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 ($\mathcal{M}$).—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 $\mathcal{M} = m \times l$.

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

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

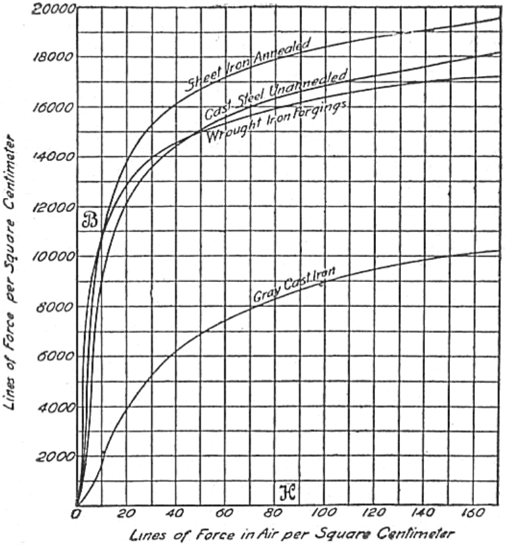
Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch $\mathbf{B}$	Square Centimeter $\mathfrak{H}$	Square Inch $\mathbf{H}$	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	1.860	12	1.480	3.758	833.3
3,100	20,000	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

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

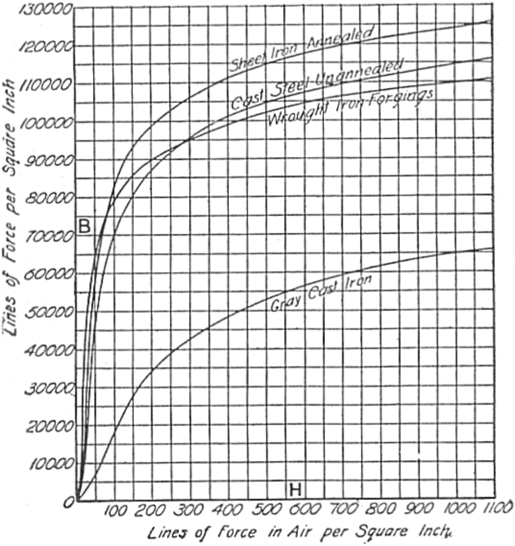


$\mathcal{B}$–$\mathcal{H}$ CURVES

Magnetomotive force $\mathcal{F}$ (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

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

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

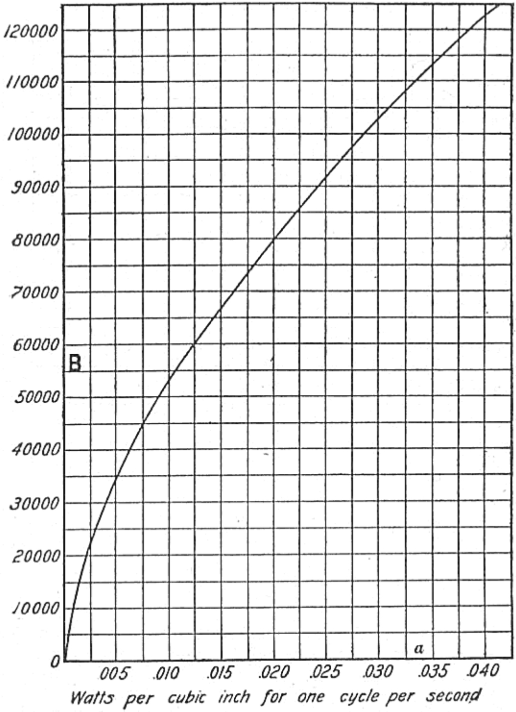


B-H CURVES

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.; $\mathbf{V}$, 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

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

where V is the volume in cubic centimeters and $\mathcal{B}$ 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;

$\mathbf{B}$ = number of lines of force per square inch.

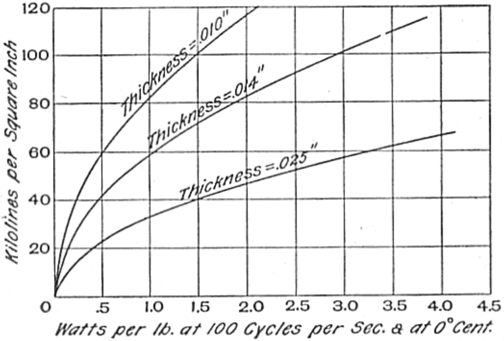
The loss decreases .5% per degree C. increase of temperature. The formula holds for iron whose specific resistance is 10 microhms per cm. cube at 0° C. and whose specific weight is .282 lb. per cu. in. For thicknesses greater than .025 in., the results given by the above formula are greatly modified.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

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

If Φ is the flux in maxwells, then $\mathfrak{F}$ 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 nonmagnetic 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,

$$\mathcal{F} = \mathcal{H}l = 1.257IT$$
$$\mathbf{H}\,\mathbf{l} = 3.192IT$$

in which l must be expressed in centimeters and $\mathbf{l}$ 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

$$IT = .796\mathcal{H}_1 l_1 + .796\mathcal{H}_2 l_2 + .796\mathcal{H}_3 l_3 + \text{etc.},$$

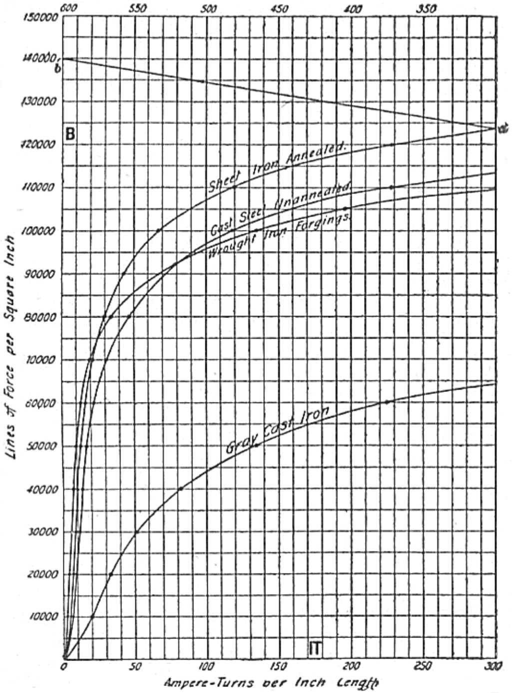
or, when the dimensions are in inches,

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

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

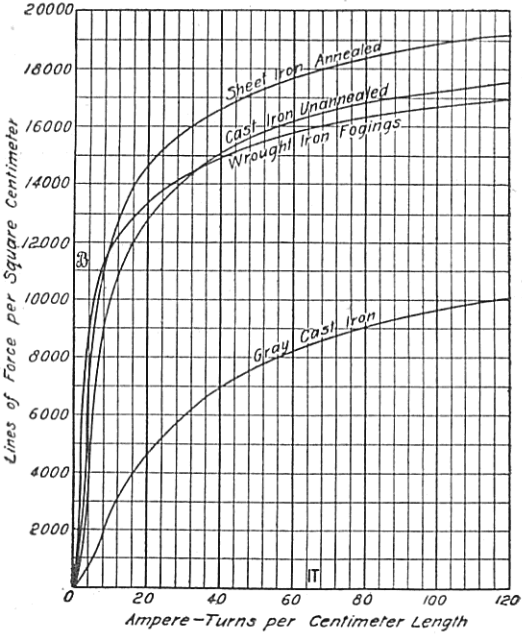
The electromotive force E in volts generated in a conductor cutting Φ lines of force in t seconds may be computed by the formula

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

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

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

AMPERE-TURN CURVE—METRIC MEASURES



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

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

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

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

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

$$L=\frac{10{,}028\mathbf{r}^2T^2}{10^{11}1}$$

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:

$$L=4\pi^2n^2m\left\{\frac{2a_0^4+a_0^2l^2}{\sqrt{a_0^2+l^2}}\right\}+8\pi^2n^2\left\{[(m-1)a_1^2+(m-2)a_2^2\right.$$
$$+\,\text{- - -}][\sqrt{a_1^2+l^2}-\tfrac{7}{8}a_1]+\tfrac{1}{2}[m(m-1)a_1^2+(m-1)(m-2)a_2^2$$
$$\left.+(m-2)(m-3)a_3^2+\text{- - -}]\left[\frac{a_1r_1}{\sqrt{a_1^2+l^2}}-r\right]\right\}\quad.$$

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

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

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.*

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.

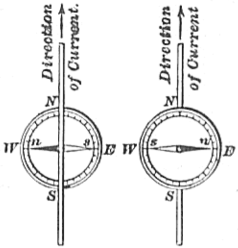


FIG. 1

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	
$\frac{1}{8}$	3	$\frac{1}{4}$	23	2	36	$\frac{1}{8}$	25	2×1	2
$\frac{1}{4}$	$3\frac{3}{4}$	$\frac{3}{8}$	23	2	36	$\frac{1}{4}$	40	2×$1\frac{1}{2}$	2
$\frac{3}{8}$	$4\frac{3}{4}$	$\frac{1}{2}$	22	2	36	$\frac{3}{4}$	45	4×2	4
$\frac{1}{2}$	6	$\frac{1}{2}$	19	2	36	$\frac{5}{8}$	50	4×2	4
$\frac{3}{4}$	7	$\frac{3}{4}$	16	2	36	$\frac{3}{4}$	60	4×4	6
1	8	1	16	2	34	1	100	7×5	12
2	10	$1\frac{1}{8}$	14	2	34	3	100	9×7	12
3	$11\frac{3}{4}$	$1\frac{1}{4}$	14	2	33	5	150	9×7	12
6	$14\frac{3}{4}$	$1\frac{1}{2}$	12	2	33	10	200	9×9	16
12	19	$1\frac{5}{8}$	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 current, then the thumb will show the direction of the motion given to the conductor.

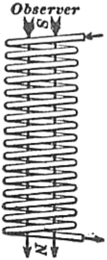


FIG. 2

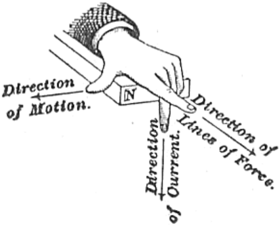


FIG. 3

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.

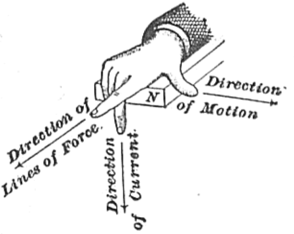


FIG. 4

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

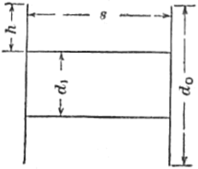
B. & S. Gauge	Bare		Single Cotton-Covered		
	Dia. Mils d	Area Cir. Mils d^2	Dia. Over Ins. Mils dx	Wires per In. $\frac{1{,}000}{dx}$	Wires per Sq. In. $\left(\frac{1{,}000}{dx}\right)^2$
0000	460	212,000			
000	410	168,000			
00	365	133,000			
0	325	106,000			
1	289	83,700			
2	258	66,400			
3	229	52,600			
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 dx	Wires per In. $\frac{1{,}000}{dx}$	Wires per Sq. In. $\left(\frac{1{,}000}{dx}\right)^2$
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 dx. The space will hold $\frac{s}{dx}$ 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	These small-size wires are seldom, if ever, covered with three layers of cotton.		
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			
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 dx^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..

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

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

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

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			1½	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	3½	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 $\frac{7}{64}$ in. thick, the 20-pair No. 22 B. & S. conductor cable has a lead sheath $\frac{3}{32}$ 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 ¼ 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

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