

flaws, and having level and polished faces. The breadth of a bar magnet should be one-twentieth of its length, and its thickness about one-seventieth of its length. In a horse-shoe magnet, the distance between the poles ought not to be greater than the breadth of one of the sides.

887. Magnetism may be imparted to steel or iron in four different ways:—1. By induction. 2. By the sun's rays. 3. By contact with a magnet. 4. By electric currents.

888. INDUCTION, A SOURCE OF MAGNETISM.—A magnetic atmosphere surrounds every magnet. A piece of iron or steel brought within this atmosphere, even without touching the magnet, has its neutral fluid decomposed, and exhibits magnetic properties. It is then said to be magnetized *by induction*.

Present half a dozen bars of iron at different angles to the positive pole of a magnet, without letting them touch it. They will all be magnetized by induction, the ends towards the magnet becoming negative poles and the opposite ends positive.

Suspend two pieces of soft iron wire by threads, parallel to each other and on the same level. On bringing either pole of a magnet a short distance below them, they become magnetized by induction. Like poles are formed in their contiguous extremities, and consequently instead of hanging parallel as before, they repel each other and diverge.

Bring one end of an unmagnetized steel bar near the north pole of a magnetic needle, and the latter will be attracted to it. Now place the positive pole of a powerful magnet near the other end of the bar, and the needle will soon be repelled. This is because the bar becomes magnetized by induction. The end nearest the needle becomes a positive pole by which the positive pole of the latter is repelled.

889. The earth magnetizes by induction. A bar of soft iron placed in the direction of the dipping needle, acquires magnetic properties by the inductive influence of the earth acting as a magnet. A few blows with a hammer on the

the magnetic intensity? What is found by applying this law? Where is the magnetic intensity found to be least? 886. Of what should artificial magnets be made? What should be the comparative dimensions of a bar magnet? What is essential in a horse-shoe magnet? 887. Name the four ways in which magnetism may be imparted to a piece of steel or iron. 888. When is a piece of iron said to be magnetized *by induction*? Illustrate magnetic induction with an experiment. Describe the experiment with two pieces of soft iron wire. What other experiment proves that a bar may be magnetized by induction? 889. How is it proved that the earth magnetizes by induction? What experiment shows the inductive influence of the earth?

upper end, by causing the particles to vibrate, help them to receive the magnetic influence.

Hold a bar of soft iron horizontally with one end near the north pole of a magnetic needle. The iron, being unmagnetized, attracts the needle. Now hold the bar in the direction of the dipping needle, give it one or two blows with a hammer, and the north pole of the needle will be repelled,—showing that the bar is magnetized, and a north pole formed in its lower end, by the inductive influence of the earth.

Iron bars that have long stood in a vertical position, or in the direction of the dipping needle, often acquire magnetic properties in an inferior degree. The same may be said of iron bars raised to a red heat and allowed to cool in the positions above mentioned, as well as of augers, gimlets, &c., that have been much used. Iron wire is frequently made magnetic by twisting it till it breaks.—All these are instances of magnetism by induction.

890. THE SUN'S RAYS, A SOURCE OF MAGNETISM.—Sun-light constitutes a second source of magnetism. The violet rays of the solar spectrum, concentrated by lenses on steel needles, have been found to endow them with magnetic properties.

891. CONTACT WITH A MAGNET, A SOURCE OF MAGNETISM.—A third and more efficient mode of exciting magnetism in iron or steel is by bringing it in contact with a magnet. Till recently this was the way in which artificial magnets were almost exclusively produced.

There are several different ways of magnetizing by contact. The principal are as follows:—

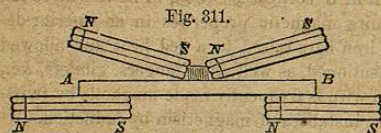
892. *Magnetizing Needles*.—An ordinary sewing needle may be magnetized by simply touching one of its ends to either pole of a powerful magnet. The end in question becomes negative if touched to the positive pole, and positive if touched to the negative.

893. *Magnetizing Bars*.—Steel bars may be magnetized either by *single touch* or *double touch*. Single Touch consists in applying but one pole of a magnet to the bar, or one pole to one-half, and the opposite pole to the other.

Give some further instances of magnetism by the inductive influence of the earth. 890. What is a second source of magnetism? How may sun-light be made to magnetize steel needles? 891. What is a third source of magnetism? 892. What is the mode of magnetizing needles? 893. What two modes are there of magnetizing steel

Double Touch consists in applying both poles at the same time throughout the whole length of the bar.

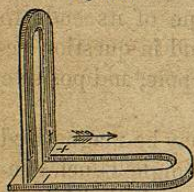
894. To magnetize a bar by single touch, apply midway of its length one of the poles of a magnet, and draw it to either end. Return it through the air to the middle of the bar, and draw it again to the same end as before. Repeat this process several times, always using the same pole and drawing it in the same direction. Then place the other pole on the middle of the bar, and draw it to the opposite extremity, repeating the strokes as in the former case. This must be done on both sides of the bar.



Another mode is represented in Fig. 311. The opposite poles of two magnets, kept about one-fourth of an inch apart by a piece of wood, are placed on the centre of the bar A B, so as to form angles of about 30 degrees with its surface. They are then slowly drawn in contrary directions from the middle to the extremities. This process is repeated several times, the magnets being raised when they reach the ends and replaced in the middle. The bar is then turned over, and the same thing done on the other side. The process is facilitated by resting the ends of the bar on the opposite poles of two other magnets, as shown in the figure.

895. To magnetize a bar by double touch, apply the opposite poles of two magnets as just described, only let them be perpendicular to the surface. Then, instead of drawing them to opposite extremities as before, move them together from the middle to one end, then through the air to the opposite extremity, and over the bar to the same end again, and so on—drawing them in the same direction over the bar, letting neither of the applied poles pass beyond its extremity, and finally stopping in the middle.

Fig. 312.

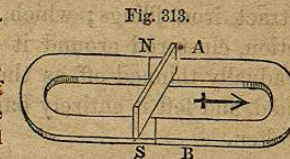


896. *Magnetizing Horse-shoe Bars.*—Horse-shoe magnets are produced by placing a piece of soft iron, as a keeper, across the ends of a steel bar bent in the proper form; and then, as shown in Fig. 312, applying perpendicularly to the extremities a horse-shoe magnet, whose arms are the same distance apart. Move it slowly to the bend, then carry it back through the air to the extremities, and draw it to the bend again. This must

bars? In what does Single Touch consist? In what, Double Touch? 894. Describe the process of magnetizing a bar by single touch. What other mode is described? 895. How is a bar magnetized by double touch? 896. How are horse-shoe magnets

be done about a dozen times; then, without removing the keeper, turn the bar over and do the same on the other side. The poles of the magnet produced will in this case be of the same character as those respectively brought in contact with them.

897. The best mode of magnetizing a horse-shoe bar is represented in Fig. 313. Lay the horse-shoe, A B, flat on a table, with its ends in contact with the poles of a horse-shoe magnet, N, S. Then place a piece of soft iron on these poles, and draw it slowly six or eight times towards



the bend of the bar, in the direction of the arrow, raising it as often as it reaches the bend, and replacing it as at first. This process performed on both sides endows the horse-shoe with strong magnetic properties. The end which touches the positive pole of the horse-shoe magnet becomes negative, and the other positive.

Two straight bars may be readily magnetized at once in the same way, by placing one extremity of each against the poles of the horse-shoe magnet, and connecting the opposite ends with a keeper.

898. *ELECTRIC CURRENTS, A SOURCE OF MAGNETISM.*—A bar of iron or steel is endowed with magnetic properties in the highest degree, by passing a current of voltaic electricity over a conductor placed in a certain position relatively to the bar. The details of this process belong to that branch of the science which is known as Electro-magnetism.

Electro-magnetism.

899. Electro-magnetism treats of the phenomena and principles of magnetism excited by the passage of electric currents.

900. *EFFECTS OF ELECTRIC CURRENTS ON THE MAGNETIC NEEDLE.*—As a science, Electro-magnetism owes its origin to a discovery made in 1819 by Prof. Oersted, of Copenhagen. He found that a wire along which a voltaic current

produced? What will be the character of the poles in the magnet produced? 897. With Fig. 313, describe the best mode of magnetizing a horse-shoe bar. How may two straight bars be magnetized at once? 898. How is a bar of steel endowed with magnetic properties in the highest degree? 899. Of what does Electro-magnetism treat? 900. To what does electro-magnetism owe its origin? Give an account

was passing tended to turn the magnetic needle from its natural position to one perpendicular to the direction of the current. The conducting wire, of whatever metal it might be, was thus rendered magnetic by the electric current which it transmitted. It was subsequently found to attract iron filings; which, when the battery was in full action, clustered around it to the thickness of a quill, but gradually thinned off as the energy of the battery diminished, and left it entirely bare the moment the circuit was broken.

The direction in which the needle is turned depends on its position relatively to the wire, and the direction in which the current is passing. When the needle is on a different level from the wire, that is, directly above or below it, it retains its horizontal position; but its north pole is turned east or west, according to whether it is above or below the wire, and according to the direction in which the current moves. When the needle is on the same level with the wire, but on one side of it, it does not then swerve east or west; but its north pole is made either to dip or to rise, according to the side of the wire it is on and the direction in which the current moves. The following rule enables us always to determine the direction in which the needle will be turned:—

Imagine yourself, with arms extended perpendicularly, lying along the conducting wire, with your head towards the point from which the current is coming, and your face turned towards the north pole of the needle; then this north pole will be deflected in the direction of your right hand, whether it be up or down, east or west.

The magnetic influence of the electric current is not therefore exerted in the plane of the conducting wire, but rather perpendicularly to that plane, so as to produce circular motion round the wire.

901. The deflection of the needle by an electric current may be shown with the apparatus represented in Fig. 314.

A brass wire is bent into rectangular form, and provided with a screw-cup at each extremity, P, N, for the reception of the wires from a galvanic battery, so that a current may be passed above and below a magnetic needle, N, S, suspended within the rectangle. The arms proceeding from P and N

of Oersted's discovery. How was it proved that the conducting wire was rendered magnetic by the electric current? On what does the direction in which the needle turns depend? How does it turn, when on a different level from the wire? How, when on the same level with the wire, but on one side of it? State the rule for determining the direction in which the needle will be turned? How is the magnetic influence of the electric current exerted? 901. Illustrate the deflection of the needle

are insulated from each other where they cross. No sooner is a positive current passed over the upper wire from north to south, than the needle is turned, its north pole deviating towards the east and its south pole to the west.

Here the *under* current, passing in the *opposite* direction to the upper one, tends to turn the needle in the same direction; and the *deflecting force*, as it is called, is therefore twice as great as if the current passed in one direction only. If the wire be bent so as to make two rectangles about the needle, the deflecting force will be twice as great as when but one is formed; if five rectangles are made, as in Fig. 315, it will be five times as great, &c. In these cases, the wire must be covered with silk thread, or some other non-conductor, so as to insulate its arms from each other, and oblige the current to traverse its whole length. It is on this principle that the Galvanometer is constructed.

902. *The Galvanometer.*—The Galvanometer is an instrument for measuring the force of galvanic currents by the deflection of the magnetic needle. It consists of a long wire bent into an oval or rectangular coil, the parts of which are prevented from touching by being wound with silk. The wire terminates in screw-cups, for convenience of connection with a galvanic battery. Within the coil a magnetic needle is delicately poised; and the instrument is placed so that the wire may have the same direction as the needle. They retain this direction till a galvanic current passes over the wire, when the needle is turned towards the east—more or less, according to the force of the current. A graduated scale fixed below the needle, with its circumference divided into degrees, measures the deflection, and consequently the quantity of electricity passing over the wire.

with Fig. 314. What is the effect of having two currents, one above and one below? What is the effect of having two rectangles? Five rectangles? In these cases, what precaution must be taken? What instrument is constructed on this principle? 902. What is the Galvanometer? Describe the galvanometer. 903. How is the gal-

Fig. 314.

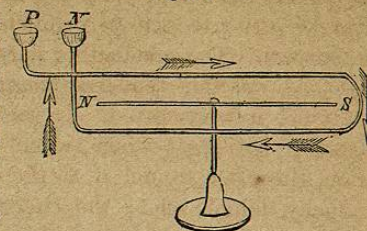


Fig. 315.

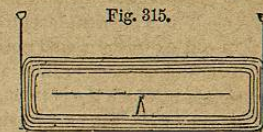
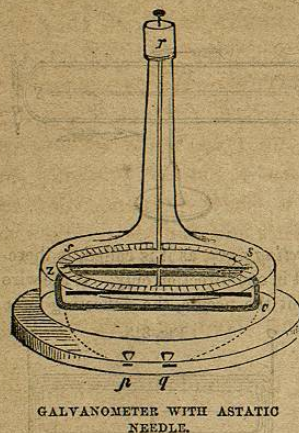


Fig. 316.



GALVANOMETER WITH ASTATIC NEEDLE.

point in opposite directions to those of the under one, it will tend to move in the same direction as the latter when galvanic action takes place.

904. CONNECTION BETWEEN ELECTRICITY AND MAGNETISM.—That there is an intimate connection between electricity and magnetism, was established by Oersted's experiment. It is further shown by the fact that compass-needles often have their poles reversed or their polarity weakened by lightning; that a spark has been drawn from a magnet; that a charge of electricity passed through a needle renders it magnetic; and that a bar may be permanently magnetized with an electric current more efficiently than in any other way.

These facts have led to the theory that magnetism is not an independent agent, but simply one of the forms assumed under certain circumstances by that subtle all-pervading agent which we call THE ELECTRIC FLUID. According to this theory, frictional electricity, voltaic electricity, thermo-electricity, magneto-electricity, and electro-magnetism, are all one and the same thing, identical in

vanometer made more sensitive, and why? Describe the Galvanometer with the Astatic Needle. 904. What was established by Oersted's experiment? How is the connection between electricity and magnetism further shown? What theory has

903. *Galvanometer with Astatic Needle.*—Instead of the ordinary needle, an astatic needle (see § 875) is sometimes used in the galvanometer. In this case, the needle, having its polarity neutralized, is more readily turned. The instrument is consequently more sensitive, indicating the presence of electric currents which would otherwise entirely escape detection.

Fig. 316 represents the Galvanometer with the Astatic Needle. The needles are suspended by two parallel silk threads from r , so that one of them may hang directly over the top of the coil zc , and the other below it. p and q are the screw-cups terminating the wire which forms the coil, and ss is the graduated scale. The upper needle hangs above the coil; but as its poles

kind, but differing in intensity, quantity, and properties, in consequence of the different modes in which they are developed.

905. ELECTRO-MAGNETIC ROTATION.—When a magnetic pole and a wire over which an electric current is passing are brought near each other, the pole tends to revolve round the wire, and the wire has a similar tendency to revolve round the magnet in a plane perpendicular to the direction of the current. With suitable apparatus, the following phenomena of electro-magnetic rotation may be exhibited:—

1. The conducting wire being fixed, the magnet will revolve about it.
2. The magnet being fixed, the conducting wire will revolve about it.
3. Both magnet and wire being left free to move, they will revolve in the same direction round a common centre, each appearing to pursue and be pursued by the other.
4. The conducting wire being dispensed with, a magnet may be made to turn on its own axis by the passage of an electric current along half its length.

906. To show the revolution of a magnet about a conducting wire, Faraday used the apparatus represented in Fig. 317. A magnet, n S, is immersed in a vessel of mercury, with its north pole, n , a short distance above the liquid, and its south pole, S , connected by a silk thread with the conducting wire C , which passes through the bottom of the vessel. ab is another conducting wire, which enters the mercury from above. When ab is connected with the positive pole of a galvanic battery, and Cd with the negative, a descending current of positive electricity passes along the conductor (the mercury completing the circuit), and the north pole, n , will revolve round the fixed wire, ab , in the direction of the hands of a watch. If, on the contrary, ab be connected with the negative

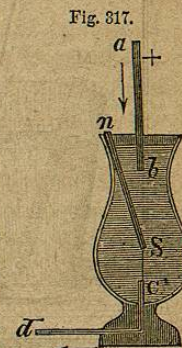


Fig. 317.

been based on these facts? 905. What follows when a magnetic pole and a wire over which an electric current is passing are brought near each other? With suitable apparatus, what phenomena connected with electro-magnetic rotation may be exhibited? 906. Describe Faraday's experiment for showing the revolution of a magnet

pole, and Cd with the positive, an ascending current will be formed, and the magnet will revolve in the opposite direction.

Mercury is used in this experiment, because, being a liquid, it allows the magnet to move through it, while at the same time, being a conductor, it completes the circuit, and carries off the magnetic influence from the south pole immersed in it. Were it not for this, the south pole, by its tendency to move in the opposite direction to the north, would keep the magnet stationary.

907. Fig. 318 illustrates the revolution of a conducting wire around a fixed magnet. Again we have a vessel of mercury, with a conducting wire, d , passing through its bottom, and another wire, ab , suspended from a hook directly over the magnet, entering the mercury from above. n is the north pole of the fixed magnet. On connecting the hook and the wire d with the poles of a galvanic battery, the wire will revolve round the magnet, the direction depending, as before, on whether the electric current is ascending or descending.

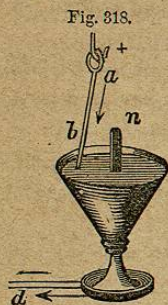


Fig. 318.

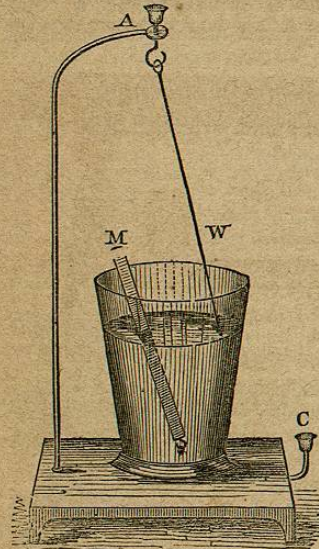


Fig. 319.

908. By ingeniously combining the two pieces of apparatus just described, we may exhibit the simultaneous revolution of both magnet and wire round a common centre. The magnet, M , is immersed in a vessel of mercury about half its length, that the current may affect only one pole. It is connected at the bottom with a conducting wire and screw-cup, C , in such a way as to allow it freedom of revolution. The wire, W , is suspended from a hook, so as to move freely. On transmitting a current, which is done by connecting A and C with the poles of a battery, both the magnet and the wire commence revolving in the same direction as if chasing one another.

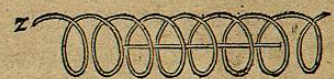
909. EFFECT OF ELECTRIC CURRENTS ON STEEL AND SOFT IRON.—The deflection of a magnetic needle by a wire

about a conducting wire. Why is mercury used in this experiment? 907. Describe the experiment which shows the revolution of a conducting wire around a fixed magnet. 908. What does Fig. 319 represent? Describe the experiment with this

over which an electric current is passing, has been described in § 900. If a bar of soft iron is placed across such a wire, it becomes a temporary magnet, as is shown by its attracting iron filings. A bar of steel so placed is made a permanent magnet.

910. *The Helix*.—The magnetizing power of the wire is greatly increased, if, instead of touching the bar in but a single point where they cross, it is wound a number of times spirally round the latter, as shown in Fig. 320.

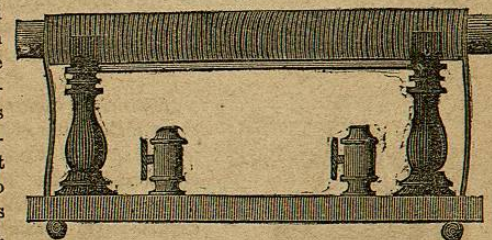
Fig. 320.



Such a coil of wire is called a *Helix* (plural, *hel-i-ces*).

A helix may be familiarly made by winding some copper wire tightly round a small bottle, and then drawing the bottle out. As the magnetizing power of the helix increases with the number of times that the electric current passes round the bar, each turn of the wire is pushed close up to the one before it; and, to increase the effect still further, several coils or layers of wire may be formed, one on top of another. Direct communication between contiguous parts of the wire must be prevented by winding silk or some other insulating material round it. When the ends of the wire are connected with the poles of a galvanic battery, the current is thus obliged to pass through its whole length. Fig. 321 represents a

Fig. 321.



A HELIX.

helix mounted on a stand. An iron bar extending through the centre is seen projecting at each end.

911. *Magnetizing Power of the Helix*.—A steel bar introduced within a helix becomes permanently magnetized the moment an electric current is passed over the wire. A needle laid inside of it is sometimes so powerfully acted on

apparatus. 909. What is the effect of a wire over which a current is passing on a bar of soft iron placed across it? On a bar of steel so placed? 910. How is the effect greatly increased? What is such a coil of wire called? How may a helix be made? How is the effect of the helix increased? With what is the wire covered, and why? What does Fig. 321 represent? 911. What is the effect of a helix on a steel bar in-

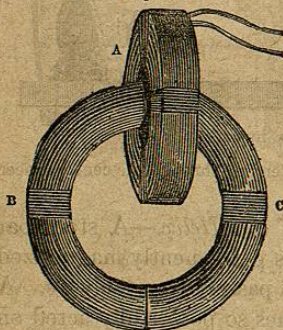
as to be lifted up and held suspended in the air in the middle of the helix. A bar of soft iron placed in the same position is endowed with strong magnetic properties for the time, but instantly loses them when removed, or when the current ceases to pass. To be magnetized, the bar must always be placed lengthwise of the helix,—that is, at right angles to the direction in which the current is passing.

Fig. 322.



One of the most remarkable effects of the helix is the suspension in the air, without any visible support, of a heavy iron bar loaded with weights. A helix consisting of a very long wire, forming several coils one upon another, and charged by a powerful battery, is held in a vertical position, as shown in Fig. 322. An iron bar brought within the helix just at its base, will be lifted up half way into it, and held there in the centre of the hollow cylinder, without touching it, as long as the current continues to pass. If pulled down a little way, it immediately springs back to its former position. The moment the current ceases, the bar falls. With a powerful apparatus, a weight of eighty pounds has been thus kept suspended in the air.

Fig. 323.



A no less interesting experiment, showing the power of the helix, may be performed with the apparatus represented in Fig. 323. The helix, A, is in the form of a ring. B, C, are two semi-circular pieces of soft iron, having their ends accurately fitted to each other. When B and C are brought together so as to form a circle, with one pair of their joined ends within the helix, they are endowed with so strong an attraction for each other that two men can hardly pull them apart.

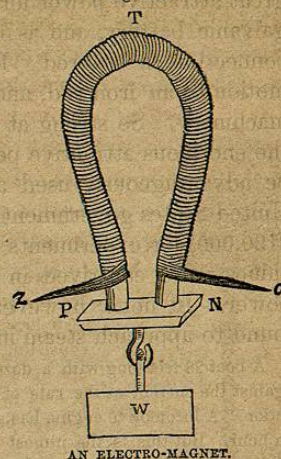
912. *Electro-Magnets.*—An electro-magnet consists of a bar of soft iron within a helix.

roduced within it? On a needle? On a bar of soft iron? To be magnetized, how must the bar be placed? What is one of the most remarkable effects of the helix? Describe the experiment. Describe the experiment with the apparatus represented

It is strongly magnetic as long as a current passes over the wire, but loses its power the moment the current ceases.

The most powerful electro-magnet is made by bending a bar of soft iron into the form of a horse-shoe, as shown in Fig. 324, and winding closely round it a large quantity of insulated copper wire so as to form a helix of several layers. The ends of the wire, Z, C, are connected with a powerful battery. A soft iron keeper, P N, connects the poles, having a hook beneath, to which weights may be attached. So strongly is this keeper attracted that an enormous force is required to separate it. An electro-magnet prepared as above has supported over 4,000 pounds.

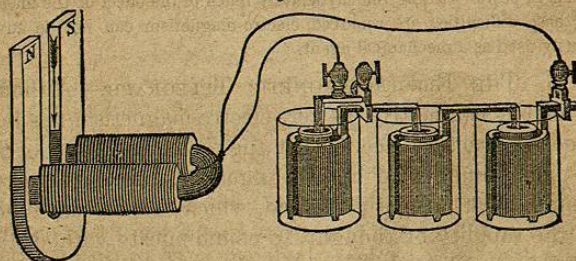
Fig. 324.



AN ELECTRO-MAGNET.

913. Electro-magnets furnish us with the most efficient means of magnetizing an ordinary horse-shoe bar. The mode of using them for this purpose is shown in Fig. 325.

Fig. 325.



The electro-magnet is applied at the bend, one pole on each arm, and drawn towards the extremities, N, S. This is done several times on both sides, when the bar is rendered permanently magnetic. To deprive it of its magnetic power, reverse the process, by applying the poles of the electro-magnet to the ends N, S, and drawing them towards the bend.

914. *ELECTRO-MAGNETISM, AS A MOTIVE POWER.*—We have seen that an electro-magnet is instantly endowed with

in Fig. 323. 912. Of what does an electro-magnet consist? How is the most powerful electro-magnet made? How great a weight has been supported with such an electro-magnet? 913. What is the most efficient means of magnetizing a horse-shoe