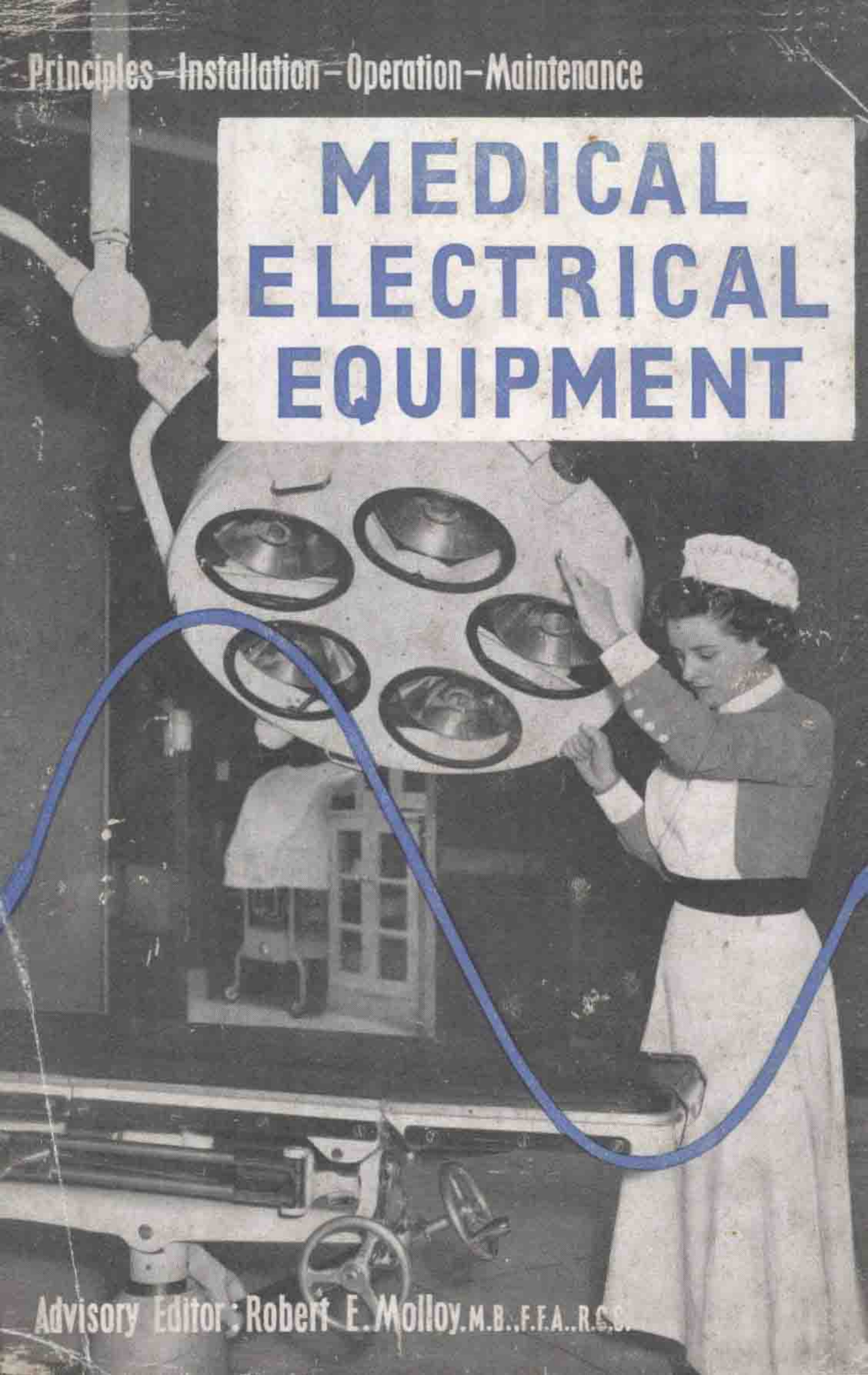
Principles—Installation—Operation—Maintenance

MEDICAL ELECTRICAL EQUIPMENT



Advisory Editor: Robert E. Molloy, M.B., F.F.A., R.C.S.

MEDICAL ELECTRICAL EQUIPMENT

Principles, Installation, Operation and Maintenance of Electrical Equipment used in Hospitals and Clinics

Advisory Editor

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PREFACE

THIS book has been prepared in the belief that there is a real and urgent need for authoritative information on the principles, operation, care and routine maintenance of medical electrical equipment, presented in terms that do not presuppose a deep knowledge of electricity.

The use of electricity in hospitals, clinics and doctors' surgeries has advanced rapidly during recent years, and there are now few fields of medical work in which electrical apparatus does not have an important role to play.

This has resulted in a tremendous inflow of electrical apparatus and devices of all kinds into the hospitals and clinics, and has placed upon the medical staff who operate them, and on the technicians who carry out the routine maintenance, the need to have a clear understanding of the principles involved, some knowledge of their construction, and, most important, information on the special care required to eliminate possible dangers to patients and staff.

Any form of shoddy electrical work or maintenance cannot be tolerated in medical work. A faulty connection in the wiring, a bulb not adjusted correctly in an operating theatre, a neutral electrode in a diathermy machine not connected correctly, static charges building up in the proximity of explosive anaesthetic gases; any such incident could result in an accident which, even if not fatal, might result in serious claims being made against the hospital.

The Editors' thanks are due to the many special contributors, who have here presented the results of their specialized knowledge and practical experience for the benefit of those concerned in the use and maintenance of the various types of medical electrical equipment and to Mr. J. Seale, for his unremitting care in seeing the work through the press and supplementing the text where it was found necessary to include certain basic information on purely electrical aspects.

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SECTION 1

INTRODUCTORY

By W. RENWICK, A.M.I.E.E.

THE application of electricity for surgical and medical purposes has made great progress during the present century and, in the sections which follow, detailed information is given on the very large variety of electro-medical apparatus which is now in common use.

A large proportion of this apparatus will be operated by persons who do not possess an intimate knowledge of the principles of electricity, but it is essential that the operator of the apparatus should at least have an elementary idea of the various forms of electrical energy available for this purpose.

PROPERTIES OF ELECTRICITY USED IN OPERATING THEATRES, ETC.

Alternating Current

The chief source of electricity for the large majority of hospitals is from the mains of the Electricity Boards and this alternating-current supply is now being standardised at 240 volts, single-phase for lighting and small power appliances and 415 volts, three-phase for power.

Alternating current (A.C.) is so called because, instead of flowing in one direction only as with direct current (D.C.), the current flows in one direction, stops and then flows in the opposite direction; the period required to complete this flow and reversal is called a cycle and in this country this cycle is repeated 50 times per second and is called the frequency of supply.

This can be shown graphically by drawing a wave called the sine wave (Fig. 1) in which it will be seen that starting from zero the voltage will gradually rise in a positive direction to a maximum, drop to zero again and then flow in the opposite, or negative, direction to a maximum value and back to zero again, thus completing a cycle which is constantly repeated at the rate of 50 times per second all the time the current is flowing in the circuit.

The voltage of an alternating-current supply is the average value of the instantaneous values, throughout one-half of the cycle, and with the standard 240 volts supply the voltage reached at the peak of the wave is approximately 340 volts (see Fig. 1).

This peak value is one of the reasons why the risk of shock from an alternating-current supply is more dangerous than from direct current with a constant potential pressure.

The great advantage of alternating current as compared with direct current is the ease with which it can be transformed either up or down from one voltage to another, so that it can be transmitted at high voltage over long distances with the least amount of transmission losses, and then transformed down to a safe working voltage at the point at which it is required to be used.

This transformation is due to the fact that when an electric current is passed through a coil of wire, a magnetic field is created in and around the coil. When the current is alternating, this magnetic field also rises and falls with the current and if another coil is introduced into the fluctuating field an electric current is induced in it. If the two coils are wound on a soft-iron laminated core the magnetic field is greatly increased.

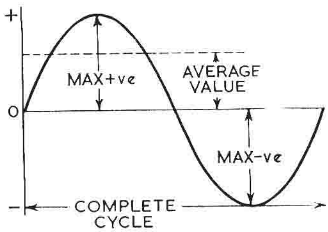

FIG. 1.—SINE WAVE

The average or R.M.S. value is obtained by taking the instantaneous values of the current over a cycle, squaring these values, and then taking the square root of the average.

The ratio of transformation is directly proportional to the respective number of turns of wire in the two coils. Thus, if the primary of the transformer is wound with 200 turns of wire and the secondary with 20 turns, the transformation ratio will be 10 to 1, and if 240 volts is applied to the primary, the secondary output of the transformer will be 24 volts.

Direct Current

Direct current is so called because the flow is in one direction only and is obtained from the following sources:

1. Direct-current generators which are still in use in some hospitals which have their own D.C. generating plant.
2. From the main supply where conversion to alternating current has not been carried out and a D.C. supply is still in existence.
3. Alternating mains supply rectified by means of mercury-arc or metal rectifiers, in which the flow of current from the A.C. source is able to pass in one direction only through the rectifier, thus giving a uni-directional flow.
4. Alternating current rectified by means of a rotary converter or a D.C. generator driven by an A.C. motor.
5. From batteries either primary, such as dry and wet cell Leclanche type (which are expendable), or secondary cells which can be recharged.

Static Electricity

Static electricity is produced by bringing two dissimilar surfaces into contact with each other and then separating them. If both the surfaces are of metal or good conductors there is no apparent static charge, but where one of the surfaces is non-conducting and the other a good conductor, a considerable charge is built up on separation and is retained on the non-conductor, and is not readily discharged without earthing the whole surface of the non-conductor.

This highly charged non-conductor can also induce a charge on any conducting material which is brought into close proximity with it, even without actually touching it. From experiments carried out it has been found that the removal of a dry blanket from a rubber sheet resting on a metal theatre trolley, which is insulated from earth by rubber wheels, can produce a static charge on the metal-work of the trolley of up to a value of between 20,000 to 30,000 volts.

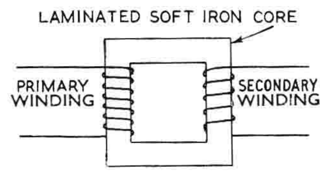

FIG. 2.—TRANSFORMER PRINCIPLE

The supply voltage is connected to the primary winding. The voltage obtained from the secondary winding depends upon the ratio between the number of turns in each winding.

In operating theatres or in any other position where explosive gases may be used, this static charge is extremely dangerous, since any charged material or apparatus brought into close proximity with any object which is earthed can produce a spark of sufficient magnitude to ignite any explosive gases which may be present in the theatre.

Personnel wearing non-conducting rubber boots, aprons, gloves, etc., can also generate static electricity by their ordinary movements and if they come into contact with any "earthed" metal, sparking will take place.

High-Frequency Currents

These are used for diathermy heat treatment and also for surgical diathermy in which a very high-frequency current is required with an alternation of not less than 500,000 per second.

This current is obtained from diathermy machines which are described in Sections 6 and 7, and the chief risk in their use is an explosive one where surgical diathermy is used in conjunction with an explosive gas in the operating theatre.

OPERATING THEATRE ELECTRICAL INSTALLATION AND EQUIPMENT

Wiring

The electric wiring installation requires to be very carefully designed and installed since any risk of failure during an operation, danger of shock or explosion, may result in the loss of life or serious injury to patients or staff.

FIG. 3.—SPARKLESS WATERPROOF SWITCHED SOCKET

For use in operating theatres where walls are hosed. Fitted with hinged brass cover, chromium plated, lipped edges, and domed to cover dolly projection.

(The Wandsworth Electrical Manufacturing Co., Ltd.)

The whole of the wiring should be permanently installed and enclosed in screwed steel conduits or mineral insulated metal-sheathed cable and the metal protection effectively "earthed". It is essential that the electrical resistance to the earth continuity return through the conduit or sheathing is low enough to ensure that in the event of an insulation fault on the wiring, the "fault" current to earth will be sufficient to blow the fuses and clear the circuit.

The resistance to earth from any point on the conduit system must not be greater than $\frac{1}{2}$ ohm if the earth continuity is through the conduit, or 1 ohm if a separate copper earth conductor is employed.

All flexible cable leads used to connect portable apparatus must be kept as short as possible, each core of the cable should be composed of not less than 23 copper conductors to provide flexibility, and sheathed with tough rubber or P.V.C. to a finished round cross section. Particular attention should be given to the termination of the cable in the apparatus and plug tops to ensure that an accidental pull on the cables will not cause the connectors to be broken, thus causing a spark if the apparatus is switched on.

Cables for use with mains-operated apparatus should be three-core, with one core forming the earth continuity circuit and connected at one end to the metalwork of the apparatus and at the other to the earth pin of the plug top.

Switches and Sockets

Fused switches or distribution boards must not be installed in the explosive area and any apparatus which is required to be controlled from the theatre suite, such as the motors on the ventilating system or suction plant, installed

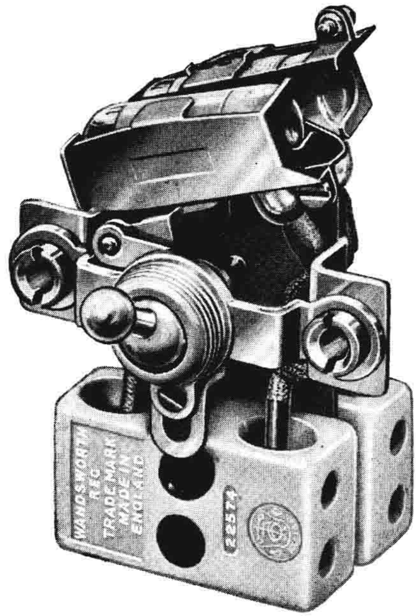

FIG. 4.—DOUBLE POLE MERCURY SWITCH FOR CONTROLLING MAIN AND EMERGENCY LIGHTING
(The Wandsworth Electrical Manufacturing Co., Ltd.)

outside the theatre area, must be started by means of mercury-tube switches connected to the operating coil of the motor starters.

All switches and sockets should be totally enclosed and should be of the sparkless type in which the circuit is made or broken by tilting a glass tube containing mercury. Sockets for mains-operated apparatus should be of the three-pin type and controlled by a mercury switch interlocked with the socket, so that the plug top cannot be withdrawn unless the switch is in the off position.

Operating theatre walls are often washed and even hosed down with water and, for this reason, it is advisable that special precautions should be taken to prevent water entering the switch or socket. Special sparkless and waterproof types have been designed for this purpose and consist of a sunk iron box with flush plate fitted with another hinged plate which closes on to a cork gasket when shut.

In all rooms of the operating theatre suite where emergency lights are installed it is advisable to control the main lighting and the emergency by means of a double-pole mercury switch. This method prevents the switching on of the emergency lighting, due to an electricity failure of any kind, when the main lighting is not in use. The main operating-table fitting is invariably controlled by a double-pole switch and, unless an operation is in progress and the light switched on, the emergency lighting in the fitting will not function. Unless all other emergency lights in the theatre suite are double-pole switched, any failure of the local fuses during a period when the theatre is not in use will cause the emergency lights to be switched on and, if not observed, may cause the emergency lighting battery to be completely discharged.

Lighting Fittings

It is not necessary to use fittings of the flameproof or gas-tight type, but all fittings should be totally enclosed in order to prevent damage to the lamp and the danger of hot fragments falling from the lamp, should it break.

Any portable type of emergency or examination lighting equipment used in the theatre should be of metal construction with an enclosed lamp. Connection to a socket point should be by means of a three-core T.R.S. or P.V.C. flexible cable, one core being used to earth the metalwork of the equipment. Portable lamps of this description are often fitted with a non-sparkless local control switch; this should be replaced by a sparkless type or, where this is not possible, completely removed and the lamp controlled by the sparkless switch socket to which it is connected.

Heating

The heating in an operating theatre is usually carried out by means of hot-water radiators or panels of sufficient heat output to cater for heat losses through the walls, windows, etc., with additional heating provided by hot air from the plenum plant, if one is installed.

During the summer months when the hospital hot-water heating system is shut down, it is often necessary on cold days to provide heating from another source. Steam radiators or convectors are often used, but if steam is not available it is necessary to install electric heaters. These should be of the totally enclosed type, preferably of gas-tight construction, if the temperature of the heating elements exceeds 300° F. With electric tubular heaters there is always the risk that they may be covered, accidentally or otherwise, by blankets or towels and all heaters should be fitted with a spark-proof thermal cut-out, in order to prevent any dangerous rise in surface temperature due to this cause.

Electric Floor Heating.—Any form of steam radiators or electric tubular heaters installed on the walls of a theatre, not only create an obstruction, but are also difficult to keep clean and in several theatres electric floor heating is either installed or is being considered.

Electric heating cables are buried in small aluminium ducts in the screed of the floor at a depth of 2½ in. to 3 in. below the surface and the heat controlled by floor and air thermostats.

This form of heating has the great advantage that it is perfectly safe with regard to shock and explosion risks and the walls of the theatre are not obstructed in any way and can be easily washed down.

It has been stated that floor heating would prove unpleasant to staff wearing rubber boots, but in one hospital in Scotland where this form of heating has been installed for nearly three years, the writer was informed by the Surgeons and Theatre Sisters that no discomfort due to hot feet had been experienced and that this heating was preferred to the radiator system of heating previously installed.

Low-voltage Apparatus

Where low-voltage surgical lighting appliances, such as endoscopes, head-lamps, etc., are employed, auto-transformers should not be used to provide the low-voltage current, since with this type of transformer there is no physical separation of the mains voltage from the low-voltage output, with a resultant danger of shock or spark.

Secondary batteries, owing to the very heavy current which can be obtained from an accidental short circuit, are also liable to be a source of danger.

Primary dry cell units can be obtained enclosed in a battery box and, owing to the high internal resistance of this type of battery, the flow of current due to a short circuit is comparatively small, also, if a fixed non-inductive current-limiting resistor is connected in series with the lamp, the possibility of an incendive spark is reduced to a minimum.

The following table gives values of the fixed non-inductive resistor which should be used to reduce sparking to a minimum.

Direct Current from Batteries		*Alternating Current from Transformers*	
Volts	*Value of Resistor (ohms)*	*Volts*	*Value of Resistor (ohms)*
0–2	0·25	0–2	1·25
2–4	1·24	2–4	6·00
4–6	3·25	4–6	14·00
6–8	7·00	6–8	25·00
8–12	27·00	8–13·5	54·00

Transformers

Any transformers used in conjunction with electro-medical apparatus must be double wound to ensure isolation between the secondary or low-voltage output and the mains supply. A substantial metal shield should be incorporated between the secondary and primary windings and the whole of the metalwork of the transformer, including the shield, should be effectively "earthed" via a three-core flexible cable to the conduit of the wiring system.

The low-voltage secondary windings must not be earthed, otherwise spark or shock risks may occur by accidental contact with earthed metalwork.

Only one appliance should be connected to the low-voltage output terminals and, if more than one is required to be used at the same time, the transformer should be provided with more than one low-voltage winding, each effectively separated from the other.

Ventilation

The risk of a build-up of explosive gases in operating theatre suites can be reduced by the installation of a properly designed ventilating system.

In modern theatres, ventilation systems are now being installed which not only ensure that the correct number of changes of air are maintained, but also provide inlet air which is washed, filtered, heated and humidified, and details of air-conditioning plants are described in Section 3.

The essential conditions of air ventilation, whether conditioned or otherwise, is that the air should be extracted at a low level, taking with it any explosive gases, which in the majority of cases are heavier than air and tend to accumulate at a low level.

The forced air inlet should be at a high level and the volume of air dealt with by the inlet fan should be 15 to 20 per cent greater than the extract fan, in order to provide a slight positive pressure in the theatre to prevent dust being drawn into the theatre under the doors by an air draught.

It is also advisable to electrically interlock the extract fan with the inlet, so that the former cannot be run unless the latter is also in operation.

SURGICAL DIATHERMY

Explosion Risks

The use of surgical diathermy for operations in which a high-frequency spark is employed, must of necessity be attended by grave risks of an explosion if inflammable anaesthetics are used. Mixtures containing ether or cyclopropane are particularly dangerous and should not be employed.

Shock and Burn Risks

In addition to explosive risks, the patient is also liable to be exposed to diathermy shock or burn if the apparatus is not earthed. This is due to the fact that the patient is maintained at a high (radio frequency) potential to earth and accidental contact between the earthed metalwork of couch or operating-table and an exposed part of the patient will result in burns or shock.

To prevent this it is essential that one of the "patient" output terminals of the machine and the earthed metalwork is permanently earthed to the wiring installation by means of a three-core flexible cable and three-pin plug.

High-frequency burns may result if the plate applied to the patient is defective or not in full contact with the patient's body.

The plate should be sufficiently flexible so that it may be moulded to give intimate contact with the part of the body to which it is applied. The plate is usually made of $\frac{1}{16}$ in. flat lead sheet, and should be enclosed in a thick absorbent covering made of lint or towelling which should be soaked in a 15 to 20 per cent saline solution and secured in position by an elastic bandage.

During a prolonged operation, the pad should be inspected to ensure that it has not dried out, and as a precaution two pads may be connected together and applied to the patient's thighs.

EXPLOSIONS OF ANAESTHETIC GASES

Owing to the use of many anaesthetics which give off an explosive gas, in operating theatres, labour rooms, etc., it is necessary to take special precautions to avoid any form of sparking which would cause an explosion to take place.

The explosive gases most commonly used are ethyl chloride, ether and cyclopropane. When any of these gases are mixed with air, nitrous oxide or oxygen, they become extremely inflammable.

Trichloroethylene is not inflammable under normal operating conditions, but if used with air enriched with oxygen may form an explosive mixture. It is unlikely, however, that it can be ignited by an electric spark, but it should not be used for surgical diathermy or cautery operations in the mouth.

Cause of Explosions

Investigations have been carried out as to the chief cause of explosions in operating theatres and these have shown that over 60 per cent were probably caused by a static spark, 14 per cent by diathermy apparatus, 8 per cent by electric spark from switch or socket and the remaining explosions from a number of different causes with a very small percentage for each.

Prevention of Static Sparking

As previously explained, the conditions prevailing in an operating theatre are highly favourable for the generation of static electricity on the apparatus in use in the theatre and also upon operating theatre staff.

Electrostatic risks can be avoided by the following methods:

1. The use of materials which do not readily build up or retain a static charge.
2. By maintaining the humidity of the air at as high a level as possible.
3. To provide means by which any dangerous static charge can be safely dissipated.

Materials

The use of plastics, non-conducting rubber, wool, rayon and nylon should, if possible, be avoided, since these materials will materially increase the generation of static electricity.

Cotton fabrics, used under normal atmospheric conditions in an operating theatre, have anti-static properties and should be employed as far as possible.

One of the chief causes of the retention of static charges, is the use of ordinary non-conducting rubber for sheeting, gloves, boots, tyres of apparatus, etc., and for the connections of anaesthetic equipment.

Anti-static or semi-conducting rubber is now being manufactured and, owing to its properties, will not only reduce the electrification of the rubber itself, but will also materially assist in the discharge of any static charges which may be built up on the apparatus in use in the theatre.

It will be realised that the use of rubber with a very low electrical resistance might prove dangerous to the user of any faulty electrical apparatus.

Experiments have been carried out to ascertain the most desirable value of resistance of the rubber, which will give both anti-static and shock-risk protection and it is now recommended that this resistance should not be less than 100,000 ohms, nor greater than 10 megohms when the rubber is new. The resistance of anti-static rubber increases with age and any equipment constructed entirely of rubber, or any items of equipment in which rubber is used, should be withdrawn from use if the resistance has increased to 100 megohms.

Where equipment or component parts of apparatus are required to be constructed of rubber with semi-conducting properties, it should be specified that all such rubber should be clearly marked "anti-static" with a conspicuous indelible marking.

Humidity

The temperature required in an operating theatre is a good deal higher than normal and if no humidifying apparatus is employed, the effect of this high temperature is to dry the air and thus increase the build-up of static charges.

The majority of modern theatres' heating installations now embody air-humidifying apparatus which can be controlled by the theatre staff to give a relative humidity of 55 to 60 per cent, but although this humidity will decrease the static risk, it cannot be relied upon and explosions have taken place with a relative high degree of humidity.

Where humidifying apparatus is not installed and ordinary rubber is used, the risk of static electrification can be greatly reduced by moistening the rubber before use.

METHODS OF DISCHARGING STATIC ELECTRICITY

As previously mentioned, it is difficult to prevent the generation of static electricity, but these static charges can be prevented from reaching a high value by providing a conducting path from the apparatus to a conducting floor.

Floors

Modern operating theatre floors are usually constructed of terrazzo, and sometimes of quarry tiles or magnesium oxychloride.

Terrazzo floors laid on a solid concrete foundation have, in the majority of cases, been proved to possess a sufficiently low resistance to dispel static charges from apparatus which is a direct contact with them.

It is not always possible for this form of construction to be used and the sub-flooring, instead of being concrete with a solid earth foundation, may be composed of hollow tiles, bison slabs and other forms of non-conducting material.

Experiments have been carried out to determine the most satisfactory way of constructing terrazzo floors and the Ministry of Health have now recommended