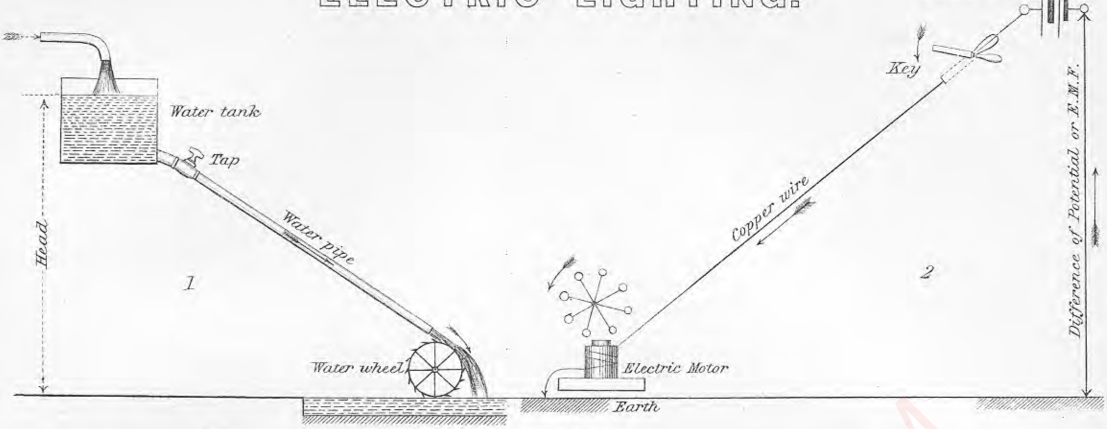
EXCERPT ON ELECTRIC LIGHTING TAKEN FROM THE NATIONAL ENCYCLOPEDIA

DATE UNKNOWN

ELECTRIC LIGHTING.

PLATE 1.



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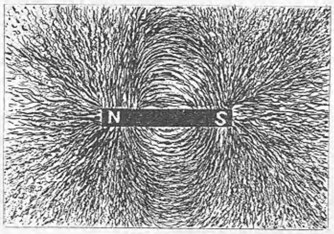

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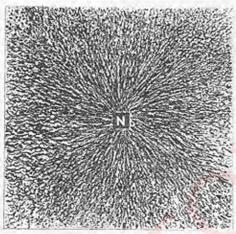

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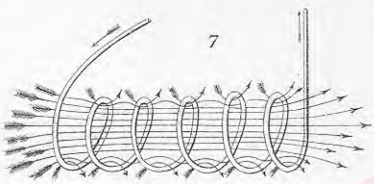

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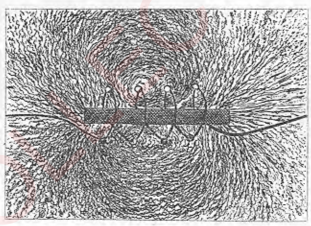

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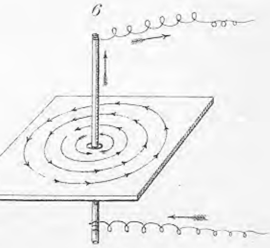

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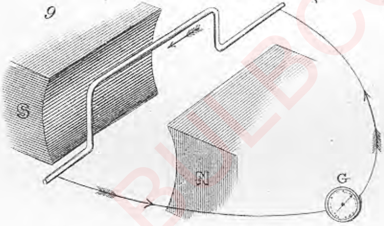

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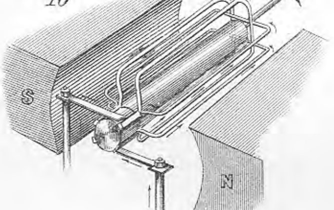

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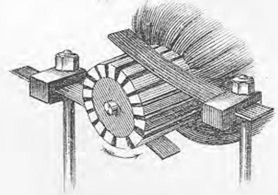

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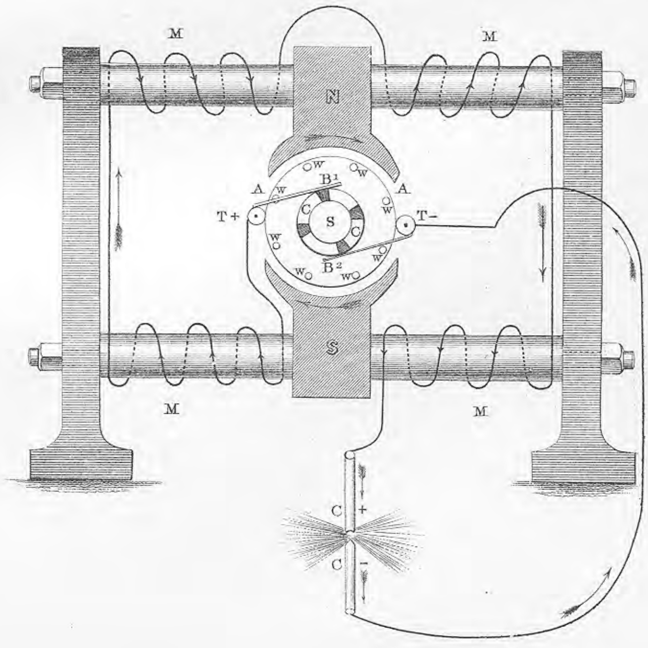

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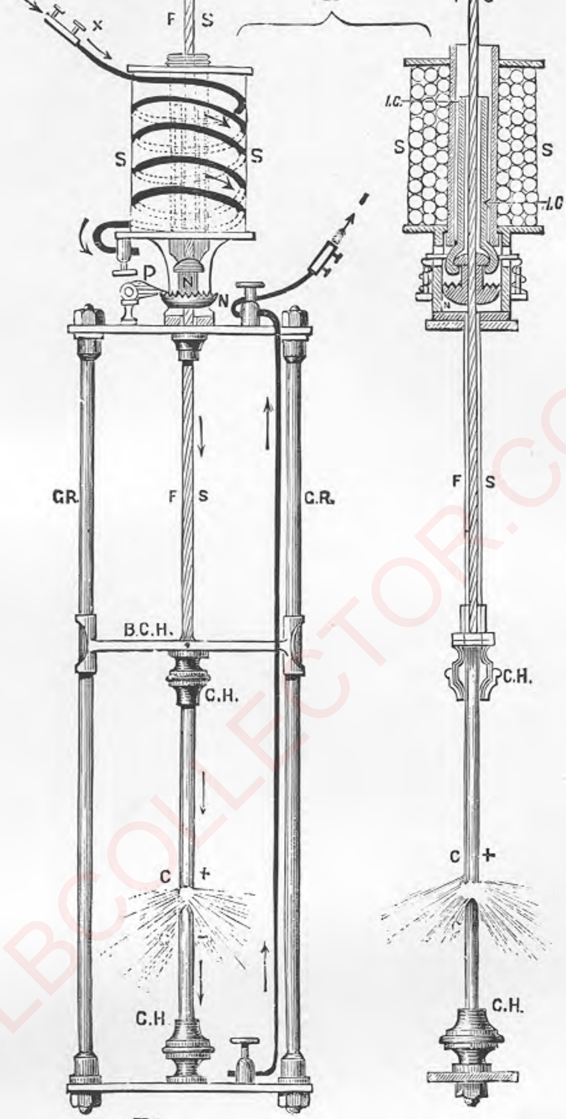

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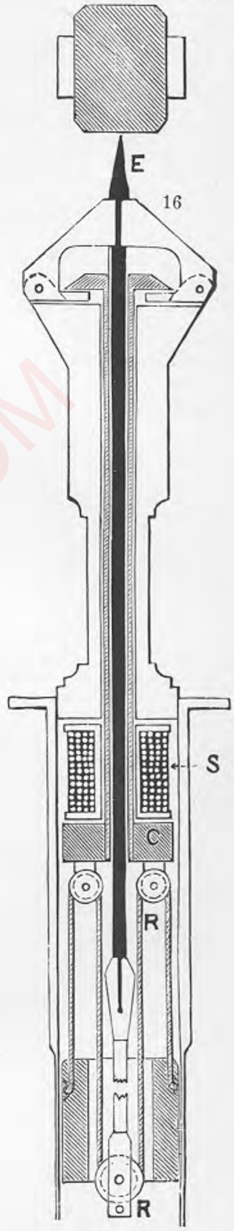

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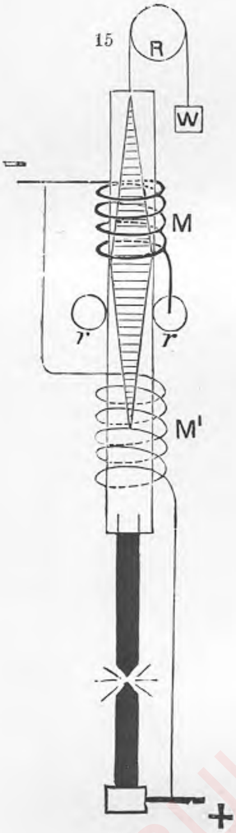

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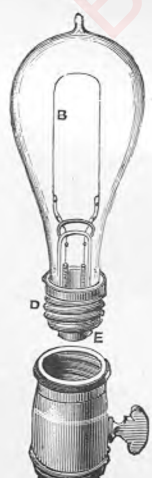

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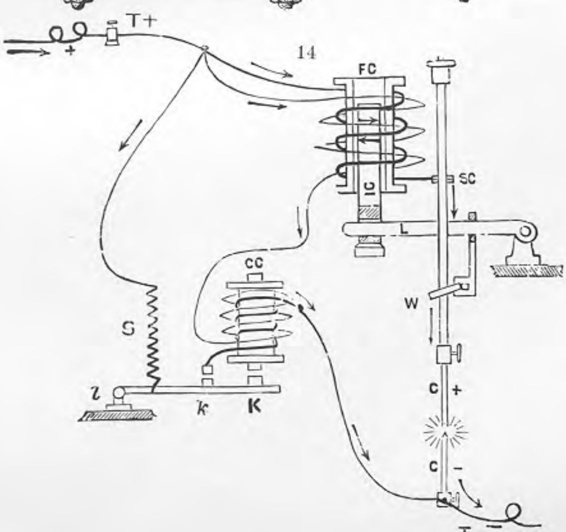

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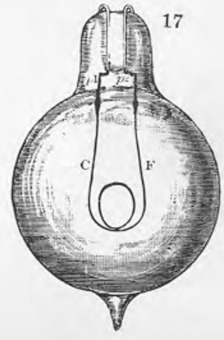

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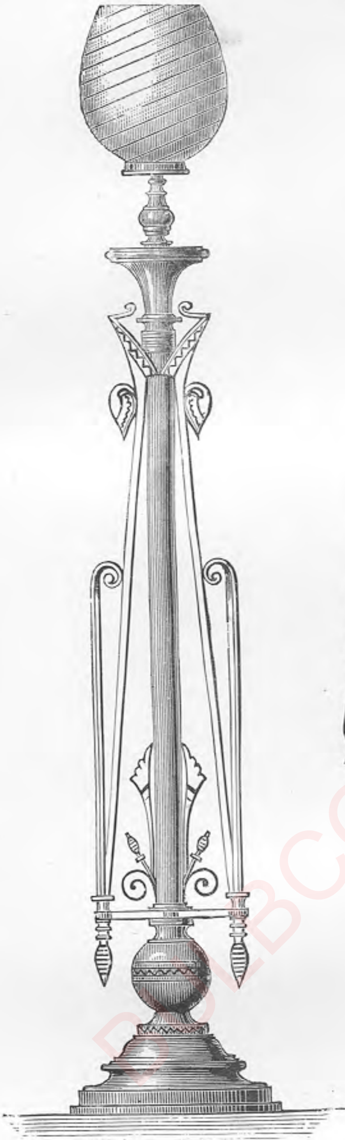

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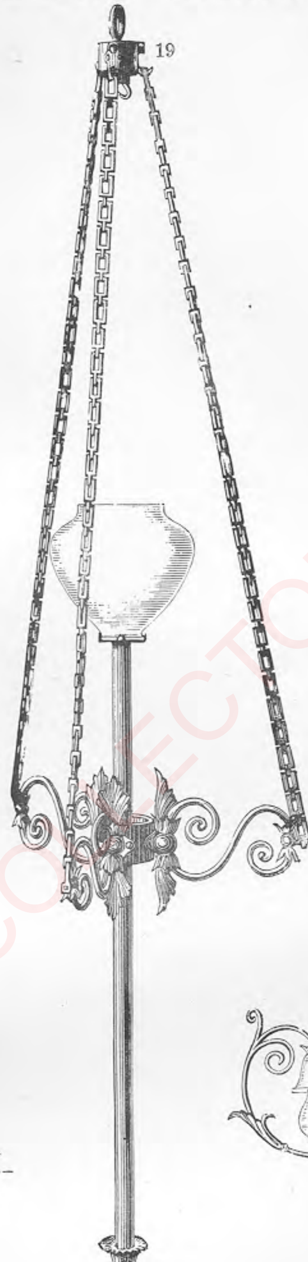

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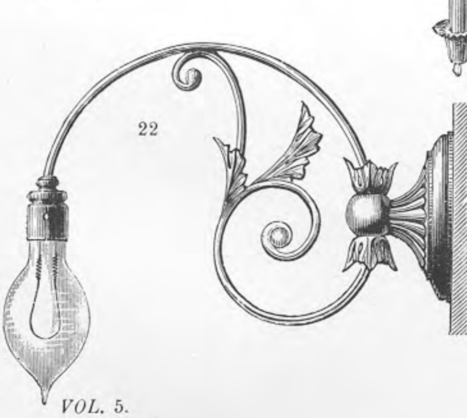

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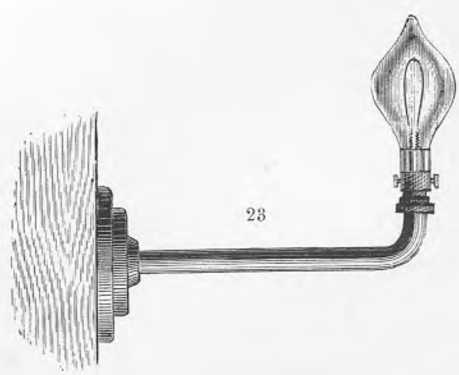


ELECTRIC LIGHTING. The subject of electric lighting began about 1880 to receive an increasing amount of attention from many of our most scientific and practical men, public interest was universally awakened regarding it, and the patent office was inundated with specifications and applications all more or less proposing to give us perfect electric lighting. Numerous companies were then formed, with large subscribed and still larger nominal capital, with a view, in some instances, only to sell patents and patent-rights; in others, with the more honourable and honest purpose of making and installing their appliances, each one claiming its speciality or system to be the best either as a whole or in some particular feature.

Our leading scientific and engineering journals have frequently given descriptions of this or that dynamo and electric lamp, or of some special installation or electrical exhibition, using terms and electrical phraseology which to many must have appeared new and difficult to understand. Therefore, an explanation of these terms at the outset will enable the general reader to more thoroughly satisfy his desire for an intimate knowledge of the laws which the phenomena of electric lighting involve, and the methods of applying electric energy to the lighting of large spaces, workshops, houses, and steamers.

Units of Measurement.—The several practical units of measurement required in measuring electrical currents in connection with electric lighting, were finally determined upon at the International Congress of Electricians, Paris, 1881, and British Association, 1882. Electricity, by whatever means generated, is the result of the expenditure of energy (mechanical energy, as a rule, in the case of electric lighting), and as the measurement of energy involves *space*, *mass*, and *time*, the three fundamental units adopted were the centimetre for length, gramme for mass, and second for time, which is termed the centimetre-gramme-second system, or shortly the C.G.S. system; and upon these fundamental units all the practical electrical units of measurement are based.

An electric current may, for all practical purposes, be considered analogous to a fluid, under conditions somewhat similar to those by which water flows through a pipe.

Electro-motive Force compared to Head or Pressure.—The difference of level or pressure due to gravity between the top and bottom of the water pipe (fig. 1, Plate I.)—in other words, the "head"—causes the flow of water along the pipe, while the difference of potential or electrical pressure between the ends of copper wire (fig. 2)—in other words, the *electro-motive force*, as it is termed (E.M.F.)—causes the flow of electricity along the wire. The potential or pressure in both cases determines the power of doing work, as illustrated by the water flowing from the elevated tank through the pipe and driving the small water-wheel when the tap is turned; and by the electricity (generated by the battery or dynamo) flowing along the copper wire and driving the small electric engine or motor when the key is turned in the direction of the arrow. The pressure of the water is measured by pounds on the square inch, or by the difference of level in feet of the free surface of the water in the tank about the outlet at the bottom of the water pipe, generally termed the "head," while the electrical pressure is measured in *volts* (a contraction for Volta, the famous physicist who discovered, in 1786, voltaic electricity), one volt being 7 per cent. less than the electro-motive force given by one good Daniell's cell [see BATTERY], or more exactly 10^8 C.G.S. units.

Electric Resistance Compared to Friction.—The *friction* generated between the running water and the inside of the pipe offers a certain amount of resistance to the flow of the water, and may be considered so far analogous to the *resistance* offered by the metallic conductor to the flow of the electricity along it. The friction between the water and the pipe is estimated by the equivalent loss of head in feet which it causes, while the electrical resistance is measured in *ohms* (a term commemorating the discoverer of the relation between current strength, electro-motive force, and resistance), one ohm being equal to the resistance offered by 240 feet of pure copper wire, No. 18, Board of Trade standard gauge ($\frac{1}{20}$ of an inch diameter), at 60° Fahr., or more exactly 10^9 C.G.S. units. The resistance of electric light copper conductors increases with temperature by 0·21 per cent. per degree Fahr., and varies directly as the length and inversely as the sectional area of the conductor.

Strength of Electric Current compared to Flow of Water.—The flow of the water through the water pipe, and the strength of the electric current along the conducting wire, are in each case determined by the pressure overcoming the resistance. The strength of electric currents is measured in *amperes* (in memory of Ampère, the propounder of the Amperian theory of electric currents, in 1821), one ampere being the current produced by the E.M.F. of one volt when acting on one ohm of resistance. One ampere is equal to 10^{-1} C.G.S units.

$$\textit{Ohm's law: } \text{Current} = \frac{\text{Electro-motive force}}{\text{Resistance,}}, \text{ or } C = \frac{E}{R};$$

using C as the symbol for current, E for electro-motive force, and R for resistance.

The Quantity of Electricity compared to the Volume of Discharge or Volume of Flow of the Water is in each case determined by the current passed in a second. The quantity of electricity flowing in any circuit is measured in *coulombs* (after Coulomb, the discoverer of the law of electric and magnetic attraction, and the inventor of the torsion balance). [See COULOMB.] One coulomb is equal to the quantity of electricity given by an ampere in a second or 10^{-1} C.G.S. units.

Power.—In order to estimate the power of the current developed in each case, we have simply to multiply the total pressure by the current passed per second. Mechanical power is measured in Great Britain by horse-power, or the power expended in elevating 33,000 lbs. 1 foot high in one minute. Electrical power is measured in *watts* (in memory of James Watt, the discoverer of the steam-engine). One watt is equal to one volt multiplied by one ampere, or $E \times C =$ watts; while 746 watts equal one British horse-power, or 33,000 foot-pounds per minute.

General Arrangement of Electric Lighting Systems.—Of these there are many modifications, but in most of them the following system of appliances is necessary:—(1) A producer of mechanical energy, (2) a dynamo or generator of electricity driven by it, (3) a system of wires conveying the electricity to (4) the lamps, where it is transformed into light There is thus a complete cycle of changes. Taking the steam-engine as the motive power, the coal burned in the furnace produces heat, converted into mechanical energy in the steam-engine, which revolves the dynamo, converting the mechanical into electrical energy. This energy on reaching the lamps through the conductors is there concentrated on the carbon of the lamp, raising it to such a temperature that it gives forth light—heat in the furnace back to heat in the lamps with light, or molecular vibration from beginning to end, until a handy form of it is reached for the purposes required. At each change which takes place there is a certain loss, so that the value in energy units of the light in the lamp is only a small percentage of the energy produced in the furnace of the steam-engine boiler; yet nevertheless such has been the ingenuity and perseverance displayed by electricians and mechanicians within the past few years, that by certain systems of electric lighting we get a wonderful return in light for the quantity of coal burned in the furnace.

Motive Power for Driving Dynamos.—The most suitable machines for producing the mechanical power to be converted into electrical energy are the steam engine, the gas engine, and the water-wheel or turbine. The force of the wind, as applied by the windmill, and the rise and fall of the tides have been proposed, but not yet put into practice. Whatever kind of machine is adopted, it is absolutely necessary that so long as the power developed by it is applied to driving a dynamo in direct circuit with the electric lamps, the motion should be as uniform as possible, in order to insure a steady current or electro-motive force. For this purpose, in the case of the steam engine, it should be fitted with a sensitive and efficient governor, and it should be capable of easily furnishing the necessary power without in any way overstraining any of its parts, and be constructed of the very best materials and in the best possible manner, so as to minimize the chance of a break-down. In the case of workshops where there is an ample reserve of power developed by the shop engine, and the demand upon its energy does not alter very rapidly, it has been found suitable in many instances to drive the dynamo by means of the same; but this should not be attempted before carefully testing and considering well the capabilities of the engine.

The demand for electric lighting has necessitated a special class of engines for this work, and several well-known makers, notably Messrs. Marshall & Sons, Messrs. Tangye Brothers, Messrs. Mather & Platt, and Messrs. Alley & Maclellan, &c., have devoted much attention to this subject. The driving connection between the engine and the dynamo is usually carried out by means of belting, either direct from the flywheel to the dynamo pulley, or by the intervention of a counter shaft, frictional and toothed gearing being but sparingly employed.

It is only in the case of steamships, or where the space is limited, that the motion is communicated direct from the engine shaft to the dynamo, without the intervention of belting or gearing, and in such cases the engine must be run at a very high speed, or the dynamo be arranged to work at an abnormally slow rate, of which an example will be given further on.

Gas engines are becoming more popular, and by using a flywheel on the dynamo shaft, with long slack belting to counteract the effect of their somewhat irregular motion, they are, in many instances, found very serviceable. A 6 horse-power Clark's gas engine has been adopted at the laboratory of Glasgow University, and at Oxford University there is a 20 horse-power Otto gas engine in use with apparently good effect.

Water power has, as yet, been but sparingly employed, either through the intervention of water-wheels or turbines, probably from the fact that where the electric light is in greatest demand water is not available; but from the ease with which it can be manipulated, it will be found quite as efficient as the best steam engine, and certainly will prove less costly.

Windmills and tidal machines are out of the question until that much-required desideratum, viz., the storage of electricity, can be economically effected.

The Theory, Construction, and Working of Dynamos or Electric Generators.—The modern dynamo-electric machine may be regarded as a combination of iron bars and copper wires, with certain parts fixed while others are rotated by the application of the mechanical power supplied by the steam engine, the gas engine, or the water-wheel in one or other of the methods already mentioned. How the relative movement of copper wires and iron bars generates electric currents is the difficulty which many fail to understand. (For further information consult "Electric Illumination," by Dredge, to which work we are indebted for some of the following illustrations.)

Consider the cases of a bar magnet and a copper wire with a current passing through it (figs. 3, 4, 5, 6, 7, 8, in Plate). The medium surrounding each is under a similar influence or stress, which may be easily rendered visible by a simple experiment. Lay a sheet of paper that has been previously soaked in melted paraffin wax above (fig. 3), and another on the end (fig. 4) of a bar magnet, with a third through a wire along which a current is passing (figs. 5, 6). Now sprinkle on these papers, from a pepper pot or gauze sieve, some fine iron filings; the filings are attracted to and lie in certain positions. Pass a hot copper bolt over the papers, keeping it about half an inch therefrom, and on removing the papers from the magnet and wire we shall have diagrams as shown, exhibiting the direction of the stresses of the medium surrounding the magnets and the wire, or, as it has been called, "the direction of the magnetic lines of force." It is not in the magnetic bar of steel or iron that we call a magnet, or in the copper wire, but in the space that surrounds these that we must search, in order to explain the following phenomena. The electric current passing through the wire (fig. 5) is the cause of magnetic lines of force in the medium surrounding it, quite as much as the magnet (fig. 4).

It is impossible to magnetize a magnet by whatever means without also magnetizing the space surrounding the magnet, and the space thus filled with the lines of force possesses properties which ordinary unmagnetized space does not possess. These lines give us definite information about the magnetic condition of the space where they are. Their direction indicates the direction of magnetic force, and their number the strength of the magnetic field. Wind a piece of copper wire into the form of a coil (fig. 7), and pass an electric current through it; the magnetic lines produced by it are naturally induced into the direction shown by the arrows, and the wire or helix has all the magnetic properties and behaviour of a bar magnet. Pass a piece of soft iron into the centre of this helix, and it immediately becomes strongly magnetized by the influence of the magnetic field surrounding the current-carrying wire. Fig. 8 represents an impression obtained in the way just described with the paraffined paper. This mode of producing a strong magnet is adopted in all the dynamo-electric machines. Faraday discovered that the converse of the above was true—viz., that when the pole of a magnet is moved into or out of a coil of wire the relative motion while it lasts produces a current; in fact relative motion between a completed or closed coil of wire and a magnet always produces a current. It is this fact that is so largely taken advantage of in the design of dynamo-electric machines.

Fig. 9 shows a single wire with its ends joined to a galvanometer, G. Being rotated between S and N, magnetic poles, a current is generated in the wire and passes as shown by the arrows. Fig. 10 is a number of wires similarly rotated, with the method of conveying away the current, by means of contact pieces and brushes (called a commutator), at the right moment and in the right direction, while fig. 11 gives a more complete view of this commutator as used in practice.

The following principles or general statements should be borne in mind:—

(*a*) To induce a current in a closed or continuous wire by means of a magnet, there must be relative motion between the wire and magnet.

(*b*) Approach of a magnet to a coil, or of a coil to a magnet, induces a current in the opposite direction to that induced by recession. See VOLTAIC ELECTRICITY for the direction of currents so caused.

(*c*) The stronger the magnetic field the stronger will be the electro-motive force induced in the coils.

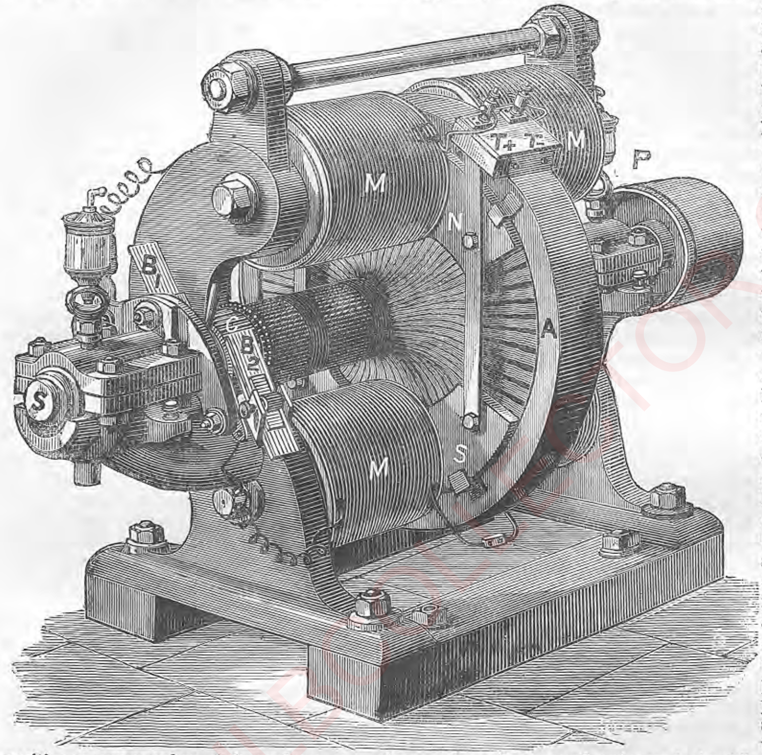
(*d*) The more rapid the motion the stronger will be the electro-motive force.

(*e*) The greater the number of turns in the coil the stronger will be the electro-motive force induced in it.

(*f*) The stronger the magnetic field the greater will be the work required to move the coil through it.

To illustrate the general principle upon which direct current series dynamos are made, attention is called to fig. 12, Plate I., representing a section of a Gramme machine. For simplicity of explanation the armature, A, with its coils of wire, W W W, is shown revolving at right angles to its natural position in the machine. The arrows show the direction of winding on the electro-magnets, M M, in order to produce the polarity, N S. S represents a spindle carrying armature, A A, which revolves between the north and south poles, N S, of the electro-magnets, M M M M, around which the wire from the positive terminal of armature, T +, is wound as shown, until it joins C +, the positive or upper carbon of the arc lamp, T —, the negative terminal of armature being joined to C —, the negative or lower carbon of the arc lamp; B_1 B_2 are the brushes which collect the current from the commutator, C, whose metallic parts are soldered to the nearest points of the revolving coil of wire, W W W, which thus forms the armature, A A.

There being always some residual magnetism in the iron pole-pieces, N S, and iron cores of the armature, A (after having once been magnetized by a battery or other dynamo), a weak magnetic field exists between N and S before starting. The magnetic lines of force pass through the armature, A A, and its iron core at right angles to the copper wires, W W W, coiled round the same; consequently, upon the armature revolving, its copper-wire coil cuts these lines of force at right angles, causing a current to be generated, as previously explained. This current is led off by the brushes in the direction shown by the arrows, still further increasing the magnetism of N and S, which, in turn, reacts on the armature core and coil, until such a speed is attained that the electricity generated and flowing round M M M M, completely saturates its iron cores and pole-pieces with magnetism. Any further increase in speed will cause unnecessary heating of the electro-magnet coils, owing to the current passing through them being in excess of that required to saturate the cores and poles. See MAGNETISM and VOLTAIC ELECTRICITY.



In the limited space at our disposal it is impossible to go into the various modifications of this parent type of dynamo. As a practical example, however, of a successful machine used in this and foreign countries, the annexed cut illustrates the Pilsen-Schuckert Dynamo, which is used for supplying current to arc, semi-incandescent, and incandescent lamps. The same letters of reference as in the typical form (fig 12) have been attached to the various parts, viz. P is the pulley for the driving belt from the engine, flywheel, or intermediate shaft; S, the dynamo spindle carrying the armature A, revolving between the N and S poles of the electro-magnets M M; B_1 B_2 the brushes for collecting the current from the commutator, C; T +, T —, the positive and negative terminals of the machine, which are connected by leading wires to the lamps. One of the advantages of this machine is that the armature can be easily removed for inspection or repair, without disturbing the electro-magnets, and the large radius of the armature permits of the machine being driven at a comparatively low number of revolutions per minute. For arc and semi-incandescent lighting the electro-magnets are joined in series with the armature and the lamps, while for incandescent lighting they are wound with fine wire and joined up as a shunt to the armature, or wound partly with fine wire and partly with the thicker armature and main circuit wire, in what is termed the "compound series and shunt" principle, with a view of maintaining a constant electrical pressure or electro-motive force in the mains, so as to admit of any number of lamps within the powers of the dynamo being turned out or in at pleasure so long as the speed is kept constant. In other words, the dynamo is rendered self-regulating for a variation of load, if the motive power is simultaneously regulated to maintain a constant speed. This latter object it is found impossible to attain except within narrow limits by any ordinary form of engine governor solely depending upon variation in speed; but with an electrical governor such as Jamieson & Alley's, where advantage is taken not only of any tendency to an increase or decrease of speed, but also of any slight variation of current in the electro-magnets of the dynamo by which to regulate the engine, the desired constancy of speed, and consequently of electro-motive force, is easily maintained.

The Leading Wires or Conductors of Electricity.—These should be composed of the very best copper wire well insulated, so as to prevent loss of current from leakage. It is false economy to use small conductors, as energy is thereby lost in heating them, with a possible danger to property; but if the following rule formulated by Lord Kelvin be followed no such undue waste or danger will accrue—viz. "when the annual cost of power wasted in heating the conductors equals the yearly interest plus depreciation and insurance on their value, then we have the most economical and safe size of leading wire." On the above basis he recommends a size of bare conductor equal to 1 square centimetre per 50 amperes of current. For the highest class of insulated leading wires for use on board ship, where the length of leads is limited and the lights are not kept alight more than half the day, Professor Jamieson, of the Glasgow Technical College, finds that 150 amperes can be carried per square centimetre of section of conductor with perfect safety and economy. The forward and return wires should be carefully separated throughout by at least one inch, with as few joints as possible, and where these are necessary the conductors should be well soldered and insulated.

Arc Lights.—The arc light essentially consists of two carbon rods, kept apart by suitable mechanism at a constant distance when at work, so as to produce a steady light, and admitting of their coming together automatically when the current is stopped, as well as of being cut out of circuit when anything goes wrong with a lamp without affecting the others worked by the same dynamo. The first two conditions are easily attained if there be but one lamp in circuit, and a simple form is shown in fig. 13, where S S represents a solenoid coil of copper wire, No. 10 B.W.G., insulated with cotton and shellac varnish; I C, iron core (hollow); F S, quickly pitched six-threaded screw ($1\frac{3}{4}$ in. pitch); N, nut with lower upturned edge milled; P, pall or lever held down by a bent spring; C H, carbon holders; C + C— carbons 13 millimetres diameter; G R, G R, parallel iron guide rods; B C H, brass crosshead.

In this lamp the current in passing from the dynamo to the upper carbon traverses the solenoid coil, S S, acting inductively on the hollow iron core, I C, and sucking it upwards, thus lifting the upper from the lower carbon by engaging the nut, N, which is fitted to the central screw, F S. The milled edge of the nut comes against the lever pall P, and is thereby prevented from turning round, thus limiting the length of arc. As the arc burns longer the resistance of the circuit increases, the current thereby necessarily diminishes in strength, and the lifting power of the solenoid becomes less, allowing the iron core to drop a minute distance, just sufficient to clear the milled edge of nut, N, from the pall, P; the nut turns round through a degree or so, which allows the carbon to drop a very small distance, the normal length of arc being in this way resumed. The above operation takes place so rapidly that the upper carbon is fed forward in almost perfect unison with the consumption, insuring a steady light.

From tests made of this lamp an actual, not nominal, candle power of 2250 candles, or 1450 candles per horse-power, $\frac{E \times C}{746}$, at the lamp was obtained—the electricity being furnished by an A Gramme dynamo.

An ambiguity which has arisen, and which is very confusing to those not acquainted with electrical phraseology, is the expression so many candles per "electrical horse-power," or so many candles per horse-power expended in the lamp. When this expression is used, it is to be understood that the electrical energy absorbed by the lamp, and developed in the form of heat and light, is according to the formula, $\frac{E \times C}{746}$ (which we stated at the beginning of this article was an actual horse-power of 33,000 foot-pounds per minute). This takes no account whatever of the energy lost in transmission through the leading wires, or that absorbed by the dynamo, or that spent on the moving parts of the engine shafting and belting through friction, &c. It is considered fairly good work, in actual practice, if we get 60 per cent. of the horse-power, as indicated by diagrams taken from the steam cylinder, in the form of electricity, at the lamp carbons or arc. The loss of power in conversion and transmission may be roughly computed as follows:—

	Per Cent.
Loss by friction, &c., in engine, &c., . . .	15
Loss in conversion of mechanical to electrical energy in dynamo, by heating, friction, &c.,	15
Loss by heating leading wires and lamp circuit coils, ...	10
Total loss, ...	40

One has therefore always to be on his guard when inquiring "how much power such and such a lamp or system gives in the form of light;" and it is generally necessary to ask the question, "Do you mean so much cylinder horse-power, or so much dynamical (brake) horse-power, or so much in the form of electrical energy at the lamp?"

Brush Lamp.—Perhaps no lamp has been so extensively adopted as the Brush lamp in workshops and streets. Its popularity and success mainly depend upon the fact that it is arranged so that a large number can be included in series and worked from one dynamo. As many as forty of these lamps have been worked, in numerous instances, by one machine while the whole system is so adjusted by means of an automatic carbon-regulator, that one or more of the lamps can be extinguished or removed without endangering the others remaining in circuit. The only danger arising from using such a large number of lamps in circuit, placed in series, is the necessarily high electro-motive force of the current, attended as it is by rapid fluctuations in strength. The normal electro-motive force or difference of potential between the terminals of each lamp being 45 volts, 40 such lamps, *irrespective* of the leading wires and dynamo, require an electrical pressure of 1800 volts, or about 2000 volts including the dynamo and leads; therefore the connections and leading wires should be well insulated, and the handling of the same should be done with care and caution. The normal strength of current is 10 amperes, so that each lamp absorbs energy to the amount of $E \times C = 45 \times 10 = 450$ watts.

By comparing the theoretical diagram (fig. 14), with the following description of details, the principle and action of the lamp will be easily understood. Only one coil and carbon are shown, for simplicity, although there are generally two. T + and T — represent lamp terminals; F C, hollow feed coil with thick copper wire (0·12 ohm resistance) wound round it in a right-hand spiral, terminating at S C, slip contact bearing on carbon holder. Also round F C is wound a thin copper shunt wire (160 ohms) in a left-hand spiral. This fine wire is continued to and wound round C O, cut-out coil (40 ohms), to terminal, T—; I C, iron core, which is sucked up inside F C, under the preponderating influence of the stronger current passing through the thick wire, against gravity and against the effect of the weaker current passing through the fine shunt wire, thus lifting L, lever, which tilts W, washer or clip ring, which in turn lifts C +, upper carbon, from C—, lower carbon, thus forming the arc.

The upper carbon falls towards the lower one periodically, being automatically retarded in its progress by the action of the varying proportions of current passing through the thick and thin wires of the feed coil, F C, due to the varying length and consequent resistance of the arc.

The cut-out coil is also wound with a thick copper wire in the same direction as the fine wire around it, but the thick wire is only brought into circuit on the carbons burning out, or extinguishing of the lamp and breaking the arc through an accident. Should this take place, a greater proportion of current than usual flows through the fine wire, strongly magnetizing the iron core of the cut-out coil, C O, which attracts the iron keeper K fixed to lever l, thus establishing a low-resistance circuit for the main current by way of spring S, lever l, contact k, through thick wire of C O, to terminal, T−, and thence to the next lamp in the series, effectually cutting the lamp in question out of circuit until repaired. This lamp gives a normal light of 600 candles with a bare arc.

The Pilsen Arc Lamp.—One of the steadiest and most handsome of arc lamps yet invented is the Pilsen, which takes its name from the town in Hungary in which the inventors, Messrs. Piette & Krizik, commenced its manufacture. It is essentially an electrical lamp, the current of electricity directly controlling the carbons, and not, as in most other similar systems of arc lighting, acting upon some clutch or clockwork, which in its turn controls the carbons.

The special and novel feature of this lamp (see fig. 15) is the use and action of a biconical or spindle-shaped iron core when suspended between, and partly through, the interiors of two magnetic solenoids, M, M^1, placed one above the other, through which an electric current is passing. When so used such a core has no positive or balanced position, and can be moved, and will remain in any new position.

The uniform action of this peculiarly-shaped iron core is due to the equal and opposite magnetic effect which appears as the result from the decrease of the mass of iron in one solenoid being compensated for by the increase of its magnetic action, and *vice versâ*, and it is this most interesting feature which constitutes the principal peculiarity in the Pilsen lamp. The normal light furnished by this lamp is about 1000 candles with a bare arc, and it can be worked twelve in series by the Pilsen-Schuckert dynamo, already described.

One great drawback to the introduction of arc lighting has been its proverbial unsteadiness and piercing white rays, but fortunately with the experience gained in its introduction to many of our large railway stations, workshops, and factories these evils have in a great measure been overcome, so that now it is possible to get a perfectly steady pure white light, or one toned to almost any desired shade, by means of suitably ground glass or opalescent globes. Its cost of working is not great, as herewith indicated by the independent statement of Mr. Kirk, M.I.C.E., the managing partner of the well-known firm of Messrs. Robert Napier & Sons, shipbuilders, Glasgow, at a meeting of the Institution of Engineers and Shipbuilders of Scotland:—

Cost of electric light maintenance per week,	£0	1	6
Man's wages, per week, ...	0	15	0
Cost of carbons (forty-nine hours a week),	0	13	9
Depreciation in value of Brush machine, lamps, lights, at 10 per cent.; interest 5 per cent. on £724, ...	2	1	9
Twelve lamps per week, ...	£3	12	0
Or each lamp per week, ...	0	6	0

"He had not put in the cost of engine power, because no one could find any appreciable difference in the coal bills for the period before and after the electric light was introduced. The dynamos used by them had been driven by the factory engine, which was quite steady enough for the arc lights. Almost any ordinarily steady engine was sufficient for the purpose. The dynamos had given no trouble except in getting the commutators removed."

Semi-incandescent Lighting.—This form of lighting by electricity is exceedingly simple and steady, although the power required to maintain it, say per 100 candle-power, is considerably in excess of that required for arc lighting pure and simple, although not greater than that for the incandescent system. The semi-incandescent lamp most in favour in this country is the Joel lamp, which consists of a long thin cylindrical rod of carbon, E (fig. 16), kept permanently in contact with a metal block, by means of a counter-weight, C, solenoid, S, and pulley arrangement, R. The current required for this lamp is of low electro-motive force, and any number of lamps may be placed in series within the limits of the dynamo generating the current, while the normal candle-power ranges from sixty to eighty standard candles.

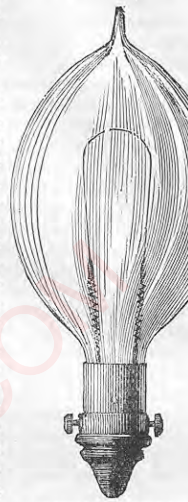
Incandescent Lighting.—When a strong electric current is passed through a conductor of small sectional area of high specific resistance, an intense heat is generated, because the energy of the current is transformed into its equivalent in heat in overcoming or forcing its way through the resistance.

Suppose a number of different conductors, such as silver, copper, iron, platinum, and carbon, all in the form of wire of the same sectional area and length, to be joined up together in one continuous string with a battery or dynamo, and the same current sent through them until the silver reached, say, a temperature of blood heat, we should find the copper uncomfortably warm for the hand to bear, the iron red, the platinum bright red, and the carbon intensely white hot, each in turn more highly heated than the former on account of its being a worse conductor of electricity, the relative conducting powers of these materials being—silver, 100; copper, 80; iron, 14; platinum, 10; carbon, ·04. It would be found, however, that the carbon would almost immediately be burned up, owing to its combining rapidly with the oxygen of the air at such a high temperature; but if it be placed inside a glass globe from which the air has been extracted, it glows with a beautiful white incandescence, without the least sign of being wasted or destroyed. If the current passed through the silver, copper, iron, or platinum wires were increased, so as to bring them respectively to a very high temperature, whether in the air or in a vacuum, they would fuse; but as carbon is practically infusible, it is by far the best of all the known substances for the purposes of incandescent lighting. True, it may be disintegrated by too strong a current, or, in other words, by excessive molecular vibration; but if the current be properly regulated to suit the size of the filament, and if the vacuum remains perfect, there is no scientific reason why a carbon filament in a vacuum should not last for an indefinite time. This fact has been known theoretically for several years, and many experimenters since 1841, such as Moleyne, Starr, King, Staite, Petrie, Konn, and others, made incandescent lamps by heating platinum, iridium, or carbon by electric currents, but they severally failed on account of the difficulty of producing a sufficiently perfect vacuum. In fact, the life of their lamps was short, because their wires or filaments got fused or burned up. The problem was laid aside as a practical impossibility until Professor Crookes, in his experiments on his beautiful radiometer in 1879–80, discovered the means of producing very high vacua by means of a Sprengel air-pump. Almost simultaneously Lane Fox, Swan, Edison, and Maxim, taking advantage of this discovery, devised lamps which all have for their fundamental principle a carbon filament in a vacuum, rendered incandescent by an electric current. Many others have also made minor improvements in the details, such as Crookes, Gatehouse, Woodhouse, and Rawson, so that now there is no difficulty in obtaining incandescent lamps which will give a light of twenty standard candles, and last on an average 1000 hours.

The Swan lamp (fig. 17) consists of the carbon filament, C F, formed into a loop, with its free ends joined by a kind of Chinese-ink gum to two platinum wires, p_1, p_2, which pass through the ends of the glass globe and finish in two loops or terminals, T+ and T−. This filament is formed by taking ordinary cotton crochet thread, immersing it for a few seconds in sulphuric acid and water (two parts sulphuric to one part water), then washing in clean water, and thus parchmentizing it. The parchmentized thread is then carbonized by placing it in a fire-clay box and heating to a high temperature for several hours in a furnace. The thread is thus rendered as hard and elastic as a steel spring. The object of using platinum as the connecting wires is, that platinum has nearly the same coefficient of expansion as glass. If copper or silver were used, these wires on becoming slightly heated by the current and proximity to the hot carbon would expand and break the glass. After the carbon filament and its platinum connections have been introduced into the globe, the air is carefully extracted by a Sprengel air-pump attached to the opposite end of the glass bulb, and during the later stages of this operation an electric current is sent through the carbon to render it red hot, and thus expel the last traces of air from the molecular spaces before hermetically sealing up the globe by the blowpipe.

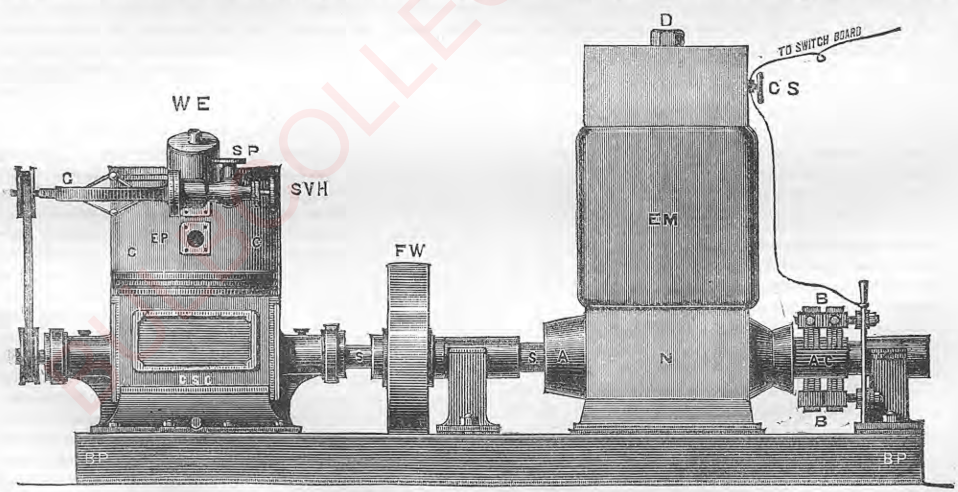
Edison's lamp, with its holder, is shown at fig. 18. Edison uses a filament produced by carbonizing a piece of bamboo fibre pared down and bent into a horse-shoe shape, as shown. The ends of his carbon filament, B, are fixed to the platinum wires which pass through the glass by an electro-deposition of copper, which insures perfect and permanent contact. One of the platinum wires is soldered to a thin metal screw, D, and the other to a central metal button, E, insulated by stucco from the screw. The holder, as shown, has a female screw, which fits the male screw on the lamp, and a contact which bears on the button when the lamp is screwed home. Between these is inserted an ordinary key or contact maker, by means of which the lamp can be turned off or on at pleasure, in the same way and with the same ease as a gas jet.

The Gatehouse incandescent lamp has been brought to great perfection by the Pilsen & Joel Electric Light Co., at their London Malden Factories, as the following tests, which were carefully taken by means of the Thomson current and potential galvanometers, show:—Date of the test, 28th December, 1883; resistance cold, 78 ohms; resistance hot, 38·4 ohms; E.M.F. 43 volts; current, 1·12 ampere; candles, 20; candles per horse-power, K × 746 ÷ E × C, 310; number of twenty-candle lamps per horse-power, 746 ÷ E × C, 15·5; watts per lamp, 48·2. If these lamps on extended trials can only show as long an existence as others, say 1000 hours, when glowing at twenty candles, then a decided economy in power required to work them has been effected. This means smaller engines, dynamos, and leads for the same candle-power. It is in this direction chiefly that improvements must be sought, for in respect to the best engines, dynamos, and wires there is not so much room left for reducing the loss of energy as there appears to be in raising the light efficiency of the lamps.



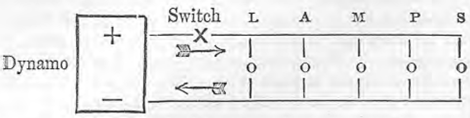
Complete Gatehouse Lamp.

The introduction of incandescent lighting has led to the production of some beautiful forms of brackets and chandeliers, or electroliers as they have been called.



Various forms of these brackets, to suit different conditions and positions, are shown in Plate III., in which fig. 19 represents a Joel lamp as suspended from ceiling, fig. 20 an ornamental standard lamp for the table, fig. 21 an ornamental electrolier for suspension, and figs. 22 and 23 forms of brackets for incandescent lamps.

Incandescent lighting has as yet made more progress in connection with the illumination of our large men-of-war and first-class steamers than in the permanent lighting of houses. At the beginning of this article a promise was made to give an example of the adaptation of electric lighting to steamships. For this purpose the installation on board the very handsome passenger steamer *Adelaide*, built and engined by Messrs. D. & W. Henderson of Glasgow, for the Adelaide Steamship Company, South Australia, will prove suitable. In this vessel there were 130 Edison 16 candle-power lamps dispersed throughout the vessel, and four of 100 candle-power placed near the gangways for facilitating passengers and their luggage being got off and on after dark when in port. The Westinghouse engine, W E, and Edison dynamo, D (see above cut), were fixed on one cast-iron bed-plate, B P, placed on the ship's floors opposite the thrust shaft and near the starting platform of the main engines. The steam pipe, S P, was attached both to the main and the donkey boiler, while the exhaust pipe, E P, was led to the condenser or hot well of the main engines; the stop-valve handle, S V H, regulated the admission of steam along with the sensitive governor G, driven by a pulley and belt from the crank shaft, S. The cranks and working parts were encased in C S C, the crank-shaft casing, half filled with oil. The fly wheel, F W, assists not only as a means of keeping up a steady motion, but also in starting the engine. The electro-magnets of the dynamo are shown at E M, the armature at A, with the north-pole piece, N, while the armature commutator is seen at A C, the brushes at B B, and the current switch at C S. The lights throughout the ship were joined up in quantities of about twenty for the different departments, saloon, saloon cabins, engine and boiler rooms, &c., each section being controlled by a main switch placed on a large switch board opposite the dynamo, as well as by another in a convenient place near the positions of the lights, while every lamp was fitted also with an independent switch and fusible wire. The lamps were all placed in "multiple arc" thus:—



The system admitted of turning off or on a certain number without endangering the others in circuit.

Such a system of lighting is much appreciated by passengers and ships' officers, and now scarcely a passenger steamer of any importance leaves the shipbuilder's hands without being fitted throughout with the electric light.

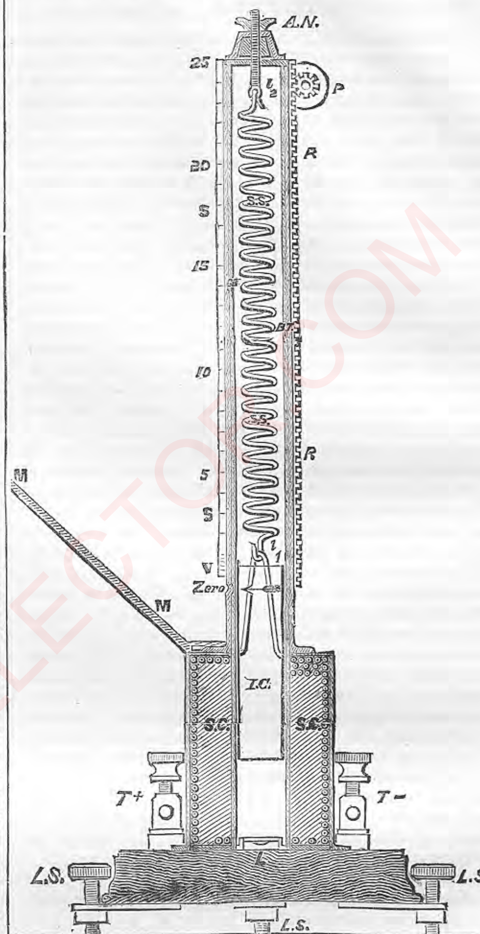
ELECTRIC METERS FOR CURRENTS AND POTENTIALS. The development of electric lighting has necessitated the invention of special instruments for measuring stronger currents and greater electro-motive forces than were demanded by those used for submarine and other telegraphic purposes. Prominent among the inventors of these instruments are Sir William Thomson, Sir William Siemens, and Professors Ayrton and Perry, Mr. Crompton, Mr. Kapp, and Professor Blyth. We select the instruments made to the designs of the latter gentleman, by Messrs. Elliott Brothers of London, not only because they remain constant and are not affected by proximity to dynamos or magnets, but also on account of the accurate workmanship and thoroughly reliable manner in which they are made and graduated.

The following cut is a section of Blyth's current meter, which is graduated by the electrolysis of water.

T + and T — represent the + and — terminals, to which wires from the battery or dynamo are attached; the current passes from T + to T — through S C, the solenoid coil, composed of some three or four turns of insulated copper wire No. 8 B.W.G., and = 0·07 ohm resistance; I C, the iron core, made of best soft iron, in the form of a thin tube. When the current passes, I C is sucked down inside S C, proportionally to the current strength, against the resistance offered by S S, the spiral spring, which is attached to I C by loop l_1, and at top by l_2 to A N, the screw for adjusting the zero of the instrument, as marked on core I C. R and P are the rack and pinion fixed to B T, the brass tube, which slides freely inside an outer brass tube; V is a vernier, fixed to B T, and which by its position indicates on S, a finely-divided scale fixed to the outer | (brass tube), the current strength or number of amperes flowing through the solenoid coil, S C; M, the mirror, by looking down upon which the zero mark on I C (which is to be seen owing to a hole and pointer in the outer brass tube), as well as the position of the vernier on the divided scale, are simultaneously observed and parallax avoided; L, a spirit level; L S, three levelling screws.

How to take a Test with this Instrument.—1. Level it by means of the three screws, L S.

2. Free the core I C by releasing three set screws not shown, and observe if its zero mark agrees with zero pointer on outer brass tube, at the same time that zero of vernier,



Section of Blyth's Current Meter.

V, agrees with the zero of scale. If not, adjust first by A N and second by R and P.

3. Attach leading wires to terminals T + and T —.

4. Switch on current (when the iron or solenoid core, I C, will be sucked down inside S C).

5. Raise I C by R and P until zero mark on I C is again opposite zero pointer on brass tube.

6. Read now the position of vernier, V, on scale S, and refer to the table attached to instrument for the corresponding amperes.

Blyth's potential meter is precisely the same in form as the instrument just described for measuring currents, only the solenoid coil is formed of long fine wire, 5000 to 6000 ohms.

By placing the current meter in direct circuit and the potential meter as a shunt to a lamp, dynamo, or battery, the current (C) in amperes and the electro-motive force (E) in volts are simultaneously found; when by the formula [see ELECTRIC LIGHTING] $E \times C$ we get the energy in watts, and by $\frac{E \times C}{746}$ the horse-power spent on the lamp or developed by the dynamo or battery. For tangent galvanometers see VOLTAIC ELECTRICITY.

ELECTRIC TELEGRAPH. See TELEGRAPH.

ELECTRI'CITY. This important agent has come into prominence only within comparatively recent times. Even until the seventeenth century its existence was unknown, and although some of its simpler effects had been observed as far back as the time of the Greek philosopher Thales, they were accounted for in the whimsical way characteristic of the ancients in explaining the origin of various natural phenomena. Everywhere throughout nature electricity seems to play an active part; but since human beings are not endowed with a sense by which to directly observe its presence, almost the whole of these manifestations take place outside our knowledge. Were we affected by electricity in a mode analogous to that in which we are affected by light, the entire face of the world and of everything around us would be revealed with a new picturesqueness, and the rapid and ever-recurring changes of electrical condition would present to us appearances which in splendour might reasonably be expected to rival the beautiful effects due to colour and light and shade. The presence of electricity can be detected only in cases where by its action it produces effects to which we are sensible. In lightning and the aurora, the most popularly known of electrical phenomena, it attracts observation in consequence of its producing light and sound (thunder) in the former case, and light alone in the latter, these *effects* being perceptible by us. In its nature it resembles an attribute or state of matter, and not matter itself; therefore a body having electricity has nothing material added to it, and is neither lighter nor heavier than when destitute of electricity. At rest it is called *statical* electricity; in motion, *current*, *voltaic*, or *dynamical* electricity. The present article will be confined to the first of these. For the other department of the subject see ELECTRIC LIGHTING, ELECTRO-CHEMISTRY, THERMO-ELECTRICITY, VOLTAIC ELECTRICITY, &c. The effects due to it when stationary differ widely from those to which it gives origin while moving or *flowing*. In almost every department of the arts electricity renders extensive and invaluable service, the leading instances of its application being telegraphy, telephony, electric-lighting, and electro-metallurgy. The contrivances by which electricity may be generated are of great variety, but all the most useful are modifications of a few types in which friction, statical induction, chemical action, magnetism, or heat is employed.

Frictional Electricity.—In the evolution of electricity by friction, opportunity is readily found for examining step by step the elementary laws of the generation of electricity, and also the different phases of its action; more particularly, however, the laws and action that pertain to electricity in the condition of rest.

Electrification by Friction.—If a tube or rod of glass be approached to within a short distance of a number of light bodies lying loosely upon a table—small fragments of tissue-paper, for example—these will remain unaffected. On substituting an ordinary stick of sealing-wax for the glass, an identical absence of result is observed. But let the same glass after having been smartly rubbed with a piece of silk, or the same sealing-wax rubbed with flannel, be now brought over the pieces of paper. These last will at once spring from the table in considerable number, affixing themselves to the rubbed body (fig. 1 in Plate). The explanation of their change of behaviour is this:—In the first case the paper was unaffected because the rod of glass and the stick of sealing-wax possessed no electricity, or are said to have been *neutral*. The pieces of paper also were neutral. In the second case the process of rubbing had excited electricity upon the surface of the glass, and also of the sealing-wax, and the attraction of the pieces of paper was effected by the electricity residing on the glass and on the sealing-wax respectively. Moreover, the pieces of paper will be attracted in this manner towards *any* body upon the exposed surface of which there exists an appreciable quantity of electricity. Therefore it is seen that friction may produce electricity, and that the attraction of neutral light bodies is evidence of the presence of electricity. Besides paper many other light bodies are equally suitable for this experiment, such as bran, small feathers, or a pith-ball suspended by a thread (fig. 2, P pith-ball, G an electrified glass rod attracting P). Here it may be remarked by the way, that some of the light bodies immediately after the adhesion already described fly back with equal alacrity towards the table, while others do so languidly and after a longer interval, a fact the cause of which will be explained further on.

Action of Electrified Bodies upon each other.—Balance a glass tube which has been rubbed with silk, and on bringing near it the flannel-rubbed sealing-wax, the former will be *attracted* towards the latter (fig. 3, G glass, S sealing-wax). The excited sealing-wax, if pivoted, will move towards the excited glass. But suppose there are two rods of glass, both rubbed with silk, then the balanced glass rod will be driven away when the other is approached to it, an effect called *repulsion* (see fig. 4). Two sticks of sealing-wax rubbed with flannel also *repel* each other. It is usual to explain these and other electrical phenomena by means of a hypothesis, the *two-fluid theory*, now known to be inconsistent, in a literal sense, with physical facts, yet serving well to furnish ideas and terms of great assistance in reasoning. This theory assumes the existence of two peculiar electrical fluids, one named *positive* (or $+$), the other *negative* (or $-$). In the previous experiments here given, glass rubbed with silk acquires $+$ electricity, while sealing-wax rubbed with flannel obtains $-$. The two fluids are said to attract each other, a fact instanced in the attraction between the $+$ glass and the $-$ sealing-wax; but each fluid repels its own kind, as in the repulsion between the two $+$ rods of glass, and also between the two $-$ sticks of sealing-wax. Equal quantities of these fluids when combined disguise each other's presence, thus restoring neutrality; and in a neutral body they are supposed to be co-existent in a state of complete combination, in equal amount, and in infinite quantity, by this means forming what is called a *neutral* fluid. Faraday advanced a new theory, which dispenses with such impossible fluids, and attributes electrical phenomena to a peculiar state of tension or stress in the molecules of bodies. Notwithstanding that this theory is now generally adopted by scientific men, they justify the retention of the old nomenclature on the ground of its convenience.

Both kinds of Electricity are always produced simultaneously and in exactly equal quantities.—Examination of the silk with which the glass was rubbed shows the presence there of $-$ electricity, the amount being equal to that of the $+$ upon the glass. With the sealing-wax and flannel rubbed together the former will be $-$ and the latter $+$ in exactly the same degree. The friction between two bodies decomposes part of the compound neutral fluid into its constituents, $+$ and $-$, so that the bodies when separated are found electrified on the surface, one with $+$ and the other with $-$ in equal quantity. The particular kind of electricity produced on one body when rubbed by another depends on some relationship between the two not yet understood; but in order that any electricity may be produced upon them they must differ either in structure, chemical constitution, or temperature. Glass when rubbed with certain substances becomes $-$, and sealing-wax may be made $+$ provided an appropriate rubber is chosen.

Conductors and Non-conductors or Insulators.—Many