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Title: The Study of Elementary Electricity and Magnetism by Experiment

Author: Thomas M. St. John

Release date: January 22, 2015 [EBook #48041]

Language: English

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The Study of Elementary Electricity and Magnetism by Experiment

Containing
TWO HUNDRED EXPERIMENTS
PERFORMED WITH
SIMPLE, HOME-MADE APPARATUS

BY
THOMAS M. ST. JOHN, Met. E.
Author of "Fun With Magnetism," "Fun With Electricity," "How Two Boys Made Their Own Electrical Apparatus," Etc.

NEW YORK
STHOMAS M. ST. JOHN
407 West 51st Street
1900

To the Student.

This book is designed as a text-book for amateurs, students, and others who wish to take up a systematic course of elementary electrical experiments at home or in school.

The student is advised to begin at the beginning, to perform the experiments in the order given, and to understand each step before proceeding. Certain principles and explanations necessarily precede the practical and perhaps more interesting applications of those principles.

In selecting the apparatus for the experiments in this book, the author has kept constantly in mind the fact that the average student will not buy the expensive pieces usually described in text-books.

The two hundred experiments given can be performed with simple, inexpensive apparatus; in fact, the student should make at least a part of his own apparatus.

For the benefit of those who wish to make their own apparatus, the author has given, throughout the work, explanations that will aid in the construction of certain pieces especially adapted to these experiments. For those who have the author's "How Two Boys Made Their Own Electrical Apparatus," constant references have been made to it as the "Apparatus Book," as this contains full details for making almost all kinds of simple apparatus needed in "The Study of Elementary Electricity and Magnetism by Experiment."

THOMAS M. ST. JOHN.

New York, April, 1900.

The Study of Elementary Electricity and Magnetism by Experiment

Part I—Magnetism

Part II—Static Electricity

Part III—Current Electricity

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MAGNETISM

A Few Dont's for Young Students.

Don't fail to make at least a part of your own apparatus; there is a great deal of satisfaction and pleasure in home-made apparatus.

Don't experiment in all parts of the house, if working at home. Fit up a small room for your den, and carry the key.

Don't begin an experiment before you really know what you are trying to do. Read the directions carefully, then begin.

Don't rush through an experiment to see what happens at the end of it. See what happens at each step, and notice every little thing that seems unusual.

Don't try to do all parts of an experiment at the same time. Understand one part, then proceed.

Don't fail to ask yourself questions, and form an opinion about the results of an experiment before you read what the author has to say about it.

Don't fail to keep a note-book. Keep all the data and arithmetical work for future reference.

Don't leave the apparatus around after you have finished the day's work.

PART I.—MAGNETISM.

CHAPTER I.

IRON AND STEEL.

1. Introduction. We should know something about iron and steel at the start, because we are to use them in nearly every experiment. The success with some of the experiments will depend largely upon the quality of the iron and steel used.

When we buy a piece of iron from the blacksmith, we get more than iron for our money. Hidden in this iron are other substances (carbon, phosphorus, silicon, etc.), which are called "impurities" by the chemist. If all the impurities were taken out of the iron, however, we should have nothing but a powder left; this the chemist would call "chemically pure iron," but it would be of no value whatever to the blacksmith or mechanic. The impurities in iron and steel are just what are needed to hold the particles of iron together, and to make them valuable. By regulating the amount of carbon, phosphorus, etc., manufacturers can make different grades and qualities of iron or steel.

When carbon is united with the *pure* iron, we get what is commonly called iron.

2. Kinds of Iron and Steel. *Cast iron* is the most impure form of iron. Stoves, large kettles, flatirons, etc., are made of cast iron. *Wrought iron* is the purest form of [4]
commercial iron. It usually comes in bars or rods. Blacksmiths hammer these into shapes to use on wagons, machinery, etc. *Steel* contains more carbon than wrought iron, and less than cast iron.

Soft steel is very much like wrought iron in appearance, and it is used like wrought iron.

Hard steel has more carbon in it than soft steel. Tools, needles, etc., are made of this.

EXPERIMENT 1. To study steel.

Apparatus. A steel sewing-needle (No. 1). [A]

[A] ***NOTE. Each piece of apparatus used in the following experiments has a number. See "Apparatus list" at the back of this book for details. The numbers given under "Apparatus," in each experiment, refer to this list.***

3. Directions. (A) Bend a sewing-needle until it breaks. Is the steel brittle?

(B) If you have a file, test the hardness of the needle.

4. Discussion. "Needle steel" is usually of good quality. It will be very useful in many experiments. Do you know how to make the needle softer?

EXPERIMENT 2. To find whether a piece of hard steel can be made softer.

Apparatus. Fig. 1. A needle; a cork, Ck (No. 2); lighted candle (No. 3). The bottom of the candle should be warmed and stuck to a pasteboard base.

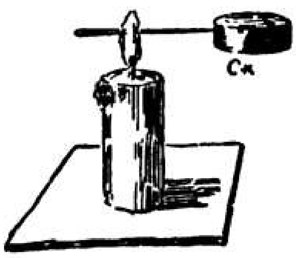


Fig. 1.

5. Directions. (A) Stick the point of the needle into Ck, Fig. 1, then hold the needle in the flame until it is red-hot. (The upper part of the flame is the hottest.)

(B) Allow the needle to cool in the air.

(C) Test the brittleness of the steel by bending it. Test its hardness with a file (Exp. 1).

6. Annealing. This process of softening steel by first heating it and then allowing it to cool slowly, is called *annealing*. All pieces of iron and steel are, of course, hard; but you have learned that some pieces are much harder than others. [5]

EXPERIMENT 3. To find whether a piece of annealed steel can be hardened.

Apparatus. The needle just annealed and bent; cork, etc., of Exp. 2; a glass of cold water.

7. Directions. (A) Heat the bent portion of the needle in the candle flame (Exp. 2) until it is red-hot, then immediately plunge the needle into the water.

(B) Test its brittleness and hardness, as in Exp. 2.

8. Hardening; Tempering. Good steel is a very valuable material; the same piece may be made hard or soft at will. By sudden cooling, the steel becomes very hard. This process is called *hardening*, but it makes the steel too brittle for many purposes. By *tempering* is meant the "letting down" of the steel from the very hard state to any desired degree of hardness. This may be done by suddenly cooling the steel when at the right temperature, it not being hot enough to produce extreme hardness. (The approximate temperature of hot steel can be told by the colors which form on a clean surface. These are due to oxides which form as the steel gradually rises in temperature.)

EXPERIMENT 4. To test the hardening properties of soft iron.

Apparatus. A piece of soft iron wire about 3 in. (7.5 cm.) long (No. 4); the candle, water, etc., of Exp. 3.

9. Directions. (A) Test the wire by bending and filing.

(B) Heat the wire in the candle flame as you did the needle (Fig. 1), then cool it suddenly with the water. Study the results.

10. Discussion. Soft iron contains much less carbon than steel. The hardening quality which steel has is due to the proper amount of carbon in it. If you have performed the experiments so far, you will be much more able to understand later ones, and you will see why we are obliged to use soft iron for some parts of electrical apparatus, and hard steel for other parts. [6]

CHAPTER II.

MAGNETS.

11. Kinds of Magnets. Among the varieties of magnets which we shall discuss, are the natural, artificial, temporary, permanent, bar, horseshoe, compound, and electro-magnet.

The Horseshoe Magnet, H M (Fig. 2), is the most popular form of small magnets. The red paint has nothing to do with the magnetism. The piece, A, is called its *armature*, and is made of soft iron, while the magnet itself should be made of the best steel, properly hardened. The armature should always be in place when the magnet is not in use, and care should be taken to thoroughly clean the ends of the magnet before replacing the armature. The horseshoe magnet is *artificial*, and it is called a *permanent* magnet, because it retains its strength for a long time, if properly cared for.

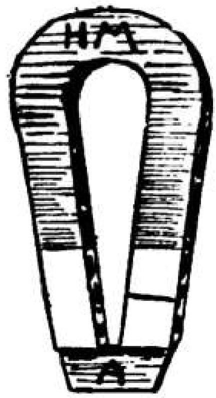


Fig. 2.

EXPERIMENT 5. To study the horseshoe magnet.

Apparatus. Fig. 2. The horseshoe magnet, H M (No. 16).

12. Directions. (A) Remove the armature, A, from the magnet, then move A about upon H M to see (1) if the curved part of H M has any attraction for A, and (2) to see if there is any attraction for A at points between the curve and the extreme ends of H M.

13. Poles; Equator. The ends of a magnet are called its *poles*. The end marked with a line, or an N, should be the *north* pole. The unmarked end is the *south* pole. N and S are abbreviations for north and south. The central part, at which there *seems* to be no magnetism, is called the *neutral point* or *equator*.

[8]

EXPERIMENT 6. To ascertain the nature of substances attracted by a magnet.

Apparatus. The horseshoe magnet, H M (Fig. 2); silver, copper, and nickel coins; iron filings (No. 17), nails, tacks, pins, needles; pieces of brass, lead, copper, tin, etc. (Ordinary tin is really sheet iron covered with tin.) Use the various battery plates for the different metals.

14. Directions. (A) Try the effect of H M upon the above substances, and upon any other substances thought of.

15. Magnetic Bodies; Diamagnetic Bodies. Substances which are attracted by a magnet are said to be *magnetic*. A piece of soft iron wire is magnetic, although not a magnet. Very strong magnets show that nickel, oxygen, and a few other substances not containing iron, are also magnetic. Some elements are actually repelled by a powerful magnet; these are called *diamagnetic* bodies. It is thought that all bodies are more or less affected by a magnet.

16. Practical Uses of Magnets. Many practical uses are made of magnets, such as the automatic picking out of small pieces of iron from grain before it is ground into flour, and the separation of iron from other metals, etc. The most important uses of magnets are in the compass and in connection with the electric current, as in machines like dynamos and motors. (See experiments with electro-magnets.)

EXPERIMENT 7. To study the action of magnetism through various substances.

Apparatus. Horseshoe magnet, H M; a sheet of stiff paper; pieces of sheet glass, iron, zinc, copper, lead, thin wood, etc.; sewing-needle. (A tin box may be used for the iron, and battery plates for the other metals.)

17. Directions. (A) Place the needle upon the paper and move H M about immediately under it.

(B) In place of the paper, try wood, glass, etc.

(C) Invent an experiment to show that magnetism will act through your hand. [9]

(D) Invent an experiment to show that magnetism will act through water.

18. Magnetic Transparency; Magnetic Screens. Substances, like paper, are said to be *transparent* to magnetism. Iron does not allow magnetism to pass through it as readily as paper and glass; in fact, thick iron may act as a *magnetic screen*.

EXPERIMENT 8. To find whether a magnet can give magnetism to a piece of steel.

19. Note. You have seen that the horseshoe magnet can lift nails, iron filings, etc.; you have used this lifting power to show that the magnet was really a magnet, and not merely an ordinary piece of iron painted red. Can we give some of its magnetism to another piece of steel? Can we pass the magnetism along from one piece of steel to another?

Apparatus. The horseshoe magnet, H M; two sewing-needles that have never been near a magnet; iron filings.

20. Directions. (A) Test the needles for magnetism with the iron filings, and be sure that they are not magnetized.

(B) Remove the armature, A, from H M, then touch the point of one of the needles to one pole of H M.

(C) Lay H M aside, and test the point of the needle for magnetism.

(D) If you find that the needle is magnetized, rub its point upon the point of the other needle; then test the point of the second needle for magnetism.

21. Discussion; Bar Magnets. A piece of good steel will attract iron after merely touching a magnet. To thoroughly magnetize it, however, a mere touch is not sufficient. There are several ways of making magnets, depending upon the size, shape, and strength desired. For these experiments, the student needs only a good horseshoe magnet, or, better still, the electro-magnets described later; with these any number of small magnets may be made. Straight magnets are called *bar magnets*. [10]

EXPERIMENT 9. To make small magnets.

Apparatus. Fig. 3. The horseshoe magnet, H M; sewing-needles; iron filings. (See Apparatus Book, Pg. 140, for various kinds of steel suitable for small magnets.)

22. Directions. (A) Hold H M (Fig. 3) in the left hand, its poles being uppermost. Grasp the point of the needle with the right hand, and place its point upon the N or marked pole of H M.

(B) Pull the needle along in the direction of its length (see the arrow), continuing the motion until its head is at least an inch from the pole.

(C) Raise the needle at least an inch above H M, lower it to its former position (Fig. 3), and repeat the operation 3 or 4 times. Do not slide the needle back and forth upon the pole, and be careful not to let it accidentally touch the S pole of H M.

(D) Test the needle for magnetism with iron filings, and save it for the next experiment.

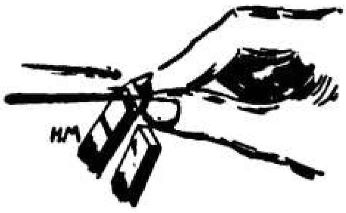


Fig. 3.

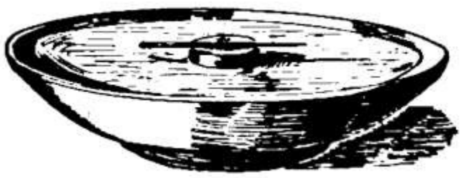


Fig. 4.

EXPERIMENT 10. To find whether a freely-swinging bar magnet tends to point in any particular direction.

Apparatus. Fig. 4. A magnetized sewing-needle (Exp. 9); the flat cork, Ck (No. 2); a dish of water. (You can use a tumbler, but a larger dish is better.)

23. Note. An oily sewing-needle may be floated without the cork by carefully lowering it to the surface of the water. All magnets, pieces of iron and steel, knives, etc., should be removed from the table when trying such experiments. Why?

24. Directions. (A) Place the little bar magnet (the needle) upon the floating cork, turn it in various positions, and note the result.

25. North-seeking Poles; South-seeking Poles; Pointing Power. It should be [11] noted that the *point* swings to the north, provided the needle is magnetized as directed in Exp. 9. This is called the north, or north-seeking pole. The N-seeking pole is sometimes called the marked pole. For convenience, we shall hereafter speak of the N-seeking pole as the N pole, and of the S-seeking pole as the S pole. We shall hereafter speak of the tendency which a bar magnet has to point N and S, as its *pointing power*. An unmagnetized needle has no pointing power.

26. The Magnetic Needle; The Compass. A small bar magnet, supported upon a pivot, or suspended so that it may freely turn, is called a *magnetic needle*. When balanced upon a pivot having under it a graduated circle marked N, E, S, W, etc., it is called a *compass*. These have been used for centuries. (See Apparatus Book for Home-made Magnetic Needles.)

EXPERIMENT 11. To study the action of magnets upon each other.

Apparatus. Two magnetized sewing-needles (magnetized as in Exp. 9); the cork, etc., of Exp. 10.

27. Directions. (A) Float each little bar magnet (needles) separately to locate the N poles.

(B) Leave one magnet upon the cork, and with the hand bring the N pole of the other magnet immediately over the N pole of the floating one. Note the result.

(C) Try the effect of two S poles upon each other.

(D) What is the result when a N pole of one is brought near a S pole of the other?

EXPERIMENT 12. To study the action of a magnet upon soft iron.

Apparatus. A magnetized sewing-needle; cork, etc., of Exp. 10; a piece of soft iron wire, 3 in. long; iron filings.

28. Directions. (A) Test the wire for magnetism with filings. Be sure that it is not magnetized. [12]
If it shows any magnetism, twist it thoroughly before using. (Exp. 19.)

(B) Float the magnetized needle (Exp. 10), then bring the end of the wire near one pole of the needle and then near the other pole.

(C) Place the wire upon the cork, hold the needle in the hand and experiment.

29. Laws of Attraction and Repulsion. From experiments 11 and 12 are derived these laws:

(***1***) ***Like poles repel each other***; (***2***) ***Unlike poles attract each other***; (***3***) ***Either pole attracts and is attracted by unmagnetized iron or steel.***

The attraction between a magnet and a piece of iron or steel is mutual. Attraction, alone, simply indicates that at least one of the bodies is magnetized; repulsion proves that both are magnetized.

EXPERIMENT 13. To learn how to produce a desired pole at a given end of a piece of steel.

Apparatus. Same as in Exp. 9.

30. Directions. (A) Magnetize a sewing-needle (Exp. 9) by rubbing it upon the N pole of H M from *point to head*. Float it and locate its N pole.

(B) Take another needle that has not been magnetized, and rub it on the same pole (N) from *head to point*. Locate its N pole.

(C) Magnetize another needle by rubbing it from *point to head* upon the S pole of H M; locate its N pole. Can you now determine, beforehand, how the poles of the needle magnet will be arranged?

31. Rule for Poles. The end of a piece of steel which last touches a N pole of a magnet, for example, becomes a S pole.

32. Our Compass (No. 18). While the floating magnetic needle described in Exp. 10,
and shown in Fig. 4, does very well, it will be found more convenient to use a compass [13]
whenever poles of pieces of steel are to be tested. Fig. 5 shows merely the cover of the box which serves as a base for the magnetic needle furnished. We shall hereafter speak of this apparatus as *our compass*, O C. (See Apparatus Book, Chap. VII, for various forms of home-made magnetic needles and compasses.)

33. Review; Magnetic Problems. To be sure that you understand and remember what was learned in Exp. 11, do these problems:

1. Using the S pole of the horseshoe magnet, magnetize a needle so that its head will become a N pole. Test with floating cork, as in Exp. 11.

2. Using the N pole of the horseshoe magnet, magnetize a needle so that its head shall be a S pole. Test.

3. Magnetize two needles, one on the N and one on the S pole of the horseshoe magnet, in such a way that the two points will repel each other. Test.

If the student cannot do these little problems at once, and test the results satisfactorily to himself, he should study the previous experiments again before proceeding.

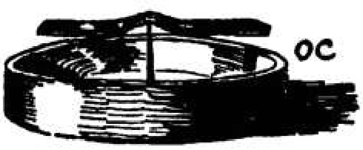


Fig. 5.

Fig. 6.

EXPERIMENT 14. To find whether the poles of a magnet can be reversed.

Apparatus. Fig. 6. The horseshoe magnet, H M; a thin wire nail, W N, 2 in. (5 cm.) long; a piece of stiff paper, cut as shown, to hold W N; thread with which to suspend the paper; compass, O C (No. 18).

34. Directions. (A) Magnetize W N so that its point shall be a S pole. Test with O C to make sure that you are right.

(B) Swing W N in the paper (Fig. 6), then *slowly* bring the S pole of H M near its point. Note result.

(C) *Quickly* bring the S pole of H M near the point. Is W N still repelled? Has its S pole been reversed?

35. Discussion; Reversal of Poles. The poles of weak magnets may be easily [14]
reversed. This often occurs when the apparatus is mixed together. It is always best, before beginning an experiment, to remagnetize the pieces of steel which have already served as magnets. The same may be shown by magnetizing a needle, rubbing it first in one direction, and then in another upon the magnet, testing, in each case, the poles produced.

EXPERIMENT 15. To find whether we can make a magnet with two N poles.

Apparatus. The horseshoe magnet, H M; an unmagnetized sewing-needle; compass, O C (No. 18).

36. Note. You have already learned that the polarity of a weak magnet can be changed (Exp. 14). Can you think of any method by which *two N poles* can be made in one piece of steel?

37. Directions. (A) Place the needle upon H M, as in Fig. 7.

(B) Keeping the part, C, in contact with the N pole of H M, and using the N pole of H M as a pivot, turn the needle end for end so that its head will be in contact with the S pole of H M.

(C) Pull the needle straight from H M, being careful not to slide it in either direction.

(D) Test the polarity of the ends with O C (Fig. 5), and save it for the next experiment.

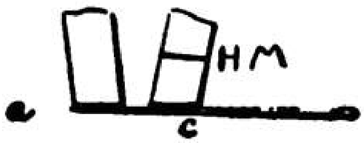


Fig. 7.

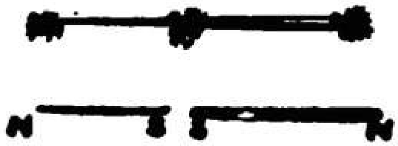


Fig. 8.

EXPERIMENT 16. To study the bar magnet with two N poles.

Apparatus. The strange magnet just made (Exp. 15); iron filings; compass, O C (No. 18).

38. Directions. (A) Sprinkle filings over the whole length of the needle and then raise it (Fig. 8).

(B) Break the needle at its center, and test, with O C, the two new ends produced at that point. [15]
Remember that repulsion is the test for polarity.

39. Discussion; Consequent Poles. Iron filings cling to a magnet where poles are located. In this case, two small magnets were made in one piece of steel; they had a common S pole at the center. The pointing power (§ 25) of such a magnet is very slight; would it have *any* pointing power if we could make the end poles of equal strength? Intermediate poles, like those in the needle just discussed, are called *consequent poles*. Practical uses are made of consequent poles in the construction of motors and dynamos.

EXPERIMENT 17. To study consequent poles.

Apparatus. An unmagnetized sewing-needle; horseshoe magnet, H M (No. 16); iron filings (No. 17); compass (No. 18).

40. Directions. (A) Let *w*, *x*, *y*, and *z* stand for four places along the body of the needle, *w* being at its point and *z* at its head.

(B) Touch *w* with the N pole of H M, *x* with the S pole, *y* with the N pole, and *z* with the S pole. Do not slide H M along on the needle, just *touch* the needle as directed.

(C) Cover the needle with filings, then lift it.

EXPERIMENT 18. To study the theory of magnetism.

Apparatus. A thin bar magnet, B M (No. 21); iron filings; a sheet of paper. Fig. 9 shows simply the edge of B M and the paper. B M should be magnetized as directed in Exp. 9.

41. Directions. (A) Sprinkle some iron filings upon a sheet of paper.

(B) Bring one pole of B M in contact with the filings (Fig. 9), and lightly sweep it through them several times, always in the same direction. Are the filings *simply* pushed about?

(C) Do the same with a stick, and compare the result with that produced with B M.

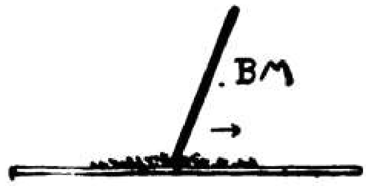


Fig. 9.

[16]

42. Theory of Magnetism; Magnetic Saturation. This bringing into line the particles of iron indicates that each particle became a magnet. This experiment should aid in understanding what is thought to take place when steel is magnetized. The pile of filings represents the body to be magnetized, and each little filing stands for a particle of that body. A bar of steel is composed of extremely small particles, called *molecules*. They are very close together and do not move from place to place as easily as the pieces of filings. A magnet, however, when properly rubbed upon the steel, seems to have power to make the molecules point in the same direction. This produces an effect upon the whole bar.

Each molecule of the steel is supposed to be a magnet. When these little magnets pull together, the whole bar becomes a strong magnet. When a magnet is jarred, and the little magnetized molecules are mixed again, they pull in all sorts of directions upon each other. This lessens the attraction for outside bodies.

Steel is said to be *saturated*, when it contains as much magnetism as possible. A piece of steel becomes slightly longer when magnetized.

It is thought, by many, that there is a current of electricity around each molecule, making a little magnet of it. (See electro-magnets.)

EXPERIMENT 19. To find whether soft iron will permanently retain magnetism.

Apparatus. A piece of soft iron wire, 3 or 4 in. (7.5 to 10 cm.) long (No. 4); the horseshoe magnet, H M; iron filings; flat cork, F C (No. 2), and the dish of water used in Exp. 10 (Fig. 4).

43. Directions. (A) Magnetize the wire (Exp. 9). Notice that the wire clings strongly to H M.

(B) Test the lifting power of the little wire magnet by seeing about how many iron filings its poles will raise. [17]

(C) Test the pointing power (§ 25) of the wire by floating it on F C (Fig. 4).

(D) Holding one end of the wire in the hand, thoroughly jar it by striking the other end several times against a hard surface.

(E) Test the lifting and pointing powers, as in B and C.

44. Retentivity or Coercive Force; Residual Magnetism. Soft iron loses *most* of its magnetism when simply removed beyond the action of a magnet. We say that it does not retain magnetism; that is, it has very little *retentivity or coercive force*. This is an important fact, the action of many electric machines and instruments depending upon it. A slight amount of magnetism remains, however, in the softest iron, after removing it from a magnet. This is called *residual magnetism*. A piece of iron may show poles, when tested with the compass, although it may have almost no pointing power.

EXPERIMENT 20. To test the retentivity of soft steel.

Apparatus. A wire nail, W N (No. 19); horseshoe magnet, H M; iron filings; flat cork, F C; the dish of water (Exp. 10, Fig. 4).

45. Directions. (A) With H M magnetize the nail; this is made of soft steel.

(B) Test the lifting and pointing powers of W N (Exp. 19).

(C) Strike W N several times with a hammer to jar it.

(D) Again test its lifting and pointing powers.

46. Discussion. Soft steel has a greater retentivity than soft iron. It contains less carbon than cast or tool steel, and is called mild steel or machinery steel. You do not want soft steel for permanent magnets.

EXPERIMENT 21. To test the retentivity of hard steel.

Apparatus. A hard steel sewing-needle (No. 1); other articles used in Exp. 20.

47. Directions. (A) Magnetize the needle with H M.

(B) Test its lifting and pointing powers (Exp. 19). [18]

(C) Hammer the needle and test again as in (B).

EXPERIMENT 22. To test the effect of heat upon a magnet.

Apparatus. A magnetized sewing-needle; the candle, cork, etc., of Exp. 2. (See Fig. 1.)

48. Directions. (A) Test the needle for magnetism.

(B) Stick the needle into the cork (Fig. 1), and heat it until it is red-hot.

(C) Test the needle again for magnetism.

(D) See if you can again magnetize the needle.

49. Discussion. Heating a body is supposed to thoroughly stir up its molecules. Jarring or twisting a magnet tends to weaken it. (See Exp. 19.)

The molecules of steel do not move about or change their relative positions as readily as those of soft iron. When the molecules of hard steel are once arranged, by magnetizing them, for example, they strongly resist any outside influences which tend to mix them up again.

A magnet does not attract a piece of red-hot iron. The particles of the hot iron are supposed to vibrate too rapidly to be brought into line; that is, the iron cannot become polarized by induction. (See Exp. 24.)

EXPERIMENT 23. To test the effect of breaking a magnet.

Apparatus. A magnetized sewing-needle; iron filings; compass, O C (No. 18).

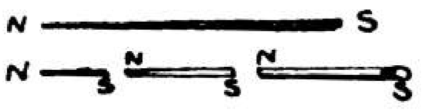


Fig. 10.

50. Directions. (A) Break the little bar magnet (needle), and test the two new ends produced for magnetism, with the iron filings. (Fig. 10).

(B) Touch the two new poles together to see whether they are like or unlike.

(C) Test the nature of the poles with O C (Fig. 5)

(D) Break one of the halves and test its parts.

51. Discussion. The above results agree with the theory that each molecule is a magnet (Exp. 18). No matter into how many pieces a magnet is broken, each part becomes a magnet. (Fig. 10). This shows that those molecules near the equator of the magnet really have magnetism. Their energy, however, is all used upon the adjoining molecules; hence no external bodies are attracted at that point. [19]

[20]

CHAPTER III.

INDUCED MAGNETISM.

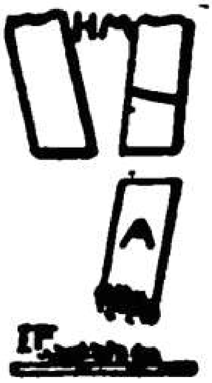


Fig. 11.

EXPERIMENT 24. To find whether we can magnetize a piece of iron without touching it with a magnet.

Apparatus. Horseshoe magnet, H M; iron filings, I F (Fig. 11).

52. Directions. (A) Hold the armature of the magnet in a vertical position (Fig. 11), its lower end being directly in a little pile of iron filings.

(B) Bring the N pole of H M near the upper end of A, but do not let them touch each other.

(C) Keeping A and the pole of H M the same distance apart, lift them. Do any filings cling to A?

(D) Without moving or jarring A, take H M away from it and note result upon the filings.

53. Temporary Magnetism; Induced Magnetism. The armature, A, was induced to become a magnet without even touching H M. Its magnetism was *temporary*, however, as the filings dropped as soon as the *inductive action* of H M was removed. A small amount of residual magnetism (44) remained in A. Soft iron is exceedingly valuable, because it has very little retentivity (44), and because it can be easily *magnetized by induction*. The armature was made of soft iron. It had *induced magnetism*. It was a *temporary magnet*.

EXPERIMENT 25. To find whether a piece of steel can be permanently magnetized by induction.

Apparatus. An unmagnetized sewing-needle; horseshoe magnet, H M; iron filings; sheet of stiff paper.

54. Directions. (A) Test the needle for magnetism.

(B) Place the unmagnetized needle upon the paper, then move H M about immediately under it, so that the needle will be attracted.

(C) Test the needle again for permanent magnetism.

[21]

EXPERIMENT 26. To study the inductive action of a magnet upon a piece of soft iron.

Apparatus. Horseshoe magnet, H M; iron filings, I F; a piece of soft iron wire about an inch long, I W (Fig. 12), placed upon the N pole of H M; compass, O C (No. 18), (§ 32).

55 Directions. (A) Test the lower end of I W for magnetism with I F.

(B) Leaving I W upon the N pole of H M, test the pole at the lower end of I W with O C, to determine whether it is N or S.

(C) Jar I W (Exp. 19), then place it upon the S pole of H M, and again test the polarity of the lower end.

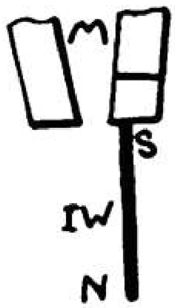


Fig. 12.

56. Polarization; Pole Pieces. The wire, I W (Fig. 12), was acted upon by induction (Exp. 24) and behaved like a magnet. Poles were produced in it, so we say that the wire was *polarized*. Pieces of iron, placed upon the poles of a magnet, are called *pole pieces*. It should be noted that the lower end of the wire has a pole *like* the pole of H M, to which it is attached.

EXPERIMENTS 27–30. To study pole pieces.

Apparatus for Experiments 27–30. Horseshoe magnet, H M; soft iron wires; iron filings, I F.

57. Directions. (A) Suspend two wires, each about an inch long (Fig. 13) from one pole of H M. Do their lower ends attract or repel each other?

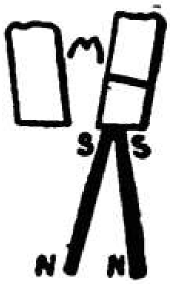


Fig. 13.

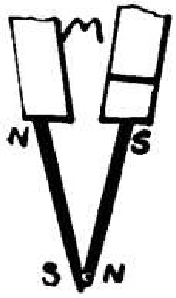


Fig. 14.

EXPERIMENT 28.

58. Directions. (A) Place the two wires just used so that one shall cling to the N pole of H M, and the other to the S pole of H M (Fig. 14).

(B) Bring the lower ends of the wires near each other. Do they attract or repel each other? [22]

EXPERIMENT 29.

59. Directions. (A) Bend a 2-inch iron wire, as in Fig. 15, and place it upon the poles of H M.

(B) See if its central part, marked X, will strongly attract filings.

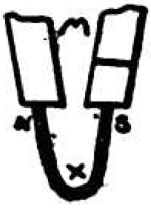


Fig. 15.

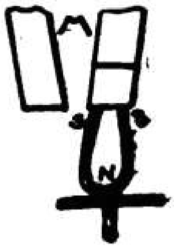


Fig. 16.

EXPERIMENT 30.

60. Directions. (A) Bend the wire just used a little more, and place its ends upon *one* pole of H M (Fig. 16).

(B) See if the iron filings and small wires will cling to its central part.

CHAPTER IV.

THE MAGNETIC FIELD.

EXPERIMENT 31. To study the space around a magnet, in which pieces of iron become temporary magnets by induction.

Apparatus. A bar magnet, B M (No. 21); a compass (No. 18); a sheet of stiff paper about 1 ft. (30 cm.) square, with a center line, C L, drawn parallel to one of its sides (Fig. 16½), and with another line, E W, drawn perpendicular to C L. (See Apparatus Book, Chap. VI., for various ways of making home-made permanent magnets.)

61. Directions. (A) Lay the paper upon the table, and place the compass over the center of the line, C L, previously drawn.

(B) Place the eye directly over the compass-needle, then turn the paper until the line is N and S; that is, until the line is parallel to the length of the needle. Pin the paper to the table to hold its center line N and S.

(C) Place B M upon the paper, as shown (Fig. 16½), its N pole to the north, and its center at the cross line, E W.

(D) Slowly move the compass entirely around and near B M, and note the various positions taken by the needle. Note especially the way in which its N pole points. This is to get a general idea of the action of the needle.

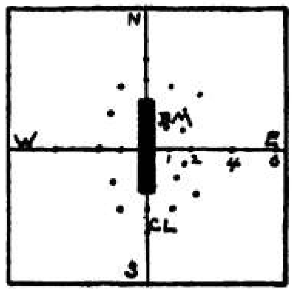


Fig. 16½.

(E) Place the compass in the position marked 1, which is on E W, about 1 in. from the line, C L. Press the wooden support down firmly upon the paper to show, by the dent made in the paper by the pin-head, the exact place on the paper that is under the center of the compass-needle. Before removing the compass from this position, look down upon it again, and make a dot on the paper with a pencil directly under each end of the needle. Remove the compass, and draw a line through the dent and the two dots just made. This will show a plan of the exact position of the needle.

(F) Repeat this for the various points marked 2, 4, 6 in. from C L, always marking on the plan [24]
the position of the N pole of the needle. Do the same with the other points marked on Fig. 16½ by dots, and study the resulting diagram.

62. Discussion; The Magnetic Field. The compass-needle was decidedly affected all around B M (Fig. 17), showing that induction can take place in a considerable space around a magnet; this space is called the *magnetic field* of the magnet. Let us consider *one* position taken by the compass-needle in the field of B M (Fig. 17), as, for example, the one in which the needle has been made black. The S pole of the black needle is attracted by the N pole of B M, and is repelled by the S pole of B M. The N pole of the compass-needle is attracted by the S pole of B M, and is repelled by B M's N pole. The position which it takes, therefore, is due to the action of these 4 forces, together with its tendency to point N and S.

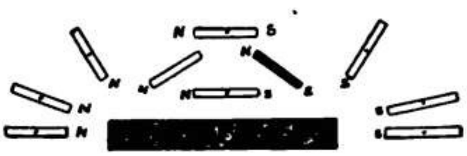


Fig. 17.

Every magnet has a certain magnetic field, with its lines of force passing through the surrounding air in certain definite positions. As soon, however, as a piece of iron or another magnet is brought within the field, the original position of the lines of force is changed. This has to be considered in the construction of electrical machinery.

EXPERIMENT 32. To study the magnetic field of a bar magnet.

Apparatus. A sheet of stiff paper; iron filings, I F; bar magnet, B M (No. 21); a sifter for the filings (No. 24); (See Apparatus Book, §48, 49, 50, for home-made sifters.)

63. Directions. (A) Place B M upon the table, and lay the paper over it.

(B) With the sifter sprinkle some filings upon the paper directly over B M, then tap the paper [25]
gently, to assist the particles to take final positions. Study the results.

64. Magnetic Figures; Lines of Magnetic Force. The filings clearly indicated the extent and nature of the magnetic field of B M. You should notice how the filings radiate from the poles, and how they form curves from one pole to the other. They make upon the paper a *magnetic figure*. Each particle of the filings becomes a little magnet, by induction (Exp. 24), and takes a position which depends upon attractions and repulsions, as discussed in Exp. 31.

Magnetism seems to reach out in lines from the poles of a magnet. The position and direction of some of the lines are shown by the lines of filings. They are very distinct near the poles, and are considered, for convenience, to start from the N pole of a magnet, where they separate. They then pass through the air on all sides of the magnet, and finally enter it again at the S pole. These lines are called *lines of force* or *lines of magnetic induction*.

The poles must not be considered mere points at the ends of a magnet. As shown by magnetic figures, the lines of magnetic induction flow from a considerable portion of the magnet's ends.

EXPERIMENTS 33–37. To study the magnetic fields of various combinations of bar magnets.

Apparatus for Exps. 33–37. Two bar magnets, B M (Nos. 21, 22); an iron ring, I R (No. 23); iron filings, I F; a sheet of stiff paper; the sifter (No. 24).

65. Note. The student will find it very helpful to make the magnetic figures of the combinations given. Thoroughly magnetize the bar magnets upon an electro-magnet, or upon a strong horseshoe magnet, and mark their N poles in some way. The N poles may be marked by sticking a small piece of paper to them.

66. Directions. (A) Arrange the two magnets, B M, as in Fig. 18, with their unlike poles about an inch apart. (The dotted circle indicates the iron ring to be used in the *next* experiment. About a quarter, only, of the magnets are shown.) [26]

(B) Place the paper over the magnets, and sift filings upon it immediately over the unlike poles. Note particularly the lines of filings between N and S.

(C) Make a sketch of the result. (See experiments with electromagnets, and the illustrations of magnetic figures with them.)

EXPERIMENT 34.

67. Directions. (A) Leaving the opposite poles an inch apart, as in Exp. 33, place the iron ring, I R (No. 23), between them (Fig. 18, dotted circles).

(B) Place the paper over it all, and sprinkle filings upon it to get the magnetic figure.

(C) Make a sketch of the resulting figure, and compare it with the figure made in Exp. 33. Why do the lines of force appear indistinct in the center of the ring and around it? (See §74.)

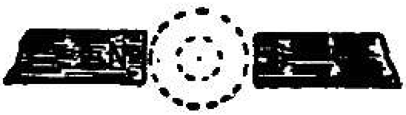


Fig. 18.

Fig. 19.

EXPERIMENT 35.

68. Directions. (A) Arrange the two bar magnets, as in Exp. 33, but with their two N poles an inch apart.

(B) Make the magnetic figure of the combination. Do the lines of force flow from one N pole directly to the N pole of the other? Do the particles of filings reaching out from one B M attract or repel those from the other B M?

EXPERIMENT 36.

69. Directions. (A) Place the two bar magnets side by side, so that their unlike poles shall be arranged as in Fig. 19.

(B) Make the magnetic figure.

EXPERIMENT 37.

70. Directions. (A) Turn one B M end for end, so that their like poles shall be near each other, but otherwise arranged as in Fig. 19.

(B) Make and study the magnetic figure.

[27]

EXPERIMENTS 38–39. To study the lifting power of combinations of bar magnets.

Apparatus for Exps. 38–39. Two bar magnets, B M (No. 21, 22), of about equal strength; iron filings, I F.

71. Directions. (A) Find out about how many filings you can lift with the N pole of one magnet.

(B) Place the two magnets together (Fig. 20), their *like* poles being in contact; then see whether the two N poles will lift more or less filings than one pole.

EXPERIMENT 39.

72. Directions. (A) Remove all filings from the two magnets just used, and hold them tightly together (Fig. 20), with their *unlike* poles in contact.

Fig. 20.

(B) Compare the amount of filings you can lift at one end of this combination with that lifted in Exp. 38 (A) and (B).

73. Discussion; Compound Magnets. Many lines of force pass into the air from two like poles. Such a combination is called a *compound magnet*. A piece of thin steel can be magnetized more strongly in proportion to its weight than a thick piece, because the magnetism does not seem to penetrate beyond a certain distance into the steel. Thin steel may be magnetized practically through and through. A thick magnet has but a crust of magnetized molecules; in fact, a thick magnet may be greatly weakened by eating the outside crust away with acid. By riveting several thin bar or horseshoe magnets together, thick permanent magnets of considerable strength are made.

74. Lines of force, in passing from the N to the S pole of a magnet, meet a resistance in the air, which does not carry or conduct them as easily as iron or steel. In the arrangement of Exp. 39 the lines of force are not obliged to push their way through the air, as each magnet serves as a return conductor for the lines of force of the other. [28]
Either magnet may be considered an armature for the other.

To show in another way that few lines of force pass into the air, the student may lay the above combination upon the table and make a magnetic figure. (See Apparatus Book, p. 38, for method of making home-made compound magnets.)

In the case where a ring was placed between the poles of two bar magnets (Exp. 34), the lines of force from the N pole jumped across the first air-space. They then disappeared in the body of the ring, until they were obliged to jump across the second air-space, to get to the S pole. The weakness of the field in the central space was clearly shown by the filings. There were no stray lines of force passing through the air, because it was easier for them to go through the iron ring. This will be discussed again under "Dynamos and Motors." (See also § 78.)

EXPERIMENTS 40–42. To study the magnetic field of the horseshoe magnet.

Apparatus for Exps. 40–42. Horseshoe magnet, H M; iron filings, I F; sheet of stiff paper.

75. Directions. (A) Place H M, with its armature removed, flat upon the table, and cover it with the paper; then make the magnetic figure. (Exp. 32.)

(B) Compare the number of well-defined curves at the poles with the number at the equator.

EXPERIMENT 41.

76. Directions. (A) Make the magnetic figure of H M with its armature in place.

(B) Is the attraction for outside bodies increased or decreased by placing the armature on H M?

EXPERIMENT 42.

77. Directions. (A) Lay H M flat upon the table, and place one or two matches between its poles and the armature; cover with paper as before, and make the magnetic figure. Do lines of force still pass through the armature?

78. Discussion; Resistance to lines of Force. It is evident, from the last 3 [29]
experiments, that lines of force will pass through iron whenever possible, on their way from the N to the S pole of a magnet. When the armature of a horseshoe magnet is in place, most of the lines of magnetic induction crowd together and pass through it rather than push their way through the air. Air is not a good conductor of lines of force; and the magnet has to do work to overcome the resistance of the air, when the armature is removed, in order to complete the magnetic circuit. This work causes a magnet to become gradually weaker. The soft iron armature is an excellent conductor of lines of force; it completes the magnetic circuit so perfectly that very little work is left for the magnet to do.

EXPERIMENT 43. To show that lines of force are on all sides of a magnet.

Apparatus. Our compass, O C (No. 18); horseshoe magnet, H M; glass tumbler, G T; sheet of stiff paper; iron filings, I F. Arrange as in Fig. 21. H M may be supported in a vertical position by placing paper, or a handkerchief, under it. The poles should just touch the stiff paper placed over the tumbler.

79. Directions. (A) Sprinkle iron filings upon the paper, and study the resulting magnetic figure.

(B) Place O C upon the paper in different positions. Does the magnetic needle always come to rest about parallel to the lines of filings?

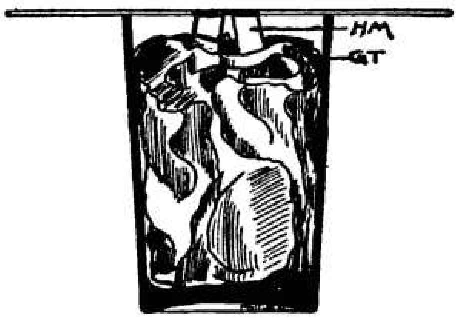


Fig. 21.

80. Discussion. The student should keep in mind the fact that the filings in the magnetic figure show the approximate extent and form of the magnetic field simply in one plane. If the paper were held in some other position near the magnet (in a tilted position, for example,) the lines of filings would not be the same as those produced in Exp. 40–42. The lines of force come out of every side of the N pole. When a magnetic needle is placed in any magnetic field, its N pole points in the direction in which the lines of force are passing; that is, it points towards the S pole of the magnet producing the field. [30]

EXPERIMENT 44. To study a horseshoe magnet with movable poles.

Apparatus. A narrow strip of spring steel, S S (No. 25); iron filings, I F.

81. Directions. (A) Magnetize the spring steel, S S.

(B) Bend S S until its poles are about ¼ in. apart, then using it as a horseshoe magnet, and keeping its poles the same distance apart, see about how many filings you can lift.

(C) Clean the poles of S S, press them tightly together, then again test its lifting power with filings.

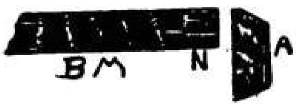


Fig. 22.

82. Discussion; Advantages of Horseshoe Magnets. When the opposite poles of the flexible magnet are pressed together, the lines of force do not have to pass through the air; there is very little attraction for outside bodies. The same effect is produced with the armature (Exp. 41). A horseshoe magnet has a strong attraction for its armature, because it has a *double power to induce and to attract*. Suppose the N pole of a bar magnet, B M (Fig. 22), be placed near one end of a piece of iron, as, for example, the armature, A. A will become a temporary magnet by induction (Exp. 24). The S pole of A, polarized by induction, will be attracted by B M, while its N pole will be repelled by B M; so, you see, that a bar magnet does not pull to advantage.

CHAPTER V.

TERRESTRIAL MAGNETISM.

83. The Magnetism of the Earth. The student must have guessed, before this, that the earth acts like a magnet. It causes the magnetic needle to take a certain position at every place upon its surface, and this position depends upon the earth's attractions and repulsions for it. The earth has lines of force which flow from its N magnetic pole, and these lines, before they can get to the earth's S magnetic pole, must spread out through the air on all sides of the earth.

As the magnetic needle points to the earth's N magnetic pole (which is more than 1,000 miles from its *real* N pole), it is evident that the compass-needle does not show the *true* north for all places upon the earth's surface. In fact, the N pole of the needle may point E, W, or even S. This effect would be seen by carrying a compass around the earth's N magnetic pole.

84. Declination. For convenience, we shall represent the true N and S, at the place where you are experimenting, by the full line, N S, in Fig. 23. The dotted line shows the direction taken by the compass-needle. The angle, A, between them, is called the *angle of variation* or the *declination*. This angle is not the same for all places; and, in fact, it changes slowly at any given place; so it becomes necessary to construct *magnetic maps* for the use of mariners and others.

Fig. 23.

[32]

EXPERIMENT 45. To study the lines of force above and below a bar magnet placed horizontally.

Apparatus. A bar magnet, B M (No. 21); compass, O C (No. 18).

85. Directions. (A) Lay B M upon the table and place O C upon its center. Note the position of the compass-needle.

(B) Slide O C along from one end of B M to the other, and study the effect upon its needle. Do lines of force curve *over* B M as well as around its sides, as shown in Exp. 31?

(C) Place O C upon the table. Hold B M horizontally above O C, and move O C back and forth under B M. Does the needle remain horizontal, or does it show that lines of force pass *under* B M on their way from its N to its S pole?

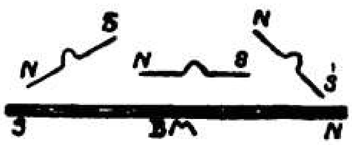


Fig. 24.

86. The Dip or Inclination of the Magnetic Needle. The needle is said to dip when it takes positions like those in Fig. 24. Compass-needles should be horizontal, when properly balanced, and entirely free from all effects other than those of the earth. The excessive dip shown (Fig. 24) is due, of course, to the efforts of the magnetic needle to place itself in the direction in which the lines of force of B M pass.

EXPERIMENT 46. To study the dip or inclination of the magnetic needle, due to the action of the earth.

Apparatus. Fig. 25. Our compass, O C (No. 18); horseshoe magnet, H M (No. 16); piece of paper.

87. Directions. (A) Place O C upon the table, and mark upon a piece of paper the height of the N pole of its needle above the table. (Fig. 25.) The paper should be held in a vertical position, and near the pole.

(B) With H M reverse the poles of the compass-needle (Exp. 13), so that its former N pole shall become a S pole.

(C) Place the needle upon its pivot again, and mark upon the paper, as before, the height of its new N pole above the table. Does the needle remain horizontal? [33]

(D) Remagnetize the needle, and reverse its poles so that it will again balance.

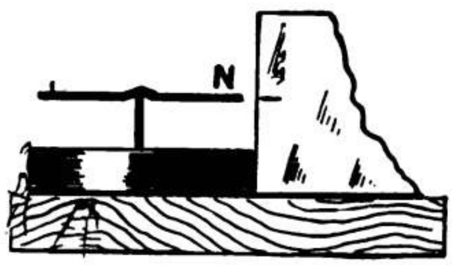


Fig. 25.

88. Discussion; Balancing Magnetic Needles. If a piece of unmagnetized steel be balanced and then magnetized, it will no longer remain horizontal; it will dip. Try this. Compass-needles are balanced after they are magnetized. Can you now see why the needle did not remain horizontal after its poles were changed? A piece of steel first balanced and then magnetized, has to have its S pole slightly weighted, as suggested by the line at S (Fig.

26 x), to make it horizontal. The magnetic needle does not tend to dip at the earth's equator, because the lines of force of the earth are nearly horizontal at the equator. As we pass toward the north or south on the earth, the lines of force slant more and more as they come from or enter the earth's magnetic poles. What position would the needle take if we should hold it directly over the earth's N magnetic pole? Fig. 24 shows what the needle does when held near the poles of a bar magnet.

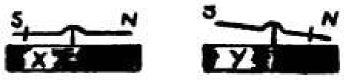


Fig. 26.

EXPERIMENTS 47–48. To study the inductive influence of the earth.

Apparatus for Exps. 47–48. Compass, O C, (No. 18); an iron stove poker, or other rod of iron; a hammer. (The iron and hammer are not furnished.)

89. Note. You have seen (Exp. 24), that iron becomes magnetized by induction when placed near a magnet. As the earth acts like a huge magnet, having poles, lines of force, etc., will it magnetize pieces of iron which are in the air or upon its surface?

90. Directions. (A) Test the poker for poles with O C, remembering that *repulsion* is necessary to prove that it is polarized. If the poker has very weak poles, proceed; but if it shows some [34] strength, hold it in an east and west direction, and hit it several sharp blows on the end with the hammer. Test for polarity again.

(B) With one hand hold the poker in the N and S line, give it a dip toward the north, and strike it several times with the hammer to thoroughly stir up its molecules.

(C) Test again for poles with O C, and note especially whether the lower end (of the poker) became a N or a S pole.

EXPERIMENT 48.

91. Directions. (A) Turn the poker end for end (See Exp. 47); repeat the striking, and test again the pole produced at the lower and north end of it.

(B) Now hold the poker horizontally in the east and west line, and pound it.

(C) Test for poles. Has this strengthened or weakened the poker magnet?

92. Discussion. Dipping the poker places it nearly in the same direction as that taken by the earth's lines of force. The magnetic influence of the earth acts to advantage upon the poker, by induction, only when the poker is properly held.

It no doubt occurs to the student that the end of a magnetic needle which points to the north is really opposite in nature to the north magnetic pole of the earth. The N pole of a needle, then, must be in reality a S pole to be attracted by the earth's N pole. It has been agreed, for convenience, to call the N-seeking pole of a magnet its N pole.

93. Natural Magnets. Nearly all pieces of iron become more or less magnetized by the inductive action of the earth's magnetism. Your poker was slightly magnetized at the start, perhaps, from standing in a dipping position.

Induction takes place along lines of force. In northern latitudes the earth's lines of force have a dip to the north. You should now see why the greatest effect was [35] produced upon the poker when it, also, was made to dip.

Parts of machinery, steel frames of bridges and buildings, tools in the shop, and even certain iron ores, become polarized by this inductive action. These might all be called natural magnets. Magnetic iron ore, called lodestone, is referred to, however, when speaking of *natural magnets*. Lodestone was used thousands of years ago to indicate N and S, and it was discovered, later, that it could impart its power to pieces of steel when the two were rubbed together.

EXPERIMENT 49. To test the effect of twisting a wire held north and south in the earth's magnetic field.

Apparatus. Compass, O C (No. 18); a piece of soft iron wire, 6 in. (15 cm.) long (No. 15). Bend up about an inch of the wire at each end so that it may be firmly held when twisting it.

Note. You have seen that we can *pound* magnetism into or out of a piece of iron at will. Can we *twist* it into a wire and out again without the use of magnets?

94. Directions. (A) Test the wire for poles with O C.

(B) Hold the wire in a N and S direction, dipping it at the same time, as directed in Exp. 47 for the poker, and twist it back and forth.

(C) Test again for poles with O C. As the poles of the wire may be very weak, bring them *slowly* toward the compass-needle (see Exp. 14), and note the *first* motions produced upon the needle.

(D) Hold the wire horizontally east and west, twist and test again. Has its magnetism become weaker or stronger than before?

EXPERIMENT 50. To test for magnetism in bars of iron, tools, etc.

Apparatus. Steel drills; files; chisels; bars or rods of iron that have been standing in an upright position; stove-lid lifters; stove pokers, etc., etc.; a compass.

95. Directions. (A) With the compass test the ends of the above for magnetism, and note which ends are S.

Notes.

STATIC ELECTRICITY

PART II.—STATIC ELECTRICITY

CHAPTER VI.

ELECTRIFICATION.

100. Some Varieties of Electricity. *Static electricity* does not seem to "flow in currents" as readily as some other varieties; its tendency is to stand still, hence the name, static. The simplest way to produce it is by friction. *Thermo electricity* is produced by changes in temperature. When certain combinations of metals become hotter or colder, a current is produced. *Voltaic* or *Galvanic electricity* is produced by chemical action. Batteries give this variety. *Induced electricity* is produced by other currents, and by combinations of magnets and moving coils of wire, as in the dynamo. This is, by far, the most important variety of electricity, and the dynamo is the most important producer of it.

Each of the above varieties of electricity will be studied experimentally with simple apparatus.

EXPERIMENTS 51–52. To study electrification by friction.

Apparatus. Ebonite sheet, E S (No. 26); flannel cloth, F C (No. 30). See what is said in preface about static electricity.

101. Directions. (A) Examine E S. Note that its surface is not smooth, like that of ordinary hard-rubber combs. Can you think of any reason for this?

(B) Hold its flat surface near your face, then near the back of your hand. Do you feel anything unusual?

(C) Lay E S upon a flat board, or uncovered wooden table, and slide it about. Can you easily pick it up?

(D) Place E S flat upon the table again; keep it from sliding about with your left hand, and rub it [40]
vigorously for a *minute* with F C. Does E S act exactly as it did before in (B) and (C)?

(E) Repeat the experiment in a dark room.

(F) Thoroughly electrify E S, and see if it will cling to the wall strongly enough to support its own weight.

102. Discussion; Electrified and Neutral Bodies. The ebonite sheet became *electrified* or *charged*; and as the *electrification* was produced by friction, we may say that the action of the ebonite indicated the presence of *frictional electricity*. No one can tell *just* why the ebonite acted so queerly, but we can learn a great deal by experimenting. Bodies which are not charged are said to be *neutral*. The table, chairs, earth, etc., are neutral. We may consider that a neutral body has been *discharged*.

103. Force; Resistance; Work; Potential Energy; Electrification. It takes *force* to raise water into a tank placed on the roof. In raising the water, *work* has to be done, and *we* have to do the work; but when we once have the water in the tank we have accomplished something. The water has *potential energy*; that is, on account of its high *position*, we can make it do some work by simply turning a stop-cock so that the water can run out and turn a water-wheel, for example.

It takes *force* to vigorously rub a piece of ebonite with a flannel cloth, for *resistance* has to be *overcome*; that is, *work* has to be done. Several things are accomplished by this work; heat is produced, for we can *feel* that the ebonite gets warm; we can *hear* sounds and *see* sparks. The simple muscular exertion on our part has been changed to heat, light, and sound. The most wonderful part of it all, however, is that we have electrified or charged the ebonite. *We* did the work at first, and now the ebonite has the power to do something, as you will soon see. *Electrification* is, then, a sort of [41]
potential energy.

104. Heat and Electrification. We say that heat passes to or from a body to make it hot or cold. Heat *produces* the sensation of warmth, but heat isn't warmth. We can force a cold body to become hot; in other words, we can get it into a hot condition in various ways, such as rubbing it, hammering it, or by placing it near or in contact with another hot body.

Electrification is, also, a condition or state into which we can force a body; but electrification isn't electricity. We know whether a body is hot or cold by its effects upon us, upon thermometers, and upon other bodies. We can tell, also, whether a body is electrified or not by the way it acts, and, in certain cases, by the sound, heat, and light which accompany the electrification.

Do not get the idea that an electrified body is covered with a layer of electricity just as a board is covered with a layer of paint.

EXPERIMENT 52.

105. Directions. Repeat Exp. 51, but in place of the ebonite, use hot tissue-paper, hot brown paper, hot newspaper, or a hot silk handkerchief. Rub your hand vigorously over them. Do these become charged?

EXPERIMENTS 53-54. To study electrical attractions.

Apparatus. The ebonite sheet, E S (No. 26); flannel cloth, F C (No. 30); small pieces of dry tissue-paper, T P (No. 31); thread (No. 32).

106. Directions. (A) Thoroughly electrify E S as before, then lift and hold it in the air. (Fig. 28.) [42]

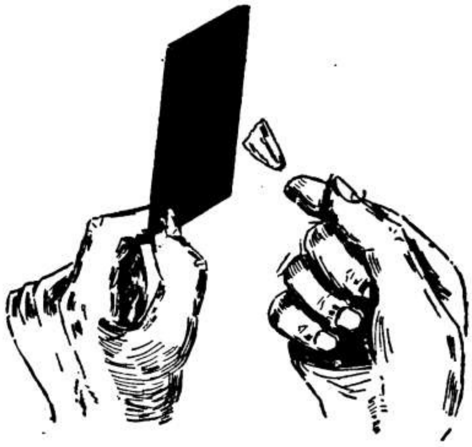


Fig. 28.

(B) See what the paper and thread will do when held loosely near E S.

107. Discussion. Exp. 53 shows that *an electrified body attracts neutral ones*. This much was known about electricity over 2,000 years ago. They didn't have ebonite then, but some of the educated men of Greece knew that amber would attract light bodies after being rubbed. The Greek word for amber is *elektron*, and from this has been made the word *electricity*.

EXPERIMENT 54.

108. Directions. Charge a sheet of hot paper by friction; lift it, by its opposite ends, and lower it over small pieces of tissue-paper placed on the table. What happens to the little pieces?

EXPERIMENT 55. To study mutual attractions.

Apparatus. The support and its attachments (See § 109); support wire, S W (No. 36); silk thread, S T (No. 33), or a rubber band, R B (No. 45); ebonite rod, E R (No. 28); flannel cloth, F C (No. 30); wire swing, W S (No. 37).

Tie one end of S T to W S, Fig. 29; tie the other end of S T to S W; adjust W S by bending, if necessary, so that it will securely hold E R. It will be found convenient to use a rubber band instead of S T; if you do, let W S straddle one end of R B (Fig. 33), and hang the other end of R B upon S W.

109. The support consists of a support base (S B, Fig. 56), a support rod (S R, Fig. 56), and a support wire (S W, Fig. 29). There is a small hole in one end of S R to receive the wire, S W, and a large hole in the other end to take the short ebonite which holds the insulating table (Fig. 32). A little paper should be wound around the lower end of S R, so that it will stand solidly in the spool which forms a part of the base.

110. Directions. (A) Electrify E R with F C, and place E R in the swing, W S (Fig. 29).

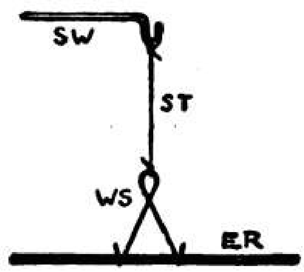


Fig. 29.

(B) Bring your finger near one side of the rubbed end of E R, then near the unrubbed end, and compare the results. [43]

111. Mutual Attractions. *A neutral body*, like the hand, for example, *attracts electrified ones*. From Exp. 53, 54, 55, it is seen that the attraction between a neutral and an electrified body is mutual; each attracts the other.

EXPERIMENT 56. To study electrical repulsions.

Apparatus. Same as for Exp. 55; ebonite sheet, E S (No. 26).

112. Directions. (A) Charge E R, and place it in W S, Fig. 29.

(B) Charge E S, and bring it slowly near one side of the charged end of E R.

EXPERIMENT 57. To study electrical repulsions.

Apparatus. A sheet of tissue-paper, T P (No. 31); shears or a knife. Cut T P, as in Fig. 30. Each leg should be about ¼ in. wide and 3 or 4 in. long.

113. Directions. (A) Heat the paper, then place it flat upon the table and electrify it by rubbing it with your hand. You must rub away from the uncut part, or you will break the legs.

(B) Raise T P, holding it by the uncut part. Note the action of legs, and make a sketch of them.

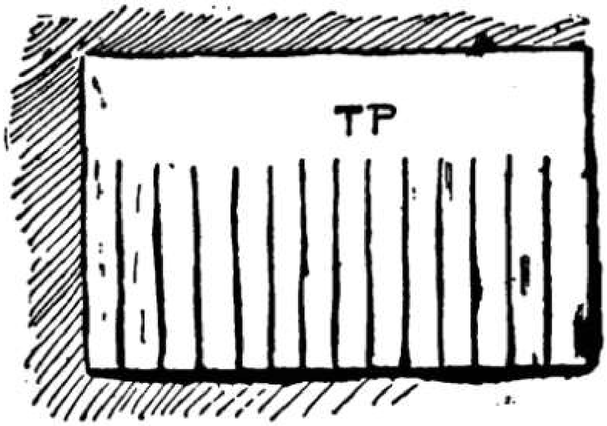


Fig. 30.

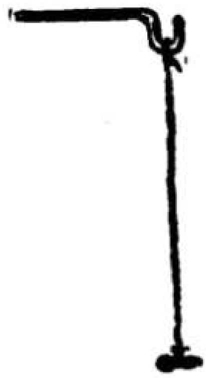


Fig. 31.

EXPERIMENT 58. To study electrical repulsions.

Apparatus. Ebonite rod, E R (No. 28); a carbon electroscope, C E, Fig. 31 (see § 114); the support complete (see § 109); small piece of damp tissue-paper.

114. The Carbon Electroscope. Light an ordinary match, and let it burn until it is charred through and through. The black substance remaining is *carbon*. This is very light; it has, also, another important property which you will soon understand. Tie a small piece of the carbon to one end of a dry *silk* thread, and fasten the other end of the thread to the support wire, S W, which is fastened to the support (Fig. 31). We shall call this piece of apparatus the *carbon e-lec-tro-scope*. (See Electroscopes, Chapter XVIII., Apparatus Book.) [44]

115. Directions. (A) Electrify E R, then hold it near the carbon of the electroscope.

(B) Bring the charged rod near little pieces of *damp* tissue-paper.

116. Discussion of Experiments 56, 57, 58. In 56 the two pieces of ebonite were made of the same material, and both were rubbed with flannel. They must have been similarly electrified. In 57, different parts of the same piece of paper were similarly electrified. In 58, the little piece of carbon took some of the electrification from the charged rod, just as it would take molasses from your finger should your sticky finger touch it. The electrification on the carbon must have been of the same kind as that on the rod. The carbon was *charged by contact*. We learn, then, that *two bodies repel each other when they have the same kind of electrification*. Do two charged bodies *always* repel each other? Is it possible that there are different kinds of electrifications?

EXPERIMENT 59. To study the electrification of glass.

Apparatus. The sheet of glass, G (No. 38), heated (a hot bottle or lamp chimney will do); a piece of silk large enough to rub G. (A silk handkerchief is just the thing, but in case you have no silk, use the flannel cloth, F C, No. 30.)

117. Directions. (A) Vigorously rub the hot glass with the silk (or flannel), also heated. [45]

(B) Test G for electrification by means of little pieces of tissue-paper and the carbon electroscope, Exp. 58.

118. Questions. Will two pieces of electrified glass repel each other? Arrange an experiment to show whether you are right or not. Is the charge on the glass exactly like that on the ebonite? Do you know how to find out?

EXPERIMENT 60. To compare the electrification produced by ebonite and flannel with that produced by glass and silk.

Apparatus. The support (see § 109); wire swing, W S (No. 37); ebonite rod, etc., of Exp. 55 (Fig. 29); the glass, G, and silk of Exp. 59.

119. Directions. (A) Electrify E R, and place it in W S, Fig. 29.

(B) Bring the uncharged glass near E R, noting the action of E R.

(C) Heat and electrify G; bring it near E R, and carefully note whether the attraction between them is stronger or weaker than before, or whether they repel each other.

120. Discussion. We know that the glass was electrified, because it lifted tissue-paper; hence, its charge was not of the same kind as that on the ebonite. Had the electrifications been exactly alike, we should have had a repulsion (Exps. 56, 57, 58).

The exact difference between these two kinds of electrifications is not known. It has been agreed, for convenience, to call that produced by glass and silk a *positive* electrification. With ebonite and flannel a *negative* electrification is produced. The sign + is generally written for the word positive, and - for negative. These signs indicate *kind*, and not more or less, as in arithmetic.

121. Laws. We have learned from the experiments these facts, which are called *laws*: [46]

(1) Charges of the same kind repel each other; (2) charges of unlike kinds attract each other; (3) either kind of a charge attracts, and is attracted by a neutral body.

CHAPTER VII.

INSULATORS AND CONDUCTORS.

EXPERIMENT 61. To study insulators.

Apparatus. Ebonite rod, E R (No. 28); flannel cloth, F C (No. 30); tissue-paper, T P (No. 31).

122. Directions. (A) Holding one end of E R in the hand, charge the other end by rubbing it with F C.

(B) With bits of the T P test each end of E R for a charge, and compare the results.

EXPERIMENT 62. To study insulators.

Apparatus. The ebonite sheet, E S (No. 26); flannel cloth, F C (No. 30).

123. Directions. (A) Thoroughly electrify E S (Exp. 51, D), then lift and hold it in the air, as in Fig. 28.

(B) By moving your rounded knuckle about near the surface of E S, see if you can get more than one spark from it.

EXPERIMENT 63. To study insulators.

Apparatus. A hard-rubber comb (not furnished); flannel cloth, F C (No. 30); dull pointed nail (No. 19).

124. Directions. (A) Electrify the comb with F C.

(B) Move the nail along near the teeth of the comb, and listen carefully.

125. Discussion of Experiments 61, 62, 63; Insulators. In 61 the electrification remained at one end of the rod. In 62 and 63 the sparks showed that all parts of the ebonite were not discharged at the same time. A substance, like ebonite, which will not allow electrification to pass from one part of it to another, is called an *insulator*. Silk and glass are also insulators. Do you now see why a silk thread was used to make the carbon electroscope?

Why do they fasten telegraph wires to glass insulators? [48]

126. Conductors. It has already been stated that water in an elevated tank has potential energy. We can allow the water to flow through a conducting pipe to another tank a little lower than the first, and it will still retain much of the potential energy, but not all.

Can we conduct from one place to another this peculiar state of things, this queer form of potential energy which we call electrification? It is clear, from the last experiments, that in order to do it we need something besides ebonite, which really acts like a closed stop-cock to the flow of electrification.

To keep electrification in one place we need an insulator; to get it from one place to another we need a *conductor*. Insulators are as important as conductors.

You saw that sparks went to the finger from the ebonite, so we call the finger a conductor. You have learned that attractions and repulsions show the presence of electrification. Can we have our charged body in one place and get attractions or repulsions at some other place?

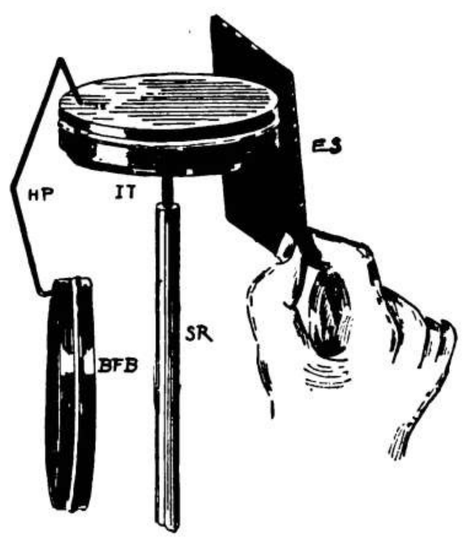


Fig. 32.

EXPERIMENT 64. To study conduction.

Apparatus. Fig. 32; the support (see § 109); a bent hairpin, H P (No. 39); ebonite sheet, E S; flannel cloth, F C; tin disk, B F B (No. 40), which is the bottom of the flat-box, F B; the insulating table, I T (see § 127).

127. The Insulating Table consists of a tin box (exactly like that used for the electrophorus cover), and an ebonite rod about 1¾ in. long. See § 139 for full details about fitting the rod into the box, etc. The lower end of the short rod fits into the large hole in one end of the support rod, S R. Arrange as in Fig. 32. B F B should swing about very easily. [49]

128. Directions. (A) Charge E S, then rub it upon I T, as shown, noting the action of B F B.

129. Discussion. Ebonite being an insulator (§ 125), we say that I T, H P and B F B were *insulated*. You can see that the electrification must have passed through I T and H P to get to the disk, B F B. H P was the *conductor*, allowing the disk, also, to become charged. The wood, S R, is a conductor, and, as it was not insulated from the earth, S R was neutral. Account for the attraction. (See § 121.)

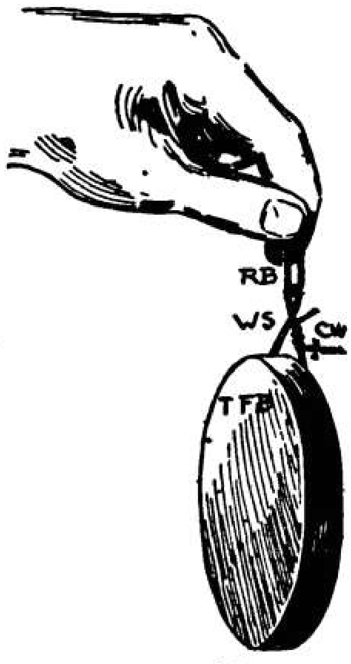


Fig. 33.

EXPERIMENT 65. To study conduction.

Apparatus. A copper wire, C W (No. 44); insulating rubber band, R B (No. 45, Fig. 33); wire swing, W S (No. 37); the other half of the flat box, T F B (No. 41); apparatus of Exp. 69.

130. Telegraph Line. To have our telegraph line using frictional electricity complete, we must have: (1) Some way of generating or making the electricity; (2) Some means of getting it or its effects to the other end of the line; (3) Some way of showing that it has been taken there.

The charged E S will be the source of the electrification. New York will represent the end at which we *send* the message, so at N. Y. we must have a *sending instrument*. See Fig. 33, which explains itself. R B or a silk thread must be used to *insulate* the sender. Around one leg of W S is twisted one bare end of the *conductor*, C W.

Boston will represent the end of the line at which the message is received, and there we need a [50]
receiving instrument. This is similar to the apparatus described in Exp. 69, Fig. 37. In addition to this, tie the middle of a moist cotton thread that is 6 in. long, to B C (Fig. 37), and let its two free ends lie over the top and reach down against the bottom of the tin; that is, on the left-hand side. Fig. 42 will give you an idea in regard to the looks of the thread; at first, however, it should be close to the bottom of the tin. Twist the other bare end of the copper wire around B C.

When the line is properly constructed and ready for use, both instruments and C W are entirely insulated. Do not let any part of C W touch the table or your clothing.

131. Directions. (A) Touch the insulated sending instrument with the charged ebonite sheet, and watch for any motion in the receiving instrument.

Note. Better results will be obtained by using the charged electrophorus cover as the source of electrification, instead of E S. (Exp. 68.)

132. Discussion. The action here was like that in the previous experiment, the difference being that a longer *conductor* was used. Electrification is always looking for some place to get to the earth, just as water will run from a roof to the ground. You will understand more about it a little later. In our apparatus just described, the only way that the earth could be reached was through the wooden rod S R. Do not get the idea that real messages are sent in any such way, or that electricity flows through a wire as water flows through a pipe.

133. Relation between Conductors and Insulators. The above terms are merely relative. Static electricity is easily conducted by dry wood, while Galvanic electricity is practically insulated by it. A substance may be an insulator for currents of low potential, while at the same time it will conduct high potential currents. (See Potential § 144.)

134. Electrics and Non-electrics. Bodies like glass, sealing-wax, amber, etc., were [51]
called electrics by the first students of electricity, because it was upon these

substances that they could easily produce electrification. They called iron and other metals non-electrics, because they could detect no electrification after rubbing them. Can you explain why they did not detect any electrification on metals? Can you devise an experiment to prove that metals may be charged? Do you see any relation between a non-electric and a conductor?

EXPERIMENT 66. To study the effect of moisture upon an insulator.

Apparatus. Same as for Exp. 65, with the exception of the copper wire; this is to be replaced by a dry silk thread about 2 feet (60 cm.) long (No. 33).

135. Directions. (A) See if a charge can be sent through the thread, in the same manner as it was through the copper. Is dry silk a conductor?

(B) Thoroughly wet the thread, being careful not to wet the rubber band insulator (Fig. 33); see if wet silk is a conductor.

136. Discussion. Dry silk is an insulator, while wet silk is a good conductor of *static* electricity. It is the water, however, which really does the conducting. Even small amounts of moisture on glass, or other insulators, will allow the charge to escape. Glass collects much moisture from the air. Do you now see why it is necessary, to get good results, to have the paper, glass, etc., hot before electrifying them?

EXPERIMENT 67. To test the effects of moisture upon bodies to be electrified.

Apparatus. Two pieces of newspaper, each about 4 in. (10 cm.) square.

137. Directions. (A) Heat one piece to make it thoroughly dry, and leave the other cold.

(B) Stroke each, say 10 times, with your hand, pressing them upon the table; then place them upon the wall at the same time, being careful not to let them touch your clothing. See which will cling to the wall the longer.

CHAPTER VIII.

CHARGING AND DISCHARGING CONDUCTORS.

138. The Electrophorus. While the ebonite sheet alone, or a good hard-rubber comb, may be used for many experiments in frictional electricity, the sparks produced are small, and the ebonite has to be electrified as often as it is discharged. To obtain real good sparks, and to avoid this continual rubbing, the student should be provided with an *e-lec-troph'-o-rus*. This is, really, a simple, cheap, and efficient frictional electric machine. An electrophorus consists of 2 insulators and 1 conductor—that is, of 3 parts: (1) insulating handle, (2) cover, and (3) a plate or base of insulating material.

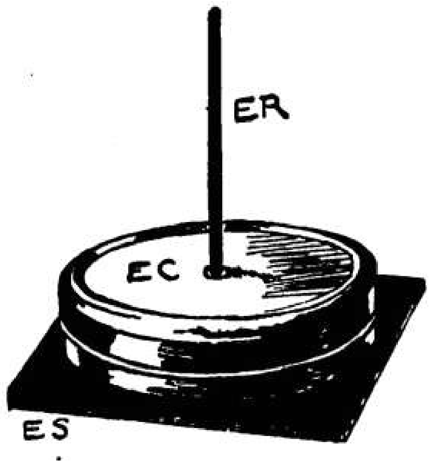


Fig. 34.

139. Our Electrophorus is shown in Fig. 34. For the insulating *handle* use the ebonite rod, E R (No. 28); for the *plate*, use the ebonite sheet, E S (No. 26). The *electrophorus cover*, E C (No. 42), furnished, is a tin box with a fancy top. A hole has been punched in the center of its top, and into the hole has been riveted a short tube, so that the handle, E R, can be firmly held. The hole has been made a little larger than E R for convenience. To make E R fit tightly in the hole, so that you can lift E C, wrap a small piece of paper around the end of E R before pushing it into the hole. You can easily find out how much paper to use to make a good fit. With a knife cut away all loose points of paper that stick out of the hole around E R; this is *important*. The top and bottom of E C should be pressed firmly together.

First learn how to use the electrophorus. With the large amount of electrification produced we can then find out how it works.

[53]

EXPERIMENT 68. To learn how to use the electrophorus.

Apparatus. Shown in Figs. 34, 35. *Do not fail to read* § 139.

140. Directions. (A) Place E S upon a *flat*, uncovered, wooden table, and rub it *vigorously* for a *minute* with the *warm* flannel, F C, to thoroughly charge it. Do not let E S slide about, and do not lift it from the table.

(B) With the right hand grasp E R at its extreme end, and place E C upon E S.

(C) Touch E C for an instant with a finger of your left hand (Fig. 35).

(D) Remove your finger entirely from E C, then lift E C by its insulating handle, E R, at the same time holding E S down to the table, if it tries to follow E C.

Fig. 35.

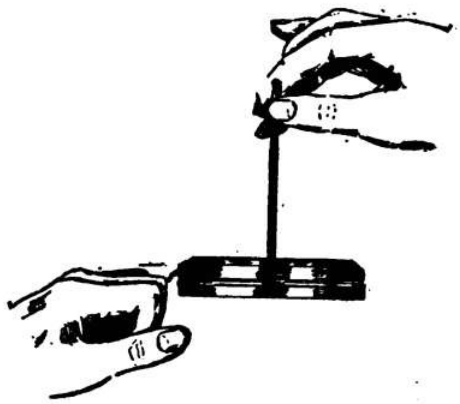


Fig. 36.

(E) Bring your left hand near E C (Fig. 36). You should get a good spark from E C.

(F) It is not necessary to immediately rub E S again. You have discharged E C by taking a spark from it. To *recharge* it, simply place it upon E S again; let it remain there while you count 5; touch it as before, and then lift by E R.

141. Extra Notes. You may repeat the above operation many times. As soon as the sparks begin to get small, electrify E S again. The charge on E C is +, although that on E S is -. You will understand, later, why this is so.

If you do not get a good spark from the electrophorus, read the directions again. The ebonite must be well electrified; the cover must be lifted by the *end* of its handle; you must *touch* the cover and *withdraw your finger* from it *before* lifting. You must allow the cover to [54] remain upon the ebonite 3 or 4 seconds each time. The board, or table, upon which E S rests, must be *flat*, and not warped, so that E C will fit down perfectly upon E S.

EXPERIMENT 69. To study "charging by conduction."

Apparatus. Fig. 37. To one end of a *silk* thread, S T, is tied a little bent clamp, B C (No. 46); the other end of S T is tied to the support wire, S W (No. 36); the bottom of the flat box, B F B (No. 40), is supported by B C, and thus *insulated* from the table and earth; the electrophorus (Exp. 68) is also necessary.

142. Directions. (A) Charge E C (Exp. 68), and bring it near B F B (Fig. 37). Note the spark.

(B) Repeat (A) twice, noting the relative sizes of the sparks. Does B F B continue to be attracted by E C?

(C) Bring your knuckle slowly towards the charged disk, B F B.

Fig. 37.

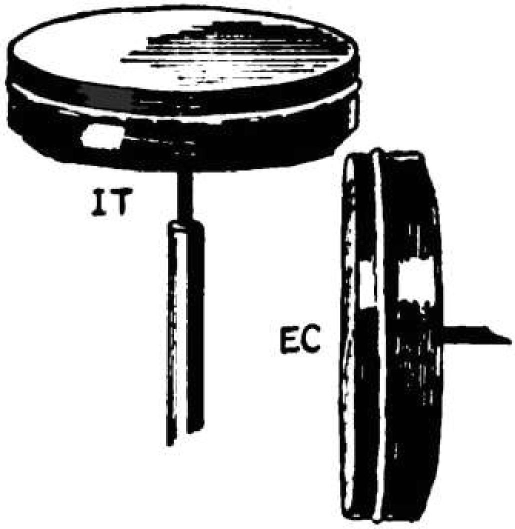


Fig. 38.

EXPERIMENT 70. To study potential; electro-motive force.

Apparatus. The insulating table, I T, Fig. 38. (For details see Exp. 64; the electrophorus Exp. 68).

143. Directions. (A) Pass a spark from the thoroughly charged E C (Exp. 68) to I T.

(B) Recharge E C, and see how many times I T will take good sparks from it, and note the [55] relative sizes of the sparks.

(C) As soon as I T refuses to take more sparks from E C, touch E C to see if it is completely discharged.

(D) Touch I T.

144. Pressure; Potential; Electro-motive Force. Water runs down hill. It always tries to run from a high place to a lower one. Electrification acts very much like water in this respect. We say that water has a *pressure*, or a *head* of so many feet. In speaking of a charge, we say that it has a *potential, or an electro-motive force*. Water may have a high or low pressure, and a charge may have a high or low potential. The greater the pressure of water, the harder it tries to break away and get somewhere; the greater the potential of a charge, the farther it will jump to your hand.

144a. Current; Spark. Electrification will easily pass from a place of high potential to one of low potential through a conductor, and when it *passes* we say we have an *electric current*, or a *current of electricity*. Water has no desire to flow on a dead level, and the electric current does not care to flow between two places of equal potential. The potential of the earth and of all neutral bodies is zero; that is, they have no charge, no potential; so it is very easy for a charge to escape into the earth.

Dry air is a pretty good insulator, but when the attraction between a charged and a neutral body gets great enough, the spark rips right through the air. Benjamin Franklin proved by experiment that lightning is caused by the electrification in the clouds and air. (See Atmospheric Electricity.)

145. Theories about Electrifications. *The "One-Fluid" Theory* suggests that neutral bodies have a certain amount of electrification, and that they have a certain potential called zero [56] potential. If the potential of a body becomes greater than that of the earth, the body is said to be positively electrified; if the potential of the body is less than that of the earth, it is said to be negatively electrified. If we fill a bottle with sea water, we have a great deal of water when we compare it with the bottle, but a very little water when we compare it with the sea. The earth is so large that small amounts of electrification taken from it or added to it do not affect its potential to any extent.

146. *The "Two-Fluid" Theory* suggests that there are two absolutely different kinds of electrification, one called positive (+), and the other negative (-). When these two are equal in quantity, the body is said to be neutral. If the body contains more + than -, the body is said to be charged positively.

It is evident then, if the two-fluid theory be accepted, that no matter how strongly a body is charged positively there must be in it *some* negative electrification; that is, we may charge a neutral body + by adding + electrification to it, or by taking - electrification from it. There must always be, then, some + and - electrifications in a body.

These theories do not require much consideration by the student of elementary electricity. The best thing he can do is to learn what electricity can do, and how it can be used.

EXPERIMENT 71. To study some methods of discharging an electrified body.

Apparatus. The electrophorus (Exp. 68); an ordinary pin (Fig. 39).

147. Note. You have seen sparks pass from E C to your rounded knuckle, and to other conductors. In all of these cases the discharge was *sudden*, one spark doing the work. Can we *slowly* discharge E C, or discharge it without sounds?

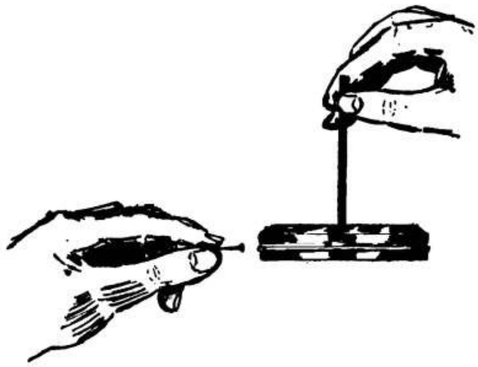


Fig. 39.

148. Directions. (A) Thoroughly charge E C, and test it with your knuckle to be sure that it is working properly. [57]

(B) Charge E C again; hold the pin in your left hand (Fig. 39), and *slowly* bring its *head* toward E C; listen for sparks.

(C) Recharge E C, and bring the *point* of the pin slowly toward it. Touch E C to see whether it has been discharged or not.

149. Disruptive, Conductive, and Convective Discharges. Sudden discharges, accompanied by bright sparks, are said to be *disruptive*. When the electrification is continuously carried away by a conductor, there is a *conductive* discharge. There is a *convective* discharge when the electrification escapes from points into the air. (See § 155.) The nature of the discharge depends upon the potential of the charge, upon the nature of the charged conductor, and upon the nature of the surrounding air and objects. Convective discharges are often *silent*, as in Exp. 71 (C). In this case, electrification passed from the earth through the pin-point to the cover to neutralize it. (See Induced Electricity.)

EXPERIMENT 72. To study intermittent or step-by-step discharges.

Apparatus. Electrophorus (Exp. 68); carbon electroscope (§ 114), (Exp. 58).

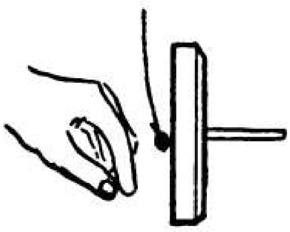


Fig. 40.

150. Directions. (A) Charge E C, then hold your hand on one side of the carbon (Fig. 40), and hold E C upon the opposite side. What should the carbon do?

151. Discussion. The carbon and E C were insulated, while the hand was "grounded"—that is, it was connected with the earth. Carbon is a good conductor; it may be quickly charged and discharged.

[58]

EXPERIMENT 73. To ascertain the location of the charge upon an electrified conductor.

Apparatus. The electrophorus (Exp. 68); the insulating table, I T (Exp. 64); the tin box, T B (No. 47), Fig. 41; a piece of moist cotton thread, C T, 5 or 6 in. long, bent double, and hung over the edge of the open box, T B. One-half of C T should be inside of T B, which, in turn, should stand on I T.

152. Directions. (A) Charge E C; pass a spark to T B, and note the action of both parts of C T.

153. Hollow and Solid Conductors. The moist thread, being a conductor, became charged as well as the box. The electrification seemed to be entirely on the outside of T B. A hollow conductor will hold as large a charge as a solid one having the same amount of surface. This refers to charges of static electricity, not to currents. An electric current passes through the whole substance of a conductor.

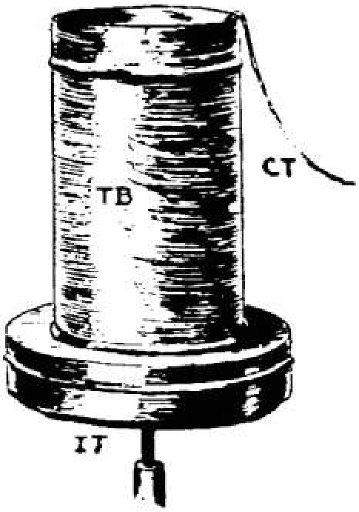


Fig. 41.

EXPERIMENT 74. To study the effect of points upon a charged conductor.

Apparatus. The electrophorus (Fig. 34); a pin, bent slightly to keep it from rolling.

154. Directions. (A) Charge E C; test its charge with your knuckle. Be sure that you get a good spark.

(B) Charge E C again, and hold it by its insulating handle, E R, long enough to count 10 before discharging it with your knuckle. Be sure that it holds its charge during this time.

(C) While E C is upon E S (Fig. 34), lay the bent pin upon E C, so that its point will project into the air. The point should stick out about ¼ in. from the edge of E C.

(D) Touch E C; raise it by E R; count 10 as before; then test with your knuckle to see if E C is still charged.

155. Electric Density; Electric Wind. A charge resides upon the outside of a conductor (Exp. 73), and it continually tries to escape. It seems to pile up at points and corners, and we say that it is denser at such places than at well-rounded parts of a charged conductor. All points and sharp places should be removed from a conductor, if it is desired to keep a charge for any length of time. [59]

Electrification may escape from a point so rapidly that currents are produced in the surrounding air. As the particles of air become charged, they repel each other. The movement of the air particles may be so great that a lighted candle will be affected when placed near the point. This current of air is called *electric wind*.

Electrification easily passes from points, and the electrophorus may be easily and silently discharged by holding a pointed pin near it (Exp. 71, C). Thorns, leaves with sharp edges, etc., have a great effect upon atmospheric electricity. They allow a silent escape of electrification from the earth to neutralize that in the clouds which is opposite in nature. (See Atmospheric Electricity.)

CHAPTER IX.

INDUCED ELECTRIFICATION.

156. Electric Field; Lines of Force. In our study of magnetism you learned that a magnet can act through the air, and induce a piece of iron to become a magnet. You saw how the iron filings arranged themselves around the magnet, showing that the lines of force reached out from the poles in a very peculiar manner. There is an *electric field* all around a charged conductor, just as there is a magnetic field about a magnet. The lines of force in the electric field pass from the positively charged body to the negatively charged one, or to some neutral one, which, you will soon see, is practically the same thing. When the positively charged electrophorus cover is held above the negatively charged ebonite sheet, a very strong electric field exists between them.

157. Note. You have seen that we can *charge* an insulated conductor by *touching* it with the charged cover, or by allowing a spark to pass to the conductor. What effect, if any, has a charged body upon an insulated conductor *before* they touch each other, and before any spark passes to the conductor?

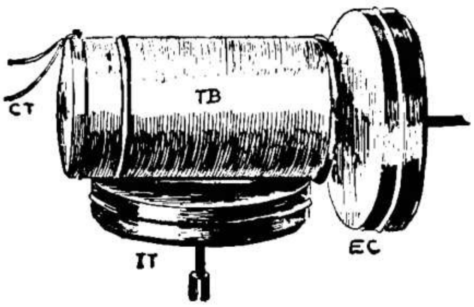


Fig. 42.

EXPERIMENT 75. To study electric induction.

Apparatus. Fig. 42. The insulating table, I T (for details see Exp. 64); tin box, T B (No. 47, Fig. 42); moist cotton thread, C T; the electrophorus (Exp. 68); tie C T around one end of the closed T B, and leave the ends of C T long enough to hang down over the end. Place a match on each side of T B to keep it from rolling. [61]

158. Directions. *Part 1.*—(A) Pass a spark from the charged E C to T B, and note the action of the thread, which will be our electroscope. Remove E C.

(B) Touch the charged T B with the finger, watching C T.

Part 2. (C) Bring the re-charged E C near the neutral T B, and parallel to its end surface; but keep them at least an inch apart, so that a spark cannot pass. Watch C T.

(D) Withdraw E C, and try to explain the action of C T.

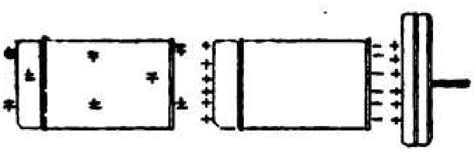
159. Electric Polarization; Theory of Induction. This experiment should remind the student of Exp. 24, in magnetism, in which a piece of soft iron was magnetized by the inductive action of a magnet. The soft iron was in a magnetic field; it became polarized. Is it possible that the box, T B, was polarized, being in the electric field of E C?

We know, by the action of C T (Fig. 42), that the top end of T B was charged while E C was in place. The charge was not conducted.

You know, from previous experiments, that + and - electrifications rush together whenever possible. Why can we not suppose that a neutral body, like the box at the start, contains an equal amount of both kinds, and that these different electrifications have already rushed together?

If you imagine a small army of positive soldiers struggling, "man to man," with the same number of equally strong negative soldiers, you can readily see that one-half of them can hold the other half from running away. A body remains neutral, then, according to this idea, as long as it has an equal quantity of the two opposite kinds of electrification. (See Theories, § 145, 146.)

As soon as the positively charged E C was brought near T B, it destroyed the neutrality of T B, by pulling at its - electrification, and by pushing back its + electrification to the top end and into C T. We say that the charged E C produced a separation of the combined electrifications of T B by *induction*, and not by contact. As soon as the inductive action of E C was removed, T B became neutral again. [62]



Figs. 43–44.

160. Note. Figs. 43 and 44 may aid the student. In Fig. 43, T B is supposed to be neutral. The "double sign" means that the + and - electrifications are united; and, as there are an equal number of both kinds, none are left free to tell the tale. Fig. 44 shows what happens when the + E C is near.

What would happen if we could cut into T B at the middle with an insulated knife while it is polarized by E C?

EXPERIMENT 76. To learn how to charge a body by induction.

Apparatus. Fig. 42, same as in Exp. 75.

161. Directions. (A) Bring the charged E C within an inch of the bottom of T B, and as soon as C T is repelled, showing that T B is polarized (Exp. 75), touch T B with your finger; then remove your finger while you still hold E C in place.

(B) Withdraw E C and its inductive action. Explain the motions of C T during the experiment. Is it still repelled by T B after E C is removed?

162. Free and Bound Electrifications. As explained in Exp. 75, and as shown in Fig. 44, T B became polarized. The - electrification was drawn towards E C; it was held or *bound* there as long as E C was near. The + was actually repelled by E C, and it was *free* to escape through your arm as soon as T B was touched, leaving the top end of T B neutral. As soon as E C was removed, the - electrification, no longer held by E C, [63]
spread all over T B and on to C T. T B was *charged by induction*. It was charged negatively by driving out + electrification.

EXPERIMENT 77. To show that a neutral body is polarized before it is attracted by a charged one.

Apparatus. The electrophorus (Exp. 68); dry tissue-paper, T P. Cut out 2 pieces of T P, each about ¼ inch square.

163. Directions. (A) Place the bits of dry T P upon a board or table, and convince yourself that they are attracted equally by the charged E C.

(B) Slightly moisten one piece of T P only. See if one is attracted by E C more readily than the other.

164. Polarization Precedes Attraction. Dry tissue-paper is not a good conductor; you have seen (Exp. 52) that it can be electrified, which indicates that it is at least a partial insulator. Insulators are not easily polarized. (Why?) Even if the pieces of T P were polarized, the opposite electrifications were so near each other that the attraction of E C for the - was nearly overcome by the repulsion for the +; the result being that T P was not strongly attracted by E C until the + had a chance to escape. The moist tissue-paper allowed its + to escape more quickly than the dry piece. A conductor is attracted by a charged body more strongly than an insulator, because the latter is not easily polarized. A neutral body, then, is really no longer neutral when it is in the electric field. *Polarization precedes attraction.*

EXPERIMENT 78. To find whether electric induction will act through an insulator.

Apparatus. Small bits of carbon (Exp. 58); bits of moist tissue-paper, T P; one-half of the flat box, T F B (No. 41); sheet of glass, G (No. 38); electrophorus (Exp. 68). Place the carbon and T P into T F B (Fig. 45), and cover with the glass.

165. Directions. (A) Charge the electrophorus cover, E C (Exp. 68), move it about a little [64]
above the glass, and see if the carbon, etc., are attracted.

166. Dielectrics. The carbon must have been polarized and attracted *through* the glass. You saw, Exp. 7, that the lines of magnetic force could penetrate and act through paper, glass, etc.; it is now evident that the electric field is not easily fenced in, even by an insulator. Substances, like the glass, which allow this inductive influence to act through them, are called *dielectrics*.

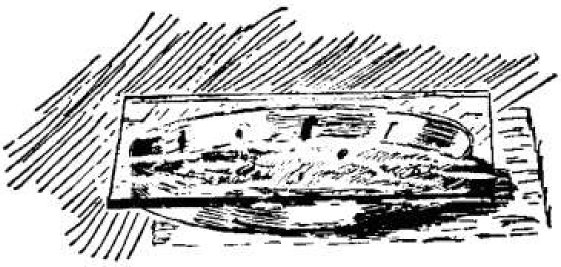


Fig. 45.

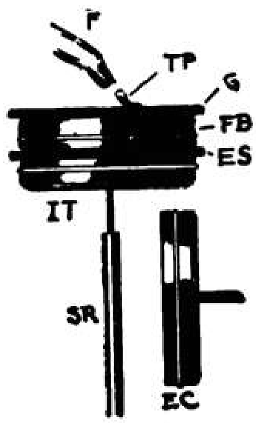


Fig. 46.

EXPERIMENT 79. To find whether a polarized conductor can act inductively upon another conductor.

Apparatus. Fig. 46. Insulating table, I T (for details see Exp. 64); ebonite sheet, E S (No. 27); flat box complete F B (Nos. 40, 41); sheet of glass, G (No. 38); small piece of slightly moist tissue-paper, T P; charged electrophorus cover, E C. Arrange as shown.

167. Directions. (A) Hold E C, charged, near and under I T, then bring your finger, F, near T P. Explain the action of T P.

168. Successive Induction. The inductive influence of E C first polarized I T; this acted through the dielectric, E S, and polarized F B, which, in turn, polarized T P [65] through the second dielectric, G. This induction after induction is called *successive induction*.

169. Inductive Capacity. Dielectrics are insulators. Two substances may be equally good insulators, that is, they may equally well resist the *spread* of electrification *over* their surfaces, or the *flow* of the electric current *through* them, while one may be, nevertheless, a better *dielectric* than the other. The better the dielectric, the easier it is for the electric field to polarize a conductor placed beyond the dielectric. A good dielectric is said to have a high *inductive power or capacity*. Glass is about 3 times as good a dielectric as dry air; and as the latter (under certain conditions) is taken as the standard, or as unity, we may say that the *specific inductive capacity* of glass is about 3.

EXPERIMENT 80. To study the action of the electrophorus.

Apparatus. The electrophorus (Exp. 68); small bits of moist tissue-paper, T P.

170. Directions. (A) Thoroughly electrify E S, Fig. 34, and place E C upon it by its handle, E R.

(B) Touch E C, as directed in Exp. 68, and listen for a small spark which should pass from E C to your finger.

(C) Again, place a little piece of T P upon E C before lowering it upon E S. Do not touch E C, but bring your finger near T P. What does T P do? Now, touch E C and see, when you bring your finger near it, if T P acts as it did before.

(D) Again, place several pieces of T P upon E C (E S being thoroughly charged); touch E C, then lift it by its handle. Note action of T P, which should be slightly moist.

171. Discussion. The electrification upon the ebonite is negative (Exp. 60). Although E S and E C (Fig. 34) seem quite smooth, there are many little hills, valleys, and air-spaces between them, which keep them from touching each other perfectly. The ebonite has the electric field at the start, and it really acts across these minute air- [66] spaces *by induction* (Exp. 75), and polarizes E C. The air-spaces form the dielectric (Exp. 78). The - electrification of E C being repelled by the - of E S, it is driven to the top of E C, while the + is drawn to the bottom. This + is kept from rushing to the - of E S by the air dielectric, and because E S is a non-conductor. By touching E C the free - escapes to the earth, leaving E C *positively* charged when it is lifted.

Fig. 47.

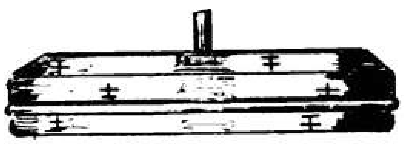


Fig. 48.

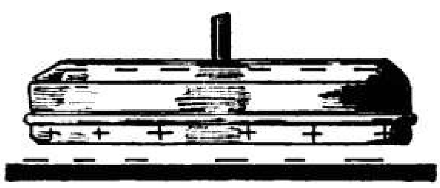


Fig. 49.

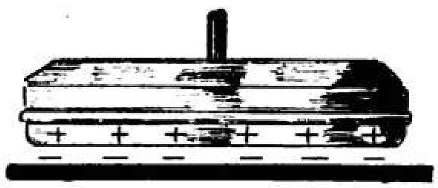


Fig. 50.

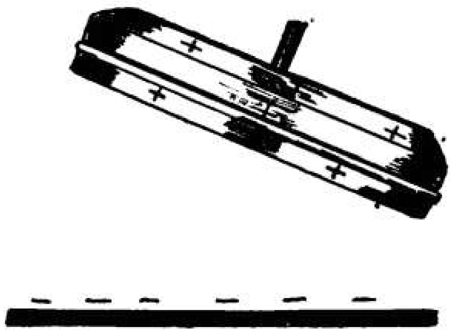


Fig. 51.

172. Details of Action. The different steps in the action of the electrophorus are shown graphically in Figs. 47 to 51. Fig. 47 shows E S negatively charged. E C is neutral at first, Fig. 48; that is, it is supposed to contain both + and -, as shown by the "double sign" (§ 160). Fig. 49 shows that E C has been polarized by the inductive action of E S. The repelled - escapes to the finger (this escaping is what gave the small spark to the finger and charged the T P in the last experiment), leaving the top uncharged, while the + is *bound* (Fig. 50). As soon as E C is lifted [67] (Fig. 51) the + spreads all over E C, which is then charged. The +, upon going to the top, charged the pieces of T P (Exp. 80, D), causing them to be repelled. The charge of - upon E S has not been removed, so the operation may be repeated many times before E S must be again electrified.

The - electrification on the ebonite acts inductively through E S, drawing up + electrification from the earth. To make this action easier a "sole," or metal conductor, is often placed under the ebonite.

EXPERIMENT 81. To see, hear, and feel the results of inductive influence and polarization.

Apparatus. Ebonite sheet, E S (No. 26); insulating table, I T; flannel cloth, F C.

173. Directions. (A) Thoroughly charge E S with F C. With the right hand bring E S near and parallel to the top surface of I T, but do not let them touch each other.

(B) Remove E S, then touch I T to see if it is charged.

(C) Repeat (A), and while you hold E S about ½ inch from I T, their flat surfaces being parallel, touch I T. Watch for any sparks, and note any peculiar actions of E S.

(D) Remove your finger from I T, then withdraw E S; finally touch I T with your knuckle.

174. Discussion. This apparatus is really the electrophorus upside down. It shows very clearly (1) the escape of the - electrification from I T, by the spark; (2) that the attraction between I T and E S is much greater than before, when this - is removed; and (3) it shows the different steps of the inducing and charging process, as described in Exp. 75, and as shown in Figs. 43 and 44.

CHAPTER X.

CONDENSATION OF ELECTRIFICATION.

EXPERIMENT 82. To find whether a large surface will hold more electrification than a small one.

Apparatus. The insulating table (for details, see Exp. 64); a large tin basin or pan (not furnished); the electrophorus (Exp. 68).

175. Directions. (A) Test the electrophorus and be sure that it is working properly.

(B) As in Exp. 70, see how many good sparks I T will take from E C (which should be recharged at each trial) before the potential of I T is raised so that it equals the potential of E C.

(C) Carefully set the basin or pan upon I T, then count the number of good sparks you can pass to it from E C (recharged at each trial). Compare the number of sparks necessary to raise the potential of the large surface until it equals that of E C, with the number found in part (B).

176. Electrical Capacity. It takes more heat to raise the temperature of a gallon of ice-water to the boiling point, than it takes for a quart of ice-water. You have just seen that a large insulated surface will take more sparks from a charged body than a small one, before its potential is raised to that of the small one, and to that of the charging body. We say that a large surface has a greater *capacity* than a small one, the shape and other conditions being the same.

EXPERIMENT 83. To find whether the capacity of a given conductor can be increased without increasing its size.

Apparatus. Fig. 52. Insulating table. I T (Exp. 64); the extra ebonite sheet, E S (No. 27); the complete flat box, F B (No. 40, 41); the charged electrophorus cover, E C (Exp. 68). Arrange, as shown, I T being [69] insulated from the earth by E S. F B should rest upon a wooden table or other large conductor.

177. Directions. (A) See how many good sparks I T will take from E C. Re-charge E C at each count, and note the relative sizes of the sparks.

(B) Discharge I T by touching it with your knuckle.

178. Condensation; Condensers. As I T easily held more sparks than it would take before (Exp. 70), we say that its *capacity* has been increased. Its potential didn't increase, because that could not get greater than the potential of E C, the charging body. To describe this state of affairs, we say that the electrification was denser than before, and that it was *condensed*. The *capacity of I T was greatly increased by the presence of another conductor, F B, insulated from I T, but "grounded*." Such a combination, 2 conductors, with a dielectric between them, is called a condenser.

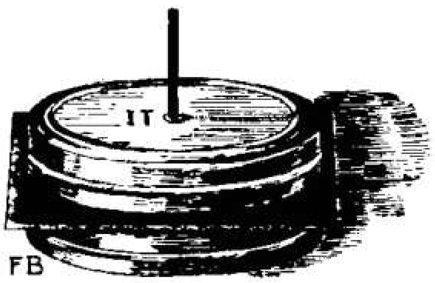


Fig. 52.

A condenser can hold much more electrification at a certain potential than an equal amount of surface can hold when not properly arranged. We might call a condenser a storage battery for static electricity. The capacity of a condenser depends, among other things, upon the area of the conducting surfaces, and upon the thickness and nature of the dielectric. Among the various forms of condensers may be mentioned the Leyden jar, and the fulminating pane.

179. The Leyden Jar consists of a wide-mouthed glass jar, with tin-foil pasted upon the inside and outside to within 2 or 3 inches of the top. The inner coat or conductor is connected to a knob or ball at the top by means of a chain. To charge the jar, the outer coat is connected with the earth by holding it in the hand, or by resting it upon a table while the electrification is [70] passed to the knob. A *Leyden Battery* consists of 2 or more connected jars, the object being to increase the area of the surface. The jar is discharged by touching one end of a *discharger* (§ 188) to the outer coat, and swinging its other end over to the knob, when a bright spark will pass between the knob and discharger. (See Exp. 86.)

180. Fulminating Panes, or Franklin's Plates, are practically the same as a Leyden Jar. The tin-foil, however, is pasted upon the opposite sides of a pane of glass, a margin of about an inch being left all around. One side of the pane is charged, and takes the place of the inside coat of the jar. The other side is grounded. The pane is discharged by connecting the two sheets of foil.

181. Induction Coil Condensers consist of sheets of tin-foil separated by sheets of paraffined paper, which act as the dielectric. (See Induction Coils.)

182. Submarine Cables, with the surrounding water, act like condensers, the result being that the condensing effect slows up the electric current and retards the signals. These make a condenser of enormous capacity. The wires inside form one conductor, and the water the other, while the insulation around the wires forms the dielectric.

EXPERIMENT 84. To study the condensation of electrification.

Apparatus. Same as in last experiment, but arrange so that F B and I T shall be near each other at one side; that is, so that the edge of E S shall be even with the edges of the two tins.

183. Directions. (A) Pass good sparks to I T from the charged E C until something happens. Watch the side where I T and F B are near each other.

184. Discussion. We may say that the electrification was condensed, in this experiment, until the charge became so great that the *condenser* suddenly discharged itself. Condensers may be made in many ways, but they all consist of 2 conductors, with a dielectric between them. One conductor is insulated, and receives the charge; the other conductor is grounded.

[71]

EXPERIMENT 85. To study the action of the condenser.

Apparatus. Fig. 53. The insulating table, I T; ebonite sheet, E S (No. 27); flat box, F B, complete (Nos. 40, 41); the electrophorus (Exp. 68). Note that this is really the same apparatus as that just used; both conductors of this condenser, however, are insulated and reversed in position.

Fig. 53.

185. Directions. (A) See that your electrophorus works properly, then find out how many good sparks you can pass from E C to F B, recharging E C each time. Note the relative sizes of the sparks, and compare the result with the number taken by the condenser in the last experiment.

(B) When F B seems to be fully charged, touch I T with your knuckle. (From your study of induction what should be the result?)

(C) Now see if F B will again take good sparks from the charged E C. Pass sparks to F B until it seems fully charged.

(D) Again touch I T, then repeat (A) and (B) several times, until a bright spark passes from F B over the edge of E S to I T.

186. Discussion. The action of the condenser, as clearly shown, depends upon induction. You should now be able to explain and show by diagram the different steps.

E C was positively charged (Exp. 80). This also charged F B positively by contact. F B acted inductively through the dielectric, E S, drawing up *some* of the - in I T, and repelling *some* of the +. As I T was insulated, this free + electrification could not escape. Before we touched I T, its + and - electrifications, although partially separated, were struggling against this inductive action; and, on account of their strong attraction for each other, our efforts to charge the condenser were retarded. Upon touching I T the free + escaped to the earth. (This was the cause of the spark.) This left *some* - electrification bound on the underside of E S, and some + bound on the upperside of E S. The capacity of F B was increased by this process, as the + [72] already put into it was very much occupied by the attractions of the induced - just under E S. As more + was given to F B, more - was drawn up under E S and more + was pushed out of I T. This action went on until the two conductors were strongly and oppositely charged. This action goes on continuously when the lower conductor is grounded. The spark between the tins was due to the rushing together of the + and - electrifications; it showed that there was a *momentary current of electricity*.

EXPERIMENT 86. To study the effect of electrical discharges upon the human body.

Apparatus. The condenser (Fig. 52), with E S centrally placed so that the apparatus cannot discharge itself; the hairpin discharger, H P D (No. 48); the electrophorus.

187. Directions. (A) Charge the condenser (Exp. 83) with 10 good sparks from E C, then touch I T (Fig. 52).

(B) Recharge the condenser with 10 sparks, then touch F B. Discharge it by again touching I T as in (A).

(C) Recharge with 10 sparks; then place your thumb against F B, and quickly swing the first finger of the same hand over to I T, and get a slight shock.

(D) Recharge with as many sparks as you think you can stand.

(E) Instead of using your hand to discharge the condenser, try the bent hairpin. Keeping one end against F B, swing the other end over near I T.

188. Shocks; Dischargers. The two conductors being oppositely charged in the condenser (Exp. 85), it is only necessary to place some conductor between them to allow the charges to rush together. Any conductor so used is called a *discharger*. The hand carried the whole current which caused the *shock*. When I T was touched first, the current was obliged to pass through your body, through the floor, and up the table-legs into F B. Always touch the "grounded" conductor first with the discharger, so that you will get a good spark and *not* a shock.

[73]

EXPERIMENTS 87–88. To show the strong attraction between the opposite electrifications in the condenser.

Apparatus. Flat box, F B (Nos. 40, 41); sheet of glass, G (No. 38); electrophorus (Exp. 68). The two parts of F B are used for the conductors of the condenser (Fig. 54) for the sake of lightness. The bottoms should be next to the glass, which is used for the dielectric on account of its stiffness. The lower tin should rest upon the table. The glass should be perfectly clean and dry (hot).

189. Directions. (A) Charge the condenser with 15 or 20 good sparks from E C.

(B) Lift the condenser by one corner of G (Fig. 54), being careful not to discharge it. Explain why the lower conductor follows the glass.

EXPERIMENT 88.

Fig. 54.

190. Directions. (A) Charge and lift the condenser as just explained (Exp. 87). Fig. 54.

(B) With your right hand touch the upper tin alone, then the lower tin alone.

(C) Touch both tins at the same time, and note the action of the lower one.

191. Discussion. This clearly shows how strongly the two electrifications are *bound* in the condenser. Each refuses to escape to the earth, but they instantly rush together at the first opportunity. The dielectric may be shattered in a very heavily-charged condenser by this strong attraction.

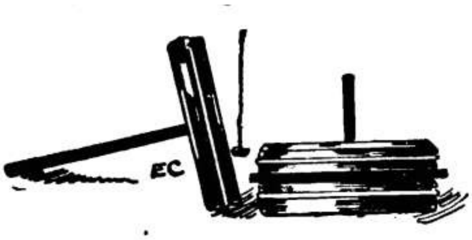


Fig. 55.

EXPERIMENT 89. To show how the condenser maybe slowly discharged.

Apparatus. Fig. 55. The condenser (Exp. 83); the carbon electroscope with support (Exp. 58); the electrophorus (Exp. 68).

192. Directions. (A) Charge the condenser by means of the electrophorus; then hang the carbon so that it can swing between the upper conductor and E C placed as shown. [74]

193. The Electric Chime. The charging and discharging of the carbon being rapid, it acts like a *chime* as it taps against the tins.

EXPERIMENT 90. To ascertain the location of the charge in the condenser.

Apparatus. The condenser, consisting of flat box, F B (Nos. 40, 41); ebonite sheet, E S (No. 27); insulating table, I T (Exp. 64); (when charging, arrange as in Fig. 52.); the electrophorus; hairpin discharger, H P D (No. 48).

194. Directions. (A) Charge the condenser with 15 or 20 good sparks from E C.

(B) Lift I T away from E S by its insulating handle, and set it upon the table. (It may be necessary to hold E S down.)

(C) Lift E S directly up and away from F B. (Lift by 2 corners; do not scrape E S along on F B; do not allow E S to touch your clothing.)

(D) Replace E S and then I T by its handle quickly, making the condenser complete again.

(E) With H P D see if the condenser still holds a charge. Touch F B first (Exp. 86).

195. Discussion. As the *conductors* were completely discharged, being left for a few moments upon the table, it is evident that the opposite electrifications must reside in and upon the *dielectric*. The conductors allow an even and *rapid* discharge from all parts of the dielectric at the same time. The dielectric is considerably strained when a condenser is heavily charged. This strain, caused by the attraction of the opposite electrifications, may be great enough to break or puncture the dielectric.

EXPERIMENT 91. To find whether any electrification remains in the condenser after it has once been discharged.

Apparatus. The condenser (Fig. 52); the electrophorus (Exp. 68); hairpin discharger, H P D.

196. Directions. (A) Thoroughly charge the condenser. [75]

(B) Discharge it with H P D, being sure to touch F B first, and to touch I T for an instant while H P D is against F B.

(C) After a few moments use H P D again, and see if you get a slight spark.

197. Residual Charge. The two electrifications on the opposite sides of the dielectric have such an attraction for each other, when the condenser is charged, that they seem to penetrate, or soak into, the dielectric. These do not completely soak out again at the discharge. The small amount left is called a *residual charge*.

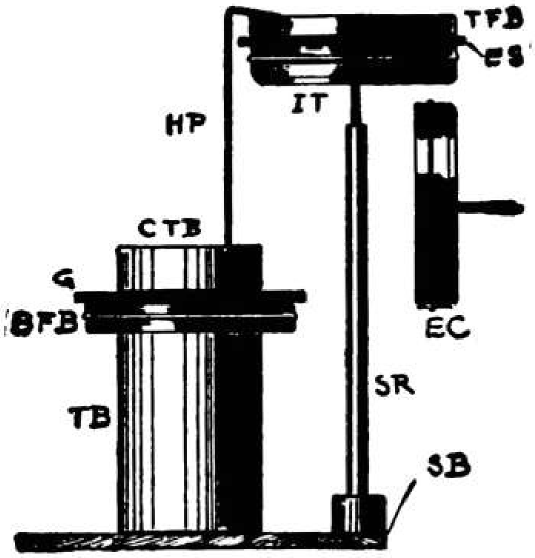


Fig. 56.

EXPERIMENT 92. To study successive condensation; the chime cascade.

Apparatus. Fig. 56. This really consists of two condensers, joined by a wire. The upper condenser consists of T F B (No. 41), E S (No. 27), and the insulating table, I T. (See Exp. 64.) The lower condenser consists of the cover of the tin box, C T B (No. 47), the sheet of glass G (No. 38), and B F B (No. 40). The tin box, T B (No. 47), is placed under this to raise it, simply. A wire or hairpin, H P, is hung upon the edge of T F B, its lower end being inside of C T B and not quite touching it. This acts like a pendulum, which is to swing to C T B at the proper time. The source of electrification is E C.

Note. You have learned that in charging the condenser with the positively charged E C, + electrification is driven from F B into the earth. Can we use this to charge a second condenser? [76]

198. Directions. (A) Pass 15 or 20 good sparks from E C to the under side of I T (Fig. 56), noting the action of H P.

(B) Hold E C in the hand, and, with its insulating handle, poke H P away from the condensers. Do not discharge them.

(C) With H P D test the lower condenser for a charge, touching T B first.

(D) With H P D touch T F B first (why?), and discharge the upper condenser.

199. Discussion. A long row of condensers may be charged in this way. There is no advantage in it, as the electrification is merely divided between them. How can two condensers be joined to get the advantages of a large surface?

CHAPTER XI.

ELECTROSCOPES.

200. Electroscopes are instruments to show the presence, relative amount, or kind of electrification on a body. (See Apparatus Book, Chap. XVIII, for Home-Made Electroscopes.) The *carbon electroscope* has been described (Exp. 58). The *pith-ball electroscope* is made by using pith from elder, corn-stalk, or milk-weed, in place of the carbon. The *gold-leaf electroscope* is a very delicate instrument. The gold-leaf is supported, as suggested in Fig. 57, at the lower end of a wire conductor which sticks through and hangs from the cork of a glass jar or flask. To the top end of the wire is soldered a ball or disk. The glass jar insulates the gold-leaf, and keeps it dry and free from dust.

201. Our Leaf Electroscope (Fig. 57) is made with aluminum-leaf. Gold-leaf is too delicate for unskilful handling, and aluminum will do for all ordinary experiments. To cut it into any desired shape, place it between two sheets of paper, then cut through paper and all.

202. Construction. Bend one leg of a hairpin, H P, as in Fig. 57, and slide it onto I T. Hang a wire, W, or another hair pin straightened, then bent, from the horizontal leg of H P. This is to support the "leaves," L, which are made from a strip of aluminum-leaf about [78] 4 in. long and ¾ in. wide. Moisten the under side of the horizontal part of W with paste or mucilage; press it upon the middle of the strip laid flat upon the table, and then lift W. The leaves should cling to W. Each leaf should be, then, 2 in. long. They should hang close together when not in use. A large chimney, or fruit-jar, may be used to surround the leaves, and to keep currents of air from them. The leaves should not touch the side of the jar when spread.

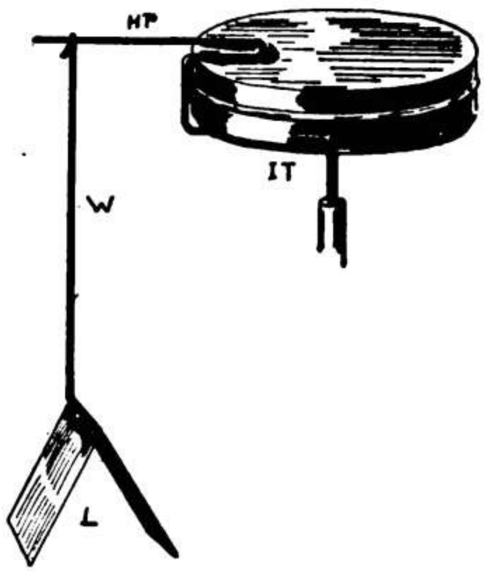


Fig. 57.

EXPERIMENT 93. To study the leaf electroscope; charging by conduction.

Apparatus. The leaf electroscope (Fig. 57, § 201, 202); ebonite rod, E R (No. 28); flannel cloth, F C (No. 30).

203. Directions. (A) Thoroughly charge E R, then scrape it along upon I T, noting the action of the leaves, L.

(B) See if the leaves will remain spread for some time.

(C) Touch I T to discharge it, and note the action of L.

204. Discussion. No explanation should be necessary for this. Are the leaves charged alike? As they were charged by contact, is the electrification on them + or -?

EXPERIMENT 94. To charge the leaf electroscope by induction.

Apparatus. Our electroscope (Fig. 57, § 202); ebonite sheet, E S (No. 27); flannel cloth, F C (No. 30).

205. Directions. (A) Charge E S with F C, then hold E S above I T (Fig. 57), their surfaces being kept parallel and about 2 or 3 inches apart. Watch the leaves.

(B) Withdraw E S. Do the leaves remain spread?

(C) Repeat (A), and before removing E S, touch I T.

(D) Remove your finger from I T, then withdraw E S. Do the leaves now remain spread?

206. Discussion. The permanent divergence of L was due to a charge given by induction. (Exp. 76.) As E S was -, what was the kind of a charge in L? Did any electrification go to the electroscope from E S? In (C) what became of the charge in L? Explain why the leaves again diverged in (D). The electroscope was charged with + [79] electrification by taking - out of it.

EXPERIMENT 95. To learn some uses of the electroscope.

Apparatus. Our electroscope (Fig. 57, § 202); ebonite rod, E R (No. 28); ebonite sheet, E S (No. 27); glass, G (No. 38); flannel cloth, F C (No. 30).

207. Directions. (A) With the charged E R charge the electroscope negatively by conduction (Exp. 93). Note the amount of permanent divergence of the leaves.

(B) Electrify the glass, which will be +, (or use the + E C), and *slowly* lower it over I T, noting the effect upon L. Raise and lower G or E C several times. Does G, which has an opposite charge to the electroscope, make L diverge more or less?

(C) Discharge the electroscope and recharge as in (A).

(D) Slowly lower the charged E S over I T.

(E) Slowly lower the palm of your hand over I T.

Note. If the + G is brought too near the -ly charged electroscope, L will first collapse and then instantly diverge again with a + charge by contact. The *first* motions should be observed.

208. Discussion. As a neutral body causes a slight *collapse* of the leaves, as well as a body charged positively (when the charge in the leaves is -), an increase of divergence is really the only sure test to tell how a body is charged. The - leaves collapse when a + body is brought near I T, because the - in them is drawn up towards the body. The leaves diverge more when a - body is brought near, because the - in I T is repelled into them.

209. The Proof-plane. Since charges of static electricity reside upon the outside of conductors, it is an easy matter to take samples of the electrification. This may be done with a little instrument called a carrier, or proof-plane. It consists of a small conductor with an insulating handle. A ring or coin may be used for the conductor, and [80] a silk thread for the handle. By touching the carrier to any charged body, it, also, becomes charged; and the nature of the charge may be determined by the use of a previously charged leaf electroscope (Exp. 95). A delicate gold-leaf electroscope would be ruined by coming in contact with a heavily charged body. The carrier allows a small sample to be tested.

CHAPTER XII.

MISCELLANEOUS EXPERIMENTS.

EXPERIMENT 96. To show that friction always produces two kinds of electrifications.

Apparatus. Fig. 58. The carbon electroscope (Exp. 58); flannel cloth, F C, doubled twice to make 4 thicknesses (see Fig. 58); ebonite sheet, E S (No. 26); ebonite rod, E R (No. 28); charged electrophorus cover, E C.

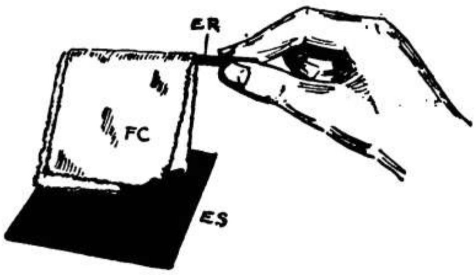


Fig. 58.

210. Directions. (A) Vigorously rub E S with F C (folded as in Fig. 58). See if you can discover any attraction between them.

(B) Rub E S again, but do not lift F C from it with the hand alone. Slip E R under the top fold in F C (Fig. 58), and lift F C straight up from E S. Do not let F C touch the table or your hand.

(C) See if F C is charged, using 2 or 3 different tests.

(D) Charge the electroscope with F C until the carbon is strongly repelled.

(E) Bring the positively charged E C slowly near the carbon, and note the result.

(F) Slowly bring the negatively charged E S near the carbon that has been charged by contact with F C.

211. Discussion. This experiment showed that while the ebonite was negatively charged, the flannel was positively charged. One kind of electrification is never produced without the other. It can also be shown that the two kinds are equal in amount.

[82]

EXPERIMENT 97. To show "successive sparks."

Apparatus. Fig. 59. The electrophorus (Exp. 68); the extra ebonite sheet, E S (No. 27); three coins (marked A, B, C, in Fig. 59). The coins should nearly touch each other, and rest upon E S. A part, only, of the electrophorus cover is shown.

212. Directions. (A) Thoroughly charge the electrophorus cover.

(B) Place your finger upon the coin marked A, to "ground" it, then quickly touch the coin C with the charged cover, at the same time watching for sparks between the coins. If you cannot see the sparks, darken the room a little, and look at the center coin, B, while doing the experiment.

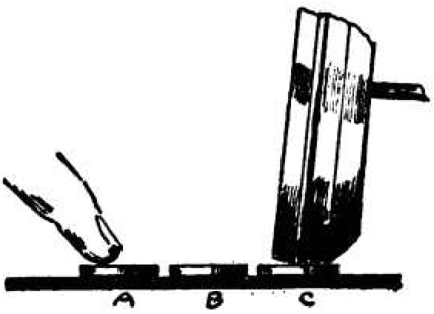


Fig. 59.

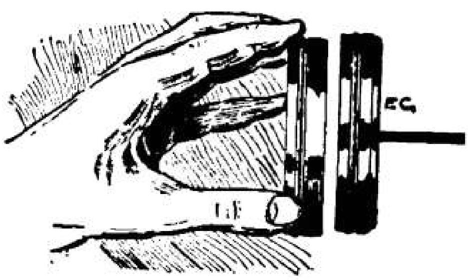


Fig. 60.

EXPERIMENT 98. To show to the eye the strong attraction between a charged and a neutral body.

Apparatus. The flat box, F B (Nos. 40, 41); the electrophorus (see Exp. 68).

213. Directions. (A) Stand F B upon its edge upon a level table, then bring the charged electrophorus cover near it.

(B) Instead of the above, use light hoops made of paper, eggshells, feathers, sawdust, etc.

EXPERIMENT 99. To feel the strong attraction between a charged and a neutral body.

Apparatus. Fig. 60. The flat box F B(Nos. 40, 41); the electrophorus (Exp. 68).

214. Directions. (A) Hold F B in the left hand, as shown, then *slowly* bring near it the charged cover, at the same time looking between them so that you can keep them the same distance apart all the way round.

(B) Bring them near enough to allow a spark to pass from E C to F B. [83]

EXPERIMENT 100. The human body a frictional electric machine.

Apparatus. Yourself; a carpet; a room with dry air, easily had on a cold winter's day.

215. Directions. (A) Scrape your feet along upon the carpet, then quickly touch your finger to some conductor, as, for example, a friend's nose.

(B) It is possible to light the gas by the above process. Have a friend turn on the gas just before you bring your finger to the jet, and be sure that the spark from your finger passes through the gas on its way to the conductor, the jet.

(C) Bring your finger quickly near a small piece of tissue paper after you have scraped your feet along to charge your body.

216. Static Electric Machines are used to produce large quantities of static electricity. In the early forms, the electrification was produced by friction. Modern machines depend upon the principle of induction. The electrophorus (Exp. 68) is really a very simple form of induction machine. The potential of these machines is very great, as the spark may jump many inches. Thousands of Galvanic cells would be needed to make a spark an inch long. When the spark passes through the air it meets with an extremely high resistance, as air practically insulates ordinary electricity. This high resistance in the circuit reduces the strength of the current. While the potential is very high, the strength of the current is very low. (See Ohm's Law.)

CHAPTER XIII.

ATMOSPHERIC ELECTRICITY.

217. Atmospheric Electricity. The air is generally electrified, even in clear weather. Its charge is usually +. Clouds are sometimes +, and sometimes -.

The cause of atmospheric electricity is not thoroughly understood. It is thought, by some, to be due to the friction of the particles of vapor upon each other. It is also thought that the evaporation of sea water, and the friction of winds, produce it.

218. Lightning. Benjamin Franklin, in 1752, proved by his famous kite experiment that atmospheric and frictional electricities were of the same nature. By means of a kite, the string being wet by the rain, he succeeded, during a thunder-storm, in drawing sparks, charging condensers, etc.

Lightning may be produced by the passage of electricity between clouds, or between the cloud and the earth, which, with the intervening air, have the effect of a condenser. If one cloud is charged, it acts inductively upon another, producing in it the opposite kind of electrification. When the attraction between the two electrifications becomes great enough, it overcomes the resistance of the air, and lightning is produced.

The flash is practically instantaneous. The direction taken seems to depend upon the conditions of the surrounding air. It has generally a zigzag motion, and is then called *chain lightning*. The air in the path of the electricity becomes intensely heated; it is this effect, and not the electricity which we see. In hot weather flashes are often seen [85] which light up whole clouds, no thunder being heard. This is called *heat lightning*, and is generally considered to be due to distant discharges, the light of which is reflected by the clouds.

The *potential* of the lightning spark is beyond all calculation. The spark jumps through miles of air, which is, really, an insulator. This spark represents billions and billions of volts.

219. Thunder is caused by the violent disturbances produced in the atmosphere by lightning. The nature of the sound depends, among other things, upon the distance of the observer from the discharge, and upon the length and shape of the path taken. Clouds, hills, and other objects produce echoes, which also modify the original sound. It takes nearly five seconds for the sound to travel one mile.

220. Lightning-Rods, when well constructed, often prevent violent discharges of atmospheric electricity. They have pointed prongs at the top, which allow the negative of the earth (which is being attracted by the cloud when it is positively charged) to pass quietly into the air above; this neutralizes the cloud. In case of a discharge, the rods aid in conducting the electricity to the earth.

221. Causes of Atmospheric Electricity. There are several theories about this. Some think that it is due to the rotation of the earth, different parts being acted upon differently by the heat of the sun.

Some claim that the evaporation of the water in the ocean produces it, while others say that the electrification is produced in the clouds by the friction of their particles [86] upon each other. The matter has not been settled.

222. St. Elmo's Fire Electrification from the earth is often drawn up through the masts of ships to neutralize that in the clouds (see § 220), and, as it escapes from the points of the masts, light is produced. This may be clearly shown by repeating Exp. 71 in the dark; the head of the pin (Fig. 39) will represent the end of a mast, and the charged electrophorus cover will be the charged cloud.

223. Aurora Borealis, also called Northern Lights, are luminous effects often seen in the north. They often occur at the same time with magnetic storms, at which times telegraph and telephone work may be disturbed. The exact cause of this light is not known, but it is thought by many to be due to disturbances in the earth's magnetism, caused by the action of the sun.

CURRENT ELECTRICITY.

PART III.—CURRENT ELECTRICITY.

CHAPTER XIV.

CONSTRUCTION AND USE OF APPARATUS.

Note.—Before taking up the study of cells and the electric current, let us perform a few experiments in order to understand the construction and use of some of the apparatus needed for such study. A dry cell will be used as the source of the electricity for these first experiments, because it is convenient. You will understand its action later. Use this cell only as directed; improper use of it might spoil it.

EXPERIMENT 101. To study the effect of the electric current upon the magnetic needle.

Apparatus. A compass (No. 18); a dry cell, D C (No. 51); wires with spring connectors attached (§ 226) for making connections. Fig. 66 shows a plan or top view of the arrangement. Any other form of cell will do in place of D C.

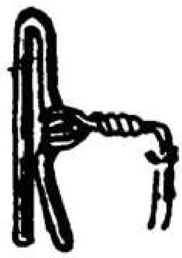


Fig. 61.

226. Electrical Connections. One must constantly join wires, connect wires with apparatus, or connect one piece of apparatus to another, to make the proper electrical connections. A very simple method of connections has been used in all the apparatus described in these experiments.

A little arrangement which we shall call a spring connector, S C, (Fig. 61), gives us a means of quickly making connections; that is, it does away with expensive binding-posts. It is made of brass, nickel plated, and may be used anywhere without affecting the magnetic needle.

Six or eight wires, about No. 24 gauge, each about 1½ ft. long, should be prepared with a connector at each end. You may use wire furnished (No. 53). Scrape the insulation from the ends of the wires for about 1½ inches, then twist the bare ends around the connectors as [90]
shown in Fig. 61. The wire should pass around tightly at least 4 or 5 times and then be twisted a little, as shown, to help tighten it. Do not put it on so poorly or in such quantity that the part, B, will spread.

227. Fig. 62 shows how the connector should be slipped upon a thin piece of metal, M, like that on the galvanoscope, for example. The wire, W, from the apparatus itself is permanently fastened under the head of the screw, S, while the wire from any other apparatus is one of those kept on hand as above mentioned and connected with S C.

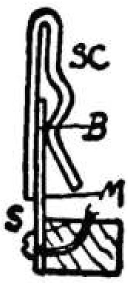


Fig. 62.

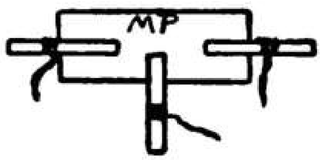


Fig. 63.

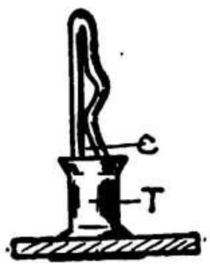


Fig. 64.

228. Fig. 63 shows how several wires may be quickly joined, electrically, by slipping the connectors at their ends upon a thin metal plate, M P, which may be a piece of tin, zinc, copper, etc. M P should not be too thick. In case the connectors become too much spread to pinch the plate, squeeze the part, A, a little more together.

229. Fig. 64 shows the method of connecting with the special form of binding-post used, for example, upon the resistance coil, R C. The end, C, of S C, is pressed down into the tube, T, until you feel, by moving it, that it springs firmly against the sides of the tube. In case you wish S C to fit very tightly in T, one of the legs may be slightly bent outwards.

Fig. 65.

230. The connector may be used in still another way; that is, by pushing the part, A, into the hole of an ordinary binding-post, (Fig. 65), and using it just the same as a thick wire.

231. Directions. (A) Stand the compass and D C near each other (Fig. 66). Attach one end of an insulated copper wire, C W, to the binding-post, C, which is on the carbon plate of the cell. Do *not* join the other end to the other binding-post, Zn, of the zinc plate.

(B) With the left hand hold C W above and near the compass-needle, and in [91]
the N and S line, so that it will extend over the entire length of the needle.

(C) Take the free end of C W in the right hand and touch binding-post, Zn, for an instant only, watching the needle. Repeat.

232. Current Detectors. We know that a magnet can act, by induction, through the air upon a piece of iron or upon another magnet. The deflection of the needle in this experiment shows that there must be a magnetic field around a wire carrying a current. This fact is of the greatest possible importance. The simple magnetic needle, when used as above, becomes a detector of electricity.

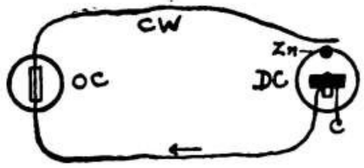


Fig. 66.

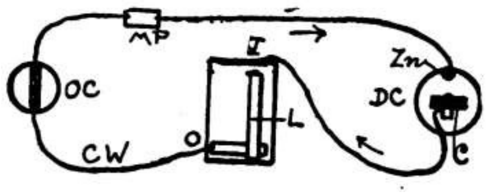


Fig. 67.

EXPERIMENT 102. To study the construction and use of a simple "key."

Apparatus. A key, K (No. 55) (§ 233); a dry cell, D C, (No. 51); a compass, O C (No. 18). *Arrange* as shown in Fig. 67, which is a top view or plan. Connect the pieces of apparatus with wires and spring connectors (§ 226). Binding-post, C, is joined to I (in) of the key; O (out) of key is joined to binding-post, Zn, the wire, C W, passing directly over and near O C, which is to be used as a detector. The current cannot pass until the lever, L, is pressed. A metal plate, M P, is used to connect two short wires (§ 228) in case C W is not long enough.

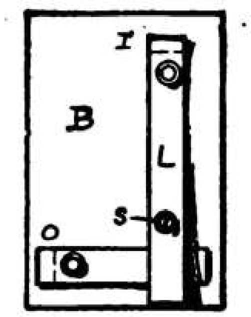


Fig. 68.

233. A key is merely a piece of apparatus by which the circuit can be conveniently and rapidly opened and closed at the will of the operator; that is, by it the electricity can be quickly turned on or off. Fig. 68 shows a simple form of key. To the base, B, are fastened two metal pieces or straps, the upper one, L, being the lever or key proper. The front end of L is raised above O, so that the two do not touch each other unless L is [92] firmly pressed down. A screw, S, keeps L from springing too far above O. For convenience we shall suppose that the wire leading to the key joins it at I (in); the wire *from* the key is joined to O (out), by means of connectors (§ 226).

The key may be put into any circuit by first cutting a wire and then joining the ends to I and O. Spring connectors make the best connections with this form of key. (For Home-Made Keys see Apparatus Book.)

234. Directions. (A) The magnetic needle being directly under the wire, press L down for an *instant only* and note the action of the needle.

(B) Press L again, hold it down for 3 seconds, not over that, and watch the needle.

Discussion. The key allows us to easily regulate the length of time during which the current passes. This experiment shows, also, that the magnetic field about the wire disappears as soon as the current ceases to pass.

EXPERIMENT 103. To study the construction and use of a simple "current reverser."

Apparatus. A dry cell, D C (No. 51); a compass, O C (No. 18); a current reverser, C R (No. 57) (See § 235); an insulated copper wire, C W, 2 or 3 feet long, with spring connectors joined to its ends (§ 226).

Arrange as in Fig. 70. The wire, C W, leading from X should be held by the left hand so that it will be just above (or below) and parallel to the magnetic needle.

The current cannot pass through C W until one of the straps or levers on C R is pressed. (See Apparatus Book for Home-Made Reversers.)

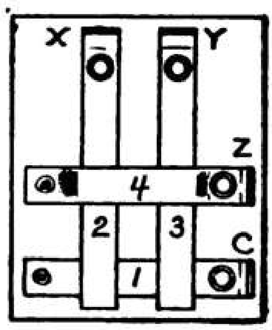
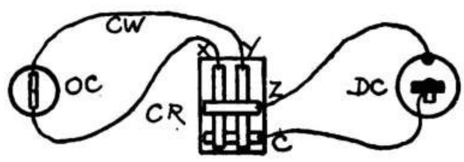


Fig. 69.

235. The Current Reverser. (No. 57.) To the wooden base (Fig. 69) are fastened four metal straps, each turned up at the end so that spring connectors (§ 227) can be slipped on to make electric connections with other pieces of apparatus.

Suppose that at C and Z connections are made with the carbon and zinc of the cell, by means of wires and spring connectors (§ 226). The current comes from the [93] cell to C. As the two straps, 2 and 3, press firmly up against strap 4, and do not touch 1, it is evident that no current can pass from 1 to 2 or to 3 until they are pressed down upon 1. Two wires are joined by spring connectors to 2 and 3 at their turned up ends, X and Y, and these wires lead to any desired instrument.

236. Directions. (A) Press down lever 2 (Fig. 70), for an instant only, at the same time noting carefully in which direction the N pole of the needle is deflected.



(B) After allowing lever 2 to spring up again, and after the needle comes to rest, press down lever 3 for an instant, watching the needle. Is the N pole of the needle deflected in the same direction as it was in (A)?

Fig. 70.

237. Discussion. The reverser gives us a quick and easy means of reversing the current which is to pass through any desired instrument, first in one direction and then in the opposite direction. Suppose (Fig. 69) that the current enters C R at C, as it does when C is joined to the carbon of the cell; the current can go no farther until one lever is lowered. If lever 2 (Fig. 69) be now pressed down, as in part (A), the current will pass along 2, which does not now touch 4, out through X to a coil of wire or any instrument, and back to the reverser by the wire joined to Y. It will then pass from 3 onto 4, to Z, and back to the Cell; that is, the current enters C W at X. When lever 3 is pressed, the current still entering C R at C, the electricity will pass onto 3 and out at Y, and back through X, 4 and Z to the cell. The current, then, can be made to pass out of X or Y at will by pressing the proper lever. This experiment also teaches something about currents, but these will be discussed later.

[94]

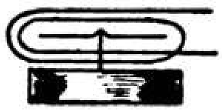


Fig. 71.

EXPERIMENT 104. To study the simple current detector.

Apparatus. The compass (No. 18); dry cell, D C (No. 51); current reverser, C R (No. 57); copper wire, C W, a few feet long, with spring connectors on its ends. (See Apparatus Book, Chapter XIII, for Home-Made Detectors.)

238. Directions. (A) Join the ends of the wire to X and Y of the reverser, C R, as in the last experiment. Coil up C W so that you can hold the coil with your left hand, as shown in Fig. 71, the magnetic needle being inside of it and parallel to it.

(B) Press lever 2 of the reverser for an instant only. Is the needle deflected more or less than it was when the wire simply passed over or under it once?

(C) Reverse the current through C W by pressing lever 3, and note the result.

(D) Get clearly in mind which way the N pole of the needle is deflected when the current enters C W at X, also when it enters at Y.

239. Discussion. The current passed *over* the needle in one direction, and *under* it in the opposite direction; that is, the part of the wire above *helps* that below. Each turn of the wire increases the strength of the magnetic field about the coil, and helps to deflect the needle. In this way, by increasing the number of turns, detectors may be made that will show the presence of very weak currents. The magnetic fields about wires and coils will be studied in a later chapter.

EXPERIMENT 105. To study the construction and use of the simple galvanoscope.

Apparatus. The galvanoscope, G V, complete (No. 58), described in § 240–246; dry cell, D C (No. 51); current reverser, C R (No. 57) (§ 235); wires, with spring connectors, to join the different pieces of apparatus (§226). (See Apparatus Book, Chapter XIII, for Home-Made Galvanoscopes.)

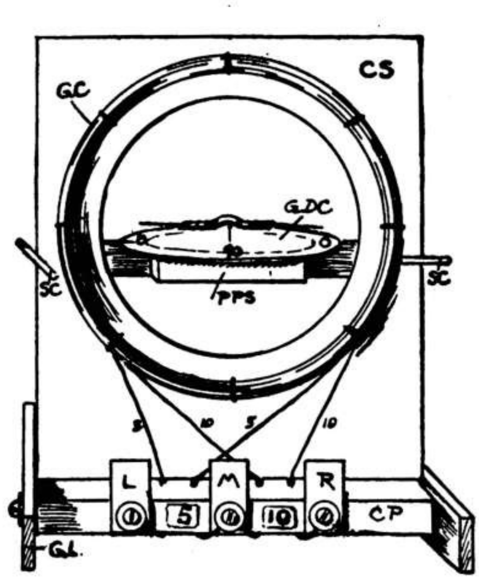


Fig. 72.

[95]

240. The Galvanoscope (Fig. 72) is more than a mere detector of electricity. With it we shall be able to study, more fully, cells, currents, etc., etc. We must first understand its construction.

241. The Coil-support, C S, is fastened to the cross-piece, C P, on which are the 3 binding-posts or coil-ends, L, M and R (left, middle, right). The legs, G L, are screwed to C P in such a way that C P is held a little above the table: this allows C S to be tipped to the front or rear to adjust it vertically. On account of the peculiar arrangement of the legs, the galvanoscope can be made to stand firmly, even upon uneven surfaces. The screws holding G L should not be put in far enough to tear the threads in the wood, C P.

242. The Galvanoscope Coils, G C, are two in number, both being fastened to the coil-support, C S. The first coil has five turns of wire, its ends being fastened to L and M; the other coil has *ten* turns, with ends at M and R. The current can, at will, be made to pass through 5, 10 or 15 turns of wire by making the proper connections.

Suppose that we have two wires direct from a cell, or from the current reverser, with spring connectors on them so that we can slip them onto L, M or R, which stand for left, middle or right. When the wires are joined to L and M the current can pass through but 5 turns; when joined to M and R it will go through 10 turns; and when to L and R it will pass through the entire 15 turns. When the current enters the galvanoscope at L and passes out at M or R, it will pass through the turns of wire from left to right, at the top; that is, it will pass in a "clockwise" direction.

243. The Compass-needle, furnished with O C (No. 18), will do also for this galvanoscope. It should be placed upon the pin-point after fixing on the pointers (§ 246). The length of the needle should be parallel to the plane of the coil when no current passes; that is, the coil and [96]
coil-support should be in the N and S line.

The needle can be centered in regard to right and left, and in regard to up and down, by properly adjusting the position of the pin-point support, P P S; this is held firmly to C S by two spring-connectors. By removing S C, the support, P P S, may be raised or lowered.

244. To place the coil in the N and S line, simply swing the galvanoscope bodily around, at the same time looking down upon the needle, until the length of the needle becomes parallel to the coil-support. When once carefully adjusted N and S, a line may be drawn upon the table as a guide for its position in future experiments. The coil should stand in a vertical plane, and this straight up and down position can be easily adjusted.

To place the coil in the E and W line, turn it until the pointers are at the 90° (90 degree) marks, —the 0° (zero degree) marks remaining, of course, as described above.

245. The Degree-Card, G D C (Fig. 72) has a dot at its center, to show where to make a pin-hole for the pin that supports the compass-needle. With this you can tell how many degrees the needle is deflected when the current passes. This card, G D C, should be pressed down over the pin-point. The zero points of G D C should be N and S, also, when the coil is in that position; that is, they should be in the plane of the coil. The pointers on the needle (§ 246) will then be at O, when the needle is at rest, no current passing through the coils. (See Apparatus Book § 272 for Home-Made Degree-Card.) G D C may be held permanently in position after it is adjusted, by sticking a short pin through it into P P S. Do not let this pin interfere, however, with the swinging of the needle.

Fig. 73.

246. Pointers (Fig. 73) should be fastened to the needle, in order to make the readings of degrees accurate. Fasten to the compass-needle a piece of No. 30 insulated copper wire, as shown. It may be cut to the proper length after it is wound around the needle. See that the wire does not touch the pin when needle is in place; balance needle by cutting a little from the [97]
heavier end of wire with shears; bend the ends of wire so that they are at opposite sides of the degree-card, both pointing at O, for example. The needle must swing freely, be nicely balanced, and the wire must not touch pin or degree-card.

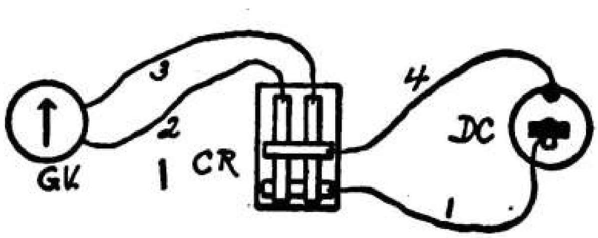


Fig. 74.

247. Directions. (A) Arrange as in Fig. 74, the coil being N and S (§ 244). Join the ends of the wires, 2 and 3, with the 5-turn coil of G V as shown. Wire, 2, is connected to L (Fig. 72). Press lever 2 of C R (Fig. 69) for an instant, watching the compass-needle and noting how many degrees it swings the first time. Get thoroughly in mind the direction in which the N pole of the needle is deflected when the current passes around G C in a "clockwise" direction. There must be no magnets, iron, or pieces of steel within 3 feet of A G.

(B) Press lever, 3, for an instant, watching the needle. The current will now pass in an "anti-clockwise" direction. Is the needle deflected about the same number of degrees as in (A)?

(C) Change the ends of the wires, 2 and 3, to the 10-turn coil (§ 242) and repeat (A) and (B).

(D) Change 2 and 3 to L and R (Fig. 72), thus allowing the current to pass around 15 turns; then repeat (A) and (B).

248. Discussion; True Readings. Is not possible to get the magnetic needle, M, exactly in the center of G C; the pointers will not exactly be in the axis of M; the coils will not be exactly N and S: hence, if you pass a certain current through the coil and the pointer reads 20 degrees, you will find, if you reverse the current, that the pointer may read 24 degrees on the other side of the zero mark. To get the *true reading*, average the two, in this case the average being 22 degrees.

The galvanoscope gives us an instrument with which we can study, more fully, cells, currents, etc. [98]

249. Note of Caution. It has already been stated that the compass-needle should be in the center of the coil (§ 243), and that the coil should be in the N and S line (§ 244). In addition to the above, see that there are no magnets near G V, when using it; tap G V occasionally to be sure that the needle swings freely, hold the eye directly over the pointers when reading degrees; the pointers should be at zero when no current passes through G V; be sure that the electrical connections are good.

There are several sources of error in taking readings, and in all the quantitative experiments given. The author takes it for granted that such errors will be looked out for by the teacher.

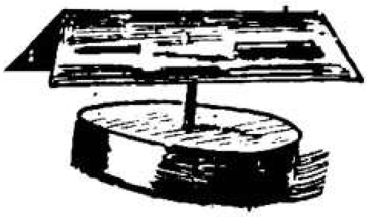


Fig. 75.

EXPERIMENT 106. To study the construction and use of a simple astatic needle.

Apparatus. Two unmagnetized sewing-needles (No. 1); horseshoe magnet, H M (No. 16); piece of stiff paper doubled and cut as in Fig. 75; a pin-point on which to support the paper. The pin may be stuck through a cork, or that of O C (No. 18) may be used.

250. Directions. (A) Draw each needle across the N pole of H M five times from point to head (Exp. 9). This should make them of nearly equal strength, both points being N poles.

(B) Stick the needles through the paper as shown, the N poles being at the same end of the paper. Balance the paper upon the pin-point. Has this combination a strong or weak pointing-power?

(C) Turn one of the needles end for end. Again test the pointing-power.

251. Discussion; Astatic Needles. By arranging the needles so that their poles oppose each other, the pointing-power becomes almost nothing. This sort of a needle is needed in some experiments in electricity. Their magnetic fields are still retained. The combination is called an *astatic needle*; it is used to detect very feeble currents. [99]
The more nearly equal the magnets are in strength, the better. They are usually arranged with one above the other (Fig. 76).

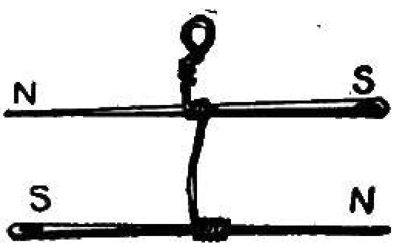


Fig. 76.

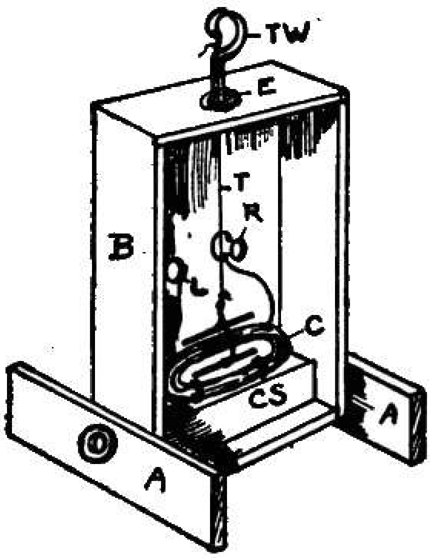


Fig. 77.

EXPERIMENT 107. To study the construction and use of a simple astatic galvanoscope.

Apparatus. An astatic galvanoscope, A G (No. 59) (§ 252–254); dry cell, D C (No. 51); current reverser, C R (No. 57) (§ 235); wires for connections (§ 226).

Arrange as shown in Fig. 80, which is a top view. The wires from C R are connected to the binding-posts of A G at the back, the spring connectors being slipped into them (§ 229).

252. Construction of the Astatic Galvanoscope. When not to be used for a long time, or for shipping, the legs, A (Fig. 77) may be removed, and the whole packed inside of the box, B.

The *Coil*, C, has a resistance of about 5 ohms, and is fastened to the coil-support, C S. The ends of the coil are permanently fastened to the binding-posts, L and R (left and right). The ends are so arranged that when the current enters at L it will pass around the coil in a clockwise direction.

253. The Astatic Needle (Exp. 106) is supported by a small thread, T, which is tied to the thread-wire, T W. This T W springs into an eyelet, E, which, in turn, rests in a hole made in the end of B. E should turn easily in the hole, but it should not wabble.

Fig. 78 shows a sectional view of the coil and needle. The wire, W, should be bent, as shown, so that the magnets can be as near the center-line of C as possible. Fig. 79 shows a front view of the needle. As a matter of convenience it will be best to arrange the poles of the needles, as shown, to agree with the descriptions of the experiments. [100]

To keep the needle from being affected by air currents, the glass plate (No. 38) may be placed in front of the box, B. Stand it upon the legs, A, and tie a string around it, and B, to hold it in place.

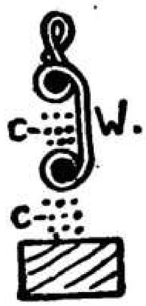


Fig. 78.

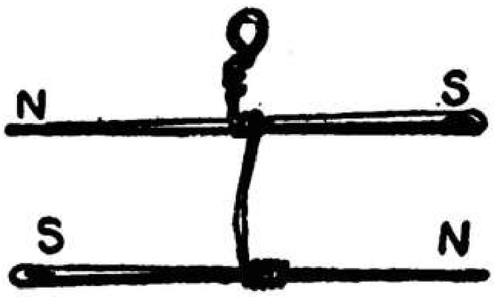


Fig. 79.

254. Adjusting the Needle. As T is tied to T W, the needle may be swung completely around by turning T W. This should be done until the length of the needle is parallel to the turns of C. The up and down position of the needle should be fixed as nearly as possible when fastening T to T W, the exact place being finally fixed by raising or lowering T W through E. The spring in T W should hold it firmly in E after adjustment. The wire, W, joining the needle-magnets should not touch the coil. It may be made to just swing free from C by tilting the box forward or backward a little. The construction of the legs, etc., makes it possible to tilt the box, and to make it stand firmly upon an irregular surface.

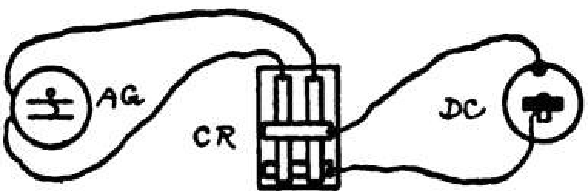


Fig. 80.

255. Directions. (A) See that there are no magnets within 3 feet of A G. Test the astatic needle, after you have it properly suspended, to convince yourself that it does not try to swing around in a N and S line. In case the needle-magnets have been in contact with other magnets, or are not equally magnetized, remagnetize them as directed in Exp. 106. They must remain in any position given them by turning T W. Finally, bring them parallel to the turns of the coil. (See § 254.) Arrange as in Fig. 80.

(B) Press lever 2 of C R (§ 235) for an instant only. This allows the current to enter A G at L. Repeat several times until you thoroughly fix in your mind the direction in which the right-hand end of the needle is deflected. Does the needle jump suddenly when the current passes? [101]

(C) Press lever 3 for an instant only. Study the result.

256. Astatic Galvanoscopes. It is evident that in the ordinary current detector (Exp. 104), the pointing power of the needle has to be overcome by the magnetic field about the coil, before the needle can be forced from its N and S line. Very weak currents will not visibly move the needle in ordinary detectors. To make a sensitive instrument we must have strong fields about both the needle and coil, and we must, at the same time, decrease the pointing power of the needle. Both of these things are accomplished by using an *astatic needle* in connection with a coil containing considerable wire. The uses of the astatic galvanoscope will be studied more fully in later experiments.

CHAPTER XV.

GALVANIC CELLS AND BATTERIES.

EXPERIMENT 108. To study the effect of dilute sulphuric acid upon carbon and various metals.

Apparatus. A piece each of copper and iron wire 4 in., (10 cm.) long; two narrow strips of sheet zinc (No. 60), one being amalgamated (§ 257); a carbon rod (No. 64); a tumbler (No. 65), partly filled with dilute sulphuric acid, (§ 258); mercury (No. 52).

257. To amalgamate one of the above zinc strips is to coat it with mercury. Remove all jewelry from the hands before proceeding. Wash the zinc with water, and with a cloth remove all dirt from its surface. Amalgamated zinc is very brittle, so lay it flat upon a piece of board or upon a plate, after dipping it for an instant in the dilute acid. Place a small drop or two of mercury upon the strip, and rub the mercury about upon both sides of the zinc with a cloth made wet with the dilute acid.

Mercury clings strongly to zinc or tin, so you may use a narrow piece of either as a spoon to carry a small drop from the supply to the zinc. Tap it upon the zinc to dislodge the drops. Do not get on too much mercury, just enough to coat it, or, at least, that part of it that will be under the acid. Be careful not to break the thin zinc when amalgamating it, as it gets very brittle. It should look bright. (See Apparatus Book § 32, 33.)

Note. Should any mercury get upon copper plates it may be removed by heating them in a flame.

258. Dilute sulphuric acid, for these experiments, should be made by mixing 1 part, by volume, of concentrated acid, with 20 parts of water. Do not let the acid get upon clothes or carpets. Do not add water to acid. Mix by *slowly* adding the acid to the water in a glass or earthen dish, stirring at the same time. Mix over a sink or out of doors. (For fuller details see App. Book; § 21, 22, 23, 24, 25.) To save time, make at least a quart of the mixture, bottle, and label it for use.

259. Directions. (A) Bend over one end of each of the wires and metal strips, and hang them upon the edge of the tumbler (Fig. 81), so that their lower ends shall be in the acid. Do not let [103] them touch each other. Stand the carbon rod in the acid.

If there is no visible action upon any of the above substances, add a few drops of concentrated acid to the tumbler.

Note carefully what takes place in the tumbler, and state which of the substances are dissolved, which simply made brighter, and which not acted upon at all.

260. Discussion. The bubbles of gas that arise from the zinc when it dissolves are hydrogen, and they indicate that a vigorous chemical action is going on in the tumbler, and that the zinc is being eaten away.

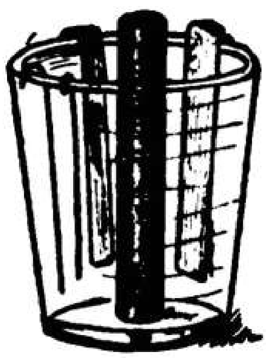


Fig. 81.

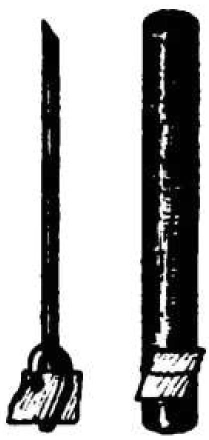


Fig. 82.

EXPERIMENT 109. To study the effect of dilute sulphuric acid upon various combinations of metals.

Apparatus. The same as in the last experiment. A small piece of amalgamated zinc, however, will be better than the whole strip.

261. Directions. (A) Twist one end of the clean copper wire around the small piece of amalgamated zinc (Fig. 82). Hold one end of the wire in the hand and dip the combination into the acid. What takes place? Watch the surface of the copper, remembering that each, alone, was not acted upon by the acid (Exp. 108).

(B) Use the clean iron wire in place of the copper wire, and repeat (A). Watch the surface of the iron.

(C) With a string or thread tie a small piece of well amalgamated zinc to the carbon rod (Fig. 82), then dip the combination into the acid. Watch the surface of the carbon.

262. Discussion. While amalgamated zinc is not rapidly dissolved by dilute sulphuric acid, a vigorous action of some kind takes place when it is in contact with another [104] metal or with carbon in the acid. The bubbles of hydrogen that are liberated do not seem to come from the zinc; they appear to grow, in the fluid, directly at the surface of the copper, iron, or other metal used with the zinc. This shows that something besides the mere dissolving of a metal takes place.

Can we arrange our apparatus so that we can get some useful results from this action?

EXPERIMENT 110. To study the construction of a simple Voltaic or Galvanic cell.

Apparatus. A narrow strip of zinc (No. 60), amalgamated as directed in § 257. (An amalgamated zinc rod (No. 74) may be used in place of the strip); a narrow strip of sheet copper (No. 67); the tumbler of dilute acid of Exp. 108; a flexible copper wire about 2 feet long, with spring connectors (No. 54) attached to its ends. (See Electrical Connections, § 226.)

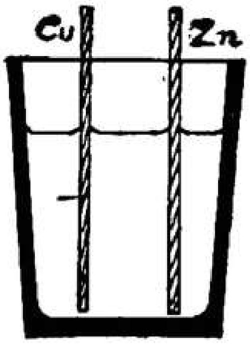


Fig. 83.

263. Directions. (A) Holding the amalgamated zinc strip in one hand and the copper strip in the other (Fig. 83), dip them into the acid, but do not let them touch each other. Note any chemical action.

(B) Touch the copper and zinc together, *below* the surface of the acid. Watch the copper.

(C) Separate the lower ends of the strips, then touch them together *above* the acid. Anything still happen to the copper?

(D) Slip one spring connector with the attached wire upon the zinc strip, then stand the strips in the tumbler, so that they can not touch each other. Now touch the copper strip with the free end of the wire, at the same time watching the copper.

(E) Raise the wire from Cu, touch it to Cu again, and repeat several times until you are sure that something takes place every time the wire touches Cu.

264. The Electric Current. Something must happen in or through the wire, and it can only happen when the two metals are joined in some way. This peculiar, invisible [105] action in the wire is called the *electric current*, and such an arrangement is called a *Galvanic cell*.

265. Source of the Electrification. When two different metals are placed in acid they are electrified unequally by chemical action. Each has a higher potential than the acid, but their potentials are not the same. This electrification tends to pass from the place of higher to the place of lower potential, and the conducting wire allows this transfer to take place. As the difference of potential is kept up by the continued chemical action, the current is continuous, and not simply instantaneous, as in discharges of frictional electricity. As heat is produced by the burning of coal, so electrification is produced by the chemical burning of zinc. Chemical energy is the source of electrification in the Galvanic cell, just as muscular energy was the source of the electrification in the experiments with frictional electricity.

266. The Electric Circuit; Open and Closed Circuits. The simple Galvanic cell just used, together with the wire which joined the metal strips, is called an *electric circuit*. If the current should pass through a telegraph instrument, for example, on its way from one strip to the other, the telegraph instrument would also be in the circuit. When the wire is cut or removed from one metal strip, the circuit is said to be *open*—that is, we have an *open circuit*. When the current passes, the circuit is *closed*. We also say *make* and *break* the circuit, and that the circuit has been *broken*.

267. Plates or Elements. The copper and zinc strips are called the *plates or elements* of the cell. The zinc, Zn, Fig. 84, is dissolved by the acid, and is called the positive plate (+ plate). The copper, Cu, is the negative plate (- plate). The copper is [106] also called the *cathode*, and the zinc the *anode*.

268. Direction of Current. It has been agreed, for convenience, that *in* the cell the current passes from the zinc through the liquid to the copper, where the hydrogen bubbles are deposited. It then passes through the wire, or other conductor furnished, back to the zinc, through the liquid to Cu again, and so on around and around thousands of times per second. The current really starts at the surface of the zinc, where the chemical action is. When carbon and zinc are used, the action and direction of the current are the same, carbon being the - plate.

269. Poles or Electrodes. If the wire were cut, the electricity

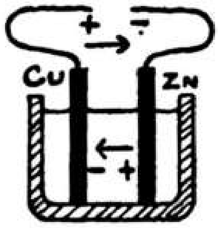


Fig. 84.

coming from the + plate would be stopped at the end of the wire marked +, Fig. 84, after passing through the acid and up Cu. This end of the wire is called the + *pole or electrode* (positive). The end of the wire joined to Zn is called the - *pole* or *electrode*; that is, the + electrode is the end of the wire attached to the - plate. The tops of Cu and Zn may be considered electrodes. The top of Cu is the + *pole* of the cell, while Cu is the - *plate*.

270. Chemical Action in the Simple Galvanic Cell. The chemical formula of sulphuric acid is H_2SO_4 (read H, 2, S, O, 4). This means that it is a compound of hydrogen (H), sulphur (S), and oxygen (O). The H_2SO_4 stands for *molecule* of acid, and the small figures show that the molecule is made up of 2 *atoms* of hydrogen (H_2), one of sulphur (S), and 4 of oxygen (O_4). The atoms are held together by *chemical attraction* or *affinity*.

There is a stronger chemical affinity between zinc (Zn) and SO_4 than between H_2 and SO_4; so, as soon as the Zn gets a chance, as it does in the cell, it drives out the H_2, and it takes its place [107] in the molecule. This chemical *reaction* may be shown by the following chemical *equation*:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

Zinc and sulphuric acid produce zinc sulphate and hydrogen.

The zinc sulphate produced weakens the effect of the acid; in fact, the acid has to be renewed occasionally, as it is changed to the sulphate which remains in solution.

271. Action in Cell Using Impure Zinc. The above action takes place in the cell when impure zinc is used, even when no current passes, heat being produced by the reaction instead of useful electricity. (See Local Currents.)

Action in Cell Using Pure Zinc. When pure zinc (or impure zinc that has been properly amalgamated) is used in the cell, it dissolves, or is eaten away, only when the current passes. It should be noted that the bubbles of hydrogen do not even then appear at the zinc; they are not seen throughout the body of the liquid. There seems to be an unseen transfer of hydrogen from the zinc, through the liquid, to the copper (or other - plate used), and it appears there in the shape of bubbles. The larger the quantity of pure zinc dissolved, the stronger the current, and the larger the amount of hydrogen produced.

As the zinc dissolves it parts with its latent energy, and this energy forces the electric current through the circuit. While the hydrogen of the decomposed acid makes its way towards the - plate, the SO_4 part of it travels towards the Zn plate, where the $ZnSO_4$ is formed. (See § 270.)

EXPERIMENT 111. To see what is meant by "local currents" in the cell.

Apparatus. Tumbler of dilute sulphuric acid. (§ 258); strip of unamalgamated zinc; crystal of copper sulphate (blue vitriol) (No. 86); a galvanized iron nail (No. 69), this being iron covered with zinc.

272. Directions. (A) Hold the nail in the acid for a few seconds, and note result.

(B) Rub the copper sulphate upon the zinc simply in one spot, then place the zinc in the acid, noting the result at the spot.

273. Local action; Local Currents. Ordinary commercial zinc contains such impurities as carbon, iron, lead, etc., in small quantities. It was seen, Exp. 109, that [108] when different metals were in contact with the zinc, the zinc was rapidly dissolved by the acid. The impurities in the zinc act like the copper plate in the simple cell, thus producing *local currents* in the zinc, which rapidly destroy it without doing any good. These currents pass from zinc to impurities, and back to the zinc, without going out into the main wire. This local action takes place even when the main circuit is open.

274. Reasons for Amalgamating Zinc Plates. Pure zinc is not affected by dilute sulphuric acid, but it is too expensive to use in cells; so amalgamated zinc is used instead, because it is cheaper, and acts the same as pure zinc. The impurities are removed from the surface of the zinc, as the zinc alone is dissolved by the mercury. There is, then, a liquid layer of pure zinc with mercury upon the surface of the amalgamated plate. This is not acted upon by the acid when the circuit is open. A stronger and more regular current is produced with amalgamated zinc than with the impure unamalgamated zinc.

EXPERIMENT 112. To study the "single-fluid" Galvanic cell.

Apparatus. The galvanoscope G V (No. 58), (See § 240, etc.); the simple cell arranged as described in § 275, the zinc being amalgamated.

275. The Simple Cell should be arranged so that the plates will be held firmly in position. The zinc, Zn (No. 60), and copper, Cu (No. 67), should be fastened to the wooden cross-piece, W C P (No. 70), as shown in Fig. 85. Care should be taken not to use longer screws than those provided for (No. 72). If the screws touch each other they will short circuit the cell. Partly fill the tumbler (No. 65) with dilute sulphuric acid (§ 258), join wires with connectors to the plates. The free ends of the wires are then ready to join to apparatus. The ends of wires *may* be fastened under the screw-heads instead of using connectors on the plates. Do not put the plates into the acid until you read the "directions."

276. Directions. (A) Arrange as in Fig. 86. Place the coil of G V, N and S (§ 244). *Before* [109]
putting the plates in the acid join them to the 15-turn coil of G V (§ 242). The compass-needle should point to zero. See that the needle swings freely.

(B) Place the plates in the acid, and *quickly* bring the needle to rest with the aid of the hand, so that you can take the reading at once before the hydrogen bubbles entirely cover the copper plate. Watch the action of the needle for a few minutes. Make a note of the reading, in degrees, at the beginning of the experiment and at the end of five minutes. (See Note.)

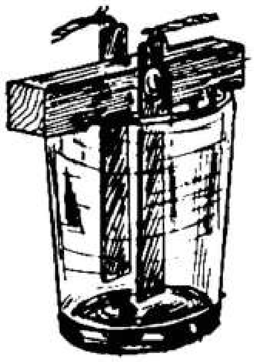


Fig. 85.

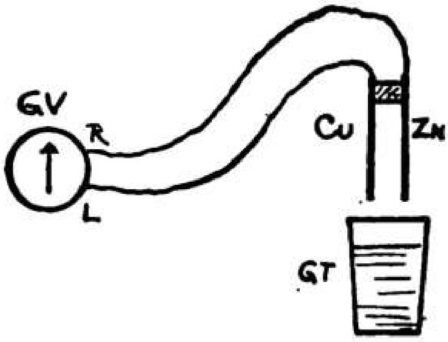


Fig. 86.

Note. If no change takes place in the position of the needle, the change beginning inside of 10 seconds after the plates are let down into the acid, withdraw the plates, then clean and thoroughly dry the copper to remove all traces of hydrogen. This may be done by heating the copper over a gas flame. Let the copper remain in the air 15 minutes, then try again. In taking the first reading you must work quickly. Catch the needle during its *first* swing. If you allow it to swing back and forth until it comes to rest, your first reading will not be what it should be.

(C) After the needle has remained in one position, without change, for 2 or 3 minutes, take hold of the wooden cross-piece, move the plates back and forth in the acid to dislodge the hydrogen bubbles, and note carefully the action of the needle. Does the current seem stronger when the plates are moved? Can you get the needle back to the first reading?

(D) Remove the plates from the acid, dry and clean the copper, let them stand in the air for 15 minutes, then take another quick reading and compare it with the first.

278. Polarization of Cells. The acid gets a little weaker, of course, as it is [110]
decomposed by the zinc (§ 270), but the chief cause of the weakening of the current is hydrogen, which forms a filmy coating upon the copper plate. This coating even seems to soak into the copper, and it takes some time for it to be thoroughly removed. The zinc plate is kept comparatively free from hydrogen by amalgamation.

279. Effects of Polarization. The hydrogen bubbles weaken the current in at least two ways. In the *first* place, hydrogen is not a conductor of electricity; so it holds the current back, as any other resistance would.

Secondly, acid acts upon hydrogen as it would upon another metal. When the copper plate becomes well covered with hydrogen, the acid cannot touch it; so we really have a *hydrogen plate* in the cell. Hydrogen acts very much like zinc in the acid; we say that it is more electro-positive than copper. The result is, then, that a new current starts up, and as this is towards the zinc, in the acid, it partially destroys or neutralizes the main zinc-to-copper current. Practical use is made of the principles of polarization (see Secondary Batteries).

280. Remedies for Polarization; Depolarizers. Any scheme by which the hydrogen may be destroyed and kept from the inactive, or negative plate, will prevent polarization. *Mechanical* means have been employed to brush away the hydrogen by keeping up a constant circulation of the liquid. *Chemical action* is another means by which the hydrogen may be side-tracked before it gets to the - plate in single-fluid cells. Substances like nitric acid and bichromate of potash, called *depolarizers*, contain large quantities of oxygen, and, during the chemical changes that take place, this oxygen unites with the hydrogen. These substances are used in zinc-carbon cells. (See [111]
§ 286, etc. for various forms of cells.)

There is another form of cell, the *two-fluid* type, in which *electro-chemical* means are employed, and in which a metal is deposited upon the - plate instead of hydrogen. The - plate is usually copper, copper being deposited upon it.

EXPERIMENT 113. To study the "two-fluid" Galvanic cell.

Apparatus. The glass tumbler, G T, (No. 65); porous cup, P C, (No. 73); the strip of zinc (No. 60), well amalgamated (§ 257), or the amalgamated zinc rod (No. 74); piece of sheet copper (No. 75), bent so that it will surround P C; copper wires, C W, with connectors; a saturated solution of copper sulphate, commonly called blue vitriol or blue stone (See § 283); dilute sulphuric acid (See § 258). With the above, set up the two-fluid cell (See § 281). The galvanoscope, G V, complete, is also needed, and if quantitative work is to be done, a pair of scales weighing to 0.1 gram is necessary. (See App. Book, Chapter I, for Home-Made Two-Fluid Cells.)

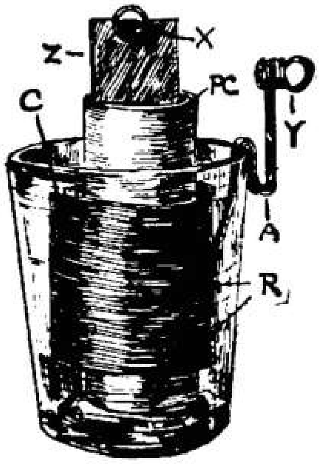


Fig. 87.

281. Setting Up the Two-Fluid Cell. Fig. 87. Stand the amalgamated zinc rod, Zn, in P C, then place P C in the tumbler, G T; put in the copper plate as shown. Pour diluted acid (§ 258) into P C until it stands about 2½ in. deep; then at once pour the copper solution (§ 283) into G T, on the outside of P C, until it stands at the same height as the acid *in* P C. As soon as the [112] liquids have soaked into P C the cell will be ready for use; but it is better to connect it with the galvanoscope at once and note the increase of current during the first few minutes while the liquids soak through P C. A crystal of copper sulphate should be put outside of P C to keep the solution full strength. This is a form of the well-known Daniell cell. Fig. 87 shows a form of home-made two-fluid cell as described in Apparatus Book. If you have the one furnished, use the rod instead of sheet zinc, and use connectors on the plates.

282. Care of Two-Fluid Cell. This experimental cell should be taken apart when not in use. It should not be left in open circuit, even for half an hour. Even after the plates are removed, copper may be deposited upon P C in case there are any metallic impurities on it. Remove the plates and P C, and thoroughly wash them. The copper solution should be put into a bottle to prevent evaporation; the dilute acid may be thrown away to be replaced by fresh acid for the next experiment.

283. Copper Sulphate Solution is made by adding the blue crystals to water until no more will dissolve—that is, the solution should be "saturated," extra crystals always being left in the stock bottle. An ounce of the crystals to half a tumbler of water will be about right, but a pint or so should be made at a time and be kept bottled to save time.

284. Directions. (A) In case you have access to a pair of scales that weigh to within 0.1 gram, carefully weigh both copper and zinc before proceeding. They should be washed and dried with a cloth. See that there are no drops of mercury upon the zinc that may fall off during the experiment.

(B) Replace the plates in the cell, and connect them with the 15-turn coil of G V, placed N and S. Allow the circuit to remain closed for half an hour, and record the position of the needle every 5 minutes.

(C) Again wash, dry with a cloth without rubbing, and weigh both the zinc and copper. Compare the new weights with those found in (A).

285. Chemical Action in the Two-Fluid Cell. In this form of cell the hydrogen is not allowed to collect upon the copper plate. The action inside of P C is like that explained [113] in § 270, hydrogen being set free. As soon as this hydrogen (H_2) comes in contact with the copper sulphate ($CuSO_4$), and it begins to do this in the walls of P C, a new chemical reaction takes place. Hydrogen has a stronger attraction for SO_4 than Cu has, so it unites with the SO_4, forming H_2SO_4 (sulphuric acid), and this at the same time throws out the Cu bodily. This Cu is then free, instead of hydrogen, to be deposited upon the copper plate. The current is constant, as there is no polarization.

286. Various Galvanic Cells; Open and Closed Circuit Cells. There is no one form of cell that is best for all kinds of work. If momentary currents only are wanted, such as for bells, telephones, etc., in which the cell has plenty of time to rest, *open circuit* cells are used. These cells polarize, however, when the circuit has to be closed for any length of time. This form of cell is always ready for use, and may not need attention for months at a time. The most common forms of the open circuit cells are the *Leclanché* (§ 287) and *dry* cell (§ 288). Open circuit cells polarize quickly, because the depolarizer (§ 280) is slow in destroying the hydrogen.

When a strong current is needed for a considerable time, such as for telegraph lines, motors, etc., a *closed circuit* cell is necessary. The depolarization must be rapid and constant. The *bichromate* (§ 289) and the *Daniell* cell (§ 290) are very common forms of closed circuit cells. (See, also, Storage Cells.)

287. The Leclanché Cell is an open circuit cell in which carbon and zinc are the plates. The carbon is surrounded with dioxide of manganese, a depolarizer; the two are either packed together in a porous cup, or the latter is compressed into blocks, which are fastened to the carbon. The porous cup stands in a jar containing a solution of sal ammoniac (ammonium chloride), which acts as the exciting fluid, and in which stands a zinc rod. The zinc is not acted [114] upon when the circuit is open. The hydrogen given off by the decomposition of the ammonium chloride is destroyed by the oxygen contained in the manganese dioxide. The E. M. F. is nearly 1.5 volts.

288. Dry Cells are for open circuit work. Sheet zinc forms at the same time the active plate and the outside cylinder or case. A carbon plate acts as the inactive or - plate. The exciting fluid is kept from spilling by its being absorbed by one of the various substances used for that purpose.

289. The Bichromate of Potash Cell is a very common one for laboratory use. It gives a strong current, and although a single fluid cell, it does not readily polarize. Zinc and carbon plates are used. In the sulphuric acid, which is the exciting fluid, is dissolved bichromate of potash. This cell is used for running small motors, induction coils, etc. It has, with fresh solutions, an E. M. F. of about 2 volts. (See Apparatus Book, Chapter I., for Home-Made Batteries.)

290. The Daniell Cell, of which the two-fluid cell used in Exp. 112 is a form, is noted for its constant current. The E. M. F. is a little over 1 volt, and it should be kept working through a resistance when not in regular use; it should not be left in open circuit. The porous cup keeps the two fluids from mixing, but it does not stop the current.

291. The Gravity Cell is a form of the above. As one of the fluids is heavier than the other, no porous cup is needed. Gravity, together with the action of the current, tends to keep the fluids separated. A copper plate is placed in the bottom of the jar, and upon this is put the copper sulphate solution. The zinc plate is supported by the top of the jar and rests in a solution of zinc sulphate, which is lighter than the blue solution below. An insulated wire extends from the copper through the liquids. This cell is used for telegraph and similar work. (See Apparatus Book for Home-Made Gravity Cell, its Regulation, etc.)

CHAPTER XVI.

THE ELECTRIC CIRCUIT.

EXPERIMENT 114. To see what is meant by "divided circuits" or "shunts."

Apparatus. The galvanoscope, G V (No. 58); astatic galvanoscope, A G (No. 59); two-fluid cell, 2-F C (see § 281); 6 wires with connectors; small thin pieces of tin or other metal, M P, for rapidly making connections (§ 226). *Arrange* as in Fig. 88. The wires, 1 and 4, from 2-F C, lead to the metal plates M P-A and M P-B, for convenience. The wires, 2 and 3, from G V, are also connected with these plates. The wires, 5 and 6 (dotted lines), lead from A G, to be used as directed in part (B) of the experiment. See that G V is properly placed. See that A G is adjusted.

292. Directions. (A) Without A G in place, take the reading of G V. The current now passes from Cu through 1, M P-B, 2, G V, 3, M P-A, 4 to Zn.

(B) Connect wires 5 and 6 to the plates, as shown by the dotted lines. Again take reading of G V, and compare it with the first reading. Does some of the current pass through A G?

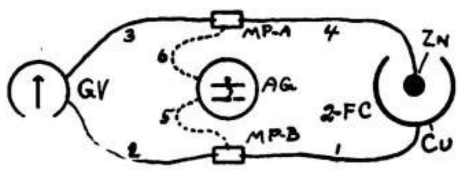


Fig. 88.

293. Divided Circuits; Shunts. The current divides at M P-B into two parts; one part may be called a *shunt* of the other. The circuit is said to be *divided*; it has two branches. If the two ends of a wire be fastened to another as in Fig. 101, the circuit is also divided. When two or more conductors lead side by side from one point to another, they are called *parallel* circuits; that is, the conductors are joined in parallel.

As strong currents would injure delicate galvanometers, a small part only of the current may be allowed to pass through the galvanometer by using a shunt. Fig. 89 shows such an arrangement, in which most of the current passes through the shunt, S. There are many practical uses of shunts. [116]

Fig. 89.

EXPERIMENT 115. To see what is meant by "short circuits."

Apparatus. About the same as in Exp. 114, Fig. 88. The astatic galvanoscope is not needed; in place of it provide a short piece of metal, such as a battery-plate, or even a jack-knife. *Arrange* as in Fig. 88, but without A G.

294. Directions. (A) With the current passing as described in Exp. 114 (A), take the reading of G V.

(B) Lay the ends of the metal, or other thick conductor, upon M P-A and M P-B. Compare the new reading of G V with that in part (A).

(C) Remove the conductor used to short circuit G V, take the reading in degrees, then touch M P-A to M P-B; watch G V.

295. Short Circuits are very apt to occur unless care is taken. Do not allow uninsulated wires to touch each other. As shown by the above experiment, practically the whole of the current may be side-tracked by a *shunt of low resistance*. A galvanic cell is short-circuited by connecting the plates directly by a wire or other conductor.

CHAPTER XVII.

ELECTROMOTIVE FORCE.

296. Electromotive Force. It has been stated that a galvanic cell has the *power* to charge one of its plates positively and the other negatively; this power is called *electromotive force*, and, for short, E. M. F. is written. The E. M. F. of a cell depends upon the kinds of plates used and their condition, the chemicals used in the exciting fluids, etc. The greater the E. M. F. of a cell the greater its power to force the current through wires, etc. The E. M. F. of a cell does not depend upon the size of its plates, as will be seen by later experiments.

297. Unit of E. M. F.; The Volt. A certain amount of E. M. F. has been taken as the standard, and, in honor of Volta, it has been called the volt. The E. M. F. of the two-fluid cell used in Exp. 113 is not far from 1 volt. If a certain cell has the power to keep up twice the difference of potential between its terminals that the Daniell cell has, we say that it has an E. M. F. of about 2 volts.

Voltmeters are instruments to measure E. M. F.

EXPERIMENT 116. To see if the E. M. F. of a cell depends upon the materials used in its construction.

Apparatus. Tumbler two-thirds full of dilute sulphuric acid (258); strips of zinc, Zn (No. 60); copper strips, Cu (No. 67); iron strip, I (No. 76); lead strip, L (No. 77); carbon rod (No. 64); the galvanoscope, G V (No. 58); 2 wires with connectors (§ 226), so that the plates can be changed quickly; the wooden cross-piece, W C P (No. 70).

Arrange as in Fig. 90. The metal strips are all of the same size; they may be held with the hand firmly against W C P, in order to have them the same distance apart in each trial. They should be lowered to the bottom of the tumbler in each case, in order to have them acted upon by the same amount of acid. Place G V properly.

298. Directions. (A) With Zn and Cu connected to G V as shown (Fig. 90), take the reading in degrees, and note in which direction (east or west) the N end of the needle is deflected. Tabulate results, as shown in Fig. 91, filling in each column of your table made out on paper. [118]

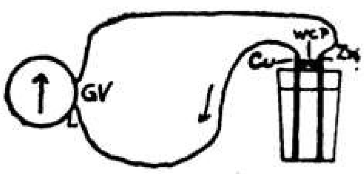


Fig. 90.

(B) In like manner try the following combinations in the order given, in each case connecting the first-mentioned plate with the left-hand binding-post, L, of G V. For (B) use zinc-iron.

(C) Use zinc-lead; (D) iron-copper; (E) iron-lead; (F) lead-copper; (G) copper-carbon.

PART	PLATES.		LIQUID.	DEFLECTION.	CURRENT IN CELL FROM
(A)	ZINC.	COPPER.	DIL. SULP. ACID.	65° WEST.	CU TO ZN
(B)					
(C)					

Fig. 91.

299. Note. Some of the combinations produce but slight currents. In case G V is not delicate enough to show clearly which way the current passes, use the astatic galvanoscope in its place for such combinations.

300. Discussion. Exp. 116 clearly showed that different combinations of metals in the acid have different powers of pushing electricity through the galvanoscope. Although some of the pairs of metals furnished so weak a current that it was necessary to use the astatic galvanoscope to study the current, all produced *some* current, and from the results can be formed an electromotive series (§ 301). The strength of acid, condition of plates, etc., affect the E. M. F. of a cell.

301. Electromotive Series. All metals are not acted upon to the same degree by dilute acid. From the results of Exp. 116 it is seen, part (B), that iron is electronegative to zinc; that is, the [119] current in the cell flows from zinc to iron. Part (D) showed that iron is electropositive to copper, as the current flowed from iron to copper in the cell. It is possible to arrange the metals in a series, one below the other, in such a way that any one will be electronegative to those above it and electropositive to those below it; that is, the list should have the most electropositive metal at the top, and the one least acted upon by the acid at the bottom. Make such a list from your results. The farther the metals used are apart in the *list*, the greater will be the E. M. F. of the cell. Good carbon is acted upon the least of all, so zinc and carbon are better than zinc and copper.

EXPERIMENT 117. To see whether the electromotive force of a cell depends upon its size.

Apparatus. Galvanoscope; two glass tumblers; dilute acid; two wooden cross-pieces; two copper and two zinc strips, the same size as those used for Exp. 112. (See § 275). These materials will form two simple cells like Fig. 85. Have about 3 in. of acid in one tumbler, and but 1 in. in the other. The plates of one cell will then be about 2½ in. in acid, and those of the other cell only ½ in. in acid. This gives us the same effect as a large and a small cell.

302. Directions. (A) Join the large and small cells with G V so that their currents will oppose each other. To do this, join the two zinc plates by means of a wire and connectors. With two other wires connect the two copper plates with the galvanoscope binding-posts, and watch for any indication of current. Does one cell oppose the other?

303. Discussion. The E. M. F. of a cell, then, does not depend upon the size of its plates. The small piece of zinc—that is, the one in but little acid—had the same potential as the large piece; they must have had, as they were joined. The large cell will give a stronger current, under certain conditions, than the small one; but this depends upon other things than E. M. F. (See experiments under Current Strength.) A zinc-copper cell, like the one just used (Exp. 117), has the same *voltage* as one of the same kind would have, even though it were made as large as a barrel.

CHAPTER XVIII.

ELECTRICAL RESISTANCE.

305. Resistance. It is harder for a horse to draw a wagon through deep sand than over a smooth pavement. We may say that the sand holds the horse back—that is, it offers a resistance. The electric current does not pass through all sorts of substances with the same ease, and when it succeeds in pushing its way through a circuit of considerable resistance, we cannot expect it to arrive at the end of its journey without being weaker than when it started. Do we expect this of a man or horse? We shall soon see that there is a definite relation between resistance and the strength of the current at the end of its journey.

EXPERIMENT 118. To study the general effect of "resistance" upon a current.

Apparatus. Galvanoscope, G V (No. 58); resistance coil, R C (No. 79) (§ 310); two-fluid cell, 2-F C (§ 281); 4 wires with connectors (§ 226). *Arrange* as in Fig. 92. The current passes as shown by the arrow, and the circuit may be opened and closed at the metal plate, M P, or by using a key in its place. Properly place G V.

306. Directions. (A) Take the reading of G V in degrees, the current passing through the entire length of R C. (See § 310.)

(B) Change the end of wire 4 from binding-post R to M, on R C, so that the current will pass through one-half only of R C. Note the reading of G V.

(C) Remove R C entirely and connect wires 3 and 4 by means of a metal plate. Compare the readings of (A), (B) and (C). What do they show?

307. External Resistance; Internal Resistance. When we consider a circuit like that shown in Fig. 92 we see [121] that it is composed of two parts, and that we have two kinds of resistances. The wires, instruments, etc., make up what is called the *external resistance* of the circuit; that is, the part that is external to the cell. The liquids in the cell offer a resistance to the current; this is called *internal resistance*. (See § 314.) The strength of the current depends upon the relation between these two resistances, as will be seen by future experiments, as well as upon the E. M. F. of the cell. As liquids are not as good conductors as metals, the internal resistance of cells may be quite high.

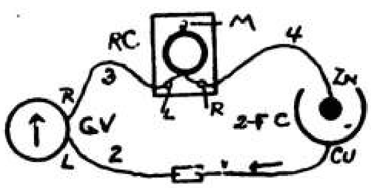


Fig. 92.

308. Unit of Resistance; The Ohm. Whenever anything is to be measured, a standard, or unit, is necessary. The unit of resistance is called the ohm, in honor of Ohm, who made careful investigations upon this subject. A column of mercury having a length of a little over 3 feet has been taken as a unit. (The column taken is 106.3 cm. with a weight of 14.4521 grams; it has a cross-section of about 1 sq. mm., at a temperature of 0°C.) Mercury is a liquid, and has no "grain" to affect the resistance. For the use of students, 9 ft. 9 in. of No. 30 copper wire, or 39 ft. 1 in. of No. 24 copper wire will make a fairly good ohm. We might, of course, take any other length as *our* standard; the above, however, will give results that are approximately correct. (See wire tables at the end of this book.)

309. Resistance Coils; Resistance Boxes. Coils of wire, having carefully-measured resistances, are called *resistance coils*. The wire for any coil is doubled at the center before it is wound into coils or upon spools (Fig. 93) to avoid the magnetic effect. The [122] ends of the coils are attached to binding-posts, or to brass blocks, in regular instruments, so that one or more coils can be used at a time; that is, so that they may be handled in a manner similar to that in which the different coils on the galvanoscope are used.

If we have 4 coils of 1, 2, 2, and 5 ohms resistance, we shall be able to use any number of ohms from 1 to 10 by making the proper connections. (See Apparatus Book, chapter XVII, for Home-made Resistance Coils.)

For protection and convenience, coils are usually placed in a box, the whole being called a *resistance box*. The ends of the coils are joined to brass blocks, placed near each other on the top of the box, and between which may be pressed plugs when it is desired to short circuit the coils. By removing a plug, the coil, whose ends are joined to the blocks touching it, is brought into the circuit.

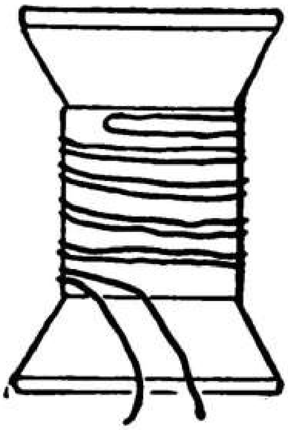


Fig. 93.

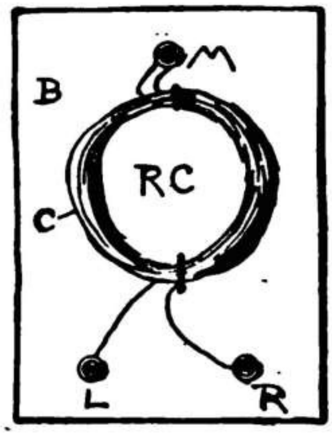


Fig. 94.

310. Simple Resistance Coil. Fig. 94 shows a simple form of coil, R C (No. 79). The total resistance is 2 ohms, L (left) and R (right) being binding-posts to which the ends of the coil, C, are joined. M (middle) connects with the middle of the wire, at which point the wire is doubled. The coil is fastened to a stiff pasteboard base, B.

Connections. When 2 ohms resistance are wanted, let the current enter at L and leave at R (or the reverse). When 1 ohm is wanted, let the current leave or enter at M, the other wire being joined to L or to R. Connections should be made with spring connectors. See § 229. [123]

EXPERIMENT 119. To test the power of various substances to conduct galvanic electricity.

Apparatus. Galvanoscope, G V (No. 58); dry cell, D C, or two-fluid cell, 2-F C; pieces of different metals; wood, dry and damp; tumbler of pure water; rubber; ebonite; silk; glass, etc., etc. *Arrange* as in Fig. 92, leaving out R C, and instead of having M P between wires 1 and 2, use their free ends to press firmly upon the ends of the substance to be tested; that is, the body under test should take the place of M P in the Fig. G V will show a deflection, of course, when the particular thing under test is a conductor.

311. Directions. (A) Make tests with the above substances, and with any others at hand, and note which are conductors and which are not.

312. Conductors and Nonconductors. It is evident, from the experiments, that bodies which conduct static electricity do not necessarily conduct galvanic electricity. The greater the E. M. F. of a current, the greater its power to overcome resistance. Some bodies, like dry wood, that readily conduct the high potential static electricity, make fairly good insulators for the low potential galvanic currents. For convenience, substances may be divided into *good conductors*, *partial conductors*, and *insulators*, or nonconductors.

Good Conductors. Metals, charcoal, graphite, acids, etc.

Partial Conductors. Dry wood, paper, cotton, etc.

Insulators. Oils, porcelain, silk, resin, shellac, ebonite, paraffine, glass, dry air.

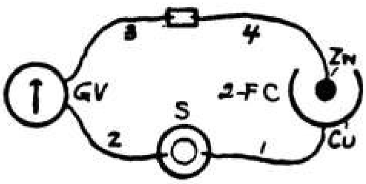


Fig. 95.

EXPERIMENT 120. To find the effect of sulphuric acid upon the conductivity of water.

Apparatus. Galvanoscope, G V; cell; 2-F C; connecting wires; saucer or tumbler, S; a little sulphuric acid. [124]

Arrange as in Fig. 95.

313. Directions. (A) Put a little pure water in S, and see if enough current can pass through it to deflect the needle of G V. The ends of the wires, 1 and 2, should be gradually moved toward each other, the needle being watched.

(B) Put 4 or 5 drops of concentrated acid into the water; stir it, then repeat the test. What effect has the acid?

314. Internal Resistance. As found in Exp. 120, pure water is not a good conductor of galvanic electricity. The acid in the simple cell, and in other single-fluid cells, acts upon the zinc and at the same time makes it possible for the current to pass, as it reduces the internal resistance.

As seen later, this resistance in cells is greatly diminished by bringing the plates near each other, and by increasing the surface of the plates that are in contact with the acid. The larger the plates the less the internal resistance, other things remaining the same. The internal resistance of a *battery* can be changed by connecting the cells differently. (See Chap. on Arrangement of Cells.)

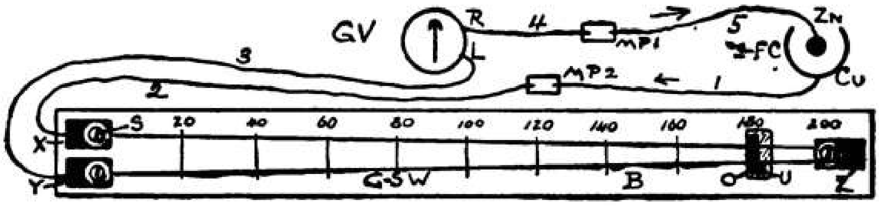


Fig. 96.

EXPERIMENT 121. To find what effect the length of a wire has upon its electrical resistance.

Apparatus. A No. 30 German-silver wire, G-S W, a little over two meters long, un-insulated (No. 81); the two-fluid cell, 2-F C (Exp. 113); galvanoscope, G V (No. 58); plate binding-posts, X, Y and Z (No. 83–84–85); copper washers (No. 87).

Arrange as in Fig. 96, so that the current will flow, at first, as shown by the arrow. The metal plates, M P 1 and M P 2, are used so that the connections may be changed without disturbing G V. The binding-posts may be fastened directly to the top of the table; but it will be more convenient to permanently fix them to a board, B, as shown, so that the same arrangement can be used for future experiments. The binding- [125] posts, X and Y, should be about ⅛ in. apart, just far enough so that their edges do not touch each other.

The binding-post, Z, should be fastened to B with its inside end 1 meter(100 centimeters, cm.) from the ends of X and Y. Marks should be made upon B, 10 centimeters apart, as indicated by the cross lines. This distance may be taken from the scale on the rule (No. 88).

Fasten one end of the No. 30 wire, G-S W, to X. To do this twist its end around the screw, S, between X and the copper washer, then turn the screw in with a screw-driver until it firmly holds X to the board. Pass the wire around the screw in Z, and bring its free end to the other binding-post, Y, to be fastened (Fig. 96). Two meters of wire then form a path for the current from X to Y. Have the board wide enough so that another set of binding-posts can be put by the side of Y. It will be best to permanently leave the No. 30 wire upon the board, and to fasten the No. 28 wire (next experiment) to another set of binding-posts, placed in the same manner as those in Fig. 96. Make holes in the wood with an awl before forcing in the screws.

315. Note. This experiment is usually done with a reverser in the circuit, first taking readings with the current passing in one direction, and then in the opposite direction. Considerable time will be saved by taking all the readings for one direction of the current at a time, simply using different lengths of German-silver wire, and allowing the current to flow constantly during each part. This obviates all danger of poor contacts in the reverser, etc.; it saves the trouble of handling the reverser, and much of the time needed for the needle to come to rest.

Length of Circ., Cm.	200	180	160	140	120	100	80	60	200	O
Deflection; West	26°	28°	30°						26°	67°
Deflection; East	25°	27°	30°						25°	67°
Average	25.5	27.5	30						25.5	67

Fig. 97.

316. Directions. (A) With the circuit arranged as in Fig. 96, and with G V properly placed, take the reading of G V, the current passing through 200 cm. of No. 30 G-S W. Record your [126] results in a diagram made like Fig. 97. The row of figures across the top shows the length of the circuit. The table is started with results from one experiment. Your results will probably be different from these.

(B) Get the deflection with the current passing through 180 cm. of wire. To do this press a piece of copper (O, Fig. 96) upon the wire at the mark 10 cm. from Z, another thin piece of metal, U, having been slipped under the wire. This will allow the current to pass across from one wire to the other. Record the deflection in the col. marked 180.

(C) Record the deflections for the lengths, 160 cm., 140, 120, 100, 80, and 60; then repeat (A) to be sure that the cell has been working uniformly. This deflection should agree with that in (A).

(D) Change the direction of the current through G V; to do this, change wire, 1, from M P 2 to M P 1, and wire 5 to M P 2. This must be done without disturbing G V.

(E) Repeat (A), (B), and (C), and record the deflections for the different lengths.

(F) Get the average deflections.

(G) Take, for future use, the deflection produced without G-S W being in the circuit. Swing the end of wire, 3, that is joined to Y, around to M P 2. The current will then pass simply through G V. Record deflection in col. marked O.

Note. It is best to do the next experiment at once with the same cell, so that the results of the two experiments can be compared. In case this is impossible, get your cell to produce the same deflection when you use it again, as shown in col. O, Fig. 97. You can regulate the deflection of the needle of G V by varying the strength and quantity of the acid in P C.

317. Discussion. The resistance of a wire evidently depends (Exp. 121) upon its [127] length. The *exact* relation between resistance and length cannot be seen from these results, however, which are used in the next experiment. It will be shown later that in a wire, other things remaining the same, the resistance varies directly as its length.

EXPERIMENT 122. To find what effect the size (area of cross-section) of a wire has upon its electrical resistance.

Apparatus. Same as in last experiment, with one change, however. Replace the No. 30 G-silver wire with a No. 28 G-silver wire (No. 82), or, what is better still, fasten it to another set of binding-posts on the board and leave the No. 30 for future use. The two should be stretched side by side for constant use.

318. Directions. (A) See that your cell is in the same condition as for Exp. 121; that is, it should produce the same deflection of the needle of G V as before, when the two, only, are in the circuit. (See Exp. 121, G.) The deflection may be changed by changing the strength and quantity of the dilute acid and copper solution.

(B) Find the average deflection of the needle with the 2 meters of No. 28 G-s wire in the circuit, arranged as in Fig. 96.

(C) Compare this average deflection with the results obtained in Exp. 121, in order to find what length of the No. 30 wire has the same resistance as 2 meters of No. 28 wire. To find how many times greater one length is than another, we divide the larger length by the smaller; hence, to find the relation between the two lengths of wire that gave the same deflection,—lengths of equal resistance,—we divide the 200 centimeters (the length of the No. 28) by the length of No. 30 found as directed.

(D) From the wire tables it will be found that the area of cross-section of No. 28 wire is about 1.59 times that of No. 30 wire. How does this quotient, or ratio, compare with that found in part (C)? What is the relation between the area of cross-section of a wire and its resistance? (See § 319, also Exp. 136.)

319. Discussion. If we find that a certain wire, X, which is 576 feet long, has the same resistance as a shorter one, Y, 360 feet long, we see (576 divided by 360) that the ratio of their lengths is 1.6. This means that the longer one, X, is 1.6 times as good [128] a *conductor* as Y; or, in other words, that the *resistance* of Y is 1.6 times that of X.

It is easier for water to flow through a large pipe than it is through a small one. The same general principle is true of electricity. A large wire offers less resistance to the current than a small one of the same material. If one wire is twice the size of another of equal length, it will be twice as good a conductor as the other; that is, it will have one-half the resistance of the smaller, provided they are of the same material. (See Laws.)

EXPERIMENT 123. To compare the resistance of a divided circuit with the resistance of one of its branches.

Apparatus. Same as in last experiment. Arrange as in Fig. 98.

320. Directions. (A) Note the deflection of the needle when the current passes through 1 meter of G-s wire, as shown. This will be considered as one branch of the divided circuit.

(B) Still allowing the current to pass as in part (A), press a piece of copper firmly across the binding-posts X and Y, to electrically connect them, and note the reading of the needle. In this case the current divides at Z through the two branches. What is learned from the results of (A) and (B)?

(C) See if you can show the same results with apparatus arranged as in Fig. 99.

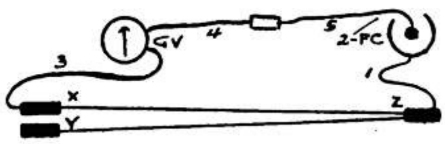


Fig. 98.

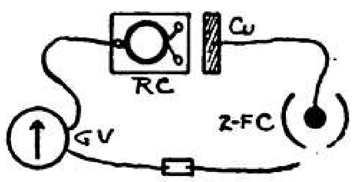


Fig. 99.

321. Discussion. Two wires placed side by side as in (B), Exp. 123, really form a conductor having twice the size (area of cross section) of one of the branches. The more paths a current has in going from one place to another, the less the resistance. [129] (See Exp. 135.) The wires are said to be in "parallel" or in "multiple arc."

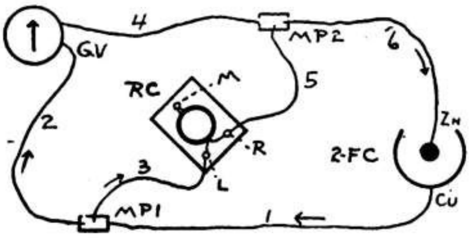


Fig. 100.

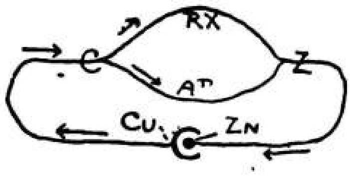


Fig. 101.

EXPERIMENT 124. To study the effect of decreasing the resistance in one branch of a divided circuit.

Apparatus. Galvanoscope, G V (No. 58); resistance coil, R C (No. 79); two-fluid cell, 2-F C (§ 281), or a dry cell; 6 connecting wires; metal plates, M P.

Arrange as in Fig. 100, so that the current divides into two branches at M P 1. The branches unite at M P 2.

322. Directions. (A) Take the reading of G V with 2 ohms resistance in the lower branch; that is, with the whole of R C in circuit.

(B) Take the reading of G V with one ohm in circuit; that is, with the end of wire, 5, connected to M instead of to R.

(C) Cut out R C from the lower branch by replacing it with a metal plate, thus joining wires 3 and 5. Compare the results from (A), (B), and (C), and explain.

323. Current in Divided Circuits. Let us consider a circuit like that shown in Fig. 101. If the points, C and Z, were at the same potential, no current would pass from C to Z. As the current does pass, Z must be at a lower potential than C; there is a *fall of potential* from C to Z. If the branch, A B, has the same resistance as R X, the same amount of current will pass through each. Exp. 124 has shown that when the branches have unequal resistances, most of the current passes through the one of small resistance. If R X has a greater resistance than A B, most of the current will pass through A B.

CHAPTER XIX.

MEASUREMENT OF RESISTANCE.

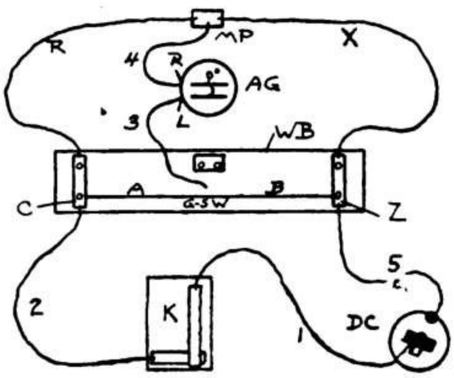


Fig. 102.

EXPERIMENT 125. To study the construction and use of a simple "Wheatstone's Bridge."

Apparatus. Fig. 102. A Wheatstone's bridge, W B (No. 80), (§ 324); astatic galvanoscope, A G (No. 59); dry cell, D C (No. 51); key, K (No. 55); 7 wires with spring connectors, two of which, R and X, are equal in length; metal plate, M P, for connecting wires.

Arrange as in Fig. 102. The carbon of D C is joined to K, and this to the point, C, of the bridge. The zinc of D C connects with the point Z on W B. The A G is placed between the branches for clearness. Wire 3 is joined to the left-hand binding-post of A G, and wire 4 joins M P with the right-hand one. When the end of wire 3 does not touch G-s W, it is evident that as soon as K is pressed, the current divides at C on its way to Z, where the branches unite again. K is used so that D C will not be polarized by steady use.

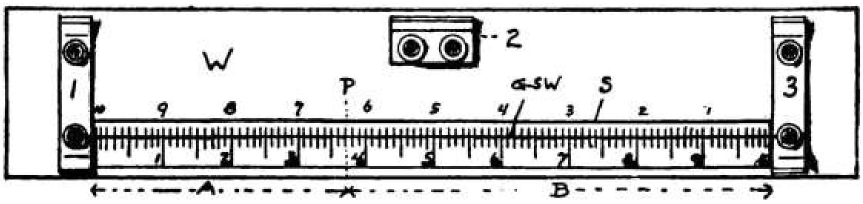


Fig. 103.

324. The Simple Wheatstone's Bridge (Fig. 103) consists of a wooden base, W, at the ends of which are fastened two aluminum conductors, 1 and 3. At one side of W is fastened another conductor, 2. In Fig. 104 are side views of the conductors. These are used merely for [131] convenience in making connections, and take the place of the metal plates used in previous experiments. A German-silver wire, G-s W, is stretched between 1 and 3, and under this is a scale, S, divided into 100 small parts, these being tenths of the larger divisions. The ends of G-s W are held between eyelets, as shown at E, Fig. 104.

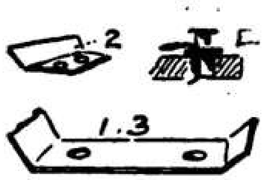


Fig. 104.

Reading the Scale. The value of part A can be read directly from the scale, using the lower row of figures. The point marked P, for example, would be read 3.7 (three and seven-tenths large divisions); B would be 6.3, found by subtracting 3.7 from 10. The sum of A and B must always equal 10. The 6.3 may also be read directly by using the upper row of figures for the whole numbers, counting the tenths to the left. Try to divide the smallest divisions into halves, at least; that is, if A = 3.75, B = 6.25. Take the readings carefully.

325. Directions. (A) Touch the free end of wire, 3, to the point, C, which has a higher potential than M P. Press down K for an instant only. Some current should pass through A G, as a shunt. Should it pass from C to M P or the reverse? Note in which direction the right-hand end of the astatic needle is deflected.

(B) Swing the end of 3 around and touch it to the point, Z, which has a lower potential than M P. Press K for an instant, watch the needle, and compare with the results in (A).

(C) Move the free end of 3 along on G-s W, touching K at intervals, until a point is found at which the needle of A G is not deflected. How does the potential of this point compare with that of M P?

326. Discussion; Equipotential Points. Since one end of the G-s W has a higher, and its other end has a lower potential than M P, there must be, somewhere on it, a point at which the potential is the same as at M P. This place is quickly found by sliding the free end of wire, 3, along, pressing K occasionally, until A G shows that no current tends to pass through it in either direction, when the current passes from C to Z through the two branches of the divided circuit. This point and M P are called [132] *equipotential points*.

If the resistance of the part, X, be increased, it should be evident that the part of the bridge-wire, B, should be also increased to find a point having the same potential as M P; that is, the end of 3 should be moved towards C.

We have, in the bridge-wire, a simple means of varying the resistance of its parts, A and B.

327. Use of Wheatstone's Bridge. It will be found, upon trial, if we put a resistance of 2 ohms in place of R, Fig. 102, and 2 ohms in place of X, that the free end of wire 3 will have to be at the center of the bridge-wire in order to get a "balance"; that is, to find the place where A G is not affected. No matter what the resistance of R and X are, provided they are equal, this will be true. The value of both A and B, on the scale, will be 5 whole spaces, no tenths. From this we see that A: B:: R: X, which reads A *is to* B *as* R *is to* X; this means that A × X = B × R. Supplying the values of the letters, we have 5 × 2 = 5 × 2. If we did not know the value of X, that is, if we were measuring the resistance of a coil of wire, using a 2-ohm coil as the standard, or R, we could find the value of X, knowing the other 3 parts of the proportion. 5 × X = 5 × 2, which means that 5 times the value of X is 10; hence the value of X is 10 ÷ 5 = 2 ohms.

Suppose that we have R = 2 ohms, which is the standard resistance coil (No. 79), and are trying to find the resistance of a coil, X. We slide the end of wire, 3, along on the bridge-wire until the correct place is found. (See Exp. 125, 126, for details.) Take the values of A and B (§ 324), supply them in the equation given, and work out the value of X.

328. EXAMPLE. R = 2 ohms; A = 3.7; B = 6.3; to find the value of X in ohms.

A: B:: R: X, which means that A × X = B × R, or 3.7 × X = 6.3 × 2. X must equal, then (6.3 × 2) ÷ 3.7 = 3.405 ohms.

Note. In practice it is most convenient to make connections as shown in Fig. 105 when measuring resistances (Exp. 126). The arrangement given in Fig. 102 is simply for explanation. It will be seen that the smaller A is, compared with B, the larger the unknown resistance compared with your standard.

[133]

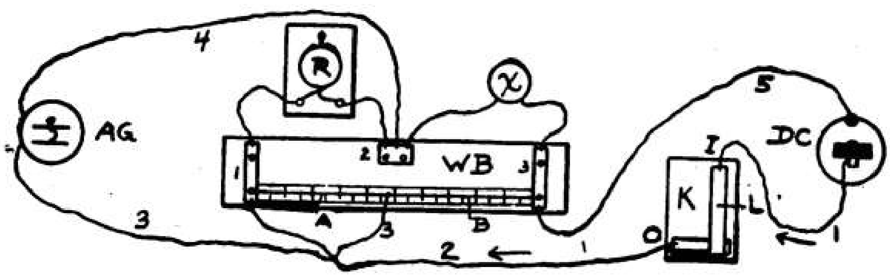


Fig. 105.

EXPERIMENT 126. To measure the resistance of a wire by means of Wheatstone's Bridge; the "bridge method."

Apparatus. Same as in Exp. 125; the two-ohm resistance coil, R C (No. 79); a coil of wire, X, as, for example, the 15-turn coil on the galvanoscope, G V (No. 58).

Arrange as in Fig. 105. You will observe that the central conductor of the bridge (2, Fig. 104) takes the place of M P in previous explanations. We still have the same kind of a divided circuit as explained in Exp. 125, A G being connected with points of equal potential. It will be found convenient to have D C at the right, and A G facing you at the left, the key being in front. (See Exp. 107 in regard to adjusting A G.)

Notice that you have a standard resistance (2 ohms) in place of R, Fig. 102, and an unknown resistance (galvanoscope coil) in place of X. (See § 330.)

329. Directions. (A) Touch the free end of wire, 3, to the left-hand side of the bridge-wire, press the key for an instant, only, and note the direction taken by the right-hand end of the needle. Move the end of wire, 3, to the right-hand side of the bridge-wire, touch key, watching needle. Does the needle move more or less than before? In the same or opposite direction? If the deflections are opposite, the point that has the same potential as binding-post, 2, must be *between* the two points touched.

(B) Be sure that all connections are good. Find the point on G-s W, at which there is no deflection, as directed in Exp. 125 (C). Note the readings on the scale, as explained in § 324.

(C) Make the proper calculation, § 327, 328, and find the resistance of the coil of G V, the resistances of the wires joining R C and G V to the bridge being neglected.

(D) Make proper allowances for the resistances of the wires just mentioned (see § 330), and [134]
compare them with the results found in part (C).

330. Allowances for connections. It should be remembered that the wires joining R C and G V to the bridge also have some resistance. Such connections, in regular instruments, are made by heavy copper straps or by thick, short wires, so that their resistances can be neglected. In case you use the ordinary No. 24 copper wire, as directed, the resistances of the pieces can be measured by means of the bridge, or you can calculate their resistances from the wire tables. The resistances should be allowed for. It is evident that your standard resistance is 2 ohms *plus* the resistance of the connecting wires, and that the resistance of the coil, X, is found by deducting the resistance of its connecting wires from that found from the proportion previously used.

Example. We see from the table that the resistance of about 39 ft. 1 in. of No. 24, B and S copper wire is 1 ohm. This equals 469 in. If 469 in. have a R (resistance) of 1 ohm, 1 in. will have a R of one-469th of an ohm; that is 1 divided by 469, which equals a little over .002 ohm. For every inch of No. 24 wire used, then, for connections, we may allow .002 ohm. This will be near enough for our purposes.

Suppose that each connection is 18 in. long, the regular wires with connectors being used. The R of the 36 in. joined to R C will then be 36 times .002 = .072 ohm. Our standard R must then be considered as 2.072 ohm. If we substitute this in the example, as stated in § 328, we have 3.7 × X = 6.3 × 2.072. X must equal (6.3 × 2.072)/3.7 = 3.528 ohm, which includes the unknown resistance and 36 in. of connections, the R of which is .002 ohm; 3.528 - .072 = 3.456, the resistance of X alone. Compare this with the answer to example, § 328. Make allowances according to length of connectors used.

Note.—Carefully keep all the results of these experiments in a note book for future reference. Be sure that connections are good.

EXPERIMENTS 127–137. To measure the resistances of various wires, coils, etc., by the "bridge method."

Apparatus. The coils of wire, etc., as stated in the "Directions" of each experiment. The details of each piece of apparatus may be found by referring, from the numbers given, to the "Apparatus List," and to descriptions in the paragraphs mentioned. Also all the apparatus of Exp. 126.

Note. Make proper allowances for connections (§ 330) in all experiments in measuring resistances.

[135]

EXPERIMENT 127.

331. Directions. (A) As explained in Exp. 126, measure the resistance of the 10-turn coil of G V, allowing for connections (§ 330). Read the bridge-scale carefully.

(B) Use one-half of the 2-ohm coil as standard and repeat.

EXPERIMENT 128.

332. Directions. (A) Measure the resistance of the 5-turn coil of G V (see Exp. 126, etc.), using 2 ohms as standard.

(B) Use 1 ohm as standard, repeat, and compare results.

(C) Add the resistances of the 5 and 10-turn coils, and compare the sum with the resistance of the 15-turn coil, as found in Exp. 126, D. The difference should be but a few hundredths of an ohm.

EXPERIMENT 129.

333. Directions. (A) Measure the resistance of the coil of No. 24 copper wire (No. 89). This coil is used for later experiments. Spring connectors are fastened to the ends of this coil, allowing it to be directly connected to the conductor on the bridge, so no allowance should be made for its connecting wires. (See Exp. 126 for details.) Mark the resistance upon the coil for future use. (See Note.)

Note. The student will be surprised, perhaps, to find that different results are obtained for the resistance of a given wire in case he uses different standard resistances in the various tests; that is, he will probably get a different result in Exp. 127 (A) from the result of Exp. 127 (B). The difference here, however, may not be large. The best results are obtained by making the standard resistance as nearly equal as possible to the resistance to be measured, so that a balance can be found when the end of wire 3 (Fig. 105) is near the center of the bridge-wire. If R, Fig. 105, is much larger or smaller than X, the point desired on G-s W will be near one of its ends, and large errors thereby produced. The approximate resistance of X can be found by trial, then more or less resistance can be used for R to suit. The student should make several coils as explained in Apparatus Book, Chapter XVII. The resistance of the different coils furnished should be measured and marked. These can be used to vary the value of R.

[136]

EXPERIMENT 130.

334. Directions. (A) Measure the resistance of the coil of No. 25 copper wire (No. 90). (See Exp. 126 for details and the Note, Exp. 129.)

EXPERIMENT 131.

335. Directions. (A) Measure the combined resistance of the two coils used in Exps. 129 and 130, when they are joined in "series"; that is, when one end of one coil is joined to one end of the other by means of a metal plate, the free ends being connected to the bridge (Exp. 126). The current has to travel through the entire length of both coils.

(B) Compare this result with the sum of their separate resistances found in Exps. 129 and 130. (See Exp. 129, Note.)

EXPERIMENT 132.

336. Directions. (A) Measure the resistance of the two coils (Exp. 131) when they are joined "in parallel." (See § 293.) They may be joined in parallel by connecting them both to the bridge at the same time, one end of each being slipped onto 2 (Fig. 103), the other end of each being joined to 3. In this way the current has two paths, side-by-side, to get from 2 to 3. (See Exp. 129, Note.)

(B) Compare this resistance with that of Exp. 131.

EXPERIMENT 133.

337. Directions. (A) Measure the resistance of 1 meter of No. 28 German-silver wire. Use the wire as arranged on a board, Exp. 122 (Figs. 96 and 98), making the connections with the bridge from binding-posts, X and Z. (See Exp. 129, Note.) The wires connecting the bridge with the ends of the G-s wire will each have to be about 2 ft. long. In making deductions (§ 330) figure according to the length used.

(B) Divide the total resistance by 100 to get the resistance of 1 cm. of the wire, and carefully mark off the board into cm. This will give 100 parts between X and Z.

EXPERIMENT 134.

338. Directions. (A) Using the No. 28 G-s wire on the board, as arranged for Exp. 122, measure the resistance of the 2 meters in series, the connections being made with the bridge from X and Y, Fig. 98.

(B) Compare the result with that of Exp. 133. What is the relation between the length of a wire and its resistance? See Summary of Laws. (See Exp. 129, Note.) [137]

EXPERIMENT 135.

339. Directions. (A) Measure the resistance of the above two meters of No. 28 G-s wire when joined in parallel. (§ 293.) The binding-posts, X and Y, can be joined by a short wire with connectors on its ends, or by clamping a thin strip across by means of spring connectors. Use the 2-ohm coil as the standard, and make proper allowances. (§ 330.)

(B) From the results of Exps. 132 and 135 what can be said about the resistances of parallel circuits as compared with the resistances of the separate branches?

EXPERIMENT 136.

340. Directions. (A) Arrange the 2 meters of No. 30 G-s wire on the table or board, again (Exp. 121, Fig. 96).

(B) Measure the resistance of one meter. Find the value of X approximately, and use a resistance for R that will suit. (See Exp. 129, Note.)

(C) Divide the result by 100 to get the resistance of 1 cm. of the wire.

(D) Compare the resistance of one meter of No. 28 G-s wire, found in Exp. 133, with the resistance of 1 meter of No. 30 G-s wire. What is the relation, then, between the size (area of cross-section) of a wire and its resistance? (See the results of Exp. 122, and § 319, also Summary of Laws.)

EXPERIMENT 137.

341. Directions. (A) Measure the resistance of 2 meters of No. 30 copper wire, arranged on a board as in Fig. 96. (See Exp. 129, Note.) Get the resistance of 1 meter.

(B) Compare the conductivities of copper and German silver by studying the results of Exps. 136 and 137. Which has the greater resistance? To find out how many times greater one resistance is than the other, divide the larger by the smaller.

EXPERIMENT 138. To study the effect of heat upon the resistance of metals.

Apparatus. Same as for Exp. 126; the coil of No. 24 wire (No. 89); a lamp or other source of heat. Arrange as in Fig. 105.

342. Directions. (A) Measure the resistance of the coil as before, Exp. 129. The result should nearly agree with that of Exp. 129, provided connections, etc., are the same. [138]

(B) Remove the coil from the bridge, hold it about a foot above a lamp or stove, to warm it thoroughly, but do not heat it enough to injure the covering. It will take a minute or so to warm it so that the heat will get to the inside also.

(C) Replace the coil, measure its resistance, and compare the result with its resistance when cold. Does heat increase or decrease the resistance of a copper wire?

343. Effect of Heat upon Resistance. Although there was but the fraction of an ohm difference in the resistances of the hot and cold coil, it was evident that changes of temperature affect the conducting power of copper. This is true of all metals; but German silver and other alloys are much less affected than pure metals, so they are used in making standard resistance coils. The resistance of liquids that can be decomposed by the electric current decreases as the temperature rises. Carbon acts like the liquids, while the resistance of metals *increases* as their temperature rises.

EXPERIMENT 139. To measure the resistance of a wire by the method of "substitution."

Apparatus. The coil of No. 24 wire (No. 89), the resistance of which has been measured, but which will be considered an unknown resistance, X; G V, 2-F C, M P, connecting wires, etc., previously used; rheostat (§ 344). Arrange as in Fig. 106 first, then as in Fig. 107.

344. Simple Rheostat. The No. 28 and No. 30 G-s wires stretched upon the board (Fig. 96), make a convenient form of rheostat. The resistance per cm. being known from the results of Exp. 133 and 136, the resistance for any number of cm. is easily found. The 10-cm. divisions should be divided into centimeters. These spaces may be marked off from the rule (No. 88).

[139]

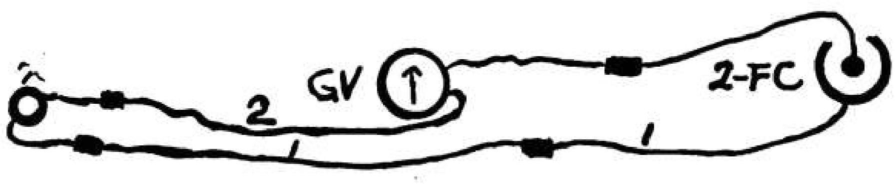


Fig. 106.

345. Directions. (A) Be sure that 2-F C gives a constant current, shown by the uniform deflection at G V, when arranged as in Fig. 106. Do not use a cell that quickly polarizes. The coil, X, forms a part of the circuit; it is joined to wires, 1 and 2, by means of metal plates, so that it may be quickly removed without disturbing either G V or 2-F C. Carefully read the deflection at G V.

(B) Remove X from the circuit, and join the free end of wire, 2, to binding-post, X, and the free end of wire, 1, to a small piece of sheet copper, which can be firmly pressed upon the G-s wire to make a contact. Move this along on the G-s wire until the deflection produced equals that of part (A), remembering that the longer the G-s wire in the circuit the less the deflection. Make two or three trials, as one or two cm. difference in length make but a little difference in the deflection. Note the number of cm. of G-s wire used, the resistance of which must equal that of the coil, X.

(C) Find the resistance of X by multiplying the length just found by the resistance of each cm., and compare the result with the value found by using the bridge method directly.

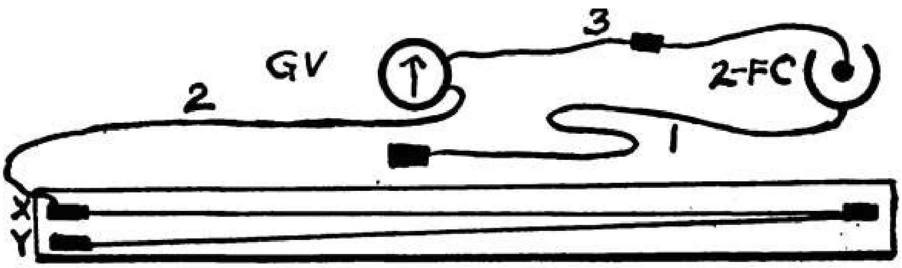


Fig. 107.

EXPERIMENT 140. To measure the E. M. F. of a cell by comparison with the two-fluid cell.

Apparatus. Rheostat (§ 344); the two-fluid cell, 2-F C (Exp. 113), the E. M. F. of which may be taken as 1 volt; dry cell, D C; galvanoscope, G V. Arrange first as in Fig. 107.

346. Directions. (A) Be sure that 2-F C gives a constant current. Take the reading of G V without the rheostat in the circuit; that is, with wires, 2 and 1, joined directly. The deflection should be 50 or 60 degrees at least, and be constant. [140]

(B) Attach a small piece of copper to the end of 1, and firmly rub it along upon the G-s wire, thus introducing resistance into the circuit, until the deflection is, say, 60° (50 or 55 degrees will do). Note the length of G-s wire used and call it (B).

(C) Gradually add more resistance by moving the end of 1 along until the deflection is 50°, 10 degrees less than before. (If the original was 50° make the new 40°). Call the number of cm. of wire used (C).

(D) Replace 2-F C with the dry cell D C. Add resistance, as before, until G V indicates a deflection of 60°, being careful not to keep the circuit closed long enough to partially polarize D C. Make 2 or 3 trials, allowing D C to rest a few minutes between each. Call the number of cm. of G-s wire used (D).

(E) Again add more resistance, as in (C), until the deflection is reduced to 50°. Call the length used (E).

347. Calculation. It is known that resistances that are able to reduce the strength of the currents equally are proportional to the electromotive forces; that is, the electromotive forces of the two cells are to each other as the two resistances necessary to produce equal changes in the deflections, which, of course, indicate equal changes in the strength of the currents. Since the resistances used in the two cases are directly proportional to the lengths used, we have:

Length (C-B): Length (E-D):: E. M. F. of 2-F C: E. M. F. of D C.

Substitute the values found and find the E. M. F. of D C.

EXPERIMENT 141. To measure the internal resistance of a cell by the "method of opposition."

> *Apparatus.* All the apparatus of Exp. 126. Two simple cells (§ 275), the plates of which should be of the same size, the same distance apart, and immersed in acid to the same extent in both. The acid in both should be of the same strength.

348. Directions. (A) Connect the two cells in opposition, so that no current will be generated by them, and so that the two can be treated as a dead resistance. Do this by joining the two [141] zinc plates by a wire with connectors, and use wires to connect the copper plates to the bridge like any other unknown resistance.

(B) Measure the resistance of the two by the regular bridge method, allowing for wires used for connections. One-half of the resistance found will give the internal resistance of one cell. (See Note.)

Note.—The standard resistance will have to be arranged to suit each particular case to make the calculations even approximately correct. (See Exp. 129, Note.) The standard resistance may be increased by adding the various coils and rheostat wires, their values being known.

349. Summary of Laws of Resistance. 1. *The resistance of a wire is directly proportional to its length, provided its cross-section, material, etc., are uniform.*

EXAMPLE. If 39.1 ft. of No. 24 copper wire has a resistance of 1 ohm, 78.2 ft. will have a resistance of 2 ohms, because 78.2 is twice 39.1; 70.38 ft. will have a resistance of 1.8 ohms, as (70.38 ÷ 39.1 = 1.8) it is 1.8 times 39.1.

2. *The resistance of a wire is inversely proportional to its area of cross-section.* The areas of cross-section of round wires vary as the squares of their diameters; so *the resistance of a wire is also inversely proportional to the square of its diameter, other things being equal.*

EXAMPLE. A No. 30 wire has a diameter of about .01 inch, while the diameter of a No. 24 wire is about .02 in.; that is, the No. 24 has *twice* the diam. that the No. 30 has. The area of cross-section of the No. 24, however, is four times that of the No. 30, so its resistance is but ¼ that of the No. 30, the lengths, etc., being the same. (See Wire Tables.)

3. *The resistance of a wire depends upon its material, as well as upon its length, size, etc.*

4. *The resistance of a wire depends upon its temperature.* (See Elementary Electrical Examples.)

CHAPTER XX.

CURRENT STRENGTH.

350. Strength of Current. The water in a certain tank may be under great pressure, but if it is obliged to pass through long tubes before it can turn a water-wheel, for example, it is evident that the work done will depend not only upon the pressure in the tank, but upon the resistance to be overcome before the water gets to the wheel. The work that the water can do depends upon its *rate of flow*, and may be used to measure the *strength* of the current.

The strength of a current of electricity is measured also by the *work* that it can do, and it depends upon its *rate of flow* at the point measured. The strength may be determined from its magnetic, heating, or chemical effects.

351. Unit of Current Strength; The Ampere. A current having the strength of 1 ampere, when passed through a solution of silver nitrate under proper conditions, will deposit 0.001118 gramme of silver in *one second*; if passed through a solution of copper sulphate, copper plates being used for the electrodes, in the solution, 0.0003277 gramme of copper will be deposited in *one second*. (See Chemical Effects of the Current.) The thousandth of an ampere is called the milliampere. The strength of a current is proportional to the amount of chemical work that it can do per second. (See § 357.)

352. Measurement of Current Strength. The *galvanoscope* previously described simply shows the presence of a current, or whether one current is larger or smaller [143] than another. When the degree-card is used to get the relative deflections, the instrument may be called a *galvanometer*.

The Tangent Galvanometer is made on the same general idea as our galvanoscope, the diameter of the coil being twenty times, or more, the length of the needle. In these the strengths of the two currents compared are proportional to the tangents of the angles of deflection produced. (See Elementary Electrical Examples.) There are several varieties of galvanometers, each designed for its special work. They are often calibrated or standardized so that the amperes of current passing through them can be read off directly from the scale.

353. The Ammeter is really a galvanometer from which may be read directly the strength of a current. The coil has a low resistance so that it will not greatly reduce the strength of the current to be tested.

The Voltameter measures the strength of a current by chemical means.

354. Unit of Quantity; The Coulomb. A current having a strength of 1 ampere will do more chemical work by flowing one hour than it can do in 1 second. In speaking of the *quantity* of electricity we introduce the element of *time*. The unit of quantity is called the *coulomb*, just as a cubic foot of water may be taken as a unit of quantity for water. A coulomb is the quantity of electricity given, in one second, by a current having a strength of 1 ampere. Coulombs are found by multiplying amperes by seconds; thus, a current of 5 amperes will give 20 coulombs in 4 seconds.

355. Electrical Horse-power; The Watt. The electric current has power to do work, [144] and we speak of the horse-power of an electric motor in the same way as for a steam-engine. A current with the strength of 1 ampere and an E. M. F. of 1 volt has a unit of power called the watt. 746 watts make an electrical horse-power.

Watts = amperes × volts.

Watts ÷ 746 = the number of horse-power.

(See Transformers, also Elementary Electrical Examples.)

356. Ohm's Law. It was first shown by Ohm that the strength of a current is equal to its E. M. F. divided by the resistance in the circuit; that is,

Strength of current (amperes) = E. M. F. (volts). / resistance (ohms).

If we let C stand for the strength in amperes, E for the E. M. F. in volts, and R for the resistance in ohms, we have the short formula, easily remembered,

$$C = E/R$$

357. An Ampere would be produced by a current of 1 volt pushing its way through a resistance of 1 ohm. Knowing any two of the three, C, E, or, R, the other may be found.

The resistance, R, it must be remembered, is the total resistance in the circuit, and is composed of the total internal and external resistances.

(See Elementary Electrical Examples.)

358. Internal Resistance and Current Strength. It is evident that the internal resistance of a cell varies with the position and size of the plates. We shall now study the effects of these changes upon the strength of the current.

[145]

EXPERIMENT 142. Having a cell with LARGE PLATES, to find how the strength of the current is affected by changes in the position of the plates, the external resistance being small.

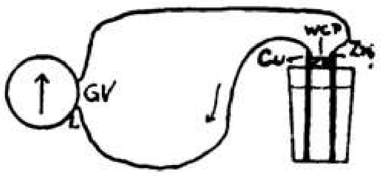


Fig. 108.

Apparatus. Galvanoscope, G V; materials for simple cell (Exp. 110); connecting wires. Arrange as in figure 108, omitting the wooden cross-piece.

359. Directions. (A) Connect the wires with the 5-turn coil of G V, which has but little resistance. Have the tumbler nearly full of dilute acid to get the effect of large plates; that is, the current has a large liquid conductor to pass through in the cell, and the *internal* resistance will be small. G V should be properly placed N and S.

(B) Place the copper and zinc plates as far apart as possible in the acid, and press them against the bottom of the tumbler. Note the reading of G V. It is not necessary to take readings with reversed current.

(C) Still pressing them against the bottom of the glass, to keep the same amount of surface under acid, slowly bring them near each other and watch the needle.

(D) Hold the plates about an inch apart, and against the bottom, and note the reading of G V. Slowly raise the plates, keeping them the same distance apart until they are out of the acid. Watch the action of the needle.

Make a note of your readings in degrees and write your conclusions. Does a change in internal resistance affect the strength of the current?

EXPERIMENT 143. Having a cell with SMALL PLATES to find how the strength of the current is affected by changes in the position of the plates, the external resistance being small.

Apparatus. Same as in Exp. 142, the acid, however, being but 1 in. deep in the tumbler; that is, we have the effect of a cell with small plates, each being about 1 in. by ½ in.

360. Directions. (A) Repeat (B) and (C) of Exp. 142, recording the reading of G V in each case.

(B) Compare the results with those of Exp. 142, remembering that the *internal* resistance is larger than before. Is the current as strong with small plates as with large plates when the [146] external resistance is small? When the external resistance is small (the 5-turn coil, for example), should the cell have a high or low internal resistance to produce the greatest effect upon the needle?

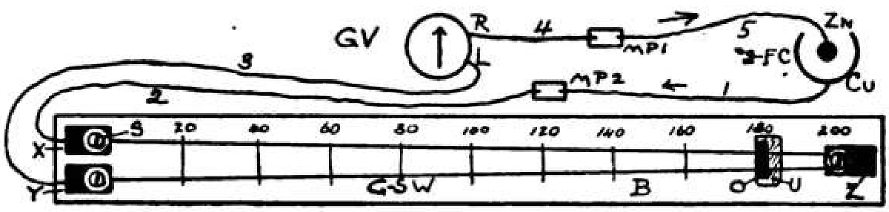


Fig. 109.

EXPERIMENT 144. To find whether the changes in current strength, due to changes in internal resistance, are as great when the external resistance is large, as they are when the external resistance is small.

Apparatus. Same as for Exp. 142, 143, also the rheostat containing the two meters of G-s wire (Exp. 121).

361. Directions. (A) Arrange as in Fig. 109, the external resistance being 2 meters of No. 30 G-s wire in series with G V. The 2-F C in the Fig. is replaced, however, by the simple cell as in Exp. 143.

(B) Find the effect upon the strength of the current of moving the plates about when but 1 in. of acid is in the tumbler.

(C) Nearly fill the tumbler with acid and repeat (B), taking readings with plates near each other and as far apart as possible. Lift them nearly out of the acid and take the reading.

(D) Still increase the external resistance of the circuit by adding coils of wire or the meter of

No. 28 G-s wire and repeat. Is the strength of the current greatly affected by *slight* changes in the internal resistance when the external resistance is large?

362. Discussion. We shall study, by means of figures, how changes in internal resistance affect the strength of the current.

Let R stand for the total external resistance of a circuit, and r for the total internal [147]
resistance of the cell or cells; ohm's law, then, will be expressed by

$$C = E / (R + r)$$

EXAMPLE. Let us take a circuit (A) when the external resistance, R, is small, and (B) when R is large compared with r, E being taken as 1 volt in both cases.

(A) Let R = 1, and r = 2; substituting these values in the formula above, we have:

$$C = 1 / (1 + 2) = 1 / 3 = .33+ \text{ ampere.}$$

Now let the internal resistance, r, be slightly increased from 2 to 3 ohms; the value of C then becomes ¼ ampere, as R + r = 4. The change in C, then, is the difference between ⅓ and ¼; and this expressed in decimals becomes .33 - .25 = .08 ampere.

(B) Let R = 200 ohms, and r = 2 ohms as in (A). Substituting these values we have,

$$C = 1 / (200 + 2) = 1 / 202 = .00495 \text{ ampere.}$$

Increasing r from 2 to 3, as before, etc., we find that C = 1 divided by 203 = .00492 ampere.

The above shows clearly (A) that the value of C is changed considerably by changes in r when R is *small*, and (B) that changes in r produce very slight changes in C when R is *large*. Review your results of Exps. 142–144. (See Elementary Electrical Examples.)

363. Arrangement of Cells and Current Strength. We have seen that internal resistance affects current strength. In joining cells, then, attention must be given to the internal resistance as well as to the E. M. F. of the combination.

364. Cells in Series. It has been shown by careful experiments that the E. M. F. of
two cells joined in series (Fig. 110) is equal to the sum of the E. M. F. of each. Ten [148]
cells, joined in series, have ten times the E. M. F. of one cell, provided they have the same E. M. F. As the Zn of one is joined to the Cu of the other, the current is obliged to pass through one solution after the other; that is, the internal resistance of the two in series is equal to the sum of their internal resistances. Ten cells, joined in series, have ten times the internal resistance of one cell, provided they have equal internal resistances.

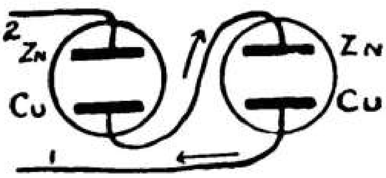


Fig. 110.

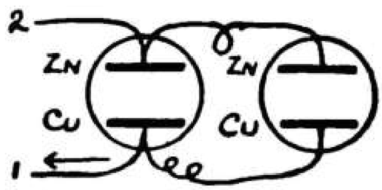


Fig. 111.

365. Cells Abreast. When the positive plates are joined together and the negative plates are also joined together (Fig. 111), the cells are said to be *abreast*, *in parallel*, or in *multiple arc*. It has been shown that two cells of equal strength, joined abreast, have the same E. M. F. as one cell. The two Cu plates, being joined, must have the same potential; all the Zn plates have the same potential, so the difference of potential at the terminals of the combination is the same as that at the terminals of a single cell.

In two cells abreast (Fig. 111) the current has two liquid paths, side by side, to get from Cu to Zn; this makes the internal resistance one-half that of one cell, provided their internal resistances are equal. Ten cells, of equal internal resistance, when joined abreast, have one-tenth the internal resistance of one cell.

[149]

EXPERIMENT 145. To find the best way to join two similar cells when the external resistance is small.

Apparatus. Two simple cells using dilute sulphuric acid, with copper and zinc elements, as in Exp. 112; galvanoscope, G V; connecting wires, etc. Have the zincs well amalgamated. Remove them from the acid as soon as readings are taken.

366. Directions. (A) Partly fill the tumblers with the acid. Join the cells in series (Fig. 110), then connect wire 1 (Fig. 110) with the left-hand binding-post of G V, and wire 2 with the middle one, thus putting the 5-turn coil into the circuit. Take the reading of G V.

(B) Join the cells in multiple arc (Fig. 111), connecting them as in (A) with G V. Write down the reading, and compare it with that found in (A).

(C) Take the reading with but 1 cell joined to G V.

EXPERIMENT 146. To find the best way to join two similar cells when the external resistance is large.

Apparatus. Same as for Exp. 145, also the rheostat containing 2 metres of No. 28 or 30 G-s wire. Arrange the G-s wire in series with the 15-turn coil of G V, as shown in Fig. 109, two simple cells being used, however, instead of 2-F C as shown.

367. Directions. (A) Take the reading of G V when the two cells are in series (Exp. 145), the external resistance being the 15-turn coil and G-s wire.

(B) Join the cells in parallel and take the reading, using the same external resistance as in (A).

(C) Increase the external resistance by adding coils of wire or 2 metres of No. 28 G-s wire and repeat (A) and (B). What does the experiment show?

(D) Take the reading with 1 cell and large external resistance.

368. Best Arrangement of Cells. It will be seen by experiments that with a given number of cells the strongest current is produced when they are arranged so that the internal resistance of the battery nearly equals the external resistance of the circuit.

When the external resistance is small, the internal resistance may be kept down by joining the cells in parallel; and, although the E. M. F. is also kept small, the value of C will be larger than it would be with a larger internal resistance and a larger E. M. F. [150]

When the external resistance is large, the internal resistance can be made large by joining the cells in series. The advantage comes, however, from having a large value of E. A large resistance can not hold back a current of large E. M. F. By joining the cells in series the value of E is made large, and the value of C becomes large even though there is an increased internal resistance. (See Elementary Electrical Examples.)

CHAPTER XXI.

CHEMICAL EFFECTS OF THE ELECTRIC CURRENT.

369. Chemical Action and Electricity. We have learned that the electric current is produced, in the cell, by chemical action. There is a definite relation between the chemical action and the current produced. We are now to study the changing of electrical energy back, again, to chemical energy.

370. Electrolysis is the name given to the process of decomposing chemical compounds by passing the electric current through them. The compound decomposed is the *electrolyte*. Fig. 112 shows a tumbler of liquid (electrolyte) through which the current is to pass in the direction of the arrow. Two carbon plates, A and C, are in the liquid, and are joined to the source of electricity. The current enters at A (*anode*) and leaves at C (*cathode*).

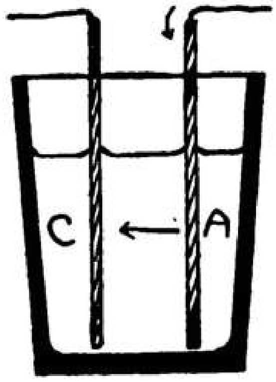


Fig. 112.

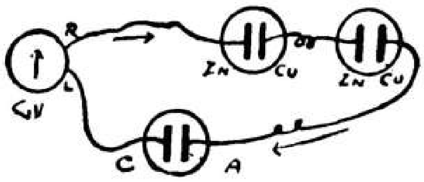


Fig. 113.

EXPERIMENT 147. To study the electrolysis of water.

Apparatus. The two simple cells (§ 275) joined in series (§ 364), although two Daniell or two dry cells will be better. A tumbler of water containing a few drops of sulphuric acid to make the water a conductor. Two pieces of sheet copper will serve as the electrodes. The galvanoscope may also be put into the circuit as in Fig. 113.

371. Directions. (A) Allow the current to pass, and note (1) whether gas is set free at both electrodes, A and C, and (2) at which the quantity of gas is the greater. If very little gas is [152] produced use more cells.

(B) Remove A and C from the liquid, to remove the gas, then watch the action of the needle of G V as the water is again decomposed.

372. Composition of Water. The two gases liberated in Exp. 147 were hydrogen (H) and oxygen (O). The chemical formula for water is H_2O, which means that it is composed of two parts, by volume, of H and one part of O. With proper apparatus these gases may be collected, tested, and the amounts measured.

373. Electromotive Force of Polarization. We know that H and O have a strong chemical attraction, or affinity, for each other. In order, then, for the current to decompose water, this attraction between the gases must be overcome; and as soon as the current ceases, these gases try to rush together again to form water. This sets up an electromotive force of almost 1.5 volts; in fact, a current is produced if the H and O be allowed to form water again (See Storage Cells). To decompose water the current must have an E. M. F. of over 1.5 volts to overcome this E. M. F. of polarization. It was seen in the study of simple cells that the current became rapidly weaker as hydrogen was deposited upon the copper plate, on account of this opposing electromotive force.

In decomposing other compounds, the anode is made of the metal which is to be deposited at the cathode. If copper is to be deposited from a solution of copper sulphate the anode should be a copper plate; this keeps the solution at same strength, and avoids the opposing E. M. F. of polarization; that is, a very weak current will do the work (See Exp. 149), because the electrodes are of the same metal.

[153]

EXPERIMENT 148. To coat iron with copper.

Apparatus. Iron nail, solution of copper sulphate (§ 283).

374. Directions. (A) Clean the nail with sandpaper, then hold it in the copper solution for a few seconds. Machinists often cover iron or steel tools with a thin coating of copper in this way.

EXPERIMENT 149. To study the electrolysis of a solution of copper sulphate.

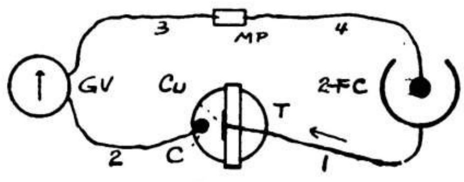


Fig. 114.

Apparatus. Galvanoscope, G V; two-fluid cell, 2-F C; a tumbler, T, containing about an inch of copper sulphate solution (§ 283); a wooden cross-piece to which is fastened a copper strip; carbon rod, C; wire 2 is held to C by a rubber band. *Arrange* as in Fig. 114, so that Cu will be the *anode* (§ 370), the current passing as shown by arrow. A dry cell may be used for short experiments instead of the 2-F C.

375. Directions. (A) The carbon being clean, allow the current to pass, C and Cu being kept about ½ in. apart. Watch the surface of C, and note the beautiful color of the deposited copper. Save the coated rod for the next experiment. Has the Cu plate been acted upon?

376. Electroplating is the name given to the process of coating substances with metal with the aid of the electric current. The copper sulphate, $CuSO_4$, is broken up into Cu and SO_4 by the current. The Cu goes to the cathode, and the SO_4 attacks the anode, gradually dissolving it if it be copper; that is, the *metal* part of $CuSO_4$ is carried in the direction of the current.

Most metals are coated with copper before they are silver or gold plated. A solution of silver is used for silver plating, silver being used as the anode.

EXPERIMENT 150. To study the chemistry of electroplating.

Apparatus. Same as in last experiment, but use two carbon rods for the electrodes. Arrange as in Fig. 114, with the Cu replaced by another carbon. Two simple cells (§ 275) are also needed. [154]

377. Directions. (A) Allow the current to pass as before. Is copper still deposited? Does anything occur now at the surface of the anode? Is the copper deposited as rapidly as before?

(B) Try the effect of the two simple cells joined in series, Instead of the two-fluid cell.

(C) After a fair coating of copper has been deposited upon the carbon cathode, reverse the direction of the current through the copper solution; that is, use the coated rod for the anode. Allow the current to pass until a change takes place in the anode.

378. Discussion. Ions are the names given to the parts into which an electrolyte is decomposed by the electric current. In the case of $CuSO_4$, the ions are Cu and SO_4, which is called an acid radical. This SO_4 can not dissolve carbon or platinum, so these are used when water is to be electrolyzed. Where copper is used as the anode for copper plating, the SO_4 attacks it, forming $CuSO_4$ again, and this keeps the solution strong. If carbon were used instead, the SO_4 would take H_2 from the water around the anode and H_2SO_4 (sulphuric acid) would be formed, the oxygen of the water being set free at the anode. The amount of Cu dissolved from the copper anode equals nearly the amount deposited upon the cathode. Exp. 150 shows that the metal is carried in the direction of the current. As hydrogen is produced at the cathode it is chemically considered a metal.

379. Electrotyping consists in making a copy in metal, of a woodcut, page of type, etc. A mould or impression of the type is first made in wax, or other suitable material (the pages of this book, for example, as set up by the printer). These moulds are, of course, the reverse of the type. They are coated with graphite to make them conduct [155]
electricity, and hung as the cathode, in a bath of copper sulphate. After a thin coat of copper has been deposited by an electric current, the wax is removed and the thin copper backed with soft metal. The metal surface next to the wax will be just like the type, only made of copper. These plates or *electrotypes* can be printed from, the original type being used to set up another page. (See "Things a Boy Should Know About Electricity.")

380. Voltameters are cells used to measure the strength of an electric current. In the *Water Voltameter* the hydrogen and oxygen produced are measured. The H acts like a metal and goes to the cathode, two parts of H being formed to one of O.

Copper Voltameter. This cell measures the amount of copper deposited in a given time by a current. The copper cathode is weighed before and after the current flows. The weight of Cu deposited is then divided by the number of seconds during which the current passed, and this result, in turn, by .000328, which will give the average strength of the current in amperes. (See § 351.) Other forms of voltameters are also used.

In all voltameters the quantity of metal deposited is proportional to the time that the current flows, and to its strength.

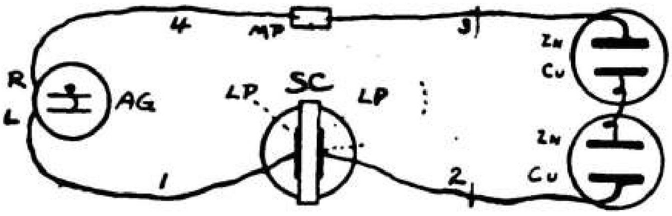


Fig. 115.

EXPERIMENT 151. To study the construction and action of a simple "storage" cell.

Apparatus. Two lead plates, L P, (Nos. 77, 78) fastened to a wooden cross-piece (§ 275). The spring-connectors should not be forced upon the thick lead. Fasten one end of the wire under the screw-head. A tumbler two-thirds full of dilute sulphuric acid (§ 258); the astatic galvanoscope, A G; wires to form connections; the two simple cells joined in series. *Arrange* as in Fig. 115. One L P is joined to binding- [156] post, L, of A G by the wire marked 1; wire 2 connects the other L P to the copper Cu. Wire 3 joins the zinc to any thin metal plate, M P, which is used for convenience, so that the spring connectors can be quickly slipped on or off. Wire 4 joins M P with binding-post R of A G.

381. Directions. (A) Get clearly in mind the direction in which the right-hand end of the astatic needle is deflected when the current passes, remembering that it passes into A G at L and leaves at R. Allow the current to flow for 10 or 15 minutes through the circuit, at the same time watching the needle to see whether the strength of the current remains constant.

(B) Remove the connector from Cu, swing it over into the position of the dotted line (Fig. 115), slip the connector upon M P and watch the needle. This cuts the cells out of the circuit; but, if you desire, also remove wire 3 from M P. Does the storage cell, S C, produce any current? Does it pass through A G in the same direction as that which came directly from the two cells?

(C) Try the dry cell in place of the two simple cells. Try 2 other cells in series if you have them.

382. Secondary or Storage Cells must be charged by a current before they can give out a current. *Electricity* is not really stored. Chemical changes are produced in the storage cell by the charging current, as in the voltameter or electroplating bath; and it is, then, potential chemical energy that is stored. When the new compounds are allowed to go back to their original condition by joining the electrodes of the charged cell a current is produced. In other words, an electric current produces chemical [157] changes in the cell by electrolysis, and these new compounds have an E. M. F. of polarization because they are constantly willing and anxious to get back to their old state. The plates are lead and are usually coated with compounds of lead. Hydrogen and oxygen are given out at the electrodes. The current from a dynamo is used to charge secondary batteries. (See "Things a Boy Should Know About Electricity.")

CHAPTER XXII.

ELECTROMAGNETISM.

383. Electromagnetism is the name given to magnetism that is developed by electricity. You have already seen that if a magnetic needle be placed in the magnetic field of a *magnet*, its N pole will point in the direction in which the lines of force pass on their way from the N to the S pole of the magnet. You have also seen that in the galvanoscope, etc., a coil of wire acts like a magnet when a current passes through it. Can we not, then, use the needle to study the lines of force about wires and coils?

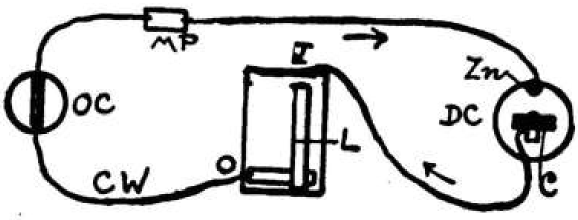


Fig. 116.

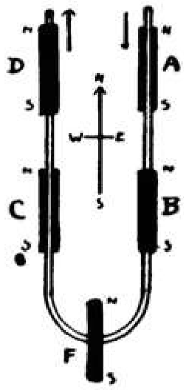


Fig. 117.

EXPERIMENT 152. To study the lines of magnetic force about a straight wire carrying a current.

Apparatus. The compass, O C; key, K; dry cell, D C. Arrange as in Fig. 116.

384. Directions. (A) Arrange the wire so that the current will flow through it from N to S over the compass-needle as soon as the circuit is closed (Fig. 117, A). Press K for an instant only, and note the direction in which the N pole is deflected. Repeat two or three times until you get clearly in mind the direction taken by the needle. Sketch the result in your note-book, and [159] compare with Fig. 118, A. The arrow shows the direction of the current.

(B) Let the current pass for an instant from N to S and *under* the needle, as shown in Fig. 117, B. Sketch result.

(C) Let the current pass for an instant from S to N *above* the needle (Fig. 117, C). Sketch result.

(D) Let it pass from S to N *under* the needle (Fig. 117, D). Sketch result.

(E) Let it pass through the wire from east to west (Fig. 117, F) above the needle, then under it, and note result. Compare the results with those indicated in Fig. 118.

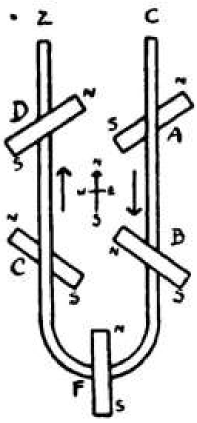


Fig. 118.

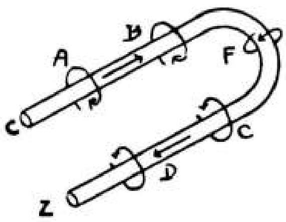


Fig. 119.

385. Lines of Force About a Wire. When a current passes through a wire, the needle, over or under it, tends to take a position at right angles to the wire. This shows that the lines of force pass *around* the wire and not in the direction of its length. The needle does not swing entirely perpendicular to the wire; that is, to the E and W line, because the earth is at the same time pulling its N pole towards the N. If the needle had no pointing power, and at the same time retained its magnetic field, it would point exactly at right angles to the wire as soon as the current passed.

If you look along the wire, Fig. 119, from the point, C, towards the positions, A and B, you will see (A) that *under* the wire the lines of force pass to the left, and that *above* the wire (B) they pass towards the right. This is because the N pole points in the directions mentioned. (See Fig. 118.) Looking along the wire from Z towards position, D and C, you will see just the opposite to the above, as the current comes *towards* you.

Rule.—When the current goes from you, the lines of force pass around the wire in a [160] clockwise direction, and when the current comes toward you they pass around it in an anti-clockwise direction.

386. Ampere's Rule may be used to remember what has been learned in Exp. 152.

If you imagine yourself swimming in the wire with the current, always facing the needle, the N-seeking pole of the needle will always be deflected towards your left hand.

When the needle is above the wire you must imagine that you swim upon your back, in order to *face* the needle.

Another Rule.—Hold the right hand with the thumb extended and with the fingers pointing in the direction of the current, the palm being towards the needle and on the opposite side of the wire from the needle. The N-seeking pole will then be deflected in the direction in which the thumb points.

387. If a wire carrying a strong current be dipped in iron filings, the magnetic field about the wire acts by induction upon the particles of filings, making magnets of them. These cling to each other simply because they are little magnets.

388. Lines of Force about Parallel Wires. When a current passes in the same direction in two parallel wires the lines of force pass around the wires in the same direction in both, and the magnetic fields attract each other. When the currents flow in opposite directions the magnetic fields repel each other.

EXPERIMENT 153. To study the lines of force about a coil of wire like that upon the galvanoscope.

Apparatus. Galvanoscope, G V; dry cell; key; compass. Arrange as in Fig. 116, using G V instead of the compass shown. The coil of G V should be placed in the E and W line. The current can pass only when the [161] key is pressed. Connect the wires with G V, so that the current will pass through the 15-turn coil from W to E on top of the coil; that is, so that the current will have a "clockwise" motion. Fig. 120 represents a front view of the coil.

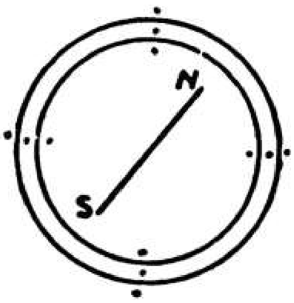


Fig. 120.

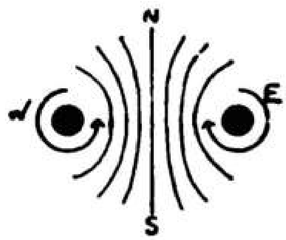


Fig. 121.

389. Directions. (A) Hold the compass in the various places marked with a dot (Fig. 120) and note the directions taken by its N pole. Make a circle similar to the one shown to represent the coil, and sketch upon it the way in which the lines of force pass around it according to your observations.

(B) Make a diagram like Fig. 121, which represents a cross-section of the coil through the center. Imagine that you have removed the top half of the coil and that you are looking down upon the ends of the wire of the lower half. Draw curved arrows about the coil at W and E to show which way the lines of force are passing. Compare your results with those in Fig. 119, remembering that at E, Fig. 121, the current is going away from you.

(C) Move O C back and forth on the center-line that runs N and S through the coil, and note the positions of the compass-needle. Does the coil seem to have poles?

(D) Reverse the current through the coil and repeat your observations.

EXPERIMENT 154. To study the magnetic field about a small coil of wire.

Apparatus. A coil of wire (No. 89), described in § 390; current reverser, C R (No. 57); dry cell; connecting wires, etc.

390. Coils of wire for some of the following experiments should be wound upon wooden spools that have been turned down thin, so that the wire will be as near the central hole as possible. [162]

They should be wound with a winder. (See Apparatus Book, Chapter X.)

For convenience we shall call the starting end of the coil, that is, the end that comes from the wire that is near the center, the *inside end*, I E. The end of the last layer of the coil we shall call the *outside end*, O E. These letters should be noted in the diagrams. See Apparatus List for details of the special coils used in these experiments.

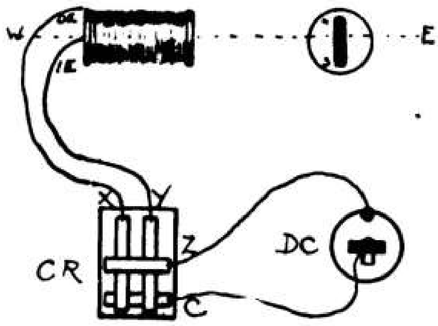


Fig. 122.

391. Directions. (A) Arrange as in Fig. 122, so that the axis of the coil will lie in the E and W line. Place O C about 2 in. from the E end of the coil. Press one lever of C R so that the current will pass around the coil for an instant in a clockwise direction; that is, so that it will enter the coil at O E. Note the action of the needle. If the needle is not affected move it nearer the coil and press the lever again. Get clearly in mind the connections, the direction in which the N end of the needle is deflected, etc. Is the E end of the coil a N or a S pole?

(B) Reverse the current through the coil. What effect has it upon the polarity of the E end of the coil?

(C) Place O C at the west end of the coil and repeat (A) and (B).

(D) Place O C in various positions about the coil and note the action of the needle when the current passes. Does this coil act like a magnet, having poles, magnetic field, etc.?

392. Polarity of Coils. It is evident from Exps. 153 and 154 that a coiled conductor has poles, magnetic field, etc., when a current passes, and that it strongly resembles a magnet, even though no iron enters into its construction. We may say that the coil becomes magnetized by the electric current. Fig. 123 shows a right handed coil or helix of wire, the current passing as shown by the small arrows. The left-hand end is a S pole because the current passes around it in a clockwise [163]
direction. When you face the right-hand end of the coil the current is seen to pass around it in an anti-clockwise direction; this produces a N pole. As the N pole of the magnetic needle is attracted toward the S pole of the coil, it is clear that the lines of force pass through the inside of the coil as shown by the large arrows. They then curve through the air and return to the S pole as with magnets.

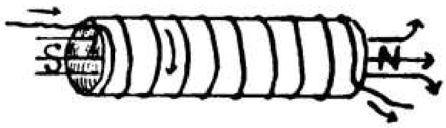


Fig. 123.

EXPERIMENT 155. To test the attracting and "sucking" power of a magnetized coil or helix.

Apparatus. The coil, battery, etc., used in Exp. 154, Fig. 122; a sewing-needle.

393. Directions. (A) Arrange the coil, etc., as described in Exp. 154. The coil need not lie in the E and W line, however, and a key may be used instead of the current reverser.

(B) Magnetize the needle so that its point will be a N pole.

Fig. 124.

(C) Tie a thread about the center of the magnetized needle, hold the thread in the hand so that the S pole of the needle will swing freely at the hole at the right-hand end of the coil (Fig. 124). If the current passes as directed, the right-hand end of the coil will be a N pole. What happens to the needle when the key is pressed for an instant.

(D) Change the needle to the left end of the coil and repeat.

(E) Try a nail, pen, iron, etc., instead of the needle.

EXPERIMENT 156. To find whether a piece of steel can be permanently magnetized by an electric current.

Apparatus. Same as for last experiment; an unmagnetized sewing-needle; the compass.

394. Directions. (A) Be sure that the needle is not magnetized. It should attract both ends of the compass-needle. How can any magnetism in the needle be removed?

(B) Place the needle inside of the coil with its *point* to the east; that is, with its point at the N pole of the coil, and its head at the S pole. Close the circuit for an instant. Test the needle again [164]
for poles. Is the point a N or a S pole?

(C) Turn the needle end for end in the coil, and see whether its polarity can be reversed.

(D) Experiment with iron wire, nails, steel pens, spring steel, etc.

Fig. 125.

EXPERIMENT 157. To study the effect of a piece of iron placed inside of a magnetized coil of wire.

Apparatus. Same as in Exp. 154; a short rod or iron *core*, I C, of soft iron (No. 92) that will fit inside of the coil. This combination is called an electromagnet.

395. Directions. (A) Arrange first as for Exp. 154, Fig. 122, with the coil in the E and W line, no core being used, and place O C about 6 in. from the right-hand end of the coil.

(B) Press the lever for an instant to see whether the field of the coil is strong enough to move the compass-needle at that distance. Move O C a little nearer or farther from the coil until the needle *just* moves, when the circuit is closed.

(C) Place I C inside of the coil (Fig. 125), and repeat (B) to see whether the magnetic field of the coil is stronger or weaker than before.

(D) Study the location of the poles. Can they be reversed?

CHAPTER XXIII.

ELECTROMAGNETS.

396. Electromagnets are important to the student of electricity. They form the principal part of nearly every electrical instrument. You have seen that a wire has a magnetic field about it the instant a current passes through it. A coil, or helix of wire, has a stronger field than a straight wire carrying the same current, because each turn, or convolution, adds its field to the fields of the other turns. By having a *core* of soft iron instead of air, wood, or other non-magnetic material, the strength of the magnet is greatly increased. The central core may be permanently fixed in the coil, or it may be removable. (See Apparatus Book, Chapter IX, for Home-made Electromagnets.)

397. Cores of Electromagnets. A strong magnet has more lines of force passing from its N pole through the air to its S pole than a weak magnet. By increasing the number of lines of force we increase the strength of a magnet. It has been seen, in experiments with permanent magnets, that lines of force do not pass as readily through air as through soft iron, and that lines of force will go out of their way to pass through iron. It was learned in Exp. 154 that inside of a helix (Fig. 123) the lines of force pass from the S to the N pole; they then spread out through the air and pass back on all sides of the coil to its S pole, as in the case of permanent magnets. The air around and inside of a helix offers a great resistance to the lines of force, and tends to weaken the magnetic field. When part of the circuit consists of an iron core, which is a [166]
splendid conductor of lines of force, the magnetic field is greatly increased in strength.

EXPERIMENTS 158–163. To study straight electromagnets.

Apparatus. A good dry cell or other source of a fairly strong current; coil with soft iron core; key; wires with connectors, etc.; small nails; iron-filings; compass; large wire nail; tin box (No. 94) to act as a base for the electromagnets.

EXPERIMENT 158. Lifting power.

398. Directions. (A) Join the cell, key, and coil, as explained in Exp. 154, so that the current will pass only when the key is pressed. Place the core inside of the coil(Fig. 125). Two good cells in series can be used to advantage.

(B) Hold the coil in a vertical position near small nails, iron filings, tin boxes, etc.; then press the key and raise coil; carry the clinging iron to another place, break the circuit at the key, and explain the result. Why do nails cling more strongly to the core than filings after the circuit is broken?

EXPERIMENT 159. Residual magnetism of core.

399. Directions. (A) After the current has passed through the coil with the core in place, remove the core and test it for magnetism with the compass. Will the small end of the core attract both poles of the compass-needle, or is it slightly magnetized?

(B) If there is any residual magnetism, strike the core with a hammer and test again.

(C) Use a soft steel wire nail for the core, and repeat (A) and (B). Why does soft iron make a better core than steel for electromagnets? Which should be the more easily magnetized?

EXPERIMENT 160. Magnetic tick.

400. Directions. (A) Join the electromagnet with the cell and key as before (Exp. 154). Hold one end of the core firmly against the top of a tin box which should stand upon the table and which should act as a sounding-board. The flat boxes used in the experiments on static electricity are good for this, or use the tin box, No. 94, for a base. Rapidly open and close the [167]
circuit by means of the key and listen for any clicks made by the core.

(B) Listen for this sound in telegraph sounders, electric bells, etc., if you have them. The armature should be held, of course, so that slight sounds can be heard.

401. Discussion. A bar of iron becomes slightly longer when it is magnetized, the particles of iron being made to point in the same direction. As soon as the current ceases to flow through the coil the particles of the soft core nearly all resume their mixed positions. The click heard is supposed to be due to the changes in the molecules of iron. The core becomes gradually warmer when it is rapidly magnetized and demagnetized by a strong current.

EXPERIMENT 161. Magnetic figures.

402. Directions. (A) Arrange as in Fig. 126. The key should be used in case a dry cell acts as the source of the current. Two good cells joined in series can be used to advantage. Lay the coil flat upon the table and place on it a piece of stiff, smooth paper, or a sheet of glass.

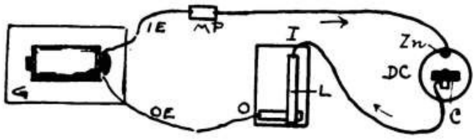


Fig. 126.

(B) Sprinkle a few iron filings upon the glass, which may be held in place by books. Gently tap the glass with a pencil while you close the circuit at the key. Do the filings arrange themselves as in the case of permanent magnets? Make a sketch of the field, remembering that you have both N and S poles, and compare it with previous results.

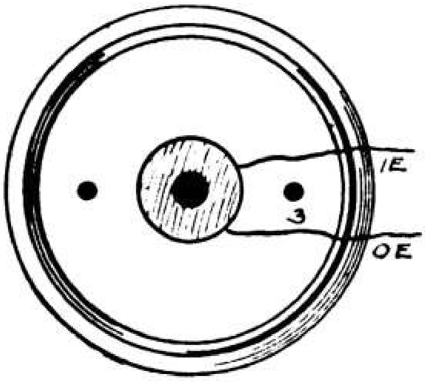


Fig. 127.

EXPERIMENT 162. Magnetic figures.

403. Directions. (A) Arrange as in Fig. 126, but stand the coil on end, using the base as directed in § 407, to hold it firmly in position. Join the ends, O E and I E, to the key as before. Fig. 127 shows a top view of the coil and base.

(B) With books, etc., fix a piece of stiff, smooth paper, or [168] glass just over the top of the core, and proceed as in Exp. 161 to study the field. See § 417 for making permanent pictures of magnetic fields.

EXPERIMENT 163. Magnetic field.

404. Directions. (A) Use same arrangement as for Exp. 162, except filings and glass, which are replaced by the compass.

(B) Hold the compass about 2 in. from the top pole of the electromagnet, close the circuit for a second or two and note action of needle. Is the top N or S, when the current enters the coil at O E? Compare result with § 392.

(C) Move the compass quickly about the pole, the circuit being closed, and note action of needle. Compare result with directions taken by particles of iron filings in Exp. 163.

(D) Reverse the direction of the current through the coil and test the nature of the pole at the top.

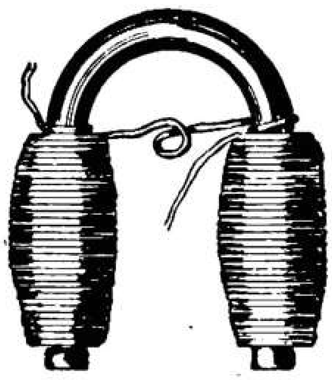


Fig. 128.

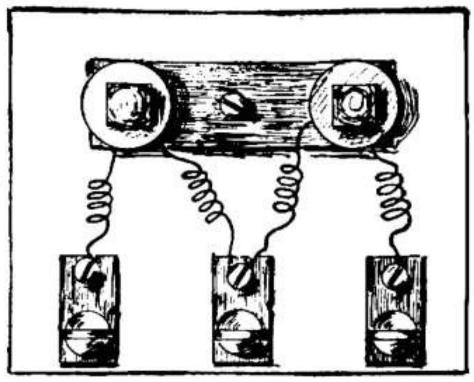


Fig. 129.

405. Horseshoe Electromagnets. Fig. 128 shows a simple form of electromagnet with two coils which have a bent piece of iron as a core for both. The coils have to be wound on by hand in this form. As this is troublesome, the coils are generally wound on two separate cores which are joined by a *yoke* (§ 406), which takes the place of the curved part in Fig. 128. The separate coils can be quickly made with a "winder" and joined to suit. (See Apparatus Book, Chapter IX, for Home-made Electromagnets.) Fig. 129 shows a top view of a home-made experimental horseshoe electromagnet. The [169] coils are joined by an iron strap, called the *yoke*, which is screwed to a wooden base. A strip of iron placed above the magnets to be attracted by them, when the current passes, is called the *armature*. (See Telegraph Sounders.)

406. Use of Yoke. It has been explained (§ 82) why horseshoe magnets are, in general, better than straight ones. The same is true of electromagnets; there are two poles to attract, and two to induce. The lines of force pass through the yoke on their way from one core to the other, and this reduces the resistance to them. The strength of the horseshoe magnet would be greatly reduced if the lines of force were obliged to pass through two air spaces instead of one; in fact, if there were no yoke we should have simply two straight magnets. The yoke should be made of soft iron.

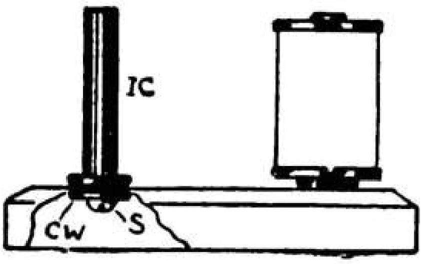


Fig. 130.

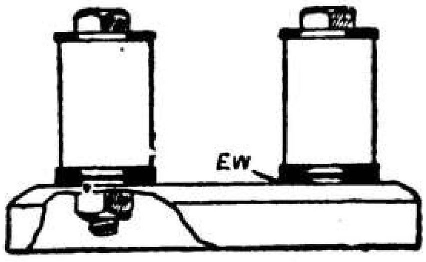


Fig. 131.

407. Experimental Magnets are quickly joined to a tin base (No. 94), which has 3 holes punched in, through which screws can be put to hold the cores in place. Fig. 127 shows plan of tin. Fig. 130 shows how removable cores are fastened to the base, the coils being on the spools, and Fig. 131 shows how home-made coils on bolts can be used. The coils on bolts should be wound as directed in Apparatus Book, Chapter X. The tin base also serves as the yoke.

Removable Cores. Fig. 130. These are of soft iron (No. 92, 93). In one end of each is a hole for the screws, S. Part of the tin has been cut away in the Fig. The copper washer, C W, should be [170]
used. (See § 408.) Connectors are fastened to the ends of the coils (§ 226–230).

Bolt Cores. Fig. 131. After winding on the coils, as directed in Apparatus Book, remove the nut and put on an extra washer, E W, so that the ends of the coils will not be pressed against the tin, but come out between the two washers. Push the screw-end of the bolt through holes (about 2 in. apart) punched in the tin, then put on the nut, as shown. Do not force the nut on too far,—just far enough to hold the cores in place. The ends of the wires are not shown in Figs. 130, 131. Connectors are fastened to them (§ 408).

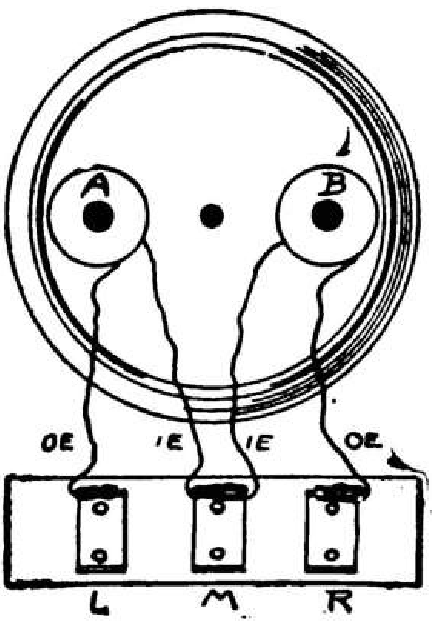


Fig. 132.

408. Method of Joining Coils. To produce the best results the poles of the horseshoe electromagnet should be unlike. As the coils are wound alike, their ends must be joined in such a manner that the current will pass around them in opposite directions; that is, if the current enters one coil at the outside end, O E, it must enter the other coil at the inside end, I E. Fig. 132 shows a plan of the connections, spring connectors being fastened to the coil-ends, to allow rapid and easy changes in the arrangement. L, M, and R are pieces of metal fastened to a strip of wood (No. 95), used to make connections from cells or other apparatus. They are turned up at each end as in Fig. 104, 3. Care should be taken not to get short circuits by allowing two wires to touch the tin base.

By changing the ends of the coils upon L, M, and R (left, middle, and right), and by changing the direction in which the current enters the "combination connecting plates" (No. 95), it is evident that the nature of the poles can be regulated to suit.

EXPERIMENTS 164–173. To study horseshoe electromagnets.

Apparatus. Coils of wire with cores and yoke like those explained in this chapter. Coils fastened to tin base or yoke with wires leading from them to the combination [171]
connecting plates (No. 95, Fig. 132), are very handy. Cells; iron filings; compass; iron strip (No. 76).

EXPERIMENT 164. To test the poles.

409. Directions. (A) Arrange as in Fig. 126, but use the experimental magnets and combination connections (Fig. 132) in place of the single coil shown in Fig. 126. Join O of the key with L, and Zn of the cell with R of Fig. 132. When the key is pressed the current will enter the magnets from L and leave at R.

(B) With the compass test the polarity of the cores as in Exp. 163, B, C. Make a sketch of the arrangement, and note which pole is N and which S.

(C) See which way the current must pass around each coil, by the way it is wound, and compare the results of (B) with Exp. 154, Fig. 123.

EXPERIMENT 165. To test the poles.

410. Directions. (A) Arrange as in Exp. 164, but reverse the direction of the current through the coils. Do this by joining O of the key (Fig. 126) with R of Fig. 132, and Zn of the cell with L.

(B) Repeat (B) and (C) of Exp. 164 and study results.

EXPERIMENT 166. To test the poles.

Fig. 133.

411. Directions. (A) Arrange all connections as in Exp. 164, then reverse the positions of O E and I E of coil A; that is, join O E to M, and I E to L, Fig. 132. This will make unlike ends come together at M; in other words, when the current enters at L and leaves at R it will pass around both coils in the same direction.

(B) Study the nature of the poles, as in Exps. 164, 165, and note results.

Note.—Fig. 133 shows simply the two cores of a horseshoe electromagnet with arrows to indicate in which direction the current is passing in each coil to produce N and S poles.

EXPERIMENT 167. To study the inductive action of one core upon the other.

412. Directions. (A) Arrange as for Exp. 164, but join the wire from Zn of the cell to M (Fig. 132). In this way coil B will be cut out of the circuit. Place the coils in the E and W line. [172]

(B) Find about how far the residual magnetism of the core of B can act upon the compass-needle, holding the compass on the side away from coil A, no current passing.

(C) Press the key for an instant, and note whether the magnetism of coil B has been made stronger or weaker. Explain the action of core A on core B.

EXPERIMENT 168. Magnetic figures.

413. Directions. (A) Arrange as in Exp. 164. With books, etc., fix a piece of smooth, stiff paper, or a sheet of glass, just above the poles of the electromagnets.

(B) Sprinkle iron filings upon the glass, and gently tap it while the circuit is closed at the key for a few seconds. Make a sketch of the magnetic figure produced. Do the lines of force from the opposite poles attract or repel each other? See § 417 for making permanent figures. (See "Things a Boy Should Know About Electricity" for drawings of magnetic figures.)

Note.—If possible, use two or three good cells in series for making magnetic figures, as a fairly strong field is best.

EXPERIMENT 169. Magnetic figures.

414. Directions. (A) Arrange apparatus as for Exp. 165, and make the magnetic figure for this combination, as directed in Exp. 168. Sketch and study the results.

EXPERIMENT 170. Magnetic figures.

415. Directions. (A) Arrange the apparatus and connections as in Exp. 166, and make the magnetic figure of this combination as directed in Exp. 168. In this case the poles are alike. Sketch and study the results.

EXPERIMENT 171. Magnetic figures.

416. Directions. (A) Arrange apparatus and connections as in Exp. 167, and make the magnetic figure of the combination as directed in Exp. 168. Compare the figure produced with that of Exp. 168. In this case the current passes through but one coil.

417. Permanent Magnetic Figures can be made in several ways for future study and comparison.

(A) *Paraffine paper figures.* Make paraffine paper as directed in Apparatus Book, page 135. For this purpose smooth, stiff, *white* paper is best, so that the filings will show plainly, and but a [173] thin coating of paraffine should be given. Place the magnets upon the table, lay over them a piece of unparaffined paper, and fix the paraffine paper directly over this. This is necessary, as the coated paper sticks when heated. For electromagnets it will be necessary to support the edges of the paper with books, etc. Sprinkle on the filings and tap the paper to make them arrange themselves while the circuit is closed. After the lines of force show plainly, the current need not be used again, provided the paper be kept perfectly still. Pass the flame of a Bunsen burner over the paper to melt the coating. This will, no doubt, make the two pieces of paper stick together, and permanently fix the particles of filings in place. Do not heat the paper too much—just enough to melt the paraffine. If you have no gas, hold a fire-shovel, containing hot coals, over the paper. As soon as the paraffine cools, the figures will stand considerable handling.

Blue print figures are very pretty, and last indefinitely. Get some blue-print paper at a photographer's, who will give you directions about "developing" it with water. Keep this in the dark, and take out but one sheet at a time for experiments. To make the figures, take your apparatus near a window where bright sunlight comes in. Pull down the curtain so that you have but a dim light when you make the magnetic figure, as directed before. After the lines of force show plainly, raise the curtain, and let the bright sunlight shine on it for 5 or 6 minutes, or until the surface of the paper has a rich, bronze color. The paper cannot be acted upon by the light under the particles of filings. Quickly shake the filings from the paper, and wash it in 3 changes of water to "develop" it, then pin the paper up to dry.

EXPERIMENT 172. Lifting power.

418. Directions. (A) Arrange the apparatus as in Exp. 164. Hold an iron strip (No. 76), a screw-driver, or other iron bar directly over and near the poles of the experimental electromagnet. Close the circuit at the key, then lift the magnets by the "armature," as the iron strip may be called, the circuit being kept closed for a few seconds. If your cell is good there should be no trouble in lifting the magnets by the armature. Open the circuit, and see whether the magnets drop.

(B) Hold the magnets upside down directly over nails, tin boxes, iron filings, or other pieces of iron. Close the circuit, move the attracted iron to another place on the table, and open the circuit. Can this principle be used for practical purposes? [174]

Note.—Some experiments illustrating practical uses of electromagnets will be given in a future chapter.

EXPERIMENT 173. Residual magnetism when magnetic circuit is closed.

419. Directions. (A) Arrange as in Exp. 164. You have already seen that each core retains some magnetism after the circuit is closed. Place the iron strip firmly across the poles, close the circuit for an instant, open the circuit, then see whether the armature still clings to the cores with some strength. The armature should fit well upon the cores for this experiment.

(B) Again press the armature upon the cores, no current being used; then lift it as in (A). Compare the attraction with that found in (A).

420. Closed Magnetic Circuits. It was seen in the study of the permanent horseshoe magnet, that the armature clung strongly to the magnet. The armature closed the magnetic circuit, the lines of force having almost no resistance. In the case of electromagnets the magnetic circuit becomes closed when the armature touches both poles at the same time. The armature clings strongly to the poles even after the current ceases to flow. As soon as the magnetic circuit is broken, however, but little residual magnetism remains. The armatures of electromagnets are usually arranged so that they can not quite touch the cores, to avoid this sticking.

CHAPTER XXIV.

THERMOELECTRICITY.

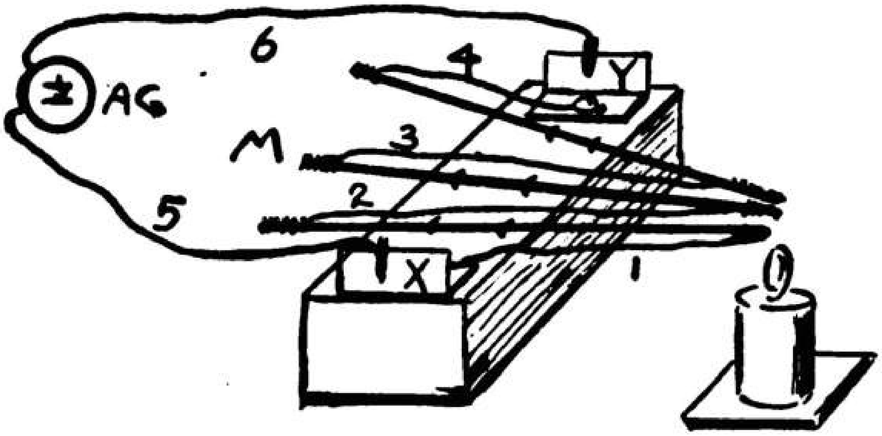


Fig. 134.

EXPERIMENT 174. To find whether electricity can be produced by heat.

Apparatus. The home-made thermopile described in §421; astatic galvanoscope; connecting wires; candle or alcohol lamp.

421. Home-made Thermopile. (Fig. 134.) For this you need 3 hairpins, copper wire, a piece of wood about 3 in. long and 1 in. square on the ends, 2 pieces of tin, and some small nails.

Straighten the hairpins and scrape the coating off with sandpaper or a file. Scrape the insulation from 4 pieces of copper wire, each about 8 in. long. Twist the ends of the copper wire about the ends of the hairpins (Fig. 134), and then fasten the hairpins to the block. They may be held firmly by small nails which should be driven partly into the block and bent over. The hairpins at the right-hand side of the Fig. are shown to be near but not touching each other. This allows all to be heated at the same time.

The tin binding-posts may be nailed or screwed to the block, and if the bare copper wires 1 and 4 be placed under X and Y before they are screwed down they will be electrically connected. The ends of 1 and 4 may be held under the screw-heads. The block may be supported upon [176]
other blocks to raise it to the proper height, which will depend upon the length of the candle.

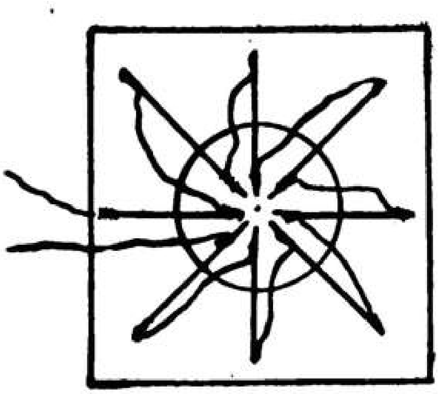


Fig. 135.

A thermopile in the form of a circle with several pairs of metals, can easily be made by fastening the hairpins to a piece of cardboard (Fig. 135) with a hole at the center. This may be supported by blocks, the heat being applied under the center.

422. Directions. (A) Arrange the apparatus as in Fig. 134. See that the astatic needle is properly adjusted, no magnets being near it.

(B) Heat the joints as shown, and watch the needle. Can a current be produced by heat?

(C) Remove the connector on wire 6 from Y to M, thus cutting one pair out of the circuit. Heat the joints again and compare the strength of the current with that produced in (B).

(D) See whether much current is produced by one pair. From results obtained do you see any relation between the strength of the current and the number of pairs?

423. Thermoelectricity is produced by heating the junction between two metals. Different pairs of metals produce different results. Antimony and bismuth are often used. If the end of a strip of bismuth be soldered to the end of a similar strip of antimony, and the free ends be connected to a galvanometer of low resistance, the presence of a current will be shown when the point of contact becomes hotter than the rest of the circuit. The current will flow from the bismuth to antimony across the joint. By cooling the junction below the temperature of the rest of the circuit a current will be produced in the opposite direction.

Thermoelectric currents have a low potential. The energy of the current is kept up by the heat absorbed.

424. Peltier Effect. The action noted in § 423 can be reversed; that is, if a current [177]
from a battery be sent through the metals, the parts at the junction become slightly

warmer or cooler than before, depending upon the direction of the current. This is known as the *Peltier Effect*, the heat not being due to the resistance to the current.

425. Thermopiles. As the E. M. F. of the current produced by a single pair of metals is small, several pairs are usually joined in series in such a way that the different currents help each other and flow in the same direction. Such combinations, usually made of antimony and bismuth, are called thermoelectric piles, or simply thermopiles. They are useful in detecting very small differences in temperature. The heat of a match, or the cold of a piece of ice, will produce a current even at some distance, the thermopile being connected with a sensitive short-coil astatic galvanometer. (See "Things a Boy Should Know About Electricity.")

CHAPTER XXV.

INDUCED CURRENTS.

426. Electromagnetic Induction. You have seen, by experiments, that a magnet has the power to induce another piece of iron or steel to become a magnet. You have also seen, in the study of static electricity, that an electrified body has the power to act through space upon another conductor. A body may be polarized and charged with static electricity by induction.

Several questions now come up. Can a *current* of electricity in a conductor induce a *current* in another conductor not in any way connected with the first? Can current electricity produce effects through space? Is there an electromagnetic induction?

It has been seen that a current-carrying wire has a magnetic field, and that magnetic fields can act through space. It is evident, then, that a conductor will be surrounded and cut by lines of force when it is placed in a magnetic field, or near a wire or coil through which a current passes. Let us study this by experiments.

EXPERIMENTS 175–182. To study induced currents.

Apparatus. The two coils of wire (Nos. 89, 90); two short, soft iron cores (Nos. 92, 93); long iron core (No. 96); bar magnet (No. 97); astatic galvanoscope (No. 59); dry cell (No. 51); key (No. 55); horseshoe magnet; connecting wires with spring connectors (No. 54) on the ends (§ 226–230); coil of wire (No. 98) wound on an iron core; compass.

EXPERIMENT 175. To find whether a current can be generated with a bar magnet and a hollowed coil of wire.

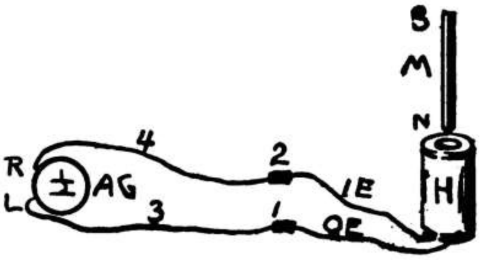


Fig. 136.

[179]

427. Directions. (A) Arrange as in Fig. 136. The coil (No. 90) of fine wire is joined to A G (No. 59) as shown. Small pieces of tin or copper, 1 and 2, are used to make connections between the coil ends and wires, 3 and 4, which are attached to the galvanoscope. It is best to use the wires, 3 and 4, so that the coil will be 2 feet at least, from A G; otherwise the needle of A G might be affected by the magnet, M (No. 97).

(B) Get clearly in mind in which direction the right-hand end of the needle is deflected when a current enters A G at L, the left-hand binding-post. If you have forgotten the results of previous experiments, use the cell for an instant, touching the wire from the carbon to L and that from the zinc to R. If any currents come from the coil, later, you should be able to tell in which direction they flow, the coil and A G forming a closed circuit.

(C) Hold the magnet, M, as shown, and quickly push it into the coil until it has the place of a core, at the same time watching the needle. If a current is produced, in which direction does it flow from the coil? Does the needle remain deflected? Is the current constant or temporary?

(D) After the magnet, M, has been placed in the coil, as in (C), and the needle has come to rest, quickly pull M from the coil, watching the needle. If a current is produced, does it pass from the coil in the same direction as before, in (C)?

(E) Turn M end for end, repeat (C) and (D), and study the results. Are lines of force made to cut the turns of the coil?

(F) Repeat (C) and (D), moving M slowly.

428. Discussion. An induced current, produced as in the above experiment, is a momentary one. No current passes when the magnet and coil are still; at least one of them has to be in motion. When the magnet is inserted, the induced current is said to be an *inverse* one, as it passes in a direction opposite to that which would be necessary to give the magnet its poles, it being considered a core magnetized by the current. A *direct* current is produced when the magnet is withdrawn from the coil. Rapid movements produce stronger currents than slow ones. (See § 439.) [180]

429. Induced Currents and Work. It takes force to move a magnet through the center of a coil, and it is this work that is the source of the induced current. When the coil is pushed on to the magnet, or when it is moved through a magnetic field, force is also required. We have, in this simple experiment, the key to the action of the dynamo and other important electrical machines. These will be discussed later.

EXPERIMENT 176. To find whether a current can be generated with a bar magnet and a coil of wire having an iron core.

430. Directions. (A) Arrange as in Exp. 175, Fig. 136, and, in addition, place an iron core (No.

92) inside of the coil (No. 90).

(B) Hold the bar magnet (No. 97) as in Fig. 136, and quickly lower it until it touches the core, at the same time watching the needle. Study results, direction of current, etc., as before.

(C) Suddenly withdraw M from the core. Is the current produced in the same direction as that from (B)?

(D) Turn M end for end and repeat (B) and (C).

(E) Repeat (C) and (D), moving magnet slowly.

How does the strength of the current compare with that of Exp. 175? Are lines of force made to cut the turns of the coil?

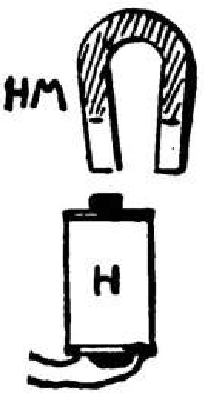


Fig. 137.

EXPERIMENT 177. To find whether a current can be generated with a horseshoe magnet and a coil of wire having an iron core.

431. Directions. (A) Arrange the apparatus as in Exp. 176, but use the horseshoe magnet, H M, instead of the bar magnet. Fig. 137 shows the coil (No. 90) with one pole of H M held over the core.

(B) Study the effect of quickly lowering and raising first one pole and then the other over the core, as with the bar magnet. Get clearly in mind the direction in which the induced current flows in each case.

432. Induced Currents and Lines of Force. In the experiments [181]
just given, it should be remembered that the permanent magnets are sending out thousands of lines of force from their N poles, and receiving them again at their S poles. As the magnet is pushed into the coil (Exp. 175), the lines of force not only cut through the turns of the coil, but the number of lines of force that cut the coil at any instant varies rapidly as the magnet is moved.

Motion is necessary, with this arrangement, to make a change in the number of cutting lines of force. The current passes only while the magnet moves; and the direction of the current at any moment depends upon whether the number of lines of force is increasing or decreasing at that moment. (See § 438, 439.)

EXPERIMENT 178. To find whether a current can be generated with an electromagnet and a hollow coil of wire.

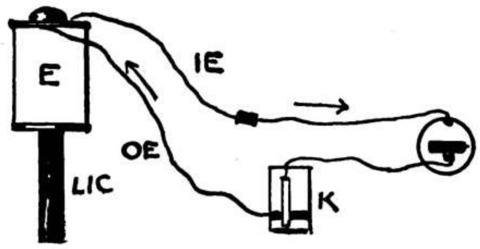


Fig. 138.

433. Directions. (A) The hollow coil (No. 90) should be joined to the astatic galvanoscope, as shown in Fig. 136. Instead of the bar magnet in Fig. 136, an electromagnet is to be used, and this should be joined in series with a cell and key, as shown in Fig. 138. The current from the cell will pass only when K is pressed.

(B) Note from the winding which way the current must pass around the coil when the circuit is closed at K, and determine whether the lower end of the long iron core, L I C (No. 96) should be N or S. With the compass test the poles of the core to be sure you are right.

(C) Quickly lower the end of L I C into the hollow coil (H, Fig. 136), the circuit being kept
closed long enough to allow the needle to partially come to rest again. Withdraw L I C before [182]
you open the circuit. Explain action of needle.

(D) Reverse the direction of the current through the electromagnet, by changing the connections, and repeat (C). Does any induced current pass through A G when the core is held still in the coil H, even though a current passes through coil E?

EXPERIMENT 179. To find whether a current can be generated with an electromagnet and a coil of wire having an iron core.

434. Directions. (A) Fig. 139 shows simply the arrangement of coils. Coil H (No. 90) with core, is joined to the galvanoscope as in Fig. 136. Coil E, with short core, should be joined to key and cell as shown in Fig. 138.

(B) Keeping in mind the polarity of the lower end of core E, quickly lower it to the core of H, the circuit being kept closed for a few seconds. Does the needle remain deflected after the motion ceases?

(C) Quickly raise E, the circuit being still closed, then open the circuit. Compare the directions taken by the induced currents in (B) and (C).

435. Discussion of Exps. 178, 179. This motion in straight lines is not suitable for producing currents strong enough for commercial purposes. In order to produce currents of considerable strength, the coils of wire have to be pushed past magnets

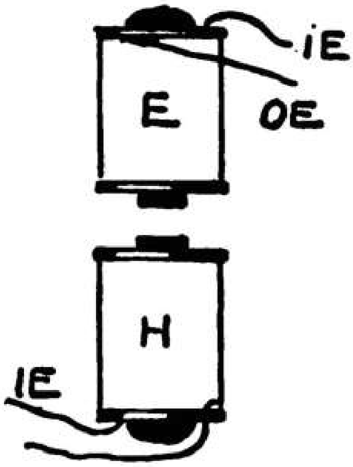


Fig. 139.

with great speed. Special machines (see Dynamos) are constructed in which the coils are wound so that they can be given a rapid *rotary motion* as they fly past strong electromagnets. In this way the coil can keep on passing the same magnets, in the same direction, as long as force is applied to the shaft that carries them.

EXPERIMENT 180. To study the effect of starting or stopping a current near a coil of wire or other closed circuit.

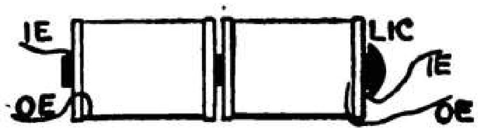


Fig. 140.

436. Directions. (A) Arrange as in Fig. 140. Place the two coils, H and E, on the same core, L I C. Connect E with the key and cell as before (Fig. 138). Connect H with the astatic galvanoscope, A G, as in Fig. 136. Keep the coils 2 or 3 feet from A G, so that the needle will not be affected by them. [183]

(B) Close the circuit at the key, watching the needle, then as soon as the needle regains its former position, open the circuit again. Compare the direction of the induced current in H with that of the current in E, (1) when the main circuit is closed, and (2) when it is opened. Is any current induced in H by a steady current in E? (See Transformers.)

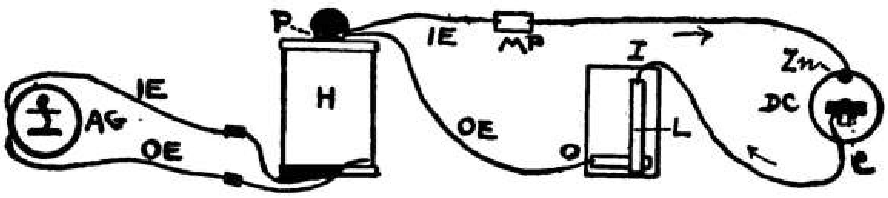


Fig. 141.

EXPERIMENT 181. To study the effect of starting or stopping a current in a coil placed inside of another coil.

437. Directions. (A) Arrange as in Fig. 141. Join coil H with the astatic galvanoscope, A G. Place the small coil P (No. 98) with core, inside of H, and connect the ends of P with the key and cell, as shown.

(B) Close the circuit at K; watch the needle, and as soon as it regains its position, open the circuit again.

Compare the direction of the induced current in H with that of the inducing current in P, (1) when the inducing circuit is closed, and (2) when it is broken. (See Induction Coils.)

438. Discussion of Exps. 180, 181. When a current suddenly begins to flow through a coil, the effect upon a neighboring coil is the same as that produced by suddenly bringing a magnet near it; and when the current stops, the opposite effect is produced.

We may consider that when the inducing circuit is closed, the lines of force shoot out through the turns of the outside coil. Upon opening the circuit the lines of force cease to exist; that is, we may imagine them drawn in again. [184]

439. Direction of Induced Current. Fig. 142 shows the magnet on its way into the coil; the number of lines of force is increasing in the coil, and the induced current passes in an anti-clockwise direction when looking down into the coil along the lines of force. This produces an *indirect* current. If a current from a cell were passed through the coil in the direction of this indirect current, the lower end of a bar of iron would become a S pole. (See § 428.)

440. Laws of Induction. (1) An increase in the number of lines of force that pass through a closed circuit produces an indirect induced current; while a decrease produces a direct one. (See § 428.)

(2) The E. M. F. of the induced current is equal to the rate of increase or decrease in the number of lines of force that pass through the circuit.

(3) A constant current produces no induced current, provided there is no motion.

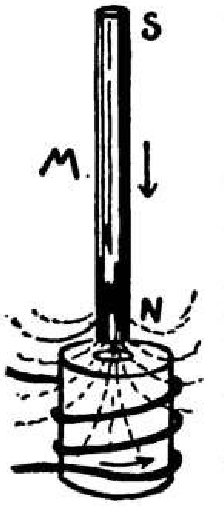


Fig. 142.

(4) Closing a circuit produces an indirect current.

(5) Opening a circuit produces a direct current.

(6) *Lenz's Law.* Induced currents have a direction that tends to stop the motion that produces them.

441. Primary and Secondary Currents. In the preceding experiments in induction, it must be kept in mind that the current from the cell did not pass through the galvanoscope. There were two entirely separate circuits, in no way connected. The *primary* current comes from the cell, while the *secondary* current is an induced one. [185]

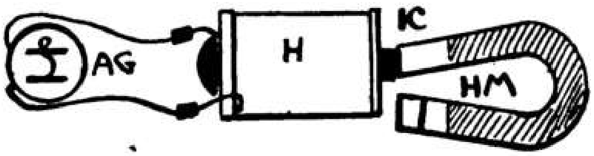


Fig. 143.

EXPERIMENT 182. To see what is meant by alternating currents.

442. Directions. (A) Arrange as in Fig. 143. Connect coil H with A G, as before. Place one pole of H M against the end of the core I C, hold H with one hand, and with the other quickly push the other pole of H M onto the core. This should produce a momentary current through A G, first in one direction, and then in the other. Let the needle come to rest.

(B) Move H M back and forth upon the end of I C, changing its polarity rapidly. A minute's practice will enable you to slide the core from one pole of H M to the other and back again rapidly—3 complete vibrations per second being about right. The needle should be parallel to the coil of A G, and if properly done, the needle will be made to vibrate back and forth slightly at each change in the polarity of I C.

443. Direct and Alternating Currents. A current that flows steadily in one direction is said to be a *direct* current. A cell gives a direct current when the circuit is closed. When the current passes in one direction for an instant, and then reverses immediately and flows in the opposite direction, it is said to *alternate*. The induced current which flowed through the galvanoscope in Exp. 182 was an alternating one. Currents of this class have great practical uses.

444. Self-Induction; Extra Currents. It has been shown that a magnetized coil can act through space and induce a current in a neighboring coil. The lines of force which [186] reach out from an electromagnet will generate a current in any conductor which happens to be in the field, or which is moved across the lines. It is evident, then, since the lines of force from each turn of a coil cut all the other turns of the same coil, that each turn acts as a conductor placed in the field of every other turn. The instant a current begins to flow through a coil, there is an inverse current of self-induction started in the coil, which opposes the current in the cell. When the circuit is broken, this *extra current*, as it is also called, is a direct one and adds its strength to that of the current from the cell; as this takes place at the instant the circuit is broken, a bright spark is seen at the key, and this shows that the E. M. F. of this extra current is high. Practical uses are made of it.

CHAPTER XXVI.

THE PRODUCTION OF MOTION BY CURRENTS.

445. Currents and Motion. We have seen, in the experiments on induced currents, that a current of electricity can be generated by properly moving magnets near coils of wire. (See Dynamo-electric Machines.) Can we reverse this process? Can motion be produced by the electric current?

EXPERIMENTS 183–190. To study the production of motion by means of the electric current.

Apparatus. The support, including base, rod, and support wire, S W (Fig. 144.) Coils of wire (No. 89, 90); iron cores for coils; cell; key; connecting wires; compass; current reverser; bar magnet; horseshoe magnet.

EXPERIMENT 183. Motion produced with a hollow coil and a piece of iron.

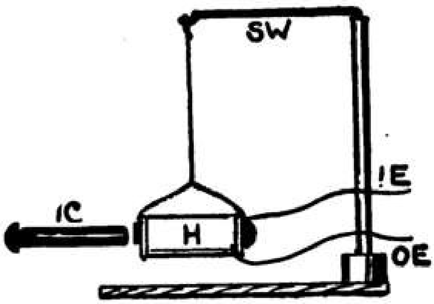


Fig. 144.

446. Directions. (A) Arrange as in Fig. 144. Coil H (No. 90) is to be used as a pendulum, and can be supported by fastening a string to it, the upper end of which should be tied to S W.

Connect the ends of H with K and D C. There will be a slight magnetic field about H as soon as the circuit is closed.

(B) Hold I C near the end of the coil. Close the circuit for an instant. Is there any motion produced in H? While the motion will be slight, there should be enough to be noticed if the cell is strong.

(C) Swing the suspended coil back and forth like a pendulum for a minute, until you get in mind the rapidity of its vibrations. Stop it, then repeat (B), closing and opening the circuit at regular intervals, so that the little impulses given by the attraction for I C will gradually cause H to [188]
vibrate. The wires leading from H should not drag upon the table.

EXPERIMENT 184. Motion with hollow coil and bar magnet.

447. Directions. (A) Substitute the bar magnet M (No. 97) for the iron of Exp. 183 (Fig. 144). Get clearly in mind the polarity of the coil from the way the current flows through it, then test it with the compass to find whether you are right.

(B) Hold the N pole of M near the left-hand end of the coil, close the circuit for an instant and study results.

(C) Reverse the magnet and repeat (B). Compare the results with those of Exp. 183. Try to make the coil vibrate.

EXPERIMENT 185. Motion with electromagnet and piece of iron.

448. Directions. (A) Arrange as described in Exp. 183, Fig. 144. Place a short core inside of the coil and repeat. (See § 446 for directions.) Why is the motion produced much larger than that given by a hollow coil?

(B) The coil can gradually be made to swing through quite a little space by closing and opening the circuit regularly (§ 446, C). Could any use be made of such a motion, if it were on a large scale? Could it be made to run a machine?

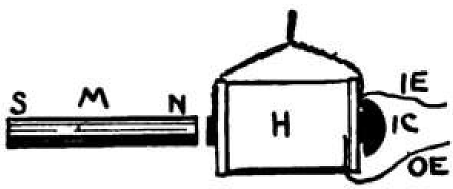


Fig. 145.

EXPERIMENT 186. Motion with electromagnet and bar magnet.

449. Directions. (A) Arrange as in Fig. 145, the coil being suspended and connected as in Exp. 183 (Fig. 144).

(B) Study the effect of closing the circuit when the N pole of M is held near the core of H. Reverse M, and repeat.

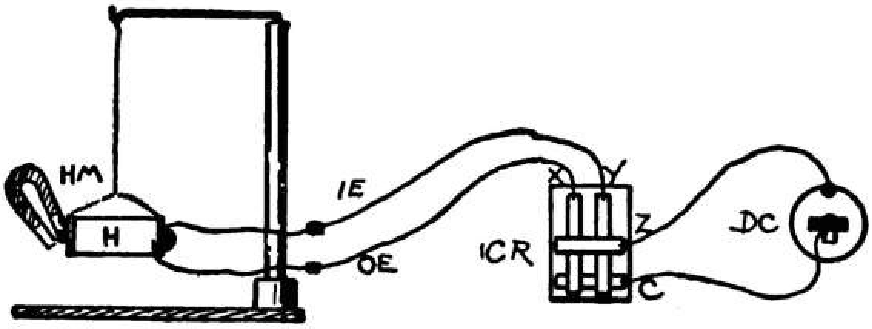


Fig. 146.

EXPERIMENT 187. Motion with electromagnet and horseshoe magnet.

450. Directions. (A) Arrange as in Fig. 146. The ends of H (No. 89) are joined to X and Y of the current reverser C R (No. 57). It is evident, then, that the direction of the current through H can be easily and rapidly reversed by C R. (See Exp. 103.) Either pole of the horseshoe magnet H M will attract I C when it is not magnetized.

(B) Place the end of I C near the N pole of H M so that it will be attracted to it. You have [189]
learned that like poles repel each other, so press the lever of C R that will produce a N pole at the left-hand end of I C. The core I C should be repelled by the N pole of H M and be instantly attracted by its S pole.

(C) Rapidly reverse the current and make I C jump back and forth from one pole to the other. The results of this experiment should be remembered, as they will aid in understanding motors. A core ¼ in. in diameter can be placed in between the poles and be made to vibrate rapidly as the current is reversed.

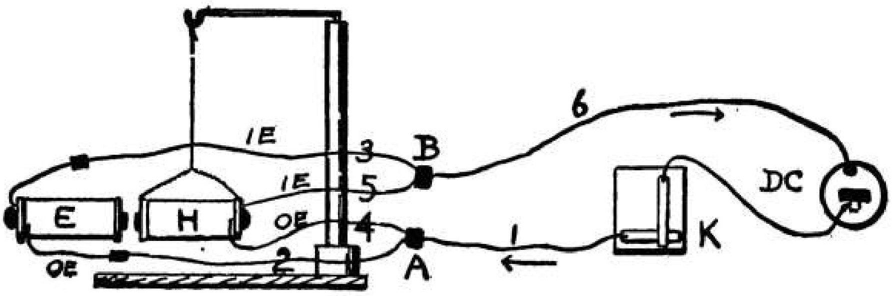


Fig. 147.

EXPERIMENT 188. Motion with two electromagnets.

451. Directions. (A) Arrange as in Fig. 147. Join the two coils, H and E, in parallel. Connect their two outside ends O E to a metal plate A, and their inside ends I E to B. Join wires 1 and 6 to K, D C, A and B, as shown. When the circuit is closed at K, the current will pass along wire 1 and divide at A, entering E and H at the same time by wires 2 and 4 and returning through 3 and 5 to B, and thence to D C.

(B) Close the circuit for an instant with wires arranged as in Fig. 147. Do the electromagnets attract or repel each other? Study out the direction in which the current passes around the [190]
coils, and see whether they *should* attract or repel.

(C) Change wire 4 to B, and wire 5 to A. The polarity of H, only, will be changed when this circuit is closed. Press the key for an instant and study the results.

452. Discussion of Exps. 183–188. From the results it is evident that motion can be produced with the aid of the electric current in many different ways. It can be produced at the ends of wires which simply reach across the room, or which reach miles from the source of the current. To get practical results for commercial purposes we require a proper source of current, proper conductors, and proper apparatus to convert the motions into useful work. The motions given to the parts of the apparatus in the previous experiments are not suitable for commercial purposes, as they are in straight lines. A rotary motion is needed to do good work; and when this is applied to a shaft, belts can be used to run all sorts of machinery. (See Electric Motors.)

EXPERIMENT 189. Rotary motion with a hollow coil of wire and a permanent magnet.

453. Directions. (A) Arrange as in Fig. 148. A key can be used instead of the reverser. The coil of the galvanoscope, G V, has a magnetic field about it when the circuit is closed. The needle has a permanent field.

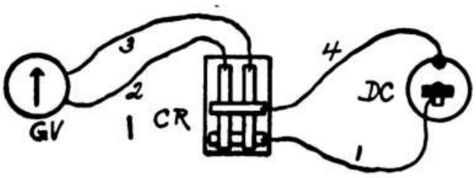


Fig. 148.

(B) Close the circuit for an instant, let the needle swing back past the zero mark, close the circuit again, etc., until the added impulses give the needle a complete turn.

(C) Keep the needle turning on its axis by opening and closing the circuit at the proper time. With a little practice you can make it turn rapidly.

(D) Reverse the motion of the needle. (See § 455.)

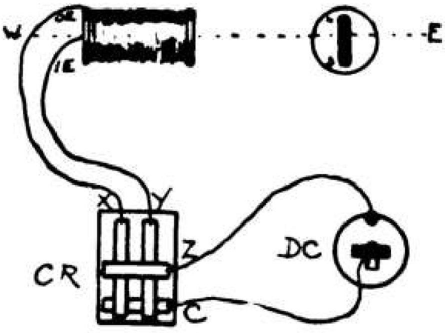


Fig. 149.

EXPERIMENT 190. Rotary motion with an electromagnet and a permanent magnet.

454. Directions. (A) Arrange as in Fig. 149. Place the compass a short distance from the end of the core of the coil H (No. 89). Close the circuit, and as soon as the needle gets part way around open it again, closing it at the proper time to give the needle a new impulse. The speed can be regulated, somewhat, by changing its distance from the core. A key may be used in place of a reverser.

(B) Reverse the direction of rotation.

455. Discussion of Exps. 189–190. We have, in these experiments, the key to the action of electric motors. By properly opening and closing the circuit, the rotary motion can be kept up as long as current is supplied. If a small pulley were attached to the top of the compass-needle in Exp. 190, a tiny belt could be attached, and we should have a machine that could do, perhaps, a fly-power of work. (See Electric Motors.)

CHAPTER XXVII.

APPLICATIONS OF ELECTRICITY.

456. Things Electricity Can Do. Among the almost countless things that electricity can do are the following: It signals without wires. It drills rock, coal, and teeth. It cures diseases and kills criminals. It protects, heats, and ventilates houses. It photographs the bones of the human body. It rings church bells and plays church organs. It lights streets, cars, boats, mines, houses, etc. It pumps water, cooks food, and fans you while eating. It runs all sorts of machinery, elevators, cars, boats, and wagons. It sends messages with the telegraph, telephone, and search-light. It cuts cloth, irons clothes, washes dishes, blackens boots, welds metals, prints books, etc., etc.

As this book deals almost exclusively with experiments, to be performed with simple, home-made apparatus, space cannot be given for a discussion of the many instruments and machines which make electricity a practical every-day thing. (See "Things A Boy Should Know About Electricity.") The principles upon which a few important instruments depend, however, will be given.

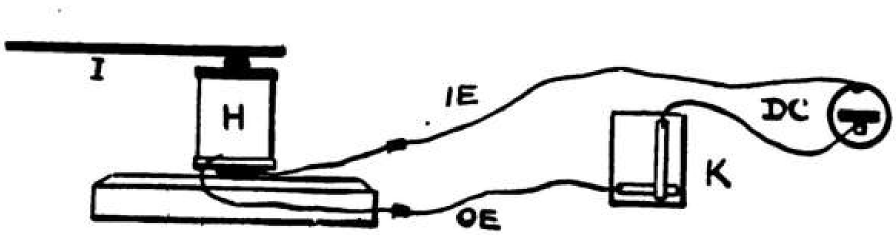


Fig. 150.

EXPERIMENT 191. To study the action of a simple "telegraph sounder."

457. Directions. (A) Arrange as in Fig. 150. The electromagnet is supported upon its base, as directed in § 407. Coil H, K, and D C are joined in series. The iron strip, I, can be held by the left hand, while K is worked with the right.

(B) Press the key, closing the circuit for different lengths of time, and note that the *armature*, I, responds exactly to the motions at K.

458. Discussion. The downward click makes a distinct sound, and in regular [193]
instruments the armature is allowed to make an upward click, also. The time between the two clicks can be short or long to represent *dots* or *dashes*, which, together with *spaces*, represent letters. (For telegraph alphabet, and complete directions for making and connecting a home-made telegraph line, see Apparatus Book.)

459. Telegraph Line; Connections. Fig. 151 shows complete connections for a home-made telegraph line. The capital letters are used for the right side, R, and small letters for the left side, L.

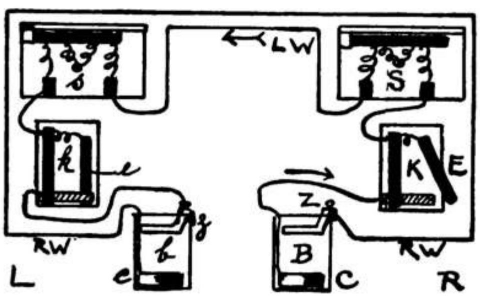


Fig. 151.

Gravity cells, B and b, are used. The *sounders* S and s, and the *keys*, K and k, are shown by a top view, or plan. The broad black lines of S and s represent the armatures, which are directly over the electromagnets. The keys have switches, E and e.

The two stations, R and L, may be near each other or in different houses. The *return wire*, R W, passes from the copper of b to the zinc of B. This is important, as the cells must help each other; that is, they are in series. The *line wire*, L W, passes from one station to the other, and the return may be through a [194]
wire, R W, or through the earth; but for short lines a return wire is best.

460. Operation of Line. Suppose R (right) and L (left) have a line. Fig. 151 shows that R's switch, E, is open, while e is closed. The entire circuit, then, is broken at but one point. As soon as R presses his key, the circuit is closed, and the current from both cells rushes around from B through K, S, L W, s, k, b, R W and back to B. This makes the armatures of S and s come down with a click at the same time. (See Exp. 191.) As soon as the key is raised, the armatures raise, making the up-click. (See § 458.) As soon as R has finished, he closes his switch, E. L then opens e and answers R. Both E and e are closed when the line is not in use, so that either can open his switch at any time and call up the other. Closed circuit cells are used for such lines. On large lines the current from a dynamo is used.

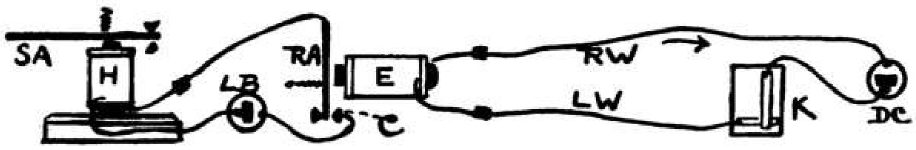


Fig. 152.

EXPERIMENT 192. To study the action and use of the "relay" on telegraph lines.

461. Directions. (A) Arrange as in Fig. 152. Place K and D C at one end of the table to represent the sending station. At the other end of the table place E, which is the electromagnet of the relay, and H, the electromagnet of the sounder. Connect the ends of E with K and D C, L W being the line wire, and R W the return. In practice, the return is through the earth. The relay armature, R A, should vibrate towards E every time K is pressed. C is a piece of copper against which R A presses each time it is attracted by E, and this closes what is called the local circuit. Connect the poles of another battery, L B, with C and H, and the other end of coil H [195]
with R A. The sounder armature, S A, should be arranged as in Exp. 191. Small springs are shown on the two armatures, and these keep them away from the cores when the circuits are open.

(B) Fasten the parts to a board, and study the connections and action of this home-made outfit.

462. The Relay replaces the sounder in the line wire circuit, and its coils are usually wound with many turns of fine wire, so that a feeble current will move its nicely adjusted armature. Owing to the large resistance of long telegraph lines, the current is weak when it reaches a distant station, and not strong enough to work an ordinary sounder. The current passes back from the relay to the sending station through the earth. The relay armature acts as an automatic key to open and close the local circuit, which includes also a battery and sounder. The line current does not enter the sounder. (See "Things A Boy Should Know About Electricity.")

EXPERIMENT 193. To study the action of a two-pole telegraph instrument.

463. Directions. (A) Arrange as in Fig. 153. Connect the two coils to the connecting plates, as described in § 408. Join a strip of copper Cu with wire 2 leading from D C, and join the zinc of D C to M. The ends of wires 1 and 3 should be near Cu but they must not touch it. If Cu be slightly curved so that its ends are raised above the table, the ends of wires 1 and 3 may be put directly under the ends of Cu; each half of Cu can then be used as a key. Two armatures, A and B, should be held as shown. D C can be placed at one side, of course, its terminals being joined to M and Cu.

(B) Press first one end and then the other of Cu, so that the current will pass through H or E at will.

(C) Paste pieces of paper to the armatures, the left one being marked with a dot, and the other with a dash. The one who sends the message can make dots or dashes at the instrument by pressing the proper key. This form of instrument can be easily made by boys, and the messages are more easily read by the eye than by the ear, as in regular sounders. [196]

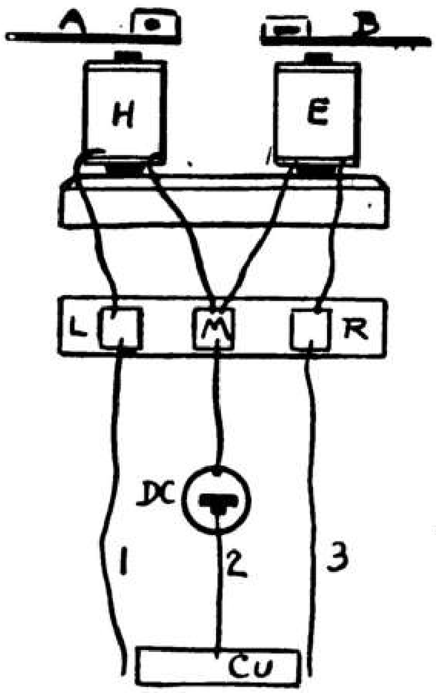


Fig. 153.

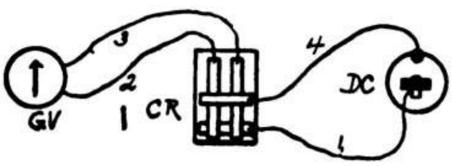


Fig. 154.

EXPERIMENT 194. To study the action of a simple "single needle telegraph instrument."

464. Directions. (A) Arrange as in Fig. 154. Stick a pin on each side of the N pole of the galvanoscope-needle through the degree-card, so that the needle can make but part of a turn when the circuit is closed.

(B) Touch one lever of the reverser C R, then the other, to see whether connections are right. The needle should be forced against one pin and then against the other. If motions to the left represent *dots*, and those to the right *dashes*, combinations of dots and dashes can be used for letters as in the "sounder" (Exp. 191).

(C) Arrange the apparatus shown in Fig. 122 so that messages can be sent.

EXPERIMENT 195. To study the action of a simple automatic "contact breaker," or "current interrupter."

465. Directions. (A) Arrange as in Fig. 155. Slip a spring connector attached to wire 1 upon the iron strip I, a short distance from its end. Hold the left-hand end of I firmly in one hand, and with the other hold the connector on wire 2 just above that on 1. The right-hand end of I should be just above the core of H.

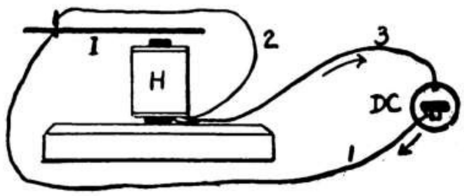


Fig. 155.

(B) Allow the current to pass through the circuit by touching the two connectors together gently. Does the armature make one click, as in the telegraph sounder, or does it vibrate rapidly?

(C) Try the connectors in various positions on I.

466. Automatic Current Interrupters are used on bells, buzzers, induction coils, etc. The principle upon which they work is shown in the above experiment (Fig. 155). [197]
The current, as it comes from the carbon of D C, is obliged to stop when it reaches I, unless the two connectors touch. As soon as the current passes, I is pulled down and away from the upper connector, and this breaks the circuit. I, being held firmly in the hand, immediately springs back to its former position, closing the circuit. The rapidity of the vibrations depends somewhat upon the position of the connectors upon I. In regular instruments, a platinum point is used where the circuit is broken; this stands the constant sparking at that point.

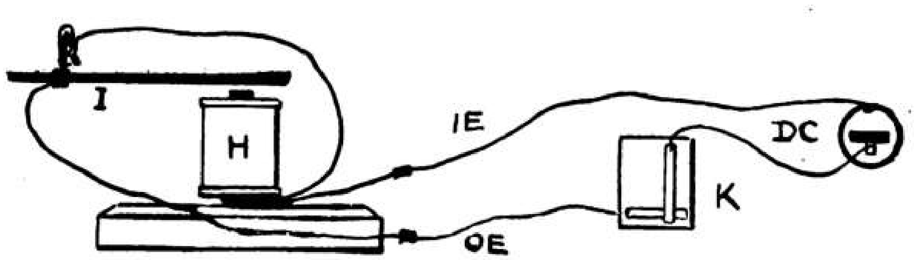


Fig. 156.

EXPERIMENT 196. To study the action of a simple "electric bell," or a "buzzer."

467. Directions. (A) Fig. 156 shows the circuit explained in Exp. 195, with a key or push-button put in, so that the circuit can be closed at a distance from the vibrating armature.

(B) Have a friend work the key while you hold I and wires 1 and 2 as directed in Exp. 195. The circuit must not be broken at two places, of course, so begin by holding the two connectors together. The armature should vibrate rapidly each time K is pressed.

468. Electric Bells and Buzzers are very nearly alike in construction; in fact, you will have a buzzer by removing the bell from an ordinary electric bell. Buzzers are used in places where the loud sound of a bell would be objectionable.

By placing a bell near the end of the vibrating armature (Fig. 156), so that the bell [198]
would be struck by it at each vibration, we should have an electric bell. By making the wires 1 and 3 long, the bell or buzzer can be worked at a distance. (See Apparatus Book, Chapter XV, for Home-made Bells and Buzzers.)

EXPERIMENT 197. To study the action of a simple telegraph "recorder."

469. Directions. (A) Cut from a tin box, or can, a piece of tin about 4 in. long and 1½ in. wide. Bend this double to make two thicknesses. This will serve as an armature I (Fig. 157). Nail to one end of I a small spool, S, and into this put a short length of lead-pencil, P, which may be held firmly in S by wrapping a little paper around it. Connect the ends of coil H to a key and cell as in Fig. 156.

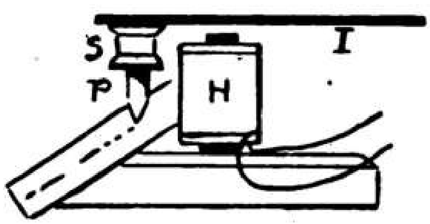


Fig. 157.

(B) Hold or fasten I in place, and have a friend make dots and dashes at the key, while you draw a piece of paper past the end of P. A little adjusting will be necessary to get the pencil to write only while the circuit is closed. In regular machines all the parts are automatic.

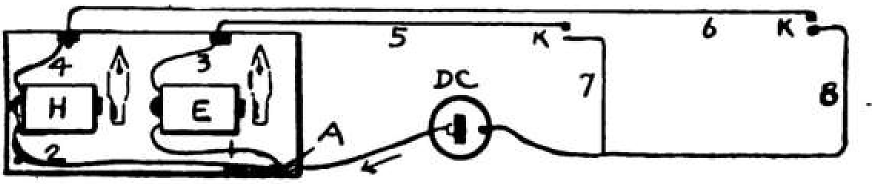


Fig. 158.

EXPERIMENT 198. To study the action of a simple "annunciator."

470. Directions. (A) Arrange as in Fig. 158. Fasten the two electromagnets, H and E, to a board or a piece of stiff cardboard. They may be held in place by passing strings over them and through the board, tying on the other side. The ends of coils H and E should be joined to pieces of tin, A, B, C, by means of connectors. K and K are keys or push-buttons, which in real instruments are in different rooms. Two steel pens may be swung on pins a short distance from [199] the ends of the cores, so that their lower ends will be attracted to the cores the instant the current passes through them. The residual magnetism should hold them against the cores until removed. Hairpins, nails, or needles can be used instead of pens.

(B) Press first one K and then the other to see whether your connections are correct.

471. Annunciators. There are many forms of annunciators in use to indicate, in a hotel for example, a certain room when a bell rings at the office. If a bell be included in the circuit between D C and A in Fig. 158, it will ring each time a key is pushed. This will call attention to the fact that some one has rung, and the annunciator will show the location of the special call. Large instruments are made with hundreds of electromagnets, each one answering to a special room. The instrument should be set, of course, after each call. A nail or screw wound with insulated wire can be used for the electromagnets of a home-made annunciator.

EXPERIMENT 199. To study the shocking effects of the "extra current."

472. Directions. (A) Use the two electromagnets joined to the connecting plates (Fig. 132), to generate a self-induced or extra current. Connect R of Fig. 132 with the zinc of a dry cell, and between L and the carbon of the cell place a key; in other words, join the electromagnets, cell, and key in series. Two good cells in series can be used to advantage.

(B) Wet the ends of two fingers of the left hand, press one upon L and the other on R, thus making a shunt with your hand. With the right hand work the key rapidly. If the current is strong enough you should feel a slight shock in the fingers each time the circuit is broken. The extra current (§ 444) causes the shock as it shoots through the fingers.

(C) If you have electric bells or telegraph sounders use them for this experiment.

473. Induction Coils are instruments for producing induced currents of high E. M. F. The apparatus shown in Fig. 141 forms a simple induction coil. The *primary* coil is [200] made of coarser wire and has less turns of wire than the *secondary* coil. The current in the primary circuit is usually interrupted by an *automatic interrupter* (Exp. 195), thus producing an alternating current in the secondary coil, the voltage of which depends upon the relative number of turns in the two coils. Induction coils are used in telephone work, for medical purposes, for X-ray work, etc., etc.

(For Home-made Induction Coils see Apparatus Book, Chapter XI.)

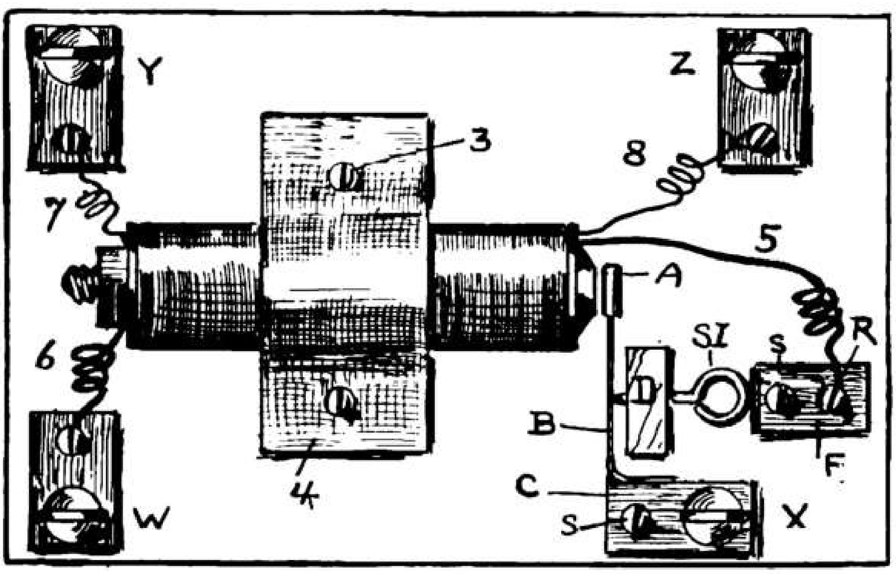


Fig. 159.

474. Action of Induction Coils. Fig. 159 shows a top view of one of the home-made induction coils described, in full, in the Apparatus Book. Wires 5 and 6 are the ends of the primary coil, while wires 7 and 8 are the terminals of the secondary coil. The battery wires should be joined to binding-posts W and X, and the handles to Y and Z. Fig. 160 shows the details of the automatic interrupter which is placed in the primary circuit.

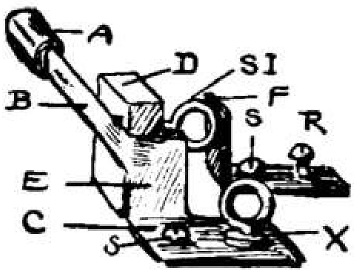


Fig. 160.

If the current enters at W, it will pass through the primary coil and out at X, after going through 5, R, F, S I, B, E and C. The instant the current passes, the bolt becomes magnetized; this attracts A, which pulls B away from the end of S I, thus automatically opening the circuit. [201] B at once springs back to its former position against S I, as A is no longer attracted; the circuit being closed, the operation is rapidly repeated. (For commercial forms and uses of induction coils see "Things A Boy Should Know About Electricity.")

475. Transformers, like induction coils, are instruments for changing the E. M. F. and strength of currents. There is very little loss of energy in well-made transformers. They consist of two coils of wire on the same core; in fact, an induction coil may be considered a transformer. If the secondary coil has 100 times as many turns of wire as the primary, a current with an E. M. F. of 100 volts can be taken from the secondary coil, when the E. M. F. of the current passing through the primary is 1 volt; but the *strength* (amperes) of the secondary current will be but one-hundredth that of the primary current. By using the coil of fine wire as the primary, the E. M. F. of the current that comes from the other coil will be but one-hundredth that in the fine coil. It will have 100 times its strength, however. Continuous currents from cells or dynamos must be interrupted, as in induction coils, to be transformed from one E. M. F. to another. Transformers are now largely used in lighting and power circuits, etc. (See "Things A Boy Should Know About Electricity.")

476. The Dynamo. We saw in the Exps. of Chapter XXV. that currents of electricity can be generated in a coil of wire (closed circuit) by rapidly moving it through the field of a magnet. As shown by the experiments, this can be accomplished in many ways. The dynamo is a machine for doing this on a large scale, the coils being given a rotary motion in a very strong magnetic field; and as the number of lines of force that cut the [202] coil is constantly changing, there is a current in the coil as long as power is applied, and this current is led from the machine by proper devices.

The dynamo is a machine for converting mechanical energy into an electric current, through electromagnetic induction.

If a loop of wire (Fig. 161) be so arranged on bearings at its ends that it can be made to revolve, a current will flow through it in one direction during one-half of the revolution, and in the opposite direction during the other half, it being insulated from all external conductors. Such a current inside of the machine would be of no value; it must be led out to external conductors. Some sort of sliding contact is necessary to connect a revolving conductor with a stationary one.

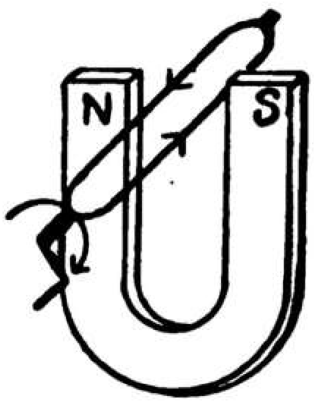


Fig. 161.

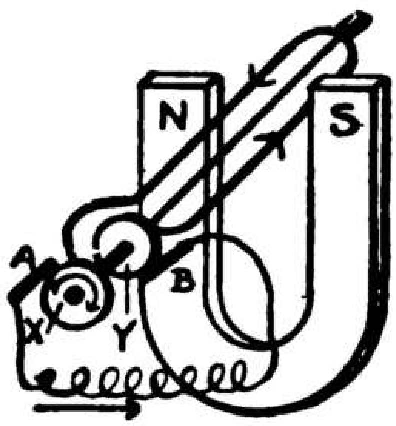


Fig. 162.

Fig. 162 shows the ends of a coil joined to two rings, X, Y, which are insulated from each other, and which rotate with the coil. Two stationary pieces of carbon, A, B, called *brushes*, press against the rings, and to these are joined wires which complete the circuit, and which lead out where the current can do work. The arrows show the direction of the current during one-half of a revolution. The rings form a *collector*, and this arrangement gives an alternating current.

In Fig. 163 the ends of the coil are joined to the two halves of a cylinder. These halves, X and Y, are insulated from each other and from the axis. The current flows from X onto the brush A, through some external circuit where it does work, and thence back through brush B onto Y. By the time that Y gets around to A the direction of the current in the loop has reversed, so that it passes towards Y; but it still enters the outside circuit through A because Y is then in contact with A. This device is called a *commutator*, and it allows a constant or direct current to leave the machine. [203]

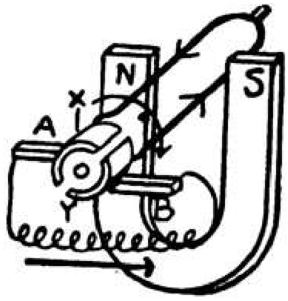


Fig. 163.

In regular machines there are many loops of wire and several segments to the commutator. The rotating coils are wound upon an iron core, so that the lines of force, in passing from one pole to the other, will meet with as little resistance as possible. The coils, core, and commutator, taken together, are called the *armature*. The magnets which furnish the field are called the *field-magnets*. These are electromagnets, the current from the dynamo, or a part of it, being used to excite them. There are many forms of dynamos, and many ways of winding the armature and field-magnets, but space will not permit a discussion of them here. (See "Things a Boy Should Know About Electricity.")

477. The Electric Motor. Experiments have shown that motion can be produced by the electric current in many ways. The galvanoscope may be considered a tiny motor.

An electric motor is a machine for transforming electric energy into mechanical power.

While the electric motor is similar in construction to the dynamo, it is opposite to it in action. Motors receive current and produce motion. The motion is a rotary one, the power being applied to other machines by means of belts or gears. [204]

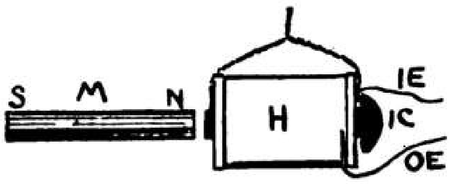


Fig. 164.

EXPERIMENT 200. To study the action of the telephone.

478. Directions. (A) Join the ends of coil H (Fig. 164) to the astatic galvanoscope. Move magnet M back and forth in front of the soft iron core, while H is held in position. Watch the needle. Imagine that vibrations in the air caused by the voice are strong enough to give M a slight motion to and fro, and you can see how a current would be sent through the galvanoscope by speaking against M.

479. The Telephone is an instrument for reproducing sounds at a distance, and electricity is the agent by which this is generally accomplished. The part spoken to is called the *transmitter*, and the part which gives the sound out again is called the *receiver*. Sound itself does not pass over the line. Although the same apparatus may be used for both transmitter and receiver, they are generally different in construction.

480. The Bell or Magneto-transmitter generates its own current, and is, strictly speaking, a dynamo that is run by the voice. You have seen, by experiments, that a current can be generated in a coil of wire by moving a magnet back and forth in front of its soft iron core. In the telephone this process is reversed, soft iron in the shape of a thin disc (D, Fig. 165) being made to vibrate by the voice immediately in front of a coil having a permanent magnet, M, for a core.

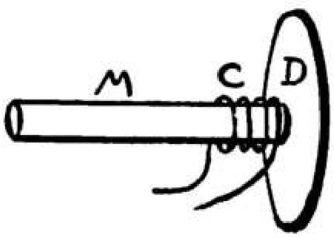


Fig. 165.

The soft iron diaphragm is fixed near, but it does not touch the magnet. The coil consists of many turns of fine insulated wire. The current generated is an alternating one and exceedingly feeble; in fact, it can not be detected by a galvanoscope. [205]

481. The Receiver has the same construction as the bell transmitter, and receives the currents from the line. As the diaphragm is always attracted by the magnet, it is under a constant strain. This strain is increased when a current passes through the coil in a direction that adds strength to the magnet, and decreased when the current weakens the magnet.

When the current through the coil is always in the same direction, but varies in strength, the diaphragm will vibrate on account of the varying pull upon it.

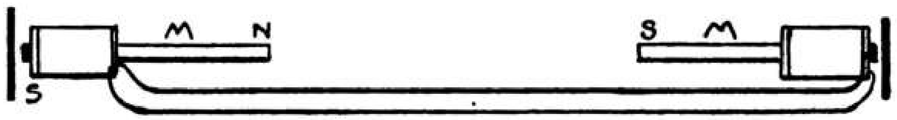


Fig. 166.

When the current through the coil is an alternating one, the same result is obtained, as the magnet gets weaker and stronger many times per minute. Fig. 166 shows two bell instruments joined, either being used as the transmitter and the other as the receiver.

482. The Carbon Transmitter does not in itself generate a current like the magneto-transmitter; it merely produces changes in the strength of a current that flows through it, and that comes from some outside source.

In Fig. 167, X and Y are two carbon buttons, X being attached to the diaphragm, D. Button Y presses gently against X. When D is caused to vibrate by the voice, X is made [206]
to press more or less against Y, and this allows more or less current to pass through the circuit, in which also is the receiver, R. This direct undulating current changes the pull upon the diaphragm of R, causing it to vibrate and reproduce the original sounds spoken into the transmitter.

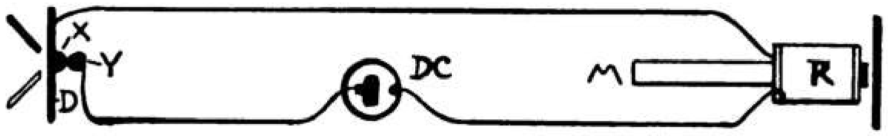


Fig. 167.

483. Induction Coils in Telephone Work. As the resistance of telephone lines is large, a current with a fairly high E. M. F. is desired. While the current from one or two cells is sufficient to work the transmitter, it is not strong enough to force its way over a long line. To get around this difficulty an induction coil is used to transform the battery current, that flows through the transmitter and primary coil, into a current with a high E. M. F. that can go into the main line and force its way to a distant receiver.

The battery current in the primary coil is undulating, but always in the same direction, the magnetic field around the core getting weaker and stronger. This causes an alternating current in the secondary coil and main line.

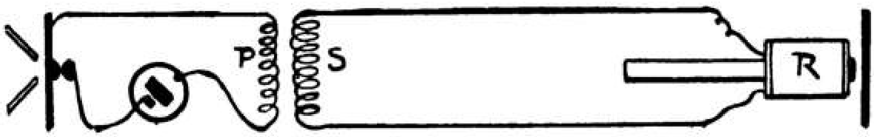


Fig. 168.

Fig. 168 shows the two coils, P, S, of the induction coil. The primary, P, is joined in series with a cell and transmitter. The secondary coil, S, is joined to the receiver. One [207]
end of S can be grounded, the current completing the circuit through the earth and into the receiver through another wire entering the earth. There are many forms of transmitters. (See "Things a Boy Should Know About Electricity.")

484. Electric Lighting and Heating. Whenever resistance is offered to the electric current, heat is produced. By proper appliances, the heat of resistance can be applied just where it is needed, and many commercial processes depend upon electricity for their success. Dynamos are used to generate currents for lighting and heating purposes. There are two great systems of lighting, the one by *arc* lamps and the other by *incandescent* lamps. (See "Things a Boy Should Know About Electricity.")

485. Arc Lamps produce a light when a current passes from one carbon rod to the other across an air-space. As the current starts through the lamp, the ends of the carbons touch, and the imperfect contact causes resistance enough to heat the ends red-hot. They are then automatically separated, and the current passes from one to the other, causing the "arc." The resistance of the air-space is reduced by the intensely heated vapor and flying particles of carbon.

486. The Incandescent Lamp consists of a glass bulb, in which is a vacuum, and the light is caused by the passage of a current through a thin fibre of vegetable carbon, enclosed in the vacuum. The fibre would burn instantly if allowed to come in contact with the air. The fibres have a high resistance, and are easily heated to incandescence.

CHAPTER XXVIII.

WIRE TABLES.

Copper Wire Tables are very convenient, and a necessity when working electrical examples. The tables here given are taken from a dealer's catalogue, and will be found sufficiently accurate for ordinary work.

Explanation of Tables. In the *first* column are given the sizes of wires by numbers. The B & S or American gauge is used. In the table below is given a comparison between the B & S and the Birmingham gauges.

The *second column* gives the diameters of wires. The diameter of No. 36 wire is 5 thousandths of an inch; the diameter of No. 24 wire is a little over 20 thousandths or 2 hundredths of an inch.

The *third column* contains what is called circular mils, a mil being a thousandth of an inch. The figures in this column are obtained by squaring those in the second; thus, for No. 36 wire, 5 × 5 = 25. This column is useful when working examples where the squares of the diameters are wanted. The rest of the table explains itself.

The table at the bottom gives a comparison between the fractional and decimal parts of an inch. Space can not be given here for a series of examples showing the many uses of this table. (See "Elementary Electrical Examples.")

COPPER WIRE TABLES. (Based on the B. A. Unit.)

Gauge	DIAMETER.	Sectional AREA	Capacity.	OHMS		
B.&S. No.	In 1000ths	In Circular Mils.	In Amperes.	Per 1,000 feet.	Per Mile.	Per Pound.
0000	.460	211600.	312.	.04906	.25903	.000077
000	.40964	167805.	262.	.06186	.32664	.00012
00	.3648	133079.	220.	.07801	.41187	.00019
0	.32486	105534.	185.	.09831	.51909	.00031
1	.2893	83694.	156.	.12404	.65490	.00049
2	.25763	66373.	131.	.15640	.8258	.00078
3	.22942	52634.	110.	.19723	1.0414	.00125
4	.20431	41743.	92.3	.24869	1.313	.00198
5	.18194	33102.	77.6	.31361	1.655	.00314
6	.16202	26251.	65.2	.39546	2.088	.00499
7	.14428	20817.	54.8	.49871	2.633	.00792
8	.12849	16510.	46.1	.6529	3.3	.0125
9	.11443	13094.	38.7	.7892	4.1	.0197
10	.10189	10382.	32.5	.8441	4.4	.0270
11	.090742	8234.	27.3	1.254	6.4	.0501
12	.080808	6530.	23.	1.580	8.3	.079
13	.071961	5178.	19.3	1.995	10.4	.127
14	.064084	4107.	16.2	2.504	13.2	.200
15	.057068	3257.	13.6	3.172	16.7	.320
16	.05082	2583.	11.5	4.001	23.	.512
17	.045257	2048.	9.6	5.04	26.	.811
18	.040303	1624.	8.1	6.36	33.	1.29
19	.03589	1288.	....	8.25	43.	2.11
20	.031961	1021.	....	10.12	53.	3.27
21	.028462	810.	....	12.76	68.	5.20
22	.025347	642.	....	16.25	85.	8.35
23	.022571	509.	....	20.30	108.	13.3
24	.0201	404.	....	25.60	135.	20.9
25	.0179	320.	....	32.2	170.	33.2
26	.01594	254.	....	40.7	214.	52.9
27	.014195	201.	....	51.3	270.	84.2
28	.012641	159.8	....	64.8	343.	134.
29	.011257	126.7	....	81.6	482.	213.
30	.010025	100.5	....	103.	538.	338.
31	.008928	79.7	....	130.	685.	539.
32	.00795	63.	....	164.	865.	856.
33	.00708	50.1	....	206.	1033.	1357.
34	.006304	39.74	....	260.	1389.	2166.
35	.005614	31.5	....	328.	1820.	3521.
36	.005	25.	....	414.	2200.	5469.
37	.004453	19.8	....	523.	2765.	8742.

38	.003965	15.72	....	660.	3486.	13772.
39	.003531	12.47	....	832.	4395.	21896.
40	.003144	9.88	....	1049	5542.	34823.

Gauge	FEET.		POUNDS.	
B.&S. No.	Per Pound.	Per Ohm.	Per 1,000 feet.	Per Ohm.
0000	1.56122	20497.7	640.51	12987.
000	1.9687	16255.27	507.95	8333.
00	2.4824	12891.37	402.83	5263.
0	3.1303	10223.08	319.45	3225.
1	3.94714	8107.49	253.34	2041.
2	4.97722	6429.58	200.91	1282.
3	6.2765	5098.61	159.32	800.
4	7.9141	4043.6	126.35	505.
5	9.97983	3206.61	100.20	318.
6	12.5847	2542.89	79.462	200.
7	15.8696	2015.51	63.013	126.
8	20.0097	1599.3	49.976	80.
9	25.229	1268.44	39.636	50.
10	31.8212	1055.66	31.426	37.
11	40.1202	797.649	24.924	20.
12	50.5906	632.555	19.766	12.65
13	63.7948	501.63	15.674	7.87
14	80.4415	397.822	12.435	5.00
15	101.4365	315.482	9.859	3.12
16	127.12	250.184	7.819	1.95
17	161.29	198.409	6.199	1.23
18	203.374	157.35	4.916	.775
19	256.468	124.777	3.899	.473
20	323.399	98.9533	3.094	.305
21	407.815	78.473	2.452	.192
22	514.193	62.236	1.945	.119
23	648.452	49.3504	1.542	.075
24	817.688	39.1365	1.223	.047
25	1031.038	31.0381	.9699	.030
26	1300.180	24.6131	.7692	.0187
27	1639.49	19.5191	.6099	.0118
28	2067.364	15.4793	.4837	.0074
29	2606.959	12.2854	.3835	.0047
30	3287.084	9.7355	.3002	.0029
31	4414.49	7.72143	.2413	.0018
32	5226.915	6.12243	.1913	.0011
33	6590.41	4.85575	.1517	.00076
34	8312.8	3.84966	.1204	.00046
35	10481.77	3.05305	.0956	.00028
36	13214.16	2.4217	.0757	.00018
37	16659.97	1.92086	.06003	.00011
38	21013.25	1.52292	.04758	.00007
39	26496.237	1.20777	.03755	.00004
40	33420.63	0.97984	.02992	.000029

Comparative Table of the Fractional and Decimal Parts of an Inch.

1/64	= .015625
1/32	= .031250
3/64	= .046875
1/16	= .062500
5/64	= .078125
3/32	= .093750
7/64	= .109375
1/8	= .125000

9/64	= .140625
5/32	= .156250
11/64	= .171875
3/16	= .187500
13/64	= .203125
7/32	= .218750
15/64	= .234375
1/4	= .250000
17/64	= .265625
9/32	= .281250
19/64	= .296875
5/16	= .312500
21/64	= .328125
11/32	= .343750
23/64	= .359375
3/8	= .375000
25/64	= .390625
13/32	= .406250
27/64	= .421875
7/16	= .437500
29/64	= .453125
15/32	= .468750
31/64	= .484375
1/2	= .500000

Comparative Table of B. and S. and B. W. Gauges in Decimal Parts of an Inch.

No. of Wire Gauge.	American (B. and S.) Wire Gauge.	Birmingham Wire Gauge.
0000	.46	.454
000	.40964	.425
00	.3648	.38
0	.32486	.34
1	.2893	.3
2	.25763	.284
3	.22942	.259
4	.20431	.238
5	.18194	.22
6	.16202	.203
7	.14428	.18
8	.12849	.165
9	.11443	.148
10	.10189	.134
11	.090742	.12
12	.080808	.109
13	.071961	.095
14	.064084	.083
15	.057068	.072
16	.05082	.065
17	.045257	.058
18	.040303	.049
19	.03589	.042
20	.031961	.035
21	.028468	.032
22	.025347	.028
23	.022571	.025
24	.0201	.022
25	.0179	.02
26	.01594	.018
27	.014195	.016
28	.012641	.014
29	.011257	.013
30	.010025	.012
31	.008928	.01
32	.00795	.009

33	.00708	.008
34	.006304	.007
35	.005614	.005
36	.005	.004
37	.004453	
38	.003965	
39	.003531	
40	.003114	

LIST OF APPARATUS
FOR
The Study of Elementary Electricity and Magnetism by Experiment.

The **100** pieces of apparatus in the following list are referred to, by number, in the experiments contained in "The Study of Elementary Electricity and Magnetism by Experiment." This list is furnished to give those who wish to make their own apparatus an idea of the approximate size, etc., of the various articles used. The author is preparing a price catalogue of the articles included in this list, and of odds and ends needed in the construction of simple, home-made apparatus.

No. 1. A package of 25 steel sewing-needles. To be suitable for experiments in magnetism, these should be of good, hard steel, and not too thick.

No. 2. A flat cork, about 1 in. in diameter and ⅜ in. thick.

No. 3. A candle for annealing steel.

No. 4–15. One dozen assorted annealed iron wires, from 1 in. to 6 in. in length. The iron should be very soft.

No. 16. One English horseshoe magnet, 2½ in. long, best quality.

No. 17. A small box of iron filings from soft iron.

No. 18. A compass (Fig. 5). The needle swings very freely; it is enclosed in a wooden pill box, the cover of which forms the support.

No. 19, 20. Two soft steel wire nails, 2 in. long.

No. 21, 22. Two pieces of spring steel, about 3 in. long and ⅜ in. wide, to be magnetized by the student and used as bar magnets.

No. 23. An iron ring, or washer, about ⅞ in. in diameter.

No. 24. A sifter for iron filings. This consists of a pasteboard pill box: Prick holes through the bottom with a pin.

No. 25. A thin, flexible piece of spring steel, about 3 in. long and ⅛ in. wide.

No. 26, 27. Two ebonite sheets (E S, Fig. 34), each 4 in. square. These are made with a special [211]
surface. They are very much better than the ordinary smooth ebonite.

No. 28. One ebonite rod (E R, Fig. 34), 3½ in. long, with special surface.

No. 29. One ebonite rod, 1¾ in. long, with special surface, used to support the insulating table, No. 43 (I T, Fig. 32).

No. 30. One piece of flannel cloth, 7 in. square.

No. 31. Six sheets of tissue-paper, each 4 in. square.

No. 32. A few feet of white cotton thread.

No. 33. A few feet of black silk thread.

No. 34. One support base (S B, Fig. 56). This is of thin wood, about 3¾ in. by 6½ in., to one end of which is fastened a spool for holding the support rod (No. 35).

No. 35. One support rod (S R, Fig. 56), 7 in. long and 5/16 in. in diameter. This rod has a hole in each end. The small hole is for holding the support wire (No. 36); the large hole is for the ebonite rod (No. 29).

No. 36. One support wire (S W, Fig. 144).

No. 37. One wire swing (W S, Fig. 29).

No. 38. One sheet of glass, 4 in. square.

No. 39. One bent hairpin (H P, Fig. 32).

No. 40. Bottom of flat box (B F B, Fig. 32), 3⅝ in. in diameter.

No. 41. Top of flat box (T F B, Fig. 33).

No. 42. One electrophorus cover (E C, Fig. 34), 3⅝ in. in diameter. This has rounded edges, and a small tube is riveted into the top of it to hold the insulating handle, E R.

No. 43. One insulating table (I T, Fig. 32). This is made the same as No. 42, and is supported by No. 29.

No. 44. One insulated copper wire, 2½ feet long.

No. 45. One rubber band (R B, Fig. 33).

No. 46. Six bent wire clamps (B C, Fig. 37).

No. 47. One tin box conductor (T B, Fig. 42). This cylindrical conductor is about the size of an ordinary baking powder box.

No. 48. One hairpin discharger for the condenser.

No. 49. Two sheets of aluminum-leaf for the leaf electroscope (Fig. 57) and other experiments.

No. 50. One bent wire (H P, Fig. 57) used in connection with the leaf electroscope.

No. 51. A dry cell, ordinary size about 7 in. high and 2½ in. in diameter. [212]

No. 52. Enough mercury to amalgamate battery zincs. A wooden pill box containing about half a thimbleful will do.

No. 53. A coil containing 25 feet of No. 24 insulated copper wire for connections.

No. 54. One dozen spring connectors (Fig. 61) for making connections. These are made of brass, nickel plated, and do not affect the compass-needle.

No. 55. A telegraph key (Fig. 68) without switch. The metal straps are made of aluminum; they are ½ in. wide, and are fastened to a neat wooden base.

No. 56. Three metal plates, each about 2 in. by ¾ in., on which spring connectors (No. 54) are to be pushed in order to join two wires.

No. 57. A current reverser (Fig. 69). The straps are made of aluminum and are fastened to a neat wooden base.

No. 58. A galvanoscope (Fig. 72) including a degree-card (No. 99). The cardboard coil-support, C S, is 5 × 6¼ in., and the hole in it is 3⅜ in. in diameter. The coil is 4¼ in. in diameter, made of No. 24 insulated copper wire.

No. 59. An astatic galvanoscope (Fig. 77). The whole may be taken apart and mailed in the containing box, B, which is 4⅜ × 3⅛ × 1 in. The coil is made of No. 31 wire, and has a resistance of about 5 ohms. Spring connectors are used to join a wire to the apparatus by pushing the connectors into the tubular binding-posts, L and R.

No. 60–63. Four strips of sheet zinc, 4 in. by ½ in., not amalgamated.

No. 64. A carbon rod, 4 in. long (Fig. 81).

No. 65, 66. Two glass tumblers (Fig. 81).

No. 67, 68. Two strips of sheet copper, 4 in. by ½ in. (Fig. 85).

No. 69. One galvanized iron nail.

No. 70, 71. Two wooden cross-pieces (Fig. 85).

No. 72. One dozen brass screws, ⅝ in. long, size No. 5, with round heads.

No. 73. A porous cup (P C, Fig. 87) that will stand inside of the tumblers (No. 65).

No. 74. A zinc rod, about ⅜ in. in diameter, like those used in Leclanché cells. [213]

No. 75. A sheet copper plate for the two-fluid cell (C, Fig. 87). This is 2 in. wide; it nearly surrounds the porous cup, and is supported upon the edge of the tumbler by a narrow strip, A, with which connections are made by spring connectors (No. 54).

No. 76. One strip of sheet iron, 4 in. by ½ in.

No. 77, 78. Two strips of sheet lead, 4 in. by ½ in.

No. 79. A resistance coil (Fig. 94). The coil is made of No. 24 insulated copper wire; it has a resistance of 2 ohms (nearly) and is fastened to a cardboard base. It is so arranged that either one or two ohms can be used at will.

No. 80. A Wheatstone's bridge (Fig. 103), including a scale (No. 100). The aluminum straps, 1, 2, 3, are fastened to a neat wooden base, 10 in. long by 2 in. wide. A No. 28 German-silver wire is used for the bridge.

No. 81. A piece of No. 30 uncovered German-silver wire, 2.1 meters long, used for resistance (Fig. 96).

No. 82. A piece of No. 28 uncovered German-silver wire, 2.1 meters long.

No. 83–85. Three plate binding-posts, consisting of bent straps of sheet aluminum (X, Y, Z, Fig. 96).

No. 86. Two ounces of copper sulphate, commonly called bluestone. The crystals may be kept in a large wooden pill box.

No. 87. One dozen copper washers.

No. 88. One combination rule, 1 ft. long, marked with English and metric systems.

No. 89. A hollow coil of No. 24 insulated copper wire (Fig. 130). The spool, on which the wire is wound, has a hole for a five-sixteenths inch core. It is turned down thin, so that the wire is near the core. The coil is about 1⅛ in. long and 1 in. in diameter. Spring connectors are joined to the ends of the coil.

No. 90. A hollow coil of No. 25 insulated copper wire, similar to No. 89, with spring connectors attached to its ends.

No. 91. Carbon rod for electroplating.

No. 92, 93. Two soft iron cores, with screws (I C, Fig. 130). These cores are 5/16 in. in diameter, and have a threaded hole in one end for fastening them to No. 94.

No. 94. A tin box with three holes punched in its top (Fig. 132). This serves as a base, as well as a yoke, for the two electromagnets, A, B, shown in plan. [214]

No. 95. Combination connecting plates (Fig. 132). Three aluminum straps are fastened to a wooden base. They are turned up at their ends so that spring connectors can be easily pushed upon them.

No. 96. One long iron core (L I C, Fig. 140). This is of soft iron, 5/16 in. in diameter, and long enough to pass through both coils (No. 89, 90).

No. 97. Bar magnet, about 4 in. long and 5/16 in. in diameter.

No. 98. Coil of insulated wire wound on a soft iron core, to act as a primary coil for induction experiments. This coil fits inside of the hollow coils (Nos. 89, 90).

No. 99. A printed degree-card for the galvanoscope (No. 58). This is printed on stiff cardboard, about 3 in. in diameter.

No. 100. A printed scale for the Wheatstone's bridge (No. 80). This is printed on stiff paper. The scale is 8 in. long, and is divided into 10 large divisions, each of which is subdivided into 10 parts, thus making 100 parts in all.

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Notes.

ELECTRICAL BOOKS

ELECTRICAL APPARATUS

GAMES PUZZLES

EDUCATIONAL

AMUSEMENTS

THOMAS M. ST. JOHN, Met. E.

A Word to Parents About Games and Educational Amusements.

Systematic play is as important as systematic work. The best games and home amusements are as valuable to a child as school-studies; in fact, they bring out and stimulate qualities in a child, which no school-study can. Fascinating home amusements are as necessary as school-books.

Boys and girls like to be busy. Their amusements should be entered into as heartily, chosen as carefully, and purchased as willingly as school-books.

Games.—Jingo and Hustle-Ball are good games.

> They are interesting and full of action.
> They arouse a child's common-sense.
> They cultivate an ability to think rapidly, judge correctly, and decide quickly.
> They educate the eye and hand at the same time.
> They are very simple, and may be played at once.

Educational Amusements.—There is a peculiar fascination about Electricity and Magnetism, which makes these subjects appeal to every boy and girl.

There is nothing better than science studies, to teach children to observe and to see what they look at; besides, it is *fun* to experiment. "Fun With Electricity" and "Fun With Magnetism" are educational amusements. They contain fascinating experiments and are systematically arranged.

Juvenile Work in Electricity.

From The Electrical Engineer, May 19, 1898.

The position that Young America is now taking in the electric and magnetic field is very clearly shown at the Electrical Show now being held at Madison Square Garden, by an exhibit of simple experimental apparatus made by young boys from the Browning School, of this city.

The models shown cover every variety of apparatus that is dear to the heart of a boy, and yet, along the whole line from push-buttons to motors, one is struck by the extreme simplicity of design and the ingenious uses made of old tin tomato cans, cracker boxes, bolts, screws, wire, and the wood that a boy can get from a soap box.

The apparatus in this exhibit was made by boys 13, 14 and 15 years of age, from designs made by Mr. Thomas M. St. John, of the Browning School. It clearly shows that good, practical apparatus can be made from cheap materials by an average boy. The whole exhibit is wired and in working order, and it attracts the attention of a large number of parents and boys who hover around to see, in operation, the telegraph instruments, buzzers, shocking coils, current detectors, motors, etc.

Mr. St. John deserves the thanks of every boy who wants to build his own electrical apparatus for amusement or for experimental purposes, as he has made the designs extremely simple, and has kept constantly in mind the fact that the average boy has but a limited supply of pocket money, and an equally limited supply of tools.

How Two Boys Made Their Own Electrical Apparatus.

CONTENTS: *Chapter* I. Cells and Batteries.—II. Battery Fluids and Solutions.—III. Miscellaneous Apparatus and Methods of Construction.—IV. Switches and Cut-Outs.—V. Binding-Posts and Connectors.—VI. Permanent Magnets.—VII. Magnetic Needles and Compasses.—VIII. Yokes and Armatures.—IX. Electro-Magnets.—X. Wire-Winding Apparatus.—XI. Induction Coils and Their Attachments.—XII. Contact Breakers and Current Interrupters.—XIII. Current Detectors and Galvanometers.—XIV. Telegraph Keys and Sounders.—XV. Electric Bells and Buzzers.—XVI. Commutators and Current Reversers.—XVII. Resistance Coils.—XVIII. Apparatus for Static Electricity.—XIX. Electric Motors.—XX. Odds and Ends.—XXI. Tools and Materials.

"The author of this book is a teacher and writer of great ingenuity, and we imagine that the effect of such a book as this falling into Juvenile hands must be highly stimulating and beneficial. It is full of explicit details and instructions in regard to a great variety of apparatus, and the materials required are all within the compass of very modest pocket-money. Moreover, it is systematic and entirely without rhetorical frills, so that the student can go right along without being diverted from good helpful work that will lead him to build useful apparatus and make him understand what he is about. The drawings are plain and excellent. We heartily commend the book."—*Electrical Engineer.*

"Those who visited the electrical exhibition last May cannot have failed to notice on the south gallery a very interesting exhibit, consisting, as it did, of electrical apparatus made by boys. The various devices there shown, comprising electro-magnets, telegraph keys and sounders, resistance coils, etc., were turned out by boys following the instructions given in the book with the above title, which is unquestionably one of the most practical little works yet written that treat of similar subjects, for with but a limited amount of mechanical knowledge, and by closely following the instructions given, almost any electrical device may be made at very small expense. That such a book fills a long-felt want may be inferred from the number of inquiries we are constantly receiving from persons desiring to make their own induction coils and other apparatus."—*Electricity.*

"At the electrical show in New York last May one of the most interesting exhibits was that of simple electrical apparatus made by the boys in one of the private schools in the city. This apparatus, made by boys of thirteen to fifteen years of age, was from designs by the author of this clever little book, and it was remarkable to see what an ingenious use had been made of old tin tomato-cans, cracker-boxes, bolts, screws, wire, and wood. With these simple materials telegraph instruments, coils, buzzers, current detectors, motors, switches, armatures, and an almost endless variety of apparatus were made. In his book Mr. St. John has given directions in simple language for making and using these devices, and has illustrated these directions with admirable diagrams and cuts. The little volume is unique, and will prove exceedingly helpful to those of our young readers who are fortunate enough to possess themselves of a copy. For schools where a course of elementary science is taught, no better text-book in the first-steps in electricity is obtainable."—*The Great Round World.*

Exhibit of Experimental Electrical Apparatus

AT THE ELECTRICAL SHOW, MADISON SQUARE GARDEN, NEW YORK.

While only 40 pieces of simple apparatus were shown in this exhibit, it gave visitors something of an idea of what young boys can do if given proper designs.

"HOW TWO BOYS MADE THEIR OWN ELECTRICAL APPARATUS"
Gives Proper Designs—Designs for over 150 Things.

Fun With Magnetism.

BOOK AND COMPLETE OUTFIT FOR SIXTY-ONE EXPERIMENTS IN MAGNETISM....

Children like to do experiments; and in this way, better than in any other, *a practical knowledge of the elements of magnetism* may be obtained.

These experiments, although arranged to amuse boys and girls, have been found to be very *useful in the class-room* to supplement the ordinary exercises given in text-books of science.

To secure the best *possible quality of apparatus*, the horseshoe magnets were made at Sheffield, England, especially for these sets. They are new and strong. Other parts of the apparatus have also been selected and made with great care, to adapt them particularly to these experiments. —*From the author's preface.*

CONTENTS.—Experiments With Horseshoe Magnet.—Experiments With Magnetized Needles.—Experiments With Needles, Corks, Wires, Nails, etc.—Experiments With Bar Magnets.—Experiments With Floating Magnets.—Miscellaneous Experiments.—Miscellaneous Illustrations showing what very small children can do with the Apparatus.—Diagrams showing how Magnetized Needles may be used by little children to make hundreds of pretty designs upon paper.

AMUSING EXPERIMENTS.—Something for Nervous People to Try.—The Jersey Mosquito.—The Stampede.—The Runaway.—The Dog-fight.—The Whirligig.—The Naval Battle.—A String of Fish.—A Magnetic Gun.—A Top Upsidedown.—A Magnetic Windmill.—A Compass Upsidedown.—The Magnetic Acrobat.—The Busy Ant-hill.—The Magnetic Bridge.—The Merry-go-Round.—The Tight-rope Walker.—A Magnetic Motor Using Attractions and Repulsions.

The Book and Complete Outfit will be sent, Post-paid, upon receipt of 35 Cents, by

THOMAS M. ST. JOHN, 407 W. 51st St., New York.

A Few Off-Hand Statements

that have been made about "Fun With Magnetism" and "Fun With Electricity" in letters of inquiry to the author. (These statements were absolutely unsolicited.)

"My little boy has your 'Fun With Magnetism' and enjoys it so much that if the 'Fun With Electricity' is ready I would like to have it for him. Please let me know," etc.

"I have had much fun with 'Fun With Magnetism.'"

"My boy has 'Fun With Magnetism' and has enjoyed it very much and would like the other. Will you," etc.

"Please let me know when 'Fun With Electricity' is upon the market, for if it is as good as this, I shall certainly want it."

"I have just received 'Fun With Magnetism' and am delighted with it. Please send me 12 sets," etc.

"I have 'Fun With Magnetism' and 'Fun With Electricity' and have enjoyed them very much. Please send," etc.

"I am much pleased with 'Fun With Electricity' and would like to have," etc.

"'Fun With Electricity' is fine and I have had lots of fun with it. Please send," etc.

"Having experimented with both of your apparatus 'Fun With Magnetism' and 'Fun With Electricity,' and having found them both amusing and instructive, I wish to ask," etc.

"I have purchased your outfits 'Fun With Electricity' and 'Fun With Magnetism,' and though they are designed for amusement, I find them a great help in my studies. Will you please," etc.

"I have one of your outfits of 'Fun With Electricity,' and I enjoy it very much, some of the experiments being very astonishing. Will you please," etc.

"I have enjoyed 'Fun With Magnetism' and 'Fun With Electricity' very much."

"My little boy has your book 'Fun With Electricity,' which has given him much amusement. He would like to have," etc.

"I am very much pleased with both outfits. I am very much in favor of such things for boys; it keeps them occupied with something that is both amusing and instructive. Send me," etc.

Things A Boy Should Know About Electricity.

(In Preparation.)

This book explains, in simple, straightforward language, many things about electricity; things in which the American boy is intensely interested; things he wants to know; things he should know.

It is free from technical language and rhetorical frills, but it tells how things work, and why they work.

It is brimful of illustrations—the best that can be had—illustrations that are taken directly from apparatus and machinery, and that show what they are intended to show.

This book does not contain experiments, or tell how to make apparatus; our other books do that. After explaining the simple principles of electricity, it shows how these principles are used and combined to make electricity do every-day work. The following are

Some of the Things Electricity Can Do:

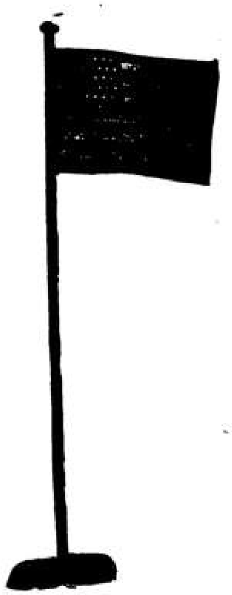
It signals without wires.
It drills rock, coal, and teeth.
It cures diseases and kills criminals.
It protects, heats, and ventilates houses.
It photographs the bones of the human body.
It rings church bells and plays church organs.
It lights streets, cars, boats, mines, houses, etc.
It pumps water, cooks food, and fans you while eating.
It runs all sorts of machinery, elevators, cars, boats, and wagons.
It sends messages with the telegraph, telephone, telautograph, and search-light.
It cuts cloth, irons clothes, washes dishes, blackens boots, welds metals, prints books, etc., etc.

Everyone Should Know About Electricity.

Things A Boy Should Know About Electricity will interest *you*. We shall be glad to send you complete information as soon as it is ready. Send us your address now.

Dewey Flag Poles

ARE LITTLE MODELS OF REAL FLAG POLES....

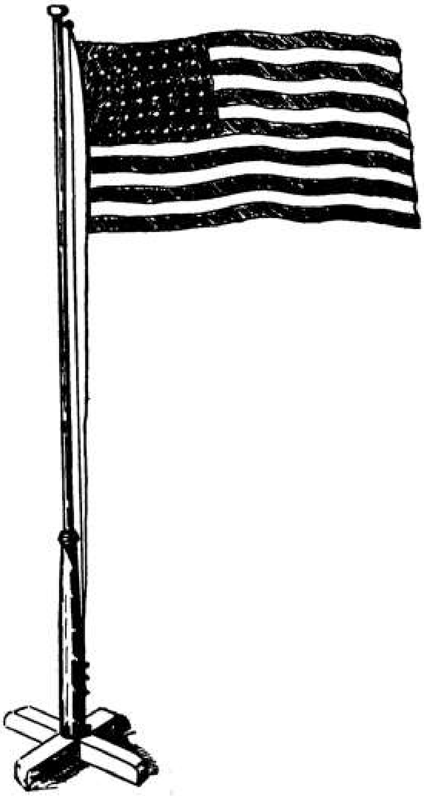


They are appropriate for any occasion, and suitable for any kind of decoration. They should stand on tables, mantels, pianos, etc.; in fact, there is no better ornament for general use.

"They should be in every home and in every school-room in the United States."

"No toy fort complete without a Dewey Flag Pole."

"The children can fasten them on the windowsill and watch them flutter by the hour."



"They hoist like big flags, at half-mast, etc."

"Invaluable for store-window decoration."

PRICES

SMALL SIZE: height 18 inches, fitted with United States or Cuban Silk Flag (4×6 in.) post-paid, 30c.
LARGE SIZE: height 24 inches, fitted with
United States Silk Flag (7 × 10 in.), post-paid, 40c.
LARGE SIZE: fitted with Cuban or British Silk Flag (8×12 in.), post-paid, 50c.

DEWEY FLAG POLES are beautifully made of hard wood, and fitted with best Silk Flags.

GAMES.

Hustle=Ball.

A quick, sharp, decisive game that is thoroughly American.

Played by means of Magic Wands, and Polished Balls of Steel.

Needed: *"A quick eye and a nimble hand."—Shakespeare*.

The Rule: Just keep cool—and hustle.

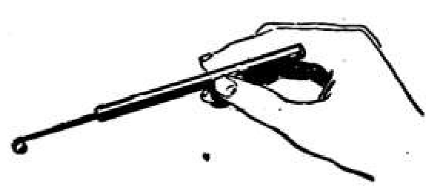
Four Games with One Outfit:

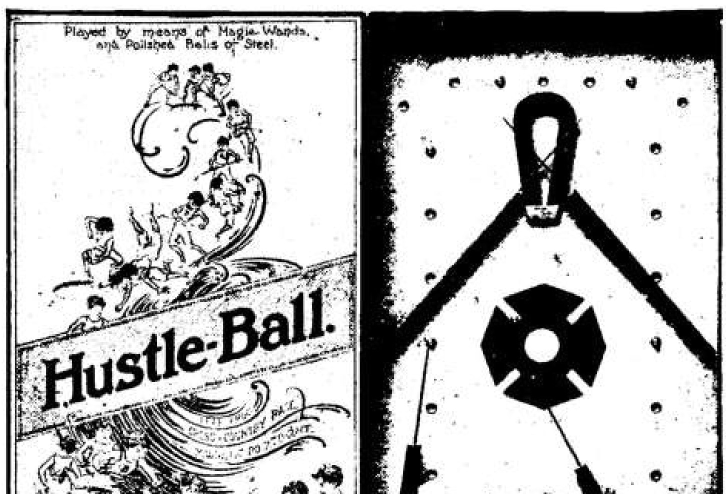
"Hustle Ball,"
"Leap-Frog,"
"Cross-Country Race,"
"Magnetic Potato-Race."

The game-board is new and original, as well as the methods of playing. The game is put up in a strong box having a beautifully lithographed cover, and measures 8 × 15½ inches. With the game-board are furnished, magic wands, polished steel balls, an "extra strength" horseshoe magnet, and a complete set of illustrated rules and directions for playing.

"Unlike all other games."
"Any one can play Hustle-Ball."
"Just the thing for progressive parties."
"Hustle-Ball games are intensely exciting."
"No waiting for some one to play."
"You win or lose a point in a few seconds."
"By handicapping the best players, all games are made equally interesting and exciting."
"A game for Grandparents, as well as for Grandchildren."

A Brand-New Idea in Games.





'***A HUSTLE FROM THE WORD GO.***'

This Exciting Game will be sent, ***Charges Prepaid***, by mail or express, upon receipt of 65 Cents.

Address THOMAS M. ST. JOHN,
407 West 51st Street,

New York City.

JINGO THE GREAT WAR GAME

Social Exciting Interesting Simple.

A Thorough War Game:—Infantry Against Infantry, Cavalry Against Cavalry, Etc.

Jingo is really a great war contest between England and America. Upon the game-board are 14 beautiful war scenes, each lithographed in 8 colors. American and English flags, coats of arms, cannon, torpedoes, etc., aid in making this game artistic, handsome and attractive. The following companies, ships, etc., are shown:—*American*, 12th U. S. Infantry,—6th U. S. Cavalry,—2d U. S. Light Artillery,—U. S. Mortar Battery,—U. S. Monitor "Miantonomoh,"—U. S. Ram "Katahdin,"—U. S. Battleship "Indiana,"—U. S. Torpedo Boat "Cushing,"—U. S Dynamite Cruiser "Vesuvius." *English*, 30th East Lancashire,—1st Royal Dragoons,—Royal Horse Artillery,—Royal Artillery,—H. M. S. "Thunderer,"—H. M. S. "Seagull,"—H. M. S. "Nile,"—H. M. S. "Australia,"—H. M. S. "Dart."

The game board is over 16 inches square when opened. Jingo is made and finished in a manner which makes it the most beautiful, artistic, and practical game ever published.

"Just what every boy likes."
"A good idea well carried out."
"The Game-board is a work of art."
"Any child can play Jingo at once."
"It is the handsomest game on the market."

JINGO JUNIOR is the Greatest Game ever Invented for Little Folks.

It is played upon the Jingo board with the extra ammunition furnished.

These Two Great Games make a most complete and beautiful outfit for home amusement.

JINGO AND JINGO JUNIOR.

Two Fascinating and Entirely Different Games, Played with One Outfit, and Complete in One Box.

***THIS HANDSOME OUTFIT* for playing the *TWO GREAT WAR GAMES* will be**

sent *CHARGES PREPAID* upon receipt of *$1.00*.

Address THOMAS M. ST. JOHN,
407 West 51st Street,
New York City.

Transcriber's Notes

In the text version, Italic text is denoted by _underscores_ and bold text by =equal signs=.

Obvious punctuation errors have been repaired.

The book contains some inconsistent hyphenation which has been left as printed.

- p. xi. (TOC) "constructiou" changed to "construction"
- p. xiv. (TOC) "The Prodution of Motion" changed to "The Production of Motion"
- p. 27. para. 73. "thick permament magnets" changed to "thick permanent magnets"
- p. 99. para 253. "wabble" may be a typo for wobble but has been left on the off chance that this could be what was intended.
- p. 118. Fig 91. The final column has been scored through but appears to read "CU to ZN"
- p. 131. para. 324, 325. German-silver Wire, G-s W used here but previously G S W used.
- p. 164. para 395. "circuit in closed" changed to "circuit is closed"
- p. 166. para 398. "core inside of the c l" changed to "core inside of the coil" after checking original scans.
- p. 169–170. It appears that a word has been omitted across the page break. "The copper washer, C W, be used." has been changed to "The copper washer, C W, should be used.". (Alternative words are possible!)
- p. 211. No. 35. 5-16 in. changed to 5/16 in.
- p. 213. No. 92, 93. 5-16 in. changed to 5/16 in.
- p. 214. No. 96. and No. 97. 5-16 in. changed to 5/16 in.
- p. 216. Entry for Coulomb moved from end of "C" to above Current.