Chapter V

HOW TO MAKE MAGNETS

This chapter is for the boy who likes to work with his head as well as with his hands. It may be a little harder to understand than what is found in the previous chapters, but a mastery of it will give a working knowledge of the design and manufacture of magnets.

PERMANENT MAGNETS

Bar Magnets—Any bar of steel can be magnetized by the methods explained previously, but to get a combination of a strong pull and a permanent quality of the magnetism it has been found best to use special steel.

Dealers in hardware and metals can get this for you from the manufacturers. The manufacturers usually supply the best grade of crucible tungsten steel, which has in it approximately 5 per cent of tungsten, a small amount of the metals chromium and manganese and about .65 per cent carbon. It is interesting to note that our home-made steel of this quality seems equal or better than any of the imported kinds.

A magnet made with this steel will hold the most of its magnetism as long as you will have any use for it.

When you make a bar magnet, select a piece of steel long and thin. It can be either round, square or oblong on the ends. A good proportion of square steel bar for experimental work is 4 inches long; the end dimensions are ¼ inch wide x ¼ inch high.

If the piece is round and ¼ of an inch in diameter, it is suitable. These dimensions are but a suggestion and you can vary them to suit your pleasure.

The next thing to do after you have the steel bar is to harden it. The best way to do this is to take the piece to the blacksmith or a manufacturer who has a steel hardening and tempering room in his factory. Ask him to heat the piece to 850 degrees centigrade, after

which he must quench it in pure running water which has a temperature of from 55 to 60 degrees Fahrenheit. If you are unable to have this done for you, you can try hardening it yourself by the following method. Put it in your gas or coal fire and heat it until it turns a bright red. Be sure that the whole piece has turned to the required color. If part of it is dark, it shows that the bar is heated unevenly, and the result will be that the temper will also be unequal. Have a pail of clean water near at hand. When the bar shows the bright red color, take it from the fire with a pair of long-handled tongs; fireplace tongs will do very well.

Plunge the steel bar into the water, but keep hold of it with your tongs. Keep it moving up and down and around in the water until it is cooled down enough so that you can hold it in your hand safely. This should make the bar as hard as glass and very brittle. For ordinary magnets this is what is desired.

For long, thin magnets, which are more than twenty times as long as they are thick, it has been found that a more complicated process is required.

It has long been known that if rods of steel are heated a brilliant red and then quenched, as already mentioned, in water, oil or mercury, they are made very, very hard.

By gently reheating the steel, it will soften a little and turn to a straw color. If still reheated, it will take on a blue shade and also becomes springy and flexible. To be sure of making this long magnet permanent, it should be tempered to either the straw color or the blue.

To any one not familiar with hardening and tempering of steel this process may seem altogether too difficult, and for them it will be much better to buy the magnet steel all hardened rather than try to make it.

The next step is to boil the magnet in water for twenty to thirty hours, after which it is ready to be magnetized. This should be done with an electro-magnet. The writer has seen a very good electro-magnet for this purpose made by using a 5-pound spool of insulated copper wire just as it comes from the manufacturers. For example, a 5-pound spool of No. 19 Brown & Sharpe cotton covered wire can be used. This usually comes on spools about 4 inches high, with ends 5 inches in diameter. The hole through the spool is ⅝ of an inch in diameter.

To make an electro-magnet of the material mentioned, place a round rod of soft steel or iron in the center hole of the spool, about 6 to 7 inches long, and make it fit tightly in the hole. Clean the ends of the wire and connect them to a direct current source of electricity having a voltage of 90 to 110 volts. Be sure to insulate the joints, connecting the wires of the spool to the outside wire so that you will not short circuit the supply circuit or do any damage to it.

Turn on the current and your magnetizer is ready for use. Touch the end of your steel bar, which is to be made into a magnet, to the end of the soft steel in the center hole of the coil. Leave it there for a minute and then turn off the current. You now have a good permanent bar magnet which will hold its magnetism for a long while. If, however, you want to improve further its lasting quality it will be well to leave it in boiling water for five hours.

If you live near an electrical contractor or dealer in electrical supplies, you can, no doubt, borrow the spool of wire from him long enough to magnetize your bar, since you do not harm or waste any of the wire. Or if you have friends who work in an electrical power house you can get them to touch the bar against a field pole of one of the generators or magnetize it for you in any other of the many ways, which they—the power house men—have at their disposal.

If you are so situated that none of the above methods are at your disposal, you can make an electro-magnet which will operate on 4 dry cells or a 6 volt storage battery, such as used on many automobiles. This will be described under the design of electro-magnets.

HORSESHOE MAGNETS

Horseshoe magnets are simply bar magnets bent into a "U" shape so that the opposite poles are brought near each other. This permits both poles to act on the same piece of metal.

Therefore, to make a horseshoe magnet, or a magnet of any shape other than straight, first heat the steel and bend it into shape. If you desire to put screw holes in it for fastening it to anything, do so after bending. The other operations are then just the same as those used for making the bar magnet.

Remember what was stated in a previous chapter that permanent magnets lose their power if roughly used, so do not hit or throw them about any more than you can help. This is especially true of newly made magnets.

Horseshoe magnets are supplied with a small piece of soft iron or steel called a "Keeper," which is put across the poles when the magnet is not in use. Every time this is slammed against the poles it weakens the magnetism, but it strengthens the magnet to remove the "Keeper" with a sudden jerk.

Keep these points in mind or you may, by carelessly handling your magnet, spoil it and lose all the work you spent in making it.

ELECTRO-MAGNET DESIGN

(SEE FIG. 88)

Before explaining the design of electro-magnets it is necessary that you understand the working principle of current electricity and the standard practice used in making the measurement (see Table B, page 103) of copper wire in addition to the theory of electro-magnets.

(1) **Strength of a Magnet**—This is a term quite different in meaning from lifting power. It is the force of magnetism of one magnet which acts at a distance on other magnets.

(2) **Lifting Power**—The lifting power of a magnet depends on the shape of the magnet and, also, its magnetic strength. A

horseshoe magnet will lift three or four times as much as a bar magnet. A long bar magnet can lift more than a short bar magnet, though each is of equal magnetic strength. Curiously enough, a magnet can be loaded to the limit one day and left in that condition. The next day you will find that you can add a little more to the load, and perhaps for several days you can, little by little, increase the weight until it is considerably larger than what the limit was at the first day.

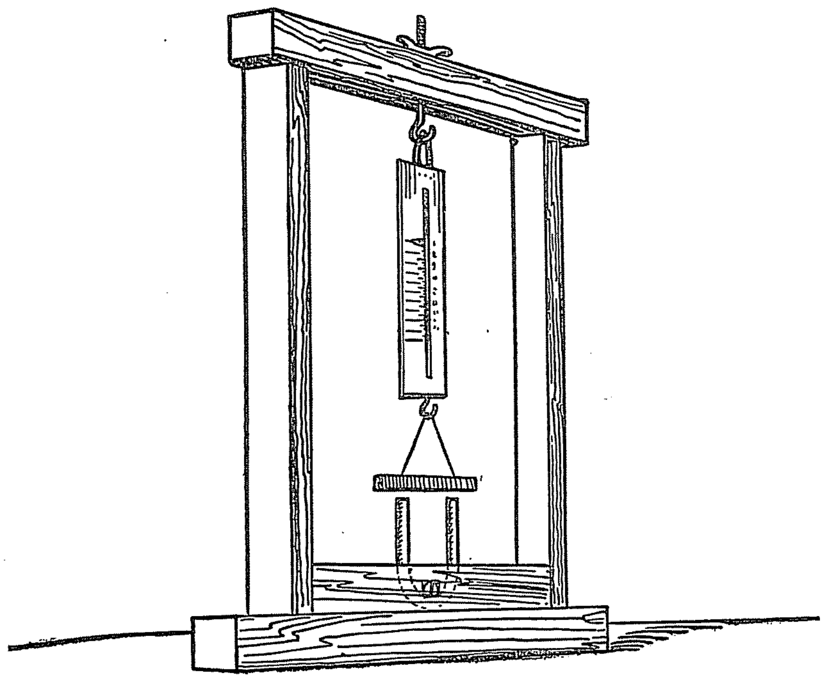

FIG. 87

But if the entire load (often called armature) is torn off, the lifting power at once falls to the limit found on the first day.

If you care to test the lifting power of a magnet, a device similar to that shown in Figure 87 can be used. This shows a magnet fastened securely to a wooden base. From the base is extended an upright, which has a cross bar directly over the top and some distance above the poles of the magnet. Through the cross bar is a screw hook in a hole large enough so that the hook can be moved up or down. The screw end of the hook is extended up through the cross bar, and a thumb nut holds it in place and also is used to adjust the height. Hang a spring balance on the hook and suspend a bar of iron on the balance. Adjust the height of the balance so that the bar is attracted to and touches the poles of the magnet. Now turn the thumb nut until the spring balance is trying to pull the armature (iron bar) away from the magnet; yet the latter has just strength enough to prevent the armature from leaving the poles. Read the pull in pounds as shown on the scale of the balance and you will find the maximum lifting power of the magnet.

The picture shows a horseshoe magnet, but the same method can be used for magnets of any type or form.

ELECTRIC UNITS

Definitions

(3) Force is the cause of movement—that is pulling or pushing ability.

(4) Work is Force moved over a distance and is spoken of as foot pounds or inch pounds, which means that a certain number of pounds are moved over a distance measured in inches or feet.

(5) Power is the completion of a certain amount of work in a given time. Thus, a horsepower is estimated as being equal to 33,000 foot pounds per minute or 550 foot pounds per second.

(6) Electro Motive Force. This is often represented by the letter "E" for the sake of brevity. The practical unit of this force is the volt.

(7) Current. This is the rate at which the electricity passes any point in the circuit and the practical unit is called the ampere, and is represented by the letter "I".

(8) Resistance. Just as water flowing from place to place meets the resistance of rocks, dams, etc., which oppose its flow toward the sea level, so electrical current meets opposition to its flow by many substances.

The unit of practical resistance is called the ohm, which electricians represent by the letter "R." A pressure of 1 volt will push the current of 1 ampere through any circuit which has the resistance of 1 ohm.

From this a celebrated scientist named Ohm made a rule for finding the current in any direct current circuit. The current in amperes (I) equals the volts pressure of the circuit divided by the ohm resistance.

If you want to abbreviate that expression it can be written $I = E \div R$ or $I \times R = E$ or $R = E \div I$.

Example. If you connect a magnet coil having 55 ohms resistance to a house lighting direct current circuit of 110 volts a current will flow which will be $\frac{110}{55} = 2$ amperes.

UNIT OF POWER

The unit of electrical power is called the watt and is equal to 1 volt multiplied by 1 ampere or, to explain it in another way, the power of any direct current circuit is the product of the volts and amperes. 1,000 watts is called a kilowatt. This is abbreviated 1 K.W. 1 K.W. equals about 1 1/3 horsepower.

SHORT CIRCUITS

A short circuit is a condition in which current escapes through breaks in the insulation where it is not intended to go, taking a shorter path than it should. It very often cuts the resistance to a dangerously low value and allows the current to flow in such a quantity that it burns out the conductor.

GROUND

Ground is that condition in electrical circuits when the electricity escapes through some part of the apparatus not intended to be a conductor and is so diverted from its true path.

GENERAL INSTRUCTIONS FOR CONNECTIONS

A few things should be remembered in making experiments with electrical apparatus. Some of them have been mentioned before, but, for the purpose of emphasis, let us run over them again hastily. Remember to treat your permanent magnet with care, as throwing it or banging it tends to weaken its magnetic strength. Where you are using electrical current be sure to make as few joints in the connecting wires as possible. Wherever joints are made, it is necessary to clean the wire until it is bright; for dirt, oil, etc., form good insulators. You can clean the wires by scraping with a knife, file, sandpaper or emery cloth. After you have made these ends clean and bright, fasten them together as closely as possible. If you are making a joint by twisting the wires, make several twists of each wire about the other and, if you can, then solder the joint, especially if the winding is to be permanent. If you are placing the ends of the wire under a screw or binding nut, twist the part around the screw; then fasten the screw or binding nut down as firmly as possible, remembering that a loose joint or poorly soldered wire increases the resistance of your circuit, therefore cutting down the strength of your current.

AMPERE TURNS

This is an expression used by electricians which means the total number of turns in any coil multiplied by the amperes flowing through it.

Example. If you have a coil of 300 turns through which $\frac{1}{2}$ an ampere of current is flowing, the result in ampere turns equals $300 \times \frac{1}{2} = 150$. The abbreviation for ampere turn is A.T.

CONDUCTORS AND RESISTORS

A material which offers little opposition to the flow of electrical current is called a conductor. Materials which strongly resist the movement of the amperes are called resistors.

The following list gives the names of materials in the order of their resistance, starting with the lowest resistance and going on toward the highest:

1. Silver
2. Copper
3. Gold
4. Aluminum
5. Zinc
6. Brass
7. Iron
8. Nickel
9. Tin
10. Steel
11. Lead
12. German Silver
13. Dry Air
14. Manila Paper
15. Cotton
16. Silk
17. Paraffin
18. Beeswax
19. Resin
20. Ebonite
21. Gutta Percha
22. Shellac
23. Glass, ordinary
24. Mica
25. Porcelain
26. Flint Glass

From this list you can see that the cheapest and best conducting material is copper. This is used for almost all electrical work,

though aluminum and iron are also used, but in very small quantities compared to copper.

The most convenient way found was to draw the copper into a wire. In order to wind it in small space, the different coils are separated from each other by a high resistance material called an insulator.

The four most common insulators for copper wire are cotton, silk, rubber and enamel. Cotton and silk thread is wrapped around the wire. The rubber and enamel is coated on the wire. All these are good insulators and keep the current flowing where it is intended to go.

The cotton and silk are put on both as a single covering and also a double covering. In choosing the insulations, the main thing to consider is the space it takes up, as you may have but little room in which to wind the required amount of wire.

COPPER WIRE

Copper wire is made in many sizes. The standard practice now is to list these sizes according to the Brown & Sharpe gauge, known as the B & S gauge.

A list of the sizes giving the outside diameter of the wire, bare and also insulated, is very useful. A list of the most useful sizes will be found on page 102, Table A.

Table B is also a very useful table, giving the largest number of turns it is possible to wind in a square inch of space.

DESIGN OF AN ELECTRO-MAGNET

Now let us design a magnet for lifting a block of iron, keeping in mind what was stated previously, that the holding force of a magnet, and this applies to an electro-magnet, depends not alone on its magnetic strength but on the shape of the poles. It also depends somewhat on the form of the material which we want to make it attract, and because of the form of the metal to be lifted as well as the shape of the poles, it is not possible to make a set of rules which will be quite true for all conditions. The following rules are very good and have been in use for many years. They are true and exact when all conditions are of the best, such as those we would have for a long magnet of comparatively small pole force area, lifting a smooth soft iron block having clean flat surfaces and offering a short magnetic path to the lines of magnetic force.

In magnets under actual working conditions, we do not find many of these good qualities and so the usual practice is to design and build our magnets in accordance with the following rules: After the coils are in place connect them with a current which can be varied and measured. Send a current through the coils of such a strength that the magnet will lift the required weight. You then can read the number of amperes flowing; and knowing the number of turns on the coil, you then multiply the number of turns by the number of these amperes and the proper ampere turns will then be found.

The rule for such a magnet is: The pounds weight to be lifted is equal to the square of the density multiplied by the area of the pole face in square inches and this product is divided by 72,134,000. The abbreviation of this rule is shown

$$P = \frac{B \times B \times A}{72{,}134{,}000} \qquad (1)$$

P = Pounds weight.

B = Density in magnetic lines per square inch.

A = Area of the pole face in square inches.

Formula (1) can be rearranged in various ways as follows: When the weight to be lifted and the area of the core pole piece is known it is

$$(B \times B) = \frac{P \times 72{,}134{,}000}{A} \qquad (2)$$

or, if the weight and the magnetic density is known, to find the area of the pole force the formula should read

$$A = \frac{P \times 72{,}134{,}000}{B \times B} \qquad (3)$$

By density we mean the number of magnetic lines passing through each square inch of the iron core of the electro-magnet.

If you use cast iron for this core, the density used should not be *over* 35,000 lines per square inch; for cast steel use 95,000 or less; and for cold rolled steel or sheet steel 100,000 lines per square inch.

Suppose we want to make an electro-magnet for use with a 6-volt battery.

Such a battery is used on many automobiles or you can make one for experimental work, where it is to be used a short time only, by connecting 4 dry batteries together in series—that is, in such a way that the outside binding post of one is connected to the inside post of the next and so on.

Imagine that this magnet will not be required to lift more than 50 pounds. Then we will make the soft steel or yoke of a "U" shaped, round, cold rolled steel rod bending it to shape.

Since we are using this horseshoe shaped yoke, the load will be carried on two poles or, in other words, each pole will carry one-half the load or 25 pounds.

From the foregoing rule, we find the following example to solve: one pole to lift 25 pounds; then the area of the pole face—that is, the area of the round end which touches the weight—to be lifted is equal to 25 multiplied by 72,134,000 and this result divided by the density B x B = $(B)^2$. We are using cold rolled steel, so let us choose a density of 95,000 magnetic lines or slightly less than our limit of 100,000. Then 95,000 x 95,000 = 9,000,000,000.

(In dealing with such large numbers the first one or two figures only, need be exact.) If you multiply the above, you find that the exact answer is 9,025,000,000.

Now our rule reads

$$A = \frac{25 \times 72{,}134{,}000}{9{,}000{,}000}$$

Solving this example we get an answer

$$\frac{1{,}800{,}000}{9{,}000{,}000} = .2 \text{ sq. in.}$$

The area of a circle is equal to the diameter multiplied by itself, that result multiplied by 3.1416, and the answer divided by 4.

$$A = \frac{3.1416 \times D^2}{4}$$

In Table E, on page 106, you will find a list of areas and circumferences for circles having diameter from 1/64 of an inch to 10 inches.

Looking at this table, we find that the nearest diameter for an area of .2 is 1/2 inch, with an area of .1963 sq. in.

Since we did not use the highest limit of magnetic density, we can afford to have our steel area just a little smaller than called for in the rule. If you solve the area formula, you will find the exact diameter required is .504 inches.

Let us make our yoke in "U" form using a 2-inch rod, 6 1/4 inches long. Bend this so that the legs are parallel and 1 3/8 inches apart.

AMPERE TURNS REQUIRED

We now have a steel rod 6 1/4 inches long, through which magnetic lines of force are to be pushed at the rate of 95,000 per square inch (density). From Table C, on page 104, we find that for every inch of length our metal at 95,000 lines is, we must have 47 ampere

turns. Since we have 6 1/4 inches, our total number of ampere turns will be at least

```
  6.25
    47
  ----
  4375
 2500
 ------
 293.75   call it 294
```

Before we decide on how many turns and what size wire we will use, let us first make a spool for holding the wire. This must slip on over the yoke and, therefore, the hole in it must be a little over 1/2 inch in diameter.

Cut a piece of tin can, or better yet a piece of sheet brass. The thickness should be about .012 of an inch. Cut two pieces 1 5/8 inches wide and 1 3/4 inches long. Slit the ends in four or six places, spaced equally apart at each end. Make the slits 1/8 of an inch deep.

Roll the pieces into the form of a tube, with the ends touching, not lapping. The length of the tube should be 1 3/4 inches and the hole through it a little larger than 1/2 inch. Smooth off all rough spots and edges with a file.

Cut two strips of paper, ordinary letter paper will do, make it 1 1/2 inches wide and long enough to wrap around the metal until the outside measures 5/8 of an inch. Wrap each tube with a paper and glue the outside end of each paper down, leaving 1/8 of an inch sticking out from each side of the paper.

Make four circular discs of heavy cardboard or fibre. These should have a hole in the center so they will be a tight fit over the end of the metal tubes. The outside diameter of these discs should not be more than 1 9/16 inches. The thickness should be about 1/16 of an inch.

It will help if you make little holes in each fibre, one near the inside and another near the outside edges, through which the ends of the wire can be pushed. Force these fibre discs on each end of the metal tube until they press tightly against the ends of paper wrapper. Lock them in place by turning up the ends of the tube where they are slit and hammer the turned up metal as lightly as possible against the fibre washers. When this is done, we have two spools on which we will wind our wire. The winding space is $1\frac{1}{2}$ inches long, leaving a little of the fibre washer standing out above the winding. The wire may be laid in layers until it is $\frac{3}{8}$ of an inch deep ($\frac{3}{8}'' = .375''$).

RULES FOR FINDING TURNS AND WIRE SIZE

Size wire in circular mils is equal to the diameter of the wire in inches multiplied by itself.

Circular Mils = Ampere turns multiplied by 1.03, and multiply this by the number of poles to be used for lifting. Divide this result by the volts supplied, then this answer must be multiplied by the mean length of turn.

The mean length of turns is the average length in inches of each turn of the winding and for abbreviation we call it M.L.T.

M.L.T. = the sum of the circumference of the tube, including insulating paper on which the coil is wound and 3.1416 multiplied by the depth of the winding.

The formula is M.L.T. = C + 3.1416D.

C = Circumference of tube,

D = Winding depth,

and the formula for circular mils then can be written

$$\text{Cir. M.} = \frac{\text{AT} \times 1.03 \times \text{No. of poles}}{6} \times \text{M. L. T.}$$

Example. First we will find the circumference of the tube formed by the paper insulation.

Our steel core is $\frac{1}{2}'' = .5''$ in diameter, our metal tube wrapping around it on each side is .012 inches thick; that gives us a diameter of

$$\begin{array}{r} .500 \\ .012 \\ .012 \\ \hline .524 \end{array}$$

then the paper builds this up to about .625. From Table D, on page 105, we find this equals $\frac{5}{8}$ of an inch. Table E, page 106, shows the circumference for this diameter is equal to 1.9635. We find the depth we will divide by to be $\frac{3}{8}$ of an inch = .375 inches. $3.1416 \times .375 = 1.1781$.

$$\begin{array}{l} 1.9635 = \text{C} \\ 1.1781 = \text{D} \times 3{,}1416 \\ \hline 3.1416 = \text{M.L.T.} \end{array}$$

$$\frac{\overset{\text{AT POLES}}{294 \times 1.03 \times 2}}{6} = \begin{array}{r} 100.94 \\ 3.1416 \\ \hline 60564 \\ 10094 \\ 40376 \\ 10094 \\ 30282 \\ \hline 317.113104 \end{array}$$

317.113104 circular mils, use 318.

Looking in Table A, page 102, we find that No. 25 wire has 320.4 circular mils and this is the nearest size to what we want. In choosing the wire, use the size which will be a little larger than required, if there is no wire exactly suitable to the size your example requires.

So we know that we may use No. 25 wire, but first we must find out whether or not the current in flowing through the wire of this size will heat the coil too much. It has been found that if we figure the watts given off in relation to the square inches of outside surface of the winding, we can determine a safe value for heating. For