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.

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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;
A = area in square inches;
$\mathcal{B}$ = magnetic density per square centimeter;
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;
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	$\mathfrak{H}$	$\mathfrak{H}=\frac{F}{m}=\frac{m}{l^2}$	Gauss, or 1 line of force per sq. cm.
Susceptibility	κ	$\kappa=\frac{\mathfrak{J}}{\mathfrak{H}}$	Has no name
Magnetomotive force	$\mathfrak{F}$	$\mathfrak{F}=\mathfrak{H}l$ or $\mathfrak{F}=\frac{W}{m}$	Gilbert (Not internationally accepted)
Magnetic density or magnetic induction	$\mathfrak{B}$	$\mathfrak{B}=4\pi\mathfrak{J}+\mathfrak{H}$	Gauss, or 1 line of force per sq. cm.
Magnetic flux	Φ	$\Phi=\mathfrak{B}A$	Maxwell, or 1 line of force
Permeability	μ	$\mu=\frac{\mathfrak{B}}{\mathfrak{H}}$	Has no name
Reluctance	$\mathfrak{R}$	$\mathfrak{R}=\frac{\mathfrak{F}}{\Phi}$ or $\mathfrak{R}=\frac{l}{A\mu}$	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}	$10^{8}\div v=\frac{1}{3}\times10^{-2}$
Resistance....	R	$R=\frac{E}{I}$ or $R=\frac{W}{I^2t}$	Ohm	10^{9}	$10^{9}\div v^2=\frac{1}{9}\times10^{-11}$
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	Quantities by Which to Multiply Practical Electromagnetic Units to Reduce to: 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;
$\mathfrak{M}$ = 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	1.587
Aluminum[2] (commercial—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[2] (pure)......	10.023	60.292		.004190	.002320	15.90	6.289
Palladium[2] (pure)......	10.219	61.471		.003540	.001970	15.60	6.410
Platinum[2] (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[2]...............	12.323	74.128		.006220	.003460	12.94	7.726
Tin[2] (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[2] (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)	Resistance of 1 Mil-Foot in Ohms	Temperature Coefficient per Degree Centigrade	Temperature Coefficient per Degree Fahrenheit	Percentage Conductivity	Relative Resistance
	At 0° C. or 32° F.	at 0° C. or 32° F.				
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,[2] *Pt* 33⅓, *Ag* 66⅔	31.582	189.980	.000243*	.000135*	5.05	19.800
Platinoid,[2] *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,[2] *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); *Sl* (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; *Sl*, .134; *P*, .043; *Cr*, 1.195. Hopkinson	17.9	7.05	108						
Chrome steel (annealed), *C*, .532; *Mn*, .393; *S*, .02; *Sl*, .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%; aluminum, 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%; *Nl*, 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 $\frac{1}{4}$ mho, and its conductivity $\frac{1}{2}$ 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 $R_t = R_{32}\ [1 + .0023708\ (t - 32°) + .00000034548\ (t - 32°)^2]$, 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:

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

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

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

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

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			Feet 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 Underwriters
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 Underwriters
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	$1\frac{1}{2}$	3,550	18,744	800	1,000
900,000	$1\frac{13}{32}$	3,215	16,975	800	920
800,000	$1\frac{11}{32}$	2,880	15,206	850	840
750,000	$1\frac{5}{16}$	2,713	14,325	850	
700,000	$1\frac{9}{32}$	2,545	13,438	900	760
650,000	$1\frac{1}{4}$	2,378	12,556	900	
600,000	$1\frac{7}{32}$	2,210	11,668	1,000	680
550,000	$1\frac{3}{16}$	2,043	10,787	1,200	
500,000	$1\frac{1}{8}$	1,875	9,900	1,320	590
450,000	$1\frac{3}{32}$	1,703	8,992	1,400	
400,000	$1\frac{1}{16}$	1,530	8,078	1,450	500
350,000	1	1,358	7,170	1,500	
300,000	$\frac{15}{16}$	1,185	6,257	1,600	400
250,000	$\frac{29}{32}$	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 ¼ 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 ¼ 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.	ρ = 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 $\frac{1}{16}$ 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 weatherproof 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 microfarads 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,

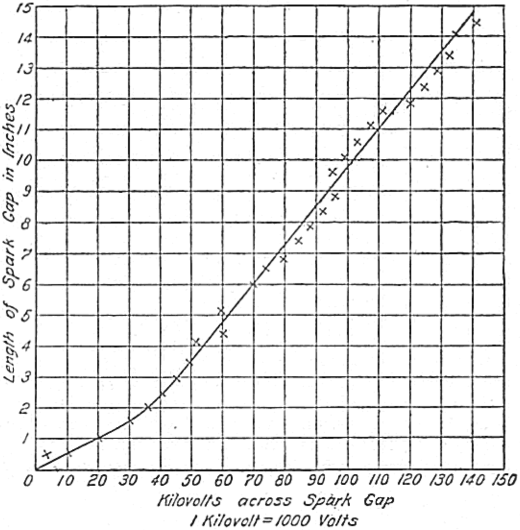
$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.}}$$

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 $2\frac{1}{2}$ 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, 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		
Centimeters	Inches	1 Cm. =.3937 In.	2 Cm. =.787 In.	6 Cm. =2.36 In.
		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.)	$10,551\times10^6$	1,055.1	$\frac{29,310}{10^8}$	252.00	778	1