The Electro Magnet.

PART III.

By Richard Varley.

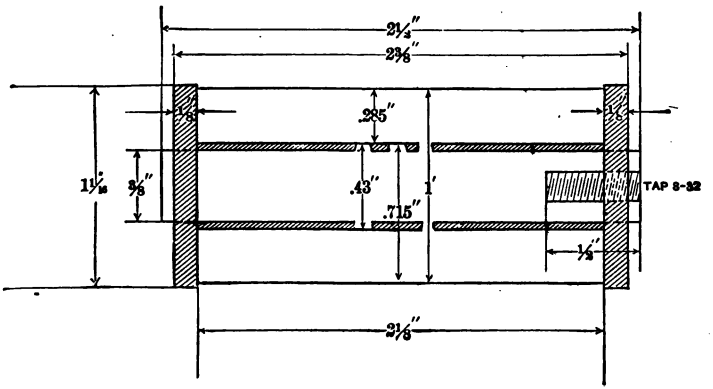
Practical Calculations of Magnet Coils.

By Richard Varley.

The Importance of Details.

The usual text-book information on the Electro-magnet is, as a rule, far too theoretical for the practitioner; the difficulties encountered in actual practice are rarely mentioned, and as a result the student who endeavors to design an Electro-magnet is disappointed to find his results do not compare favorably with his calculations.

These difficulties are caused by apparently small details usually regarded as being of little consequence, not only by the student but by the Manufacturer and Engineer as well, but which when considered show almost startling results.



In the above sketch is shown the winding dimensions of a bobbin, the core is three-eighths of an inch and the flange is one and one-sixteenth inches.

Before winding, the core is wrapped with two or three layers of paper and the winding is discontinued a little under one and one-sixteenth inches. The winding length being two and one-eighth inches, the student estimates 687 ohms as the amount of No. 35 B & S single silk covered wire that will be contained in the bobbin and is surprised to find only 567 ohms when finished, having lost over seventeen per cent. somewhere.

When the bobbin was wound it appeared to be full whereas its true diameter was one inch and with ordinary spring calipers, the core to be wound on was three-eighths full, its exact value being forty-three hundredths, and as the amount of wire contained in the bobbin is proportional to $D^2 - d^2$, we obtain a value .985 equal to ($1.0625^2 - .375^2$) in the first case and only .815 equal to ($1^2 - .43^2$) in the second case, a difference of 17 + per cent.

Again if this particular wire is stretched during the winding so that the diameter is reduced from .0056 to .0055, an amount too small to detect with a micrometer, there will be an increase in resistance of 6½ per cent.

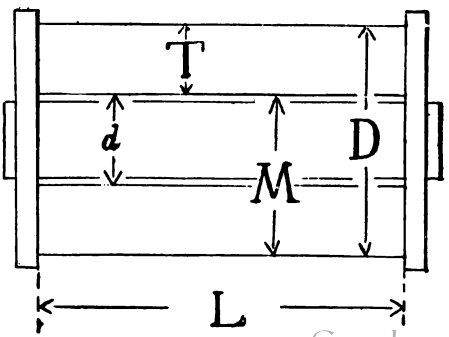
A slight variation in the thickness of the insulation will also make a marked change in the amount of wire in a winding.

In a given bobbin if a wire .005″ in diameter insulated to .007″ in diameter had a resistance of 2212 ohms, this same wire, insulated to .0065 in diameter, would have a resistance of 2565 ohms, an increase of 16 per cent.

It then becomes important to know the weight of the insulated wire in the finished magnet; the weight of the silk compared with the weight of the copper is often assumed to be too small to consider, and here appears another error of 11½ per cent. assuming that the .0056″ bare wire is insulated to .0081 or to a 2½ mil increase.

It is the purpose of the author to call the student's particular attention to apparently negligible factors and show clearly how materially they affect the results.

Actual Calculations.



Let D = true diameter of winding in inches,
d = diameter of core + sleeve " "
L = length of winding in inches.
M = average diameter of winding space or average diameter of one turn in inches.
T = thickness of winding space in inches.
n = number of layers.
N = number of turns.
Δ = diameter of wire in inches.
i = increase in diameter in inches due to insulation.
g = diameter of wire + insulation in inches.
Λ = length of wire in inches.
ρ = resistance of winding in ohms.
E = volts.
I = current in amperes.
W = watts.
h = constant for cotton covered wires = .1547.
Ω = ohms per pound for bare wires.
b = constant for silk covered wires = .1161.
a = % of copper in insulated wire.
A = weight of cotton in any size of cotton covered copper wire.
ω = ohms per inch for bare wires.
B = weight of silk in any size of silk covered copper wire.
θ = ohms per pound for insulated wires.
Δ^2 = cross section of wire in circular inches.
Σ = cross section of the insulation in circular inches.
λ = weight of insulated wire in pounds.
c = constant = .00000271056.

$$K = \frac{c}{\Delta^2} = \pi\,\omega$$

$$R = \frac{K}{g^2}$$

$$W = \frac{R}{\theta}$$

Referring to the sketch above it is evident that the amount of wire that will be contained in the magnet is proportional to M L T, which is equal to $\frac{D^2 - d^2}{4} L$. It is found convenient to use both of these expressions. The length of wire A that can be coiled on a bobbin $= \frac{\pi M L T}{g^2}$

The resistance of the wire $\rho = \frac{\pi \times \text{ohms per inch} \times M L T}{g^2}$

If we assign to the letter K the value represented by $\pi \times$ ohms per inch and assign to g the values as furnished by the manufacturers, we can put $R = \frac{K}{g^2}$ and with a prepared table giving the R values for all sizes of wire insulated with either cotton or silk the formula for resistance becomes simply $\rho = R M L T$.

The resistance of a copper wire for any length, multiplied by the area of its cross section, is equal to the resistance of any other copper wire of the same length multiplied by the area of its cross section.

The factor W bears the same relation to the weight of wire that the factor R bears to the resistance of the wire, and represents the weight of insulated wire which will be contained in a winding space having an M L T of unity.

Therefore $\gamma = W M L T$

$$n = \frac{T}{g}$$

$$M = \frac{D - d}{2}$$

$$T = \frac{D - d}{2} \qquad M T = \frac{D^2 - d^2}{4}$$

$$i = g - \Delta$$

Working Formulas.

$$N = \frac{T\,L}{g^2} = \frac{(D-d)\,L}{2\,g^2}$$

$$\Delta = g - i$$

$$I = \frac{W}{E} = \frac{E}{\rho} = \sqrt{\frac{W}{\rho}}$$

$$\rho = \frac{E^2}{W} = \frac{E}{I} = \frac{W}{I^2}$$

$$W = E\,I = I^2\,\rho = \frac{E^2}{\rho}$$

$$E = \frac{W}{I} = I\,\rho = \sqrt{\rho\,W}$$

$$K = \frac{c}{\Delta^2} = \pi\,\omega = R\,g^2 = W\,\theta\,g^2 = W\,a\,\Omega\,g^2$$

$$R = \frac{K}{g^2} = \frac{c}{\Delta^2 g^2} = \frac{\pi\,\omega}{g^2} = W\,\theta$$

$$\theta = \frac{R}{W} = \frac{K}{g^2 W} = \frac{c}{W\,\Delta^2 g^2} = \frac{\pi\,\omega}{W\,g^2} = a\,\Omega$$

$$W = \frac{R}{\theta} = \frac{c}{\theta\,\Delta^2\,g^2} = \frac{K}{\theta\,g^2} = \frac{\pi\,\omega}{\theta\,g^2}$$

$$\omega = \frac{K}{\pi} = \frac{c}{\Delta^2\,\pi} = \frac{R\,g^2}{\pi} = \frac{W\,\theta\,g^2}{\pi}$$

$$g = \sqrt{\frac{K}{R}} = \sqrt{\frac{\pi\,\omega}{R}} = \sqrt{\frac{c}{\Delta^2 R}} = \sqrt{\frac{K}{W\,\theta}} = \Delta + i.$$

$$c = K\,\Delta^2 = \pi\,\omega\,\Delta^2 = R\,g^2\,\Delta^2 = W\,\theta\,g^2\,\Delta^2$$

$$\Omega = \frac{\theta}{a} = \frac{R}{a W} = \frac{K}{a W g^2} = \frac{c}{a W \Delta^2 g^2} = \frac{\pi \omega}{W g^2 a}$$

$$a = \frac{\theta}{\Omega} = \frac{R}{\Omega W} = \frac{\pi \omega}{\Omega W g^2}$$

$$\Delta^2 = \frac{c}{K} = \frac{c}{R g^2} = \frac{c}{\pi \omega} = \frac{c}{W \theta g^2}$$

From the data given the following values are obtained :

$$\rho = R M L T = \frac{R L (D^2 - d^2)}{4} = \frac{E^2}{\pi D L}$$

$$i = \sqrt{\frac{c}{K \Delta^2}} - \Delta$$

$$R = \frac{4 \rho}{L(D^2 - d^2)} = \frac{4 E}{I L (D^2 - d^2)} = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$$

$$E = \sqrt{L \pi D \rho} = \frac{I R L (D^2 - d^2)}{4} = \frac{I N K (D + d)}{2} = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$$

$$L = \sqrt{\frac{4 E^2}{\pi D R (D^2 - d^2)}} = \frac{E^2}{\pi D \rho} = \frac{2 N g^2}{(D - d)} = \frac{4 \rho}{R (D^2 - d^2)} = \frac{4 E}{R L (D^2 - d^2)}$$

$$D = \frac{E^2}{\pi \rho L} = \sqrt{\frac{4 \rho}{R L} + d^2} = \sqrt{\frac{4 E}{I R L} + d^2} = \frac{2 N g^2}{L} + d = \frac{2 E}{I N K} - d.$$

$$d = \sqrt{D^2 - \frac{4 E^2}{\pi D R L}} = \sqrt{D^2 - \frac{4 E}{I R L}} = \sqrt{D^2 - \frac{4 \rho}{R L}} = D - \frac{2 g^2 N}{L}$$

$$= \frac{2 E}{I N K} - D$$

$$I = \frac{E}{RMLT} = \frac{4E}{RL(D^2-d^2)}, \quad N = \frac{TL}{g^2} = \frac{L(D-d)}{2g^2}$$

$$IN = \frac{E}{MK} = \frac{2E}{K(D+d)} = \frac{2E\Delta^2}{c(D+d)}.$$

$$n = \frac{T}{g} = \frac{D-d}{2g}$$

$$g = \sqrt{\frac{L(D-d)}{2N}}$$

$$K = \frac{2E}{IN(D+d)}.$$

$$\Delta = \sqrt{\left(\sqrt{\frac{cL(D^2-d^2)}{4\rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

$$\Delta = \sqrt{\left(\sqrt{\frac{c\pi DL^2(D^2-d^2)}{4E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

$$i = \sqrt{\frac{cL(D^2-d^2)}{4\rho\Delta^2}} - \Delta = \sqrt{\frac{c\pi DL^2(D^2-d^2)}{4E^2\Delta^2}} - \Delta$$

Diameter of Wire to Carry Given Current.

To find the diameter of the wire which will safely carry a continuous current we have $R = \frac{E^2}{\pi D L^2 MT}$ by allowing 1 watt per square inch for radiation, no allowance being made for end flanges or core. If the winding is of great depth or closely confined another constant must be substituted for π in the formula. A fair example where π is the constant is in a winding where $D = 2.5''$ $L = 2''$ $d = 1\frac{1}{8}''$. In calculations where the size of insulated copper wire is required the value of R may first be found, then by reference to the table, in which are given the values of R for

the various sizes of insulated wires, the size of the wire and of the insulation may be found.

In case the value of R in the problem lies between two values of R in the table, the value of R for the smaller size of wire may be taken and with it a new D may be found which will satisfy the conditions of the problem.

EXAMPLE: Let $D = 1$, $d = .43$, $L = 3$ $\rho = 125$

$$D^2 - d^2 = 1. - .185 = .815$$

From (1). $$R = \frac{4\ \rho}{(D^2 - d^2)\ L} = \frac{500}{.815 \times 3} = \frac{500}{2.445} = 204.5$$

In the table the value for R (204.5) lies between the values of R for No. 30 and No. 31 single silk covered wire. Taking the value of R for No. 31 single silk covered wire (261.6) and solving for the new D:

$$D = \sqrt{\frac{4\ \rho}{R\ L} + d^2} = \sqrt{\frac{500}{261.6 \times 3} + .185}$$

$$= \sqrt{.638 + .185} = \sqrt{.823} = .907$$

From the above it is evident that it is very important to know the *exact* value of R.

Tables giving values of K for all sizes of wire and values for R for all sizes of wire and insulation, both cotton and silk, are printed on page 76.

A rod of soft drawn commercial copper 1" in diameter (1 circular inch in cross section) and one foot in length, has a resistance @ 68° F, of .000103535 68 international ohms.

Then a wire .001 in. in diameter (.000001 circular in. in cross section) and one foot in length, under the same conditions, has a resistance of 10.353568 ohms, or in other words:—

A commercial copper wire one circular mil in cross section has a resistance @ 68° F. of 10.353568 ohms per foot.

Since $K = \pi\,\omega$ and also $\frac{c}{\Delta^2}$

$$c = \pi\,\omega\ \Delta^2 = \frac{3.1416 \times 10.353568 \times .000001}{12}$$

$$= \frac{.00003252677}{12} = .00000271056$$

Therefore to find the value of K for any size of wire, divide the constant c by the cross section of the wire in circular mils.

Likewise with the factor R which is equal to $\frac{K}{g^2}$ in case the insulation thickness is different from that given in the table, a new R may be easily determined.

Diameter of Wire to have Given Resistance.

To find the exact diameter of a copper wire which will satisfy the conditions for a given bobbin when the resistance required is also given and the insulation previously determined on, proceed as follows:

Since $g^2 = \frac{c}{\Delta^2 R}$

$$g^2\,\Delta^2 = \frac{c}{R}$$

$$g\ \Delta = \sqrt{\frac{c}{R}}$$

Since $g = \Delta + i$

$$\Delta^2 + \Delta\ i = \sqrt{\frac{c}{R}}$$

Completing the square:—

$$\Delta^2 + \Delta i + \frac{i^2}{4} = \sqrt{\frac{c}{R}} + \frac{i^2}{4}$$

$$\Delta + \frac{i}{2} = \sqrt{\sqrt{\frac{c}{R}} + \frac{i^2}{4}}$$

$$\Delta = \sqrt{\left(\sqrt{\frac{c}{R}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

Substituting $\frac{\rho}{M L T}$ for R we have

$$\Delta = \sqrt{\sqrt{\frac{c}{\frac{\rho}{M L T}}} + \frac{i^2}{4}} - \frac{i}{2}$$

$$= \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$$

Thickness of Insulation in a Given Coil.

To find the thickness of insulation necessary to insulate a given wire, to satisfy the conditions of the bobbin and resistance.

$$\Delta^2 + \Delta i = \sqrt{\frac{c}{R}}$$

$$i = \frac{\sqrt{\frac{C}{R}} - \Delta^2}{\Delta}$$

$$= \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$$

A serious error made in computing tables for insulated wires is the allowance of 90% of the gross weight for the wire and 10% for the insulation.

The table on page 78 shows the fallacy of this method. The table is computed on the following principle:

The specific gravity of copper is to that of cotton as 86.6:13.4

The specific gravity of copper is to that of silk as 89.6:10.4

If then a copper wire having an end area Δ^2 be insulated with Σ cotton, 86.6 Δ^2 is the relative weight of copper, and 13.4Σ is the relative weight of cotton in the insulated wire.

Therefore, $$\frac{86.6\ \Delta^2}{86.6\ \Delta^2 + 13.4\ \Sigma} = \% \text{ of copper.} \qquad (1)$$

Likewise with a copper wire insulated with silk:

$$\frac{89.6\ \Delta^2}{89.6\ \Delta^2 + 10.4\ \Sigma} = \% \text{ of copper.} \qquad (2)$$

Multiplying the weight of the insulated wire by the per cent. of copper the weight of the copper is obtained, and by subtracting the weight of the copper from the weight of the insulated wire, the weight of the cotton is obtained; or the weight of the cotton can be found after the manner of finding the weight of copper. The same operation is repeated for finding the weights of copper and silk. Since a = per cent. of copper in either case formulae (1) must always be used for cotton insulated wire and (2) for silk insulated wire.

Weight of Copper in a Given Coil.

Given the gross weight of a coil of No. 25 silk insulated wire, the diameter of which including wire and insulation = g and the diameter of the copper Δ, to find the weight of copper.

$$g^2 - \Delta^2 = \Sigma$$

Let $g = .03396$,

$\Delta = .03196$,

Then $\Delta^2 = .001022$

$\Sigma = g^2 - \Delta^2 = .001152 - .001022 = .00013$

Substituting values of Δ^2 and Σ in (2)

$$a = \frac{89.6 \times .001022}{(89.6 \times .001022) + (10.4 \times .00013)} = \frac{.091571}{.091571 + .0001352}$$

$$= .985 \text{ or } 98.5 \text{ per cent.}$$

Having found the relative weights of copper and cotton, and copper and silk, a new table giving "Ohms per Pound" is shown on page 77 computed from this principle.

It is very evident that unless the exact ohms per pound of a given wire is known, the error will be very great. A comparison between the table on page 77 and other tables will show the discrepancy in the latter.

Referring to the table on page 77 which gives the Ohms per pound for all sizes of bare copper wire, any size wire may be selected and by reversing the operation the Ohms per pound for any style of insulated wire may be found.

Thus, in the last example:—

In the table the wire .03196 inches in diameter has 3.278 ohms per pound and the ohms per pound of the wire with .002 inches insulation will be only 98.5% of the ohms per pound of the bare wire.

Thus:, $3.278 \times .985 = 3.23$,

which is the value given in the table on page 77.

The weight of cotton in any size of cotton covered copper wire is equal to,

$$\frac{\Sigma}{\Delta^2} \times \frac{13.4}{86.6} = \frac{\Sigma}{\Delta^2} \times .1547,$$

or for silk

$$\frac{\Sigma}{\Delta^2} \times \frac{10.4}{89.6} = \frac{\Sigma}{\Delta^2} \times .1161.$$

Therefore to find the weight in pounds of insulation that will insulate a given bare copper wire to any thickness, divide the continued product of the area of the cross section of the insulation in circular inches, the constant for that style of insulation, and the weight of the given wire in pounds by the cross sectional area of the copper in circular inches.

Thus: For silk, $B = \frac{\Sigma\ b\ \lambda}{\Delta^2}$

For cotton, $A = \frac{\Sigma\ h\ \lambda}{\Delta^2}$.

EXAMPLE: Given the weight and size of a bare copper wire, to find the weight of cotton required to insulate it to .004 in. increase:

Let $\Delta = .0403$ (No. 18 B & S)

$\lambda = 980$

Then $g = \Delta + i = .0403 + .004 = .0443$

$$A = \frac{\Sigma\ h\ \lambda}{\Delta^2} = \frac{h\ \lambda\ (g^2 - \Delta^2)}{\Delta^2} = \frac{151.6 \times .0003384}{.00162409} = \frac{.05130144}{.00162409}$$

$$= 31.58.$$

Transforming above rule :

FOR SILK.	FOR COTTON.
$B = \frac{\Sigma\ b\ \lambda}{\Delta^2}$	$A = \frac{\Sigma\ h\ \lambda}{\Delta^2}$
$\Delta^2 = \frac{\Sigma\ b\ \lambda}{B}$	$\Delta^2 = \frac{\Sigma\ h\ \lambda}{A}$
$\Sigma = \frac{B\ \Delta^2}{b\ \lambda}$	$\Sigma = \frac{\Delta^2\ A}{h\ \lambda}$
$b = \frac{B\ \Delta^2}{\Sigma\ \lambda}$	$h = \frac{\Delta^2\ A}{\Sigma\ \lambda}$
$\lambda = \frac{B\ \Delta^2}{\Sigma\ b}$	$\lambda = \frac{\Delta^2\ A}{\Sigma\ \lambda}$

THE VALUES SHOWN IN COLUMNS "R" AND "W" OF THIS TABLE REPRESENT RESPECTIVELY THE RESISTANCES AT 68° F., AND THE WEIGHT IN POUNDS, OF COTTON AND SILK INSULATED WIRE WINDINGS WHEN M.L.T = 1.

Size of Wire B&S	Diam. in inches △	Circ. inches △²	K	COTTON. Insulation I	g in inches	g² Circ. inches	R	Ohms per pound θ	W	SILK. Insulation I	g in inches	g² Circ. inches	R	Ohms per pound θ	W
10	.1019	.01038	.000961	.008	.1099	.0121	.02155	.0808	.7						
11	.09074	.008234	.000329	.008	.09874	.00975	.03377	.049	.589						
12	.08081	.006530	.000415	.008	.08881	.00788	.0537	.0777	.675						
13	.07196	.005178	.000523	.008	.07996	.0064	.0818	.123	.665						
14	.06408	.004107	.00066	.008	.07208	.0053	.127	.196	.851						
15	.05707	.003257	.000833	.008	.06507	.00423	.1965	.3085	.638						
16	.05083	.002583	.001049	.008	.03883	.00346	.302	.488	.621						
17	.04526	.002048	.001323	.008	.05326	.002835	.467	.768	.608						
18	.04030	.001624	.001668	.008	.04830	.002335	.718	1.213	.588						
19	.03589	.001288	.002103	.008	.04388	.001935	1.0925	1.915	.570						
20	.03196	.001023	.002651	.004	.03596	.001296	2.05	3.15	.65	.0095	.03446	.001185	2.225	3.23	.695
21	.02846	.000810	.00335	.004	.03246	.001058	3.18	4.97	.64	.0095	.03096	.000958	3.49	5.1	.685
22	.02535	.0006434	.00423	.004	.02935	.000863	4.895	7.87	.622	.0095	.02785	.000776	5.42	8.06	.672
23	.02257	.0005095	.00533	.004	.02657	.000706	7.55	12.45	.606	.0095	.02507	.000636	8.48	12.8	.662
24	.0201	.000404	.00671	.004	.0241	.000580	11.56	19.05	.59	.0095	.0226	.000511	13.1	20.85	.645
25	.0179	.0003204	.00846	.004	.0219	.000479	17.66	30.9	.572	.0095	.0204	.000416	20.3	32.2	.631
26	.01594	.0002541	.01065	.004	.01994	.000397	26.96	48.5	.554	.0095	.01844	.000340	31.4	50.9	.617
27	.0142	.0002015	.01345	.004	.0182	.000333	40.5	76.5	.530	.0095	.0167	.000279	48.3	80.8	.597
28	.01264	.0001598	.01696	.004	.01664	.000277	61.2	120.	.510	.0095	.015145	.0002292	74.	127.5	.581
29	.01126	.0001267	.0214	.004	.01526	.000233	91.5	190.5	.482	.0095	.01376	.0001895	113.8	201.5	.56
30	.01003	.0001005	.02695	.004	.01403	.000197	136.8	294.5	.464	.0095	.01253	.000157	171.6	315.	.539
31	.008928	.0000797	.034	.004	.012928	.000167	203.5	461.	.441	.0095	.011428	.0001305	260.5	503.	.518
32	.00795	.00006321	.0429	.004	.01195	.000142	299.8	717.	.418	.0095	.01045	.000109	393.	790.	.498
33	.00708	.00005018	.0541	.004	.01108	.000122	439.5	1115.	.394	.0095	.00958	.0000918	569.	1138.	.517
34	.006305	.00003975	.0683	.004	.010305	.000106	645.	1715.	.375	.0095	.008805	.0000775	890.	1940.	.453
35	.005615	.00003153	.086	.004	.009615	.0000925	980.	2640.	.352	.0095	.008115	.0000658	1307.	3040.	.43
36	.005	.000025	.10845	.004	.009	.0000810	1340.	4070.	.329	.0095	.0075	.0000563	1930.	4730.	.409
37	.004453	.00001983	.1365	.004	.008458	.0000714	1915.	6180.	.309	.0095	.005953	.0000354	3940.	7970.	.494
38	.003965	.00001573	.1725	.004	.007965	.0000635	2715.	9430.	.288	.0095	.005465	.0000299	5770.	13350.	.459
39	.003531	.00001247	.217	.004	.007531	.0000567	3835.	14300.	.27	.0095	.005031	.0000258	8590.	19600.	.438
40	.003145	.000009888	.2741	.004	.007145	.0000511	5360.	21300.	.252	.0095	.004645	.0000216	12690.	30800.	.412

OHMS PER POUND OF INSULATED WIRE COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B & S)	Diam. of Wire, bare	Diam. Insulated with Silk	Diam. Insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01236	.01336	104.5	4.5	12.95
29	.01126			113 95		

Size of Wire B & S Gauge	Diam. in Inches	OHMS, PER POUND						
		Bare @ 68° F	SILK				COTTON	
			SINGLE			DOUBLE	SINGLE	DOUBLE
			1½ mil increase	2 mil increase	3 mil increase	4 mil increase	4 mil increase	8 mil increase
20	.03196	3.278	3.245	3.23	3.21	3.175	3.15	3.02
21	.02846	5.212	5.150	5.125	5.08	5.025	4.97	4.72
22	.02535	8.287	8.17	8.12	8.05	7.96	7.87	7.44
23	.02257	13.18	12.95	12.90	12.78	12.65	12.45	11.7
24	.02010	20.95	20.55	20.45	20.20	19.95	19.65	18.25
25	.01790	33.32	32.65	32.4	31.9	31.5	30.9	28.45
26	.01594	52.97	51.8	51.3	50.5	49.7	48.5	44.3
27	.0142	84.23	82.2	81.4	79.8	78.3	76.5	68.8
28	.01264	123.9	130.	129.	126.	123.5	120.	106.5
29	.01126	213.	206.5	204.	199.	194.	190.5	164.
30	.01003	338.6	326.	322.	318.	306.5	294.5	252.
31	.008928	538.4	516.0	510.	498.	477.	461.	384.5
32	.00795	856.2	817.	808.	775.	747.	717.	585.
33	.00708	1361.	1290.	1265.	1215.	1165.	1115.	880.
34	.006305	2165.	2020.	1995.	1900.	1810.	1715.	1315.
35	.005615	3441.	3210.	3140.	2980.	2820.	2640.	1960.
36	.005	5473.	5070.	4880.	4630.	4340.	4070.	2890.
37	.004453	8702.	7970.	7680.	7180.	6660.	6180.	4230.
38	.003965	13870.	12550.	12100.	11150.	10250.	9490.	6150.
39	.003531	22000.	19600.	18850.	17000.	15600.	14200.	8850.
40	.003145	34980.	30800.	29300.	26400.	23650.	21300.	12500.

COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B & S)	Diameter of Wire (bare)	Diameter insulated with Silk	Diameter insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

JERSEY CITY, July, 1900. R. VARLEY.

WEIGHT OF COPPER IN 100 LBS. OF INSULATED WIRE.

Size of Wire B & S Gauge	SILK				COTTON	
	SINGLE			DOUBLE	SINGLE	DOUBLE
	1½ mil increase	2 mil increase	3 mil increase	4 mil increase	4 mil increase	8 mil increase
20	99.	98.5	97.8	97.	96.2	92.2
21	98.8	98.3	97.5	96.5	95.5	90.8
22	98.6	98.	97.2	96.2	95.	89.8
23	98.4	97.8	96.8	95.8	94.8	88.6
24	98.2	97.7	96.3	95.2	93.7	87.
25	98.	97.2	95.8	94.6	92.8	85.5
26	97.8	97.	95.3	93.8	91.8	83.8
27	97.5	96.7	94.8	93.	90.8	81.7
28	97.2	96.2	94.2	92.2	89.7	79.5
29	96.8	95.7	93.4	91.2	88.5	77.
30	96.3	95.2	92.6	90.6	87.	74.5
31	95.8	94.6	91.7	88.6	85.5	71.3
32	95.4	93.8	90.5	87.3	83.7	68.3
33	94.8	93.	89.25	85.7	81.8	64.7
34	94.2	92.2	87.8	83.7	79.4	61
35	93.4	91.2	86.7	82.2	76.8	57.
36	92.6	89.25	84.7	79.3	74.3	52.8
37	91.6	88.4	82.6	76.7	71.2	48.7
38	90.5	87.2	80.4	73.8	68.	44.4
39	89.2	85.7	77.2	70.8	64.6	40.2
40	88.1	83.8	75.5	67.7	60.8	35.8

COMPUTED FROM THE FOLLOWING DATA:—

Size of Wire (B&S)	Diameter of Wire (bare)	Diameter insulated with Silk	Diameter insulated with Cotton	Weight of Product	Weight of Silk	Weight of Cotton
29	.01126	.01326		104.5	4.5	
29	.01126		.01526	112.95		12.95

JERSEY CITY, July, 1900. R. VARLEY.

Standard Copper Wire Table.

(Copied from the "Supplement to Transactions of American Institute of Electrical Engineers," October, 1893.)

Giving Weights, Lengths, and Resistances of Wires @ 20° C. or 68° F., of Matthiessen's Standard Conductivity, for A. W. G. (Brown & Sharpe).

A.W.G.	DIAMETER	AREA.	WEIGHT.		LENGTH.		RESISTANCE.	
B. & S.	Inches.	Circ'l'r Mils.	Lbs. Per Foot.	Lbs. Per Ohm.	Feet Per Lb.	Feet Per Ohm.	Ohms Per Lb.	Ohms Per Foot.
			.0000030274 x C. M.	.0000002984 x C. M.	$\frac{330330}{C.M.}$	.096585 x C. M.	$\frac{3420000}{C.M.^2}$	$\frac{10.353568}{C.M.}$
0000	0.460	211,600.	0.6405	13,090.	1.561	20,440.	0 00007639	0.00004893
000	0.4096	167,800.	0.5080	8,232.	1.969	16,210.	0.0001215	0 00006170
00	0.3648	133,100.	0.4028	5,177.	2.482	12,850.	0.0001931	0.00007780
0	0.3249	105,500.	0.3195	3,256.	3.130	10,190.	0.0003071	0 00009811
1	0.2893	83,690.	0.2533	2,048.	3.947	8,083.	0.0004883	0.0001237
2	0.2576	66,370.	0.2009	1,288.	4.977	6,410.	0.0007765	0.0001560
3	0.2294	52,630.	0.1593	810.0	6.276	5,084.	0.001235	0.0001967
4	0.2043	41,740.	0.1264	509.4	7.914	4,031.	0.001963	0.0002480
5	0.1819	33,100.	0.1002	320.4	9.980	3,197.	0.003122	0.0003128
6	0.1620	26,250.	0.07946	201.5	12.58	2,535.	0.004963	0.0003944
7	0.1443	20,820.	0.06302	126.7	15.87	2,011.	0.007892	0.0004973
8	0.1285	16,510.	0.04998	79.69	20.01	1,595.	0.01255	0.0006271
9	0.1144	13,090.	0.03963	50.12	25.23	1,265.	0.01995	0.0007908
10	0.1019	10,380.	0.03143	31.52	31.82	1,003.	0.03173	0.0009972
11	0.09074	8,234.	0.02493	19.82	40.12	795.3	0.05045	0.001257
12	0.08081	6,530.	0.01977	12.47	50.59	630.7	0.08022	0.001586
13	0.07196	5,178.	0.01568	7.840	63.79	500.1	0.1276	0.001999
14	0.06408	4,107.	0.01243	4.931	80.44	396.6	0.2028	0.002521
15	0.05707	3,257.	0.009858	3.101	101.4	314.5	0.3225	0.003179
16	0.05082	2,583.	0.007818	1.950	127.9	249.4	0.5128	0.004009
17	0.04526	2,048.	0.006200	1.226	161.3	197.8	0.8153	0.005055
18	0.04030	1,624.	0.004917	0.7713	203.4	156.9	1.296	0.006374
19	0.03589	1,288.	0.003899	0.4851	256.5	124.4	2.061	0.008038
20	0.03196	1,022.	0.003092	0.3051	323.4	98.66	3.278	0.01014
21	0.02846	810.1	0.002452	0.1919	407.8	78.24	5.212	0.01278
22	0.02535	642.4	0.001945	0.1207	514.2	62.05	8.287	0.01612
23	0.02257	509.5	0.001542	0.07589	648.4	49.21	13.18	0.02032
24	0.02010	404.0	0.001223	0.04773	817.6	39.02	20.95	0.02563
25	0.01790	320.4	0.0009699	0.03002	1,031.	30.95	33.32	0.03231
26	0.01594	254.1	0.0007692	0.01888	1,300.	24.54	52.97	0.04075
27	0.0142	201.5	0.0006100	0.01187	1,639.	19.46	84.23	0.05138
28	0.01264	159.8	0.0004837	0.007466	2,067.	15.43	133.9	0.06479
29	0.01126	126.7	0.0003836	0.004696	2,607.	12.24	213.0	0.08170
30	0 01003	100.5	0.0003042	0.002953	3,287.	9.707	338.6	0.1030
31	0 008928	79.70	0.0002413	0.001857	4,145.	7.698	538.4	0.1299
32	0 007950	63.21	0.0001913	0.001168	5,227.	6.105	856.2	0.1638
33	0 007080	50.13	0.0001517	0.0007346	6,591.	4.841	1,361.	0.2066
34	0 003305	39.75	0.0001203	0.0004620	8,311.	3.839	2,165.	0.2605
35	0 005615	31.52	0 00009543	0.0002905	10,480.	3.045	3,441.	0.3284
36	0.0050	25.0	0 00007568	0.0001827	13,210.	2.414	5,473.	0.4142
37	0 004453	19.83	0 00006001	0.0001149	16,660.	1.915	8,702.	0.5222
38	0 003965	15.72	0 00004759	0 00007210	21,010.	1.519	13,870.	0.6585
39	0 003531	12.47	0 00003774	0 00004545	26,500.	1.204	22,000.	0.8304
40	0 003145	9.888	0 00002993	0 00002858	33,410.	0.9550	34,980.	1.047

[For Explanatory Remarks on this Table, see opposite page.]

EXPLANATION OF TABLE.

The data from which this table has been computed are as follows:—Matthiessen's standard resistivity, Matthiessen's temperature coefficients, specific gravity of copper = 8.89. Resistance in terms of the international ohm.

Matthiesson's standard 1 metre-gramme of hard drawn copper = 0.1469 B. A. U. @ 0° C. Ratio of resistivity hard to soft copper 1.0226.

Matthiesson's standard 1 metre-gramme of soft drawn copper = 0.14365 B. A. U. @ 0° C. One B. A. U. = 0.9866 international ohms.

Matthiesson's standard 1 metre-gramme soft drawn copper = 0.141729 international ohm @ 0° C.

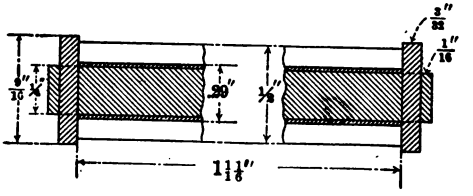
Temperature coefficients of resistance for 20° C., 50° C., and 80° C., 1.07968, 1.20625, and 1.33681 respectively. 1 foot = 0.3048028 metre, 1 pound = 453.59256 grammes.

Although the entries in the table are carried to the fourth significant digit, the computations have been carried to at least five figures. The last digit is therefore correct to within half a unit, representing an arithmetical degree of accuracy of at least one part in two thousand. The diameters of the B. & S. or A. W. G. wires are obtained from the geometrical series in which No. 0000 = 0.4600 inch and No. 36 = 0.005 inch, the nearest fourth significant digit being retained in the areas and diameters so deduced.

It is to be observed that while Matthiesson's standard of resistivity may be permanently recognized, the temperature coefficient of its variation which he introduced, and which is here used may in future undergo slight revision.

F. B. CROCKER, W. E. GEYER,
G. A. HAMILTON, A. E. KENNELLY, Chairman,
Committee on "Units and Standards."

EXAMPLE No. 1.



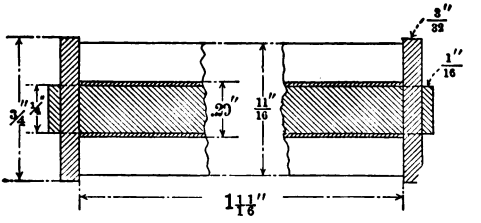
Wire No. 30 S. S. C.

$$\rho = \frac{171.6 \times 1.6875 \times (.5^2 - .29^2)}{4}$$

$$= 12 + \text{Ohms.} \quad \text{(Answer).}$$

EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 d^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{R (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

EXAMPLE No. 2.



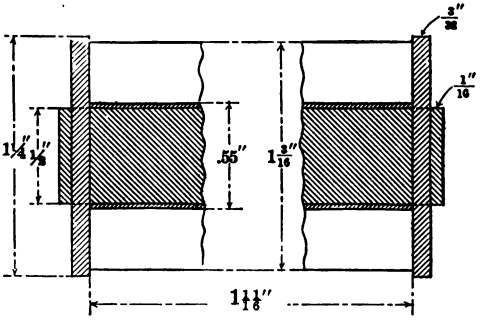
Wire No. 35 S. S. C.

$$N = \frac{1.6875\,(.6875 - .29)}{2 \times .0000658}$$

= 5100 Turns. (Answer).

EXAMPLE 1. Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2. " Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 d^2}$	"	85
3. " Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4. " Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5. " Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6. " Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7. " Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8. " Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9. " Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{K (D + d)}$	"	99
10. " Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11. " Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12. " Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13. " Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14. " Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15. " D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16. " D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17. " D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

EXAMPLE No. 12.



Volts 20.

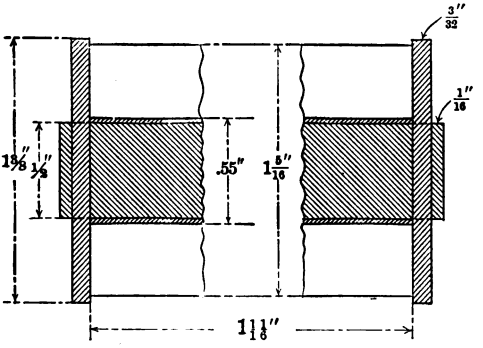
Insulation .004".

$$\Delta = \sqrt{\left(\sqrt{\frac{.0000000271 \times \pi \times 1.1875 \times 1.6875^2 (1.1875^2 - .55^2)}{4 \times 20^2}} + \frac{.004^2}{4}\right)} - \frac{.004}{2}$$

$$= .01'' \quad \text{(Answer).}$$

$$= \text{to No. 30 Wire.}$$

EXAMPLE 13.



Wire No. 30.

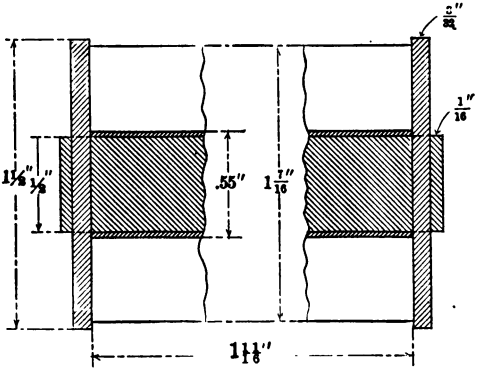
Resistance 75 Ohms.

$$i = \sqrt{\frac{.00000271 \times 1.6875\,(1.3125^2 - .55^2)}{4 \times 75 \times .01^2}} - .01$$

$$= .0047'' \text{ (Answer).}$$

EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 d^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^4 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

EXAMPLE No. 14.



Wire No. 22.

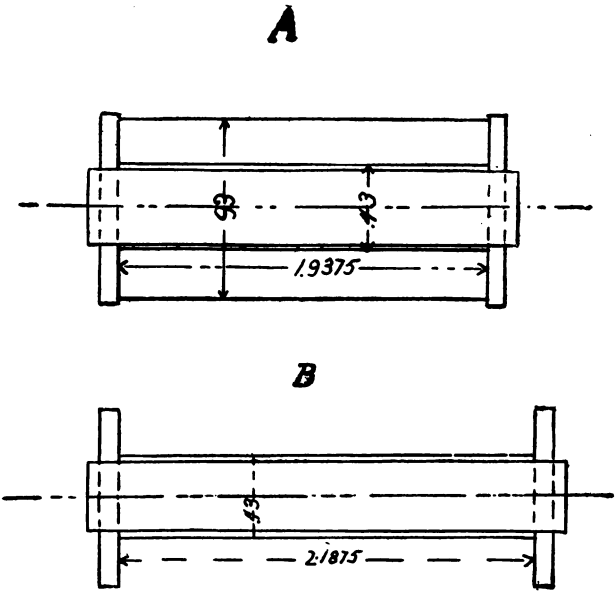
Volts 5.

$$i = \sqrt{\frac{.0000271 \times \pi \times 1.4375 \times 1.6875^2 (1.4375^2 - .55^2)}{4 \times 5^2 \times .02535^2}} \quad .02535$$

$$= .0056'' \quad \text{(Answer).}$$

EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 g^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{K (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right) - \frac{i}{2}}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D_1 d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D_1 d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D_1 d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

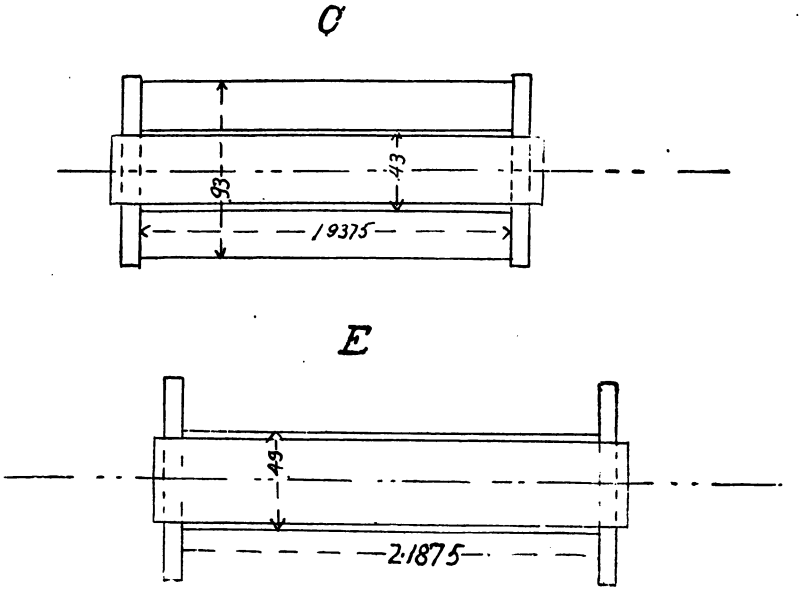
EXAMPLE No. 15.



$$D_1 = \sqrt{.43^2 + (.93^2 - .43^2)\ \frac{1.9375}{2.1875}}$$

$$= .8875'' \quad \text{(Answer).}$$

EXAMPLE No. 16.

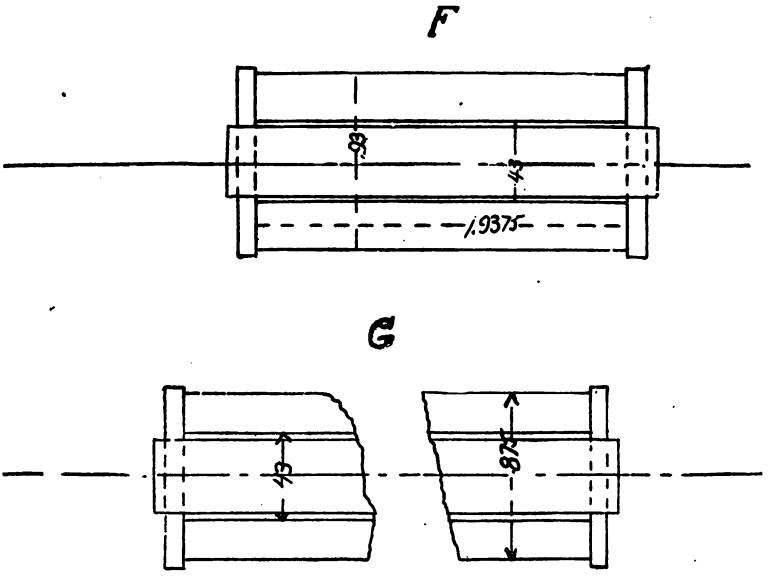


$$D_1 = \sqrt{\cdot 49^2 + (93^2 - 43^2)\ \frac{1.9375}{2.1875}}$$

$$= .918'' \quad \text{(Answer).}$$

EXAMPLE 1.	Given Bobbin and Wire, find Resistance	$\rho = \frac{R L (D^2 - d^2)}{4}$	See page	83
2.	" Bobbin and Wire, find Turns	$N = \frac{L (D - d)}{2 d^2}$	"	85
3.	" Core, Length, Wire and Resistance, find Diameter	$D = \sqrt{\frac{4 \rho}{R L} + d^2}$	"	87
4.	" Bobbin and Resistance, find Wire	$R = \frac{4 \rho}{L (D^2 - d^2)}$	"	89
5.	" Core, Insulated Wire, Diameter and Resistance, find Length	$L = \frac{4 \rho}{R (D^2 - d^2)}$	"	91
6.	" Bobbin and Voltage, find Wire	$R = \frac{4 E^2}{\pi D L^2 (D^2 - d^2)}$	"	93
7.	" Diameter, Length and Voltage, find Resistance	$\rho = \frac{E^2}{\pi D L}$	"	95
8.	" Bobbin, Voltage and Wire, find Current	$I = \frac{4 E}{R L (D^2 - d^2)}$	"	97
9.	" Core, Diameter Voltage and Wire, find Ampere Turns	$IN = \frac{2 E}{R (D + d)}$	"	99
10.	" Bobbin and Wire, find Voltage	$E = \sqrt{\frac{\pi R D L^2 (D^2 - d^2)}{4}}$	"	101
11.	" Bobbin, Resistance and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c L (D^2 - d^2)}{4 \rho}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	103
12.	" Bobbin, Voltage and Insulation, find Bare Wire	$\Delta = \sqrt{\left(\sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2}} + \frac{i^2}{4}\right)} - \frac{i}{2}$	"	105
13.	" Bobbin, Resistance and Bare Wire, find Insulation	$i = \sqrt{\frac{c L (D^2 - d^2)}{4 \rho \Delta^2}} - \Delta$	"	107
14.	" Bobbin, Voltage and Bare Wire, find Insulation	$i = \sqrt{\frac{c \pi D L^2 (D^2 - d^2)}{4 E^2 \Delta^2}} - \Delta$	"	109
15.	" D, d and L of bobbin A, find D_1 of bobbin B, d equal d_1, L_1 given winding volumes equal	$D_1 = \sqrt{d^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	111
16.	" D, d and L of bobbin C, find D_1 of bobbin E, L_1 and d_1 given winding volumes equal	$D_1 = \sqrt{d_1^2 + (D^2 - d^2) \frac{L}{L_1}}$	"	113
17.	" D, d and L of bobbin F, find L_1 of bobbin G, D_1 given and d_1 equal to d, winding volumes equal	$L_1 = \frac{L (D^2 - d^2)}{D_1^2 - d_1^2}$	"	115

EXAMPLE No. 17.

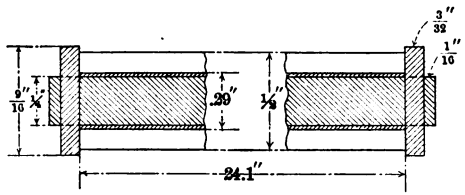


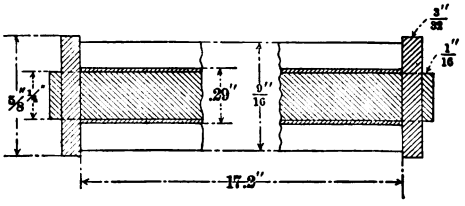
$$L_1 = \frac{(.93^2 - .43^2)\ 1.9375}{.875^2 - .43^2}$$

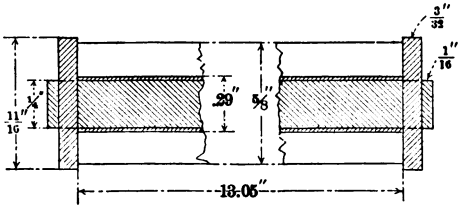
$$= 2.27'' \quad \text{(Answer).}$$

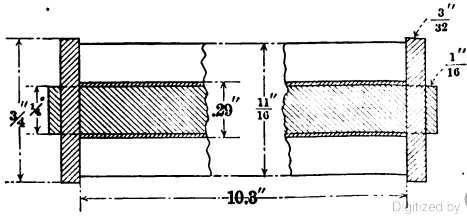
The following line drawings show nearly all sizes of Telegraph and Telephone magnet bobbins. Six sizes of cores are given, also various sizes of washers. The diameter to wind to, is usually $\frac{1}{16}''$ less than the diameter of the washer. The diameter to wind on is the outside diameter of the paper sleeve which is wrapped around the core. The cuts are shown full size in all dimensions except length. The actual numerical value for length is given which would make M x L x T equal to unity in each case. The values of R and W are equal to the Resistance and Weight of the winding when that size wire opposite said values is used.

The resistance in ohms and weight in lbs. of wire contained in each bobbin will vary directly as the length between washers other things remaining constant. If it is desired to know the resistance for any winding length other than that indicated in the drawing, the desired resistance will bear the same ratio to the value R as the desired Length bears to the Length indicated in the drawing.









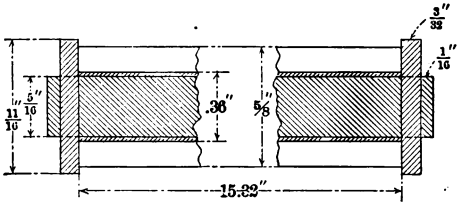
SIZE OF WIRE B. & S. GAUGE.

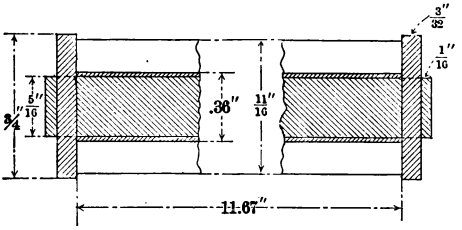
These bobbins, wound with ar. wire indicated in first column, will contain that resistance shown in columns R.

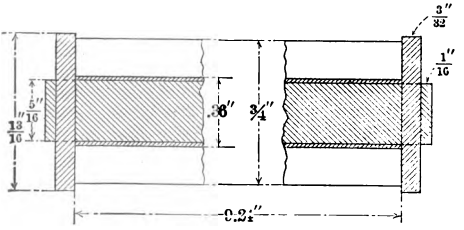
Columns W indicate the weight of wire in pounds.

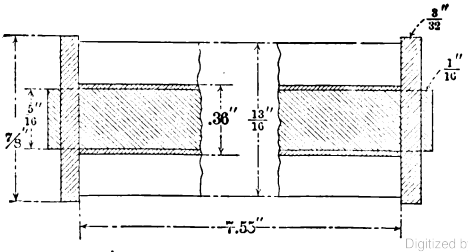
The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.636		
16	.308	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.235	.606
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.663
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	208.5	.441	260.5	.518
32	299.8	.418	398.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	980.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3685.	.27	8590.	.436
40	5960.	.252	13690.	.413







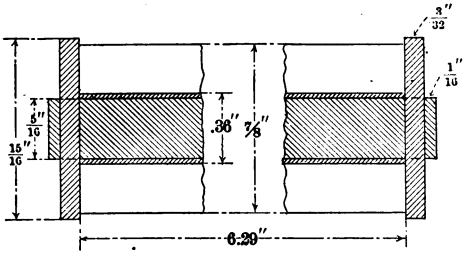


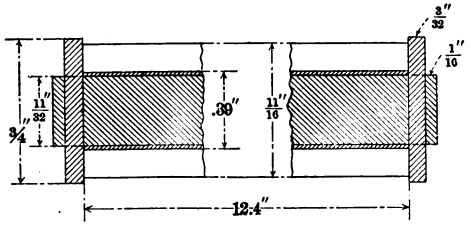
These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

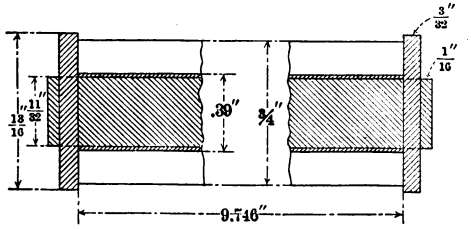
Columns W indicate the weight of wire in pounds.

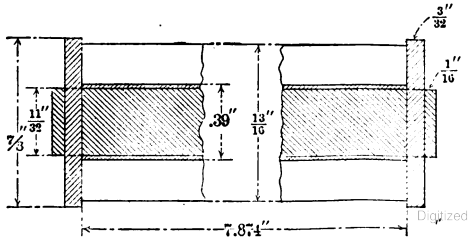
The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.285	.690
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.663
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.516
32	299.8	.418	393.	.496
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3885.	.27	8590.	.436
40	5900.	.253	13090.	.412









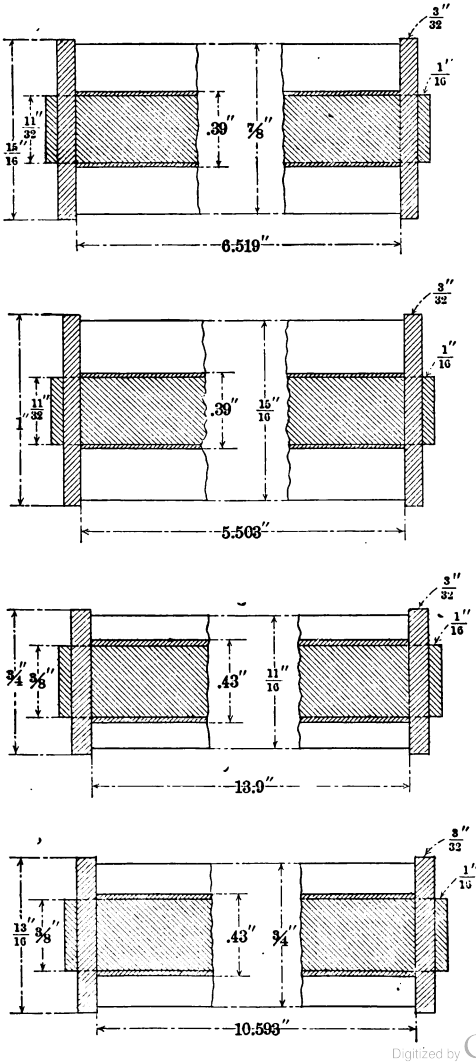
These bobbins, wound with ar[illegible] wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.

	COTTON.		SILK.	
	R	W	R	W
10	.02135	.7		
11	.03375	.689		
12	.0537	.675		
13	.0816	.665		
14	.127	.651		
15	.1965	.638		
16	.308	.631		
17	.467	.608		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.235	.696
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3885.	.27	8590.	.436
40	5800.	.252	12690.	.413

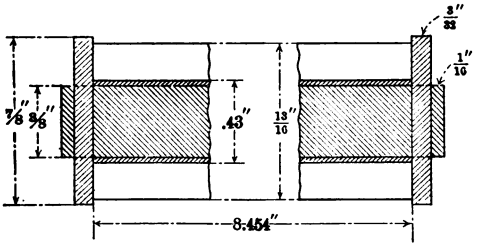


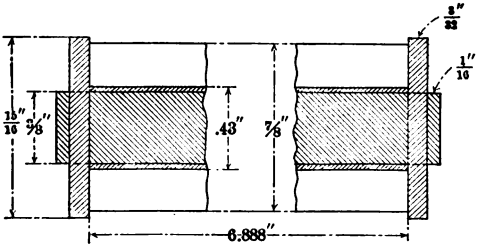
These bobbins, wound with ar wire indicated in first column, wi.. contain that resistance shown in columns R.

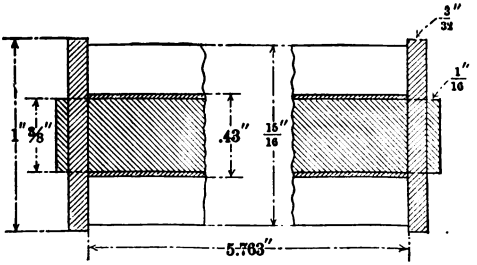
Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 75 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0618	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.235	.606
21	3.18	.64	3.49	.585
22	4.895	.622	5.43	.572
23	7.55	.606	8.43	.562
24	11.56	.59	13.1	.545
25	17.66	.572	20.3	.531
26	26.86	.554	31.4	.517
27	40.5	.539	48.2	.507
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	208.5	.441	260.5	.518
32	299.8	.418	398.	.496
33	439.5	.394	589.	.517
34	643	.375	890	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8390.	.436
40	5360.	.253	12690.	.412





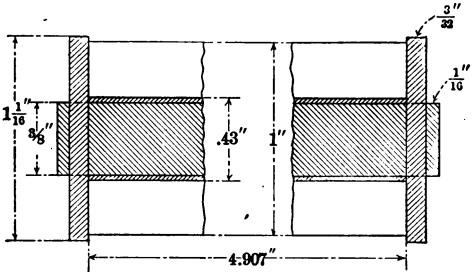


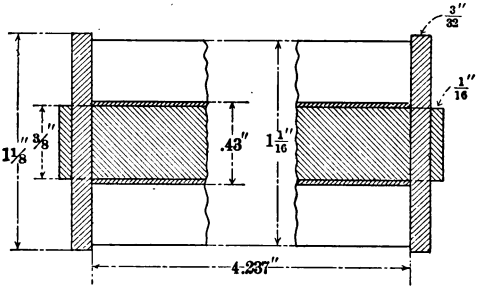
These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

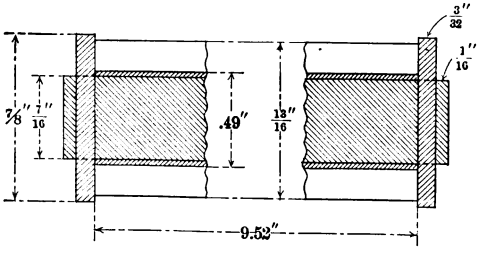
Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.03158	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.636		
16	.303	.631		
17	.467	.609		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.285	.695
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.673
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.3	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.496
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1919.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5366.	.253	12690.	.413





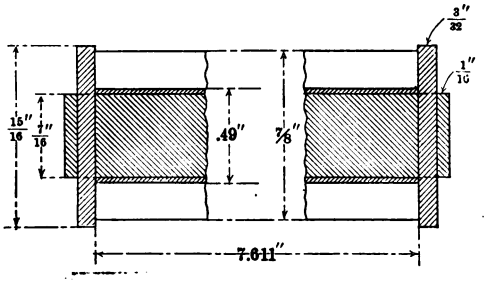


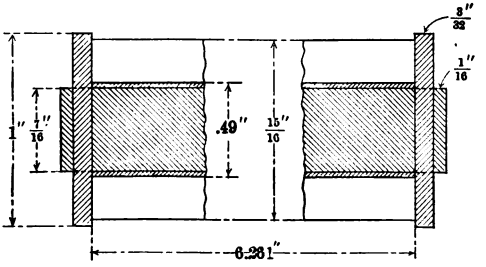
These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

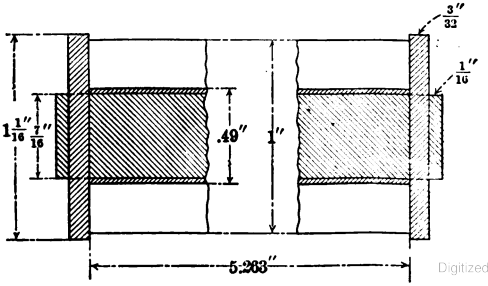
Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.235	.695
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.673
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.573	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.9	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	208.5	.441	260.5	.518
32	299.8	.418	398.	.496
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3886.	.27	8590.	.436
40	5860.	.253	13690.	.413





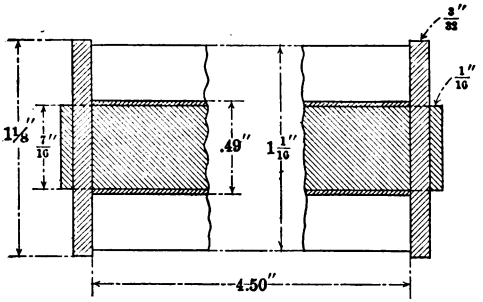


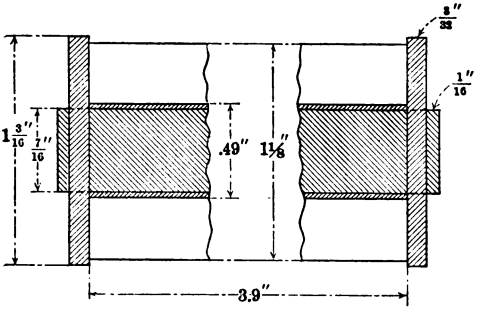
These bobbins, wound with a wire indicated in first column, will contain that resistance shown in columns R.

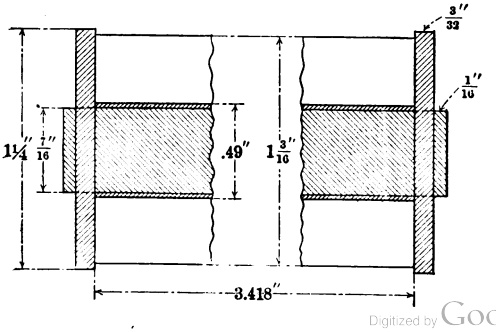
Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.09155	.7		
11	.03375	.689		
12	.0637	.675		
13	.0618	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.608		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.235	.696
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.561
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	208.5	.441	260.5	.516
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5366.	.252	12660.	.412





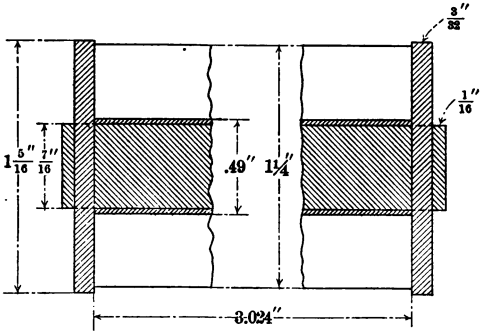


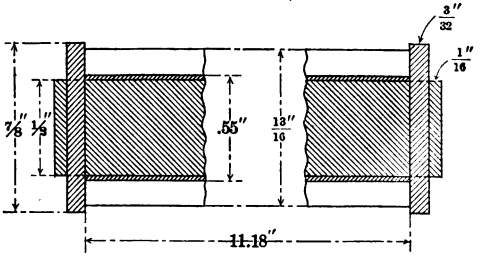
These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

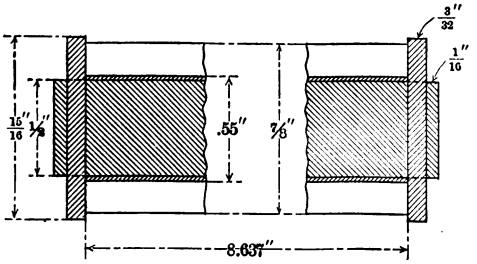
Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.02375	.689		
12	.0537	.675		
13	.0618	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.576		
20	2.05	.65	2.235	.696
21	3.19	.64	3.49	.655
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.663
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.6	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	398.	.496
33	439.5	.394	599.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.464
38	2715.	.286	5770.	.436
39	3885.	.27	8590.	.426
40	5360.	.253	12690.	.413







These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.

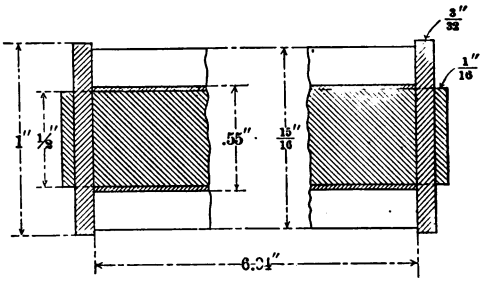
	COTTON.		SILK.	
	R	W	R	W
10	.02156	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.631		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.225	.695
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.561
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	398.	.496
33	439.5	.394	589.	.517
34	648	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12690.	.413

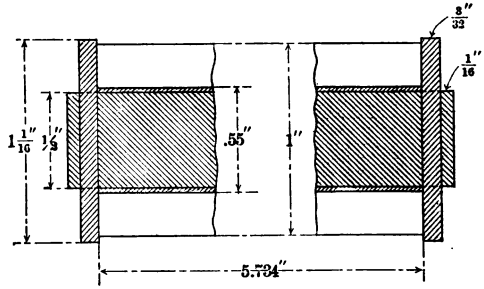
These bobbins, wound with ar. wire indicated in first column, will contain that resistance shown in columns R.

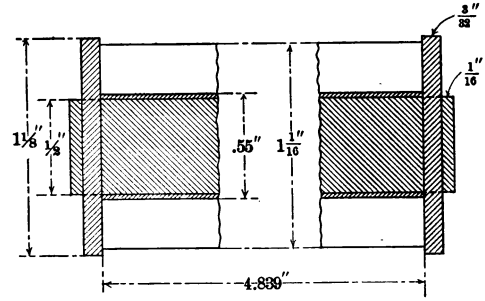
Columns W indicate the weight of wire in pounds.

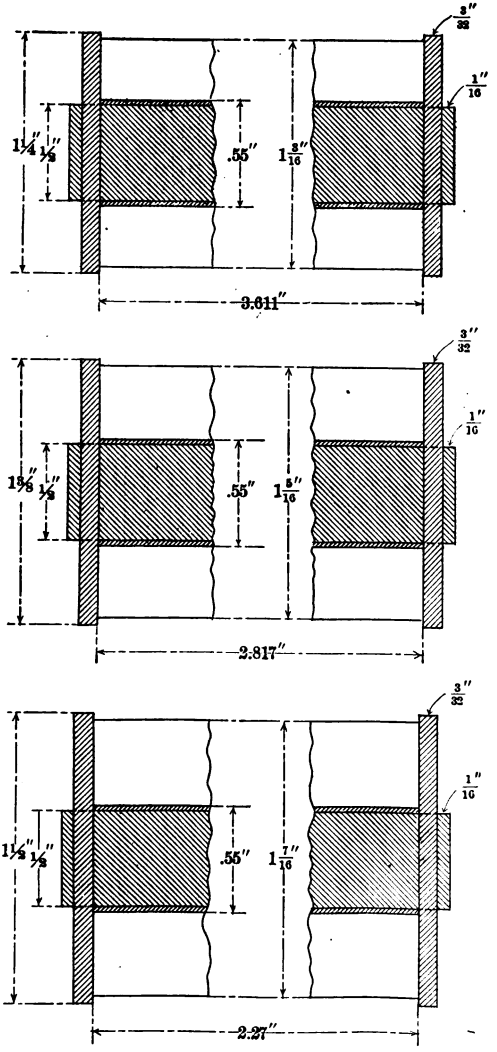
The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.689		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.638		
16	.303	.621		
17	.467	.608		
18	.713	.588		
19	1.0925	.570		
20	2.05	.65	2.235	.695
21	3.18	.64	3.49	.685
22	4.893	.622	5.43	.672
23	7.55	.606	8.48	.662
24	11.56	.59	13.1	.645
25	17.66	.572	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.518
32	299.8	.418	393.	.498
33	439.5	.394	589.	.517
34	643	.375	880	.453
35	930.	.352	1307	.43
36	1340.	.329	1930.	.409
37	1912.	.309	3860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.252	12890.	.413









These bobbins, wound with ar wire indicated in first column, will contain that resistance shown in columns R.

Columns W indicate the weight of wire in pounds.

The assumed allowance for insulation is shown in table on page 76 from which table the values R and W are taken Temp 68° Fahr.

SIZE OF WIRE B. & S. GAUGE.	COTTON.		SILK.	
	R	W	R	W
10	.02155	.7		
11	.03375	.699		
12	.0537	.675		
13	.0818	.665		
14	.127	.651		
15	.1965	.636		
16	.303	.621		
17	.467	.606		
18	.713	.586		
19	1.0925	.570		
20	2.05	.65	2.235	.696
21	3.18	.64	3.49	.685
22	4.895	.622	5.43	.672
23	7.55	.606	8.48	.663
24	11.56	.59	13.1	.645
25	17.66	.573	20.3	.631
26	26.86	.554	31.4	.617
27	40.5	.530	48.2	.597
28	61.2	.510	74.	.581
29	91.8	.482	112.8	.56
30	136.8	.464	171.6	.539
31	203.5	.441	260.5	.516
32	299.8	.418	393.	.496
33	439.5	.394	589.	.517
34	643	.375	880	.452
35	930.	.352	1307	.43
36	1340.	.329	1950.	.402
37	1912.	.309	2860.	.484
38	2715.	.288	5770.	.459
39	3835.	.27	8590.	.438
40	5360.	.253	12690.	.413

LOGARITHMS OF NUMBERS.

Natural Numbers.	0	1	2	3	4	5	6	7	8	9	Proportional Parts. 1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

Natural Numbers.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.								
											1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ANTILOGARITHMS.

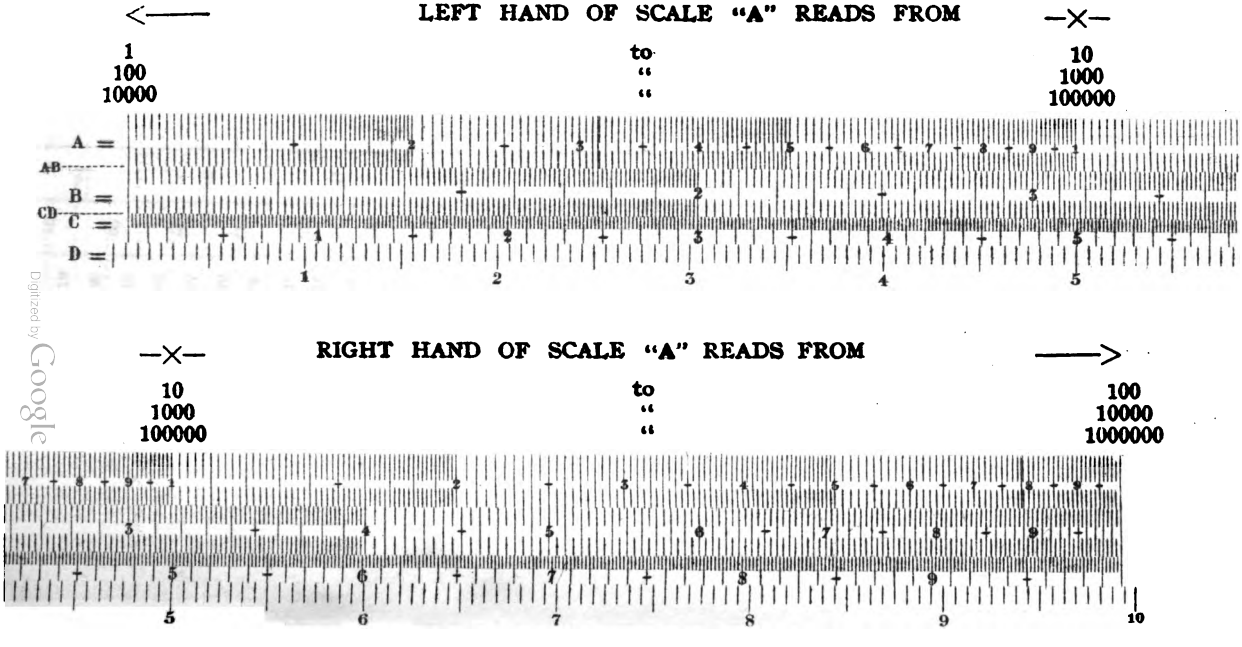
Logarithms.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.							
											1	2	3	4	5	6	7	8	9
.00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
.01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
.02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
.03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
.04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
.05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
.06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
.07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
.08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
.09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
.10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
.11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
.12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
.13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
.14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
.15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
.16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
.17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
.18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
.19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
.20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
.21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3
.22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
.23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
.24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
.25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
.26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
.27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
.28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
.29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
.30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
.31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
.32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
.33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
.34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
.35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
.36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
.37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
.38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
.39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
.40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
.41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
.42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
.43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
.44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
.45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
.46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
.47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	2	3	3	4	5	5	6
.48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
.49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

ANTILOGARITHMS.

Logarithms.	0	1	2	3	4	5	6	7	8	9	Proportional Parts.							
											1	2	3	4	5	6	7	8	9
.50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
.51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
.52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
.53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
.54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
.55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
.56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
.57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
.58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
.59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
.60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
.61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
.62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
.63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
.64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
.65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
.66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
.67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
.68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
.69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
.70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
.71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11
.72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
.73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
.74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
.75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
.76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
.77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
.78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
.79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
.80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
.81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
.82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
.83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
.84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
.85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
.86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
.87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	3	5	7	9	10	12	14	16
.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

8ths.	16ths.	32ds.	64ths.	Decimal Equivalent
			1..	.015625
		1..	.....	.03125
			3..	.046875
	1..	.....	.....	.0625
			5..	.078125
		3..	.....	.09375
			7..	.109375
1	.....	.....	.....	.125
			9..	.140625
		5	.....	.15625
			11..	.171875
	3.	.....	.....	.1875
			13..	.203125
		7..	.....	.21875
			15..	.234375
	.....	.....	.....	.25
			17..	.265625
		9..	.....	.28125
			19..	.296875
	5	.....	.....	.3125
			21..	.328125
		11..	.....	.34375
			23..	.359375
3.	.....	.....	.....	.375
			25..	.390625
		13..	.....	.40625
			27..	.421875
	7	.....	.....	.4375
			29..	.453125
		15..	.....	.46875
			31..	.484375
	.....	.....	.....	.500000
			33..	.515625
		17..	.....	.53125
			35..	.546875
	9..	.....	.....	.5625
			37	.578125
		19..	.....	.59375
			39	.609375
5	.....	.....	.....	.625
			41..	.640625
		21..	.....	.65625
			43..	.671875
	11..	.....	.....	.6875
			45..	.703125
		23..	.....	.71875
			47..	.734375
	.....	.....	.....	.75
			49..	.765625
		25..	.....	.78125
			51..	.796875
	13..	.....	.....	.8125
			53..	.828125
		27..	.....	.84375
			55..	.859375
7..	.....	.....	.....	.875
			57..	.890625
		29..	.....	.90625
			59..	.921875
	15..	.....	.....	.9375
			61..	.953125
		31..	.....	.96875
			63..	.984375

This logarithmic scale gives the squares, cubes, square roots, cube roots and the logarithms of all numbers from one to infinity. With the assistance of the logarithms any root or power of any number can immediately be found.



Referring to line A B all numbers above are the squares of the numbers immediately below.

All numbers below are the square roots of the numbers immediately above.

Referring to line C D, all numbers below, in scale C are mantissas of the logarithms of the numbers above, in scale B, i. e., the mantissa of the logarithm is shown immediately below the numbers of scale B; the characteristic being found in the regular way.

Scale D is simply the rule divided into sixteenths of an inch.

To get the square and square root of any number:

Select any number in scale B, call the number 4. This number 4 is immediately under 16 in scale A, and 4 is the square root of 16.

Find 25 in scale B, then 25 times 25 is 625, which value in left hand of scale A is immediately above the 25 of scale B. It also follows that 25 is the square root of 625. If 25 is the square root of 625, 2.5 is the square root also of 6.25 and 250 is the square root of 62500. But to get the square roots of .625, 62.5 and 6250, these values are found on the right hand of scale A, in scale B between 6 and 7, the answer being .79+, 7.9+ and 79+ respectively.

A little practice will enable the operator to locate the decimal point. It will be observed that scale A runs from left hand, commencing at 1, the middle of the scale being 10. The extreme right hand end of the scale being 100. The left hand of scale A therefore reads from 1 to 10 or 100 to 1000 or 10000 to 100000. The right hand of scale A reads from 10 to 100, from 1000 to 10000 and from 100000 to 1000000. This will explain the reason for finding the square root of 6.25, 625 and 62500 immediately under line AB, left hand of scale A, whereas the square root of .625, 62.5 and 6250 will be found under the line AB, right hand of scale A in scale B.

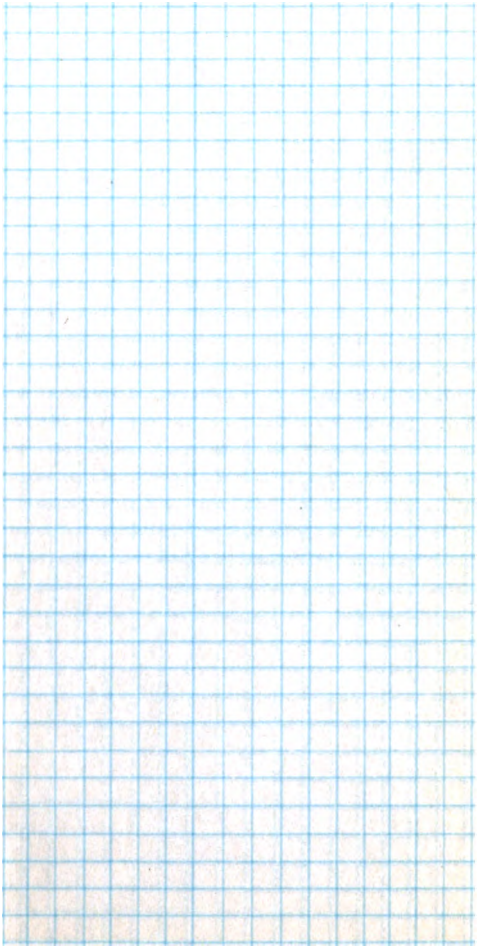
To find the cube root of any number:

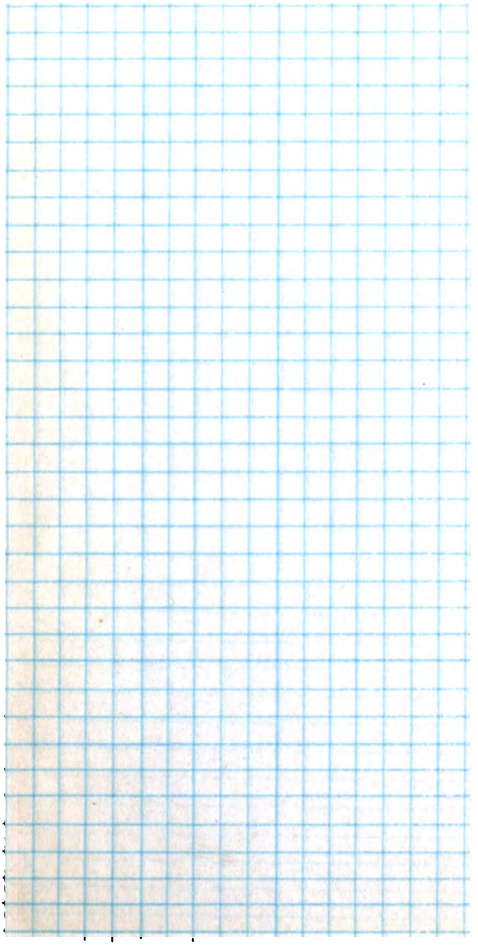
Select the number from scale B. Take for instance number 27: first put down the characteristic of the logarithm, which is 1, the mantissa is immediately under 27 in scale C under the line CD. This mantissa is .431, therefore the logarithm of 27 is 1.431; dividing this value by 3 we get .477. Find value .477 in scale C located along the line CD; immediately above .477 we find 3 in scale B, which is the number required or the cube root of 27. We will next take the number 270; the characteristic will be 2. Get the mantissa the same as that of 27, viz., .431; hence the logarithm of 270 is 2.431, and dividing this logarithm by 3 we get the logarithm of the cube root of 270, or .81; then looking along the line CD in scale C find .81 and immediately above .81 is 6.45+ in scale B, which is the cube root of 270. The decimal point in the answer being fixed by the characteristic, hence the characteristic being zero the answer is 6 45 plus. To get the 4th, 5th, 6th and 7th root the logarithm is divided by 4, 5, 6 and 7 respectively.

See also

C.R. Underhill "Elec. World" Dec. 21st 1907

" " " - Jan 1909





was found to be an additional "flattening out" of the insul

was found to be an additional "flattening out" of the insu-