CHAPTER XIII.

SEARCH AND ARC LIGHTS.

Arc Lights.

If two pointed pieces of carbon be joined to a circuit in connection with a source of D.P., and the two points be placed very close together, no current will flow between them. But if they be made to touch, the circuit will be completed, and they will become white hot. If now the source of D.P. be about 45 volts, these points may be slowly separated to some half or even three-quarters of an inch, and the current will still flow in the circuit, the carbons remaining white hot and emitting light.

Although a D.P. of, say, 80 volts is quite unable to force a current through the very high resistance of half an inch of air space, yet when the points of the carbons were made to touch, the circuit was completed and the current commenced to flow, and the resistance at the point of contact being high, considerable heat was developed at that point. If the carbons were kept together, the surfaces in contact would become more or less incandescent, but the amount of light emitted would be very small, as the ends of the carbons would screen each other. If, however, we separate the carbons, the air space between them will be filled with a great quantity of minute particles of carbon, rendered incandescent by the heat produced by the current; and these particles form a bridge by whose means the current continues to pass from one carbon to the other. This bridge is called the *arc*, and separating the carbons and establishing the arc between them in this manner is called *striking the arc*.

If the carbons be examined after the light has been burning for some time it will be seen that the one attached to the positive source of D.P. has a crater formed in it, whilst the other carbon has become pointed. Both carbons will have been burnt away, but about twice as much of the positive will have been consumed as of the negative.

The amount of light emitted by a substance depends greatly on its temperature, and on the amount of surface which is at this temperature. It will be seen that in the case of the arc light the crater contains the largest amount of surface at a high temperature, and it is therefore the state and condition of the crater which must chiefly be studied with a view to obtaining as much light as possible. By measurement it has been found that about 85 per cent. of the total light emitted by an arc light is obtained from the crater, 10 per cent. is obtained from the negative carbon, and 5 per cent. only from the arc.

The action that takes place during the burning of an electric arc has been made the subject of much discussion. It is apparent that the resistance offered to the passage of a current from one carbon to the other does not strictly follow Ohm's law, inasmuch as this resistance does not vary proportionately to the length of the arc. The most recent theory is that during the burning away of the carbons, a film of carbon vapour of high resistance forms between the carbons, and that the resistance of this film varies not so much with the length of the arc as with the strength of the current. To overcome this resistance a considerable voltage must be applied to the carbons, and in practice this varies from 40 volts to 60 volts (and in enclosed arcs to 80 volts), depending on what current and length of arc it is required to use.

Artificial Resistance.—The good burning of an arc light depends greatly on the supply of a constant current to the lamp. If the lamp were joined directly to a source of constant D.P., so that the resistance of the arc were the only resistance in the circuit, the current through the lamp would vary very much, and a great strain would be brought on the dynamo. By inserting a resistance in the circuit in series with the lamp, and increasing the voltage supplied, a very much more constant current can be obtained; for, the steadying resistance having a constant value, the variations of the arc resistance do not now affect the total resistance of the circuit to such an extent, and the strength of current through the circuit of course depends not on the arc resistance but on the total resistance of the circuit.

There are also the less important considerations that, by using this resistance, the arc lamp can be fed from the main dynamos of the ship, the surplus voltage of the dynamo above what is required for the arc light being absorbed in the resistance; and that the use of this resistance plays an important part in the working of the automatic gear for feeding the carbons together as they burn away.

The greater the value of the artificial resistance, the greater will be the steadying effect; for good burning, the voltage absorbed by the resistance should be not less than half the voltage applied to the lamp terminals.

Arc Lights in series.—Provided that the voltage is high enough, lamps can easily be burnt in this manner, but they will never have the same steadiness as when joined in parallel, and unless special arrangements are made for shunting a lamp if it goes out, the failure of one lamp will mean the extinction of all. For this reason it is not recommended that search light lamps should be joined in series.

When lamps are burnt in parallel, however, one resistance cannot be used for two lamps, as in this case the fluctuations of one light would affect the burning of the other, and the amount of resistance required would differ according to whether both or only one lamp were being used. The same pair of leads can, however, be used for a pair of lamps up to the point where the resistances are joined in.

Construction of Carbons.

On the nature and quality of the carbons depends to a great extent the good burning of the light. The carbons are made of gas retort carbon dust mixed with tar and soot and compressed into the required shape. On account of the higher rate of burning of the positive carbon it is always made of larger diameter than the negative; and to assist in the formation of a good crater it is made with a central core of softer carbon.

Early types of search light carbons were covered with a copper sheath to improve the conductivity of the carbon and to prevent the shedding away of the outsides due to the heat. The pieces of fused copper dropping into the mechanism of the lamp, however, gave so much trouble that later types are only lightly coppered for portions of their lengths.

The strength of current to be used with a lamp is generally fixed either by the power the lamp is designed to use, or (as in the case of a search light) by the limit of heat the surrounding fittings can stand. On this strength of current depends the quantity of light given off, but, in the case of an arc light, not the intensity of the light. The temperature at which carbon vapourizes is the highest obtainable temperature, and therefore the intensity cannot be increased beyond a certain value. An increase of current simply results in a larger surface of carbon being brought to this temperature.

Sizes of Carbons.

Every carbon of a particular diameter has a strength of current most suited for it. If this be exceeded the carbon will be overheated, and if uncoppered will shed its outside considerably. If less than this amount be used, the whole of the end of the carbon will not be burning at the same rate, and the arc will have to travel round the outside of the carbon and burn away a portion at a time. In a search light lamp it is essential that the light should emanate from as near the centre of the carbon as possible, and it is therefore a disadvantage to have the carbon larger than necessary; for the outside of a large carbon is farther from the centre than is that of a small one.

Again the negative carbon is generally so placed in a lamp that it is acting as a screen to the light coming from the crater, and it is therefore important to keep it as small as possible. Lastly, most carbons are constructed of such diameters that the $+^{ve}$ and $-^{ve}$ will burn at approximately equal rates.

The Search Light.

In the search light projector, as it is commonly known, the light from a powerful arc lamp is collected by a concave mirror and is reflected from it in a nearly parallel beam of great intensity. To enable this to be done the mirror must be of parabolic form and the arc light must be at a point called the focus, situated at a definite distance called the focal length from the centre of the mirror. It is not proposed to deal with the theory or construction of mirrors in this chapter; some remarks on the subject will be found, however, in Chapter XIV., page 247 and onwards.

Search Light Projectors.

There are three principal sizes of projectors in the Service, namely, those taking 36-inch, 24-inch, and 20-inch diameter mirrors. We will now proceed to describe the 24-inch projector fitted to take the inclined hand lamp.

24-inch Projector.

The mirror is held by clips to a brass ring which fits inside a steel barrel, closed at the back by a steel cover, and at the front by a glass door.

The lamp is fitted on slides in a lamp box attached to the lower part of the barrel, and is secured in place by a spring stop on a travelling nut. This nut may be moved in and out by a screw, and the lamp thus moved towards or away from the mirror to enable the light to be accurately focussed.

The barrel is supported in horizontal trunnions by arms bolted to a turntable, which revolves on rollers, secured to the top of a coned pedestal. A central bolt passes through the pedestal and turntable to keep it in position. Toothed gearing is fitted to the barrel and pedestal to enable tilting or training motions to be given to the light by means of hand wheels. These gears can be readily disconnected so that "free" training or tilting can be obtained. Clamps are also fitted to lock the light in any desired position.

Sighting holes are fitted in the barrel and lamp box to allow access to the lamp, and copper hoods are fitted on the top which afford the necessary ventilation, but prevent the escape of light.

The electrical connections between the fixed and moving parts of the projector are made by spring plungers and ring contacts; the tilting motion being allowed for by wandering leads from the ring contacts to the lamp terminals. A switch is fitted on the side of the pedestal through which the positive lead is taken. The spring plungers are connected either to permanent leads coming up into the pedestal direct from the switchboard or to two terminals fixed on the pedestal, these terminals being connected by flexible leads to a terminal box near by. This latter method is used particularly when the projector is mounted on rollers and rails to enable it to be run in to a special stowing position.

These projectors can be easily altered to take the automatic horizontal lamp.

The alteration consists of removing the lamp box and focussing gear, and fitting the special slides and focussing screw supplied with the lamp.

All new projectors are being fitted to take this lamp.

Slight alterations in the barrel have also to be made when using a 12-inch focal length mirror in these projectors, to enable the arc to be brought to within 12 inches of the mirror.

20-*inch Projector.*

All torpedo boat destroyers and torpedo boats are supplied with a projector of this size, which is identical in design with the 24-inch just described. It can be fitted to take either a horizontal or inclined lamp. A new 20-inch projector has been fitted to the latest torpedo boats. It is specially designed for lightness and has improved training and elevating gears. No switch or contact rings are fitted, the leads being brought direct from a terminal box to the lamp. Special clips are fitted to the turntable to hold the cables and prevent any strain coming on the lamp terminals.

36-*inch Projector.*

There are two types of this projector. One is intended to be controlled by hand only, and the other, in addition to the hand control, is fitted with electrical control gear so that it can be trained or elevated from a distant part of the ship by means of motors and controllers.

Two of the latter are being fitted to some battleships and first-class cruisers. The latest battleships and armoured cruisers have 36-inch projectors only (except for one 24-inch for signalling purposes), a large proportion of them being fitted for hand control only. Both types are similar in principle to the 24-inch projector, but, in consequence of their size, they are very heavy and unwieldy, the total weight of the electrically controlled projector being 19 cwt. Arrangements are made for balancing the barrel in the trunnion bearings, by securing the trunnions to two horizontal rods on each side of the barrel, so that the trunnions can be shifted in position horizontally, and the barrel thus accurately balanced. This arrangement will be fitted to new projectors of all sizes. The turntable carries 16 rollers, which travel round a path on the top of the pedestal. In addition to the contact rings and plungers for supplying the current to the lamp, there are two smaller rings and plungers for supplying two indicator lamps to illuminate a graduated training arc placed at the centre of the turntable. A further description of the electrically controlled projector is given on page 235.

Care and Maintenance of Projectors.

All the working parts of the projectors should be kept thoroughly well oiled and in good repair. If the projectors are much exposed, it is advisable to keep the mirrors, if possible, unshipped in bad weather, so as to prevent them being damaged by the wet. This can easily be done in the new pattern projector, the mirror being separate from the back.

The mirrors should never be cleaned except with the feather brush supplied for that purpose.

Diverging Lenses and other Fittings.

Divergent lenses are supplied to ships to diverge the beam in a *horizontal direction* only. A certain amount of divergence is obtained, from the fact that the crater has a definite diameter, which allows rays to diverge at a small angle instead of following a true parallel direction. Should it be further required to illuminate a larger space laterally, a lens of peculiar construction is placed in front of the projector; this lens consists of vertical strips of glass of convex section, which act in a horizontal plane precisely as a convex lens would do, but which do not disperse the rays, except laterally. The illumination is much greater than would be the case if the light were dispersed in a cone instead of in a fan shape.

Two kinds of lenses of this description are supplied to His Majesty's ships, viz.: (1) lenses with an angle of dispersion of 16°, and (2) lenses with an angle of dispersion of 30°; the latter are only supplied to flagships. No effective range can be definitely laid down for their use, as the purpose of their employment as well as atmospheric conditions vary.

They are easily shipped and unshipped, and are useful for short ranges. When there is no time to ship these lenses the lamps may be put out of focus.

On account of the weight of these lenses, and the amount of light they absorb, diverging mirrors have been introduced lately. These are shipped into the projector in the place of the parabolic mirror when required. No more of these are being procured however, as it is considered unlikely that it will ever in future be required to diverge the beam of light of a naval search light.

Signal Flashing Shutter.—These are supplied in two sizes for signalling purposes and can be fitted in front of the front glass of 24-inch or 36-inch search lights and be held there either by hooks or clips.

Search Light Lamps.

Inclined Hand Lamp.

The inclined hand lamp, as shown in Plate XXVI., consists of two holders, which are capable of motion towards or away from one another in a straight line, at an angle of 20° to the vertical. The carbons are clamped into the holders by screw bolts, which bear against filling pieces. A right and left-handed screw, moved by the hand wheel at B in the plate, cause the motion of the carbons in the plane of their inclination.

The upper carbon is the positive one, and is capable of motion either forward or backward, and also sideways, over the lower or negative carbon. These motions are imparted by means of two screws SS at the side of the top carbon holder, which are turned by a special key.

Both carbons may be moved up and down together by the ebonite star wheel on the side of the lamp (not shown in the elevation), and the crater thus raised or lowered without disturbing the burning, so as to adjust it accurately to the focus of the mirror. A shield A is placed in front of the carbon points to cut off any direct rays, which would otherwise diverge and spoil the beam.

The electrical connections are simple. The positive terminal on the lamp box is in connection with the metal of the lamp, and by this with the positive carbon holder.

The negative terminal N is insulated, and the current is led by insulated strips C C inside the lamp to the bottom of the lower carbon holder, which is insulated from the body of the lamp with an asbestos or mica washer, and ivory bushes for the securing screws. A cover, D in the plate, goes over the joint, to prevent melted copper falling and short-circuiting across the insulation.

The whole lamp is supported on a bottom plate with spiral springs E E between it and the lamp, to minimise the liability to damage from concussion of gun fire. The spring stop for focussing the lamp passes through a hole in this plate, but is insulated from it by means of an ebonite bush.

This lamp can be used in a 24-inch or a 20-inch projector. In all torpedo boats, except those of the latest types, the lamps have smaller carbons taking less current.

The Automatic Horizontal Lamp.

All search light lamps of recent manufacture are of this type, and all new projectors are constructed to take this lamp. The object of the lamp is automatically to "strike the arc" and automatically to close the carbons together as they burn away. The advantage of such a mechanism is sufficiently obvious. In addition, the lamp is much easier to burn by hand than is the old inclined type.

It will be seen from the diagram of the circuit that there is a series coil in series with the main circuit through the lamp, called the "arc striking coil," and a shunt coil across the terminals of the lamp. When a current passes through the series coil, it drags a soft iron rod into the coil, and this piece of iron, being connected to the $+^{ve}$ carbon holder, draws the $+^{ve}$ carbon away from the $-^{ve}$ carbon.

When the E.M.F. across the lamp terminals exceeds a certain value the shunt coil attracts an armature, and as it is fitted with a make and break arrangement like a trembler bell, the armature vibrates. This vibration is made to work a ratchet which feeds the carbons together.

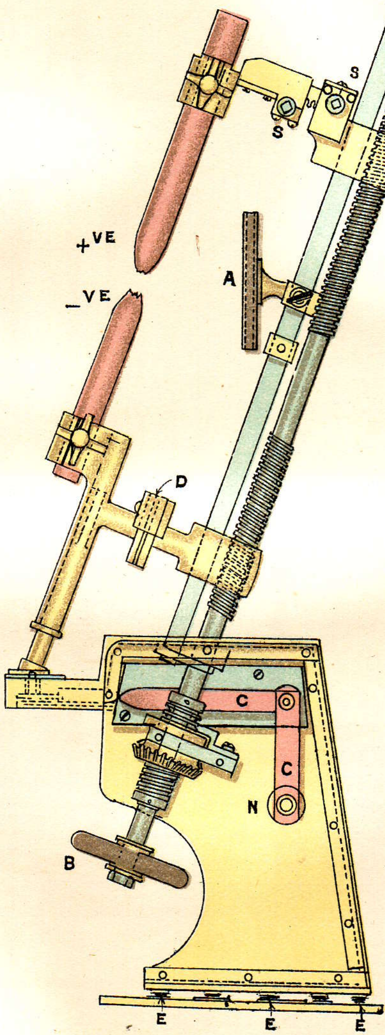
The action is therefore as follows :—

When the current is switched on, if the carbons are separated, 100 volts D.P. will be put across the lamp terminals. The vibrating armature commences to work and feeds the carbons together. Directly the carbons touch, the D.P. across the lamp

Inclined Hand Lamp

Scale 2" 1=Foot.

Elevation with Cover at Side Removed.



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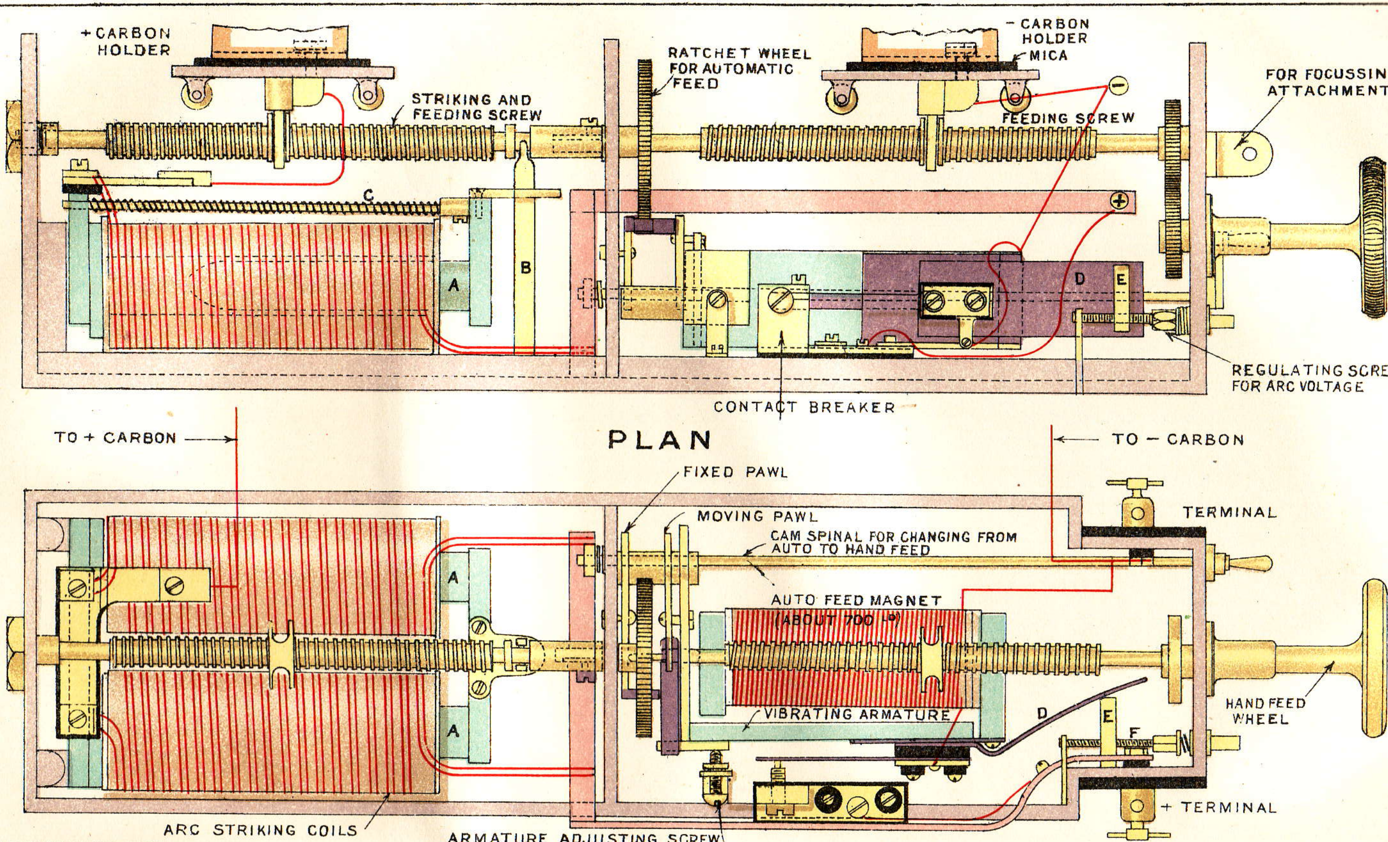
Weller & Graham, Ltd. Litho, London.



HORIZONTAL AUTOMATIC LAMP.

Plate XXVII.

terminals falls and the feeding armature stops. At the same time a large current passes through the carbons and the series coil, which latter is energised and draws back the $+^{ve}$ carbon about half an inch, thus "striking the arc."

The arc continues to burn, and as the carbons waste away, the arc gets longer and the automatic feed worked by the shunt coils recommences and feeds the carbons together. If the arc is blown out, or the current is taken off for a few moments from any cause, the series coil will lose its magnetism, and the $+^{ve}$ carbon holder will be forced back by a spring so that the two carbons touch one another. On switching on again the lamp will then strike the arc as before.

Plate XXVII. shows a detailed sketch of the Service lamp, manufactured by Messrs. Crompton.

The carbons are horizontal and are carried in holders, the $+^{ve}$ holder being adjustable, so that the carbons may be properly aligned. These holders are mounted on small trolleys, each having four rollers, running on paths in the body of the camp.

A projecting lug on the bottom of each holder attaches it to the longitudinal screwed shaft. This shaft has a left-handed screw thread on the $-^{ve}$ carbon end and a right-handed screw thread on the $+^{ve}$ end. The rod is connected in the middle by a sleeve, and a set screw working in a groove, so as to allow of the $+^{ve}$ end moving in a longitudinal direction, while both shafts revolve together.

Under the $+^{ve}$ carbon holder is the arc striking series arrangement. This consists of four coils in parallel, wound to form two solenoids, into which two iron rods (AA) are sucked. The rods are connected by a lever (B) to the "striking and feeding screw," and when they are drawn into the solenoids, the lever draws the screw, and with it the $+^{ve}$ carbon holder, away from the $-^{ve}$. A spring (C) keeps the carbons together when no current is passing through the series coil.

The automatic feeding device is under the $-^{ve}$ holder. A ratchet wheel is fitted on the feeding screw shaft, and is revolved by a feeding pawl worked by the vibrating armature. This armature is attracted by the shunt coil when the voltage across the latter is sufficient, and it has attached to it a make and break like a trembler bell, so that as it is attracted to the magnetic coil it breaks the circuit of the coil, and is brought back by the spring (D), when the circuit of the coil is made again and the operation is repeated.

On each *return* stroke of the armature, the feeding pawl pulls the ratchet wheel round one tooth, and it is then held from easing back by the fixed holding pawl. The rotation of the ratchet wheel thus revolves the feeding screw shaft and closes the carbons together.

The resistance of the shunt coil is about 700 ohms. A sliding block (E) is fitted on a shaft (F) worked from outside the case. This block bears against the armature spring and alters its tension. By this means the voltage at which the feeding gear works can be regulated. There is also an adjustable stop against which the armature bears, and which therefore limits the travel of the armature.

The feeding screw shaft is geared into a hand wheel outside the case, for working the lamp by hand if necessary. Before revolving this wheel, however, the pawls must be lifted clear of the ratchet wheel by the cam shaft which can be worked from the outside by a small lever and handle marked "On" and "Off." In addition, this handle also breaks the shunt circuit when put to hand (Off) by forcing the shunt armature away from the make and break screw. This remains broken the whole time the lever is to Off.

Current enters the lamp at the $+^{ve}$ terminal, insulated from the body of the lamp by mica, and is led by a stout copper strip, insulated with tape and varnish, to a "busbar," to which the four ends of the series coils are attached. The other ends of the series coils are attached to the brass block from which a lead of flexible wire, plaited up in asbestos insulation, is taken to the $+^{ve}$ carbon holder, which is insulated from its trolley by mica sheets.

The circuit, after passing through the carbons, leads down the negative holder to the $-^{ve}$ terminal of the lamp.

The shunt circuit is from the copper strip joined to the $+^{ve}$ lamp terminal, to an insulated platinum-tipped screw.

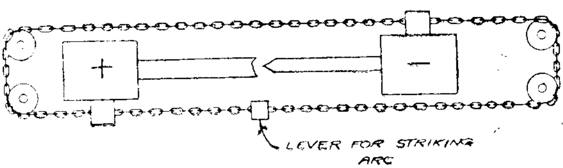
Through the make and break arrangement on the vibrating armature, through the shunt coil, and away to the $-^{ve}$ terminal of the lamp. All points in the circuit are insulated from the body of the lamp.

The carbon holders are curved back so as to get the arc at the proper focal distance from the mirror.

36-*inch Auto-Horizontal Lamp.*—The lamp, although considerably larger in every way, differs only in one point from the 24-inch design. To overcome the effect of gravity on the positive carbon holder when the projector is elevated, the carbon holders are connected together by an endless chain, worked by the arc striking lever. The negative carbon holder is not connected to the feeding shaft, but is worked entirely by the $+^{ve}$ carbon by means of the chain (Fig. 144). By this means the weights of the two carbon holders balance each other.

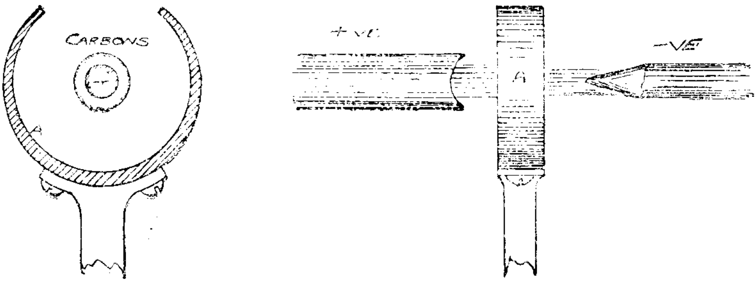
A flexible corrugated copper strip connects the body of the $+^{ve}$ carbon holder with the carbon clamps to avoid heating, due to bad contact in the adjusting gear.

FIG. 144.



Arc Deflector.—When burning an arc light the hot gases given off from the burning carbons tend to rise and so cause a draught which draws the arc upwards. As will be seen later, in the inclined hand lamp this tendency is made use of, and is in fact the cause of the carbons being inclined at this angle; but in all horizontal lamps a special fitting, named the arc deflector, is placed so as to encircle the arc and to blow or force the arc down. It consists of an iron sector A in Fig. 145 open at the top and held on a standard so as to embrace the centre of the arc.

FIG. 145.



An electric arc has magnetic properties, exactly as has any other conductor carrying a current. The lines of force round the arc, are concentrated in the iron sector A, and the tendency of any conductor to place itself so that the greatest number of lines are induced causes the arc to be drawn down into the sector.

20-inch Auto-Horizontal Lamps.—The body of these lamps is of the same size and design as the 24-inch lamp, but their carbon holders are made shorter, to enable the carbons to be placed in the centre of the smaller barrel.

There are two patterns of these lamps designed for 80 and 60 amperes respectively; the series coil of the latter is specially wound so as to strike the arc and hold the positive carbon with this reduced current.

Inclined Lamp fitted for Auto Burning.—A modification is being made to existing inclined hand lamps which will enable them to burn automatically. They are being supplied to a number of old classes of ships and to some torpedo craft. The arc is struck by a series coil which draws the negative carbon down against a spring. The shunt coil revolves a worm which drives a worm wheel connected to the same shaft as is the hand-feeding wheel. This worm can be thrown out of gear when required to work by hand. The adjustment of the shunt coil is effected by a milled headed screw on the outside of the lamp body which alters the tension on a spiral spring that controls the shunt-coil armature.

It is not possible to break the shunt-coil circuit by means of the hand lever; the coil, therefore, drives the worm, even if working by hand, with the worm disconnected.

The lamp box of the projector has to have special doors cut in it to give access to the adjusting screws.

Principle of Automatic Feeding.

The automatic feeding of a lamp depends on the fact that although the dynamo may be generating a constant voltage, yet by inserting the artificial resistance in series with the lamp, the voltage obtained at the lamp terminals is different for every value of current passing through the circuit. The voltage absorbed by the artificial resistance depends on its resistance multiplied by the current passing through it at the time, or C × R; so that if a large current is flowing through the circuit, the artificial resistance will absorb a large proportion of the voltage supplied by the dynamo, leaving a low voltage at the lamp terminals. This occurs when the carbons are close together. On the other hand, if the arc is broken, and no current is flowing through the circuit, the resistance will absorb none of the voltage, and the full voltage of the dynamo will be applied to the lamp terminals. The shunt magnet must be of a certain strength before it can do its work against the spring opposing it. In other words, the voltage across the lamp terminals must rise above a certain value before the shunt magnet will feed. By varying the strength of the opposing spring it is possible to alter this value which the voltage must reach, and it is therefore possible to adjust the coil to feed at any required voltage.

The voltage depends on what length of arc it is intended to use. Every arc length has definite E.M.F. and current values most suitable for it, and the artificial resistance must be adjusted so that with the required length of arc these values are obtained. Then, if the arc lengthens due to the carbons burning away, the current through the circuit decreases, the artificial resistance absorbs less voltage and the E.M.F. at the lamp terminals rises, thus causing the shunt coil to commence feeding in the carbons until the arc is of the correct length again. The voltage at the lamp terminals will then again be of its correct value and the shunt coil should stop feeding. As it is impossible to adjust the shunt coil so that it will work at exactly the correct voltage, it is usual to allow it a range of 4 volts, that is to say, it must be adjusted to commence feeding before the voltage has risen 2 volts above its correct value, and it must stop feeding before the voltage has fallen 2 volts below that value.

Arc Lengths.

Referring to page 220, it can easily be seen that the screening due to the negative carbon will be much reduced if the length of the arc can be increased.

For many years the length of arc used in 24-inch lamps has been about half an inch, this length requiring 100 amperes and a pressure of 50 volts across the lamp. It has lately been found, however, that an arc length of 1 inch can be well maintained in these lamps if a current of 110 amperes and a pressure of 60 volts be used.

To obtain these values of pressure and current it is necessary to reduce the amount of resistance used in the circuit, and this can easily be done in all types of artificial resistances. It is not possible to increase the arc length any more, as if this were done the amount of artificial resistance in the circuit would be reduced to such an extent that it would not have sufficient steadying effect.

For this reason it is not considered advisable at present to use a long arc unless the voltage of supply is 95 or above.

The following table gives the correct strengths and voltages required for various search lights using horizontal carbon lamps:—

Projector.	Size of		Long Arc.			Short Arc.		
	+ve Carbon.	—ve Carbon.	Length.	Current.	Voltage.	Length.	Current.	Voltage.
	mm.	mm.	In.			In.		
36-inch - - -	35	25	$1\frac{1}{8}$	150	62	$\frac{1}{2}$	120	50
24-inch - - -	30	20	1	110	60	$\frac{1}{2}$	100	52
20-inch T.B.D. - -	30	20	—	—	—	$\frac{1}{2}$	80	48
„ T.B. - - -	25	18	—	—	—	$\frac{1}{2}$	50 to 60.*	48

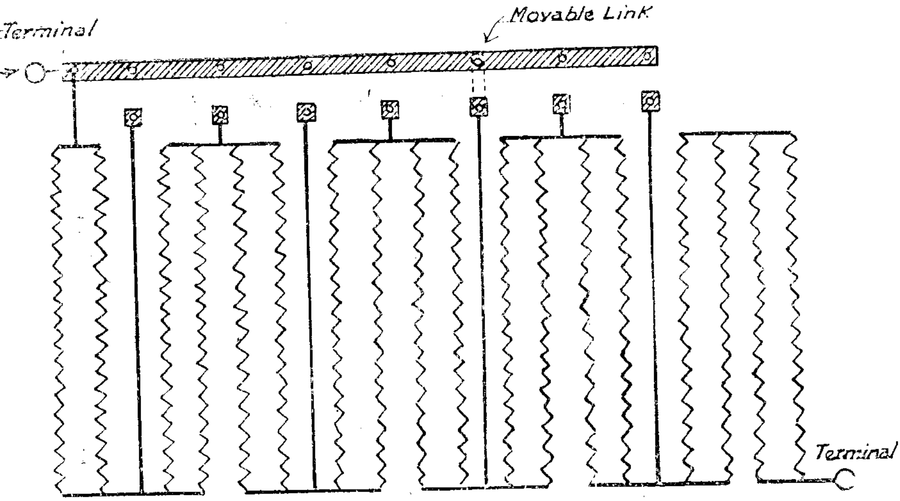
* According to capacity of dynamo.

Artificial Resistances.

There are a number of different resistances for the various search lights in the Service. The various patterns are made of Eureka, platinoid, or manganin wire, generally wound on porcelain rollers or drums and held in an iron frame well ventilated by perforated sheets of zinc. The resistances consist of two or more circuits in parallel, the total values of the resistances varying according to what lamp they are designed for. The old pattern 100-ampere resistance for the 24-inch projector has two circuits of ·4 ohms each, capable of carrying 50 amperes; so that its total resistance is ·2 ohms. In 80-volt ships one of these is used for each projector, and in 100-volt ships two of them are joined in series. Spare wire is issued to ships for re-winding these resistances. The 36-inch resistance consists of spirals hung vertically between connecting blocks, eight spirals being joined in parallel.

Fig. 146 shows a diagram of the new pattern of adjustable resistance for 24-inch projectors. The resistances consist of coils of Eureka wire wound on porcelain drums enclosed in an iron case. The drums are arranged in pairs, there being nine pairs joined in series with each other, each pair being in parallel and

Fig. 146.



having a branch connection to an insulated block placed on the top of the frame. Running parallel to these blocks is a long bar joined to one of the mains and to one end of the resistances. The other main wire is joined to the opposite end of the resistance, so that there is always one path for the current through all the resistance. By placing a strip of copper across from the long bar to any required contact block it is possible to short-circuit any number of the resistance drums and so vary the value of the resistance from ·13 to ·57 ohms.

With an adjustable resistance of this description it is possible to adjust accurately the total steadying resistance of the circuit, taking into consideration the resistance of the search light leads.

None of these artificial resistances must be placed near to inflammable material, as they become excessively hot when the light is burning. They are all in future to be placed in positions behind armour in ships. They must be kept clean and dry, otherwise the wire will deteriorate. The resistances in which the wire is not wound on drums must be so placed that the wires hang vertically, otherwise the wires will sag and short-circuit each other, or earth themselves on the iron casing.

Search light cables consist of lead-covered cable for the permanent parts and special flexible cable for the portable leads to the projector.

Referring to page 221, we see that in some cases the permanent leads are led into the pedestal, and sometimes to a terminal box close to the projector. The latest method is to take the permanent leads to a terminal box placed under armour and to run flexible cable from that box to the projector. These leads are in some cases led direct to the lamp without going through the pedestal switch and contact rings.

Each search light should have a separate switch at the switchboard, but in some cases two lights are fed from one switch. The artificial resistance is placed in the positive lead of the permanent circuit.

The ends of the flexible leads are fitted with spills of two different sizes to prevent them from being cross connected by accident.

Testing and Adjusting.

To test an automatic horizontal lamp. Put the lever to Hand or "Off" (this breaks shunt circuit). Join up a Menotti to the terminals of the lamp and test for non-contact with the carbons separated, and then for continuity with the carbons closed. Disconnect one lead of the Menotti and touch it to earth; no swing should be obtained. This tests all parts of the lamp for insulation. Put the lever to automatic and separate the carbons. Test for continuity of the shunt coil.

Search light circuits should be frequently tested with the lamps in place and everything correctly joined up. The Menotti should be joined to the search light mains at the switchboard, and the complete circuit tested in a similar way to that described above, except that in addition, any switch in the circuit, such as the pedestal switch, should be tested to see that it breaks the circuit correctly, and that also it must be remembered that there are frequently two search lights joined up to one circuit bar. Should a fault be discovered it is advisable to commence looking for it from the lamp end, first cutting out the lamp and then the projector, and noting whether the fault is thereby cut out also.

Inclined hand lamps can be similarly tested, particular care being taken to see that these lamps are well insulated from the barrel of the projector on account of the body of the lamp forming part of the circuit.

Inclined automatic lamps must have their shunt coil disconnected, as the hand lever does not break the shunt coil circuit in these lamps.

To adjust a horizontal automatic lamp:—

(1) Examine all working parts to see that they are free, particularly the striking and feeding mechanism. See that the flexible leads are clear, and that the lamp terminals are not loose.

(2) Test the lamp as described above.

(3) Adjust the striking gear spring so that it is just strong enough to throw the positive carbon forward when the current goes off.

(4) Put the lever to automatic. Work the shunt coil armature with the finger and adjust its travel until the pawl just

catches a tooth every time. See the voltage screw eased well back whilst doing this, so as to test the strength of the spring.

(5) Join up the lamp, including a voltmeter. Separate the carbons and switch on. Adjust the make and break screw until the armature vibrates and the lamp feeds.

(6) Strike the arc. Separate the carbons by hand carefully until the voltage is 70. Put the lever to automatic and allow the shunt coil to feed in. Note at what voltage it stops feeding, and adjust the voltage screw accordingly. Repeat the operation until it stops feeding at the required voltage. The lamp is now in adjustment.

Notes on the above Adjustments.

It must be clearly understood that if correctly adjusted to stop feeding at the proper voltage, the lamp must then also be in adjustment for commencing to feed. If one is in adjustment, the other must also be so. If there is time, however, it may form an additional test to allow the carbons to burn away, and to watch at what voltage they commence feeding together.

Great care must be taken not to make the striking gear spring too strong, or the series coil will not be able to hold the positive carbon back.

The shunt coil armature must not be given too much travel or it will work too slowly, and may make earth on the frame of the lamp.

Working the armature with the finger will test whether the pawls are in working order. If the gear does not feed, the pawls must be looked to, or there may be some dirt or burrs on the toothed wheels.

When making the fine adjustment in 6, it will probably be necessary to make a slight alteration to the adjustment of the make and break screw which is only put into rough adjustment in 5.

Always start adjusting with the voltage screw eased back (*i.e.*, with small pressure on the spring), and then gradually raise the adjustment.

Always screw up the set nuts of the two adjusting screws when the adjustment is correct.

When the shunt coil has warmed up and its resistance has become higher, it will not feed quite soon enough, and the voltage screw will have to be lowered slightly.

To adjust an Inclined Automatic Lamp.

The principle to be followed is similar to that for the horizontal lamp. There is, however, no adjustment possible for the striking magnet spring. The exact amount of travel of the armature is not of such importance as in the horizontal lamp, as the armature vibrates very quickly whatever may be the travel. Great care must be taken to set up the check nut of the make and break adjusting screw.

To adjust a Search Light Resistance.

Join up a lamp in the projector for which the resistance is intended, using the proper leads for that projector. Insert an ammeter in the circuit and join up a voltmeter across the lamp terminals. Run the dynamo at exactly the voltage at which it runs when burning search lights. Burn the lamp by hand and get a good steady arc before taking any readings. Alter the length of the arc until the required current value is obtained, then note the voltage and the length of the arc. If the voltage is too low, the resistance is too great, and some must be taken out. Take another reading, first again bringing the current to the required value by altering the arc length. By repeating this operation several times an adjustment will be obtained which gives the required current with the correct voltage at the lamp. It will then be found that the arc is of correct length.

NOTE.—To obtain correct burning of search lights and feeding of the lamps it is essential that the dynamos should be always run at exactly the voltage for which the lamps were adjusted.

Burning Search Lights and Practical Working.

To prepare a Search Light for Burning.—If there is time always test the circuits, and the adjustment of the lamps beforehand. The greatest care must be taken in fixing the carbons in their holders so that they are perfectly in line both when facing the front and side of the lamp. Unless this is done, the crater will not form evenly and an unsteady light will be obtained. Never put in a carbon which is not absolutely straight. The carbons should always have the crater and point formed on them beforehand. This can be done by burning them in the day time, but in the case of horizontal carbons it can best be done by turning them out in a lathe. The crater should have a depth of three-eighths of the diameter of the carbon; the point should be of one diameter's length.

The gear for adjusting the positive carbon should always be tested to see that it is free enough to enable it to be worked easily, but that it is not so loose that the carbon drops down by its own weight when the set screw is eased up.

The position of the carbons must be adjusted so that the crater is opposite the centre of the mirror when the vertical adjustment of the positive carbon is in its central position. In the inclined lamp this can easily be done by the star wheel, the crater being placed 21¼ inches above the base plate. In the horizontal lamps the negative carbon holder must be clamped at the correct height by careful measurement when in the projector; half an inch error is sufficient to spoil the beam.

No rags or gear should be stowed inside the pedestal or in the barrel on account of the danger of fire, and of the liability of their jambing the mechanism.

Always join up the leads and everything ready for burning before it gets dark.

To burn the Light.—Put the switch in the pedestal to "On" and make any other switches that may be in the circuit. Then close the carbons.

Inclined Hand Lamp.—As soon as the points appear incandescent, separate them slowly, and keep them within about a quarter of an inch from one another, as the crater begins to heat. When the carbons are well hot and a crater is beginning to form, separate the carbons to about half an inch, and keep them at that distance by closing them in slightly as they burn away. Watch carefully to see if the crater is forming in the lower carbon. If the arc appears beaten down, this probably will occur, and the polarity of the machine is reversed, or the leads are incorrectly joined up. Keep a look out to see that the crater burns evenly. If any portion of it does not burn away sufficiently, alter the position of the $+^{ve}$ carbon, so that the arc will play against that part, taking care to replace the carbon in line as soon as the crater is properly reformed.

The arc, when burning properly, will remain quite silent, but if the carbons are bad ones or the crater is badly formed, the arc will flicker about from one portion of the surface to the other, and a great deal of hissing and flaming will occur. The only cure for this is to close the carbons slightly to heat them up well, and to alter the position of the positive carbon until the crater is re-formed. The hissing and bad light will be probably increased whilst this is being done, but it cannot be avoided.

If a button forms on the negative carbon, it shows they have been kept too close together. In this case separate the carbons and chip off the button with a knife, since while the button is there the light will never burn steadily.

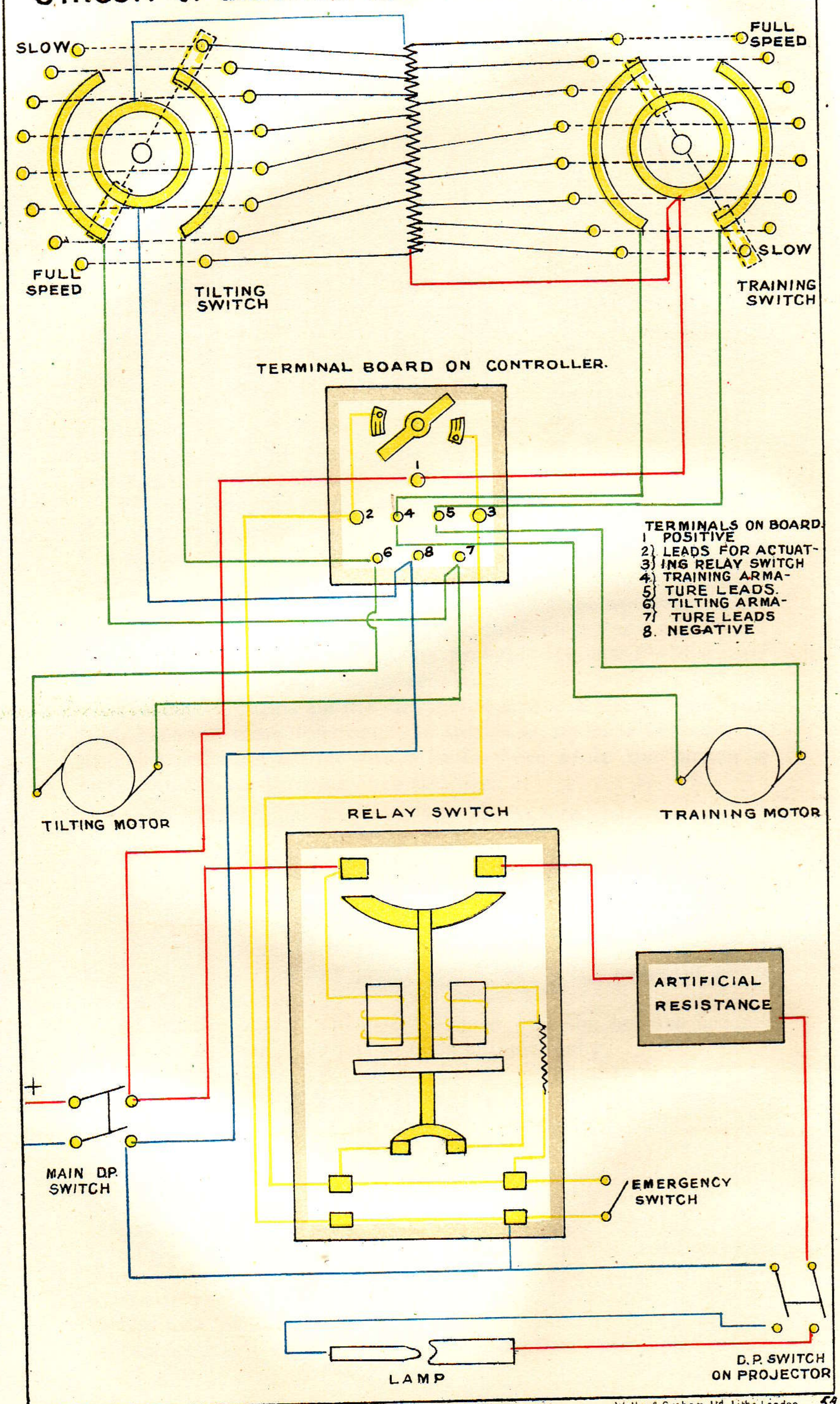
With an Automatic Lamp the arc should always be struck by hand, for the automatic gear takes too long to close the carbons in. The instant that the carbons touch each other, the series magnet of the lamp will separate them, and it is therefore not necessary to separate them by hand.

Great care must be taken never to work the hand wheel unless the lever is first put to "Hand" (or "Off"), otherwise the pawls will soon be damaged.

When the crater is properly formed, and the arc has become silent, the lamp may be put to burn automatically.

Should the lamp not feed in when it is seen that it should be doing so, do not at once alter the adjustment of the voltage screw, as this adjustment has been carefully made with a voltmeter, and it is very possible that it is not the cause of the failure. First work the shunt armature with one finger, and see that the pawls are working. Secondly, make sure that the make and break screw is in good order. If the armature is heard to be vibrating but no feeding is occurring, there is probably some friction in the gear, or the pawls are at fault. Put lever to hand and work hand wheel to see if the gear is free. A burr on a tooth or a particle of carbon may jamb the mechanism. If "pumping" of the positive carbon occurs, it may be due to any one of the following causes:

Circuit of Electrically Controlled 36" Projector.



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To face page 235.

spring acting against striking coil too strong; striking coil faulty; insufficient current passing through the lamp.

General Remarks on Burning and Management.—Keep the doors of the barrel closed as much as possible whilst burning, so as to keep the wind away from the arc.

To put the light out, always separate the carbons and so break the arc before breaking any switch. If a lamp will not burn when in the projector, test for a break with an incandescent lamp between various points on the mains. If the lamp burns in one position of the projector only, the spring contacts must be at fault.

Always keep the beam carefully focussed; the beam should be as narrow as possible, providing that the rays do not cross. If one half of the beam is brighter than the other half it may be due to the bad burning of the crater, or because the crater is not in line with the centre of the mirror.

Allow the projector to cool slowly after use, and do not expose the mirror to a cold draught of air.

36-inch Electrically Controlled Projector.

A brief reference is made to this projector on page 222, and Plate XXVIII. shows a diagrammatic view of the circuit.

The projector is fitted with two small shunt wound motors in its pedestal which can be made to train and elevate the projector at varying speeds by means of a controller, generally placed aloft, which has separate switches for elevating and training, but which makes use of the same resistance and feeding mains for both motors.

The controller is fitted with a switch and terminal box at its base, and cables are led from here to each armature and to the fields. The box is fed by a lead brought direct from the mains on the dynamo side of the artificial resistance, thereby supplying the full voltage of the ship to the motors. In the early types of these mountings the main lamp leads were brought up to this switch, to enable the light to be switched on or off from this position. To save the weight of cable this necessitates, a relay switch has been introduced which is placed with the resistances down below behind armour. Small leads now only have to be brought from the switch to the controller, and the latter switch now only operates an electro-magnet which puts the main switch on. A small switch is also placed at the projector for operating the relay switch.

The speed of the motors is varied by altering the voltage applied to their brushes, the fields having been put on when the main D.P. switch is "On" and kept constant the whole time. (For simplicity these are not shown in the plate.) The resistance is wound on two cylinders, one of which fits inside the other, but which are joined in series with each other and permanently joined across the mains, so that a current is flowing through the resistance the whole time that the main switch is on. The full voltage of the mains is therefore being absorbed by this resistance, and by tapping off leads from various points along the resistance it is possible to obtain any required voltage up to that of the mains. In the plate it will be seen that the two half segments of each controller supply the armatures, and the contacts round the outsides of the controllers are joined to various points on the resistance. The inner ring of each controller is joined to one end of the resistance so that by moving the controller wheel the inner ring is connected to one armature brush, and the other brush is connected to some point on the resistance which has a certain D.P. between it and the end of the resistance. The full speed is obtained when the maximum amount of resistance is between the brushes and the D.P. between them is therefore the greatest. The reversal is obtained by moving the controller the other way round.

The relay switch consists of an electro-magnet joined across the mains with a resistance which can be joined in series with the magnet when the switch is on. This resistance is thrown in or out of the circuit by means of a small short-circuiting contact on the main shaft of the switch. When the switch goes on this contact is broken and the resistance is thrown in series with the magnet. By this means a full field is obtained for actually pulling the switch on, but when once on, the resistance allows only sufficient current through the coils to hold the switch on and prevents overheating.

Coaling Arc Lights.

In addition to those for use in the search lights, arc lamps are supplied for coaling and other purposes. They are four times as effective as the old "yard-arm group," with the consumption of less than half the current.

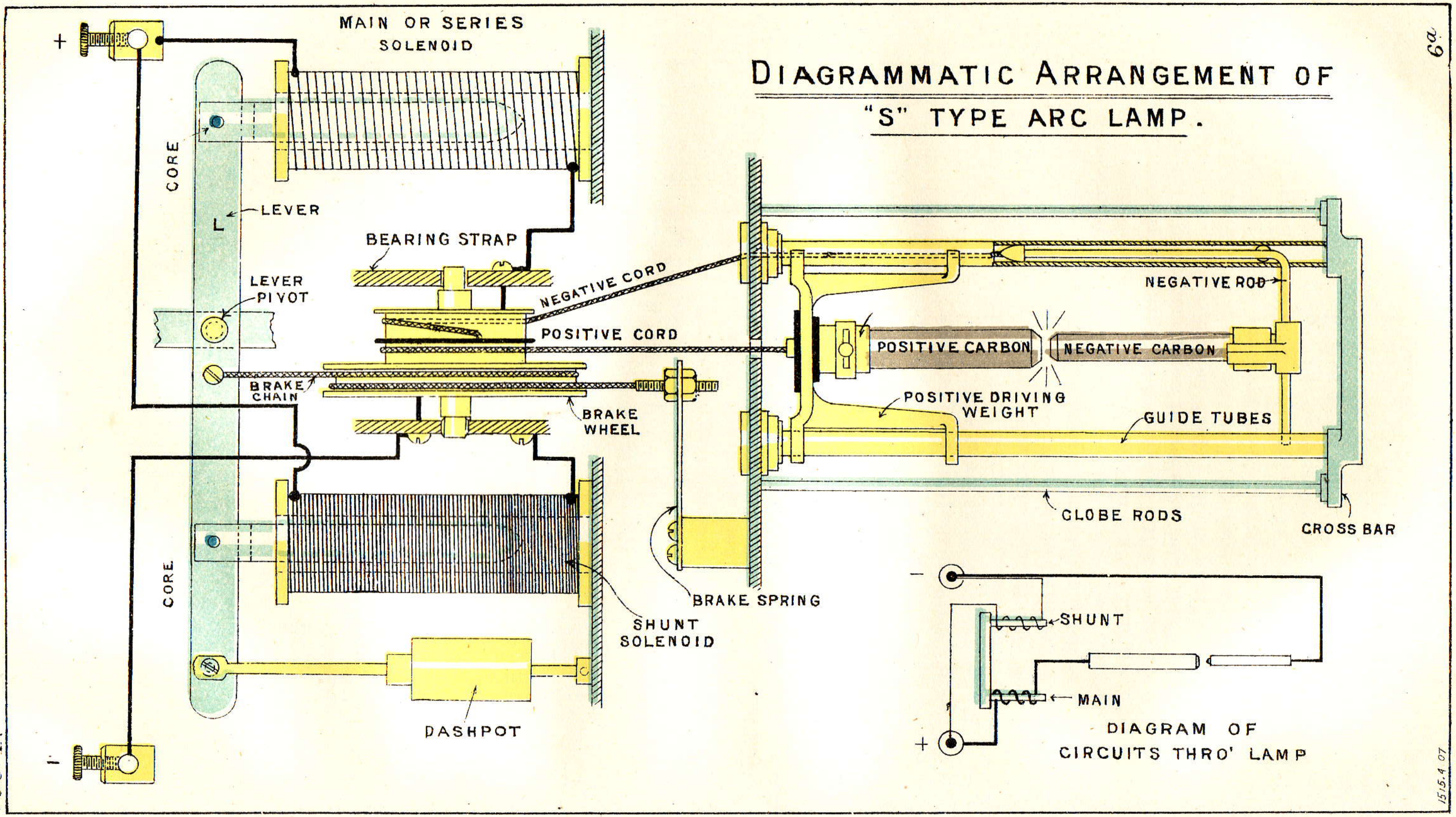
Small arc lamps (except the "flame arcs" described later) all have their carbons vertical and are of course automatic. Their feed arrangements are a combination of gravity with either—

(1) A shunt and a series coil.
(2) A series coil only.
(3) A hot wire in series with the arc.

As an example of the first type, a lamp much used in the Service manufactured by Messrs. Crompton will be described.

It is known as the coaling arc lamp "S" type, and is shown in Plate XXIX.

The lamp consists of a framework, containing the feeding arrangements in its upper half and the carbons in the lower half. The $+^{ve}$ carbon is the upper one, and is supported by a wire which passes up through an insulated hole to the drum, which it is wound round. The wire supporting the $-^{ve}$ carbon is wound round the drum the opposite way, so that if the drum turns, the carbons mutually recede or approach one another. The $+^{ve}$ carbon and its holder are made heavier than the $-^{ve}$, so that if the drum is unrestrained, the carbons run together. This is their normal position when no current is flowing. When the lamp is switched on, however, the core of the series solenoid is sucked down. This pulls down on the large lever (L) and pulls up on



DIAGRAMMATIC ARRANGEMENT OF "S" TYPE ARC LAMP.

To face page 236.

the brake chain. This movement first tautens the chain on the brake wheel and then, continuing to pull up, it revolves the brake wheel and drum, pulling the carbons apart, and striking the arc. The carbons burn till the arc begins to get too long, when the voltage across it rises, and the shunt solenoid overcomes the series and pulls the other end of the lever (L) down. This slackens the brake chain, which allows the drum to rotate till the carbons have approached one another sufficiently far for the series solenoid again to take charge of the brake drum.

A dashpot is fitted to prevent the mechanism from pumping or "chattering," by delaying the movements of the lever. The shunt end of the lever is heavier than the series end, so that when the lamp is switched off, the lever falls at the shunt end, and the carbons run together. The current enters at the $+^{ve}$ terminal of the lamp and passes through the series coils, the end of the series coils being led to a bearing of the brake drum and thence to the right hand part of the drum, both this drum and its bearing being insulated from the frame. From the drum the current passes down the suspending wire to the $+^{ve}$ carbon, carefully insulated from its guides. From the $-^{ve}$ carbon the current passes up the $-^{ve}$ suspension wire to the other half of the drum and thence to the $-^{ve}$ terminal of the lamp.

The points at which insulation is required and which should be examined if short-circuits occur are:—

$+^{ve}$ lamp terminal—brush and washers each end.
$+^{ve}$ side of drum—insulated from $-^{ve}$ side by sheet mica.
$-^{ve}$ side of drum—screws connecting to $+^{ve}$ side bushed.
$+^{ve}$ suspension wire insulated from frame by porcelain bush.
$+^{ve}$ carbon holder insulated from its guides with sheet mica top and bottom.
$-^{ve}$ terminal insulated at "series" end.

Guides to carbon holders insulated at the upper ends with bushes and washers above and below frame.

Globe rods bushed at lower ends.

The lamp takes 10 amperes and requires about 45 volts at its terminals, hence with 100-volt mains, a resistance of 5·5 to 6 ohms is required in series.

An artificial resistance is supplied with each lamp. It is in two parts, and each part is capable of adjustment up to 3·75 ohms, making a total of 7·5 ohms.

Two nuts are fitted to connect the spring to the lower end of the brake chain, and to allow of adjustment of the length of the chain. The brake chain should be adjusted, so that when the shunt end of the rocking lever is about $\frac{1}{8}$ inch above the top flange of the shunt former the carbons are free to run together.

The lantern (not shown) is lowered on the lantern rods shown at the side of the side tubes, these rods being first of all sprung into the clips attached to the upper part of the lantern spinning.

Small flexible connections are attached to each half of the brake wheel so as not to rely on sliding contacts alone, and as far as possible, micanite is used for insulation.

The resistance of the series coil is ·2 ohms and of the shunt about 170 ohms.

The carbons are 8 inches long, the $+^{ve}$ being 0·72 inch and the $-^{ve}$ 0·48 inch in diameter.

Gilbert's coaling arc lamps, some of which are in use in the Service, are examples of the second type—*i.e.*, gravity feed controlled by a series coil only.

A diagrammatic sketch is given in Fig. 147.

The carbons are, as usual, vertical, connected over a pulley (F) by a flexible wire. The positive carbon and holder are heavier than the negative, so if unrestrained the carbons run together.

When the lamp is switched on, the current through the series coil sucks up the core (A), raising the lever pivoted at (E). This puts down the clutch (B), which first grips the $-^{ve}$ suspension bar (D), and then pulls it down. This causes the carbons to recede and strikes the arc. When the current decreases sufficiently, due to the lengthening of the arc, the core (A) falls down, releasing the clutch (B), and allowing the rod (D) to slip through it, so that the carbons again approach one another, and so the feed is maintained.

The sliding block of the clutch (B) requires very careful adjustment, so that the bar (D) slips through it when the core is down and is gripped directly the core rises.

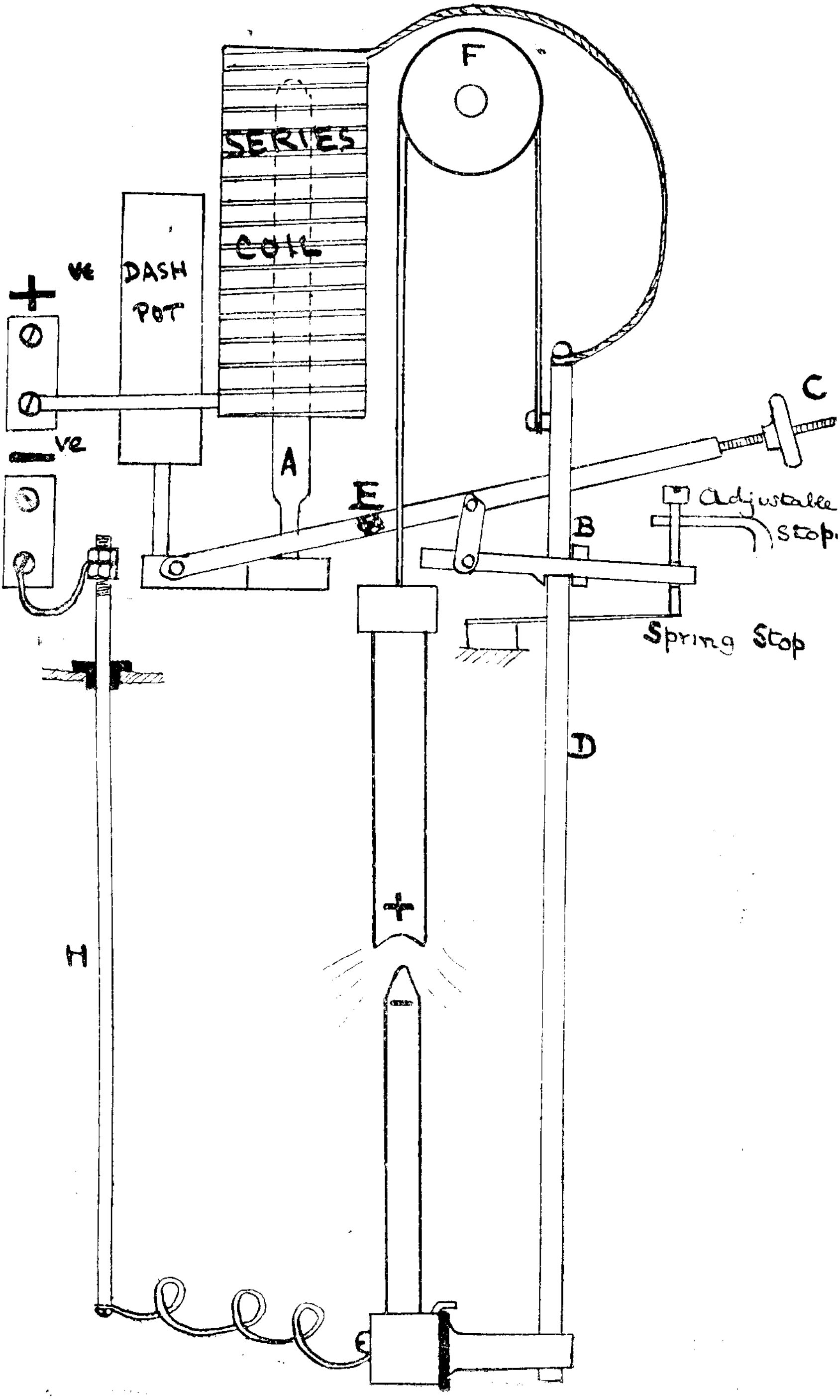
The counterbalance weight (C) is also adjustable, so as to regulate the amount of current which will suck up the core (A).

The current enters at the positive terminal of the lamp, and passes through the series coil on to the suspension wire of the carbon holders. From this point it is entirely uninsulated from the body of the lamp, so $+^{ve}$ current may be said to flow through the series coil on to the body of the lamp and to the $+^{ve}$ carbon. From the $-^{ve}$ carbon and holder, which are well insulated from the suspension bar, the current passes through a flexible connection to the rod (H), carefully insulated from the frame, and thence to the $-^{ve}$ lamp terminal.

Both Crompton's and Gilbert's lamp can be burned in series, and two in series do not require any artificial resistance, the leads absorbing sufficient D.P. to leave about 45 volts on each lamp.

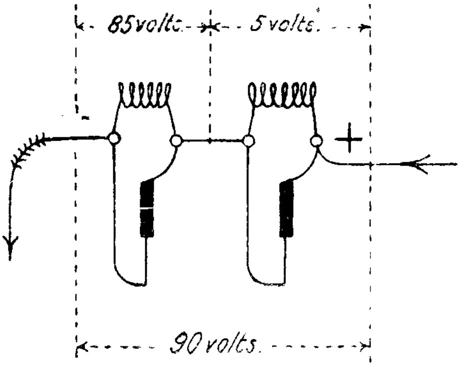
If these lamps are burned in series the dashpots must be efficient, or they will "chatter" and the light will flicker; also the brake chains in the Crompton lamps, and the clutch in the Gilbert lamps, must be carefully adjusted so that each lamp takes about the same voltage. In Crompton's lamps, if one lamp becomes shorted, or the carbons remain together from any cause, 80 or 90 volts D.P. will be set up across the shunt coil of the other lamp, and the coil will, if left in this condition, get very hot, finally burning out (*see* Fig. 148). To avoid the chance of this the shunt coils may be joined in series with one another across the two lamps, but they do not then burn quite so steadily and require an additional lead. Gilbert's lamps, having no shunt coil, are not exposed to this accident.

FIG. 147.


F
SERIES
COIL
DASH POT
+ ve
— ve
A
E
C
B
Adjustable stop.
Spring Stop
D
H
+

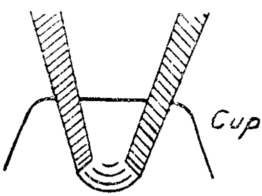
As a representative of the third type, viz., gravity feed controlled by a hot wire, a short description of a flame arc lamp is given, the lamp described being also fairly representative of the general type of flame arcs now coming into use.

FIG. 148.



It has been found that a longer and more luminous arc of warm pleasant light is formed between carbons treated with fluor spar and certain other substances. At the same time increased economy is secured. The carbons for flame arc lamps are inclined towards one another as in Fig. 149, and the arc is

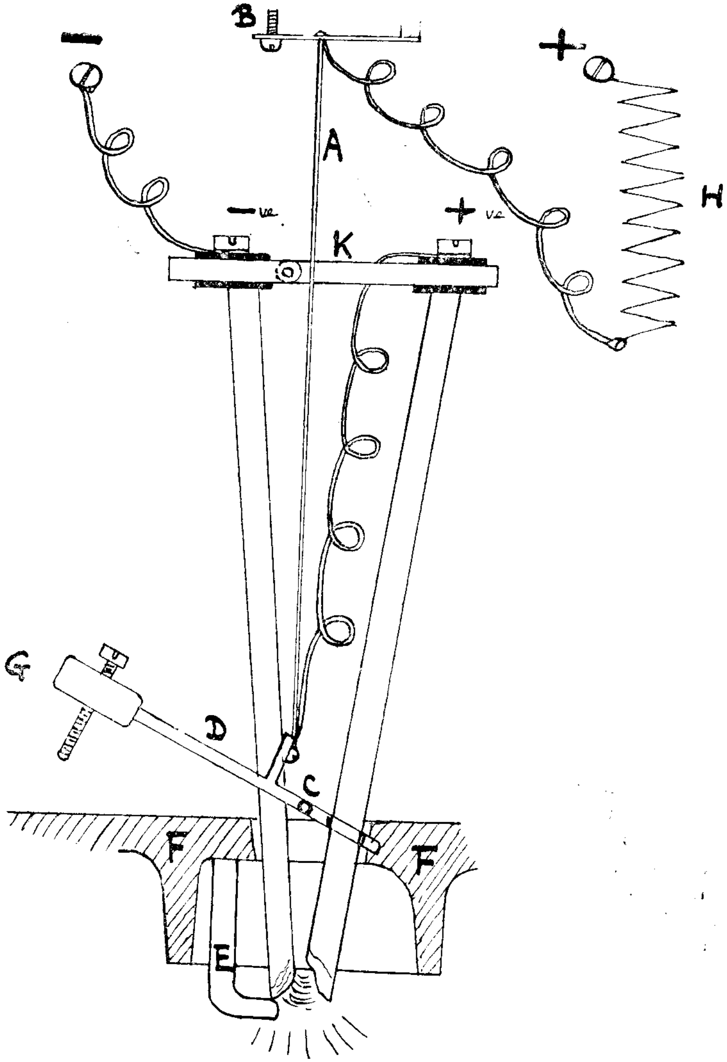
FIG. 149.



formed between their ends. If in the open air the arc would be carried up into an upward bow by the hot air ascending, but in these lamps the arc is made to bow downwards, in some cases by placing the pole of an electro-magnet in series with the main current, over the arc to blow it down, in other cases by having an inverted cup of metal or some infusible substance over the arc, stopping the ascent of hot air. Fig. 150 shows a typical flame arc lamp with hot wire feeding and striking arrangement.

The two carbons are supported at their upper ends in a holder (K), which keeps them at the same level. The –ve

IG. 150.



carbon rests on a small support (E), which prevents it falling right down. The holder (K) keeps the end of the $+^{ve}$ carbon level with it. The arrangement to regulate the length of the arc consists of the lever D, pivoted at C. The lower end of this lever holds the $+^{ve}$ carbon in a fork.

When the lamp is not in use, the metal strip A keeps the weighted end of the lever up, and the forked end down, thus allowing the carbons to touch.

When current is passed through the lamp, the metal strip expands and allows the weighted end of the lever to fall. The forked head rises and, since it revolves about C, it forces the $+^{ve}$ carbon away from the $-^{ve}$, thus striking the arc. As the $-^{ve}$ carbon burns away, it slips down so as to keep its lower end on the support E, the holder keeping the $+^{ve}$ opposite to it.

There are two adjustments of this lamp. The first is the screw B, for regulating the tension of the metal strip A. The second is the screw G, for adjusting the amount of fall of the weighted end of the lever and thus adjusting the length of the arc.

There is an adjustable steadying resistance in series with the $+^{ve}$ circuit, wound on two columns inside the lamp. An additional series resistance is, however, required outside the lamp when using it on 100-volt mains.

The cup F is placed round and over the arc, as before mentioned, to prevent the upward current of hot air blowing the arc upwards.

This cup also performs the office of a reflector, throwing any rays which strike upwards, down into the illuminated area. It is further assisted in this duty by the deposition on its surface of a brilliantly white powder, given off in the decomposition of the salts contained in the carbons.

A number of flame lamps are now on trial in the Service and are proving satisfactory; several of the types have a shunt and series coil feed mechanism similar to the open arc lamp first described. The hot wire system of striking the arc has the disadvantage of taking a long time to strike again should the arc suddenly be blown or shaken out, as the hot wire has first to cool to allow the carbons to close together.

A type of lamp, of which there are some on trial in the Service, has the arc enclosed in a globe to which the access of air is limited. This is found so to retard the combustion of the carbons that they will last at least five times as long as in the open type lamp.

In some types of lamps two globes are used to prevent the access of air. The light given by these lamps is generally white and diffused; the burning is very steady on account of the slow burning and absence of draught.

The enclosed type of lamp requires about 80 volts across the arc, and is therefore not so economical electrically as the open type; but when burning the lamp on a 100-volt circuit through a resistance it must be remembered that an equivalent saving in power is obtained by using the smaller resistance. The automatic gear of the enclosed lamp generally consists of shunt and series coils similar to the type first described.

Lamp.	Watts absorbed.	Candle Power.	Watts per Candle.
Open arc lamp - - -	503	1,365	0·368
Enclosed arc lamp - - -	510	710	0·718
Flame arc lamp - - -	515	2,125	0·242

This table, though it probably exaggerates the disadvantages of the enclosed lamp, clearly shows the increased economy of the flame arc.

For signalling purposes a small arc lamp, known as the cruiser arc flashing lamp, is in use. It is a hand-fed lamp and takes about 10 amperes; a shutter worked by a lever is fitted on the front of the lamp.

An artificial resistance similar to that for the coaling arc lamp is supplied with each lamp; its resistance is about 4 ohms.

When fitting new carbons into these lamps open out the carbon holders to the full extent, and see that the end of the carbon is flush with the end of the carbon holder.

CHAPTER XIV.

SEARCH LIGHTS—*continued.*

IT will be as well before entering on the more theoretical portion of the study of the search light to trace briefly the elementary relations between light and heat.

We must imagine the molecules of all bodies to be in a state of incessant vibration, and that this vibration increases as the temperature of the body rises, and decreases as its temperature falls. These vibrations of the molecules cause waves to be formed and travel in the surrounding ether; these waves are usually called heat waves, because it is through them that heat is conveyed from one body to another through the ether of space.

These waves are not all visible; that is, although they strike the eye, they are not all of the right *pitch* to affect the nerves of the retina. Light waves, on the other hand, are in reality only those heat waves which happen to be so timed as regards wave length and rapidity of vibration that they can affect the eye and produce the sensation of light.

Light waves occupy only a small portion of the whole range of heat waves, and of them each different wave length affects the eye in its own particular manner, producing the sensation of a different colour. But, what for the present concerns us most, is the fact that *light waves are but heat waves of special length*, and that the more we raise the temperature of a body the quicker will be the vibration of the molecules and the more rapid the vibration formed in the ether. This can easily be shown by taking a bar of iron into a dark room where it is quite invisible, and heating it gradually; as its temperature rises, we feel it getting hotter and hotter, radiating its heat to us through space, but it remains invisible till its temperature reaches about 1,000° F., when it gradually appears to be giving out a dull red light. As its temperature is still further increased, the light it gives out becomes yellow, and, at last, at a very high temperature, it becomes almost white. At the same time, the more it is heated the greater will be the quantity of light each little area of the iron gives out; or if we use the term *intensity* to express quantity given out by each unit area, the more *intense* the light will become. Evidently, there must be a limit to the intensity of light any particular body is capable of giving out, since all bodies, if raised beyond a certain limiting temperature, vapourise or in some way alter their state.

The higher the temperature to which a body can be raised without change of state, the greater will be the intensity of light that can be obtained from it by the application of heat. Carbon, for instance, can be raised to a very high temperature before it volatilises, and consequently, at its temperature of volatilisation, gives out a very intense light. The intensity is constant for any size or shape of carbon that may be used, provided its temperature is kept constant. Of course, the larger the area of the piece of carbon so heated, the greater will be the total quantity of light given out by the whole surface; but the quantity given out by each little unit area, or, as we have chosen to call it, the intensity of that source of light, will remain the same provided the temperature is the same in each case.

Gases differ from solids in that they emit but little light although raised to a very high temperature, but gases so heated may be made to play upon solid bodies, raising them to a very high temperature, when they in their turn will emit a very intense light. The gaseous portion of the electric arc lamp, although at a very high temperature, gives only about 5 per cent. of the total light of the lamp.

In dealing with light we shall for the future assume that the light issues in straight lines in all directions from the source of light; these lines are termed rays of light.

It will not be out of place here to explain the various terms that will be subsequently used in dealing with the phenomena of light.

Reflection of light is the bending of rays of light that strike a perfectly smooth surface. They are bent back at an equal angle to the surface to that at which they strike. This produces an image of the illuminating object in the direction at which the reflected rays are proceeding when they strike the eye.

Diffusion of light is the reflection of rays of light from the irregular surfaces of rough bodies. No image of the source of light is produced, but the surface itself becomes *visible* by the diffused light which its surface reflects.

NOTE.—A mirror is, comparatively speaking, invisible, from the fact that all rays of light are reflected, and reproduce the image of objects from which they emanate; but a rough surface is visible, since it diffuses light, different in colour or brightness to that which other surrounding surfaces diffuse.

Absorption.—When rays of light strike a diffusing substance some of the rays may be absorbed and not diffused; hence the remainder, travelling to the eye, no longer produce the sensation of white light but that of a definite colour, which colour depends on the quality of the diffused rays.

Refraction.—A ray of light is bent at the point where it passes obliquely from any one substance to another; for instance, from air, into water or glass. This bending is in such a direction that the ray is always more nearly perpendicular to the surface of the denser substance. The amount through which the ray is bent is termed the angle of refraction.

Intensity of a source of light is the quantity of light emitted by each unit area of the source.

Candle power of a source of light in a given direction, is the intensity with which it radiates light in that direction. Unit candle power is given by a standard spermaceti candle burning 120 grains of wax per hour.

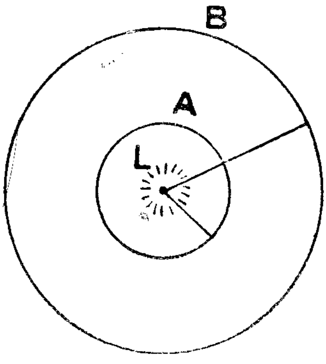
Illumination of a surface is the quantity of light falling on it per unit area.

Brightness of a diffusing surface may best be defined by saying that a surface has a brightness of one candle power per square foot, when an area of one square foot acts like a lamp of one candle power, normal to the surface.

Reflecting power of a diffusing surface is the ratio of the amount of light reflected to the total amount of light falling upon it.

In the case of a source of light dispersing rays in every direction, the illumination, or light per unit area, at two different places, varies inversely as the square of their distance from the source of light.

FIG. 151.



This can be seen to be true by supposing the light L (Fig. 151) to be at the centre of two glass globes A and B of different sizes. The same amount of light passes through each globe, but as there is more surface on the larger one, the light is more spread out. The illumination of the globes, therefore, varies inversely as their areas, that is, as the square of their distances from the centre.

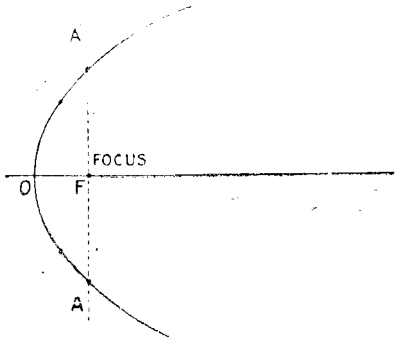
If now, instead of allowing the light to disperse over these large areas, the light be collected and made to travel in a parallel beam, then it will be seen that the same amount of light will illuminate the same area, however far off, so, if no other losses to the light occurred, an object in the beam would be equally illuminated, however far it was off.

This is done in the search light by means of the mirror referred to on page 221, which is placed so as to receive as much light as possible from the search light lamp.

Parabolic Mirrors.

Theoretically the nature of the curve required for such a mirror is a parabola, since it has the particular property of reflecting all rays incident on its surface in parallel directions, provided the source of light is placed in a certain position, called the focus. Fig. 152 shows the curve known as a parabola. F is the focus, O F is termed the focal distance.

FIG. 152.



A mirror of such a shape is extremely difficult to grind, and would give much trouble, on account of heating, &c. In practice, therefore, only a small portion of the curve is made use of, the arc light being brought as close as possible to the mirror, so that the angle subtended by it shall be as large as possible.

As the crater has been shown to be by far the most effective portion of the source of light, we need only consider how we can throw the greatest amount of light from the crater on to the mirror. By considering how much of the surface area of the crater is showing towards any part of the mirror, we can calculate how much light each part of the mirror receives.

For instance, if the $+^{ve}$ carbon be placed horizontal, with the crater at the focus, viewed from the points A or A^1, the edge of the crater only would be visible, and the light falling on that part of the mirror would be very small. Viewed from O, although the full surface of the crater is showing in that direction, no portion of the crater would be visible on account of its being screened by the negative carbon.

Fig. 153 shows the relative quantity of light emitted by the crater of an inclined lamp in any direction, the amount being proportional to the distance of the curve from the crater in that direction. It can now be seen why the rising of the hot gases of the arc, mentioned on page 227, may assist materially in the light giving. In rising they tend to eat away the front lip of the crater, thus opening out the crater towards the mirror, and showing a large surface towards the centre. With this lamp then, the mirror need only subtend an angle of about 40° each way to collect almost all the useful rays.

FIG. 153.

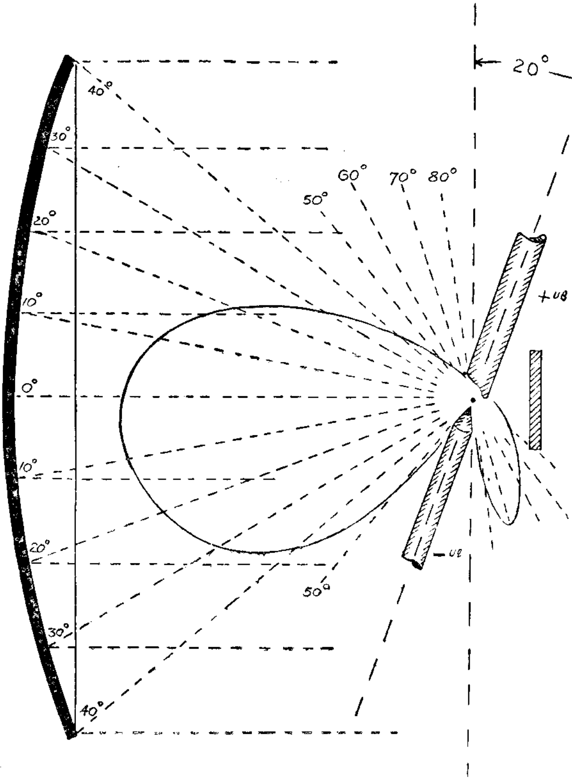
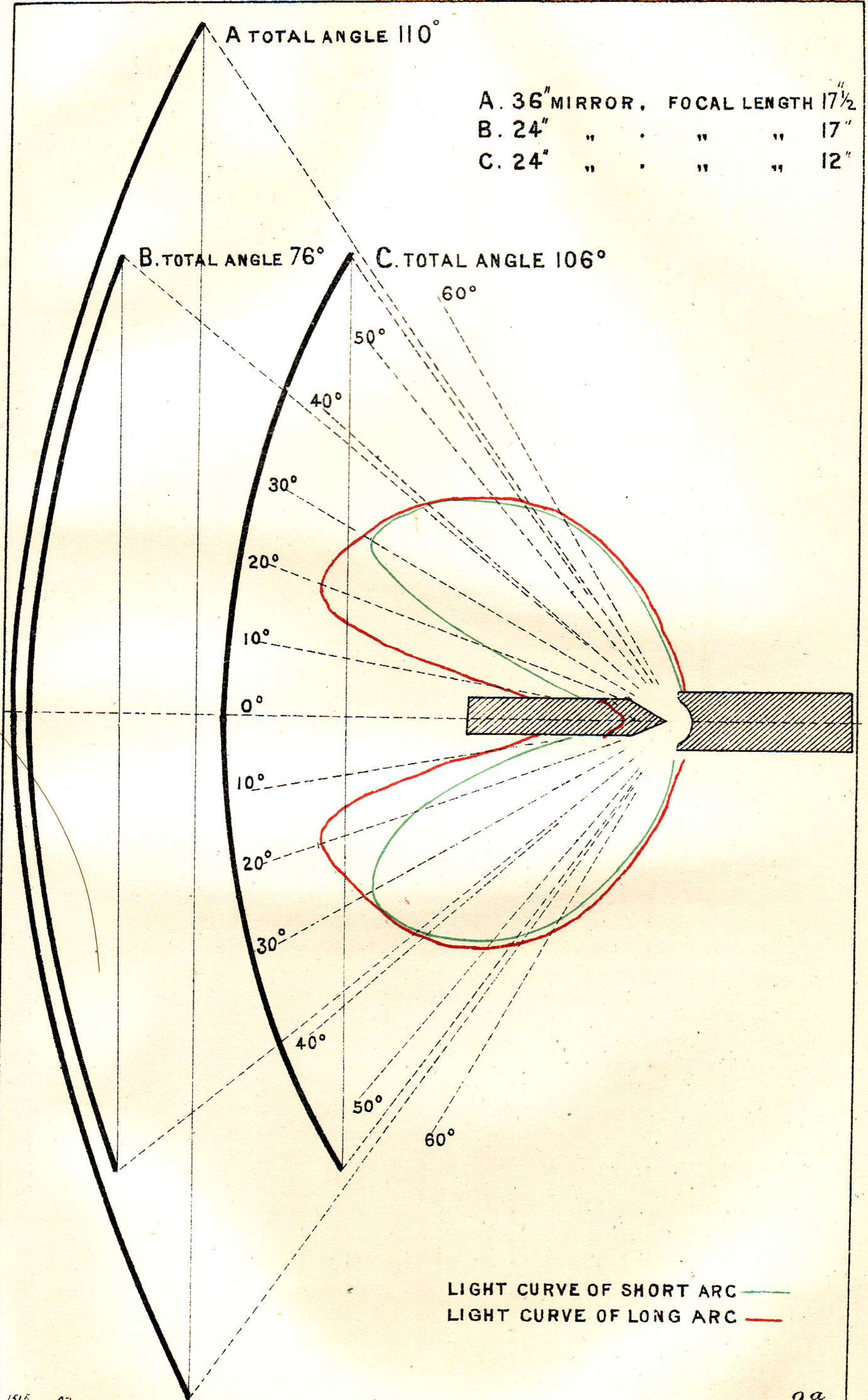


Plate XXX. shows a similar light curve for a horizontal lamp and includes the various mirrors used in the Service, placed at their respective focal distances from the crater. The maximum quantity of light is now emitted in the direction, making an angle of 30° to the centre line, whilst at an angle less than 10° nearly all light is screened by the negative carbon.

The portion of the curve shown in red indicates the additional amount of light obtained by the use of a long arc, as described on page 229, Chapter XIII.

It can now be seen that the 24-inch mirror, with a focal length of 17 inches, intercepts but a small amount of the light; and in consequence of this, the new 24-inch and 20-inch mirrors are constructed with a focal length of 12 inches. By this means they collect practically the same proportion of light as does the 36-inch mirror with its focal length of 17½ inches.



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It appears from this consideration that it is of great importance that the focal length of a mirror should be made as small as possible. There are, however, other points to be weighed with regards to this, the first one being that the mirror may be damaged by excessive heating if the crater be brought too close to it. For this reason it is proposed to reduce the current to be used in the lamp with a 12-inch focal length mirror to 80 amperes. This necessitates the use of smaller carbons, and reduces the total amount of light emitted.

Secondly, we must consider the divergence of the rays of light due to their emanating from the crater of the positive carbon instead of from a point. The parabolic mirror will only reflect rays in a parallel beam which come from the focus; but as the crater has an appreciable diameter a large proportion of the rays do not come from this point, and are therefore reflected as diverging rays.

FIG. 154.

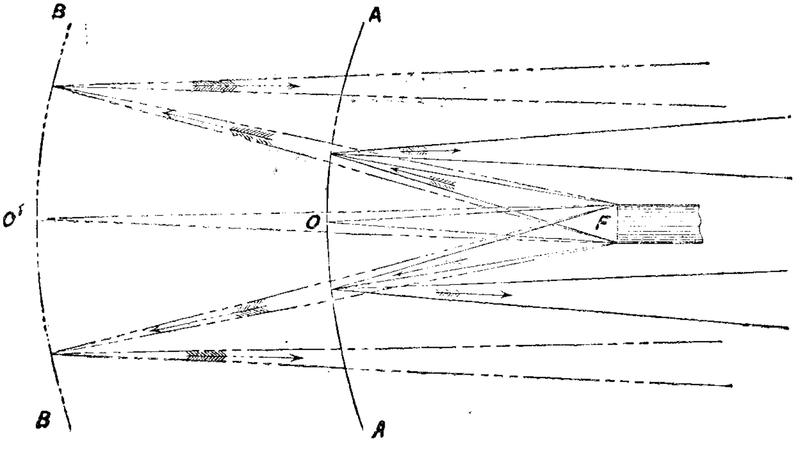


Fig. 154 shows the passage of the rays from such a source of light. Here it will be seen that the light striking each point of the mirror A A is really composed of a cone of rays having the crater as its base; these are reflected at equal angles to the normal, and consequently leave the surface of the mirror in a cone of dispersion instead of in horizontal lines.

Reference to the dotted portion of Fig. 154 shows that when the focal distance of the mirror is increased from F O to F O'_1 the angle at the apex of the cone, or the angle of divergence, is reduced. This small divergence plays an important part in the practical use of the beam. If in reality all the rays did travel in a perfectly parallel beam, a space only just the size of the aperture of the projector would be illuminated on the horizon; this of course would be useless, as it would appear a mere point, so that a slight divergence is necessary for the practical use of the light. The amount of this divergence should be about 3°. A slight calculation will show that at 2,000 yards, the area illuminated will be a circle of about 100 yards diameter; this is perfectly sufficient for searching purposes, and any further divergence had better be obtained in a horizontal direction only. If the divergence was increased to 3° 30′ the area illuminated would be about 120 yards diameter, and the illumination, therefore, in this case would be as $\frac{10^2}{12^2}$ or 100 : 144, or nearly 50 per cent. in illumination would be sacrificed. On the other hand, a diminution in divergence to below 2° would light up too small a circle.

We now have the following facts established:—

1. An increase of focal length reduces the divergence.

2. An increase of the diameter of the crater increases the quantity of light thrown on the mirror, and also increases the divergence.

3. An increase in the diameter of the mirror may or may not materially increase the amount of light reflected. This depends on the shape of the light curve, and on the angle subtended by the mirror at the focus. If, as in the 24-inch 12-inch focal length mirror, the greater portion of the light from the crater is already being collected by the mirror, an increase in diameter is of little use. But with the same sized mirror of 17-inch focal length, only a small proportion of the light is caught by the mirror, and a great increase is obtained by using a larger mirror.

In connection with this it will be seen that although a small area of crater only may be showing towards the outer edge of a mirror, and that a small quantity of light per square inch is in consequence thrown on this portion of the mirror, yet a small increase in diameter of the mirror results in a considerable increase of surface, and that therefore an appreciable amount of light may be reflected by the outer edges.

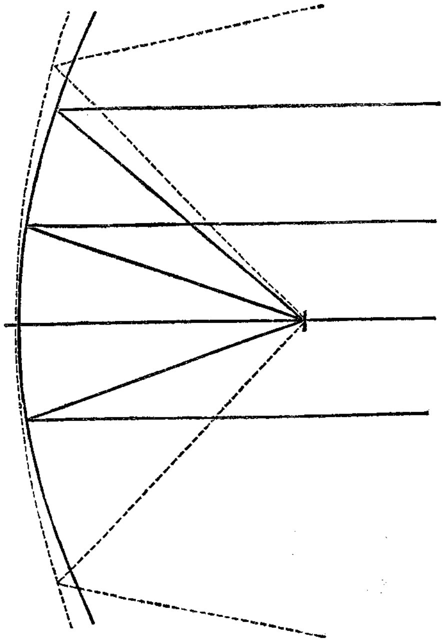
We see from this that the 36-inch projector has not necessarily any great superiority over the 24-inch projector in intensity of illumination. Comparing it with a 24-inch mirror of 17-inch focal length, it receives about double the amount of light, and the intensity is considerably increased. Compared with a 24-inch mirror of 12-inch focal length, the 36-inch mirror produces a slightly increased intensity.

4. The divergence of the rays which strike the central portion of the mirror is greater than that of the rays striking the outer circumference, and this, together with the screening of the centre of the mirror by the negative carbon, tends to make the intensity of the beam not uniform throughout its section.

Mirrors.

Even to grind a true parabolic mirror of this small arc is a very difficult and expensive matter, and it is only of late years that such a thing has been possible, whereas a spherical mirror was a far easier and cheaper form to manufacture, The dotted line, Fig. 155, shows how the arc of a circle departs from the parabolic form, and the rays of light there given show how their direction deviates from the true parallel beam, considerable divergence being obtained from striking the surface at more than 20° to the axis.

FIG. 155.

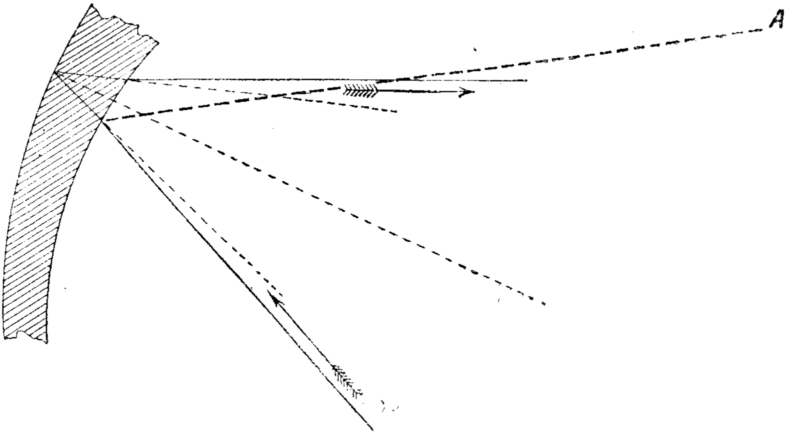


Margin Mirror.—To get over this, Mangin used a clever device, utilising the fact that rays of light travelling through glass have their course altered or *refracted.* Applying this principle, he made a mirror whose inside and outside surfaces were arcs of spheres of different radii, the inner surfaces having the smaller radius; by this means the thickness of the glass was gradually increased from the centre towards the edge, so that a ray of light striking the glass, was bent towards the inner surface, and therefore reflected at a less angle than if it had continued on its old course.

On emerging, the ray was bent again away from the normal, but the net result was that the path of the ray was far nearer the horizontal than would have been the case had the glass been thin.

Fig. 156 shows the path of such a ray, the dotted line A showing its path had the glass practically had no thickness, the full line showing its path in a Mangin mirror.

FIG. 156.



Parabolic Mirrors have now almost entirely superseded the Mangin mirror in the Service. The mirrors can be either ground or cast to the correct shape. The ones supplied to the Service are cast mirrors and have the great advantage of cheapness over the Mangin and the ground parabolic mirror. They are also much lighter than the former.

Metallic Mirrors.—The advantage of a metallic mirror over one of glass is that of not being liable to fracture by a bullet or during transport. Experiments have been conducted with them for many years, but in all cases up to the present the great heat of the arc has soon reduced their reflecting powers.

Gold-plated mirrors are now under trial and have the very great advantage of not giving a white woolly beam. The yellow light reflected from them appears to have greater penetrating power than the present light, and although about 40 per cent. of the light of the arc is lost by reflection in these mirrors, they appear to compare very favourably with the glass mirrors which only absorb about 4 per cent. of light in reflection.

Illumination by a Search Light.

All objects, which do not themselves emit light, become visible to the eye from the fact that they, or their surroundings, diffuse light, and in doing so reflect this diffused light either with different intensities or with different colours.

To be able to see an object, two things are necessary. First, there must be sufficient light reflected to travel back to the eye and affect it; and secondly, the body must differ optically from its surroundings, that is, must reflect a different amount or a different sort of light to that which is reflected by its surroundings, so that a contrast is produced on the eye. This necessity for contrast is so important for the definition of objects that we will consider more closely its relation to their visibility.

While light, such as sunlight or the electric light of an arc lamp, is composed of waves of light of different lengths, each different wave length as it strikes the eye produces the sensation of a definite colour, the exact colour depending on the wave length. If waves of all lengths simultaneously strike the eye all colours are produced at the same time, and the result of this mixture is what we call white light. We may, therefore, look upon white light as a mixture of *rays* (*see* page 245) of every different colour.

If these rays now strike an object and are all reflected to the eye, the object appears white, since the light coming from the object produces the sensation of all the rays, or that of white light, on the eye. If, however, any ray or rays are stopped and absorbed by the body and not reflected, the remainder will still travel on to the eye, but since some of the rays are missing the sensation of white light is no longer produced, but that of some definite colour, the exact nature of the colour depending on the rays that are not destroyed. If a body does not reflect any rays of light but absorbs them all, then no rays strike the eye, a blank is produced, and the object appears black.

A very common example of this is to be seen with sunlight shining on the black hull of a ship if well polished. If the light strikes nearly at right angles to the ship the light is all absorbed and the hull appears black, but from portions where the light can glance off, at a large angle to the eye, much of the light will be reflected without being absorbed, and that part of the hull appears white and shining. Again, blacks differ much in the amount of light they will reflect. A *dead* black, that is, one whose surface is quite dull and not at all glossy, reflects light badly, whereas a black varnish, as we have seen, at times reflects light fairly well.

Another point to remember, is that the amount of light reflected from different portions of an object to the eye depends on the angle that those different portions make with the direction of the rays, so that an object, such as a boat, does not appear of a uniform intensity of colour all over since shade (that is, less reflected light) is produced in some places, such as the hollow of the bows or under the quarter.

We may, therefore, say that the visibility of an object depends on the difference, either in quantity or quality, of light reflected by it, compared with that reflected by its immediate surroundings. A white disc held against a white screen is hardly distinguishable from it a few feet away from the screen, but a black disc would be distinguishable as long as it were visible. The more nearly the quantity of light returning to the eye approaches that returned in ordinary daylight (the intensity to which the eye is most accustomed), the more clearly will small differences in shade and colour be detected; with a weak light such differences will be hardly noticeable, and with a very strong light the eye is blinded.

The surface of nearly all objects is rough, not smooth and polished like a mirror, consequently they do not reflect light in the same manner as a perfect surface would, but diffuse it, that is, the rays, striking the small roughnesses, are reflected off in all directions to the eyes of observers situated in different positions as regards the object.

We are now in a position to discuss the use of the search light for illuminating objects on the water, and the various occasions on which a search light may be required, and in doing so we must distinguish between detection and illumination.

Use of a Search Light.

A search light may be intended to detect the approach of an enemy, or only to illuminate and follow a moving object when it has been discovered by other means.

Detection of an object feebly illuminated depends, to a large extent, on the eye adapting itself to the particular quantity of light it is receiving, and also to the vision being directed exactly on that particular object. It is a matter of common knowledge that it is easier to keep an object in sight, when once seen, than to detect one, and that an object may be followed with the eye with ease to a far greater distance than at which it can be picked up. If, again, a moving light be used, unless the beam is moved very slowly, the eye cannot accustom itself to quick changes in small intensities of light, consequently an object will often not be noticed by a beam sweeping over it, though it might easily have been detected in passing through a stationary beam to which the observer's eye had become fully accustomed.

If a search light be kept burning from a ship with the view of detecting an enemy, it must be remembered that the light will reveal the presence of the ship, and attract every torpedo boat to her for miles around, particularly if the light be a moving one. Considering the uncertainty of detection of boats from a ship even when burning search lights, and the difficulty of destroying the boats if they are sighted, it would probably be fatal to show any light from the ship, whether in harbour or at sea, until the boat is actually discovered and fired upon, and very possibly it would be unwise to do so even then.

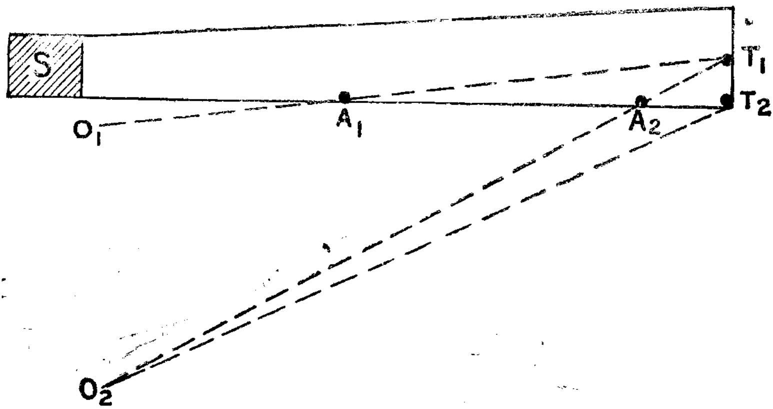
In view of the above we may conclude that maximum range is not the primary consideration in the choice of positions for search lights. The more important duties of a search light are to enable the gunlayer to see the target, and the control officer to observe the fall of shot.

Positions for Search Lights.—The visibility of an object may be due to one of two causes. The rays may be striking the object and then reflecting back into the observer's eye, or the rays may be lighting up the background, and the object is forming a screen to the rays going to the observer's eye. In this case the object looks dark against a bright background.

A search light beam, in travelling through the air, lights up innumerable small particles of dust and water; each one of these reflects a small amount of light, so that the beam appears milky and opaque.

The visibility of an object depends greatly on the distance that the rays reflected from the object have to travel, through this woolly beam, before reaching the observer's eye.

FIG. 157.



In Fig. 157, if S be a search light throwing a beam on to a target T_1, the rays reflected from T_1 have to pass through a distance T_1. A_1 before reaching the observer O_1, but the rays going to the observer O_2 only have to pass through T_1 A_2 of the search light beam.

O_2 therefore can distinguish the object much better than can O_1.

For the same reason it can be seen that if the object be situated in the edge of the beam nearest the observer at T_2, say, there will be practically no woolly beam for the reflected rays to pass through.

It may be stated then that the observer should be removed as far as possible from the light, either vertically or horizontally, and that the beam of light should be so directed that the object is in that part of the beam which is nearest the observer.

The selection of positions for search lights is governed by these considerations, but there are several other points which have to be taken into account. At least two observers have to be considered, the gunlayer and the controlling officer. A search light placed in the best position for one gun may seriously hamper another gun. The final position, therefore, must be a compromise which as nearly as possible fulfils all the requirements.

A search light placed high up will illuminate a small area only, and the laying of the projector must be very exact. If placed very low down, the search light is only available in absolutely smooth weather, as every roll and sea would occult the beam and light the ship up greatly by reflection; also the low position of the projector would cause light to be reflected from the water, and largely increase the haziness of the beam.

Searching Beams.—It may be necessary on some occasion to use the search light for detecting the enemy, and it is as well to consider how it can best be done. It has been pointed out that a fixed beam is of greater value than a moving one for this purpose, but although a fixed beam could well be used when defending the entrance to a harbour, yet if a ship has to maintain a search all round the horizon, it is obvious that with the limited number of search lights on board, the lights must be made to search through small arcs of the horizon, each one having its own arc. There are several methods which can be employed in searching this arc, the object of them all being to ensure that each point of the horizon has the beam passed over it at equal intervals of time. It is essential that a sweeping beam should be moved slowly and regularly through its arc, otherwise the object will be passed over by the beam without being seen. Look-outs must be placed to keep a constant watch on the beam with binoculars, as it is most unlikely that the beam will illuminate the object for longer than two or three seconds, and the man working the light cannot possibly keep a look-out.

Control of Search Lights.—From the above it can be seen that the man working the search light cannot be expected to keep the beam on an object which he probably cannot see unless he receives definite orders continually as to the training and elevation of the beam. These orders should be instantly carried out, the required motions being given to the projector by means of wheel gearing working at a slow speed, so as to obtain a smooth motion. If the gearing is of the correct speed, it will be found to give a superior control over the projector to that obtained by free working. The only time when free working may be found advantageous is when the ship is rolling or pitching; in this case it may be easier to hold the projector steady at the required elevation, providing that the object or the horizon can be seen from the projector. It is seldom, however, that this can be done, but if it can, it will be easier to use the geared elevating wheel.

With electrically controlled projectors, the difficulties of control are largely diminished, as the man working the light can now see what he is doing, but in spite of this great advantage a considerable number of objections to the system have been raised.

Transporting Projectors.—With a view to preventing damage being done to projectors during a day action, they should be stowed behind armour during the action, and replaced in their proper positions before nightfall.

Positions must be selected for the projectors between decks, and every care should be taken in transporting them.

All small fittings, liable to be broken in transport, should be removed, and stowed separately.

The mirror should be carefully treated and never be allowed to rest on its back.

The horizontal lamp should never be lifted by its carbon holders, as these parts are made as light as possible, and backlash will soon appear if the gear is strained.

Burning Search Lights at a Distance.

The best method of defending ships at anchor against hostile torpedo boats is to land one or more projectors near the mouth of the harbour; the most suitable positions in which they can be placed depend on the configuration of the land.

The ship may then be left in darkness so that the attacking boats will not discover her position.

In some cases when the entrance to be protected is wide, it may be found advisable to place projectors in launches moored in selected positions; if this is done, however, it should be borne in mind that a very slight sea is sufficient to cause considerable rolling of the boats, which will prevent the beams being of any practical utility.

The usual plan followed is for the projectors laid out for this purpose to show fixed beams extending across the entrance to be protected, diverging lenses being used or not according to circumstances, armed guard boats being stationed to observe and signal the approach of the enemy.

After the attacking boats have been detected in passing these fixed beams, opinions differ as to whether use should then be made of the projectors of the ships, to follow them up, or not. This would appear to depend largely on the nature of the background, and the conditions of weather and darkness.

To burn the light the current must be supplied to the projector from a ship. For this purpose 1,000 yards of cable, Patt. 1,100, is issued to all "A" class ships, which includes battleships and first-class cruisers; flagships carrying an additional 1,000 yards. This cable is intended to be used with a single dynamo, and therefore, since it will have to carry 100 ampères of current, its resistance must be kept low.

A 1,000 yard reel of Patt. 1,100 has a resistance of ·36 ohm; hence, with the full current flowing through it, the D.P. absorbed will be ·36 × 100, or 36 volts; thus if an earth return is used, the light can be worked up to a distance of 1,000 yards from the ship.

It is evidently necessary that the resistance of the earth return should be as small as possible. Experiments have proved that by using suitable earthplates, which will presently be described, it may be reduced as low as ·015 or ·02 ohms, and so absorbing about 2 volts more. This, if an 80-volt dynamo is being used, will leave 80 — 38, or 42 volts at the lamp; a few more revolutions of the machine will produce 45 or 48 volts, which is quite sufficient to maintain a good light. In ships supplied with 100-volt dynamos, it can be seen that the voltage will be amply sufficient without any increase of speed of the machine.

It is advisable to put the positive terminal of the machine to earth, since the positive carbon is connected to the body of the lamp, and any leak between the lamp and projector will be of little consequence; also, by so doing, the operator will be free from shocks.

Earth Plate.—The best form of earth plate to be used at the projector has been found by numerous experiments to be made as follows:—Take five 4-fathom lengths of 2-inch steel wire rope, and arrange them in the form of a star by crossing them in the centre. They should be securely seized together with a wire racking seizing, so arranged as to keep the different parts well spread out. The core of a piece of Patt. 820A lead-covered wire, or other cable capable of carrying 100 ampères, should be soldered to the centre, and led to the positive terminal of the projector. The earth plate thus formed should be placed under water, care being taken to keep the legs well spread apart by means of a spunyarn tricing line if required.

Laying out the Cable.—The Patt. 1,100 cable should be hoisted out on its reel, and placed in a pinnace or launch, supported on an iron bar so that the reel may revolve freely. The inboard end should be led in through the hawse pipe or over the bows of the ship, and sufficient slack allowed for the ship swinging. It is desirable, however, when practicable, to lay out a stern anchor, as if the ship does swing and the cable fouls, the latter may get damaged, and may be difficult to clear. The cable is then laid out from the boat and unreeled as required, the shore end being joined to the negative terminal on the projector pedestal. For landing, the projector should previously be taken to pieces; this will increase its portability, and the mirror will not be so likely to suffer damage. The parts can then be easily taken on shore in a small boat, and the projector set up again in the desired position.

A separate dynamo, when available, should be used for burning lights at a distance, since it is inadvisable to introduce an earth on the incandescent lighting of the ship.

It will generally be found convenient to connect the cable to the negative terminal of one of the foremost search lights, thus putting it in direct communication with the negative bar of that search light on the switchboard. Should the artificial resistance be in the negative lead, it must of course be short-circuited.

The earth connection should be made from the positive bar of the same search light to the hull of the ship, by a piece of 100 ampere wire fitted with a flat metal eye soldered at its end. Any convenient nut in an iron bulkhead or beam can be unscrewed, the surfaces thoroughly cleaned, and the nut then screwed hard down on the eye; or connection can be made to a copper pipe. In either case this earth plate will have an area represented by the whole of the ship's bottom. If the cable is connected to the switchboard, the switchboard cut-outs will suffice; but if connections are made direct to the dynamo, a 200-ampere cut-out should be inserted between the negative terminal and the main lead.

The question of earth plates is of great importance in considering the burning of search lights at a distance, since their resistance should be as low as possible, and every superfluous resistance carefully avoided. It is experimentally found that so long as the surfaces of the earth plates are large, thus providing an easy passage from the metal into the water, their resistance will be very small and quite irrespective of their distance apart. Two methods of measuring the resistance of an earth plate are given in Chapter XXII. (page 383).

The following regulations are to be observed in laying out and weighing a search light cable:—

(1) The cable is always to be kept stowed on the wooden reels on which it is supplied.

(2) The cable is to be run by hoisting the wooden reel into the running boat and supporting it suitably on a spindle.

(3) The cable is to be weighed by reeling it straight up on to the reel, taking out any kinks as it comes in.

(4) The cable, when unreeled for drying or repair on board, is to be stretched out or coiled down in large bights.

(5) All damage to the braiding is to be repaired as soon after weighing as possible. Where the braiding has been entirely removed for short distances, small spun yarn whippings, not more than 3 inches apart, should be put on.

(6) If the braiding becomes very bad the cable should be defected, and if in otherwise good condition returned to store to be sent to the makers to be re-braided.

(7) In the yearly reports of torpedo exercises of ships, the place, method of stowage, method and result of running the cable, as well as details as to its condition, should be fully stated.

Burning Lights with Two Dynamos in Series.

It has been seen that with an 80-volt machine a light may be burnt up to a distance of 1,000 yards from a ship; if the cable be available with a 100-volt machine, this distance can be increased to 1,500 yards. If it is desired to burn a light at a greater distance it will be found necessary to couple two machines in series so as to obtain the required D.P., and their speed should be so adjusted as to get about 60 volts at the lamp, and to maintain a current of about 110 amperes in the circuit.

The method of coupling two dynamos in series is described in Chapter IX., p. 161 and onwards.

Signalling with Search Lights.

Reference is made to a flashing shutter on p. 223. This is made somewhat on the principle of the Venetian blind, and fits on to the front of the projector.

The projector is kept steady, pointing in the direction in which the signal is required to be conveyed, and long and short flashes made by opening and closing the shutters with a lever fitted for the purpose. Good results have been obtained up to a distance of 25 or 30 miles. An advantage claimed for this system is that the signals made are only visible in the direction desired.

This method is used by day and by night. When using it by day, if the ship being signalled to is low down on the horizon, great care must be taken to lay the projector correctly. For this purpose carriers are being fitted to the barrels to take a telescope, which can be aligned to the centre line of the beam. Care must be taken that the lamp is at its correct focal distance.

As an alternative method by night, the beam may be moved up and down in a vertical arc in the sky, making long and short flashes.

Also great distances can be signalled across if the beam be used to light up some low cloud from which the light may be reflected to the other ship.

The operator should consider the state of the clouds and atmosphere before deciding in which direction to flash. A beam when no clouds are present is of but little good for long distances; everything depends on the state of the air.

For lighting up boats embarking men, or on other occasions at night, if possible use a divergent lens. It is not required, as a rule, to give a brilliant illumination; this only dazzles the men and intensifies the shadows. Remember also, that an area always appears more intensely lighted to people in that area than to those on board, for reasons already discussed. A good, evenly diffused light is what is required, without the blinding glare of the full light.

If the distance is too far for the divergent lens, the parallel beam will probably not be too strong, if the beam is slightly spread by putting the lamp out of focus.

The use of guard boats when defending a harbour requires but few remarks. Such boats would usually be employed at considerable distances from the light, and their outlook would be in a direction away from the light, hence, the direct rays would have but little blinding effect on them. The whole surrounding area of water would be lighted with an even diffused light and render objects easily visible.

To the advancing torpedo boats the guard boats will form conspicuous objects if lying between them and the beam, since they form a sharp silhouette against the lighted background, and this, in a well-lighted area, it is difficult to avoid, hence the guard boats should remember that they will probably be first seen, and that the enemy will have the advantage in this respect.

Boats attacking Ships burning Search Lights.—To the boats advancing to an attack it is of the utmost importance that they should study the distribution of light, and try, as far as possible, to keep out of the beam. The moment they enter a lighted area they are certain to be observed by the guard boats, and if they are discovered, a straight course for the ship is probably their best procedure. They will, when approaching a ship in a beam, meet with two difficulties :—

1st. The blinding effect due to the direct rays from the projector.

2nd. The light diffused from the water and particles in the air.

These two act in totally different manners.

The blinding effect of the direct rays is dazzling and injurious to the eyes, preventing even a straight course being steered for the ship. This may possibly be overcome by merely screening the source of light with a hand-shade or small metal disc, which relieves the eyes, by cutting off the intense rays.

Screening caused by the Search Light.—The light diffused from the water is far more serious in its effects, since it renders objects behind the illuminated water invisible. The visibility of a ship depends on the difference between the light reflected by it and the light reflected from its surroundings. At night this difference is very small and cannot be appreciated when a screen of luminous particles of dust and water is thrown up in front of the observer. It is impossible to mitigate this effect by the use of coloured shades, since all the sources of light will have their intensity reduced by equal amounts, hence the rays from the hull, its surrounding water, and background will be obliterated long before the light diffused from the floating particles in the air has been appreciably reduced. Such considerations teach two things, which are fully borne out in practice :—

1st. That it is the fact of the beam playing on the water in front of the boat that screens the ship.

2nd. That the instant the boat leaves the illuminated water the hull of the ship may probably become visible.

The direct light from the projector being diffused by the particles in the air, can have but little effect in screening the ship, since the greater portion of the light is thrown in a direction opposite to that of the advancing boat, whereas that reflected from the surface of the water may be thrown towards the boat.

Conclusion.—Thus it will probably be found that the moment the boats leave the illuminated water the hull will become fairly visible. The object of the advancing boat should be, therefore, to edge or dart to one side of the beam to obtain a view of the hull, judge her distance, and so determine the interval of time before turning to attack.

Burning Search Lights on 220-volt Circuits.

The use of artificial resistances to reduce the voltage from 220 to 60 would be too wasteful of electrical power and would add too greatly to the weight of material. It has also been shown on page 219 that it is inadvisable to burn the lamps in series. A special motor generator is, therefore, being introduced which acts as a negative booster, so as to supply the necessary voltage to the lamp, and at the same time automatically regulates this voltage so as to enable the automatic feeding gear of the lamp to work. The efficiency of these machines, that is to say, the ratio of the output obtained to the input, varies from about 50 to 70 per cent. Compared with 27 per cent., which would be the efficiency if artificial resistances were used, this is a great saving in power.

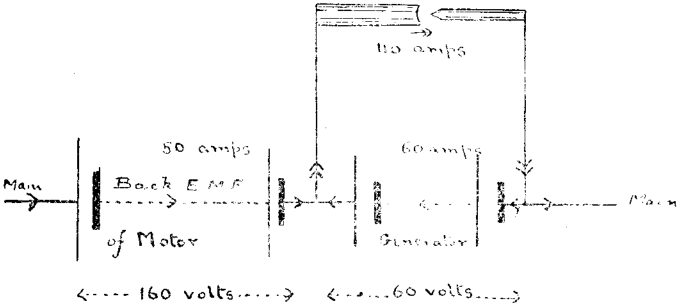
There are at present two types of these machines, the makers being the British Thomson Houston Co. and Messrs. Mather and Platt.

Both types have the motor and generator armatures joined in series across the 220-volt mains, and the searchlight lamp joined across the generator terminals.

Fig. 158 gives a diagrammatic view of the connections, and shows how the 220-volts pressure is distributed through the circuit.

The back E.M.F. of the motor and the voltage of the generator are represented by batteries, and the arrows show the direction of the current.

FIG. 158.



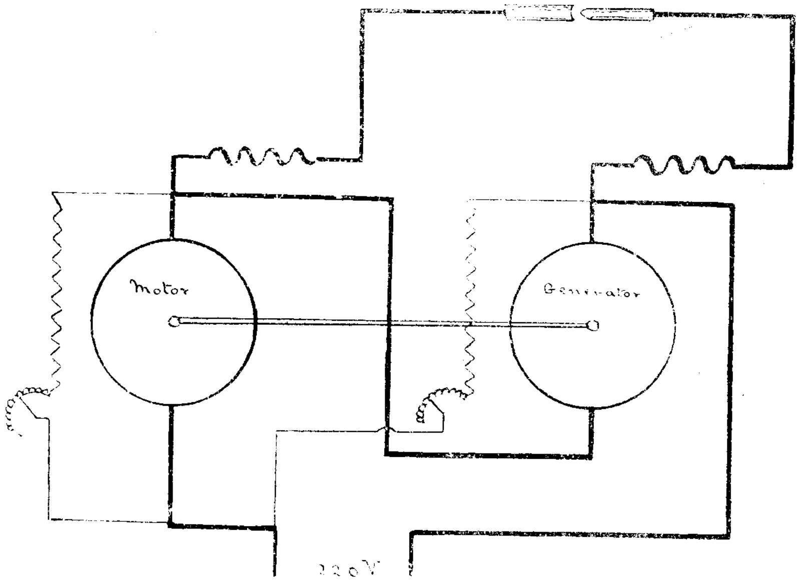
The self-regulation is obtained by entirely different methods in the two types.

In the B.T.H. machine, Fig. 159, the motor and the generator are compound wound, the series windings being joined in series with the lamp circuit in such a way that the motor winding is accumulative (*i.e.*, series and shunt windings generating the same field); whereas the generator winding is differential (or in opposition to the shunt). As the lamp current falls therefore due to the carbons burning away, the motor increases its speed, and the generator field is increased in strength, both actions combining to increase the voltage across the arc.

The shunt fields of the motor and the generator are both fitted with regulating switches, the maximum output being obtained with no resistance in either regulator.

Fig. 159.

British Thomson Houston Motor Generator.



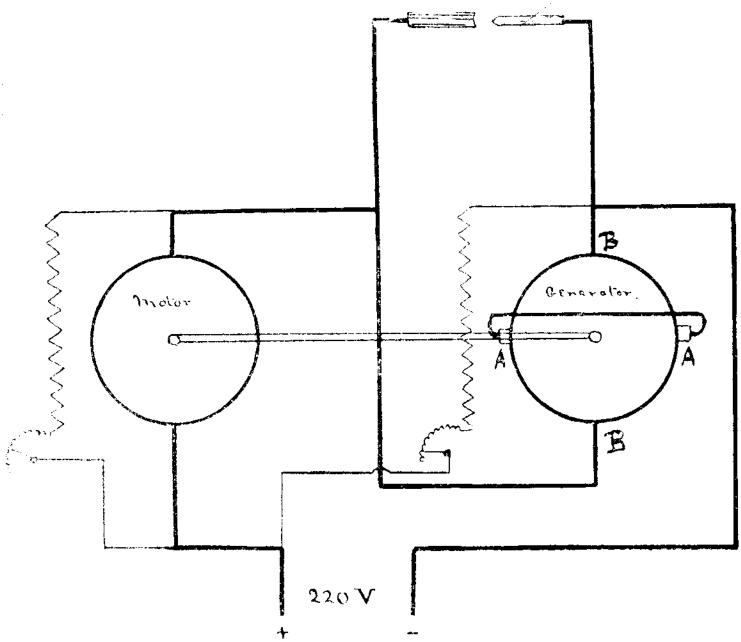
The Mather and Platt machine, Fig. 160, has shunt fields only for both motor and generator. The generator has two poles with a high reluctance magnetic circuit, so that a weak magnetic field is produced, giving a low voltage at the brushes A A, which are short-circuited. The current which in consequence flows through the armature and the short-circuit produces a strong field and a high voltage at the brushes B B which feed the arc.

This arrangement produces a constant current machine, that is to say, a constant current is sent through the carbons whatever may be their resistance and at whatever speed the motor is running at. This is best explained by saying that the current through the armature and brushes B B sets up a field which opposes the field due to the current through the brushes A A, and so reduces the voltage across B B. Suppose the current in the lamp to fall slightly, the field due to it will also fall, and the field due to current through A A will rise. This will increase the voltage at B B, and so restore the current through the lamp to its proper value.

Difficulty is experienced on account of the heavy current that passes through the short-circuited brushes when the lamp circuit is broken, when there is in consequence no opposing field. Also the brushes A A and B B are collecting current from commutator strips which are generating E.M.F., and there is therefore considerable sparking.

FIG. 160.

MATHER AND PLATT MOTOR GENERATOR.



CHAPTER XV.

Incandescent Lighting.

Incandescent Lamps.

Besides the arc lamps, another method of obtaining light from electrical energy is by using the current to heat a fine filament of carbon. We have previously seen that the heat generated by the passage of a current C through a resistance R is proportional to $C^2 \times R$: so that if the current be kept constant the heat generated will be increased as the resistance of the circuit is increased.

To obtain light we have seen that a substance must be heated to a very high temperature indeed. If conductors be heated to this high temperature in air, the air will combine with them and they will oxidise. Two things are therefore necessary in a lamp constructed on this principle, namely, (1) a conductor that will stand a very high temperature without melting or disintegrating, and (2) the exclusion of all air from contact with the heated conductor. Carbon has, until quite lately, been found the best conductor that can be used under these conditions, owing chiefly to the very high temperatures to which it can be heated without change of state. A filament or thread of carbon, inside a glass globe from which all the air has been excluded, forms the incandescent lamp used in electric lighting.

The ends of the carbon filament are fixed to platinum wires which are fused into the glass and protrude through it. The connection from the circuit is made to these wires. The reason for using platinum is that its coefficient of expansion is nearly the same as that of glass, so that the heating of the lamp produces no tendency for the wire to crack the glass.

The candle-power of such a lamp depends on the *surface area* of carbon that is heated, and the *temperature* to which it is heated.

Carbon behaves differently to metal when heated. The resistance of nearly all substances increases as they are heated, but the resistance of carbon decreases; so that a lamp when incandescent has less resistance than when cold. The resistance of an 80-volt, 16 candle-power lamp when cold is about 160 ohms; when burning, about 100 ohms.

It is most essential that these thin carbon filaments should never be heated above a certain temperature, otherwise they will rapidly go to pieces, so that the only way of getting more light is to increase the surface area of the filament.

Now the area of a filament can be increased in two ways, either by increasing its diameter or by increasing its length. In one case the resistance is decreased and in the other increased. At the same time, if the diameter be increased, more current can be safely passed through since the conductor is made larger.

For efficient lighting it is essential that all the lamps on the circuit should have maintained at their terminals the voltage at which they are intended to be burnt. The length and diameter of the filament are so arranged that its area will give the required candle-power when heated to a certain temperature, and this temperature depends on the correct voltage being applied.

The efficiency of a lamp is the amount of electrical energy (in watts) consumed per candle-power. This efficiency varies from 1 watt per candle-power in the most efficient, to 4 watts per candle-power in the least efficient lamps; the power consumed depending on the temperature to which the filament is raised. Lamps may be used having any efficiency between these two limits.

Taking as an example a 16 c.p. 80-volt lamp of $2\frac{1}{2}$ watts efficiency, it will require to be supplied with $\frac{16 \times 2 \cdot 5}{80}$ or $\cdot 5$ amperes of current; whereas a 4-watt lamp for the same purpose would require $\frac{16 \times 4}{80}$ or $\cdot 8$ amperes.

Thus, the fewer the watts used per candle-power the greater will be the economy in the current consumed. In practice, however, we had to consider that the lasting power of the lamp, generally known as its "*life*," is much shorter when it is burned at a high temperature; as, first, the filament is more easily broken by an accidental shock or vibration; and, secondly, the glass globe of the lamp becomes quickly blackened by the deposition of fine carbon particles on its interior surface.

In deciding on the efficiency of lamps to be used we must be guided, therefore, by two considerations, the cost of electric energy on the one hand, and the price of lamps on the other.

There is a tendency, as the price of lamps has been very much reduced of late years, to introduce lamps of higher efficiency.

Low efficiency lamps of 4 watts per candle-power are used in the Service.

The following table shows the *candle-power* (written c.p.) *resistance when burning, and current,* consumed in each of the various sizes of 80-volt lamps:—

C.p. - -	8	16	50	100
R. (hot) - -	200	100	32	16
Current - -	·4	·8	2·5	5

The average life of the above lamps is from 1,000 to 2,000 hours or more. All lamps are marked on the glass with the number of volts at which they are intended to be burnt, and the candle-power.

8 c.p. lamps are used in places where not much light is required, for lighting up of engine-room telegraphs, helm indicators, &c.; and a special form for masthead flashing lamps.

16 c.p. lamps are used for general illumination about the decks.

32 c.p. lamps are used in starboard bow lights.

50 c.p. lamps are fitted in the yard-arm reflectors, and as bunker lights.

100 c.p. lamps are supplied to flagships for use in the apparatus for the examination of the bores of guns.

It is important that the current should be supplied to lamps at their correct voltage, as it is found that a very small reduction in the voltage produces a very marked diminution in the candle-power. This is clearly shown in the following table, which is the result of experiments carried out in the "Majestic":—

Proper Voltage.	Voltage supplied.	Fall of Voltage.	Candle Power obtained.
80	80	0	16
80	78·5	1·5	13·8
80	78	2	13·5
80	77	3	12·5
80	76	4	11·8
80	75	5	10·6
80	74	6	9·0
80	72·5	7·5	7·6
80	70·5	9·5	6·6
80	68	12	5·5

Other Forms of Incandescent Lamps.

Metallic Filament Lamps.—Of late years much progress has been made in the manufacture of incandescent lamps, in which the filaments are of substances other than carbon, mostly the rarer metals, such as tantallum, osmium, &c. The only one of these that has as yet been tried in the Service is the tantallum lamp, and this has given very good results, but has not yet been definitely adopted.

Tantallum is an intensely hard metal, and is very nearly infusible, so that it can be heated to a very high temperature without any fear of its melting. The resistance of a tantallum filament is very much less than that of a similar filament of carbon, and consequently, for lamps that have to burn on the same voltage, the tantallum filament must be either very mnch longer or very much thinner. It is usual to make them longer, since a filament is easily broken if made too thin, and the necessary length is got into a bulb of about the usual size by winding the filament up and down over a number of wire supports, that protrude radially from a glass column in the middle of the bulb. The bulb is exhausted of air as is the bulb of a carbon filament lamp.

The resistance of tantallum, like that of most other metals, rises with its temperature, and the resistance of the filament when glowing is about six times its resistance when cold.

The efficiency of a tantallum lamp is very much better than that of a carbon lamp, whose life is the same, being about 1·4 watts per c.p., as against 4 watts per c.p. That is to say, a tantallum lamp takes only a little over one-third of the current of a carbon filament lamp of the same candle-power, so that it is considerably more economical.

Nernst Lamp.—In the Nernst lamp the filament is made of 85 per cent. of oxide of zirconium, and 15 per cent. of oxide of yttrium, two of the rarer metals. When this mixture is heated to such a temperature that it glows and gives out light, the zirconium is deposited out of the oxide, and unless oxygen is present to combine with it again, the filament will deteriorate. It is consequently necessary that air should have access to the filament when it is glowing, and it is therefore not enclosed in an air-tight bulb, but is open to the air, being merely covered with a globe to protect it from mechanical injury. The resistance of the filament, which, when it is cold, is so high that scarcely any current flows, falls very rapidly as the temperature rises.

Certain fittings, therefore, which are not found on carbon filament lamps, are required on Nernst lamps, and these are:—

(1) A heating coil, which, when the lamp is first switched on, warms up the filament until its resistance is low enough to conduct the necessary current; and

(2) A compensating resistance, made of iron or some other substance, whose resistance rises with the temperature, to prevent the current rising to too high a value. This resistance is in series with the filament.

The heating coil consists of an open spiral of copper or iron wire, coated with porcelain to protect it from the heat of the glowing filament. It surrounds the filament, and is connected across the terminals of the lamp, so as to receive the whole voltage of the supply when the lamp is first switched on. A small magnetic switch, whose coil is in series with the filament, breaks the circuit of the heating coil when the current through the filament reaches a certain value.

The compensating resistance, which is made of thin iron wire, is in series with the filament, and is enclosed in a glass bulb, from which the air is exhausted, so that it shall not oxidise when it reaches a high temperature. As the current rises, the resistance of the filament falls, while that of the iron wire rises, so that the current will go on increasing until the rise in the resistance of the iron balances the fall in the resistance of the filament, and will then remain steady.

The compensating resistance in its bulb is made exactly like an incandescent lamp, with a bayonet joint fitting, so that it can be easily replaced by a spare one if damaged.

If the heating coil gives out, the lamp can be made to light up by heating up the filament with a flame until it begins to glow.

These lamps give a very powerful white light, and their efficiency is good, being about 2 watts per c.p. They are used in the Service in the miniature search lights for deflection teachers.

Mercury Vapour Lamps.—There is another form of lamp which, though not used in the Service, is interesting on account of its extraordinary efficiency—about ·3 of a watt per c.p. It is known as the Cooper-Hewitt lamp, and consists of a long glass tube, exhausted of air, but containing a small quantity of mercury, the remainder of the tube being filled with mercury vapour. There is a platinum electrode at each end of the tube, and if a current is established between these electrodes, the mercury vapour glows brightly, and gives out a strong light. The character of this light, which is of rather a blue colour, prevents this lamp from being very extensively used, except in certain cases where the colour is not of much importance.

Arrangement of Lighting Circuits.

In a large ship the number of incandescent lights required often amounts to 1,000 or more, and these have all to be arranged in parallel with one another. It would be obviously undesirable to run separate wires from the switchboard to every lamp, so the method adopted is to divide the ship into sections, generally six, and to supply all the lights in each section by separate large wires led from the switchboard to ***section boxes.*** In these the current is divided up, passing by means of sub-mains to ***distributor boxes,*** where it is again split up among smaller wires which feed the individual lamps.

The general arrangement of the circuits is usually as follows :—

(1) Engine room and stokeholds.
(2) Magazines. Forward and aft.
(3) Store rooms. Forward and aft.
(4) Forward upper circuit.
(5) Central upper circuit.
(6) After upper circuit.

The most important of the above, are Nos. 1, 2, 3, and 5, as a failure of the lights in any parts of the ship which these circuits supply would greatly impair her fighting efficiency.

Lead-covered cables are fixed to the bulkheads with brass clips. Brass is chosen so that the chemical action will not injure the lead covering.

Wherever wires pass up through the deak, deck pipes are provided; they consist of copper tubes about 2 feet high, fitted with an india-rubber gland. They should always be placed against a bulkhead for support, and the glands should be sufficiently high to be above the ordinary amount of water likely to be on a deck.

Wherever a wire leads through a bulkhead it passes through a watertight gland. These are very simple in construction, and consist of a brass stuffing box, through which the cable passes secured into the hole in the bulkhead with a red lead joint. The packing is spunyarn, well saturated with red lead, and it is kept in place by a brass gland, which screws into the stuffing box.

Plate XXXI. will enable the reader to understand more clearly the method of distribution above described. The positive and negative main conductors of each circuit are led to a junction box (J.B.) where they divide into two branch mains, running forward and aft respectively along the deck, care being taken to keep the main cables under armour protection as much as possible. On these branch mains are placed a series of section boxes (S.B.), these being so arranged that the current passes through one section box and on by a continuation of the main to the next, there being often as many as five or six of these boxes to each main. Each section box supplies current to four distributor boxes; five may be supplied from the end section box on the main, as shown (S.B.) B. From each of the distributor boxes eight pairs of positive and negative single lamp leads branch out, and convey current to the various lamps.

Sometimes it may be necessary to feed two lamps from one pair of wires, when a small cut-out box (C.B.) is used for branching the leads. Switches (SS) are fitted to control single lamps where required. Switches and cut-outs are also fitted in the distributor boxes, and when "Off" all the lamps supplied from any particular distributor box will be out, except the lamps P_1P_2 called *police lamps*. These latter are supplied independently of the switches, and consequently are not affected by them; such police lights are placed in dark corners, or where a light is required when the other lamps are off. Some distributor boxes such as those for officers' cabins have no switch, every lamp being fitted with an individual one instead. Each section box also contains a switch as well as cut outs to each sub-main, so that a group of altogether 32 lamps may be turned off at one section box.

Sometimes one of the pairs of sub-mains from a section box is taken to a terminal box specially fitted for the attachment of temporary leads to a *yard-arm group*, which will be described later on.

All the cables used in this method of distribution are fitted with flanges where they enter the various boxes; these flanges are soldered to the lead sheathing of the cable, and a watertight joint is made by red lead to the side of the box. The lamp fittings are also made watertight, as will be presently described; thus the whole of the circuit from the switchboard should be proof against damp, of which experience has shown the absolute necessity.

Lighting Mains.

The wires of the lighting mains of ships are all made of stranded copper wire cable, insulated with india-rubber and vulcanised rubber, and covered with a lead casing.

The pattern numbers, sizes, and current carrying capacities of the various lead-cased cables in use in the Service, are given in Table A. in Appendix V.

The current capacity assigned to the various cables in this table is calculated at a loss of 2 volts per 100 yards main and return. It will be seen that a certain loss of voltage must always

To face page 270.

System of Distribution of Current for Incandescent Lighting

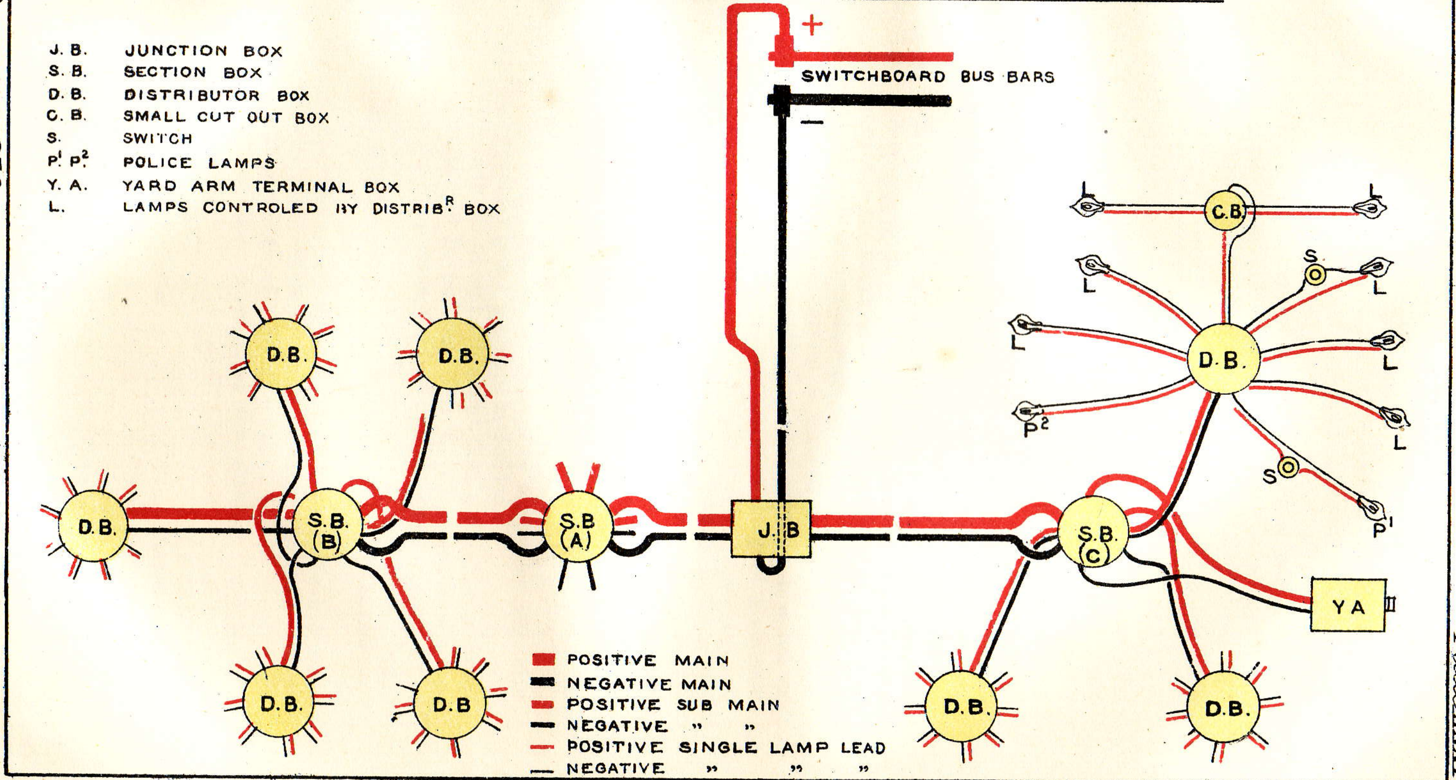


Plate XXXI.

Weller & Graham, Ltd Litho. London 1515 .07

take place in the mains owing to their resistance, and that this loss is converted into heat and wasted in warming the cables. Although a considerably greater current might be, and in many cases is used, without danger of overheating the copper, still with such the D.P. at lamps in distant parts of the ship is so much reduced that their light is seriously impaired, as can be seen from the table on page 267.

Cut-outs.—To prevent the possibility of a wire carrying a dangerous current, cut-out wires are inserted in the circuit. Such a current might arise in any part of the circuits, through the accidental short-circuiting of a positive and negative main, sub-main, or lead, which might be caused by damage from an enemy's fire, the flooding of a compartment, or leakage to earth from both mains.

The cut-out wires are made of easily fusible metal, and are of such a diameter as to heat and melt before the current can rise to a dangerous strength. The cut-outs supplied for the switchboards, lighting circuits, of later ships consist of 11 copper wires, each enclosed in a wrapping of asbestos, stretched between two blocks which are secured to the terminals. They are known as Patt. 2160. A little thought will show that wherever the wires branch, that is, at the points where the current is divided up in the section and distributor boxes, &c., smaller cut-outs must be inserted in the circuit with these branches, to fuse at a dangerous current for them.

For instance, if a sub-main of 25-ampere capacity be joined in a section box to a main of 60-ampere capacity, the cut-out in the 60-ampere wire could in no way act as a safeguard to the smaller wire beyond; as the latter would be red hot, and perhaps causing a fire, before the cut-out fused. Again, the more the lights are sub-divided by means of cut-outs, the less number will probably be extinguished by a cut-out fusing.

For these reasons, therefore, cut-outs of a suitable size are placed at every point where the circuit is divided.

If leaks occur in mains and sub-mains, then the lights on those particular circuits will be put out; but if, as is more likely, the leak occurs in the lamp leads, then, as there are never more than two lamps (as will be seen when we describe a distributor box) on a cut-out, only these two will be extinguished by the cut-out fusing.

Another important use of cut-outs, is that they afford convenient breaks in the circuit for locating faults, and for this reason they are fitted in both positive and negative wires.

Wire of three sizes is supplied for making cut-outs, as follows:—

Gauge.	Length of Fuse.	Safe Current Capacity.	Current to Fuse.
No. 10 L.S.G.	1 inch.	85 amps.	100 amps.
No. 18 L.S.G.	$\frac{5}{8}$ inch.	20 amps.	25 amps.
No. 25 L.S.G.	$\frac{5}{8}$ inch.	8 amps.	$8\frac{1}{2}$ amps.

These are intended for use in the junction, section, and distributor boxes respectively.

The amount of current given in the table that the cut-outs can carry must be taken as approximate.

The fusing of a cut-out depends on the rise in temperature of the cut-out wire. The heat is generated by the passage of the current. The rate at which this heat is made, compared with the rate the wire is able to dissipate it, determines the rise of temperature of the wire. If, as soon as the heat is generated, the wire is able to get rid of it, naturally no extra heat will remain in the wire to raise its temperature, but if heat is generated at a much quicker rate than the wire can get rid of it, then the heat remaining is employed in raising the temperature of the wire, which at a certain point fuses. The wire can get rid of the heat in two ways—by radiating it to surrounding objects, and by dissipating it along its length to the blocks at the ends, or conducting it to the surrounding air. Air is a bad conductor of heat, that is, it will not easily allow one layer of heated air to pass its heat on to the next, and so on; but a motion of the air, such as a draught, removes the heated layers from near the wires, and substitutes cool ones ready to be heated. This is why a draught of air cools heated bodies. The most important effect for us to consider, however, is the conduction of the heat along the wire itself. The rate of conducting the heat from the centre to the ends of the wires naturally depends on the length of the wire. The result is, the longer a cut-out wire, the more the centre will be heated and the higher its temperature will rise, until at last the wire fuses. This is the reason for cut-out wires, as a rule, fusing in the centre. If they fuse at one end it will show that excessive heating took place at that part, probably owing to bad contact or dirt.

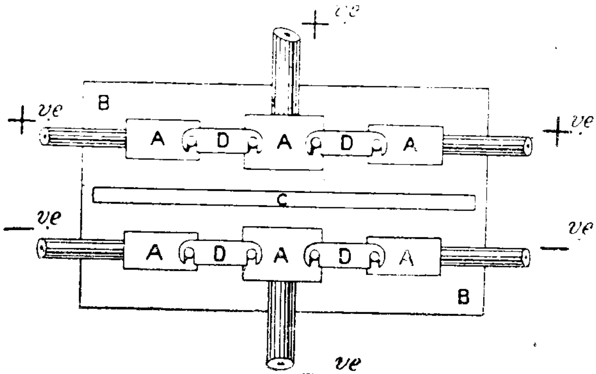
From this it may readily be seen that in enclosed places, such as section and distributor boxes, the current required to fuse any given cut-out will be much smaller than if it were in the open air.

The cut-outs on the Portsmouth and Clarke Chapman switchboards are made of flat plates of fusible metal shaped so that they can be easily placed underneath the screw terminals, which are specially provided for the purpose. Plates of this metal are supplied in two thicknesses ($\frac{1}{8}''$ and $\frac{1}{16}''$) for making fresh ones when required.

Cut-outs are frequently termed "safety fuses" on shore, but the former term has been retained in the Service to distinguish them from the fuses used for firing guns and mines.

Main Junction Boxes.—These, as before stated, are placed in circuits between the mains from the switchboard and the various section boxes, where the number of section boxes is large. They consist essentially of a watertight gun-metal box into which the positive and negative main leads are introduced through watertight glands; the ends of these conductors having had their strands well sweated together, are tucked into holes in stout metal blocks, themselves secured to a slate base, and they are then screwed down tight in the holes so as to form a good connection. The branch mains going to the various section boxes enter the junction box in a similar way and are also connected to smaller metal blocks on the same slate base. Large flat cut-outs between the blocks form the connections across from the switchboard mains to the section branch mains.

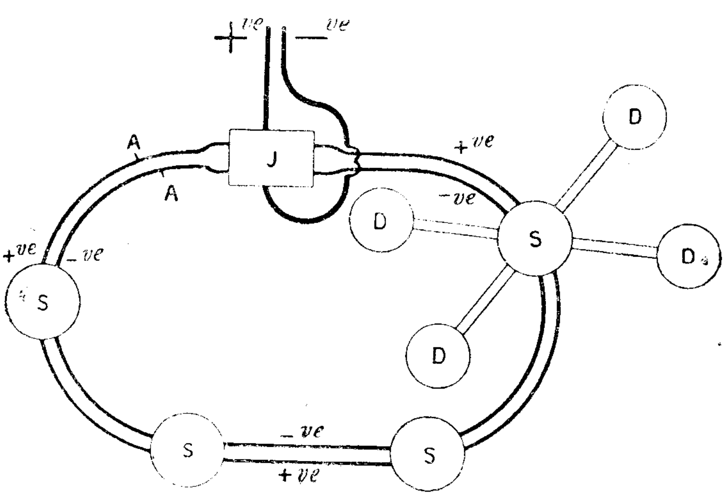
Fig. 161.



In Fig. 161, A A are the metal blocks, B B the slate base, C a slate separator between the positive and negative leads, D D the cut-outs.

It will be seen that if the mains from the junction box of any circuit to the section boxes were cut (by hostile gun fire, or accident) near the junction box, the supply of current to several

Fig. 162.



section boxes would be cut off, thus plunging a large portion of the ship into darkness.

In ships built since 1900 a *ring system* has been adopted in fitting their lighting circuits. In this system the two mains form two complete rings, on which the section boxes are placed, all parts of the ring being of cable sufficiently large to carry the total current required by all the section boxes (*see* Fig. 162).

Thus in the event of the mains being broken at A A all the lights will still burn without undue current in any part of the cables. This system has the further advantage that, as larger mains are necessary, the fall of voltage in them is reduced, and consequently a better light obtained.

Section Boxes.—These are circular brass boxes with slate bases and a brass cover screw on to the box. In the earlier patterns the box is divided diametrically inside into two parts by a slate partition, one half being used for all wires connected to the positive, and the other for all wires connected to the negative terminals (*see* Plate XXXII.). The main wires (one on each side of the central partition) are led into the box through watertight glands, and are connected to two metal strips which lie parallel to the partition and under the slate base. To the other ends of these strips are connected the main wires leading on from the sectional box to the next one, the size of these main leads being reduced as necessary, except where they are fitted on the "ring system," as previously explained.

Pivoted on the centre of each of the metal strips is a switch bar which "makes" or "breaks" connection between each main, and a metal terminal block on each side of it.

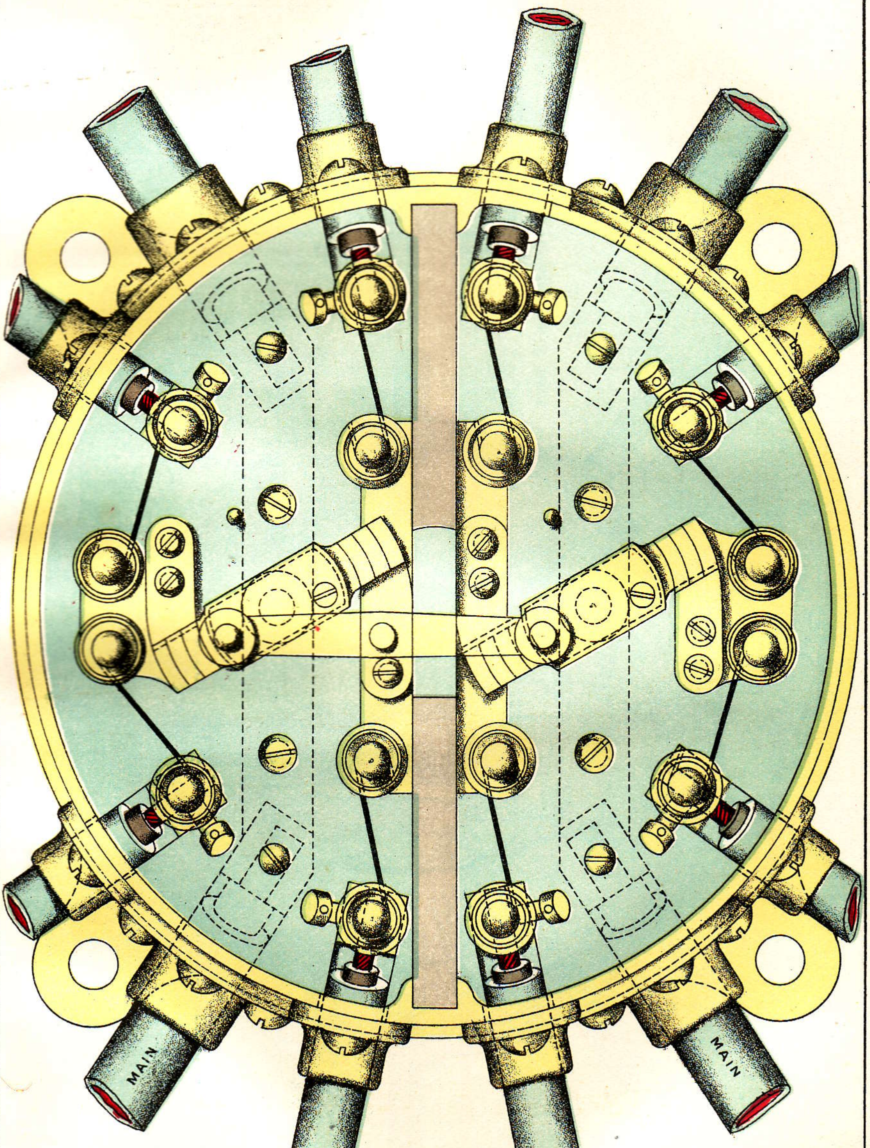
The switches are *double-pole* switches, and the switch bars are connected by a central link insulated from both bars. The link enables the circuit on both main and return sides to be closed or opened simultaneously by means of a key worked in the cover. On each side of the partition there are four terminals, and to these are connected the sub-main wires, led in through watertight glands, each of these terminals being connected by a cut-out wire to one of the two brass blocks which lie on each side of the main, two cut-outs going to each block. It will be seen that, by this arrangement, the mains are tapped by four sub-mains (on $+^{ve}$ and $-^{ve}$ side), each sub-main having its own separate cut-out.

Several modifications have been introduced in a later type of box, Patts. 1519 and 1520. The former of these is made of aluminium bronze and the latter of gun-metal, otherwise their construction is similar (*see* Plate XXXIII.). The base and screen are vulcanite instead of slate, the mains enter and leave the box at the same end. Each incoming main is connected to one block, and the outgoing main to another block alongside it, and these blocks are joined together by a metal link, secured to each by a screw. These links can be removed when necessary for testing, as described in Chapter XVI. The sub-mains are so arranged that their positive and negative leads come out close together in pairs. The double-pole switch is on a much improved principle, called the

WATER-TIGHT SECTION BOX.

SCALE = HALF SCALE.

PLAN – COVER REMOVED.



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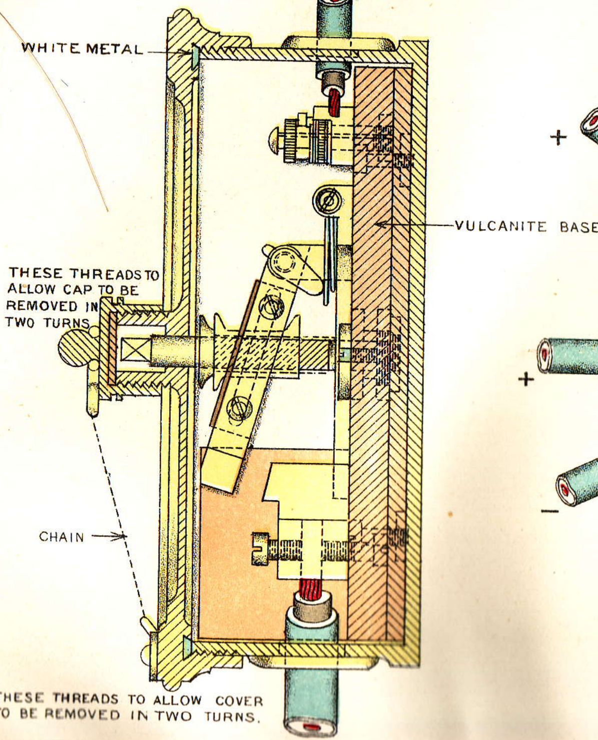
Weller & Graham. Ltd. Litho, London. 1515 07

W.T. Section Box. Patt. No (1519 Aluminum Bronze.) (1520 Gun Metal.)

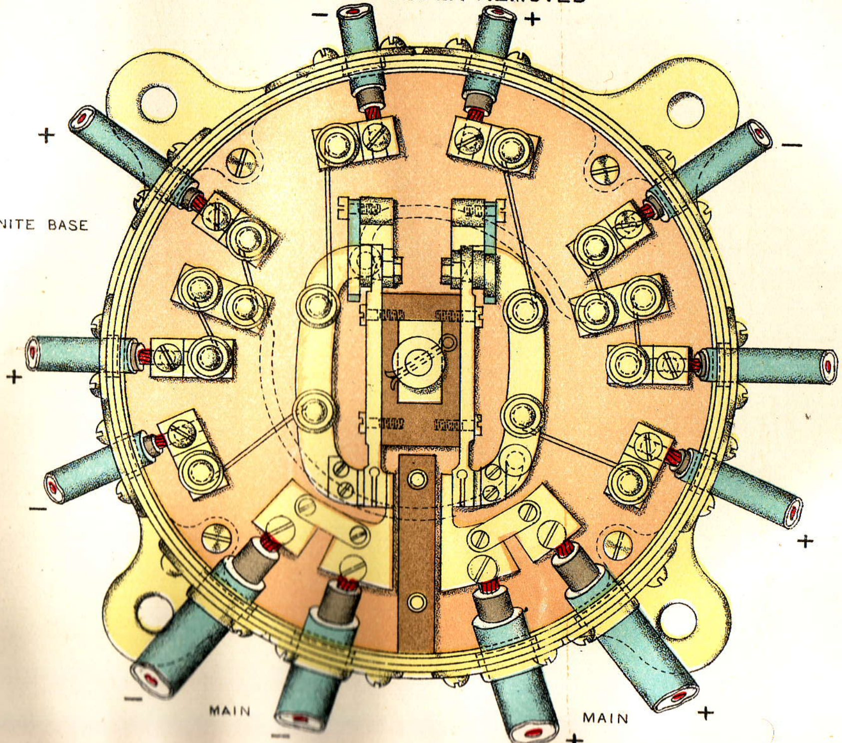
SCALE 3/8 FULL SIZE

58 .5.5. .07

SECTIONAL ELEVATION



PLAN WITH COVER REMOVED



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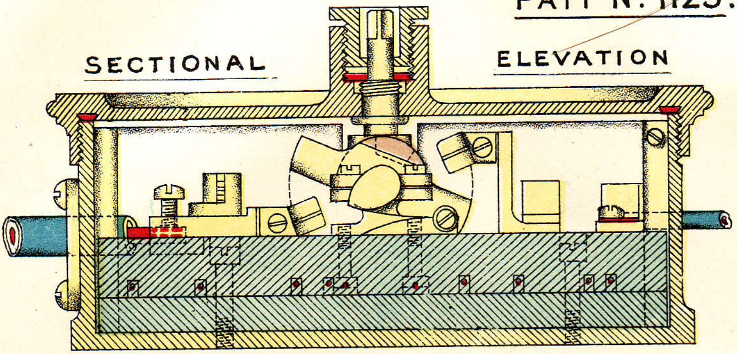
To face page 274.

Water-Tight Distributing Box.

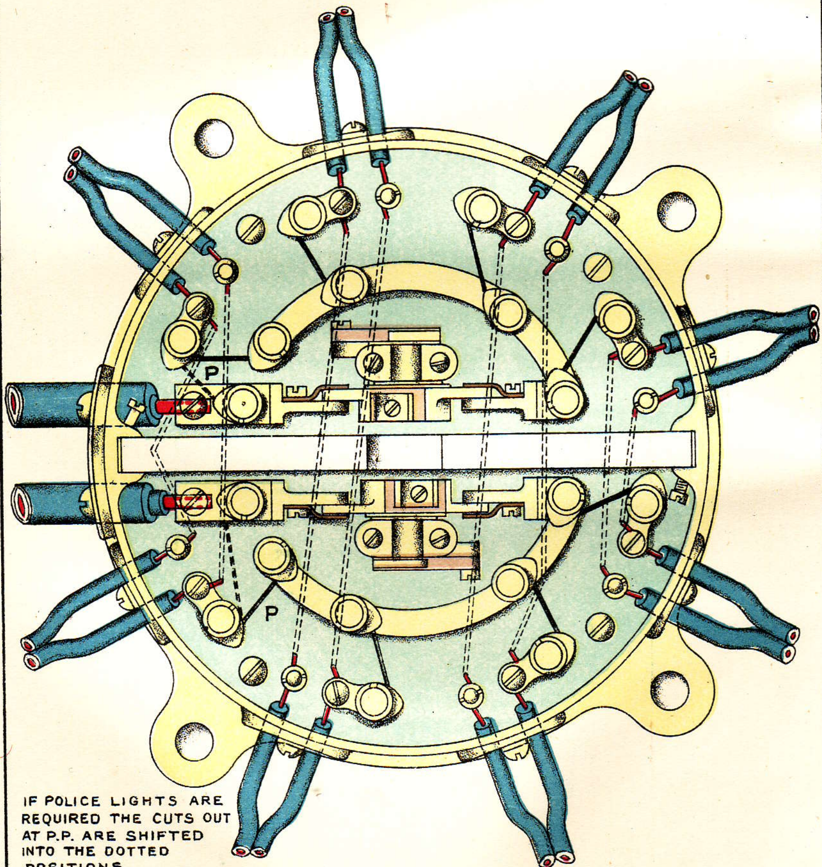
Patt No. 1125.

SECTIONAL ELEVATION



PLAN COVER REMOVED.

Scale 3/8 = Full Size.



IF POLICE LIGHTS ARE REQUIRED THE CUTS OUT AT P.P. ARE SHIFTED INTO THE DOTTED POSITIONS.

60.

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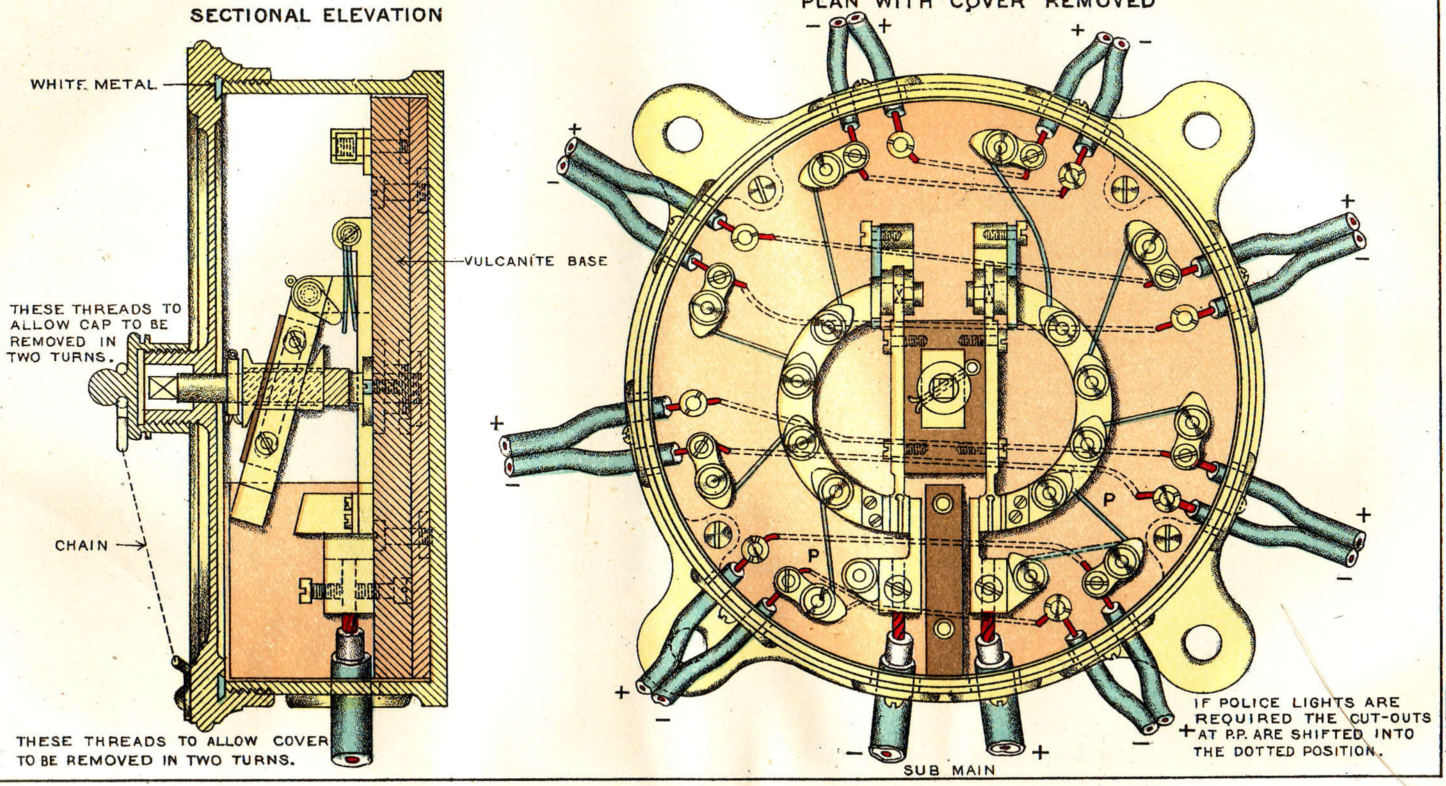
Weller & Graham, Ltd Litho, London. 1515. 07.

W. T. DISTRIBUTING BOX. PATT. No. (1517. ALUMINUM BRONZE.) (1518 GUN METAL.)

SCALE 3/8 FULL SIZE



Weller & Graham, Ltd Litho, London. 1515. 07

"knife" or "chopper" type. The switch bars are pivoted at one end, and are actuated by means of a vertical spindle fitted with a key or handle, and cut with a square thread which revolves on turning the key. This spindle is connected by means of a travelling nut to the centre of the switch bars, and so moves their free ends rapidly up or down, thus "breaking" or "making" the circuit. The action of "break" is assisted by a spring to ensure its rapidity.

Distributor Boxes.—These also are circular in shape and watertight. The sub-main wires are brought into the box through watertight glands, and connected to separate brass plates. On each side of the box a curved piece of metal is fixed on a slate base, and is so arranged that it can be connected to, or disconnected from, the sub-main plate of its side by a switch. There are several patterns of distributor boxes, which vary mainly in their forms of switch. Patt. 1125 has its switches pivoted at their centres (*see* Plate XXXIV.), and when actuated by a switch handle outside the box, they "make" and "break" at four points. Patts. 1517 and 1518 (*see* Plate XXXV.), which correspond to the latest pattern section boxes, are fitted like them to "make" and "break" at two points only; moreover, they have vulcanite fittings instead of slate.

Round the distributor box are eight watertight glands, four on each side, and in through each are led the main and return wires for one lamp; one wire being connected to a terminal and the other to a screw. Each terminal is fitted with a spring connection for a cut-out wire (leading to the curved piece of metal of its side), and is also permanently connected to the screw of the corresponding pair of leads on the other side of the box.

By this means all the cut-out wires to the main branches are on one side of the box, and those for return wires on the other side; the lamps burning in pairs, with one cut-out in the positive lead and one in the negative lead for the pair.

The number of lamps fed off any two leads on one side, however, frequently exceeds one, thus causing a pair of cut-outs to control more than two lamps; the general principle of control by pairs of leads of course remains the same.

Should police lights be required, the cut-outs at P P (*see* plates) are shifted into the positions shown by the dotted lines.

Switches.—The requirements of a good switch are as follows:—

(1) That the connection should be made as rapidly as possible when it is "switched on"; and, what is far more important, should be broken instantaneously when the switch is turned to "Off."

(2) That when "On" the surfaces should be kept in intimate contact, in spite of vibration, wear, and other causes.

(3) That the surfaces, and all parts of the switch, should be large enough to stand the current for which it is designed, without heating.

To fulfil these requirements many different forms of switches have been tried, and are in use in the Service and on shore.

It has previously been explained that on "breaking" a current of electricity a spark is formed, due to the self-induction of the current, which spark is of the nature of an arc, and if not quickly broken results in the fusing of the metal at the points where the arc forms. The rapidity of the break by hand cannot be relied on to produce the necessary quickness of motion. In most switches, therefore, a spring is inserted to assist the hand.

In the Portsmouth switchboard, the switches are in the form of plungers which are forced in contact with the dynamo bar, and then held there by a spring hook which is afterwards "hardened up," inclined surfaces being used. In breaking, a spring forces the plunger rapidly back. The objection to this method is that the whole time that the circuit is "On" this spring remains compressed, and consequently its tendency is to then reduce the closeness of the contact, or in other words to push the plunger away from the dynamo bar.

In the switches in the new pattern section and distributor boxes above described, a spring to ensure a quick "break" of the circuit is used; but the great advantage in this form of switch lies in the excellent contact that is made between the parts of the switch when it is switched on, owing to the fact that the switch bars are grasped between flat springs. This "knife" or "chopper" type of switch is largely used in shore installations.

Single Switches.—The Service watertight switch, Patt. 1086 (*see* Plate XXXVI.), consists of a gun-metal case with fittings mounted on vulcanite. The switch bar is actuated by a spindle fitted with a ⊤ handle. The older patterns had a mill-headed screw, which was not so easily turned.

In switching to on, turning the spindle by means of the handle revolves the switch bar until it is firmly grasped by the contact springs. On switching to off, however, since the switch handle is only in connection with the switch bar by means of a stud travelling in a slotted groove; as soon as the friction between the surface of the bar and the springs of the contact box becomes small, a spring causes the switch bar to revolve independently of the handle, while the slotted groove allows it to do so. Thus the motion of switching off cannot be checked by a slow motion of the hand.

A larger size of single switch, Patt. 1140, on a somewhat similar principle, with slate fittings, is sometimes found in connection with yard-arm groups, &c. It is fitted with a key which, when reversed, forms a watertight cap in the centre of the cover in the same manner as the keys fitted to section boxes.

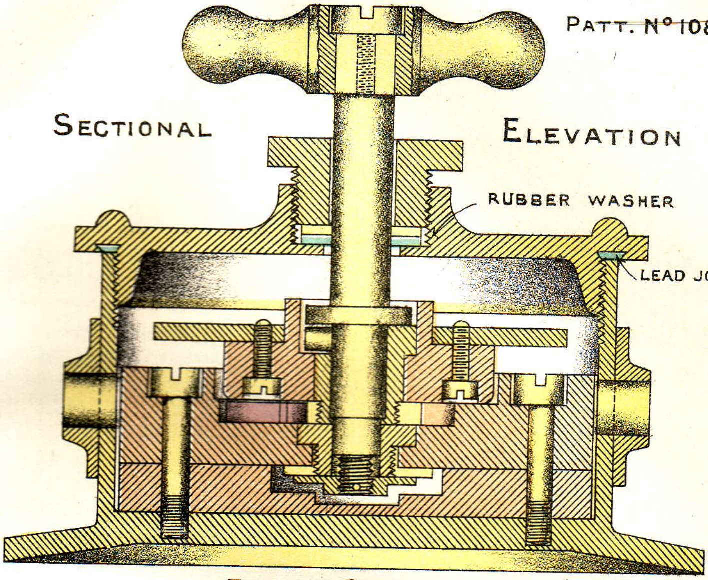
Lampholders.—The Service lampholder for incandescent lamps is known as the *bayonet joint* lampholder, and is identical with those used almost universally on shore.

The base of the bulb is embedded in plaster of Paris capped with vitrite, and surrounded by a brass collar which carries two lugs. Two flat contact pieces are embedded in the vitrite, flush

Watertight Switch.

Patt. N° 1086.

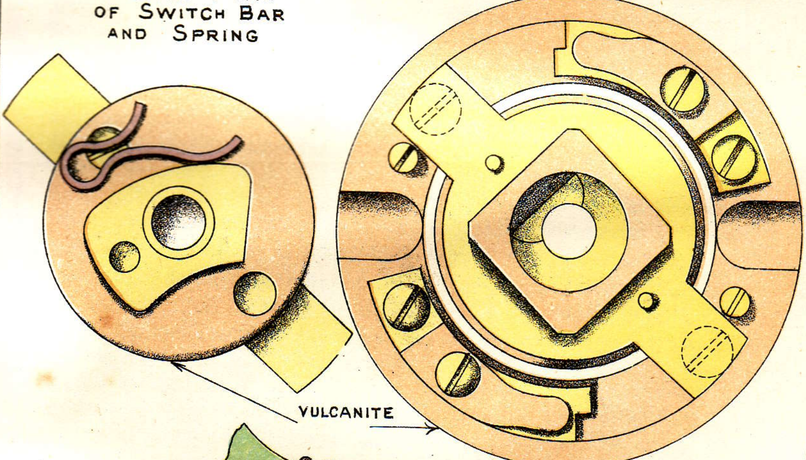
Sectional Elevation

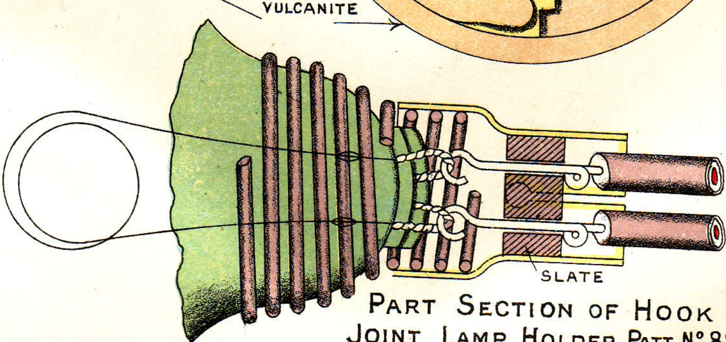


Full Size

Inverted Plan of Switch Bar and Spring

Plan with Cover Removed





Part Section of Hook Joint Lamp Holder. Patt, N° 892.

Weller & Graham Ltd Litho, London 1515 07

with the flat end, and connected to the ends of the filament by the platinum wires mentioned above, which pass through the glass.

The lampholder consists of a brass tube in which two spring plungers are mounted on a porcelain base. These plungers bear against the contact pieces on the base of the lamp, and the ends of the wires of the circuit are secured to the plungers by small screws. The lamp is kept in position by the lugs on the brass collar locking into a bayonet joint in the brass tube, and when in position the springs of the plungers are compressed so as to make good contact.

These lampholders are fitted everywhere in ships except in certain places, such as gunhouses, &c. where the vibration is liable to be excessive, where the hook and loop fitting is used.

The hook and loop lampholder (*see* Plate XXXVI.) which before the introduction of the bayonet joint fitting was universal in the Service, consists of a small brass tube containing a slate insulator with two holes bored through it. Through these holes the ends of the circuit wires are passed, having been first stripped of their insulation and kinked to prevent them drawing through, and hooks are formed at their ends.

The platinum wires that are connected to the ends of the filament of the lamp and pass through the glass, are formed into loops on the outside, and these loops are hooked on to the circuit wires. To keep the hooks taut in the loops, a spiral spring of German silver is used, one end of which bears against the brass tube of the holder and the other against the bulb of the lamp.

The advantage claimed for this system is that the lamp, being held in position by the flexible spring only, will not be damaged by concussion or vibration. On the other hand, the loops of many lamps become broken, thus rendering them useless, as they cannot be repaired. It is for this reason that, as mentioned above, these fittings are now only used in gunhouses and other similar positions, where vibration may be expected to be excessive.

The ends and sockets of all broken incandescent lamps are to be taken on charge in the Torpedo Warrant Officer's store accounts, and returned to the dockyard on occasions of replenishing stocks of lamps. The number of ends and sockets returned should equal the number of new lamps drawn from store and, in cases where there is a difference, the reason should be stated on the return notes. Any case where the difference is large, *e.g.*, exceeds 25 per cent., the loss is to be investigated by the Commanding Officer, and the return notes accompanied by a special report stating the cause of difference.

Lamp Fittings, &c.—There are many forms of lamp fittings in use in the Service, such as those for bulkhead, overhead, pendant, and bunker lights, &c. The lamps enclosed in them are made watertight by means of glass shades screwed down by brass collars on to india-rubber washers. A watertight joint is also made where the wires enter the lamp fitting, by means of glands and india-rubber washers.

Before these watertight fittings were introduced into the Service, it was found that owing to rain and spray on deck, and drippings of water from steam pipes, &c., in engine rooms and other places below, the lamp leads quickly deteriorated.

Section, distributor, and cut-out boxes should be kept carefully screwed up so as to be watertight in case of an emergency. Spanners suitable for the various boxes are supplied.

Mess Deck Lights.—The lighting of a mess deck is generally arranged as follows:—Lamps are fitted one for each mess, of the pendant or bulkhead type as convenient; these are controlled by the distributor boxes. The lamps in the passages being fitted as "police" lights, remain burning when the boxes are switched off. Stated times should be arranged, summer and winter, for switching on and off these boxes.

Fighting Lamps.—These are fitted in the casemates, and in rear of the upper deck guns. They are supplied with a cone shade which can be raised or lowered as desired; when down, the shade prevents the light from the lamps showing outboard through the ports, &c.

Navigation Lights.—One or two section boxes are generally fitted to supply the lights on the fore bridge, including bow and steam lights, binnacle lights, lights for telegraphs and indicators, and lights for the conning tower and chart-house.

These are important, and at the same time exposed circuits, and therefore require great attention; since the fusing of a cut-out in the steam or bow light circuits is a great inconvenience, as also is a sudden loss of light in the binnacles and chart-house, particularly at a critical point in the pilotage of a channel.

Similar arrangements are made for supplying the after bridge and conning tower.

Position Lights.—These are fitted on the ensign staff, the lower one sometimes being used as a stern light as well. A special shade is consequently fitted to the lower lamp for use at sea, to prevent its showing forward of 2 points abaft the beam. Switches are fitted on the fore bridge to control the position lights.

Speed Lights.—Electric speed lights are now being fitted to ships, and they consist of 8 candle-power lamps in portable lamp fittings which can be secured to the halyards, and flexible circuits. They are not burnt at full brilliancy, but are either double filament lamps, with two filaments in series, or else ordinary lamps burnt in series with a resistance.

"Not Under Control" Lights.—These are also being fitted as electric lights, the lanterns being the same as those for the speed lights, but with red glasses, and the lamps being 32 candle-power burnt at full brilliancy.

Magazine Lamps.—Electric light circuits are not generally to be led into or through magazines or shell rooms, but the lights are fitted in light boxes which are only accessible from outside.

No watertight fittings are necessary in these light boxes, as they are themselves watertight, and are always to be kept closed and locked.

In certain cases where it is not possible to light the magazines satisfactorily by means of light boxes, circuits are permitted to be led in, provided that the leads are made as short as possible, are completely enclosed in steel piping, and so arranged by covering in or otherwise that nothing can be suspended from them.

For this purpose, heavy weldless steel tube with screwed joints is employed, such as is specially made for this purpose, and care should be taken to make it electrically continuous and to see that it is efficiently earthed. The lead covering of the cables and the material used for covering in the tubes, if metallic, should also be in electrical connection with the tubes.

A switch is to be fitted in each lead of the circuit of each lamp, and both these switches are to be open before anything is done to the lamp in the way of disconnecting, repairing, or replacing it.

Engine and Boiler Rooms.—The engine and boiler room circuits are those which are liable to give most trouble. The vibration of the engines, the constant condensation of moisture, and the large variations of temperature, all combine to damage circuits and fittings.

Portable hand lamps are fitted where required. They are connected by means of flexible, steel-braided, twin-core wires, Patt. 1388, to watertight plug boxes. From thence connection is made to the positive and negative leads running to a distributor box.

Portable leads are a fruitful source of trouble unless carefully looked after. The braiding should be sweated at the ends to the body of the lamp fitting, otherwise the wire will soon be broken at the nip.

Bow and steam lights are fitted in the same manner as portable lamps, a special form of lamp fitting being supplied to enable it to be shipped inside the ordinary lantern; 16 candle-power lamps should be used in the *port* and *steaming* lights, and 32 candle-power lamps in the *starboard* lantern, since in the latter case it has been found that more rays are absorbed by the green glass.

To prevent the possibility of a mistake in shipping these lights the incandescent lamps are ordered to be tipped with green paint for starboard, and red for port lamps.

Bunker Lights.—The general system of lighting bunkers consists of one fixed bunker light of the ordinary pattern, 50 candle-power for large bunkers, and 16 candle-power for small ones, and one 16 candle-power portable lamp with a wandering lead, whose circuit is controlled from a distributing box outside the bunker.

The following instructions are to be strictly complied with in using the portable bunker lamps, in order to eliminate any chance of short-circuiting and sparking inside a coal bunker:—

(1) The lamp, when not in use, should be hooked up inside its box, switched to "Off," and the box closed.
(2) When required for use, the lamp can be taken out and switched to "On."
(3) On no account is the lamp to be left where it can be covered by falling coal.
(4) If by any accident the lamp or circuit is buried so that it cannot be cleared until the bunker is being emptied, the holder should be disconnected from the socket, the box closed, and the cut-outs removed from the feeding distributor box.

Boiler Tube Lamp.—A special form of lamp is supplied for the internal examination of boiler tubes. It consists of a telescopic rod, at the end of which is fitted an 8 candle-power tubular lamp with an inclined mirror. It is fitted with a lead of flexible braided wire, and a portable plug connection.

Divers' Lamp.—A lamp fitted with a strong guard is supplied in a box for use under water by divers, to ships with "A" proportion of stores, and all flagships. The box is fitted with a watertight switch and a reel containing 30 fathoms of flexible wire, Patt. 902. Care should be taken that the lamp is not switched on until after it is under water, otherwise the glass will be cracked.

Whitehead Lamp.—A 10-volt lamp, fitted with a guard and mounted on a flexible holder, is supplied for viewing the interior of the engine room or balance chambers of Whitehead torpedoes. It is connected by means of a small steel-braided wire to a special plug, which is placed in series with a 16 candle-power lamp; one of these is supplied to each Whitehead store room.

Yard-arm Groups.

It is very convenient to possess a means of quickly and brightly illuminating some portion of the upper deck for coaling, anchor work, &c.; and for this purpose groups of lamps fitted inside a reflector have been supplied, and are known as "yard-arm groups."

They are, moreover, exceedingly useful for temporarily lighting up any portion of the ship below which would otherwise be plunged into darkness by the lighting circuits failing, in the case of fire, or in action, &c.

A yard-arm group consists essentially of a circular concave reflector made of sheet brass 24 inches in diameter and $6\frac{3}{4}$ inches deep. It is painted inside with white enamel, and has long hooded slots fitted for ventilation. A centre-piece is connected to the reflector by means of six screws; it carries eight lampholders fitted with 50 candle-power lamps, and connection is made from these to two gun-metal terminals with ebonite bushing, fixed on the outside of the reflector by means of wire, Patt. 104. It is sometimes convenient, if the lights are being used in fine weather, for instance, during coaling, to take out this centre-piece, and fix it outside on the top of the reflector turned upside down and white-washed. Used in this way yard-arm groups give more light, but the lamps are necessarily unprotected.

Large ships are allowed six groups, and gunboats one, other ships in proportion, according to their size.

The leads of each reflector are of twin wire, Patt. 546, and are 50 yards in length. Fifty yards of spare wire is also supplied. The ends of the twin wires furthest from the lights are connected to convenient section boxes by means of *yard-arm switch boxes.* These are oblong watertight metal fittings with a hinged lid. They are fitted inside with switches on the spring "break" principle, and cut-outs on both positive and negative leads, the twin wires going into the box through a watertight gland and the cables leading away to the section box, passing out through similar glands on the opposite side of the box.

Signalling Lamps.

Flashing with an electric lamp may be produced in three different ways—

(1) Mechanically by means of a shutter worked by a string.
(2) By electro-magnets, actuating a screen.
(3) By switching on and off the circuits.

The first method is used in the "Gravity" and destroyers' flashing lamps.

Equilibrium, or Gravity Flashing Lamp.—The lower portion of the lantern of this lamp consists of a stout metal cylinder which is fitted over the top of a pole or small mast, in the centre of which is fixed a bayonet joint lampholder, into which is locked a 50 candle-power lamp.

Four vertical metal standards are screwed at equal distances apart around the flanged circumference of the cylindrical base, and form a support for the metal top of the lantern, and also act as guides to an inverted metal cup inside them. This cup when down covers the lamp; when it is raised to its full height the lamp will show all round the horizon. The cup is pulled up by hand, by means of a chain passing over rollers on the top of the lantern. When the chain is let go, the cup falls, due to its own weight, and eclipses the light.

In some of these lamps a spring is fitted to assist in bringing the shade back over the light quickly when the string is let go.

An arrangement is also fitted so that the light may only show in a given direction. This is done by means of a circular shade which is immediately outside the standards; the shade itself has an opening which can be increased or reduced in size as necessary by means of a slide, thus regulating the arc through which the light will be visible. If it is required to make an "all round" signal, the circular shade is simply pushed up clear of the lamp, and held there by means of a pin.

Signal Lamp for "Destroyers."—This consists essentially of a metal cylinder fitted with apertures, in which is placed a 5 or 10 candle-power 80-volt lamp. The lamp can be made to show a white or red light, by surrounding it with a clear or ruby glass cylinder. The incandescent lamp is of special form and is mounted on an ebonite base fitted with two contact holes, to which the ends of the filament are connected by means of platinum wires. The lamp socket, also of ebonite, has two plugs mounted on it which are attached to the ends of two short leads of insulated wire, the plugs being intended to fit into the holes in the base of the lamp. Leather washers at each end of the glass shades render the fitting watertight.

The flashing shutter is similar to that fitted in the gravity flashing lamp.

The second method has been adopted in "Scott's Flashing Lamp," in which a number of vertical shutters are arranged round the circumference of the lamp. Under ordinary conditions, they all touch one another right round, so that the lamp is entirely shut in and obscured, but, when the key is pressed, they all turn round edgewise to the lamp so as not to obscure it at all. This lamp has not been adopted in the Service as yet.

The third method is adopted in the Service masthead flashing lamp. The lantern is fitted on top of the truck, with a small derrick above it to assist in unshipping. Eight 6 candle-power lamps are mounted in small bayonet joint lampholders in a circle on the base of the lantern, and eight more in a similar circle on the roof of the lantern. These latter are upside down, so that all 16 lamps are close together.

The lamps are carbon filament lamps of high efficiency, 2½ watts per candle-power, and to get this efficiency the filaments must be made veryfine. The reason for the use of these lamps is that a fine filament lights up very quickly when the current is switched on, as there is not very much carbon to be heated up, and also cools down at once when switched off, so that the light follows the motion of the flashing key at once, without any delay. This is important, in order that signalling may be carried on at a fair pace without the signals running into one another.

A switch is fitted in one of the leads of the circuit to the lamp, and in the other are two or more flashing keys in parallel, one being fitted on the fore, and the other on the after, bridge. In parallel with the keys is a condenser, which serves to absorb the spark which would otherwise take place at the key whenever the circuit was broken. The capacity of the condenser is 2·4 microfarads.

A lamp similar to the above has lately been fitted as a yard-arm flashing lamp, in place of the gravity flashing lamps hitherto fitted. It consists of four of the small lamps that are used in the masthead lamp arranged in a circle at the base of a small lantern, and worked by an ordinary flashing key. The condenser across the key is not absolutely necessary, as the current taken by the four lamps is so small.

Non-watertight Switches and Lamp Fittings.—These are used in cabins, officers' messes, and other places where such fittings are not liable to be exposed to damp. The non-watertight switches are very similar to the watertight pattern in their action, but their covers are merely fitted for protection from mechanical injury, and are not watertight. There are many different forms of open lamp fitting in use, but it is not necessary to describe them here.

220-*volt Installations.*

The 220-volt installations that are being fitted in the "Invincible," "Defence," and probably some later ships, are arranged on a different principle to the 100 and 80-volt installations hitherto described. The "ring main" system has been introduced, and a description of this will now be given.

Three ring mains, positive, negative, and equaliser, are run right round the interior of the ship, under and behind the heaviest protection. All the dynamos supply their current in parallel into these mains by the shortest path. Every important watertight compartment is supplied by one or more tappings from these rings, the distribution being effected vertically as far as possible, so as to avoid piercing watertight bulkheads; at the ends of the ship a certain amount of horizontal distribution is unavoidable. Current required above the protective deck is derived from tappings separate from those supplying compartments below the protective deck.

Each dynamo is provided with an electrically controlled circuit breaker in a watertight case, arranged to break the circuit (*a*) if an overload is maintained for a certain time on the positive, negative, and equaliser leads, and (*b*) instantaneously if the current is reversed through any dynamo. This circuit breaker is fitted as near the dynamo as possible, and is controlled by means of two push buttons, one to put it "On," and the other to put it "Off." There is a similar pair of push buttons for each dynamo at the central control position. This circuit breaker is known as a "Supply Circuit Breaker."

At every point where the ring main is tapped, whether for dynamos or out-going circuits, the whole of the tapping is enclosed in a watertight box, known as a "Service Box," which is filled completely with an insulating compound.

Branch Circuit Breakers.—At each point where current emerges from the ring main is placed a circuit breaker, which will open the circuit, (*a*) if the current exceeds a predetermined amount for a certain time, or (*b*) if the pressure is wholly withdrawn from, or greatly reduced on, the ring mains for one second. This circuit breaker is controlled by a pair of push buttons, fixed on the apparatus, one to put it "On," and the other to put it "Off." There is also a single push button at the central control position, which puts it "On" only. This circuit breaker is known as a "Branch Circuit Breaker."

Central Control Position.—At the central control position there is fitted for each dynamo:—

(1) The pair of push buttons already referred to for controlling the supply breaker.
(2) A voltmeter connected to the dynamo side of the supply breaker.
(3) A pilot lamp, connected in parallel with the voltmeter, fitted behind a perforated brass plate showing the word "Running."
(4) An ammeter, showing the current in the "return" lead to the dynamo.
(5) The field regulator of the dynamo. This is of the vertical pattern, consisting of a single movable contact moving over a straight row of fixed contacts.

The apparatus enumerated for each dynamo is all arranged on a single dynamo panel.

Besides the gear for the dynamos, all the push buttons for putting on the various branch breakers are arranged on a single panel at the central control position. Each button is labelled with the name, or number, of the branch breaker that it controls, and has a small lamp or indicator beside it to show whether the breaker is "On" or "Off." On this same panel are two ammeters, showing the current in the starboard and port sides of the ring mains respectively.

This "circuit panel" is placed in the middle, and the dynamo panels are arranged on either side of it.

A pair of earth lamps is fitted on the circuit panel, one labelled "Positive" and the other "Negative." They are connected respectively to the positive and negative ring mains, and thence each through a separate switch to earth.

This central control position takes the place of the main switchboard fitted in earlier ships.

General System of Distribution.

Every motor whose full load current exceeds 60 amperes is connected directly to the ring main through a separate branch breaker. Motors of exceptional importance, even though they take less than 60 amperes, are also supplied from separate branch breakers.

Incandescent lamps are arranged in circuits, the current in each of which must not exceed $2\frac{1}{2}$ amperes, so that there can be eight 16 candle-power lamps on each circuit.

The lighting mains are arranged as follows:—

A junction box, designed for the reception of a current of 250 amperes at 220 volts and its distribution over five circuits, is fed directly from a branch breaker on the ring mains. This junction box contains two bus bars, to which the feeders are connected, and five separate contacts facing each of them, to which the smaller circuits are connected. These contacts are connected to the bus bars by means of fusible cut-outs, each of which will stand a current of 60 amperes, though, if the total current to the junction box exceeds 250 amperes, the circuit will be broken at the branch breaker. No switch is fitted in the junction box, as it is connected direct to the branch breaker.

Each circuit from the junction box feeds either a motor or a section box for lighting, which is designed for the reception of a current of 60 amperes, and its distribution over five circuits. Inside the section box is a double-pole switch, which is worked by a handle outside the box, through which the 60-ampere circuit feeds the two bus bars of the section box. The section box is similar to the junction box, except that it is smaller and is fitted with the double-pole switch. The fuses are capable of carrying 30 amperes each, but should the total current through the section box exceed 60 amperes, the cut-out in the junction box, of course, will go.

The circuits from the section boxes feed small motors and distributor boxes. The distributor boxes are designed for the reception of a current of 20 amperes, and its distribution over eight circuits, each taking 2½ amperes. They are similar to the section boxes, but are, of course, smaller, and there are eight separate contacts on each side instead of five. Seven of the circuits are connected by fusible cut-outs to the bus bars, but the cut-outs of the eighth can be connected either to the bus bars or to the incoming leads short of the double-pole switch, so that, if necessary, the eighth circuit can be used for police lights.

All these boxes are made watertight, and the lids are secured by a single nut in the middle, which is tightened up by means of a special key. The insulation in all cases is micanite, and nothing else is allowed to be used. The boxes are subjected to the following tests when received from the makers :—

(1) An alternating pressure of 2,000 volts is applied for 10 minutes between earth and all parts designed to carry current, all cut-outs being in place, and the switch to "On." The same pressure is then applied for the same time between earth and all parts connected to the positive pole, the remainder of the insulated parts being connected to earth.

(2) The insulation resistance must not be less than 20 megohms, both between the two sides of the box, and between either side and earth.

(3) Ten per cent. of the boxes are tested for watertightness by being immersed in not less than 3 feet of water for one hour.

Cut-outs.—The cut-outs for the distributor boxes are 2 inches long over all; those for the section boxes are 5 inches long, while those for the junction boxes are 5½ inches long. It is thus impossible to put a cut-out larger than the proper size into any box.

Size of Mains.—The size of the conductors is so calculated that the drop in voltage between any point in the ring mains and any other point does not exceed 2½ volts when all motors and lamps which could be in use in any Service conditions are connected and supplied. The drop of voltage in any circuit tapped off the ring main, measured between the farthest lamp or the farthest motor, and the internal terminals of the branch breaker from which it is supplied, must not exceed 2 volts for lamps and 8 volts for motors, when all lamps and motors supplied from that branch breaker are working at their normal full load.

The cables used for the ring mains are made of stranded copper, insulated with layers of paper impregnated with some insulating compound of a resinous nature. Outside the paper there is a lead casing covered with a layer of jute yarn, and the whole is then armoured with galvanised steel wires.

This paper insulated cable is used instead of rubber insulated cable, as it stands heat better, and parts of the ring mains are in positions in which the heat is very great.

For the remaining circuits in the ship, Patts. 241 to 255 cables are used (*see* Appendix), according to the current that each has to carry.

100-*volt Ring Main Systems.*—Some of the later ships are being fitted with 100-volt ring main systems, and these are exactly the same as the 220-volt system described above, except that there can only be four lamps on any single circuit instead of eight. The same fittings are used, but the maximum drop of voltage allowed is only 1 and 3 volts for distant lamp and motors respectively, as against 2 and 8 volts allowed on the 220-volt systems.

CHAPTER XVI.

Management of Circuits and Temporary Lighting.

Management of Circuits.

1. Arrange a routine for the staff in large ships, and always have one L.T.O. at least doing duty on the circuits, and responsible for everything connected with them. He should switch on and off the mess lights, and forward and after lights above water, as occasion requires, according to the darkness of the deck. He should make all small repairs, replace lamps, and in ships with the old switchboards, where there is no switchboard watch keeper, he should attend at the board when changing over from one dynamo to another. He should always be ready to make good any damage as it occurs, and should always have with him a screwdriver, pair of pliers, and several sizes of cut-out wire. He should know the circuits thoroughly.

2. Men should be told off for cleaning electric light fittings, *i.e.*, globes, lamps, reflectors, and should work gradually through the ship, otherwise everything will be dirty and give a bad light. Dirty lamps and globes may be easily and efficiently cleaned with soda.

3. Certain parts of the ship can stand worse lighting than others, so that old lamps may be placed there to run the end of their time, and new ones shipped in the more important positions.

4. All section and distributor boxes should be overhauled at intervals and cleaned; at the same time look out for signs of heating, and have the cause rectified. Whenever specially good and constant lights are required (*e.g.*, in action, &c.), see the main cut-outs in good condition.

5 If the lights go out suddenly a cut-out has probably fused, in which case the first thing to be ascertained is whether all or only a portion of the circuit is in darkness. This will give an indication of the position of the cut-out which has failed. If the lights flicker and fade out, it is probably the dynamo that is at fault.

6. Flickering of the light is probably caused by the governor not working well and wanting lubrication.

7. A sudden flicker is probably a cut-out gone on some portion of the circuit.

8. The failure of hook-joint lamps is very often due to their being badly hooked on.

9. Never leave lamps in important places, such as binnacles, signal, bow, and masthead lanterns, chart-house, signal-house, Captain's and Admiral's cabins, magazines, engine-rooms, &c., until worn out, but change them after burning for some

1,000 hours, or on any sign of the filament becoming uneven in its resistance. (This may be tried by switching off and seeing that all parts of the filament lose their brightness at equal rates—discard any that appear to have bright spots.) Lamps so changed can be used in other unimportant parts of the ship, but failure of important lamps means confusion.

10. All deck tubes, bulkhead glands, and similar fittings through which cables pass, should be frequently inspected to see that they are watertight and well screwed up. They are a fruitful source of trouble if this is not done.

11. The electric light party should frequently make sure that there are no earth leaks anywhere in the ship.

12. If earth leaks are found they should be removed at once if possible, but it will be found most convenient to do this at some period during the *day*, when the loss of light due to taking off the circuits will be least felt.

Changing over Dynamos.

If it is necessary at any time to start another dynamo either to take over the work that the running machine is doing, or for some other work, such as boat hoists, &c., it is most important that the extra machine should be started in plenty of time. It is very injurious to the engine, especially if it is of large power, as are the machines fitted in later ships, to put a load on it before it is properly warmed through.

The instructions laid down in Chapter IX. are always to be strictly adhered to.

Management of Circuits in case of Fire or Collision.

On the alarm of fire the first consideration of the lighting party is "What circuits are in danger?" The circuits and ship should be so well known that there should not be an instant of doubt. Suppose the worst place—a store room through which the dynamo mains of the machine running are led. Should these be destroyed the whole ship will be plunged into darkness. A second machine should therefore be started at once, and the safe circuits shifted to it. Means should be taken for lighting the pumps with yard-arm reflectors, if any of those pumps are lighted by the endangered circuits. If the mains of any circuit pass through a compartment which is on fire it may be necessary to run temporary leads between the section boxes on either side of this compartment, so as to maintain the supply of current to parts of the ship beyond. The circuit mains where they lead into, and out of the compartment on fire, should be disconnected from the section boxes, or cut if necessary.

If the fire simply threatens the particular circuit at the seat of the fire, then yard-arm reflectors should be got ready to replace those lights, their leads being joined up to the nearest or most convenient section boxes. The officer must use his discretion as to switching off and disconnecting a portion of a threatened circuit to save the main cut-outs and prevent the loss of light to the whole circuit. But the whole question is one which in each ship should be well thought out, the torpedo staff being instructed as necessary.

In cases of accident—such as the filling of a compartment from collision, &c.—the great thing is to localise the loss of light. The quicker temporary mains are run, the quicker will the work of shoring up and stopping the leaks in watertight bulkheads become. If everything is at hand in the way of leads and binding screws, and the exact place for making the connection to search light or other idle leads is known, a serious mishap may be averted.

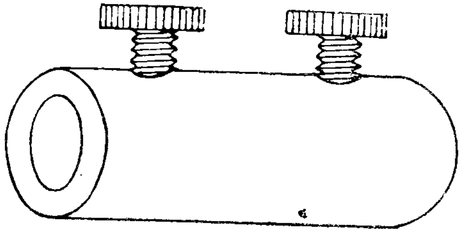
In action, the preservation of light is equally important and far more difficult, since both the above contingencies are possible, and, in addition, there is the damage due to the enemy's fire.

In large ships at General Quarters two parties, each consisting of an L.T.O. and two hands, should be stationed to undertake immediately any repairs that may become necessary; each party should be provided with the same gear as previously enumerated for the fire party. In smaller ships one party will be sufficient.

It should be borne in mind that the immediate repair of the portions of circuits which facilitate the supply of ammunition or the working of the guns is of the utmost importance.

Scrap cable, Patts. 816A to 825A, with the lead covering removed, is supplied to ships for making temporary repairs in fire or action. Gun-metal connections, Patt. 1937, as shown in Fig. 163, are also supplied for this purpose.

Fig. 163.



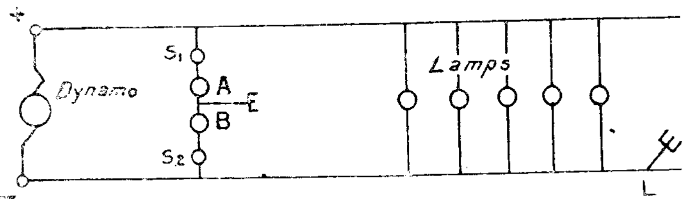
Testing Circuits.

Circuits properly looked after, if originally well fitted up, give but little trouble, and every endeavour should be made to keep them as free of earth leaks as possible. No one in charge of circuits should be satisfied till every trace of a leak is removed. One leak is easy to localise and repair, whereas several are more difficult, and if left, faults may accumulate to such an extent that the lights cannot be burnt.

The detection of a leak, therefore, becomes of much importance, and it is essential that the method of detection should be thoroughly understood by persons in charge of circuits. The practical method of detecting and testing for leaks will therefore be treated at some length.

FIG. 164.

EARTH LAMPS.



Suppose Fig. 164 to represent a portion of an incandescent circuit, with earth lamps fitted as described in Chapter IX., one terminal of each being connected through switches, S_1 and S_2, to the two bus bars, and the other terminals each connected to earth. If there are no earth leaks on the circuits, when either switch is put on alone, the lamps will not burn; but if both are closed together, each lamp will burn at half brilliancy, since they are in series across the mains.

Suppose now an earth leak L exists on one of the mains, the negative, say. Then, when the switch S_1 is closed, the lamp A will burn. If it is a "dead earth," that is, a good contact between the main and earth, A will burn at full brilliancy; but if it is only a small leak, so that there is considerable resistance in series with A, the lamp will only burn dully. In the same way, if there were a leak on the positive main, the lamp B would burn more or less brilliantly according to the resistance of the leak, as soon as its switch S_2 were closed.

The advantage of this method is that leaks can be found by it without stopping the dynamo.

Finding Earth Leaks.

Suppose a leak at L (Plate XXXVII.) is shown to exist by the earth lamps. The procedure to locate it is as follows:—

First. Determine whether it is on the positive or negative main; let us assume that we find it to be on the positive main.

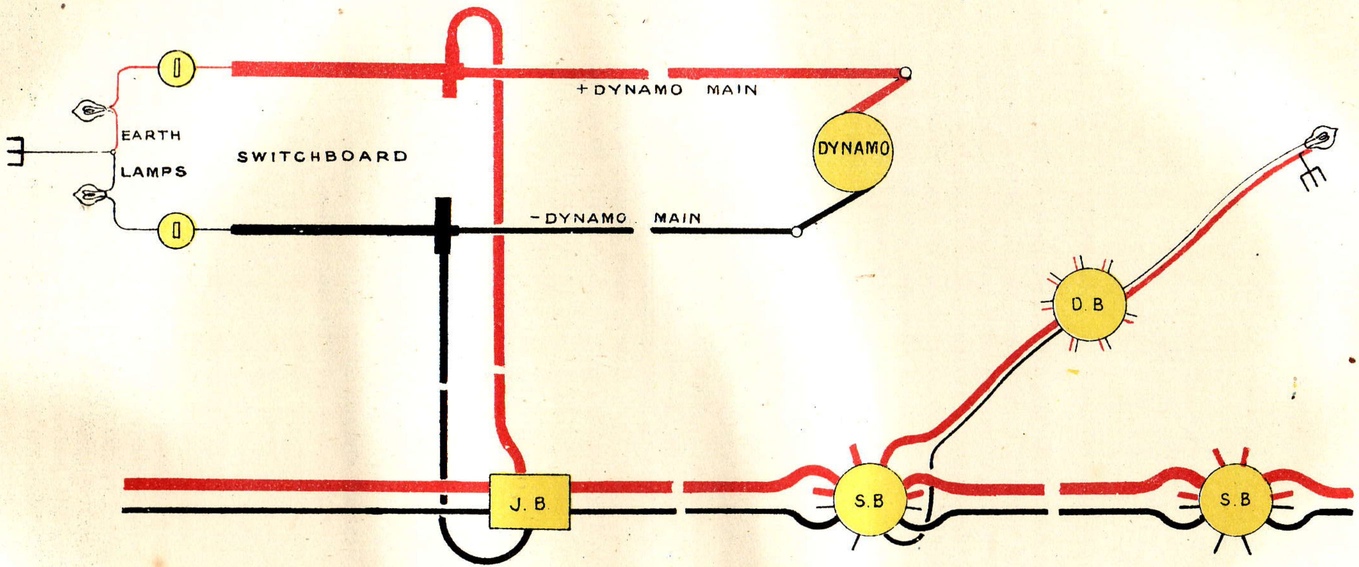
Secondly. Determine on which of the circuits the leak is.

Each circuit must be disconnected from, and then reconnected to, the bus bars in turn, one at a time; the earth lamps being carefully watched. If the leak is seen by the lamps to disappear, this will show that it is on the circuit which is disconnected at that moment. Having thus found which circuit the leak is on, the next thing to do is to locate it.

Thirdly. See the connections are well made at the switchboard and switch off the earth lamps; this is important. Take a testing lamp (consisting of a lamp and holder, and two flexible leads about 2 feet long each) and proceed along the circuit to the nearest section box. Remove the cover, and test the earth lamp by seeing that it burns correctly when its wires are in contact with the mains.

To face page 291.

TESTING BY EARTH LAMPS.



Weller & Graham Ltd Litho. London.

Make sure which main the leak is on by joining one wire of the test lamp to earth, and touching the other first on one side of the supply and then on the other. When the opposite side to that on which the leak is, is touched, the lamp will burn. It will burn in this case when the lamp is connected between the negative and earth. Switch off the boxes and see if the lamp still burns; if it does not, then the leak is on one of the circuits fed from the box: but if it does, then we must go on to the next box.

Go through the same procedure in this case. If the lamp still burns with the second box switched off, then proceed to the third, and so on all round the ring. When the box that feeds the leaky main is reached, the lamp will cease to burn when that box is switched off. If it still burns in every case when the box is switched off, then the leak must be on the mains that feed the ring, and we can proceed to find the faulty section of main as follows:—

Make a break in the ring by removing the links that connect the incoming and outgoing mains in one of the section boxes nearest to the junction box. The whole circuit must be taken off at the switchboard while this is being done, as these links may be carrying a considerable amount of current. Then, having put the circuit on again, go to the section box next to the one from which the links were first removed, and see whether the lamp still burns with the links in this box removed. If it does not, then the leak is on that portion of the mains between the first and second boxes; but if it does, replace the links in second box and go to the third. Carry out the same routine all round the ring until the faulty length of main is discovered. When this has been done, the actual position of the fault, if not apparent, can best be found by means of the telephone test, described later.

Let us consider the case, however, of the leak being found to be on a circuit fed from one of the section boxes. We can then proceed to locate it further as follows:—

Fourthly. We now wish to ascertain on which of the distributor boxes fed by this section box the leak is. To do this the cut-outs leading to the positive sub-mains of these distributor boxes must be removed one at a time. The testing lamp used after each is disconnected will show the faulty distributor box. Great care should be taken to switch the box "off" whilst the cut-outs are being removed or replaced, and to switch it "on" again when testing. Note that it is unnecessary to remove the cut-outs leading to the negative sub-mains, as we have assumed that our earth lamp, in the first test undertaken, indicated a leak in the positive main. Had the leak been on the negative main it would of course have been necessary to remove the negative sub-main cut-outs instead of the positive. The faulty distributor box having been thus discovered, go to it and switch it "off" and take out the police light cut-outs and test again at the section box to see if the leak is in the sub-main between the section and distributor box; if not, the cut-outs should be replaced in the section box and its cover screwed on.

Fifthly. Take out the cut-outs in the distributor box leading to the positive lamp leads, one at a time. The testing lamp being used as before, will locate the fault down to a particular pair of lamps. The leak must therefore be either on one of these lamps, or in the wires supplying it. The lamp leads of one lamp may be disconnected, thus showing which of the two is at fault. A careful inspection of the leads and lamp, and disconnecting the latter from the holder, will generally show the bad place; or if in the lead, it may be most readily found by the "telephone test" described later.

Sixthly. Now let us suppose that when disconnecting the circuits singly from the dynamo bar at the switchboard, the earth lamps continued to indicate a leak all the time. In this case there may be a leak on the positive mains of two or more circuits, and to find them the circuits must be broken two at a time, until the two faulty ones are discovered, or the following method may be adopted:—"Break" all the circuits in succession without "making" again, in the following order: 1, 2, 3, 4, 5, 6, until the fault disappears. Let us suppose that the leak is no longer shown when No. 4 is broken. Then No. 4 must be *one* of the faulty circuits, and Nos. 5 and 6 must be correct. It remains to discover whether the other faulty circuit is No. 1, 2, or 3. Put "on" No. 1 first, and then No. 2, and then No. 3; the faulty one will be at once detected, by watching the earth lamps, when it is connected. This method involves keeping the circuit "off," and consequently the ship in darkness, somewhat longer than the other, but generally gives more satisfactory results.

Seventhly. If when all the circuits are together disconnected the leak still shows, it must be either on the switchboard, in the mains leading to the dynamo, or in the dynamo itself or its voltmeter and pilot lamp connections. The circuits may be put on again at the switchboard, and an endeavour made to localise the leak by disconnecting the leads to the voltmeters, pilot lamps, &c. Should the leak not be discovered in any of these it is presumably either in the dynamo itself or its mains. Which of the two could be determined by means of the telephone test; but since the leak cannot be repaired whilst the machine is running the lights, this is of little use. A fresh dynamo should therefore be started if practicable and the circuits shifted to it, so as to proceed with the testing without leaving the ship in darkness. As soon as this has been done, disconnect the dynamo mains from the machine terminals, and with a test battery see if the main leads are faulty. If so, they should be carefully examined along their whole length, or the leak discovered by means of the telephone test.

The dynamo can be easily tested for insulation without stopping it, if desired, if all the circuits are off it. Use a test lamp fitted with two short leads; connect one of the leads to earth, and with the other touch the negative terminal of the machine. If the lamp burns, there is a leak from the positive terminal to earth. To locate the leak the dynamo must be stopped and tested as previously explained.

Telephone Test.

A telephone and induction coil are supplied for the purpose of locating, in lead-coated or armoured wires, a fault which exists at some unknown place between the core and sheathing. It will also locate a fault in Patt. 600 if earthed. The induction coil consists essentially of a fine wire No. 27 L.S.G., of 25·5 ohms resistance, wound in a groove cut in the edge of a flat oblong mahogany reel, about 11 inches long by 2½ inches wide. The two ends of the wire are secured to two gun-metal terminals let into the woodwork of the reel, and from them connection is made to the telephone by means of two flexible leads.

To use the telephone test on an incandescent circuit. Take a 50 candle-power lamp fitted with two leads, to the switchboard; test it, and then connect it to the sound main on one side, and to "earth" on the other; it should burn. The extra current flows along the faulty wire as far as the fault by the shortest route. Keep "making" and "breaking" the connection of the lamp to earth, making by this means pre-arranged signals such as three sharp taps at a time, so that the noise will not be confused with others. Holding the induction coil edgeways against the faulty circuit, follow the noise along by listening in the telephone, until it ceases. This will occur immediately the leak has been passed. Do not be misled at a fork in the cable; here the noise, of course, will not be heard in the sound wire.

Any number of leaks may be found by this system without interfering with the lighting of the ship, and should a 50 candle-power lamp not provide sufficient current, one or two yard-arm groups could be substituted for it.

There is a theoretical objection, which is that the lead casing of the cable is not always making earth with the hull, and might possibly only be making good contact beyond the leak. To obviate this it may be necessary to join the lead wire to the iron of the hull at intervals.

Telephone testing may also be done by using ordinary cells to supply the necessary current. The method is fully explained in the Drill Book.

Induction coil telephones, especially of the old "Pony" type, should be kept away from the vicinity of a dynamo which is running, as they are liable to develop consequent poles.

Temporary Lighting.

It is often necessary to run up temporary lighting circuits for public functions or entertainments as well as for coaling, provisioning, &c. The best arrangements to be adopted depend on the size of the space on board the ship or the rooms to be illuminated; and a careful estimate should therefore be made of the amount of light required, and plans drawn of the circuits and fittings to be used.

The ordinary lighting mains should not be disturbed, but may be used for a portion of the light, any extra lamps required being put on temporary circuits. These extra circuits should be fitted as completely as possible, with cut-outs and switches of suitable sizes placed in accessible positions. In important places it is as well, when practicable, to have the circuits halved and fed from two separate mains, so that the failure of one will only reduce the light, and not leave the place in total darkness.

The method of extemporising lighting circuits most used in the Service is as follows:—Take two lengths of Patt. 600 wire and stop them together; short leads of Patt. 733 should then be forked in at such intervals apart as the lamps are required, the junctions being insulated with tape and solution.

The junctions should not be exactly opposite one another in the two leads, but should be about half an inch apart.

A good extempore lampholder for loop lamps may be made of cork, grooved at the sides and base, care being taken that the grooves are of such a depth as (*a*) to hold the glass neck of the lamp firmly, and (*b*) to allow the wires to be slightly further apart than the loops of the lamp. A taut whipping of twine will make this a very firm holder; it is even better than the Service loop lampholder when exposed to the wind, and does not take long to fit. It is occasionally difficult to rig circuits with the lamps in place without breakages; when this is likely to be the case short lengths of Patt. 733 should be fitted as described to the lamps, and short branch wires at the proper intervals in the circuits. The lamps can then be quickly joined up and insulated after the circuits are in place.

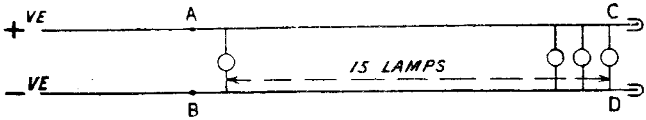
For bayonet joint lamps, small lampholders of wood, fitted with a bayonet joint lamp fitting, are supplied together with the other stores for illuminating ship.

Precautions should be taken to reduce the loss in D.P. at the furthest lamps as much as possible, so as to keep all the lights burning at an equal brilliancy.

Fifteen 80-volt or twenty 100-volt 16 candle-power lamps is the most that should be placed on one circuit of Patt. 600, as its current capacity is only 12 amperes, and if more than this number are connected, it will be found that the voltage of the end lamps will be so reduced as to diminish their brilliancy appreciably.

If more than 15 lamps are required on one circuit, a good plan is to supply the current to the centre of the circuit, instead of at only one end. (*See* Figs. 166 and 167.)

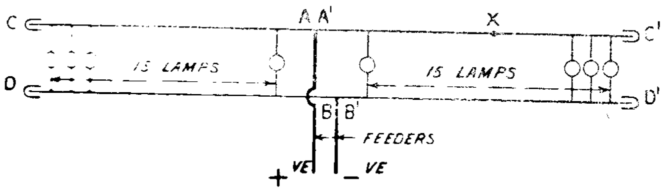
FIG. 165.



In Fig. 165 it will be seen that 15 lamps are connected up to two leads (Patt. 600), the ends C D on the right being insulated, and those at A B joined by two leads, called *feeders*, to a source of D.P. In this case the current at A and B will be 12 amperes, and will be gradually reduced in the circuit, until at C D (beyond the last lamp) it is nothing.

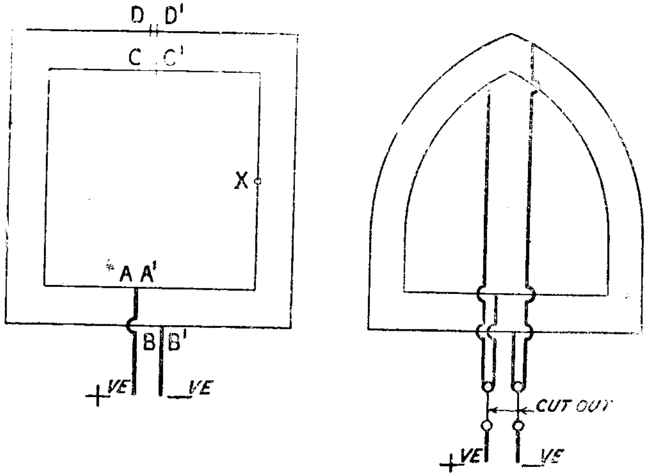
Fig. 166 shows how 30 lamps can be put on one circuit, the feeders being connected to its centre. Here the current at A B A^1 B^1 will be 12 amperes in each case, and therefore the feeders must be of 24-ampere capacity.

FIG. 166.



If a space, such as a room or quarter deck, is to be lit by lamps running round the walls or ridge ropes, the ends C C^1 and D D^1 respectively may be joined together, making a complete *loop* or *ring* of the circuit. (*See* Fig. 167.)

(*a*) FIG. 167. (*b*)



The only advantage gained by this, is, that if a break occurred say at X (Fig. 167 *a*), the lamps between C″ and X would be fed through A C. Although these lamps would be prevented from going out altogether, the circuit would be overloaded.

In fitting up temporary circuits, moreover, a considerable disadvantage attaches to this method, as when joining up the far ends the greatest care must be taken not to cross the leads, *i.e.*, join C to D^1 and C^1 to D, for should this be done the result will be a short-circuit between the positive and negative mains and the immediate fusing of cut-outs. For this reason, in fitting circuits and feeders all the ends should be carefully marked $+^{ve}$ or $-^{ve}$ and *tallied*, and the main wires of circuits should be marked at intervals with bunting.

Fig. 167 (*b*) shows a further development of this system where the "ring" (of Patt. 600) is fed at two opposite points, and may consequently be fitted with 60 lamps without overloading any portion of the circuit. In such a case the cut-outs should be arranged as shown, and no separate cut-outs can be fitted to the ring or feeders, since their fusing would bring a dangerously large current on the remaining cut-outs.

Patt. 546, the flexible twin wire supplied for use with yard-arm groups, will be found most convenient for use as feeders, but it must not carry more than 18 amperes.

Illuminating Ship.

The general idea when illuminating ship is to outline the forecastle, superstructures, bridges, quarter deck, and water-line; as well as the masts, yards, and funnels.

The circuits should be divided into sections of not more than 48 lamps, connected by means of feeders to search light terminals (with artificial resistance cut out); or to yard-arm terminals. The former should not be loaded to more than 120 amperes, nor the latter to more than 42 amperes.

Lamps should be 5 feet apart on the hull, 6 feet apart up and down masts and funnels, 4 feet apart along yards, and round bridges and chart-houses. After joining lamps into circuits, they should be stopped up to the circuit itself to prevent them blowing about in the wind, and to insure them being at the proper distance apart. Small ships with only 100-ampere dynamos or less, are reminded that 100 amperes limits them to 125 16 candle-power lamps, or 250 8 candle-power lamps.

We will now proceed to describe the arrangements made for illuminating ship in a battleship of the "Majestic" class.

These ships are fitted with six search-lights: two in the tops which serve for the mast circuits, and one at each end of the fore and after bridges respectively, between which should be divided the circuits for hull, superstructures, &c., so as to bring, as nearly as possible, an equal load on each. If there are no search lights aloft, special feeders will have to be fitted for the mast circuits.

Short lengths of wire, Patt. 1200, should be fitted for bridging the artificial resistances of the search lights, and for joining the distributing boards shown in Fig. 168 to the search light terminals.

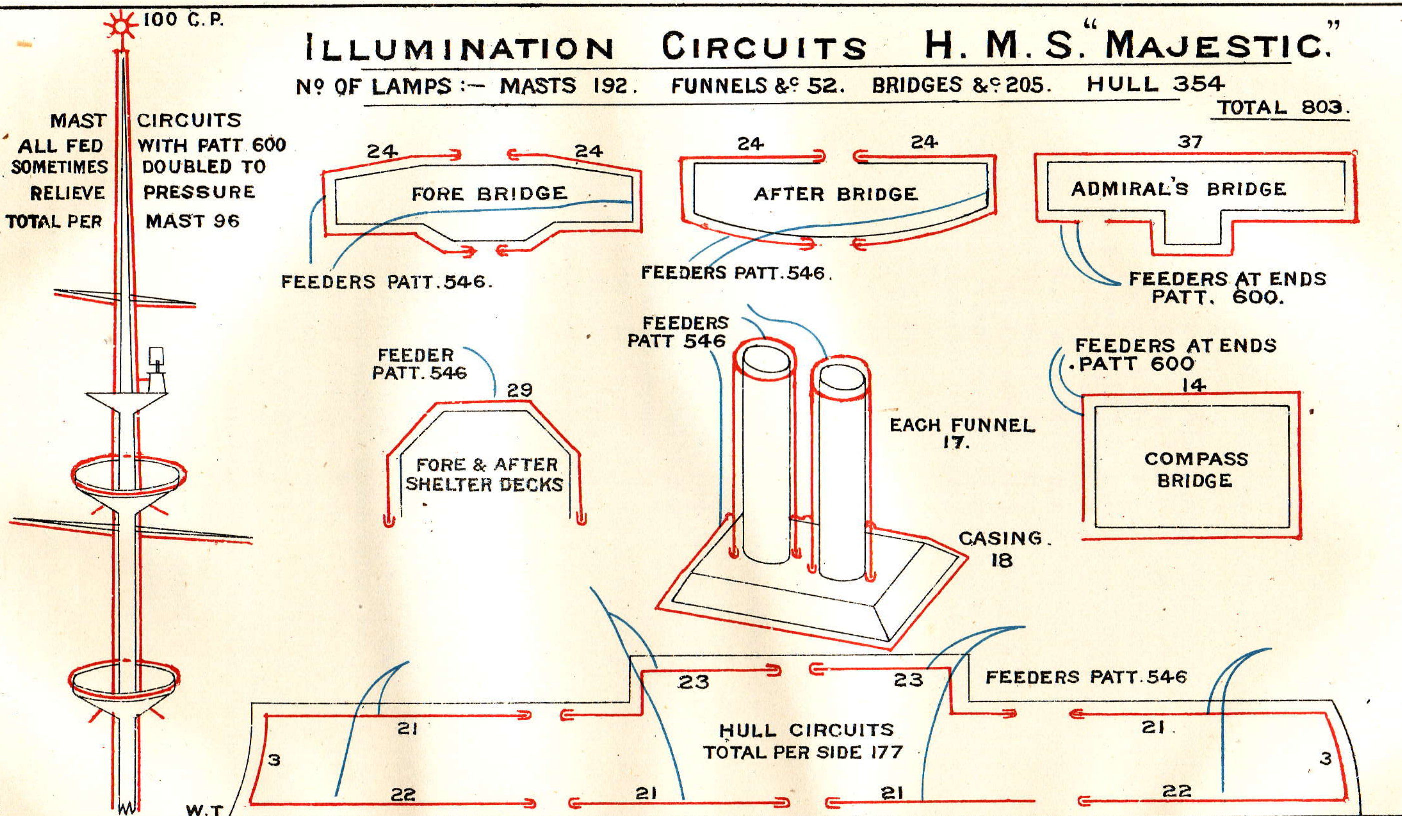
These boards can be easily improvised in the ship. They should be made of rectangular shape, about 15″ by 24″, of stout deal. Two brass plates are screwed on to them, each fitted with

To face page: 297.

ILLUMINATION CIRCUITS H. M. S. "MAJESTIC."

Nº OF LAMPS :— MASTS 192. FUNNELS &c 52. BRIDGES &c 205. HULL 354

TOTAL 803.



CIRCUITS IN RED FEEDERS IN BLUE

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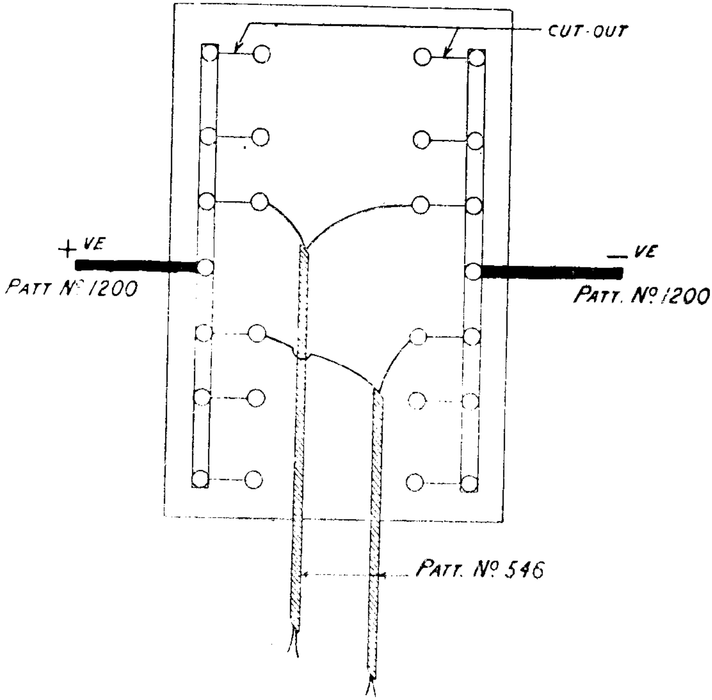
Plate XXVIII

FIG. 168.



a large terminal for the Patt. 1200; and six smaller terminals for cut-outs, leading to the six terminals to which the feeders are connected.

If there is insufficient time to fit proper terminals, large wood screws, with washers screwing down on to the wires, may be used.

Plate XXXVIII. shows the distribution of the various circuits.

Hull Circuits.—The plate shows clearly the circuits and lamps required for one side of the hull, the circuits being of Patt. 600, and the feeders of Patt. 546. The circuits along the forecastle and quarter deck are stopped to the centre berthing chain. The water-line circuits should be accurately parallel to the surface of the water, and never given a sheer. They should be placed high enough to be clear of the wash of the water. Six feet above the water-line will keep them clear of boats in ordinary weather. A good plan is to stop these circuits to a stout wire jackstay with its bight over the stem, set up under both quarters with a tackle, a loop under the bow keeping the fore end at the required height.

Both deck circuits should be stopped to a jackstay passing outside davits, &c.

There should be a stem and stern circuit on either side of the ship, and great care is necessary to preserve the correct outline of these parts.

Mast and Yard Circuits.—All feeders and circuits are of Patt. 600, the former being doubled in places to relieve pressure. A 100 candle-power lamp is placed at each masthead and fitted with a separate twin lead. The 16 candle-power lights at the masthead are placed outside the semaphore arms. The 100 candle-power lamps are mounted on broom handles, so as to stand well above the top 16 candle-power lamp. Lamps on the after side of the mast should interspace those on the fore side.

Circuit.	No. of Lamps.	How fed.
Topmast - -	26 - - - - -	Both ends.
Under Topsail Yard	13 - - -	Centre.
Upper Top Rim -	11 and 2 under -	Centre.
Under Lower Yard -	18 - - - -	Centre.
Between Tops - -	10 - - - -	Centre.
Lower Top Rim -	11 and 2 under -	Centre.
Under Lower Top -	3 - - - - -	Attached to Bridge Circuit.

Funnels.—One circuit for each funnel with a ring encircling its top is required. These should be hung from "outriggers" projecting about 18 inches from the funnel. A third circuit is used for the funnel casing. The feeders are of Patt. 546. Sometimes four upright lines of lamp are used for funnels, one on each bow and quarter.

Bridges and Shelter Decks.—The arrangement of these circuits can be seen in the plate. Feeders are of Patt. 546, except that for the compass bridge (Patt. 600).

Total number of lamps required:—

Masts - - - - -	192
Funnels - - - - -	52
Bridges, &c. - - - - -	205
Hull - - - - -	354
Total - -	803

General Arrangements.

Men should be told off in pairs for the various sections, such as port quarter, mainmast, funnels, &c. They should be provided with sticks for measuring the distance apart of lamps, and for the height of water-line circuit above the water. Hook lamps should be secured on the circuits before they are placed, the circuits being then carefully coiled into baskets, which are drawn with the other illuminating stores. They can thus be easily transported to the place required, or stowed away below when not in use.

Experience shows that the largest number of lamps are disabled by their loops being broken when they are being hooked to, or unhooked from, the circuits.

Bayonet joint lamps should not be put into the holders until the circuits are in place.

It is most desirable to trim the lights of any circuit to the same angle, so that the whole of any line will be obscured or revealed simultaneously when the ship swings. Care is also necessary to place all lamps clear of obstructions which at certain angles would eclipse them, and thus destroy the continuity of an otherwise perfect line.

All switching "on" and "off" should be done from the switch-board. By "making" all the negative mains beforehand, all the circuits can practically be put "on" and "off" together at a pre-arranged signal, such as a bugle.

To give the best effect, the instantaneous lighting up and eclipsing of the whole illumination cannot be too carefully studied.

All the stores that are allowed to be drawn by different sized ships for illuminating, will be found in the "Establishment of Gunner's Naval Stores."

Trophies.

When trophies are used they should be simple in design; anything very elaborate will lose its effect at a very short distance from the ship, more especially if it consists of a number of different colours.

Simple designs can be most effectively traced out on a wooden frame 20 feet square, interlaced by spunyarn. An Admiral's flag or an ensign can easily be outlined in lamps of different colours. White lights in this case should be 2 feet apart, red 18 inches, and if blue or green lights are used they should be closer still.

The lights may be coloured as desired by dipping them in the paint, which should always be allowed to harden before the lamps are used.

Another very effective way of lighting up masthead flags and ensigns, which was used by the Americans in the 1897 Review, is to throw a steady beam from a search light on each of them.

Other Temporary Lighting.

Lighting under Water.—The divers' lamp supplied for the purpose will generally be found sufficient, but if the operations are likely to last long, the best way is to rig up a temporary installation below water, as divers do not care to be hampered by having to carry lights.

In shallow water, ordinary watertight lamp fittings will do as well as divers' lamps; and fair extemporary lamps may be fitted by putting primer tin bungs in ordinary pendant lamp shades.

Temporary Lighting when in Dock.—For lighting ships in dock without steam up, dockyards are supplied with large motor-generators, supplied from the power station of the dockyard, which are portable and can be placed alongside the ship that requires to be lit. The leads from these generators should be connected to the bus bars of the ship's switchboard, and all the dynamos disconnected.

CHAPTER XVII.

Secondary Batteries.

Secondary batteries, as distinguished from primary batteries, are those voltaic cells which can only be used as a source of electric power if they have already been "charged up" by having a current sent through them in the opposite direction to the current that they give out.

They provide a means of storing up electrical energy, to be given up again and used when it is required, and are therefore also called "accumulators."

The energy required for lighting and working the auxiliary machinery in the Service is obtained by burning the coal in which it is stored, and converting the mechanical energy thus obtained into electrical energy, by means of dynamos. As an example it may be stated that the amount of energy to be obtained in this manner from, say, 200 lbs. of coal, would burn about 45 Service lamps for ten hours, with an engine using 5 lbs. of coal per I.H.P. per hour; whereas the weight of a set of secondary cells of the latest type to do the same work, would amount to about 7,000 lbs., that is, 35 times the weight of the coal.

Besides the objection of their great weight, secondary cells are expensive, and their life is limited to a few years; moreover, the storage in large quantities of the acid they require is undesirable on board ship.

Thus, until very considerable improvements have been introduced in secondary batteries, especially in the direction of reducing their weight, they are not likely to come into extensive use in the Service.

In submarine boats, since the burning of coal is impracticable when submerged, these cells are used as a means of obtaining propulsion, by supplying current to a motor.

The name *secondary cells* or *accumulators* is given to cells in which the energy of chemical change can be stored up, and given out again when required in the form of an electric current. In reality it is not electricity which is stored or accumulated when charging, but rather a quantity of the active constituents of the cell, and it is the subsequent chemical action between these constituents which causes the current to flow when discharging.

For example, suppose a reversed current to be urged through a Daniell cell, in which the copper sulphate has been exhausted, the copper plate will be partially dissolved and copper sulphate re-formed, while zinc will be deposited on what remains of the zinc plate. The cell would then be able to again generate a current of its own. In practice the amount of energy restored to a Daniell cell in this manner would be very small, so that if we wish to have such a reversible battery we must use other combinations of plates and liquids, which admit of a reverse action taking place on the passage of a current.

Lead plates in sulphuric acid are capable of such action, chiefly in consequence of the fact that if a current be passed through such a cell, one plate is altered from lead to an oxide of lead, which combination in sulphuric acid gives a D.P. of about 2 volts. On using the cell, part of the oxygen leaves the oxidised plate and goes over to attack the opposite one, till both are reduced to the same substance and the D.P. becomes nothing. On passing the current again the oxygen all accumulates on one plate, and the D.P. is again produced, and so on for every charge and discharge.

This is a general outline of the action of a lead secondary cell. Before going more fully into its details and action it will be necessary to consider the different combinations which lead is capable of forming with oxygen.

Lead combines with oxygen in many different proportions The only ones we need consider are—

Oxide of lead, or litharge - -	PbO
Red oxide of lead, or minium - -	Pb_3O_4
Puce, or peroxide of lead - - -	PbO_2

All these three substances are absolutely different from lead, and from one another in colour, physical and chemical properties. They are as different as iron is from brass, or lead from copper. They are all formed from lead and oxygen only, but since the proportions of the constituents of the molecules are different, the substances made are also different from each other.

Litharge is almost cream coloured.

Red lead is a rich bright red.

Peroxide is a dark plum colour.

Sulphuric acid is a thick oily liquid with very corrosive properties. It is heavier than water. Its chemical symbol is H_2SO_4.

It is easy to see that if sulphuric acid be heavier than water the more water that is mixed with it the lighter the mixture will become, so that a good method of telling the strength of the acid, is by comparing its weight with that of water. A very simple method of doing this is available, by floating an instrument in it called a hydrometer, and seeing how far it sinks.

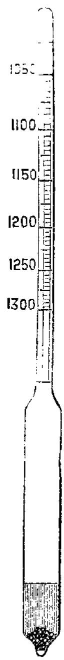
The principle of the hydrometer depends simply on the fact that any body floating in a liquid *displaces* exactly its own weight of that liquid.

Fig 169 shows an ordinary glass hydrometer, which consists of an air-tight bulb ballasted with shot and surmounted by a graduated glass stem. The instrument works as follows:—

Suppose the acid to be fairly strong and the hydrometer floating in it; all the bulb and part of the stem are immersed, and it floats at a place, say, marked 1250 on the stem. Now dilute the acid by adding more water. Each cubic inch of this mixture will be lighter than a cubic inch of the old, therefore to displace an equal weight of the new mixture, the hydrometer must sink and immerse more of its stem, and the level of the liquid must rise to a mark, say, of 1100 on the stem. By this method a very simple way of comparing the weights of equal volumes of different strengths of acid, is available.

The specific gravity of a liquid is the weight of a given volume of that liquid compared with the same volume of water. This is

Fig. 169.



also called its *density*. The graduations on the stem of the hydrometer show various densities, the density of pure water being taken as 1000.

Strong sulphuric acid has a specific gravity or density of 1840.

The resistance of a 1250 specific gravity solution is the lowest, and that the resistance rises as the density is either increased or diminished, till practically, for very strong and concentrated solutions it is seven times as great. The bearing of this on the action of the cell will be discussed later on.

Action of a Secondary Cell.

If we take two lead plates and place them in dilute sulphuric acid, join them to a suitable source of D.P., and allow a current to pass, the plate attached to the positive source of D.P. will gradually assume a brownish colour, while the other will remain as before. This colouring is due to the surface of the lead plate being changed from lead to PbO_2, which may be explained as follows:—If the water, H_2O, of the dilute acid be broken up by the current of electricity, the oxygen will come off the plate where the current enters, and the hydrogen where the current leaves. The oxygen in contact with the lead attacks it and forms PbO_2 and the hydrogen streams off the rough surface of the opposite plate without affecting it.

So far this action is very simple. If now the charging source be disconnected, we have a voltaic cell of two plates, one of PbO_2, the other of Pb, in dilute sulphuric acid. If we measure the D.P. we will find it to be about 2 volts, with the plate with the peroxide formed on it $+^{ve}$ to the lead plate.

If now this cell be discharged the $+^{ve}$ plate will lose its brown colour and assume a dark grey, and the $-^{ve}$ plate will slightly darken in colour; this latter change, however, may be scarcely noticeable. The action that has been going on during discharge has resulted in both plates becoming plates of PbO, and therefore no D.P. exists between them. Such is the elementary idea of a lead reversible cell, but several important points require special attention before such a cell can be of any practical use.

Efficiency.—By this we mean the proportion of the energy stored up which can be reclaimed from the cell. To obtain a high efficiency, cells should be made large, so that but little energy is wasted in overcoming their resistance.

Capacity, or the amount of energy the cell will store up, measured in *ampere hours.*

By *ampere hours* we mean the number of amperes × the number of hours the current is flowing. If 10 amperes run for one hour, this is called 10 ampere hours; if 100 for three hours, 300 ampere hours. It is a measure of the quantity of electricity that can be obtained from the cells; and from a knowledge of the capacity we can calculate how many hours the cells will discharge at any given rate.

On what does this capacity depend?—Evidently on the amount of lead that is converted into PbO_2, for it is from the energy given up by the PbO_2 in changing to PbO that the electrical energy of the cell is derived. If, then, we want a cell which will be able to give a certain number of ampere hours of current, we must have sufficient lead converted into PbO_2 to be able to supply the requisite electrical energy. To do this is not so simple a matter as it might at first seem, without cumbrously increasing the weight of the plates.

The main thing to be attained, if a large capacity is required, is the exposure of a large *surface* of lead to the action of the liquid. The conversion of lead to PbO_2 goes on very slowly behind a coating of *oxide*, so that the action ceases and the cell becomes what is called *fully charged*, as soon as the whole surface is covered with a thin coat of PbO_2.

There are several methods of increasing the capacity of a cell: one is by altering the surface of the lead so as to expose a larger amount than would be exposed in the case of the flat plate; and the other is by building up a plate of paste made of an oxide of lead. These two broad distinctions in the manufacture of plates practically divide cells into two types, the former called Planté type, and the latter Faure type.

We will first consider the *Planté* type, as being the less complicated. To get capacity or large surface in a lead plate, Planté used the device of making the lead spongy, or porous, so as to honeycomb the lead and present innumerable little passages for the liquid, through the immediate surface of the plate. The sides and ends of these little channels were all capable of conversion into PbO_2 by the liquid being in contact with them, and, therefore, a large amount of paste could be stowed in each plate. To do this he continually reversed his charging current.

The continuation of this operation caused each plate to become spongy or porous, till, when the greatest amount of practical sponginess had been produced, the cell was looked upon as *formed*.

Faure saw that a cheaper and perhaps more efficient cell might be obtained by covering the lead plates with a coat of paste made of the oxides of lead, so as to do away with the necessity of the long and expensive method of forming adopted by Planté. He, therefore, coated plates of lead thinly with minium or litharge, and placed porous felt between them and subjected them to a good charge. He found the paste on the $+^{ve}$ plate converted into PbO_2, and that on the $-^{ve}$ into lead. This particular arrangement was found to be bad, since lead crystals gradually pierced the felt and short-circuited the plates. Moreover, it was most difficult to get the paste to adhere to the plates. In later improvements in this type, therefore, the paste was mechanically fixed to the plates and a space left between them for the acid to circulate.

In recent years, the manufacture on separate and distinct principles of the positive and negative plates has been adopted; care being taken in their mechanical construction to obtain a large active surface, whilst reducing the weight as much as possible.

We will now assume a cell of either type fully charged—that is, with the active surface of the positive plate completely coated with PbO_2, the negative being lead Pb—and trace the change during discharge, and afterwards again during charge. Hitherto we have only considered the action of the water on lead plates; we must now consider the part that sulphuric acid (H_2SO_4) plays in the cell.

As the cell is discharged the PbO_2 gradually gets reduced to PbO, and the lead plate rises from Pb to PbO. As this PbO forms, the sulphuric acid attacks it and converts it into $PbSO_4$, lead sulphate, so that the act of discharging is to produce a mixture of PbO and $PbSO_4$. The formation of this sulphate would be much as shown below :—

$$PbO + H_2SO_4 = PbSO_4 + H_2O.$$

By this we see that the acid gets gradually reduced in strength, and a certain portion of it is turned into water, because the SO_4 leaves the acid and is replaced by H_2O. The hydrometer for this reason is a good guide as to the state of charge of a cell.

A cell should never be discharged to its full amount, for if this is done the weakened acid at the plates attacks them and forms an insoluble form of lead sulphate hard to get rid of, which greatly damages and shortens the life of the cell. Cells should never be discharged below the point when the D.P. has fallen to 1·9 per cell.

The fall of D.P. on the discharge of the cell is due to two causes. The first is that the active material of the positive plate is being reduced to $PbSO_4$ and PbO. The second, that the acid near the surface of each plate is getting weaker, and has not time to diffuse and spread itself amongst the stronger acid of the cell, so that although the hydrometer in the body of the liquid may show but a small difference in specific gravity, still at each plate, there may be a film of very dilute acid in contact with it.

Fig. 170.

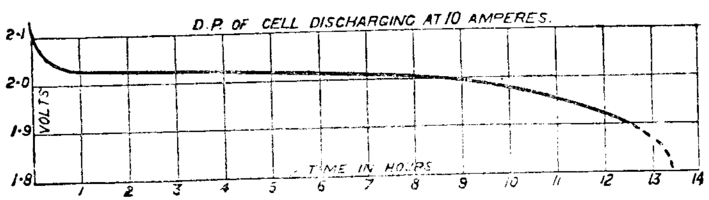


Fig. 170 shows a curve of the discharge of a cell, where it will be seen that at first the D.P. falls rapidly, then very slowly for some time, until after about 1·9 volts is reached the D.P. falls very rapidly indeed. A cell, however, left to itself for a short time will probably, owing to the diffusion of the acid bringing a stronger layer in contact with the plate, show a marked rise in voltage.

The action going on in charging a cell is the exact reverse; the current turns the $PbSO_4$ into PbO_2, and the SO_4 is again driven back into the acid in the following manner :—

$$PbSO_4 + H_2O \ldots H_2O + PbSO_4 = PbO_2 + H_2SO_4 \ldots + H_2SO_4 + Pb,$$

so that a portion of the water is converted into H_2SO_4 and the density of the whole rises, as is shown by the hydrometer. As the charging continues the voltage slowly rises, and when nearly charged gases are given off at the positive and negative plates which, by the bubbles formed, give the acid a boiling and milky look. At the same time the voltage continues rising until, when the cells are fully charged, it often stands as high as 2·4 volts, but after a short rest gradually falls to 2·1 volts. The reason for this high voltage at the end of the process of charging is probably that the acid becomes concentrated near the active surface of the plates ; the diffusion occurring as soon as charging ceases, accounts for the subsequent fall.

Three phenomena, therefore, point to the cell being charged :

(i) *The boiling*, due to there being more current flowing than can be usefully employed in transforming the paste, and which therefore merely breaks up the water.

(ii) The rise in specific gravity, due to the sulphate being turned out of the paste into the acid.

(iii) *The voltage*, due to the transformation of the paste and acid.

These three taken together form an excellent guide. Taken separately as a sign of the charge they are useless, for the following reasons :—When cells are left discharged for any length of time, or when discharged too much, a gradual formation of sulphate of lead takes place on the grid and surface of the paste. This sulphate differs from that formed during normal discharge in that it is far harder to reduce and is most injurious to the plate since it prevents the charging current being able to attack and convert the paste, and therefore allows further formation of the same sulphate to continue. If this sulphate forms, the acid must slightly lose in density, since part of the sulphate remains in the plates after charge, instead of having returned to the liquid. But the boiling and bubbling will go on as before, since the current has no useful work of paste-converting to do, and therefore, were this only taken as a sign of the cells being fully charged, without consulting the hydrometer, much sulphate might still be left on the plates to work their ruin. Always, therefore, consult the hydrometer after charging cells.

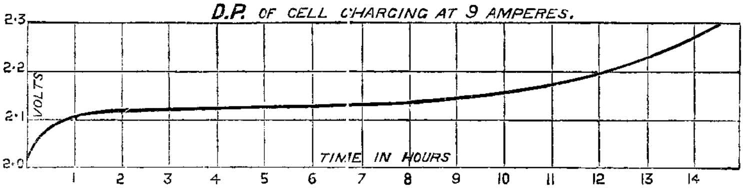
Again, the hydrometer itself cannot be looked on solely as a guide, since the evaporation of the water is constantly causing a slight increase in the density of the acid, and the cell might be considered charged before the paste was all converted.

The voltage of the cells is simply a rough guide in detecting a bad cell among a group, and of identifying the one at fault, by measuring the voltage of each separately.

The internal resistance of the cell varies during charge, increasing rapidly towards the end. This increase is probably owing to the rise in resistance of a dense acid film near the plates and must vary in every type of cell according to the size of plates and distance they are apart, and the facility for diffusion and circulation of the acid. It does not alter much in most types during the discharge of the cell between the limits of voltage of 2·1 and 1·95.

Fig. 171 shows the curve of the charge of a cell; it is very much the same in character as that for discharge, except that the voltage is higher all through.

FIG. 171.



A rapid rise in D.P. takes place at the beginning and again towards the end of the charge.

The previous sketch of the internal action in secondary cells is necessarily very incomplete. Very little is known about the more complex actions that go on between the lead and acid, and many of the theories are subject to much doubt. As far as possible, only those facts which are practically undisputed have been touched on, and only sufficient of those to enable a man to understand practically the working of the batteries under his charge.

Setting up and Charging Large Batteries for the first time.

Batteries for lighting purposes are not supplied to sea-going ships, but the following hints are given on the best way of setting them up, should it be necessary to do so:—

They should be mounted on a wooden shelf, whitewashed over (to detect leakage of acid) and placed on glass or oil insulators. The position chosen should be airy and not near anything that is likely to be injured by the acid thrown off. Two or three inches clearance should be left between each cell, and the connecting strips should be large. Glass plates should be cut having an area of about three-quarters of the surface area of the liquid; these should be mounted on wooden blocks on the edge of the cell, to prevent the ascending gas carrying off a spray of acid. The glass must not overlap the edge of the cell, otherwise the acid will drip outside it on to the bench.

On being received on board, the plates should be unpacked and carefully cleaned by blowing any straw, &c. from between them with a pair of bellows. The wooden frame should then be placed in the bottom of the cell and the plates placed centrally on it.

The acid should be mixed ready for charging the cells and allowed to cool, the reading of the hydrometer being taken when cold. The specific gravity required depends on the type of battery.

When all arrangements are ready the cells should be filled as quickly as possible, and their charging should be started *at once*, according to the instructions received with them.

If too large a current is used when charging, the plates are liable to *buckle*, which causes the paste to fall out, plates to touch, and the grids to be destroyed.

The first charging will occupy a very long time, as much as 90 hours in the case of a submarine boat's battery. It should be continued until the specific gravity and voltage have risen to the amounts specified in the maker's instructions, and should be continuous without any interruptions.

When this has been done a moderate discharge is a good thing for the cells. They should be discharged at a fair working rate to about half their total capacity, and then re-charged.

Several discharges and charges will probably be required before the cells settle down into a uniform specific gravity and voltage.

Any backward cells should be carefully examined to see that no foreign matter has lodged between the plates, as such short-circuiting would tend to prevent that particular cell charging and delay its boiling and rise of specific gravity. If one cell or more lag particularly behind the others, the faulty ones should not be discharged but should be cut out during that operation, and afterwards re-charged with the remainder.

During the second charge given to a new set of cells it may be necessary to add dilute acid to the liquid, but this should only be done in accordance with the manufacturer's instructions. After this, water only will be required to replace that lost by evaporation. In all cases the extra liquid should be added when the cells are *boiling*, so as to ensure its mixing quickly with that already in the cell.

When cells are in regular work, the charge put into them should exceed the number of ampere-hours taken out by 15 or 20 per cent.

Excessive charging has been found to ruin the negative plates.

When fully charged the positives should be a good dark plum colour, in some cases almost a blue-black; when discharged, a brick-red. The negatives should vary from a dull grey to a dark grey colour.

Specks of white on either plates should be treated with suspicion; if they can be syringed off or removed with a gentle touch of a strip of ebonite, they may be disregarded, as merely a dust that often settles on the plates, especially if much chalk is present in the water. If hard and not easily moved, they are probably sulphate.

Sulphating.—Sulphate is the bugbear of a badly looked after installation, or of old cells; it is caused usually by letting the cells discharge too much, or leaving them in a low state. The best cure is by repeated overcharging, with a low rate of current just sufficient to prevent excessive bubbling. If the sulphate remains obstinate, remove the acid from the cell and fill up with fresh water. There will be enough acid adhering to the plates to render the water conductive, and if the cell is then given a long charge at a very slow rate, the sulphate will be gradually dissolved.

This process is long and troublesome, and consequently every care should be taken to prevent the plates from sulphating. A battery should never be left for any length of time unless fully charged up, and when not in use it should be charged up at intervals, say once a week, since the cells always run themselves down slightly through local action, which can never be entirely eliminated.

The ordinary routine of charge and discharge should, in a battery of good condition, cause the specific gravity to rise and fall between certain definite limits. For E.P.S. cells, as a rule, it runs between 1200 and 1175; for chloride cells, between 1215 and 1180. The exact range varies in different types of cells, depending on the ratio of the amount of acid to active material of the plates. The discharge should be stopped when the acid reaches the lower limit in either case.

The specific gravity of each cell should be always taken after charge, and any variation noted and the offending cell overhauled It will be found at times that plates buckle; this is almost entirely confined to the positive plate, and its cause is usually due either to too rapid charge or discharge, to short-circuiting of the plates by paste falling out and bridging across, or to foreign substances finding their way into the cell. This buckling, if not corrected, will speedily destroy the battery. Immediately it is detected ebonite forks, or glass rods, should be passed between the positive and negative plates until the cell can be thoroughly overhauled, which should be done at the earliest opportunity; for the very fact of one side of a plate being nearer a negative than the other, will cause a more rapid alteration in the paste on the side closest to the negative and tend to continue the buckling.

When opportunity occurs the cell should be unbuilt, boards the exact size of the space between the positive plates should be carefully inserted between them, and a gently increasing pressure applied until all the plates appear flat. The boards may then be taken out, the negatives inserted, and the cell rebuilt.

It will be found that a certain amount of mud will collect at the bottom of the cells, owing to flaking and wastage from both plates. This does not matter, provided it does not come up to the level of the bottoms of the plates and short-circuit them, in which case the plates should be removed and the acid strained and replaced.

Finally, the following important facts should be borne in mind:—

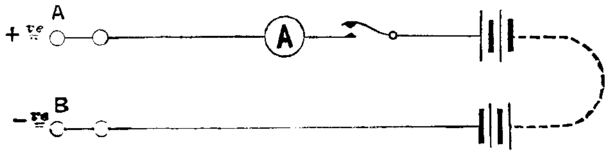
(1) Cells should never be charged or discharged above their proper rate, which is laid down by the makers. If these rates are exceeded the plates will probably buckle.

(2) The discharge should be stopped when the D.P. has fallen to 1·9, or the density of the acid has reached the lowest limit allowed by the makers.

(3) If anything goes wrong with any cell, it should be attended to immediately, and the defect remedied. If it is left alone it will rapidly get worse, and the cell will probably be ruined.

Circuits for charging Secondary Cells.

FIG. 172.



Suppose A B a source of E.M.F., such as a dynamo, with its $+^{ve}$ **terminal** joined to the $+^{ve}$ of the cells and $-^{ve}$ to $-^{ve}$ of **cells.** Cut-outs should be placed in the circuit, together with a switch and ammeter. Evidently A B must be at a greater D.P. than the cell terminals, otherwise the cells will discharge through the machine. The first question is, how much greater should this D.P. be. This must naturally depend on the current required to **charge** the cells. Suppose this to be 60 amperes.

Now to get 60 amperes we must have sufficient D.P. between A B to overcome the back E.M.F. of the cells, and leave a balance enough to force a current of 60 amperes through all the resistances of the circuit, which practically, in this case, consists of the **internal** resistance of the battery.

If, then, E be D.P. of machine, ϵ be D.P. of cells, r their **internal resistance,** then

$$E - \epsilon = 60 \times r.$$

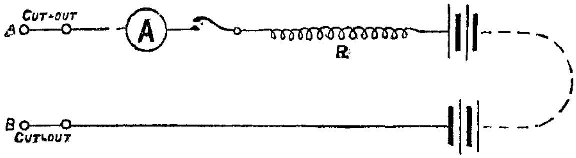
To take a numerical example, where it is desired to charge 20 cells, whose D.P. is 40 volts and internal resistance (r) is ·003 per cell.

Then

$$E - 40 = 60 \times (\cdot 003 \times 20)$$
$$E = 40 + 3\cdot 6$$
$$E = 43\cdot 6 \text{ volts},$$

so that 43·6 volts will be required to force the current of 60 amperes through the cells. It will be seen that in such a case, a very small fall in speed of the dynamo will cause the D.P. of the cells to be above that of the machine, and the cells will discharge through it; this is objectionable, although, as will be presently seen, it depends greatly on the type of machine used whether the disadvantage is great or not, but the chances of this happening are greatly reduced by inserting a resistance in series with the cells. This is not economical, but is extremely convenient, as the speed of the machine can be kept constant throughout the charge, and the resistance gradually reduced by a switch as the cells charge. Such a circuit is shown in Fig. 173, where R is the adjustable resistance.

FIG. 173.



The amount of the resistance differs according to circumstances. If 80-volt lamps are being burned at the same time off the machine charging the cells, then taking the same figures as before

$$R = \frac{80 - 43 \cdot 6}{60}$$

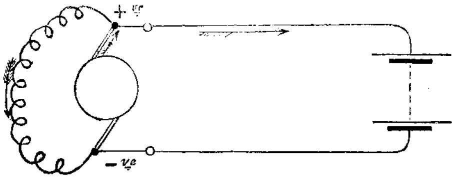
$$= \frac{36 \cdot 4}{60} = \cdot 6 \text{ ohms.}$$

By watching the ammeter any increase or decrease of the current may be noticed, and the resistance altered to keep the current normal.

Before switching on, care should be taken that the machine is at the right voltage, and joined up properly.

The shunt machine is the best type of machine for use with secondary batteries, since it cannot possibly reverse itself while the cells are being charged.

FIG. 174.

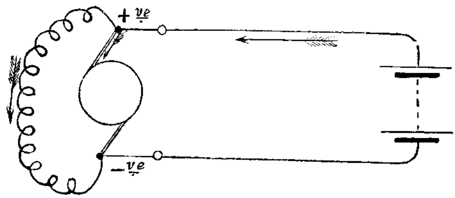


If Fig. 174 be a diagrammatic view of a shunt machine charging cells, and the arrows show the direction of the charging current, it will be seen that the current flows from $+^{ve}$ to $-^{ve}$ round the shunt coil.

Fig. 175 shows the state of things if the cells discharge through the machine. The current in the shunt coil flows from $+^{ve}$ to $-^{ve}$ still, and therefore the polarity of the machine will not be reversed, and an increase in speed of the dynamo will be all that is needed to continue the charge.

It will be seen from these considerations that a shunt dynamo is very suitable for charging cells, but this is not the case with a series machine, since any reversal of current will produce reversal of polarity and put the machine in series with, instead of in opposition to, the cells.

FIG. 175.



A compound dynamo can be used for charging cells, but if it is, means must be provided of preventing the cells from discharging through the dynamo in any circumstances, since, if a large reverse current were to pass through the series coils, the machine might be reversed notwithstanding the shunt coils.

In large installations, an automatic cut-out is used for this purpose, somewhat similar to that fitted on a parallel switchboard, but in charging small batteries on board ship this is not necessary.

The voltage of the dynamo is very much larger than that of the cells, and the usual method of charging is through a resistance that absorbs the extra D.P. This resistance is very high compared with the E.M.F. of the cells, and consequently even if the dynamo were to stop altogether, the cell would only give out a very small current.

It is most important, before switching on the charging current to a set of cells, especially in large installations, to see that they are joined up the right way. The polarity of the dynamo can be ascertained in any of the ways described in Chapter VII.

The general arrangement of a chloride 19 plate R type cell is shown in Plate XXXIX. It is propesed to give a short description of this form of cell, which may be taken as embodying the latest improvements in accumulators, although of course there are many other types in existence. The batteries in submarine boats are composed of Chloride cells, though they are of course much larger than the R type, and the containers are different.

The positive plates are joined together at their adjacent corners by a lead bridge. These plates consist of lead grids or agrtings, with circular coils of "gimped" lead ribbon driven into the grid holes, thus giving a large active surface. The negative plates are placed alternately between the positive plates, and there is one more of the former than of the latter, so that every positive has a negative on either side of it. The negatives are also joined together by a lead bridge, and are also formed of lead grids. In these grids are embedded *Pastilles* of spongy lead. The fact of the pastilles being made from lead chloride—the chlorine being removed in manufacture by an electrical process—has given the name to the cells.

Both the positive and the negative plates have hooks cut in their sides near the upper edges, and by these hooks they are suspended from two vertical glass plates resting on a wooden base in the glass container or from porcelain ledges in the top of the cell. The plates are kept separated to their right distance apart (about $\frac{1}{4}''$ to $\frac{3}{8}''$) by glass or ebonite rod insulators.

This method of suspension is a great improvement on the older forms of cells, where the plates stood upright on the bottom of the container, and tended to buckle to a greater extent in consequence. Moreover, the deposit of particles of dirt at the bottom of the cell was apt to short-circuit the plates, unless the cells were frequently cleaned out.

First Charge of the Battery.—The batteries are supplied dry, and must be charged as follows:—The sulphuric acid supplied for the purpose should be mixed to a specific gravity of 1215; this may be done in a wooden tub or an earthenware vessel. In mixing acid it is important to remember that the water should be first placed in the vessel and the acid gradually added to it, until the desired strength is reached. The mixture should then be allowed to cool, and its specific gravity again carefully checked. Distilled water should be used.

The acid must on no account be poured into the cells unless the charging can be started immediately afterwards.

The charging must be continued until the following indications show that the cells are fully charged:—

(i) The average voltage should be 2·2 volts per cell.

(ii) The cells should *boil* freely, gas being disengaged from both $+^{ve}$ and $-^{ve}$ plates.

(iii) The density of the acid should be over 1215.

After the first charge, acid should never be added to the cells, but the plates should be kept completely covered by the addition of pure fresh water as required.

Secondary batteries are at present only supplied to sea-going ships for working the small portable hand lamps for use in magazines.

The batteries consist of from two to four cells in a box, joined in series to the lamp which is carried on the outside. The tops of the cells are closed with some sort of sealing material of the nature of pitch, a hole being left in the top of each for filling and to allow gas to escape while charging.

They are best charged by being connected across the lighting mains, as many incandescent lamps in parallel as are necessary to give the requisite current being included in the circuit.

As it is impossible to get at the acid to test its density, they must be charged until the voltage rises to the proper value and the cells are gassing freely.

To face page 314.

SECONDARY BATTERY CHLORIDE R. 9. TYPE.

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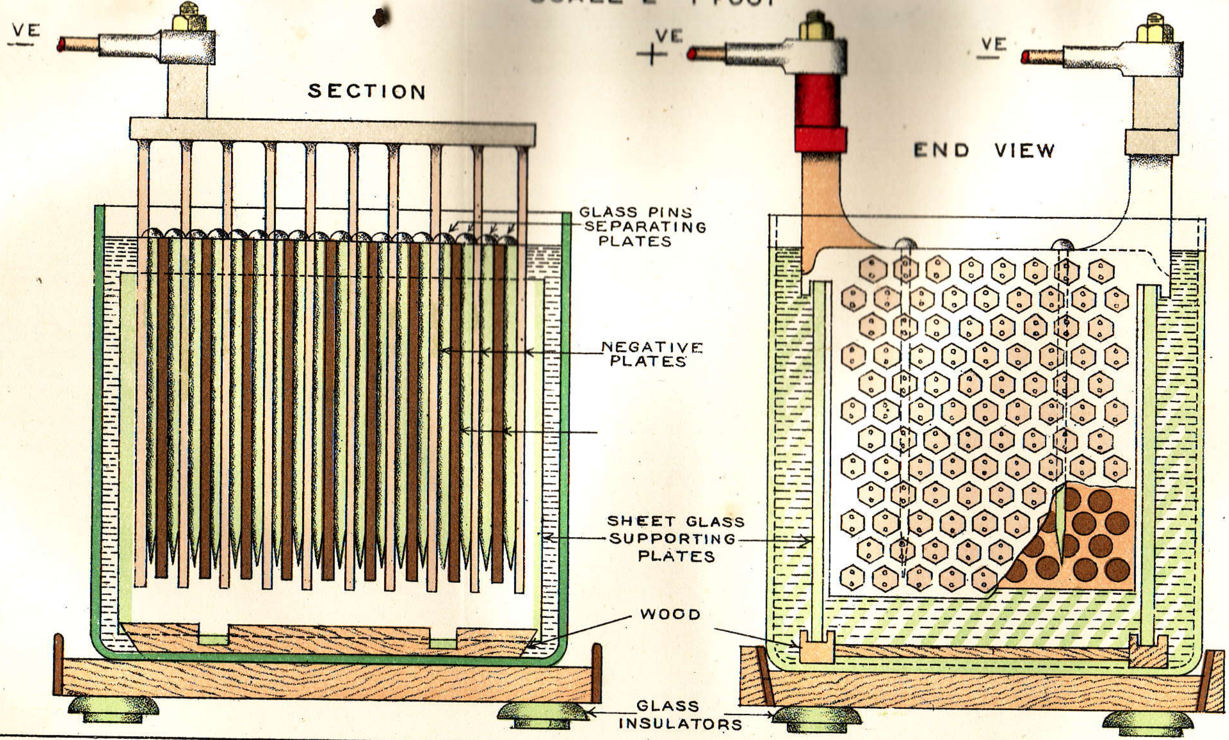

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