than through an impedance coil, readily flow through the receiver-condenser circuit.

At station *1* is shown a minor desk-stand set; at station *2*, a major wall set; and at the answering station, a major desk-stand set equipped as an answering station. The answering station is provided with two trunk jacks *Jt* instead of one, as at the regular intercommunicating stations; an extra plug *P* for holding the exchange trunk line; and an extra box in which is mounted the holding coil *H*, a polarized bell *E* and condenser *C*, the bell and condenser being bridged, as an ordinary extension-bell set, across the exchange trunk line, to serve as a signal from the exchange to the answering station.

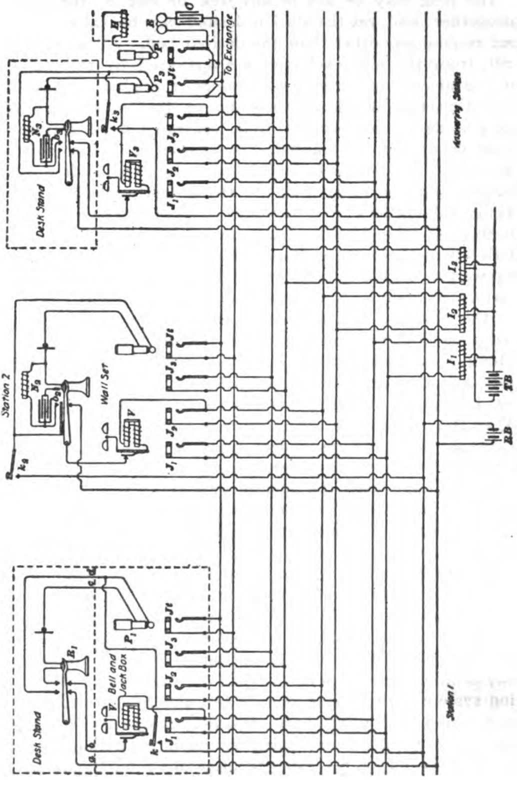

Desk Stand
Station 2
Wall Set
Desk Stand
Bell and Jack Box
To Exchange
Answering Station
Station 1

FIG. 52

The plug may be left in any jack or out of the jacks altogether, and yet the station desired can be called without ringing any other than the desired bell. All incoming calls from the city exchange are answered by the party at the answering station, who inserts the plug associated with this talking circuit into one of the trunk jacks *Jt* after a signal is received from central. After learning what department is wanted, the answering party inserts the plug *P*, across whose cords is connected the holding coil *H*, into the second jack of the trunk line, withdraws the regular talking plug from the other jack of the trunk line and inserts the same into the jack corresponding to the party with whom the party on the trunk line wishes to talk, and presses the ringing button, which rings the bell of the called party. As soon as the called party answers, he is notified by the party at the answering station to answer on the exchange line; the called party takes the plug out of the intercommunicating jack and inserts the same into the trunk jack, and the answering party withdraws both plugs from the jacks, restoring this station to its normal condition. When through talking, the receiver is hung up, which automatically gives the disconnect signal at central. To talk with an exchange subscriber, the intercommunicating subscriber merely inserts the plug into the trunk jack and takes down the receiver; this operates the exchange line signal and the exchange operator connects this line with the exchange subscriber desired in the usual manner.

Stromberg-Carlson System.—In Fig. 53 is shown the central-energy intercommunicating system made by the Stromberg-Carlson Telephone Manufacturing Company and the way in which it may be connected to a telephone instrument belonging to a magneto-exchange system. A person may communicate from any station on the intercommunicating system with outside parties, but the central exchange cannot be called, nor can the central-office operator ring the bell of any telephone belonging to the intercommunicating system only. It is necessary to place one intercommunicating telephone, which is termed the answering station, near the exchange telephone or an extension bell connected to it,

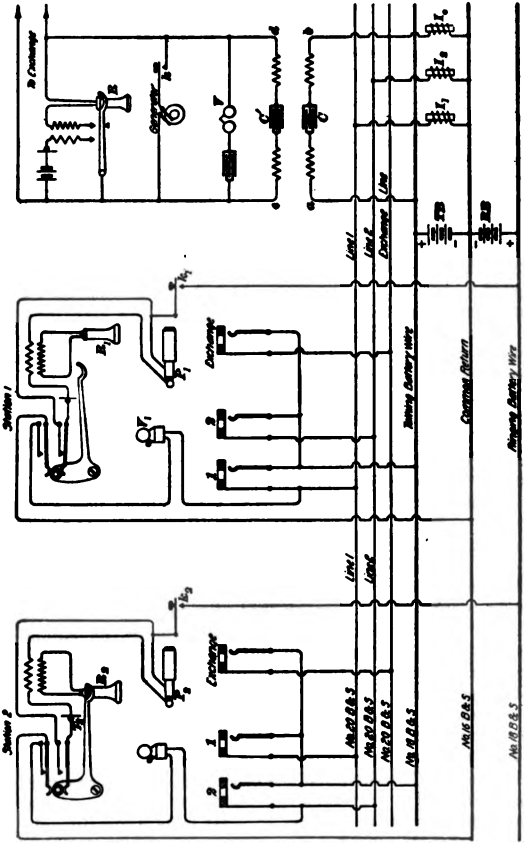

Station 1
Station 2
Generator
Line 1
Line 2
Exchange Line
Talking Battery Wire
Common Return
Ringing Battery Wire
No.20 B&S
No.16 B&S
No.18 B&S

FIG. 53

so that the party that answers the exchange telephone may signal the intercommunicating station desired and also the exchange operator when some one at another intercommunicating station calls up and requests the answering station to do so. If the plug is not in the home, or left-hand, jack, where it should be placed after any conversation, the bell can still be rung but nothing can be heard at the station called until the plug is inserted in the home jack. The exchange telephone is connected to the intercommunicating system by means of the repeating coil *abcd.* The condenser *C*, connected in the middle of the winding *ab*, prevents a constant waste of current from *TB* through this winding, and the condenser *C'* is necessary to avoid short-circuiting the ordinary 1,000-ohm polarized bell *V* in the exchange telephone instrument.

Holtzer-Cabot System.—In Fig. 54 is shown one way in which local-battery telephone instruments of an intercommunicating system may be connected with the instrument located at station *3*, which is supposed to be connected with a central-energy city-exchange system. No change whatever is made in the wiring of the central-energy instrument, which is located at station *3*, the line wires simply being connected from the binding posts *a*, *b* to the pair of wires *3* running through all the stations in the intercommunicating system. At station *1* is shown the plan of wiring used by the Holtzer-Cabot Electric Company in connection with its Ness automatic intercommunicating switch. The two levers *w*, *v* are insulated from each other, but are mechanically connected together, so that moving *w* by its handle moves both levers. Pressing the lever *w* by its handle against the strip *d* allows current to flow from the ringing battery *RB* through the contact button and line wire to which *w* is turned.

At station *2* is shown practically the same arrangement, except that an automatic switch is not necessary and a push button *P* is used in place of the ringing strip *d* in the Ness automatic switch. If the city-exchange instrument is operated on the central-energy plan, the resistance of the secondary s_1 and the receiver R_1 must be of approximately

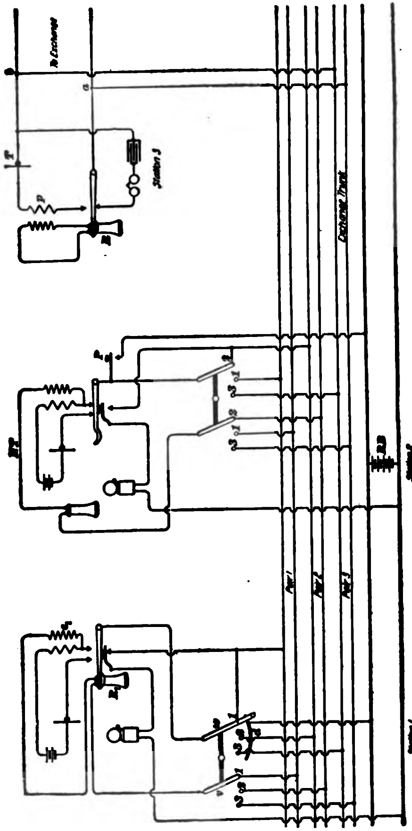

To Exchange
Station 3
Exchange Trunk
Station 2
Pair 1
Pair 2
Pair 3
Station 1

Fig. 54

the same resistance as that of the transmitter *T* and primary coil *p* in the central-energy system, in order that hanging up and taking down the receiver at the intercommunicating telephones will properly operate the signals at the central-energy exchange. The central-energy exchange may be called up from any instrument on the intercommunicating system by turning the intercommunicating switch, in this case to contact *S*, and taking the receiver off the hook. It is impossible (and not usually necessary) for the exchange to ring the bell at any of the intercommunicating telephones, and for this reason one of the intercommunicating instruments must be placed alongside the exchange instrument. The party that answers the exchange instrument at station *S* must call up the proper intercommunicating station, and, by means of the intercommunicating instrument alongside it, inform the party that answers to turn his switch so as to connect the instrument with the trunk line running to the city exchange, then hang up the receiver *R* of the exchange telephone and also the receiver belonging to the intercommunicating instrument at the answering station.

AUTOMATIC-SWITCH SYSTEMS

With the original house systems it was absolutely necessary for the calling party to return the intercommunicating switch to the home position when through with a conversation, in order to avoid leaving the station cut out so that no other station could ring it up; with more modern systems this is not the case, but it led to the development of automatic-return switches and systems. An *automatic intercommunicating switch* is one that automatically restores all connections to their normal positions when the receiver is hung on the hook switch.

Holtzer - Cabot Automatic System.—The Holtzer - Cabot automatic central-energy house system, which has all batteries located at some one convenient place, is shown in Fig. 55. Only two stations in a three-station system are shown, but the switches are made for any number of stations up to twenty. The current for all the transmitters is supplied by the battery *TB*; for ringing the bells, current is supplied from both the batteries connected in series Normally, the switch S_1 rests upon the home button and does not touch the strip *d*. To call up station *2*, for instance, the switch S_1 is turned to contact *2* and the handle is pressed down, so as to touch the strip *d* as well as button *2*, thereby ringing the bell V_2. When both receivers are removed from

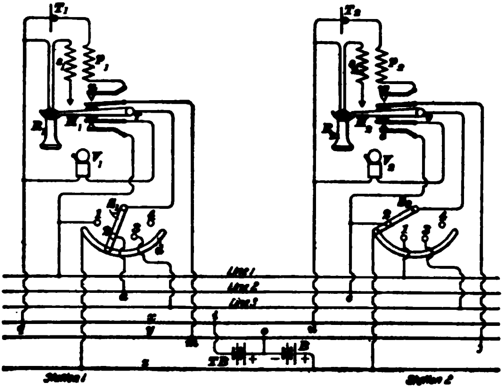


FIG. 55

their hooks, current flows through TB–o–m–n–p_1–T_1– q–line x–i, and also from o–through j–w–p_2–T_2–u–i. The voice currents flow from s_1 through R_1–q–line x–u–R_2–s_2–H_2–v–S_2–contact *2*–c–line *2*–a–contact *2*–S_1–r–H_1–s_1. When receiver R_1 is hung up, an automatic device restores the switch S_1 to the home contact.

TELEPHONES FOR APARTMENT HOUSES

In the vestibules of modern apartment houses, or flats, there is usually a row of push buttons that ring bells in the different apartments and a row of speaking tubes for communicating with the tenants. Telephone systems may be used to advantage in place of the speaking tubes. The telephone systems for such cases should be very simple, and all batteries should be located preferably in the janitor's quarters. Callers should be able to communicate with any tenant and any tenant with the janitor. In addition, it is sometimes desirable to arrange for communication between the tenants. It should only be necessary for a caller to

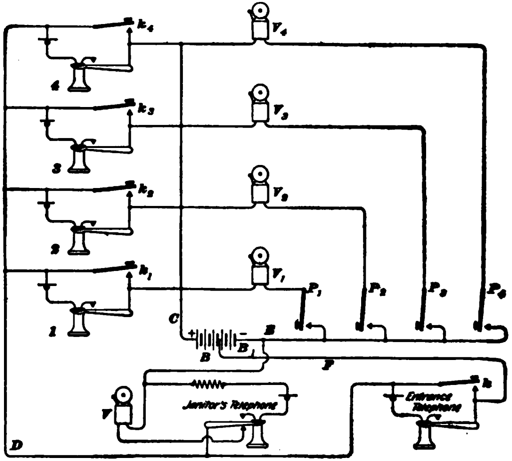


FIG. 56

press one push button associated with the telephone of the desired tenant and to take down the receiver. No system requiring the manipulation of a switch of any kind by the caller, who may not be familiar with such a system, is admissible.

Push-Button Bell System.—Fig. 56 shows a system suitable for apartment houses and it can be installed where push-button bell circuits have been used. The original bell circuits include the push buttons P_1, P_2, P_3, P_4 at the entrance, the bells V_1, V_2, V_3, V_4 in the various apartments, the common-return wire C, and a battery. It will usually be necessary to run a third wire D or to use a ground return in its place. In each apartment, there is a simple telephone with a transmitter and receiver in series, a push button and a battery bell. One terminal of the entrance telephone is connected to an intermediate point in the battery, in order that it

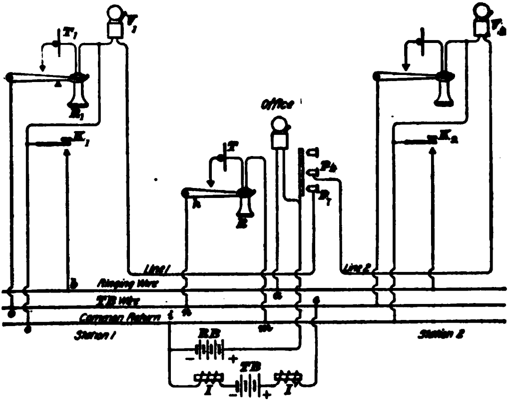


FIG. 57

may be used to talk with either the janitor or any tenant. In most cases, the entrance telephone would be nearer the janitor's telephone than any tenant's telephone; hence, a fewer number of cells would be required in B_1 than in B, while the entire battery would be required for conversations between the janitor and tenants. The push buttons k, k_1, k_2 etc., when pressed, ring the janitor's bell V.

Couch & Seeley Speaking-Tube System.—Fig. 57 shows a central-energy speaking-tube system made by the Couch & Seeley Company. It is suitable for a house, flat, or building requiring only three or four telephones and where communication between a central office and the stations only is required. The battery *TB* supplies the current for the transmitters, and the battery *RB* the current for ringing purposes. Impedance coils *I*, *I'* are connected between the battery *TB* and the two wires, over which flows the current for all the transmitters. To call up the central office from station *1*, for example, it is simply necessary to press the push button K_1. When the central office wishes to call a substation, say station *1*, the push p_1 is pressed.

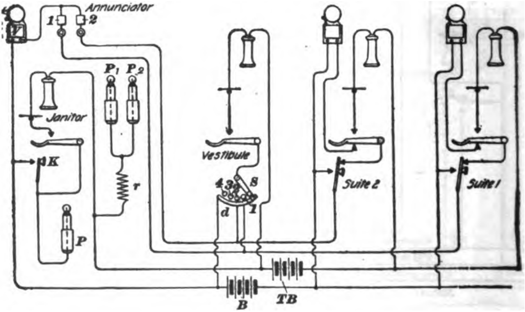


FIG. 58

Holtzer-Cabot Apartment-House System.—Fig. 58 shows what the Holtzer-Cabot Electric Company terms its *vestibule system* for apartment houses. In the vestibule is placed a telephone, equipped with an automatic switch, for calling and talking to any tenant. In the janitor's apartment is an annunciator provided with one signal, and immediately below it a jack for each suite, or apartment, one bell *V* through which all annunciator circuits return to the battery *B*, one plug *P* for answering ordinary calls by inserting it in the jack under the displayed signal, and a push button *K* for ringing, through plug *P* and the proper jack, the bell in any apartment. A pair of plugs P_1, P_2 may also be provided for connecting together any two apartment telephones by inserting them in the proper jacks. Each suite is provided with a telephone, bell, and push button; by means of the latter the annunciator and bell in the janitor's apartment may be operated. To call any suite from the vestibule, the switch *S* is turned to the desired number and pressed to make contact with strip *d*, which will cause the desired bell to be rung with current from *B*. When the two receivers are taken down, the talking battery *TB* is connected in series with the two transmitters and two receivers. Hanging up the receiver in the vestibule restores the switch to its normal home position.

HOTEL TELEPHONE SYSTEMS

In a hotel, almost any switchboard system can be used, but it is customary to install only central-energy systems with very simple instruments in the guests' rooms. In most cases, only communication between the stations and office is required, but sometimes communication between the stations is afforded by means of simple jacks and plugs at a central-office switchboard. Very often a telephone system is to replace or to be added to an annunciator system, the wiring for which is already installed. In such cases, the same wires between the various stations and the office can, and generally must, be used for the telephone system. In large city hotels, it is becoming quite customary to install a private-branch switchboard, so that the telephone in any room may be connected to any other telephone in the hotel or in the entire city-exchange system.

ANNUNCIATOR TELEPHONE SYSTEMS

Fig. 59 shows a Couch & Seeley *automatic switch system* suitable for a small hotel. The office is equipped with a telephone, an annunciator, automatic switch, a talking battery *TB*, two impedance coils *i*, *j*, and a ringing battery *RB*. To call station *2* from the office, press in button *2* (which will remain in until the office receiver *R* is taken down and hung up, and also press the ringing push button *p*.

thereby ringing the bell V_2. When both receivers have been taken down, the transmitter circuits of the two telephones are in parallel, both being supplied with current from the battery *TB* through the impedance coils *i j*. To call the

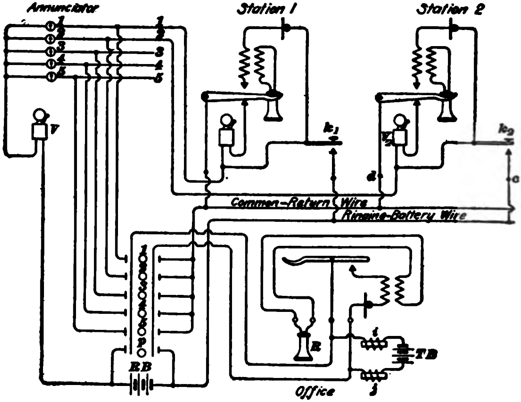


FIG. 59

office from station *1*, press the push button k_1, which will operate the annunciator *1* and bell *V* in the office. The office attendant pushes in the corresponding button *1* on the automatic switch, restores the annunciator, takes down the receiver, and attends to the call.

HOTEL-SWITCHBOARD SYSTEMS

Communication Between Office and Substations Only. In Fig. 60 is shown a simple *hotel-switchboard system* that admits of communication between the office and any substation and vice versa, but does not admit of cross-connecting between any two substations. D_1 and D_2 represent ordinary annunciator electromagnets, and J_1 and J_2 the spring jacks of a simple plug switchboard. The talking battery *TB*

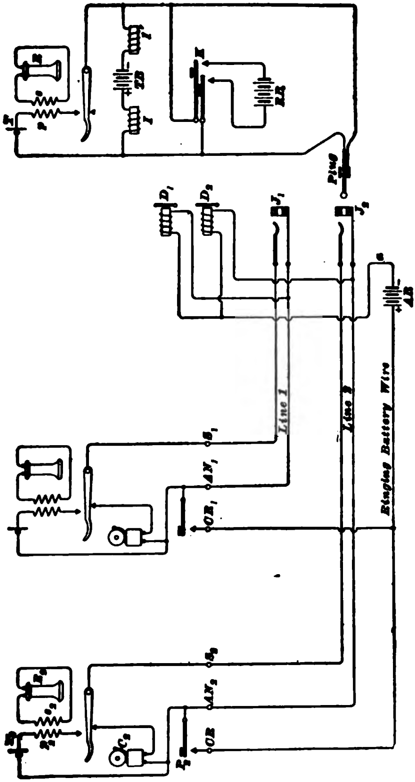


FIG. 60

supplies all the current for talking purposes. The substation instruments can be simplified and cheapened by connecting the receiver and transmitter directly in series, omitting the induction coil. The spring jacks and plug may be replaced by a simple, or automatic, two-wire intercommunicating switch.

Any substation calls the central office by merely pressing a push button, and it makes no difference whether the substation receiver is on or off the hook. The office attendant inserts the plug in the spring jack corresponding to the drop shutter that has fallen, and takes the office receiver *R* off its hook. To call up any substation, the office attendant inserts the plug in the proper jack and closes the ringing key *K*, thereby ringing the substation bell. When both substation and office receivers are removed from their hooks, the two parties can converse. *RB* and *AB* may be the same battery, and, if desired, a bell or buzzer may be included in the circuit at *a*, so that it will ring whenever any drop is operated.

Communication Between Any Two Stations.—The simple system shown in Fig. 61 allows communication not only between the office and any substation, but also between any substations through the office plugboard; this is a system designed by Couch & Seeley Company for ordinary hotels. All batteries are located in or near the central office, where an ordinary annunciator, plug board, connecting cords, and plugs are also provided. This system is not intended for use where more than two substations would need to be connected together at any one time, although there could be two or more listening jacks and two or more pairs of connecting plugs. Only three impedance coils I, I', I'', one talking battery *TB*, one bell battery *RB*, one annunciator battery *AB*, one office bell or buzzer *C*, one listening jack, one operator's plug, and one pair of connecting plugs would be required, no matter how many substations there may be on a small system, for which this arrangement is only intended.

The removal of a receiver at a substation is all that is necessary to call up the office. To answer a call, the

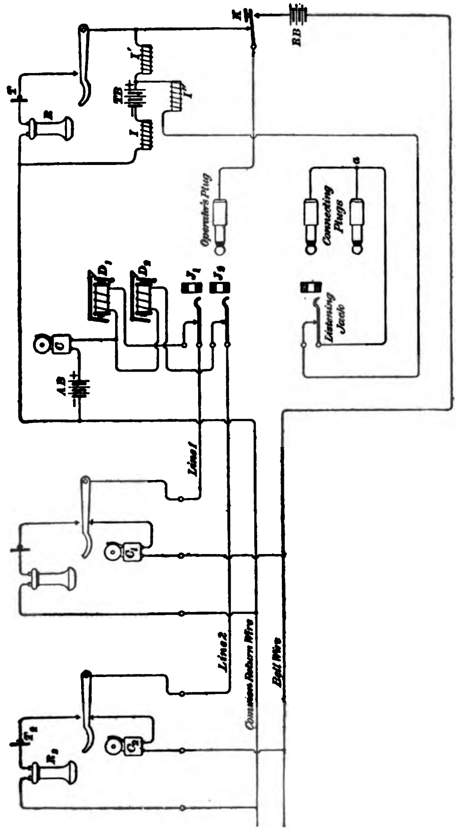

K
RB
T
R
TB
I
I'
I''
Operator's Plug
Connecting Plugs
a
Listening Jack
D1
D2
J1
J2
C
AB
Line 1
C1
Line 2
Common Return Wire
Bell Wire
T2
R2
C2

Fig 61

office attendant inserts the operator's plug in the jack corresponding to the drop whose shutter has fallen. To call up a substation, the operator's plug is inserted in the jack associated with the substation desired and the key K is closed to ring the bell. To connect together any two substations, the connecting plugs are inserted in the corresponding jacks. The office attendant must insert the operator's plug in the listening jack to determine, by listening, when the conversation is completed.

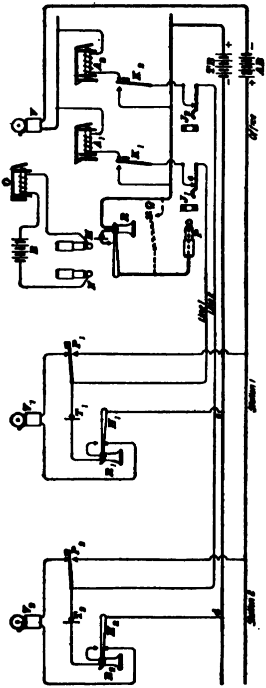


FIG. 62

Return-Call Annunciator-Telephone System. In Fig. 62 is shown a Holtzer-Cabot telephone system, suitable for a hotel. Since exactly the same line wires are used as in the Holtzer-Cabot return-call annunciator system, it is a simple matter to convert their return-call annunciator system into this telephone system. If the push button K_1 is pressed, the bell V_1 at station *1* rings. When the plug P is inserted in the jack J_1 and the receivers R, R_1 are removed from their hooks, the office and station *1* may converse, the talking battery TB supplying current for both transmitters. To call up the office, the push button is pressed at the substation, thereby causing the shutter of the corresponding annunciator to fall and the bell

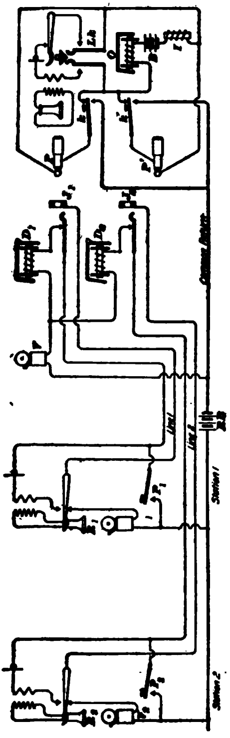


Fig. 63

V to ring. The central-office attendant responds by inserting the plug P in the corresponding jack, and restores the annunciator. If, for instance, the party at station *2* desires to communicate with station *1*, the operator will remove the plug P from jack J_2 and insert the plugs M, N in the jacks J_1, J_2.

The *Holtzer-Cabot hotel-switchboard* or *school system* is shown in Fig. 63. It has a centrally located switchboard, centralized talking and ringing batteries, and connecting cords for intercommunication between the various stations. In the common connection of the annunciator drops is the bell V, which therefore rings whenever any annunciator shutter falls. The operation of this system is very simple and only a brief explanation is necessary. When two parties are conversing, the battery B supplies current for both transmitters and also energizes the clearing-out drop O. When both receivers are hung on the hooks, the clearing-out drop releases its shutter, which signifies that the conversation is completed, and both plugs should be withdrawn from the jacks. The impedance coil I,

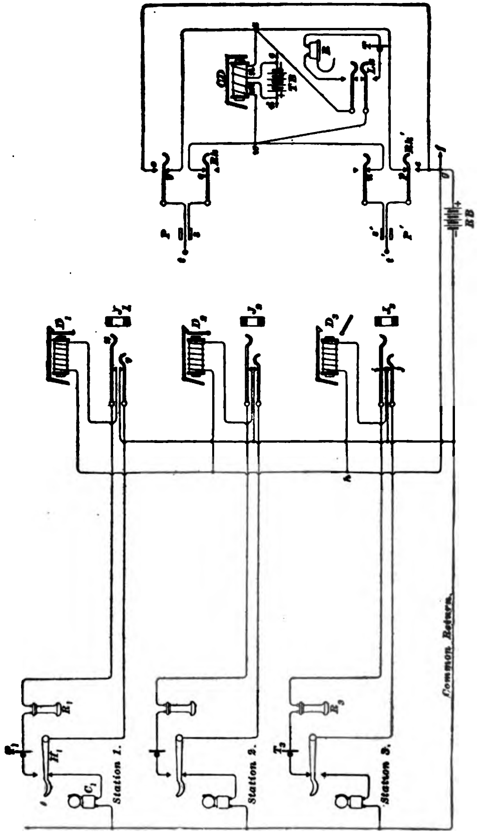


FIG. 64

having the same resistance and inductance as the clearing-out drop O, causes the system to be evenly balanced.

The *Couch & Seeley Company's hotel-switchboard system*, shown in Fig. 64, allows communication not only between the office and any substation, but also between any two substations through the office switchboard. As this system is more elaborate and complete, it is suitable for a larger hotel than the one illustrated in Fig. 61. It is a central-energy system, the talking battery TB being connected through two impedance coils m, n across each cord circuit. The two impedance coils in each cord circuit are so arranged as to constitute a clearing-out drop CD for that cord circuit. There is one listening key Lk and two ringing keys Rk and Rk' for each cord circuit. There is a separate battery RB for ringing the subscribers' bells and operating the line drops D_1, D_2, and D_3. There may be as many cord circuits and clearing-out drops as required. One operator's set may be connected to each listening key; the lead f runs to contacts o, e on each ringing key, and leads c, d to each clearing-out drop.

If the receiver R_3 is removed from the hook, the shutter of D_3 drops. The operator inserts one plug, say P', into the corresponding line jack J_3, and closes the listening key Lk; this bridges the battery TB, through the coils m, n of the clearing-out drop, across the cord circuit and also across the operator's receiver R and transmitter T, thereby supplying both the substation and the operator's set with current. Furthermore, the shutter of the clearing-out drop is raised. If station *1* is desired, the operator will insert the other plug P of the same pair in jack J_1 and close the ringing key Rk, thereby ringing the bell C_1. When both receivers are hung up, the shutter of the drop CD falls. The shutter remains up only while one or both receivers are off the hook.

TELEPHONE RELAYS

The *telephone relay* suggested itself almost contemporaneously with the appearance of the telephone, and probably thousands of devices have been brought out having for their object the accomplishment for telephony what the telegraph relay has done for telegraphy. A telephone relay may be defined as an arrangement of apparatus and circuits whereby the usual telephone current traversing a line of usual length may, by passing through the telephone relay, cause a telephone current of similar characteristics to be transmitted by the aid of another battery through another section of the line. One of the first methods suggested was to attach a transmitter to the diaphragm of a receiver located at an intermediate station, the transmitter operating the second section of the line. This did not prove satisfactory, however, and it was found better to replace such a telephone relay by a continuous line. An efficient repeater should increase the loudness without decreasing the clearness.

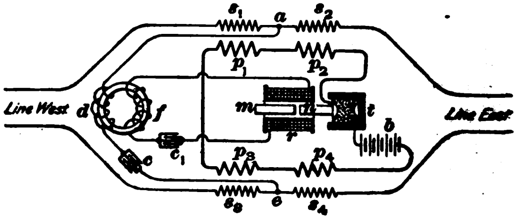


FIG. 65

In 1883, Edison patented a telephone relay that did not prove successful, but recently a slight modification of the circuit and improvements in the construction of the apparatus were made, and this same arrangement of apparatus seems to be successful in the hands of the American Telephone and Telegraph Company. The arrangement is shown in Fig. 65, in which *d* is a special repeating coil with two equal windings; c, c_1 are condensers; s_1, s_2, s_3, s_4 one winding and p_1, p_2, p_3, p_4 the other winding of a repeating coil; and *r*, a so-called receiving magnet, having a permanent magnet as a core *m* and a light piece of soft iron running part way inside the coil and having the carbon button of a White solid-back transmitter fixed to one end. The transmitter *t* has the solid back electrode firmly fixed in position. The east and west lines must be equal in resistance and probably also in capacity and inductance; if not, they must be made so artificially, that is, by the insertion of resistance, capacity, and inductance.

Imagine a current originated in the west line; it passes through the windings s_1 and s_3 in reaching the points a, e. Here, this current subdivides, a portion passing on to the east line and a portion passing through one winding of the repeating coil d and condenser c. The current passing through d induces a current in the winding f that causes the coil r to vary the pull of the permanent magnet m upon the soft-iron core n, thereby varying the resistance of the transmitter t, and the current passing through it in unison with tne current in d and in s_1, s_2, s_3, s_4. This fluctuating current thus produced in p_1, p_2, p_3, p_4 induces in s_1, s_2, s_3, s_4 a current that it superimposed upon that flowing in these coils from the west line, and thus produces in the east line a stronger current so near the same form as to give stronger and sufficiently articulate sounds in the receiver at the end of the east line. The condensers c, c_1 are probably proportioned to neutralize the self-induction of the coils d, f, and thus eliminate any difference in phase between the currents in the line and in d, f, r, and in p_1, p_2, p_3, p_4. All moving parts of the transmitter are as light as practicable, in order to reduce the inertia as much as possible. This repeater will evidently repeat equally well in either direction.

NATIONAL ELECTRICAL CODE

When electric lights first came into use, the insurance companies discovered that there were many fires of electrical origin. Therefore, the various associations of underwriters formulated rules in accordance with which they required that all wiring be done, or they would not insure buildings containing it. These rules are reduced to a uniform code, known as the *National Electrical Code*, which has received the indorsement of practically all the fire-inspection bureaus throughout the United States, besides that of many other organizations. A few cities have rules of their own that differ slightly from this code. Every wireman should be supplied with a copy of the latest edition of the National Electrical Code, and do work in compliance with those rules, whether additional laws exist or not. Copies of the code and of all other information published by the Underwriters' Association, for the sake of reducing the fire hazard, can be obtained from the National Board of Fire Underwriters, Chicago, or by applying to the nearest Underwriters' Inspection Bureau. The rules are revised as often as changes in the electrical art make such revision necessary.

In addition to this code of rules, about every year, the National Board of Fire Underwriters publish a list of approved fittings for use in connection with the code. This list contains the names of articles that have been found entirely satisfactory, together with the names of the manufacturers. This publication, however, does not contain all fittings that will pass inspection, and many good articles are not listed in its pages.

TELEGRAPHY

MORSE TELEGRAPH SYSTEMS

Electric telegraphy is the art, science, or process of transmitting intelligible signals or signs between distant points by means of electric impulses moving between those points. The first successful system for an electric telegraph was patented by Samuel F. B. Morse in 1837.

Morse Closed-Circuit System.—Fig. 1 shows the arrangement of an ordinary telegraph circuit having two terminal stations *W*, *E*, and one intermediate, or way, station *I*. This, practically, is the arrangement devised

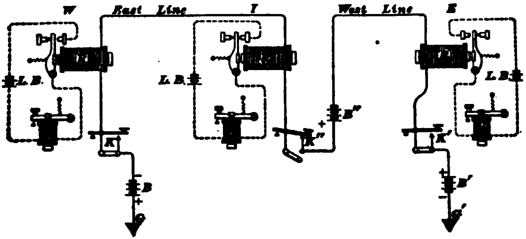


Fig. 1

by Morse, and is the one extensively used at the present time in America. At each station there is a relay *R*, a key *K*, and a battery *B* in series in the line circuit, the ground forming the return circuit. Each relay controls a local circuit containing a sounder *S* and a battery *LB*. Normally, all keys are closed; hence, the operation of any key, that is, opening and closing the key will cause each relay to open and close the local circuit containing its sounder. Thus, by sending a message in the Morse code by means of any one key, each sounder will give forth a

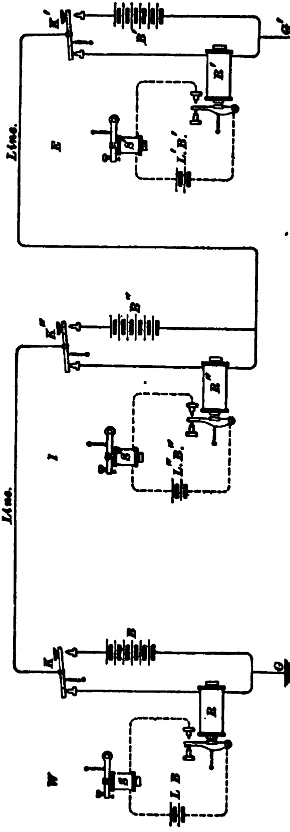


Fig. 2

click each time the line circuit is opened or closed, thereby enabling an experienced telegraph operator to read the message by sound.

Almost any number of intermediate telegraph offices may be connected in the same line circuit with two terminal offices. All cells required may be connected at any one point in the circuit, or they may be distributed at any two or more of the stations. This arrangement of apparatus is known as the *Morse closed-circuit system*, because, in normal condition, all keys are closed and current flows through the whole circuit.

Line circuits containing 150-ohm relays require about 40 milliamperes, and the local 4-ohm sounders, 250 milliamperes. For distances up to about 30 miles, main-line sounders having a resistance of 20 or 40 ohms and requiring about 180 or 70 milliamperes, respectively may be connected directly in the line circuit in place of the relays.

Morse Open-Circuit System.—The arrangement of apparatus in the Morse open-circuit system, as used in some European countries, is shown in Fig. 2. It will be noticed that equal main-line batteries B, B', B'' are required at each station, that only one is ever in use at any one time, and that each one must be powerful enough to operate all relays in the line circuit. However, all batteries are on open circuit when not in use.

TELEGRAPH CODES

The *Morse telegraph code* for letters and numerals and the *Phillips code* for punctuation are used throughout the United States and Canada. The *Continental code*, or *universal code*, as it is sometimes called, is used for submarine telegraphy all over the world and for land telegraphy in nearly every country except the United States, Canada, and parts of Australia. The Morse and Continental codes for alphabets, numerals, and punctuation marks and the Phillips code for punctuation marks are given on pages 352 and 353.

The dot is taken as the unit by which the length of the dashes and spaces are measured. The dash is made equal to the length of 3 dots. Theoretically, the extra-long dash (*0*, cipher) should be 9 units in length, but in practice it is usually made only 7 units. The space between parts of a letter is made 1 unit in length, while the space between spaced letters, as in *c*, *o*, *r*, *y*, *z*, &, in the Morse code, should be 2 units in length. The space between the letters should be 3 units, and the space between words 6 units in length.

The *Phillips code of abbreviations* is a sort of shorthand applied to telegraphy, and consists of single letters and combinations of two or more letters that arbitrarily represent figures, words, and whole phrases. For instance, *Cqas* means "closed quiet and steady," an expression extensively used in reporting stock quotations. This code, which contains several thousand characters and abbreviations, is published separately in book form. There are numerous other so-called codes, which are really abbreviations used to

ALPHABETS

LETTERS	MORSE	CONTINENTAL
A	· —	· —
B	— · · ·	— · · ·
C	· · ·	— · — ·
D	— · ·	— · ·
E	·	·
F	· — ·	· · — ·
G	— — ·	— — ·
H	· · · ·	· · · ·
I	· ·	· ·
J	— · — ·	· — — —
K	— · —	— · —
L	⸺	· — · ·
M	— —	— —
N	— ·	— ·
O	· ·	— — —
P	· · · · ·	· — — ·
Q	· · — ·	— — · —
R	· · ·	· — ·
S	· · ·	· · ·
T	—	—
U	· · —	· · —
V	· · · —	· · · —
W	· — —	· — —
X	· — · ·	— · · —
Y	· · · ·	— · — —
Z	· · · ·	— — · ·
&	· · · ·	

NUMERALS

FIGURES	MORSE	CONTINENTAL
1	· — — ·	· — — — —
2	· · — · ·	· · — — —
3	· · · — ·	· · · — —
4	· · · · —	· · · · —
5	— — —	· · · · ·
6	· · · · · ·	— · · · ·
7	— — · ·	— — · · ·
8	— · · · ·	— — — · ·
9	— · · —	— — — — ·
0	⸺	— — — — — or —

PUNCTUATIONS, ETC.

		Morse	Continental		Phillips
.	Period	..——..	.. .. ..		..——..
:	Colon	—.— . .	———...	*KO*	—.— . .
:—	Colon dash			*KX*	—.— .—..
;	Semicolon	.—.—.	—.—.—.	*SI*	... ..
,	Comma	.—.—	.—.—.—		.—.—
?	Interrogation	—..—.	..——..		—..—.
!	Exclamation	———.	——..——		———.
—	Fraction line	.	——		.
—	Dash			*DX*	—.. .—..
-	Hyphen		—....—	*HX*	.... .—..
'	Apostrophe		.————.	*QX*	..—. .—..
$	Dollars			*SX*	... .—..
c	Cents			*C*	.. .
£	Pound sterling		.— .—..—	*PX*	..... .—..
/	Shilling mark		...		..— —
d	Pence			*D*	—..
	Capitalized letter			*CX*	.. . .—..
: "	Colon followed by quotation			*KQ*	—.— ..—.
.	Decimal point		.——		—.——
¶	Paragraph	————	.—.—..		————
	Italics or underline		.—.. .—..	*UX*	..— .—..
( )	Parenthesis	.—..—	—.— —.—	*PN*	.....—. .....—.
[ ]	Brackets			*BX*	—... .—.. —... .—.
" "	Quotation marks		.—. .—.	*QN*	..—. —. ..—. —.
	Quotation within a quotation " ' ' "			*QX*	..—. .—.. ..—. .—..

reduce the cost of telegraphing, especially in submarine-cable telegraphing.

Speed of Telegraphing.—The highest recorded speed of legible telegraphy, in which the Morse code was used, was

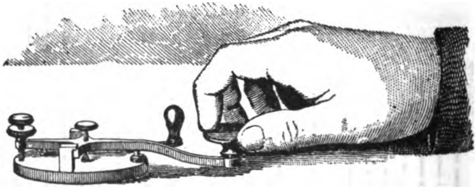


FIG. 3

made in a contest in which 265 words were sent in 5 min. However, a steady working rate of 25 to 30 words per minute is regarded as good sending. The proper way to hold a telegraph key while sending a message is shown in Fig. 3.

TELEGRAPH SWITCHBOARDS

A *terminal switchboard* used where dynamos supply the current for the line circuits is shown in Fig. 4. The long vertical brass strips are connected to the part of the spring jack immediately below it. A side view of six jacks and the various ways of connecting them, also instruments connected through flexible cords and wedges, are shown. All metal disks in any one horizontal row are connected together, and different voltage dynamos may be connected through incandescent lamps L, L', or through non-inductively wound coils used as safety resistances to 5 or 6 rows of disks. Thus, by means of metal plugs, any vertical strip may be connected to any horizontal row of disks, thus enabling a large variety and number of connections to be made on a switchboard of this character. In this one, a circuit is formed from ground through dynamo–lamp L'–fourth row of disks–vertical strap q–jack Q–set W–third row of disks–vertical strap c–jack C–line. On some switchboards, every other pair of disks in hori-

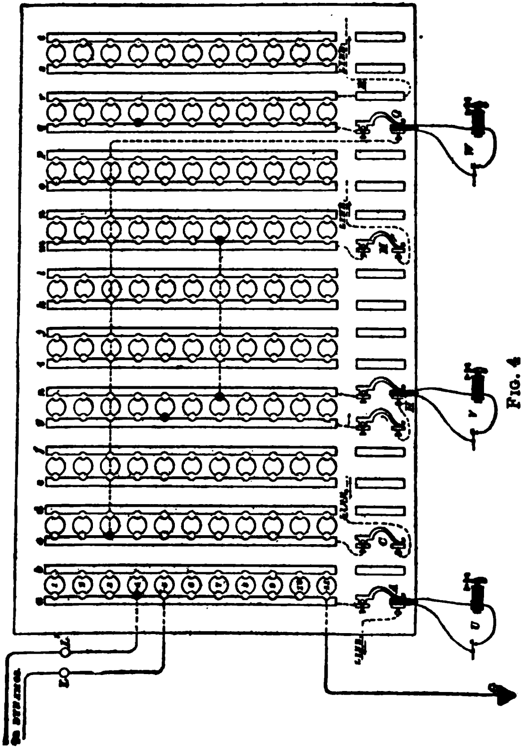


FIG. 4

zontal rows across the board have saucer-like depressions to enable the chief operator to follow connections that he makes across the board more easily, thus reducing the liability of making wrong connections.

The way in which line wires and relay sets are connected by means of a small plug switchboard at an intermediate station is shown in Fig. 5. By properly placing metal plugs between metal strips *t s*, *p*, *o* and metal disks *m*, *l*, *c*, *a*, *n*, *i*, *d*, *b*, either relay may be connected in either line circuit, or the

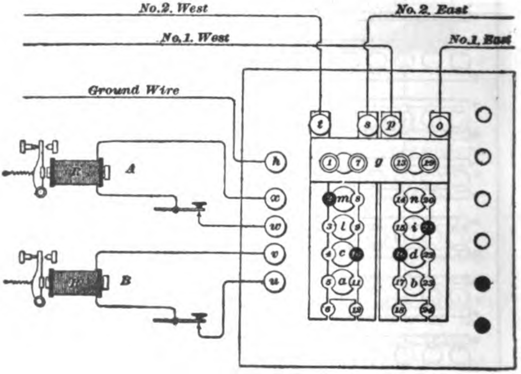


FIG. 5

relays may be cut out entirely, or any line may be grounded with or without the relay in circuit with it. A plate *g* is connected with the grounded terminal *h*, being separated from the metal strips *t*, *s*, *p*, *o* by a thin sheet of mica, thus forming a static lightning arrester. With four plugs placed in the black holes *2*, *21*, *10* and *16*, the set *A* is connected in series with wires No. *2* west and No. *1* east and lines No. *2* east and No. *1* west are connected together. At larger intermediate and terminal stations, larger switchboards of very much the same construction are generally used.

SOUNDERS OPERATED FROM LIGHTING CIRCUITS

Current for operating both the local and the line circuits of telegraph systems is now being obtained as much as possible from dynamos or electric-light or power circuits instead of from primary batteries, as it is much more economical. Fig. 6 shows an arrangement now extensively used for sup-

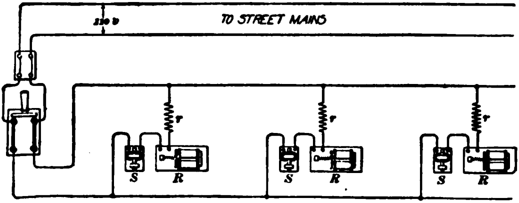


FIG. 6

plying local sounder circuits with current from electric-light, 110-volt, direct-current mains. Each sounder S is wound to a resistance of 200 ohms and connected in series with a 4,000-ohm, non-inductive, resistance coil r, this circuit being connected through the contacts of the relay and across the leads running to the street mains.

TELEGRAPH REPEATERS

A *telegraph repeater* consists of an arrangement of telegraph instruments and apparatus whereby signals coming over one line are repeated or sent forward on another line by a separate battery. By the use of repeaters it is possible to work longer lines with wires of a reasonable size, fair insulation, and E. M. F.'s not unreasonably high, than would be possible with only one continucus and unbroken wire. In the United States, it is not customary to operate a circuit over about 600 mi. in length directly, although in some cases circuits up to 1,200 mi. are worked without repeaters. Repeaters may be divided into two classes: button repeaters and automatic repeaters.

A *button repeater* requires the turning of a switch, formerly called a button, manually by an attendant, in order to change from repeating in one direction to repeating in the opposite direction. With such repeaters, the repeater attendant must listen to what is passing and be ready at any moment to turn the switch in order to reverse the direction in which the message may be sent and thus allow the operator at the receiving end to become the sender and vice versa. Button repeaters are generally employed for temporary purposes only, and are not very extensively used.

An *automatic repeater* is one that will automatically repeat in either direction without the necessity of turning a switch. An operator, however, is always needed at the repeater station to adjust the instruments and care for the batteries. There are a large number of automatic repeaters, some of which are no longer in use. Only one automatic repeater will be described.

ATHEARN REPEATER

In Fig. 7 is shown a general view of an *Athearn repeater* used by the American Telephone and Telegraph Company. Two ordinary 150-ohm relays are provided with the usual front stops *e*, *e'*, and back stops *f*, *f'*. In addition, each relay has two slender springs *a*, *b* separated by a hard-rubber washer *n*. These springs are fastened to the base and fit in between the two coils of the relay, although for the sake of clearness they are shown in this diagram as being in front of the coils. The armature lever *c* is very light and extends downwards from the pivot *d* to *c*, where it has a second armature facing the holding magnet *H* of 20 ohms resistance. Both relays, with their respective holding magnets, are mounted back to back on one long base.

In the normal condition, all circuits are closed. If the western operator desires to send and opens his key, there is no current in the circuit: west line–*c*–*b*–west relay–*MB'*–*g*, and hence the west relay releases its armature. The first backward movement of this armature opens the circuit between *e'* and *a'*; this opens a shunt circuit to ground around the holding magnet *H*. This prevents the release of the armature *o* of the east relay when, a moment later, the balance of the backward movement of the armature *c* of the west relay opens the east line by breaking the contact between the spring *b'* and the armature lever *c'*. Thus, the east line is opened at *c'*, but the ***west line does not open*** at the repeater. When the western operator closes his key, the west relay attracts its armature, closes the east line between *b'* and *c'*, and then closes the shunt between *e'* and *a'* around the holding magnet *H*. All circuits are now restored to their normal condition.

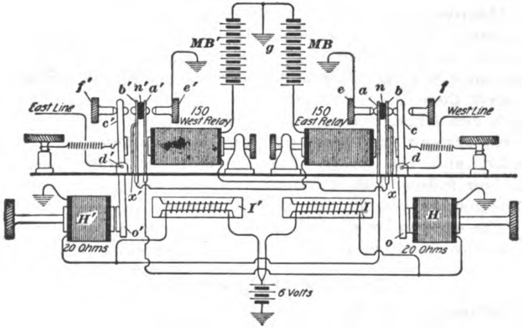


FIG. 7

Should the eastern operator, desiring to break, open his key while the east line is also open between *c'*, *b'*, the first complete forward motion of lever *c'*, due to the closing of the western key and west relay, closes the circuit between *a'*, *e'*, and shunts the magnet *H*, which then releases the lever *o*, which, in its first backward movement, opens the circuit between *a*, *e*, thus removing the shunt from around the magnet *H'*, which then holds the west relay lever closed. The eastern operator can then send to the western operator.

A novel feature of this repeater is the limiting resistances *I*, *I'*, which instead of being non-inductively wound are wound on iron cores with heavy end lugs. It is stated that because of this inductance the magnets H, H' are rendered much quicker in action because, when the shunt is removed from one of these magnets, the inductance coil gives an instantaneous kick of much more than 6 volts, which helps to overcome the high impedance of the holding magnet for a rapidly increasing current and, therefore, to more rapidly build up its magnetism.

MULTIPLEX TELEGRAPHY

Multiplex telegraphy is the transmission of two or more messages over the same wire at the same time. The transmission of two telegraphic messages simultaneously over the same wire is called *duplex telegraphy*. In the duplex system there is one sending and one receiving operator at each end office, that is, four operators in all. There are three systems of duplex telegraphy: the *differential*, the *polar*, and the *bridge*. The simultaneous transmission of four independent messages over one wire, two in one direction and two in the other, is termed the *quadruplex*. In the quadruplex system, there are two sending and two receiving operators at each end, or eight operators in all.

DUPLEX TELEGRAPHY

Differential Duplex.—The theoretical arrangement of apparatus and circuits constituting the *differential-duplex system* is shown in Fig. 8. In order to show clearly the principles only of the differential-duplex system, the diagram has been made as simple as possible by omitting practical details and the local sounder circuits controlled by the levers of the relays in the usual manner. The keys K, K_1, which have rear and front contacts, are operated by electromagnets, the coils of which are connected with batteries in local circuits under the control of ordinary telegraph keys. The batteries B, B_1 contain the same number of cells, and hence have the same E. M. F. The resistance and capacity of the circuit from m through the coil c, resistance r, and condenser C to G should be equivalent to the resistance and capacity of the circuit from *m* through *d-e-f*-d_1-*n*-a_1-J_1-G_1. Similarly the resistance and capacity of the circuit from *n* through c_1 to G_1 should be equivalent to that of the circuit from *n* through d_1-*f-e-d-m-a-J-G*. The circuit from *g* to *G*, containing *r* and *C*, and the circuit from *h* to G_1, containing r_1 and C_1, are called the *artificial lines;* the coils *c* and c_1, the *artificial-line coils*, and the coils *d* and d_1, the *line coils* of the differentially wound relays *R* and R_1. The resistance *J*, which is equal to the internal resistance of the battery *B*,

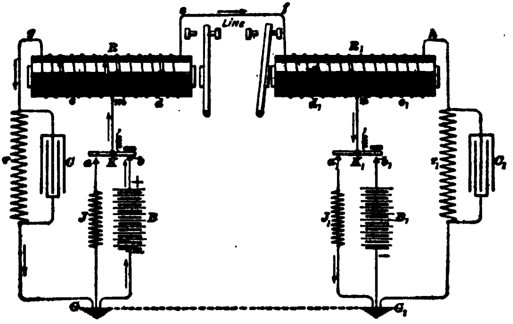


FIG. 8

gives a path of equal resistance from *m* to the ground *G*, whether the key *K* rests on the front or the rear contact. J_1 is a similar resistance equal to the internal resistance of B_1.

The condensers *C*, C_1 are arranged to give a capacity equivalent to that of the line wire. The differential relays have two coils of equal resistance and the same number of turns. Hence if a current flows from *K* to *m* and there divides equally through the two windings of the relay *R*, the relay will not be magnetized at all; but if the current flows in only one of the two coils, or if the current flowing in one coil is enough stronger than the current flowing in the other coil, the relay will be magnetized. In this figure, the relays are represented as having only one core, but as a matter of fact they would have two cores, as in the ordinary relay, and half of each coil would be wound on each core.

When both keys are open, there is no current in any part of the circuit; consequently, the armature of neither relay will be attracted and both local-sounder circuits will therefore be open. If the key K is closed, current from the battery B will flow to point m, where it will divide, half flowing through the line coil d–e–f–d_1–n–a_1–J_1–G_1–G, and half through the artificial-line coil c–g–r–G. However, little of the current will flow from n through the artificial-line coil c_1–h–r_1–G, because r_1 has a very large resistance compared with J_1. The magnetizing effect of the current in the coil d will neutralize the magnetizing effect due to the current through the coil c, because the currents in these two coils are equal and are flowing around the iron core in opposite directions; consequently, the relay R will not attract its armature. However, the relay R_1 will attract its armature, because a current of sufficient strength flows in coil d only, thereby causing the core to attract its armature.

For similar reasons, when key K_1 is closed and K is open, the relay R will attract its armature, whereas, the relay R_1 will not be affected. When both keys K, K_1 are closed, the positive pole of B will be connected to m, and the positive pole of B_1 to n; consequently, there will be no difference of potential between the points m and n, and hence no current will flow in the line coils of either relay. However, there will be a current of normal strength flowing in both artificial-line coils c, c_1, and hence both relays R, R_1 will be magnetized and will attract their armatures, thus closing both local-sounder circuits. It has now been shown that the operation of key K controls the action of the relay R_1 only, and the operation of key K_1 controls the action of relay R only. The levers, K, K_1 can be constructed so as to operate very quickly; consequently, the interval during which the lever K touches neither the front nor the back stop is so short that any trouble this tends to produce can be overcome.

Polar Duplex.—In the *polar-duplex system*, differentially wound polar relays and pole-changing keys are used; in other respects, the system resembles the differential duplex. A *polarized relay* is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to the other. A current in one direction will keep the local-sounder circuit closed at the front stop of the relay, and a current in the reverse direction is required before the local-sounder circuit can be opened at this point. The mere absence of a current will leave the armature of the relay against whichever stop the last current may have moved it. Dots and dashes are made by currents flowing in one definite direction, and spaces by currents flowing in the opposite direction, the length of the dots, dashes, and spaces depending on the interval of time during which the current is allowed to flow in the same direction. Polarized relays are used principally in polar-duplex and quadruplex systems.

In Fig. 9 are shown the theoretical connections of the polar-duplex system extensively employed in the United States. PR, PR_1 are differentially wound polar relays, and K, K_1 are keys that control battery reversing instruments called pole changers. The resistances Rh and Cr and the condenser C represent the artificial line at the left-hand station, and Rh_1 and C_1 represent the artificial line at the right-hand station. These artificial lines are arranged somewhat different, but they accomplish practically the same purpose; that is, the arrangement in each case gives a circuit of equal resistance and electrostatic capacity to that of the line wire. All four main-line dynamos, two at each end, generate the same voltage. When both keys K, K_1 are open so that the levers k, k_1 rest upon their rear contacts a, a_1, there will be no difference of potential at the two ends of the line circuit; consequently, there will be no current in the line coils of either relay. There will, however, be a current at each end, flowing from the batteries into the ground through the artificial-line coils of both relays and back into the battery. The relays are so polarized that current flowing in this direction through only the artificial-line coils will cause the permanently magnetized armatures to rest against their back stops, and thus keep both local-sounder circuits open. If key K

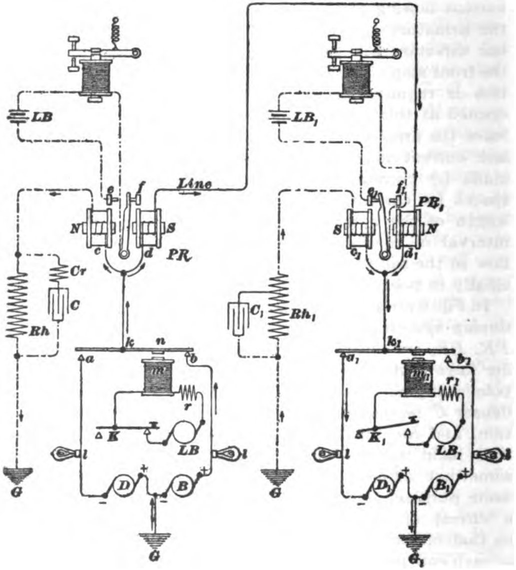


FIG. 9

is closed, the dynamo B has its positive pole connected through contact b to K. Hence, the dynamos B and D_1 are connected in series in the line circuit and, consequently, there will be a current in the line circuit of double the strength that would be produced by one dynamo acting alone in the same circuit. There will also be a current flowing from *k* through *c–Rh–G–G–B*. There is now flowing through *c* a current of the same strength as before, but in the opposite direction, and through *d* a current of twice the strength of that through *c*, and in such a direction as not only to neutralize the magnetizing effect of *c*. but also to magnetize the relay in the same direction as before, consequently, the relay *PR* remains open. Furthermore, the current flowing from the line through the coil d_1, having twice the strength of the current flowing through c_1, not only neutralizes the effect of the current in c_1 but also reverses the polarity of the relay PR_1, and hence causes the permanently magnetized armature to move from the back to the front stop e_1 and thereby close the local-sounder circuit; consequently, only the local sounder at the right-hand station will reproduce the signal made with key *K*. In a similar manner, the closing of key K_1 will cause the polarized relay *PR* and its sounder to respond without affecting the polarized relay PR_1. When both keys *K*, K_1 are closed, the positive poles of equal dynamos will be connected at each end of the line circuit; consequently, there will be no current in the line circuit. Current, however, will be flowing through both artificial-line coils *c*, c_1. This current flows through the artificial-line coils of the relays in the right direction to reverse the normal polarity of the relays, and hence both armatures will be moved and both local sounders will be closed.

Bridge Duplex System.—The *bridge duplex system*, a simple diagram of which is shown in Fig. 10, is similar in its action to the Wheatstone bridge. *S* is a rheostat so arranged that as the lever is turned upwards, resistance is taken out of the arm *ac* of the bridge, and is added to the arm *ad* and vice versa if the lever is moved in the other direction. The four arms of the bridge are *ad*, *ac*, dG_1, and from *c* through the line and apparatus at the other station to the grounds G_1 and G_2. Hence, the resistance of the artificial line at each end must be equal to the resistance of the line wire plus the resistance from the distant end of the line to the ground, through the apparatus at the distant station, assuming, as is usually the case, that the resistance of *ac* is equal to that of *ad*. When this is the case, there is no difference of potential between the points *d* and *c*. The resistance *Z*, key *K*, and battery *B* are controlled in the same manner as already explained in connection with the differential duplex.

If *ac* bears the same relation to *ad* that the circuit from *c* through the line and apparatus at the distant station to ground bears to dG_1, then the relay *R*, which in this case

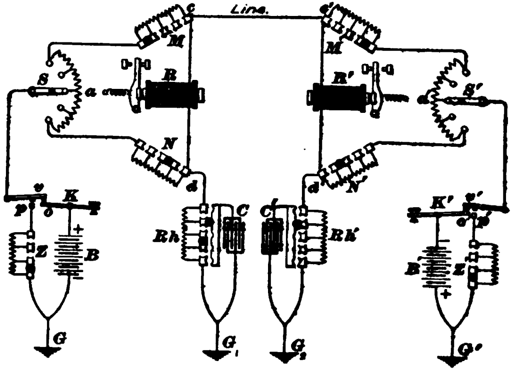


FIG. 10

corresponds to the galvanometer in the Wheatstone bridge, will not be affected by the outgoing current from the battery *B*, for the same reason that the galvanometer in the Wheatstone bridge is not deflected when the bridge is balanced. If key *K'* is pressed down and key *K* is up, that is, open, some current will pass along the line and will divide at the point *c*, part of it passing through and operating the relay *R*. The position of the key *K* will in no way affect the operation of the relay *R*, because the position of *K* does not alter the resistance of the circuit between *a* and *G*.

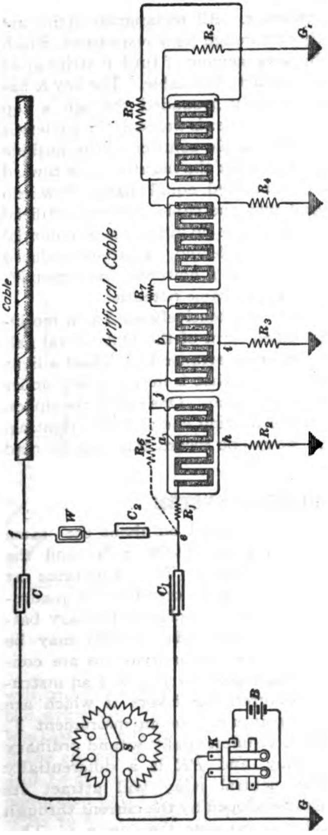


FIG. 11

Thus, the relay at one position will be operated only by the key at the distant station.

Cable Bridge Duplex.—In Fig. 11 is shown the bridge duplex as used for submarine cables. As the signals depend on the electrostatic capacity of the cable as well as on its resistance, condensers are freely used in the various arms. The artificial cable is made up of a large number of sections, each consisting of a pile of tin foil and paper strips. On one side of the paper, the tin foil is cut in zigzag strips, as indicated in the figure, while on the other side the tin foil strips are rectangular. The zigzag strips are connected in series; thus, their resistance is made equal to that of the cable conductor. All rectangular strips are grounded, either directly or through high resistances, which retard the charges. This arrangement of tin-foil strips gives the necessary capacity to the artificial cable. The key K has two handles that are normally grounded through a top grounded metal strip. When either is pressed, the battery is connected in the circuit, one handle connecting the positive pole toward the line, and the other the negative pole toward the line. When the key is operated, equal charges flow into the condensers C, C_1 and into the cable and the artificial cable; thus, the points f and e have no difference of potential and the siphon recorder W is not affected. Charges produced at the distant end and arriving at f, however, will affect W, because e is not necessarily at the same potential.

The *siphon r corder*, which is extensively used as a receiving device at W, is a modified form of the D'Arsonval galvanometer, the moving coil being arranged to deflect a light glass siphon across a paper tape that is moved along under it by clockwork or motor mechanism. One end of the siphon dips into an ink well and the moving end is kept vibrating, thus producing a dotted wavy-line record that can be read by cable operators.

QUADRUPLEX SYSTEM

All *quadruplex systems* are operated on about the same principle, which is a combination of the polar and the Stearns differential-duplex systems. The apparatus at each end is exactly the same. For the operation of quadruplex systems, dynamos are rapidly displacing primary batteries. The principle of the quadruplex system may be explained by the aid of Fig. 12. Four dynamos are connected as shown to the contact points a, b, c, d of an instrument PC, called a *pole changer*, the levers of which are connected to the contact points e, f of an instrument T, called a *transmitter*. NR is a differentially wound ordinary relay, called a *neutral relay*, and PR is a differentially wound *polar relay*. The neutral relay will attract its armature if the magnetism developed by the current through its coils is strong enough to overcome the spring s. This spring is so adjusted that the magnetism must be three, and in some cases four, times its normal strength in order to draw the armature against the back stop *j*. The polar relay has a permanently magnetized armature and is so adjusted that it would remain against either stop if no current flows in either winding of the relay. If the current magnetizes the cores of the relay in one direction, the armature

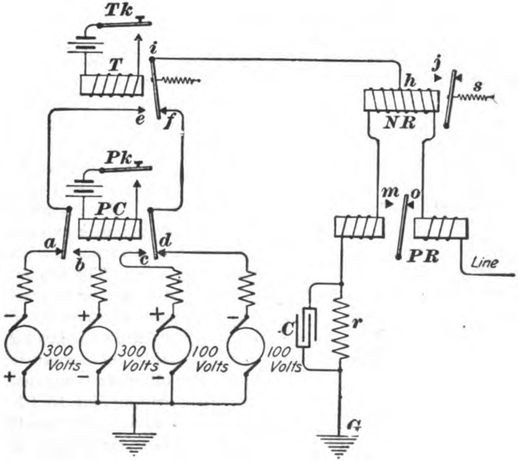


FIG. 12

will be held against the stop *o*; if the magnetism is reversed, the armature will move against the other stop *m*. The weakest current used will move the armature of this relay if the current is reversed in direction. When both keys *Pk* and *Tk* are open, the negative pole of the 100-volt machine is connected to the point *h*. Closing *Tk* only will connect −300 volts to *h*. Closing *Pk* only will connect +100 volts to *h*, and closing both *Pk* and *Tk* will connect +300 volts to *h*.

Thus, it will be seen that *Pk* controls only the direction in which the current tends to flow in *ih*, while *Tk* controls only the intensity of the E. M. F. and, hence, only the strength of the current that tends to flow in *ih*. The two windings on each relay have equal resistances and the same number of turns, and *r* is equal to the resistance and *C* to the capacity of the line circuit, this combination of *r* and *C* being called the *artificial line*. Whatever current flows in *ih* tends to divide equally through the line and the artificial-line circuits that are joined together at *h*.

Since whatever dynamo is connected to *h* tends to send a current of equal strength through the two windings of each relay, it follows that these two relays will not move their armatures, no matter which one of the four dynamos at this station may be connected to *h*. These relays can be operated, however, by varying the potential applied to the line at the distant station, due to the operation of a transmitter and pole changer located there. For instance, normally −100 volts is applied to similar points *h* at each end; no current therefore flows in the line, and the current in each artificial line leaves all the relays open. The neutral relays are open because the current due to 100 volts in one winding only is not sufficient to overcome the springs *s*. The polarized relays are open because they are so polarized that a current flowing from *h* to *G* holds the armature against the back stop. Suppose that +100 volts is applied at the distant end by closing the key corresponding to *Pk*. There is now 200 volts acting in the line circuit, which sends a current from the line to *h*; this current is so strong that it not only neutralizes the effect of the current flowing from *G* to *h*, due to the 100 volts applied only at this end, but also remagnetizes both relays in the opposite direction. Hence, the polarity of *PR* is reversed and it will attract its armature. The polarity of *NR* is also reversed, but the magnetization produced is not strong enough to overcome the spring *s*. The operation of the distant key corresponding to *Tk* would operate only the neutral relay *NR*, because it increases the potential applied at the distant end and, hence, the current is increased enough to overcome the spring *s*; but the current has not been reversed in direction, consequently the polar relay *PR* is not affected. Moreover, it can be shown and is a well-known fact that all four transmitting keys may be operated simultaneously or in any practical manner, and that each key will operate only one particular relay at the distant end.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY

The transmission of telephone and telegraph messages over the same circuit at the same time, without one interfering with the other, is called *simultaneous telegraphy and telephony.* An arrangement of circuits that will allow the transmission of one telephone and one telegraph message at the same time over *one pair* of wires is termed the *simplex system.* When telephone apparatus is substituted for telegraph apparatus in the arrangement just mentioned, thus permitting two telephone messages to be transmitted over the same pair of wires at the same time, the arrangement is called *duplex telephony. Multiplex telephony* is applied to arrangements whereby it is possible to transmit, simultaneously, three or more telephone messages over two or more pair, respectively, of line wires.

An arrangement of circuits that will allow the transmission of one telephone and two telegraph messages at the same time over one pair of line wires is termed the *composite system;* this term is also given to a similar arrangement of apparatus that will allow the transmission of one telephone and one telegraph message at the same time over a single line wire. In the latter arrangement, the ground is used as a common return for both telephone and telegraph currents.

SIMPLEX SYSTEM

Impedance-Coil Simplex.—In Fig. 13 is shown a *Bell simplex system,* using two 500-ohm impedance coils, which are bridged across each end of a pair of long-distance telephone wires. The condensers prevent the flow of telegraph

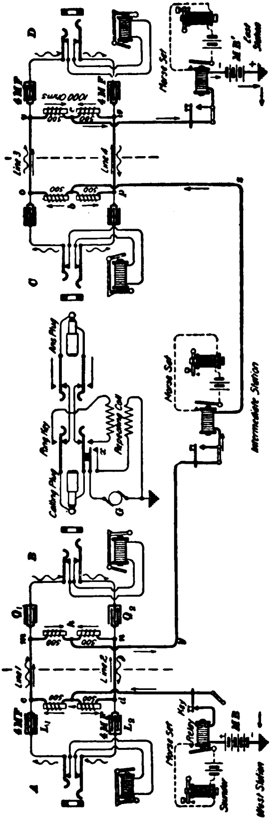


FIG. 13

currents through the jacks and the telephone apparatus therewith connected, while the impedance coils prevent the flow of the telephone current through the telegraph apparatus or from one line wire to the other through the impedance coils. In this figure are shown two terminal telephone and telegraph offices and one intermediate telephone and telegraph office. The ringing generator, which is usually grounded at all telephone exchanges, is arranged as shown at *G*, with a repeating coil or transformer interposed between it and the ringing key, so that neither line wire is grounded, which would unbalance the circuit, even while ringing over the line. The straight arrows show the path taken by the telegraph currents, while the wavy arrows show the path taken by the rapidly fluctuating voice currents. It will be seen that the

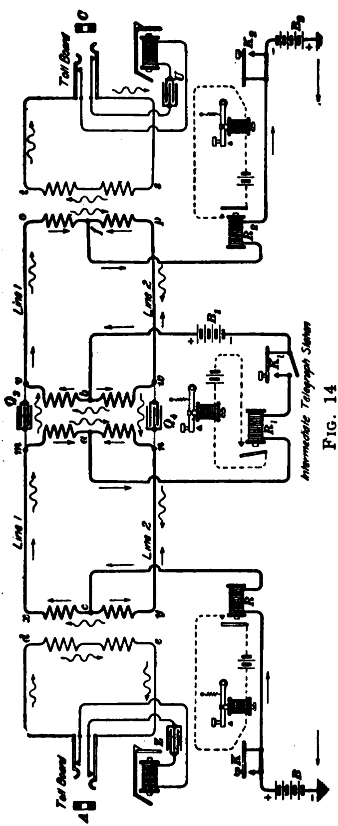


FIG. 14

two line wires are used in parallel for one side of the telegraph circuit, the ground being used as a return circuit, while the same two line wires constitute a complete metallic circuit for the telephone currents, the ground not being used for these currents.

Repeating-Coil Simplex.—A simplex system using one repeating coil across each end of a pair of long-distance lines and wherever an intermediate telegraph station is required is shown in Fig. 14. The repeating coils *dexy*, *mnvw*, and *opts* must be designed to transmit both voice and ringing currents, but such coils are not the best for transmitting voice currents over long toll circuits. This system, as used by the American Tele-

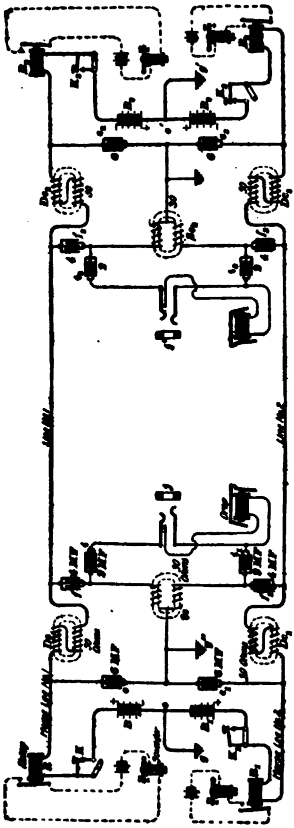


Fig. 15

phone and Telegraph Company, has proved to be superior to the impedance-coil method, and it has the advantage that regular cord circuits and ringing machines may be used in connecting together two such circuits, without affecting the telegraph apparatus adversely.

Composite System. A *composite system* is shown in Fig. 15. One pair of line wires is used as a telephone circuit, while each line wire with a ground return constitutes two separate telegraph circuits. The telephone currents are prevented from entering the telegraph circuits by the use of the impedance coils Dc, Dc_1, Dc_2, Dc_3, while the telegraph currents are excluded from the telephones by the use of the condensers i, i_1, i_2, i_3. Whatever sharp telegraph impulses may happen to get through the condensers f, f_1, f_2, f_3 can readily pass through one-half the impedance coil Sc or Sc_2 to ground. The impedance coils Dc, Dc_1, Dc_2, Dc_3 have their two coils so connected as to magnetize the iron core in opposite directions when the relatively slow changing, telegraph current passes through them; thus, each one presents but little inductive opposition to the flow of the telegraph current, and hence does not appreciably affect the operation of the telegraph apparatus. However, the two windings on each coil act, to the rapidly fluctuating voice currents, practically as two separate inductance coils connected in series, and hence compel the voice currents to pass through the various condensers and telephone apparatus connected, when in use, to the jacks jj'.

For signaling over the telephone circuit, it is customary to use a special ringing apparatus that converts the usual ringing-generator current into an alternating current of much higher frequency; therefore, this current will not readily pass through the coils Dc, Dc_1, Dc_2, Dc_3, and interfere with the operation of the telegraph relays which would otherwise be the case.

DUPLEX AND MULTIPLEX TELEPHONY

For *duplex telephony*, the circuits are arranged in about the same manner as in simplex telephone and telegraph

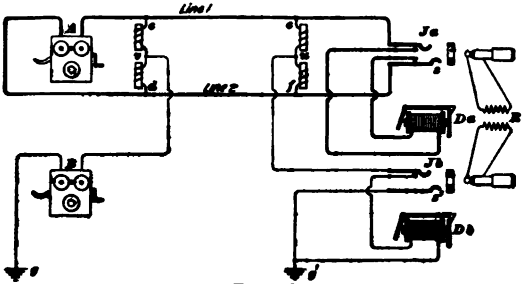


Fig. 16

systems, telephone instruments being substituted for the telegraph apparatus.

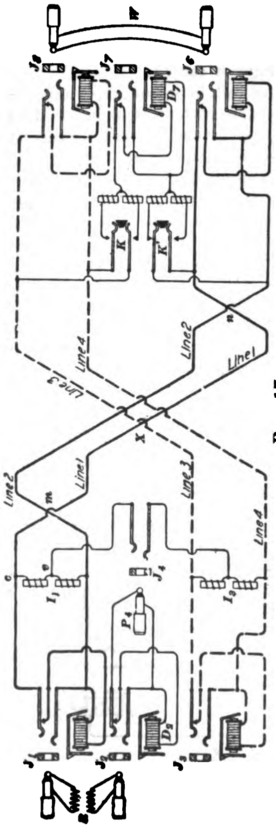


FIG. 17

Impedance-Coil Method.—In Fig. 16 is shown a duplex telephone system using *impedance coils cd* and *ef* across one pair of line wires. Telephone *A* uses the metallic circuit and has a jack *Ja* and a drop *Da* at the exchange, while telephone *B* uses the two line wires in parallel as one conductor and the ground as a return conductor; the latter also has a jack *Jb* and a drop *Db* at the exchange. The circuit $B\text{–}v\text{–}\left\{\begin{matrix}c\text{–}e\\ d\text{–}f\end{matrix}\right\}\text{–}u\text{–}Db\text{–}g'\text{–}g$ is called a *phantom circuit*, because it is an extra circuit obtained without the actual addition of any more line wires than were already in use for the telephone *A*.

Three Circuits Over Two Pair of Wires.—Usually, more satisfactory results are secured by arranging two complete metallic circuits, as shown in Fig. 17, so as to obtain three telephone circuits. The third circuit may be brought through a jack J_4 and a plug P_4 to jack J_2 and drop D_2 or two keys K, K' may be used to connect the impedance coils across the two line circuits. To use the third, or phantom, circuit, the plug P_4 must be inserted in the jack J_4 and the keys K, K' closed. The line wires constituting the metallic circuits should be transposed, as indicated at *m*, *n*, as would any two pair of parallel and adjacent telephone line wires, to eliminate cross-talk between the two pair. Furthermore, one pair of wires should be transposed with respect to the other pair, as shown at X, in order to eliminate cross-talk between the phantom circuit and any other circuit parallel and adjacent but not associated with this duplex circuit.

Repeating-Coil Method.—In Fig. 18 is shown a duplex telephone system using *repeating coils cd* and *ef* across one pair of telephone line wires. The ground is used as a return

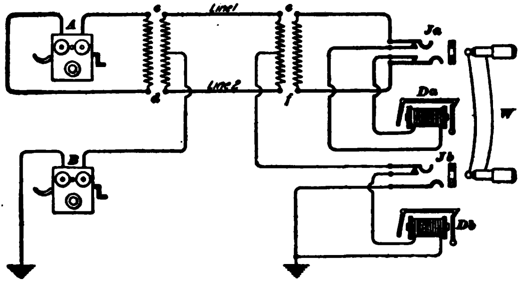


FIG. 18

for the phantom circuit containing the telephone B. *Ja* and *Da* are the jack and the drop, respectively, for telephone A, and *Jb* and *Db* for telephone B.

Three telephone circuits may be obtained over two pair of line wires by the arrangement shown in Fig. 19. When the phantom circuit is to be used, the plug P_4 is inserted in jack J_4 and the corresponding plug at the other station is also inserted in its jack.

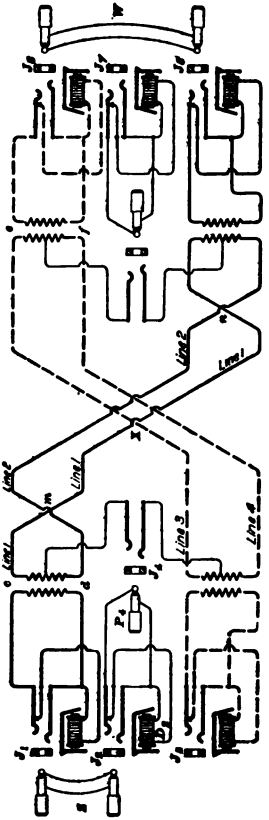


Fig. 19

Phantom Cord Circuits.—Where phantom circuits are obtained by the use of impedance coils, as in Figs. 16 and 17, a *cord circuit* containing a repeating coil should be employed to connect a telephone on a phantom circuit with a telephone on the metallic circuit from which that particular phantom circuit is derived. Otherwise, the half, for example, *cv*, Fig. 16, of the impedance coil connected to one side of one metallic circuit will be short-circuited, while the other side of the same metallic circuit, for example, line wire *2*, will be connected directly to the ground, or to the middle of the impedance coil I_3, in Fig. 17, across the other metallic circuit. In either case, the sounds heard in one telephone due to talking in the other would be due mostly to a large amount of cross-talk caused by a badly unbalanced circuit. To connect the circuits terminating in jacks J_6, J_8, Fig. 17, and J_a, J_b, Fig. 18, a cord circuit *W* without a repeating coil may be used. Generally, repeating coils should not be inserted in cord circuits *W*, *Z*, Figs. 18 and 19, used in duplex systems obtained by means of repeating coils.

WIRELESS TELEGRAPHY

The most successful methods for telegraphing through space without connecting wires depend on the propagation through space of electromagnetic waves frequently called *Hertzian waves*. These waves are identical in some respects to light waves, but have different frequencies and wave lengths. The principles of transmitting and receiving apparatus for wireless telegraph systems may be briefly explained by the aid of Fig. 20.

At the left is shown the *transmitting apparatus*, which consists of a Ruhmkorff induction coil, through the primary *p* of which current from the battery *B* may be sent

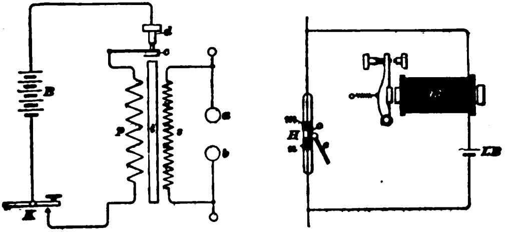


FIG. 20

by closing the key *K*. The secondary *s* has its terminals connected to brass rods terminating in small brass balls. The gap *ab* between the balls is called the *spark gap*. When the spark gap is properly adjusted and the apparatus is in working order, closing the key *K* will cause a torrent of sparks to pass across the spark gap. These sparks cause electromagnetic waves to pass out in all directions through space.

The *receiving apparatus* is shown at the right of Fig. 20, and consists of a device *H* called a *coherer*, which is connected in series with the relay *R* and a weak battery *LB*. The coherer consists of a glass tube, usually exhausted, in which are placed two silver plugs. The small space between the faces of the two silver plugs is only partly filled with coarse filings—usually 90% nickel and 10% silver. Normally, the resistance through these filings is very high, several thousand ohms, but if the coherer is placed where electromagnetic waves of sufficient intensity strike it, its resistance decreases enormously, thereby allowing sufficient current from the local battery *LB* to flow through it and the relay, to close the relay. The tapper *e* of an ordinary vibrating bell is arranged to tap the tube whenever the relay closes its local circuit. The slightest tapping will readily restore the resistance of the coherer to its high normal value, provided the electromagnetic waves are no longer present to act upon the coherer. The current through the relay is thus reduced to its normal strength and the relay will open. It is impossible to show here all the apparatus and details of the circuits necessary in a successful wireless-telegraph station. Usually, the terminals *b* and *n* are grounded, and the terminals *a* and *m* are connected to wires that may extend high in the air and are called the *aerials*. The electrical disturbances emanating from high aerials produce waves that are able to travel greater distances than would otherwise be possible.

It is usually necessary to prevent sparking at relay or other contacts and to reduce the inductance of receiving devices as much as possible. For these reasons, it is customary to shunt all make-and-break contacts with condensers or high non-inductive resistances and to connect in parallel with each relay or other electromagnetic device a non-inductive resistance of at least four times the resistance of the device.

The distance over which it is possible to transmit signals depends on the power of the transmitter, the sensitiveness of the receiving device, and the height of the aerial conductors; whether the intervening surface is comparatively smooth like the ocean, or rough like the land; and whether it is day or night. With the same apparatus, greater distances can be covered at night, and about three times as far over the ocean as over the land; the distance varies

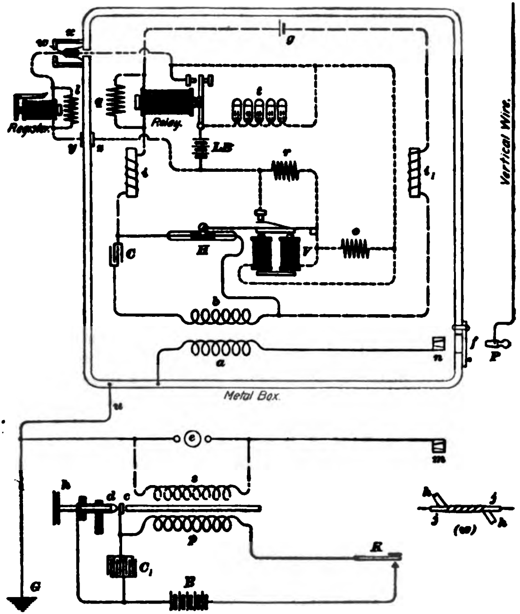


Fig. 21

about as the square of the height of the vertical conductor. The energy received is said, by different authorities, to vary as twice the square of the distance to the transmitter, as the square of the distance, and even as the distance itself.

Marconi's System. — One arrangement of transmitting and receiving apparatus used by Marconi is shown in Fig. 21. The aerial wire ends in a plug P that may be connected to the transmitting apparatus by inserting it in m, or to the receiving apparatus by opening the metal door f and inserting it in n. The receiving apparatus is enclosed in a metal box, so that no waves from the home sending apparatus can damage the coherer. a, b are the two windings of an induction coil without any iron core; this induction coil is frequently called a *jigger*. All electromagnets and sparking contacts are shunted by non-inductive resistances except the relay contact, which is shunted by five polarizing cells t. The choke coils i, i_1 assist in compelling the rapidly alternating current to pass through the coherer H instead of through the relay. The wire coming out at x is first covered with insulating material and then tin-foil, as shown at (w), so as to make a metallic screen through which no waves will pass into the box.

Electrolytic Wave Detectors.—The *electrolytic wave detector*, which was first described by Fessenden, and shortly afterwards by Schlomilch, consists essentially of a cell having a fine point, usually of platinum, as one electrode and a larger piece of platinum or some other metal as the second electrode. The cell in its most effective form contains an electrolyte, the decomposition products of which are gases. When an E. M. F. is applied to such a cell, powerful polarization ensues, so that scarcely any current passes unless the E. M. F. exceeds a certain critical value. When electric oscillations pass through this cell, the resistance is decreased, and the current for the moment is increased, only to return to its former small value as soon as the oscillations cease.

Fig. 22 shows the simple connections for using the electrolytic wave detector. A telephone receiver t is used to detect the oscillatory currents that pass through the cell e and produce the change in its resistance. The cell made by the National Electric Signaling Company consists essentially of a minute platinum cup, containing the electrolyte into which a platinum wire about .002 mm. in diameter dips. This platinum wire is drawn in silver, and the silver is dissolved in acid, leaving the bare platinum point ready for use. By means of the resistance *r*, any desirable potential due to the battery *b* may be applied to the circuit containing the electrolytic wave detector *e*. The potential applied to the circuit containing this electrolytic cell may vary from about 1 to 2.7 volts, but the best pressure across the cell is 1.6 volts. The telephone used in this circuit has a resistance of about 1,300 ohms. For the electrolyte, a 50% solution of hydrochloric acid, a 20% solution of nitric acid, or a 30% solution of sulphuric acid may be used. The hydrochloric-acid solution seems to be the most sensitive. The resistance of the detector for small alternating currents varies from about 20,000 to 400 ohms, according to the polarizing E. M. F. applied. For rapid oscillations, the capacity effect of the point electrode probably has some influence on the action of the cell. When the E. M. F. is increased or decreased .02 volt, using a solution of hydrochloric acid, the resistance change is about 13,000 ohms. The action is likely to be more regular with the point electrode as the anode. The current changes are ample for a telephone receiver, but are too small to operate a relay with certainty.

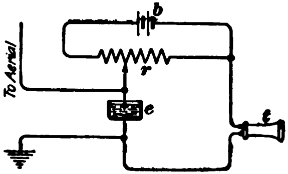


FIG. 22

Instead of connecting the terminals of the electrolytic cell *e* to the earth and to the aerial wire, a transformer or jigger may be interposed, in which case the terminals of one winding of the transformer will be connected to the aerial wire and to the earth, while the terminals of the other winding will be connected to the terminals of the electrolytic cell. The arrangement would otherwise be the same as already shown.

De Forest Audion.—The *audion*, so called by De Forest and shown in Fig. 23, consists of an exhausted incandescent lamp *c*, preferably a tantalum 4- to 6-volt lamp, to which are added two metal parallel wings *e*, *f*. The battery *a* varies from 4 to 8 volts, for which three storage cells are generally used, and *b*, from 6 to 18 volts, for which dry cells that will last at least 6 months are used, as the current produced by them is very small. De Forest claimed, in 1906, that tuning with the audion was sharper than with any other

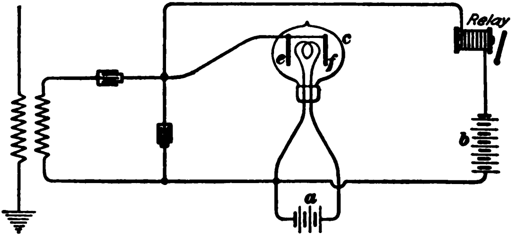


FIG. 23

form of receiver, and that the same signals, for practical distances, were louder than with the electrolytic receiver. The relay will operate fast enough to allow a speed of at least 35 words a minute. The oscillatory waves passing from the wings to the filament reduce the conducting power of the attenuated gas between them, and thus the current through the relay is decreased.

Other Wave Detectors.—Besides those already explained, there are several other devices used to some extent to detect the waves produced by wireless transmitting apparatus. The *carborundum detector* consists of a crystal of carborundum clamped between metal electrodes. This detector is connected in the circuit in exactly the same manner as a coherer, but a telephone receiver is used to receive the message instead of a relay.

The *silicon detector*, invented by G. W. Pickard, consists of a piece of pure silicon held across two low-resistance metal electrodes. The incoming oscillations in passing across the contacts heat one more than the other, thereby causing a direct thermoelectric-current impulse for each oscillation and producing a sound in a telephone receiver as long as the oscillations persist. A fragment of silicon held with suitable pressure against two flat-ended brass rods is said to give excellent results. The silicon detector requires no battery in the telephone-receiver circuit and is claimed to be twice as sensitive as the carborundum detector, and about as sensitive as the electrolytic detector.

Poulsen's Undamped Oscillation Transmitter.—Most oscillations produced by wireless telegraph transmitters are very much damped, that is, succeeding waves decrease greatly in amplitude, so that only a few waves have sufficient intensity to be effective. Poulsen has succeeded in producing waves that are so much less damped that they are called *undamped waves*. Undamped oscillations are very desirable for selective or tuned systems, but so far it has not been possible to produce damped waves that are as powerful as undamped waves.

Poulsen's undamped transmitter is a so-called singing, or flaming, arc maintained between a positive copper and a negative carbon electrode. When the capacity and the inductance that shunt the arc are suitably adjusted, rapid oscillations of uniform amplitude are produced in the circuit, including the aerial wire. The energy given off by this method is low, however, and it remains to be determined whether weak, undamped waves are as useful as stronger damped waves, or whether more powerful undamped waves can be produced by this or some other method.

WIRELESS TELEPHONY

For a wireless telegraph transmitter, it is necessary to have some method for modifying the electromagnetic waves so as to impart to them the fluctuations characteristic of the current in a circuit containing a telephone transmitter. The form of the electromagnetic wave must be varied exactly to correspond with the sound wave due to the words spoken at the transmitting station; and at the receiving

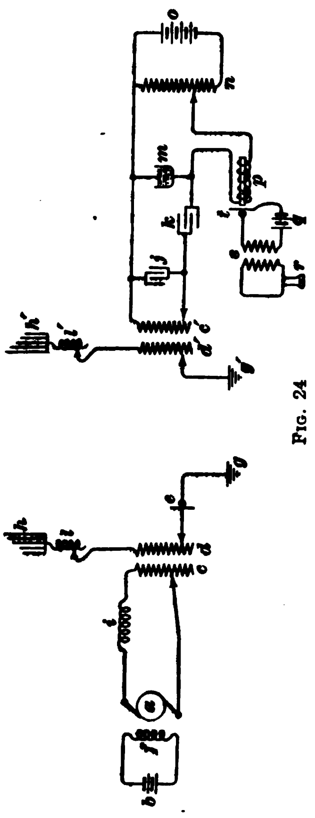


Fig. 24

station the apparatus must be capable of retransforming the energy into sound waves of like character to those originated at the distant end of the system.

Fessenden's arrangement of apparatus, in 1906, for transmitting telephone messages between two stations about 10 miles apart is shown in Fig. 24. The battery *b* excites the field *f* of a special dynamo, the armature *a* of which produces a sine-wave alternating current having a frequency of 60,000 cycles per sec., a voltage of 60, and an output of about ½ kilowatt at a speed of 10,000 rev. per min. This dynamo, when run by a steam turbine, is capable of giving 100,000 cycles per sec. The internal resistance of the armature is approximately 6 ohms, and the drop due to inductance at full load is about equal to the drop due to its resistance. The bearings are kept cool by forcing oil through them with an air pump. The machine, which was designed and built by the General Electric Company, has run daily for 6 or 7 hr. with practically no attention. The dynamo current passes through an inductance *i* and one winding *c* of an air-core transformer, thereby inducing a constant E. M. F. in the other winding *d*. Both windings are arranged so that the number of turns may be varied to suit different conditions. In series with the winding *d* is connected a variable inductance *l*, which is adjusted to tune the circuit *g-e-d-l-h* with *a-i-c*. The aerial wires are shown at *h* and a variable-resistance telephone transmitter at *e*. Thus, *e* varies the strength of the current produced in the circuit *g-e-d-l-h*, and hence the electromagnetic waves emitted, in accordance with the sounds spoken into the transmitter *e*.

The receiving aerial circuit contains the aerial wires *h'*, an adjustable inductance *l'*, and a winding *d'* of an air-core transformer, as at the transmitting station. The condenser *j* is adjustable, while *k* has a fixed capacity; *m* is a liquid barreter, or electrolytic cell, consisting of a minute platinum point dipping into a 20% solution of nitric acid contained in a minute platinum cup. The electrolytic cell has a voltage of about 1.6 applied to it by means of the cells *o* and the potentiometer arrangement *n*. The telephone receiver may be connected directly at *p*, and the variation of current produced by the varying polarization of the cell *m* when variable electromagnetic waves are received at *h'* will cause the receiver to reproduce the sounds spoken at *e*. However, these sounds are probably weak, as a telephone repeater at *p* was used for a distance of 10 mi. between *h*, *h'*, this repeater may be described as follows: It is an ingenious type of relay, using differential windings on the cores of magnets, between the poles of which is mounted an armature attached to one electrode of a microphone transmitter. Variation of the current traversing the windings causes a shifting of the magnetic field to one side or the other, producing a corresponding series of changes in the position of the plate controlling the movable transmitter electrode. This relay is claimed to be very sensitive and improvements made in 1907 are expected to improve its efficiency. A double relay of the same type has been used as a calling device to operate a loud-speaking telephone, or a bell, or a Morse register.

It is claimed that the speech is as distinct as over a short open wire line, somewhat more distinct than over cables, and that there is a total absence of extraneous noise, also no distortion of sounds with increase of distance, as in wire lines. With an ordinary granular transmitter, ½ ampere is all that can be used, and even with special transmitter buttons, 2½ amperes seem to be the limit. A multiple-button transmitter cannot use over 10 amperes. At the transmitting station the transmitter and a primary battery may be connected in a local circuit with one winding of a telephone induction coil, the other winding of which is connected to the winding of a telephone repeater, the transmitter part of the telephone repeater being connected in place of the transmitter *e*. This description was abstracted from an article in The American Telephone Journal, for February 2, 1907.

RUHMER'S PHOTOPHONIC SYSTEM

An ingenious system for the wireless transmission of speech has been developed by Ruhmer, who used the photophone originally devised by Bell. A beam of light from an

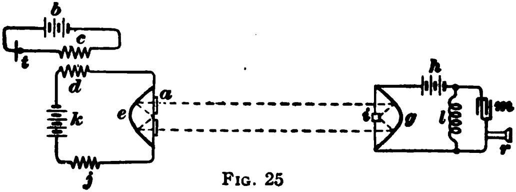


FIG. 25

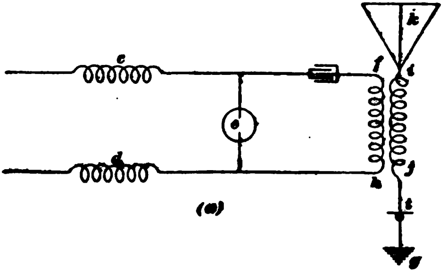
arc light *a*, Fig. 25, is allowed to fall on a parabolic mirror *e*, which reflects the light in a parallel beam through the space to the receiving station. The light is here converged to a point in the focus of a parabolic reflector *g* and impinges upon a selenium cell *i*, which is in series with a battery *h*, condenser *m*, and a telephone receiver *r*. The selenium cell is constructed by forming a grid of conducting wires between fused selenium, the resistance of the selenium cell varying with the intensity of the light that falls upon it.

Varying the resistance of the transmitter *t* by speaking into it, varies the current from *b* in the primary winding *c* of an induction coil. This induces an alternating current in the secondary winding *d*, which, being superimposed on the steady-direct current produced by battery *k*, causes a variable current to flow through the arc *a*. This produces both a light and a sound, which vary in intensity and character with the sound waves produced before the transmitter. The light waves strike the parabolic mirror *g*, which reflects them to a point at its focus, where the selenium cell *i* is placed. The resistance of the selenium varies with the light that is reflected upon it, and hence the current developed by the battery *h* varies; sounds are therefore produced by the receiver *r* corresponding to those produced before the transmitter *t*. An inductance coil *l* allows a larger direct current to flow through *i* but confines all the fluctuating current to the condenser *m* and receiver *r*.

The transmission depends on an uninterrupted line of view between the transmitter and receiver, and on the power of the light and the sensitiveness of the receiving device. By this method messages have been transmitted about 9 mi. Ruhmer used a regular 350-mm. diameter, parabolic, search-light reflector with carbons fed by hand, a battery supplying from 4 to 5 amperes for a distance of 2 Km., 8 to 10 amperes for 3 to 4 Km., and 12 to 16 amperes for 5 to 7 Km. The electromagnetic waves produced are short, and the selenium cell decreased in resistance from 120,000 ohms in the dark to about 1,500 ohms when placed near a 16-c.-p. incandescent lamp. A permanent record of the sounds may be obtained by passing a sensitive photographic film through the beam of the talking arc and developing it; then, by drawing the film over a seleneum cell with a strong light behind it, a telephone connected with the cell will reproduce the original sounds.

DE FOREST SYSTEM

Dr. Lee De Forest, by his wireless telephone system, has succeeded in transmitting telephone messages a distance of 12 mi. without connecting wires. In Fig. 26 (*a*) is shown the transmitting circuit. The source of current may be a storage battery or lighting mains with suitable impedance



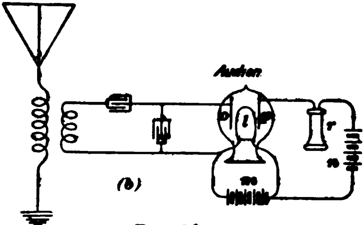


FIG. 26

coils *cd* to eliminate undesirable variations in the current. At *o* is shown the oscillator, which may be any form of high-frequency interrupter, although De Forest uses an enclosed arc and an alternating current, thereby producing in *fh* an alternating current of sufficient frequency. There is thus produced a high-frequency current in the winding *fh* of a transformer. The current induced in the secondary *ij* has its strength varied by the variation in resistance produced in the ordinary microphone transmitter *t* when speaking into it. Thus, variable radiations are sent out from the aerial wires *k*. The intensity of these radiations and the distance at which they are effective depend on the length and frequency of the waves produced by the oscillator, the power supplied to the oscillator, and the height of the antenna, which project into the air.

In Fig. 26 (*b*) is shown the receiving circuit, which resembles the transmitting circuit. The De Forest audion, which is a modified incandescent tantalum lamp, has its filament *l* lighted by a storage battery *m*. One side of the circuit is connected to a platinum grid *o*, while a platinum wing *p* is connected to an ordinary telephone receiver *r*, which is in turn connected to a battery *n*. The incandescent filament is said to cause the highly rarefied gases in the bulb to separate into very minute particles, called *ions*. When the waves reach this receiving device, they produce a change in the resistance of the interior and the receiver promptly responds. The received waves apparently pass between *o* and *l*, while the variable current from the battery *n* passes between *p* and *l*.

ELECTROLYSIS OF CABLE SHEATHS

Earth Currents.—*Electrolysis* means here the eating away of cable sheaths, underground pipes, rails, or other grounded or buried conductors by stray currents from street-railway or other circuits. Currents due to electric-railway or other systems carrying large currents and using earth returns are likely, in choosing their path back to the power station, to select the sheaths of underground cables or of any other metallic bodies that offer paths of comparatively low resistance.

Danger Points.—Except in a few cases, the current in flowing from one kind of a conductor to another will be compelled to pass through the earth, and it is at the points where the current emerges from the conductor and enters the moist earth that electrolytic action occurs to the probable destruction of the conductor. So long as the cable sheath is negative to all of the surrounding conductors it is in no danger from electrolysis, for this indicates that the current is flowing from the surrounding conductors to the sheath. If, however, a point is found where the cable sheath is positive to the surrounding conductors, the current is flowing from the cable to the other conductors through the ground at that point. The maximum positive point on the cable should be determined, and a heavy copper bond should be run from this point to the rail or return feeder of the electric-railway system, or other conductor, to which the readings indicate the current to be flowing.

Under certain conditions, the chemical actions produced where the current leaves a pipe causes no eating away of the metal pipe. This may be due to the fact that the energy expended per unit area of the pipe surface may not be great enough to decompose the salts in the damp earth. Electrolytic action may also take place for a while and then cease, owing to the character of the earth around the pipe having become changed by the decomposition of the salts contained therein and rendered incapable of acting longer as an electrolyte. Underground conductors may also become corroded by the simple chemical action of the salts in the earth. The only sure way of determining this point is to bury a similar-sized piece of exactly the same metal, insulated from but alongside the metal that becomes pitted, for about 6 mo. At the end of that time, note the difference, by weighing or by observation, in the effect on the insulated and uninsulated similar pieces of metal. The relative effects of corrosion from the two sources can thus be determined.

Lead is eaten away nearly twice as rapidly as tin, over twice as rapidly as zinc, over three times as rapidly as copper or iron, and over twelve times as rapidly as aluminum. Underground lead sheaths are, under similar conditions, eaten away very much more rapidly than iron pipe. Wrought-iron pipe is eaten much more rapidly than cast iron, probably due to impurities, which form a kind of scale on the cast-iron pipe and protect it.

Locating Danger Points.—The method of procedure in each case, in order to locate the danger points on a cable, is usually to measure the difference of potential, with a voltmeter or, preferably, with a millivoltmeter, between the cable sheath and the surrounding conductors, such

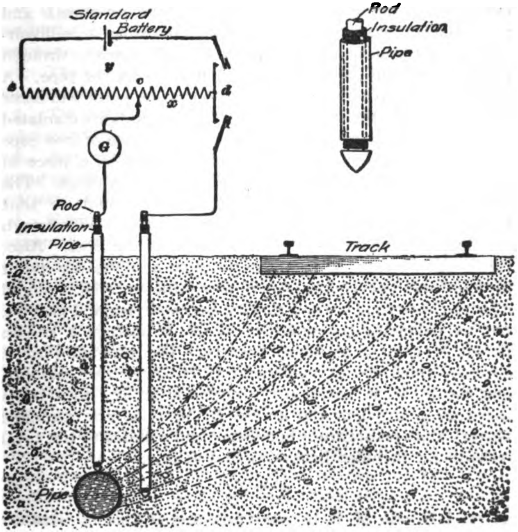


FIG. 27

as water pipes or the rails of electric railways, at frequent intervals along the cable line. The voltmeter may be connected to the upper ends of two metallic rods, about 10 ft. long, the lower end of one being provided with a conical steel tip for making contact with the earth, rails, or other conductors, and the lower end of the other rod being provided with a wedge-shaped tip for making contact with the lead sheaths of the cables. The readings should be recorded in tabular form and a curve constructed from them; their location may also be useful.

Herrick's Method.—The following method is recommended by A. B. Herrick as being much more reliable for determining the potential between a pipe or sheath and the adjacent earth than the method of using a millivoltmeter. An insulated pointed rod *a*, Fig. 27, is driven through the soil until the point comes in contact with the pipe. A second insulated rod *b* is driven in so that its point will come close to the pipe but will not touch it. Both rods are insulated and protected by running them through a piece of iron pipe lined with insulating material, as, for example, a piece of lined conduit such as is used for wiring buildings. The earth-potential point is covered with cadmium so that there will not be a local E. M. F. set up, which will disturb the difference of potential due to the earth currents. Also, the E. M. F. existing between the pipe and the test point is measured not by means of a voltmeter, which would disturb the normal current flowing between pipe and ground, but by balancing the unknown E. M. F. against a known E. M. F. from a standard battery. The resistance *cd* is adjusted until the galvanometer *G* indicates zero current, and the E. M. F. between the pipe and ground then bears the same relation to the known E. M. F. of the standard battery that resistance *x* between *c* and *d* bears to the total resistance *y* included between *e* and *d*; or,

$$E_1 = E\frac{x}{y}$$

in which E_1 = E. M. F. between pipe and ground;
E = E. M. F. of standard battery;
x = resistance *cd*;
y = total resistance *de*.

It is not necessary to know the values of *x* and *y*, in ohms; it is sufficient if the ratio of their resistances is known. Resistance *y* can be in the form of a slide-wire bridge or a bare high-resistance wire wound on a cylinder and provided with a sliding contact and scale, so that the divisions read off for any position of the contact will be proportional to the resistance x.

Prevention of Electrolysis.—A large system of piping forms a conducting network of very low resistance in parallel with the car track, hence it is a very difficult matter to prevent part of the current from leaving the track. However, if proper steps are taken, the bad effects of electrolysis can be largely avoided. The following are the main points that experience has shown should be observed:

1. The trolley wire should be made the positive side of the system.
2. The track should be thoroughly bonded and the bonds maintained in good condition.
3. Any metallic connections that may exist between piping or lead-cable systems and the track should be located and removed.
4. Return feeders should be run out from the station and connected to those pipes or cables that carry the greater part of the current. Thus, the current in the pipes or cables will be "drained" off without passing from the pipes or cables to the ground.
5. Where service pipes, cables, or underground conductors pass under tracks or through other regions where they are exposed to electrolytic action, they can often be protected by covering them with glazed tile or by placing them in a trough filled with asphalt.
6. If, in any part of a system, the rail return carries an excessive current, return feeders should be run so as to relieve the rail of part of the current and prevent an excessive fall of potential along the rail. The greater the fall of potential in the rails, the greater is the tendency for the current to pass off to neighboring pipes.

The remedy given under 3 is important. Very often accidental connections exist between the rails and pipe or cable, so that the current can pass directly to the piping or cable system. This is especially the case where pipes or cables run across iron bridges that also carry railway tracks. Before attempting to drain off the current from a piping system, it is needless to say that all metallic connections between track and pipe or cable sheath must be removed. Where pipes or cables pass across iron bridges, the best plan is to insulate them from the bridge, or if this is impossible, insulate them by the insertion of insulating joints at either end of the bridge.

Remedy 4 is very commonly practiced and gives good results if properly applied. The return feeders should be attached to the pipes or cable sheaths that carry the most current and, as a rule, the current so returned to the power house will not be more than 5 or 6% of the total railway current; if it exceeds this amount, it is probable that there is a metallic connection somewhere between the track and pipes.

Service pipes crossing under street-car tracks are particularly subject to electrolytic action, and when they are being laid or repaired it costs but little to cover them with tile or to run them in a box, as explained in 5.

Another method consists in providing, at a danger point, a very large ground plate, which may be cheaply and efficiently provided by excavating a hole, at the bottom of which a ton or two of coke is placed, and on top of this a load of old iron, such as worn-out car wheels, old rails, chips from machine shops, etc. The cable sheath should be connected to the ground plate by copper wire of good size. A large sleeve should be used to make the best possible metallic contact with the cable sheath that it is desired to protect, either by soldering the sleeve to the cable sheath or by securing metallic continuity by the use of some flexible amalgam that is manufactured for making bonds with rails and similar purposes. The connection to the ground plate may be made in a manner similar to that with the lead sheath. It is well, however, where soldered-joint connections are made, and, especially to the ground plate, to paint the soldered joint thoroughly with some good waterproof paint, in order to resist electrolytic action between the two kinds of metal at the joint. Since the copper wire is of much lower resistance than the surrounding ground, the current will usually follow the wire to the ground plate and thus the flow of electricity into the ground directly from the cable sheath, and the resulting electrolytic action is reduced. Of course, there will be more or less electrolytic action at the ground plates, but this plate is so large that it will resist corrosive action for a long time, and, moreover, it is cheaper to occasionally replace this ground plate, if necessary, than to have the cable sheath damaged by electrolysis. This is also usually cheaper than to provide a copper return cable or wire of sufficient size to carry the stray current back to the power station.

Method of Bonding to Cable Sheaths.—With most telephone companies, a standard method has been adopted for bonding the cable sheaths. Bonds are placed between all the cables of an underground line in every manhole through which they pass. The wire used is No. 8 B. & S.

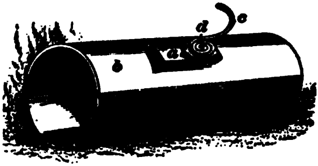


FIG. 28

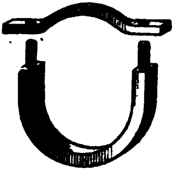


FIG. 29

gauge bare copper tinned. The surfaces of all the sheaths are scraped clean of mud, but great care must be taken not to cut away too much of the sheath. The end of the bond wire is then heated in a portable furnace and placed on the bright surface of the sheath, and solder applied. A soldering iron is then used to heat the sheath to the required temperature. The surface of the next sheath is cleaned in turn, and the bond wire bent down and soldered to it.

If the bond wire runs to a gas pipe, it may be soldered as in Fig. 28, in which *a* is a piece of sheet copper, which is soldered to the surface of the pipe *b* that has been previously brightened and tinned. The bond wire *c* is then coiled as at *d* and soldered to the copper plate.

Where it is necessary to bond to a water pipe, with which, while containing water, it is almost impossible to make a soldered connection, a yoke, shown in Fig. 29, may be made of strap iron and securely clamped in place on the water pipe, the surface of which has been previously brightened. The whole should then be given a heavy coating

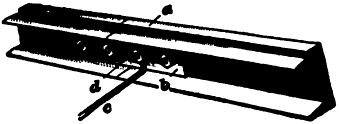


FIG. 30

of asphaltum to prevent corrosion. The method of bonding to a rail is shown in Fig. 30, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.

MEMORANDA

MEMORANDA

MEMORANDA

MEMORANDA

SEE FOLLOWING PAGES

Now District Manager

NORTH DAKOTA INDEPENDENT TELEPHONE CO.
Casselton, N. Dak.

I am with the North Dakota Independent Telephone Company, holding the position of district manager. Wish to inform you that my salary has trebled since I took out the Course with you. When enrolling I was engaged in farm work. If it had not been for my Course I would not be where I am now. I shall be more than pleased to recommend the Schools to any one.

A. O. HEDBERG,
District Manager

FROM FARM LABORER TO ASSISTANT MANAGER

When E. N. EGGE, Oxnard, Calif., enrolled for a Telephone Engineering Course he was working on the farm for his parents, doing also a little telephone line construction work, making about $300 a year. He is now assistant manager of the Home Telephone Company, of Oxnard, Calif.

BECOMES WIRE CHIEF

When F. E. BRUMFIELD, 346 W. Cambridge St., Alliance, Ohio, enrolled for the Telephone Engineering Course he was working as an errand boy in a small electrical shop, earning but little wages. Through the help of his Course he has been advanced, until he is now wire chief in his home town in an exchange having 1,800 subscribers. His salary has been increased more than 600 per cent.

SALARY STEADILY INCREASED

ARTHUR A. BURDICK, 74 Eagle St., Albany, N. Y., had reached the third grade in high school when he began work in the electrical line. Feeling the need of technical education to secure advancement in the telephone business he enrolled for the Telephone Engineering Course, and in due time secured his Diploma. At the time of his enrolment he was earning $16.50 a week with the New York Telephone Company, Albany District, Hudson Division. His salary was soon increased to $18; then $20; and then $27 a week. He is now combination troubleman at the main exchange at a salary almost double what he received at the time he enrolled.

NOW MANAGER

W. A. COOPER, New Smyrna, Fla., had only a seventh-grade education and was working as a button cutter when he first enrolled with the I.C.S. Having made a success as a clerk he later enrolled for the Telephone Engineering Course, gaining one promotion after another, until now he is manager of the Brevard County Telephone Company, having five exchanges under his direction.

I.C.S. DIRECT CAUSE OF INCREASED SALARY

JOHN M. COSGROVE, Hickman Mills, Mo., knew very little about electricity and had almost no practical experience when he enrolled for the Telephone Engineering Course. The reports of progress sent to his employer from the Students' Aid Department were the direct cause of increasing his salary $25 a month. He is now manager of the exchange at Hickman Mills, which position he declares is due to his I.C.S. Course.

GENERAL INSPECTOR AT LARGE SALARY

When FORREST G. DAVIS, Bluffton, Ind., enrolled with the I.C.S. for the Telephone Engineering Course he was only 18 years old. His Course has advanced him to the position of general inspector for the United Telephone Company, at a salary which has been increased more than 150 per cent.

General Manager of Two Large Companies

I was a telephone lineman earning $50 a month at the time I enrolled with the I.C.S. for the Telephone Engineering Course. Although I had only reached the seventh grade in the public school I found your Course could be mastered by any one who seeks advancement. The knowledge I gained has been very valuable to me and I am glad to recommend the Course to any one who has not had the advantage of a good education in this line. The cost is small in consideration of the benefits to be derived therefrom. I am now general manager of two large telephone companies, The Home Telephone and Telegraph Company, of Santa Barbara, and the Home Telephone and Telegraph Company, of Santa Barbara County, with a combined investment of more than half a million dollars. I have entire charge of all construction, maintenance, and operation. My salary has increased 400 per cent.

ALBERT SCHULER, Santa Barbara, Calif.

Manager of a Telephone Company

Some fifteen years ago I took up the Telephone Engineering Course with the International Correspondence Schools. Prior to that time I was employed in several lines of business, none of which required any special training. The advantage to me from the Course I took is best shown by the position I now have as Manager of the Citizens Telephone Co., and I am sure the I.C.S. deserve a good share of the credit for whatever success I may have had.

E. W. LUTZ,
Circleville, Ohio

650 Per Cent. Increase

When I enrolled with the I.C.S. for the Telephone Engineering Course I was at the bottom of the ladder in the East Exchange of the Cleveland Telephone Company. I had only passed the eighth grade in the public school and knew nothing of algebra at the time of my enrolment. At first I got "cold feet" on this study, but finally mastered it with no other help than that furnished by my I.C.S. instructor. Through the Students' Aid Department I was brought to the attention of the superintendent, who gave me my first promotion. I was gradually advanced until I am now chief clerk in the traffic department of the same company with an increase in salary of 650 per cent.

W. F. JOHNSON,
8811 Harkness Road, Cleveland, Ohio

I.C.S. Advanced This Man

When I enrolled with the International Correspondence Schools, I was working for the Western Telephone Company, getting $25 a month, digging holes and learning to climb poles. In the same year I was transferred to Brookfield, Mo., as troubleman for the same company. As I had already begun my I.C.S. Course, the manager, Mr. Hyde, was notified of my progress right along. My salary was raised and when the local manager left I was given his job. Later when the Bell Telephone Company absorbed this plant, I was manager for them for three months until they sold out to a home telephone company.

I am now manager of the D. G. Evans Telephone Company and have had offers to go to still better positions but do not wish to leave my home town. I give all the credit of my advancement to my I.C.S. Course.

JAS. A. SCHOOLER,
Box 182, Unionville, Mo.

Now the Superintendent

I completed a Telegraph Engineering Course with your Schools some years ago and believe that it has helped me a great deal. To my mind such a Course offers the best, and often the only opportunity an operator has to get a technical knowledge of his business. The supply of competent wire chiefs is limited and any one who has a natural inclination for this work, and has access to the electrical machinery of a large telegraph office, and, if willing to work for what he gets, can hardly help being benefited by his Course.

R. F. Fisher,
Superintendent, The Colo. & Wyo. Tele. Co.
Denver, Colo.

SALARY THREE TIMES AS LARGE

R. F. THAMER, 20 Alma St., Berlin, Ont., Canada, was clerking in a store at the time of his enrolment for the Telephone Engineering Course. A year or so later he gained a position with the Bell Telephone Company as inspector. He has since advanced to the position of wire chief in his home town at a salary three times what he received when he started with the company.

NOW WIRE CHIEF

At the time when DENNIS W. MOORE, Leadville, Colo., enrolled with the Schools, he was just starting in at telephone work, at the age of 21. His Course enabled him to work out all kinds of difficult problems while in the employ of the Bell Telephone Company. He is now wire chief, Mountain States Telegraph and Telephone Company.

A GRADUATE'S SUCCESS

GEORGE B. FOX, 460 E. 18th St., Paterson, N. J., was employed as a troubleman at the time of his enrolment for the Telephone Engineering Course. Before obtaining his Diploma he was promoted to the position of wire chief. Since then he has graduated and has now the right to place "Manager" after his name. He says that the knowledge acquired from his Course has been of inestimable value to him, and that his salary has been largely increased.

NOW FOREMAN, WITH A LARGE SALARY

GEORGE B. SWARTHOUT, 147 Mulberry St., Rochester, N. Y., was earning $30 a month on a construction gang when he enrolled with the I.C.S. for the Telephone Engineering Course. Later he entered the employ of the Rochester Railway and Light Company as cable splicer. Next he became assistant foreman, and in August, 1914, he was promoted to the position of foreman of the underground department, receiving about $1,500 a year.

ADVANCED TO MANAGER AND SECRETARY

C. L. PICKETT, St. Paul, Neb., was earning $25 a month when he enrolled with the Schools for a Telephone Engineering Course. This enabled him to advance to various positions as troubleman, electrician, and superintendent, and to become manager and secretary of the Howard County Telephone Company at a salary which has increased several hundred per cent.

SALARY INCREASED $75 A MONTH

CARL LUND, 1521 N. Rockwell St., Chicago, Ill., is working for the Chicago Telephone Company as switchboard foreman. When he enrolled he was switch tester for the Automatic Electric Company. He attributes his advancement in position and salary to the I.C.S. Telephone Engineering Course. His salary has increased $75 a month since he enrolled.

Head of Two Companies

When I enrolled with the I.C.S. for the Telephone Engineering Course, my only education along electrical lines was what little I had picked up from reading journals treating telephone work. I am now secretary, treasurer, and general manager of the Light and Power Company of this place, also secretary and general manager of the Franklin County Telephone Company. I have selected all of the machinery, electrical apparatus, etc., used by the company. I could not have planned and cleared up many difficulties but for the knowledge gained from your Course and from reading books on electric light and power which the Telephone Course made intelligible to me. My earnings are several times what they were when I took up your Course. You may use this letter as you like.

B. L. Fisher, Rocky Mount, Va.

Four Times His Former Salary

My position when I enrolled for my Telephone Engineering Course with the I.C.S. was that of Telephone Inspector, earning a salary of $600 a year. I am now General Manager of the Peoples' Home Telephone Co., at a salary of $2,400 a year.

The technical knowledge I secured through my Course, together with the practical knowledge I was able to attain in my additional work enabled me to make rapid progress.

I especially recommend an I.C.S. Course to young and middle-aged men who are now engaged in some definite line of work, for I believe that in this way practice and theory are harmoniously blended.

H. W. SEXTON,
Leavenworth, Kansas

Makes as Much in a Day as He Did in a Week

When CHAS. F. SCHATTLE, 305 Renwick Ave., Syracuse, N. Y., first enrolled with the Schools for an Electric Power and Lighting Course, he was earning $6 a week for ten hours hard work as a bicycle repairer. Before he graduated from this Course his salary was increased. Later he enrolled for a Telephone Engineering Course, in which he also obtained a diploma. He now has charge of the power department, both steam and electrical, in the E. C. Stearns & Company plant. He says that the price paid for his Course was the best investment he could have made, since he now earns about as much in one day as he then did in a week.

Recommends I.C.S. to His Employes

At the time of my enrolment I was working as a telephone lineman, receiving very good wages for that class of work. At the end of three years I received my Diploma in the Telephone Engineering Course and was drawing a salary over 100 per cent. greater than what I was receiving when I enrolled.

Without your instruction my advancement would have been much slower, as I have enough confidence in my ability to believe that I could have made good some time. To me your assistance has been that of a "Short Cut" to a better position and the years I saved by this "Short Cut" are now being used in further correspondence study, with the hope that I may continue increasing my ability and earning capacity.

I always recommed your Schools to my employes, giving your pupils the preference whenever I can.

D. B. White,
Sec. & Treas., Home Tele. Co.,
Clarksville, Tenn.

300 Per Cent. Increase

L. L. LUTHER, 146 West Kennedy St., Syracuse, N. Y., has now graduated from our Telephone Engineering Course. When he enrolled he had just left the high school and was working as a day laborer. Before he graduated he obtained a position with the Moravia Electric Light, Heat and Power Company through the Students' Aid Department. He is now electrician for the Merrill-Soule Company, of Syracuse, N. Y. His work consists of electric installation and operation of electrical machinery in the Syracuse plant, and the installation of lighting systems in the new pure food plants of the company as constructed in other cities, together with the supervision of electrical work required in their other plants. His salary has increased at least 300 per cent.

Gives His I.C.S. Course the Credit

I started my Course with the I.C.S. when a wireless operator. I am now Managing Editor of the Pacific Radio Publishing Company, publishing a wireless monthly magazine. I could never have accepted a position as editor without my knowledge of Engineering.

I expect rapid advancement in a short time. Here is wishing the International Correspondence Schools big success.

HENRY W. DICKOW,
427 26th Ave.,
Merchants Exchange Bldg.,
San Francisco, Calif.

Messenger Boy Becomes General Manager

I cannot express my thanks for what your Schools have done for me. When I enrolled in your Schools in 1900 I was employed by the Napoleon Home Telephone Company as messenger boy, earning but $4 a month. Before I completed my Course the I. C. S. from time to time recommended me to the company for a better position, and in a few years I advanced to inspector, then to superintendent, and at present am general manager of the Napoleon Home Telephone Company, having in my charge six exchanges.

Again thanking you for the interest your Schools have taken in me, I beg to remain

F. P. Diemer, Napoleon, Ohio