BIRZEIT UNIVERSITY

Electrical Installations and Drawings ENEE4202

Lecture Notes

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ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

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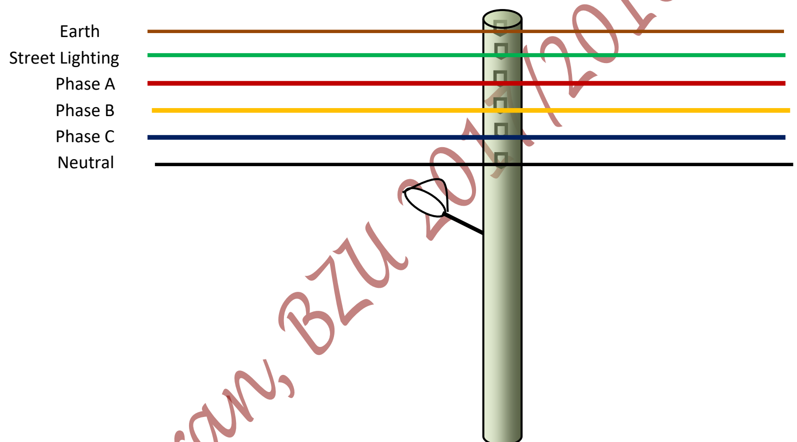
PART I

Introduction to Distribution Boards

Introduction:

The power is transmitted to consumers via the electricity grid, which consists of either:

1) Bare Aluminum (or Copper) Conductors in overhead transmission lines



2) Aerial Bundle Conductors or Cable (**ABC**) for overhead transmission lines

3) Underground cables: Poly Vinyl Chloride (**PVC**) cables or Cross Linked Poly Ethylene (**XLPE**) cables

The power then is supplied to our homes via 3 or 5 core cables; the number of conductors depends on the load type and size.

The voltage at the receiving end should be limited between **220 + 10%** and **220 - 4%V**. The size of the cable is dictated by the expected load and the electricity supplier. Table # 1 shows the rated current for various sizes of Copper core cables. More detailed specifications are shown in Table # 2.

***Table # 1**: The Rated Current for Copper Core Cables*

Copper conductors cross sectional area	**Recommended rated current**
3X6mm^2	32A
3X10mm^2	40A
5X16mm^2	50A
5X25mm^2	70A

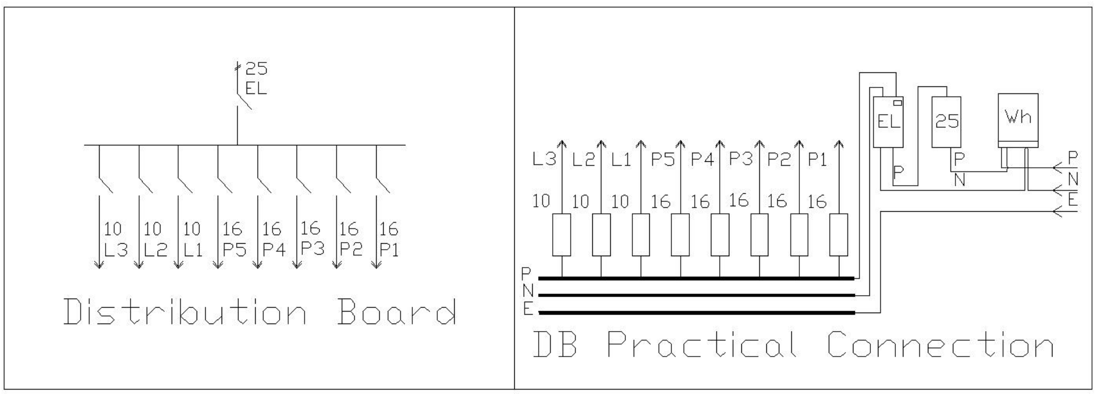
***Table # 2:** Specifications of Single Core Cables of 650V Rating*

				Unsheathed Cables		Sheathed Cables			Current Rating Amp	
Cond. Area Sq. mm	Conductor Construction No./ Dia	Max. DC Conductor Resistance at 20°C in ohm / km		Insulation thickness	Overall Diameter	Insulation thickness	Sheath thickness	Overall Diameter		
		Copper	Aluminum	Nominal mm	Approx mm	Nominal mm	Nominal mm	Approx mm	Copper	Aluminum
1	01/01/12	17.7	-	0.7	2.6	0.6	0.8	4.1	10	8
1.5	01/01/38	11.9	19.7	0.7	2.9	0.6	0.8	4.4	13	10
2.5	01/01/78	7.14	11.8	0.8	3.5	0.7	0.8	5	20	15
4	01/02/24	4.47	7.39	0.8	4	0 8	0.9	5.85	26	20
6	01/02/76	2.97	4.91	0.8	4.5	0.8	0 9	6.4	35	27
10	01/3.55 Al	01/08/09	2.94	1	5.7	1	0.9	7.55	44	34
	7/1.35 Cu	-	-	-	6.2	-	-	8.05	45	35
16	07/01/70	1.13	1.87	1	7.2	1	1	9.3	55	43
25	07/02/14	0.71	1.18	1.2	8.9	1.2	1.1	11.2	75	58
35	07/02/50	0.51	0.85	1.2	10	1.2	1.1	12.3	90	70
50	07/3.00	0.38	0.63	1.4	11.9	1.4	1.2	14.4	120	92
	19/1.78	-	-	-	11.9	1.4	1.2	14.4	120	92
70	19/2.14	0.26	0.44	1.4	13.6	-	-	-	150	116
95	19/2.50	0.19	0.31	1.6	15.8	-	-	-	175	135
120	02/03/37	0.15	0.25	1.6	17.5	-	-	-	200	155
150	02/24/37	0.12	0.2	1.8	19.4	-	-	-	230	175
185	37/2.50	0.1	0.16	2	21.7	-	-	-	265	205

Types of Consumer Installations

A) Single Phase Installations:

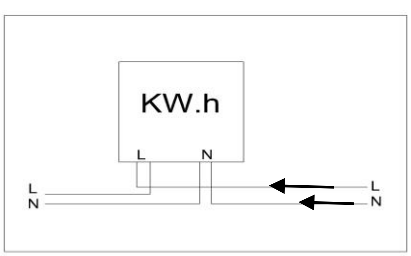
For an individual house (small domestic load), a small commercial load or a small business, a single phase source is sufficient; the feed in cable chosen is usually 3X6mm^2; a Phase (P), a Neutral (N) and an Earth (E) *conductors*. Usually, the main cable (3X6mm^2) is protected by a double-pole single-throw Miniature Circuit Breaker (MCB) or a Fuse. The nominal current rating of the MCB or the Fuse is set by the electricity company, usually 25A. A schematic diagram of the wiring of a single phase installation is shown in the Figure below.

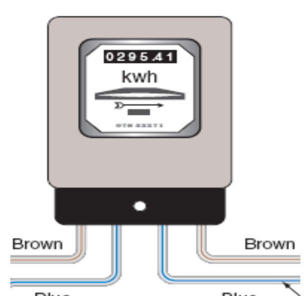


Main Components in Single Phase Installation:

1) KiloWatt-Hour (kWH) meter:

It is an energy meter designed to measure the number of kiloWatt–Hours of energy consumed. It has digital readouts or dials. The reading of the kWH is proportional to I, V, pf and time. The reading represents the consumed energy. Connection of the kWH meter depends on the manufacturer; its datasheet should be revised. Examples of kWH meters and their possible connections are shown in the Figures below. However, the datasheet of each kWH meter must be studied before installation as the connection varies from one manufacturer to another.





2) Miniature Circuit Breaker (MCB): 

It disconnects the circuits if the current is greater than its nominal current value by a Factor (called Fusing Factor). It protects the circuit against overload and/or short circuit currents. The commonly-available preferred values for the nominal (rated) current are: 6A, 8A, 10A, 13A, 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A…

3) Earth Leakage (EL) or Residual Current Device (RCD): E.L.

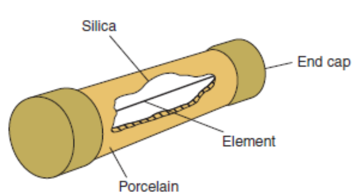
It detects any leakage current by comparing the current in the phase with that in the neutral. It has the phase and the neutral connected directly to and out of it. Usually, it operates when the difference between both currents exceeds 30mA. It has a test button **[T]** to have the functionally of the device checked periodically.

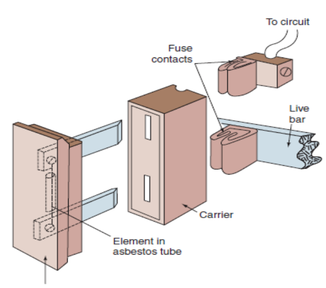
4) Distribution Board (DB)

It is a box made of PVC or other polymers located in an accessible location within the flat/house. It includes the Main MCB, EL or RCD, timers, and all other MCBs. It has also three bus-bars; one for the phase, a second for the neutral and the third for the earth. An example of a DB is shown in the Figure next. There are different sizes of Distribution Boards according to number of MCBs they can accommodate: 8, 12, 16, 24, 32, 48…

5) Fuses:

A Fuse is a device which carries a metal element, usually tinned Copper, which melts and breaks the circuit when an excessive current flows; it acts as a sacrificial device to provide over-current protection. Thus, it forms the weakest link in a circuit and protects the circuit conductors and equipments from damage. There are many different types, ratings and sizes of Fuses.





6) Wires

Wires of various cross sectional areas and colors are used in lighting, extra low voltage and power circuits. Table # 3 shows the wire's cross sectional area, the recommended protective Fuse or Miniature Circuit Breaker (MCB) nominal current ratings, and typical application circuits. More details about the wires and cables can be obtained from standard tables; an example was shown in Table # 2 for single core wires of 650V rating. On the other hand, Table # 4 shows the color code used generally in wiring single phase circuits.

__Table # 3:__ Wire's Cross Sectional Area, Protective Fuse or MCB Rating, and Typical Applications

Wire's cross sectional area [mm^2]	Nominal current of a protective Fuse or Miniature Circuit Breaker [A]	Application
0.5	4	Extra Low Voltage circuits
1.5	10	Lighting circuits
2.5	16	Power circuits
4	20	Heavy heating and cooking loads
6	32	Main supply for single phase loads
10 (or more)	40 (or more)	In three phase circuits

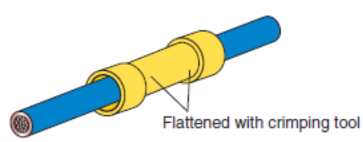
__Table # 4__: Color Code for Wiring in Single Phase Installations

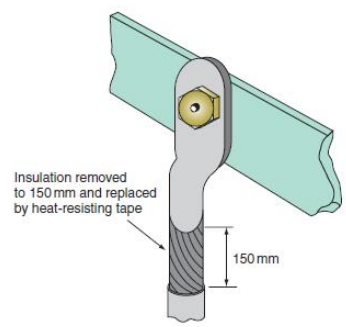
Wire colors	Application
Brown (or Red)	Phase or the Line conductor
Blue (or black)	Neutral conductor
Yellow with Green stripes	Earth/Ground
Violet, Green, Grey, Brown with Black stripes, Brown with Orange stripes, or any other color	Strapper or traveler conductors

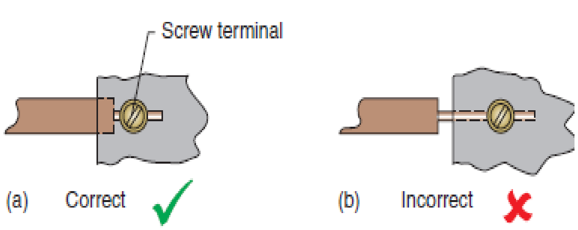
A detailed study of every single component will be presented later in this course.

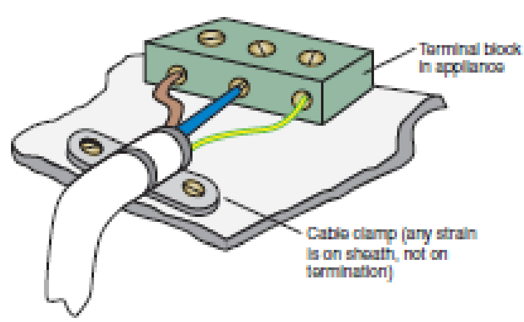
Notes:

- Cables and wires should run without twist; they must be unwound in the same way as they were wound (or wrapped) around the drum!
- Special power circuits may be designed for heavy heating loads; for some boilers or heaters, conductors of $4mm^2$ (or more) and an MCB rating of 20A (or more) are needed – exact calculations will be discussed in later lectures.
- Terminal blocks, proper joints, cable shoes, or lug termination should be used for proper connection.
- Loose connections must be avoided, as they cause corrosion of conductors, result in bad connections, and undesirable transients, which may be very dangerous.
- The joint or the cable shoe material must be of the same material as the cable conductor; copper or Aluminum…
- Special crimping tools are used to flatten (fasten) the joint or lug termination with the conductors.
- Heat resistant tape (or shrinkable tape) must be used to cover the bare end of the cable next to a cable shoe, lug termination or joint
- A reasonable length of the cable insulation is removed to make any joint or connection
- Cable clamps should be used where necessary.







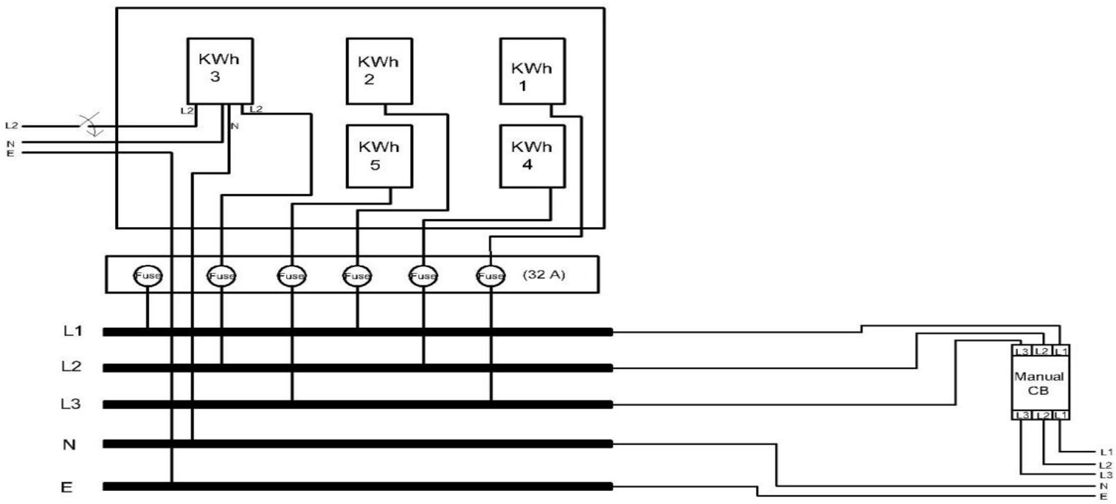


B) Three Phase Distribution Boards

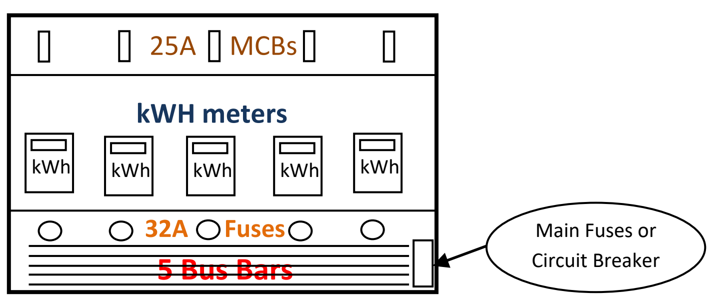
For a building, a large industrial or commercial load, 3 phase supply is needed. The power is supplied through a cable of 5 conductors, whose size depends on the load size and the estimated load.

B.1) Main Distribution Board for a Building

For a building, the Main Distribution Board has five bus bars (3 Bus Bars for phases, a Neutral Bus Bar and an Earth Bus Bar), kWH meters (depending on the number of apartments to be fed), Fuses (32A) and MCBs (25A) for each consumer (apartment). The Figure below shows a typical three-phase Main Distribution Board for a building that has several floors and flats.

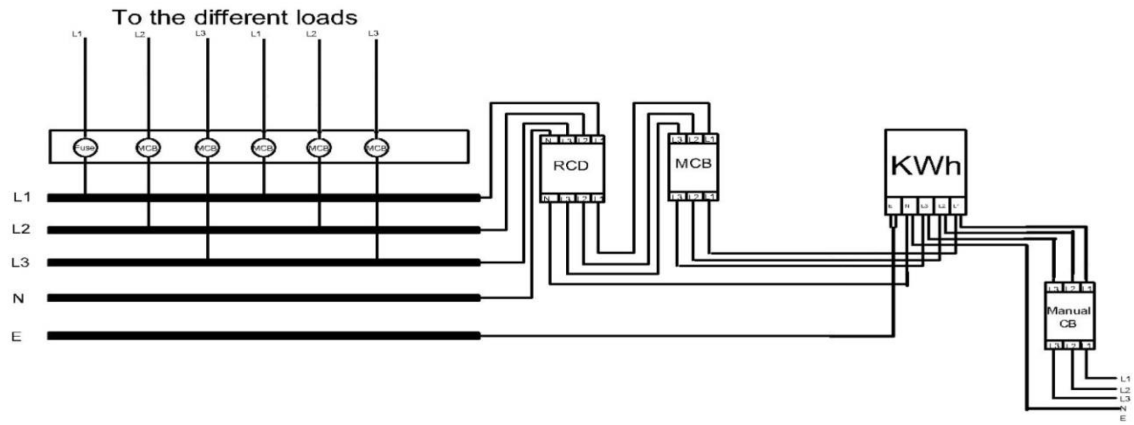


The front view of a typical Main Distribution Board is shown in the Figure below.



B.2) Large Individual Three-Phase Load

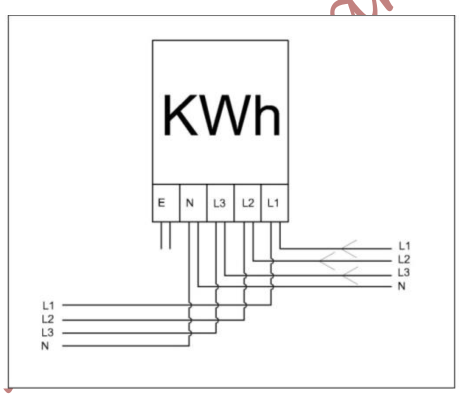
For an individual three-phase load, such as a factory or a large commercial load, the Main Distribution Board has five Bus Bars (3 bus bars for phases, a Neutral Bus Bar and an Earth Bus Bars), a three-phase kWH meter, three-phase CB, three-phase RCD (not always installed in the Main Distribution Board), Fuses and any auxiliary components for measurement (current, voltage, frequency, Power Factor, and indicator lamps for each phase).



Main Components in Three-Phase Installations

1. Three-Phase kWH meter

It consists of 3 phase inputs for each 3 phase lines (L_1, L_2 and L_3) and 3 outputs connected to each load phase. It also consists of an input/output for the Neutral line and a connection for the Earth conductor. The connection of kWH meters differs between manufacturers; the datasheet (the device manual) must be consulted prior to installation. The Figures below show a schematic of three-phase kWH meter and a typical three-phase kWH meter photo.



2. Three-Phase Miniature Circuit Breaker (MCB)

It consists of 3 inputs and 3 outputs. The three input are the 3 phase lines, whilst the three outputs are the 3 phase feeders or load terminals. Some breakers have a common node for the neutral. The MCB operates if the current in one line exceeded the pre-set value by a Factor; the breaker will interrupt the current flow and the source will be isolated from the load. MCBs differ according to their purpose, rating and functionality. Circuit Breakers (CBs) are used for current ratings above 100A and/or voltage rating above 1000V. The Figure next page shows a typical three phase MCB.


3. Three Phase Residual Current Device (RCD) or Earth Leakage (EL)

It consists of 4 inputs and 4 outputs. The four inputs are the 3 phase lines and the Neutral, the 4 outputs are the 3 phase load terminals and the neutral. It operates by comparing the current sum in the three phase lines with the current in the Neutral, via a magnetic field mechanism. If the magnetic field produced by the sum of the current in the three phase lines is equal to the magnetic field produced by the Neutral current, neither a fault is recorded nor a tripping is activated. In contrast, if the difference exceeds a threshold value (30mA, 100mA or 300mA …), the RCD will trip isolating the main source from the load and so preventing more damage to the system or shock risks. The Figure below shows a typical three phase RCD.

4. Fuses

The Fuses are sacrificial devices such that if the current exceeds the operating current of the Fuse, the filament of the Fuse will melt and an open circuit will occur. A Fuse is usually inserted in 3 phase wiring along each line for extra protection in case of failure of other protection devices. The Figure below shows a typical medium voltage Fuse.

5. Three Phase Cables

As the name indicates, three phase cables are used to connect the main electricity grid lines to the premises. They, usually, consist of 5 or 4 lines; 3 lines for the main 3 phases and the fourth line is for the Neutral. If the cable has a fifth line then it is for Earth connection. The Neutral is usually of smaller cross sectional area. The color code depends on the manufacturer of the cable but usually RED, Yellow and Blue are the 3 phase lines, and the Neutral is the Black one. The standard cross sectional area of the phase conductors in a three phase cable is 6, 10, 16, 25, 35, 50, 70, 95 and 120 mm^2. These three phase conductors are wrapped with a guided plastic cover (Black, Green or White). The cable type depends on the insulation material; e.g. **XLPE Cables:** Cross linked Poly Ethylene cables, **PVC Cables:** Poly Vinyl Chloride cables, or High Voltage Cables (oil or gas filled cables)…. To be studied in details later.

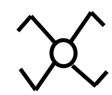
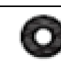
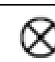
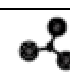
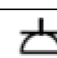
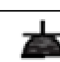
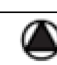
6. Other Components

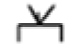
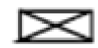
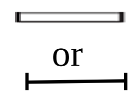
In factories, it is essential to monitor and/or record the voltage, the current, the frequency, Power Factor and the reactive power. Meters to record, these values are usually installed in the Main Distribution Board. The method of connecting these instruments should be obvious for electrical engineers. The ammeters rely on current transformers to measure the current. The voltmeters are connected in parallel between any two lines to measure the line to line voltage. Power factor meters are connected in a way to measure the current, and the voltage between the line and the neutral, with a certain mechanism; it provides the value of the power factor.

PART II

Electrical Plans and Drawings

Main Installation Symbols

On/Off One Way Switch	مفتاح مفرد	
Two Circuit Switch (Double switch), two-gang switch	مفتاح مزدوج	
Two-way Switch	مفتاح درج (فكسل)	
Cross (intermediate) Switch	مفتاح صليب	
Double-pole single-throw switch with indicator Lamp	مفتاح قطع ثنائي القطبية مع لمبة اشارة	
Dimmer switch	مفتاح لتقليل شدة الاضاءة	
Push Button	ضاغط	
Ceiling Lighting Point	نقطة انارة سقفية	
Ceiling Lighting Point Water proof	نقطة انارة سقفية ضد الماء	
Side Lamp	نقطة انارة جانبية	
Pendant Lighting Point	نقطة انارة سقفية ثريا	
Power socket outlet-single phase	مخرج كهرباء 16 امبير	
Power socket outlet -Water Proof	مخرج كهرباء 16 امبير ضد الماء	
Telephone socket outlet	مخرج تلفون	

Television socket outlet	مخرج تلفزيون	
Satellite socket outlet	مخرج ستلايت	
Intercom socket outlet	مخرج انتركم	
Data socket outlet	مخرج انترنت	
Main Distribution Board + Extra Low Voltage	لوحة كهرباء رئيسية مع جهد منخفض جداً	
Sub Distribution Board	لوحة كهرباء فرعية	
Extra Low Voltage Box	علبة الجهد المنخفض جدا	
Earth Leakage or Residual Current Device	قاطع تسريب ارضي	E.L.
MCB: 10 , 16 , 20 , 25, 32A.....	مفتاح نصف اتوماتيك	
1X36 Watt Fluorescent	وحدة انارة فلورسنت 1X36 واط	
2X36 Watt Fluorescent	وحدة انارة فلورسنت مزدوجة 2X36 واط	
2X36 Watt with Reflector	وحدة انارة فلورسنت مزدوجة 2X36 واط مع عاكس	
2X36 Watt Fluorescent (Water Proof)	وحدة انارة فلورسنت مزدوجة 2X36 واط ضد الماء	
Timer, Step relay, Impulse relay	مؤقت درج	T

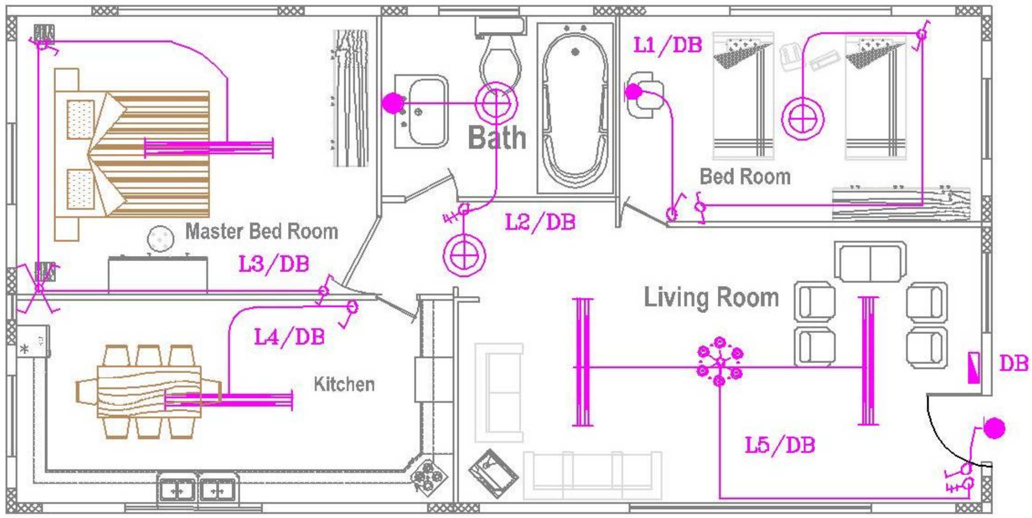
Electrical Plans (Drawings)

A) Lighting Plans (Drawings)

They are sketches specifying the location of luminaries (lighting fixtures), their type, and location of control switches.

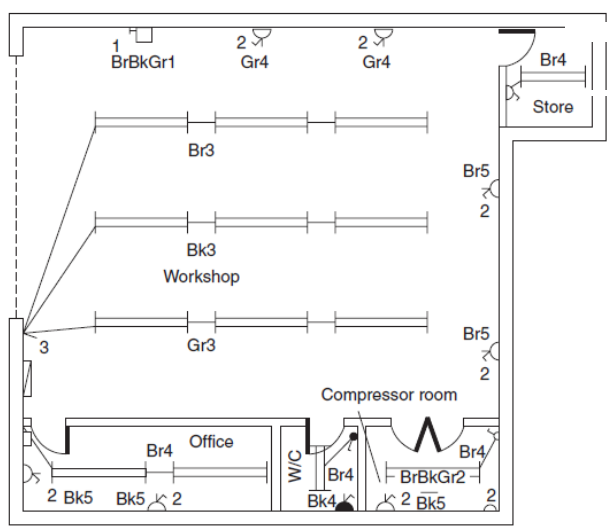
Table of Symbols

	1*36 WATT FLUORESCENT LIGHT
	2*36 WATT FLUORESCENT LIGHT
	ON/OFF One Way Switch
	Two circuit Switch (Double Switch)
	Side Lamp
	Ceiling Lighting Point
	Cross Switch
	Two Way Switch
	Electrical Bell
	Dimmer Switch



Notes:

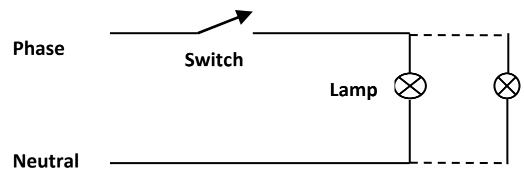
- The luminaries should be located such they provide a uniform and a comfortable light for the whole space
- The location of switches should be convenient and at appropriate height; e.g. next to room entrance or exist at a height of **140cm-160cm**, and at **60cm** next to bed (in bedrooms).
- A Gang switch is used to control more than one luminary (light) from the same location, individually; e.g. two-gang switch, three-gang switch, and four-gang switch…
- An example of three phase electrical plan for a garage/workshop is shown in the Figure next.
- The load should be distributed almost equally at all phases (Brown, Grey, and Black in this case).



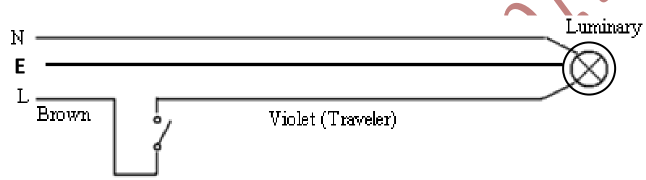
Lighting Switches and Circuits

1) A Single Switch Controlling One or More Luminaries (Lamps)

The switch is connected in the line (phase or live conductor) and in series with the lamp/s. The circuit diagram is shown below:



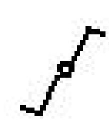
The wiring diagram is as follows:



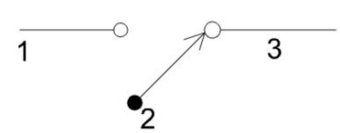
Notes:

- In general the wire's cross sectional area for lighting circuits is 1.5mm^2.
- The protective device (Fuse or MCB) nominal current rating for lighting circuits is 10A.
- The earth conductor must be connected to the metallic frame or case of the Light fixture.
- The color code for wires in single phase Installations was shown in Lecture Notes-1-**Table # 4**.
- Sleeves may be used at the terminals of wires to indicate the proper color code (if a wire of inappropriate color was used, i.e. a blue wire for the phase).

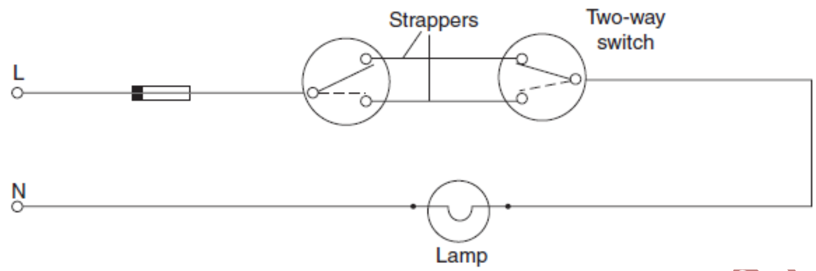
2) Two-Way Switching



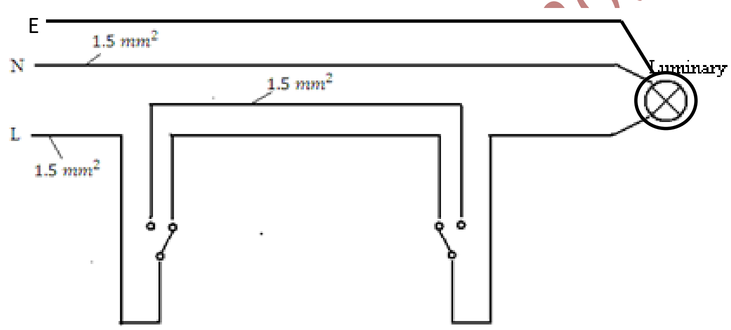
A luminary can be controlled from two different locations by using a pair of Two-way switches, whose symbol is shown next. A Two-way switch is called so because it has three wiring terminals that can be connected in two different positions, as shown in the Figure next. One terminal is called the common terminal (pin 2) and is connected to the live conductor or the lamp. The other two terminals (1 & 3)are called traveler terminals. Two conductors, called travelers or strappers, run from the traveler terminals of the first Two-way switch to the traveler terminals of a second Two-way switch.



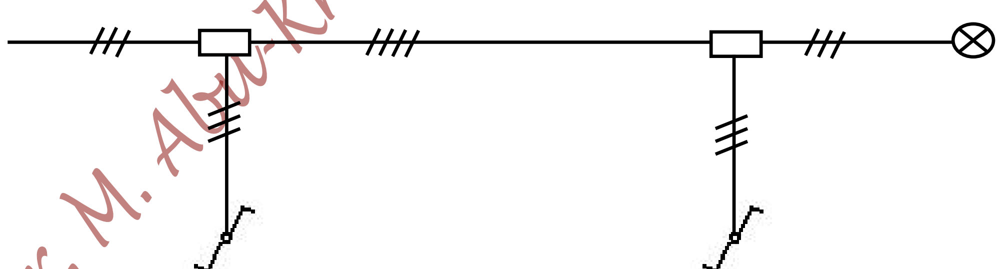
The circuit diagram for Two-way switches used to control a lamp from two different locations is shown in the Figure below (notice that for the shown position, the light is **on**).



The wiring diagram for Two-way switching is:

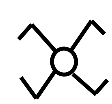


The current flow diagram for Two-way switching is:

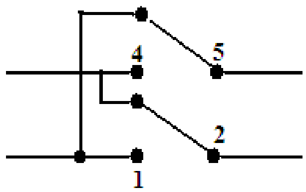


3) Two-Way and Cross (Intermediate) Switching

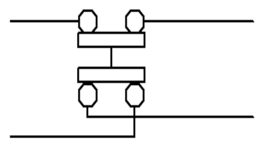
It is used to control a luminary (or luminaries) from three or more different locations by using a pair of two-way switches and one (or more) cross (intermediate) switches. This type of switching is used in lighting Bedrooms, corridors, or stair cases. An Intermediate (cross) switch symbol is as:



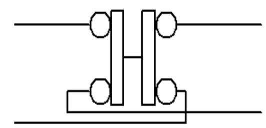
The equivalent circuits of a cross (an Intermediate) switch are shown in the Figures below. The cross switch has four terminals that can be connected in two different positions as illustrated below.



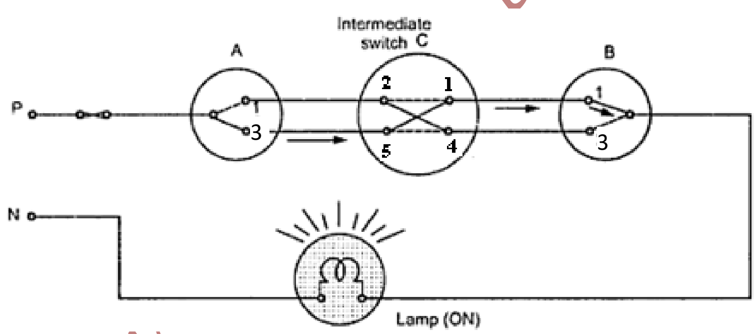
or



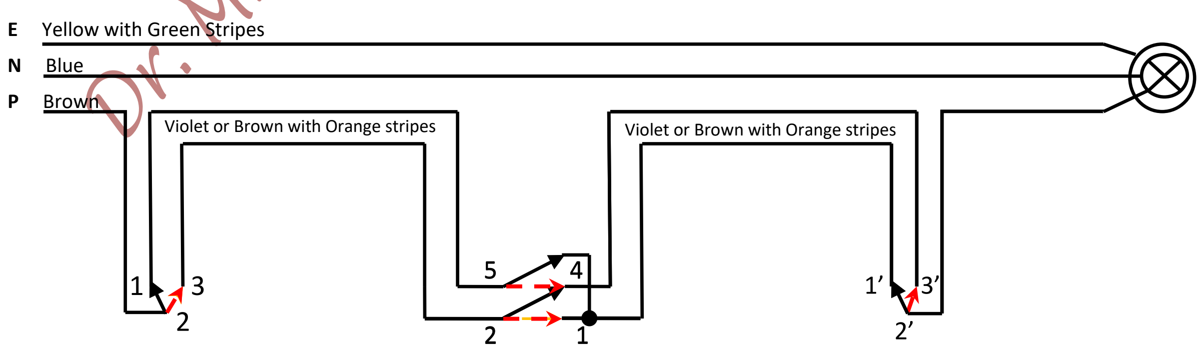
or



Two-way and Intermediate switching consists of a pair of Two-way switches (A and B) and one cross (intermediate) switch C. The circuit diagram used to control the lamp from three different locations is shown in the Figure below. Two sets of traveler conductors run between Two-way and cross switches. The intermediate switch has the following switching states (connections): $1-5$ and $2-4$ as shown, or $1-2$ and $4-5$ shown dotted. In the position shown in the Figure, the lamp is ON.



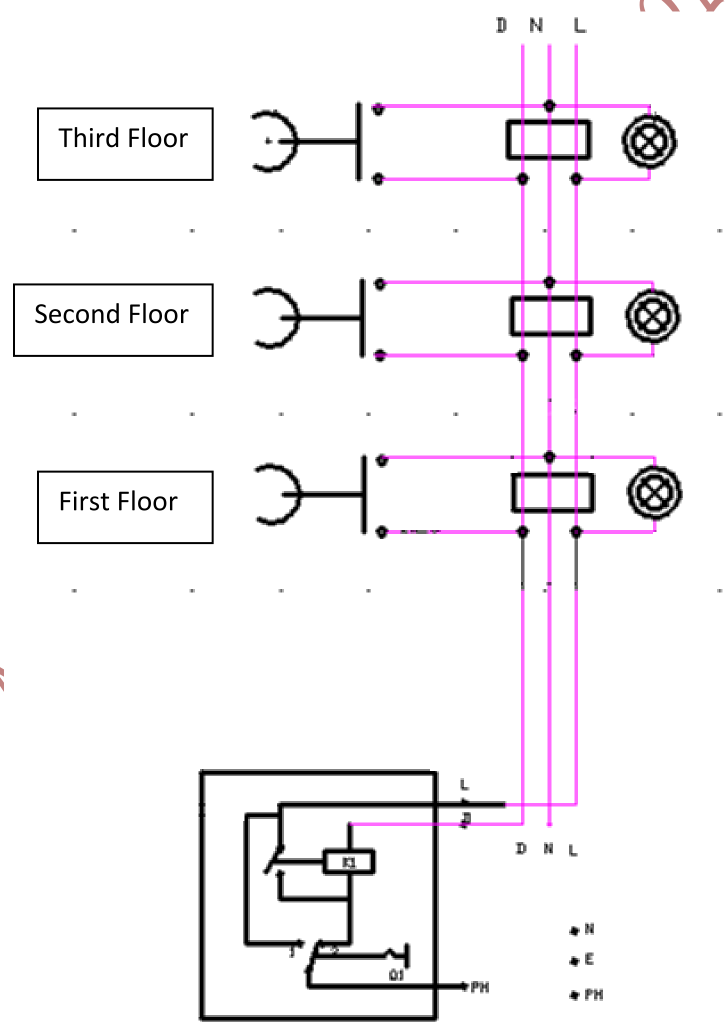
The Wiring Diagram:



Draw the current flow diagram of the above circuit!

4) Lighting a Stair Case by a Timer or a Step Relay

- A Timer or a Step Relay is used to control lighting of a stair case.
- A Timer or a Step Relay is used to keep a device on/off for a preset time.
- The connection depends on the type of timer used.
- The time is set for seconds up to few minutes; e.g. 1-7 minutes.
- Usually, push buttons and lamps have direct connection to the Neutral conductor.
- If the push buttons have indicator lamps, then a phase conductor is also needed.
- The Figure below shows a schematic of Time-controlled lighting



Considering the Specifications of Schneider Timers Controlling (a Stair case) Lighting:

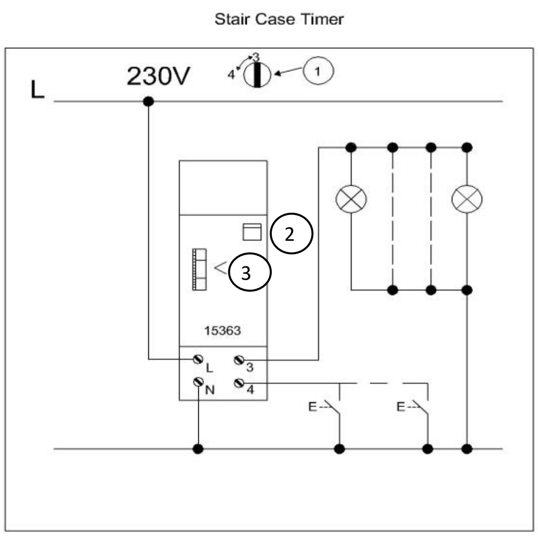
They have various selectors for different settings:

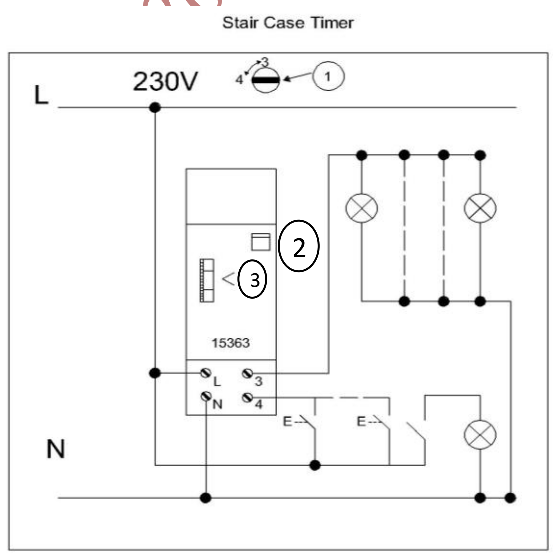
Selector ①: For the selection of wiring configuration of lamps and push buttons. It is located at the right side of the Timer. The Figures below show the connections when the selector is set to position '**3**' or position '**4**'. Position '**3**' configuration will be used in the Laboratory experimentation. Further information is found in the Timer datasheet.

Selector ②: A. permits the control of light for adjustable period (1 to 7 minutes) by the time delay setting (selector ③)

B. continuous light is possible.

Selector ③: Adjusts time delay setting





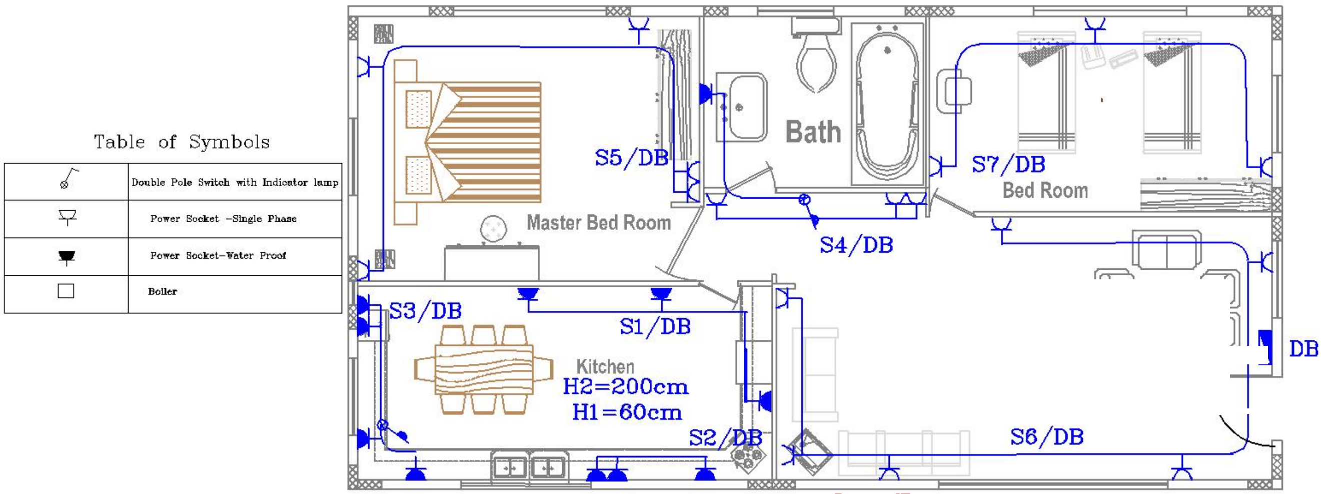
Schneider Timer Capacity: 2300W: for resistive load, Incandescent or Halogen

2300VA: for Fluorescent without correction or series correction

1300VA: for Fluorescent with parallel correction

B) Power Electrical Plans (Drawings)

They are sketches showing the locations and types of power socket outlets.



Plugs and Socket Outlets

- AC power plugs and socket outlets are devices for connecting electrically operated devices to the primary power supply in homes and buildings.
- Electrical plugs and sockets differ by country in voltage and current rating, shape, size and type of connectors. The types used in each country are set by national standards.
- Generally the plug is the movable connector attached to an electrically operated device's power cord as shown in the left Figure below, and the socket is a fixture on an equipment or a home structure as shown in right Figure.

- Plugs have male circuit contacts, while sockets have female contacts. The plug has protruding prongs, blades, or pins that fit into matching slots or holes in the socket.
- A wall-mounted socket is also called a receptacle, outlet, or power point. It is enclosed by a cover variously called a wall plate, face plate, outlet cover, socket cover, or wall cover.

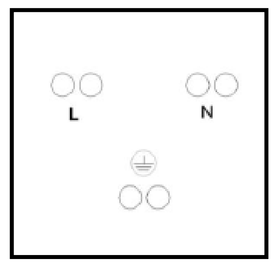
- Different types of wall sockets can be found within homes and other buildings:

1. A single wall socket accepts only a single power cord, and is typically used for large appliances like refrigerators or washing machines.

2. A double-socket outlet consists of a pair of holes that are designed to accept up to two power cords. Four-way wall sockets can accept as many as four cords. Some modern wall sockets may also include openings for USB ports to allow users to charge phones and other electronics.

3. A water proof socket, which is usually installed in a bathroom, a kitchen, a balcony, or any space subject to moist or water splashes. Also, water proof socket outlets are installed on Ceramics, Tiles, fair faces, outdoors or stone walls.

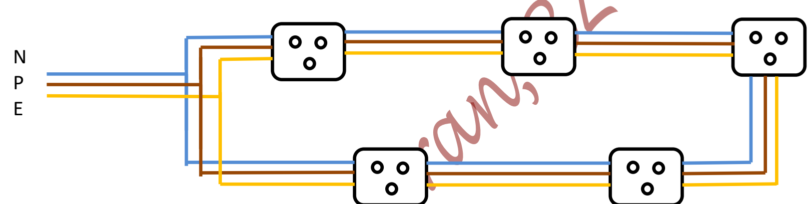
- More than one socket can be fed from the same line.
- Twin–socket outlet counts as two single socket outlets.



- The power socket outlet has 3 pins. The rear view of a socket outlet is shown in the Figure next. It is clear that line or phase is connected to the left pin, the neutral is connected to the right pin, and the earth is connected to the middle-lower pin.
- Each wall socket consists of a metal or plastic frame that fits within the surrounding drywall. This frame, or box, serves as a vessel for electrical wiring and helps to reduce the risk of electrical fires. A receptacle is connected to the wires and is held within the box with screws, then a plastic or metal cover plate is fastened on top to complete the wall socket.

- Many building codes have very specific requirements related to how wall sockets must be placed within a building to maximize safety. Most specify a minimum height at which these sockets must be mounted above the floor (***60 – 80 cm***). Others require outlets to be placed at specific intervals around the room to ensure a safe and adequate power supply for the building's occupants.
- The locations of the sockets depend on furniture, decoration, and space function.
- At least two sockets are installed in any room (three are very common). However, the number or socket outlets depends on the size and function of the room/space.
- Usually, 2.5mm^2 single core cable (wire) is used in power circuits.

- The nominal current rating of the Miniature Circuit Breaker is 16A.
- Boilers or water heaters must be supplied from a double–pole single throw-switch with indicator lamp. They may be fed via $4mm^2$ conductors, and the nominal current of the MCB is 20A, depending on power rating.
- The power circuits, lighting circuits and ELV circuits must be separated from each other (even in conduits).
- Conduits of 3/4" or 16mm diameter are usually used, however the size of conduit depends on the number of conductors to be run within it.
- Every appliance with a metallic frame/case must be earthed.
- All socket outlets are connected in parallel.
- Ring or radial circuits may be used.
- In a ring circuit, the socket outlet is fed from two directions, as shown below:

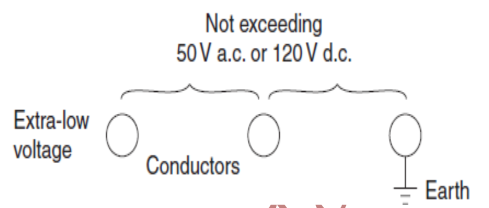


- To reduce the risk of an electric shock, plug and socket systems can incorporate a variety of safety features. For example, sockets can be designed to accept only compatible plugs and reject all others. There are many systems which block the socket holes with insulators when a plug is not inserted, and some systems are designed such that a dangerous voltage is never present on an exposed contact. Exposed contacts are present in some sockets, but are used exclusively for grounding (earthing).
- Many wall socket outlets are **polarized** to make it impossible for users to plug objects into the wall incorrectly. Polarized outlets are configured to only accept a plug in such a position that the grounding and live wires within the wall correspond to the same wires within the plug. In a simple two-pronged outlet for example, one of the plugs is designed to be wider than the other so that the plug will only fit when inserted correctly. Non-polarized wall sockets accept plugs of any configuration, and pose added risk to users.

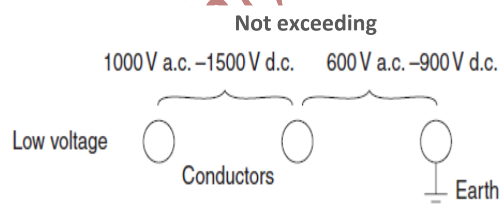
C) Extra Low Voltage Plans (Drawings):

Voltage Bands:

1. ***Extra Low Voltage (ELV):*** is defined as any voltage not exceeding **50Vac** or 120Vdc, between conductors or conductors and earth.



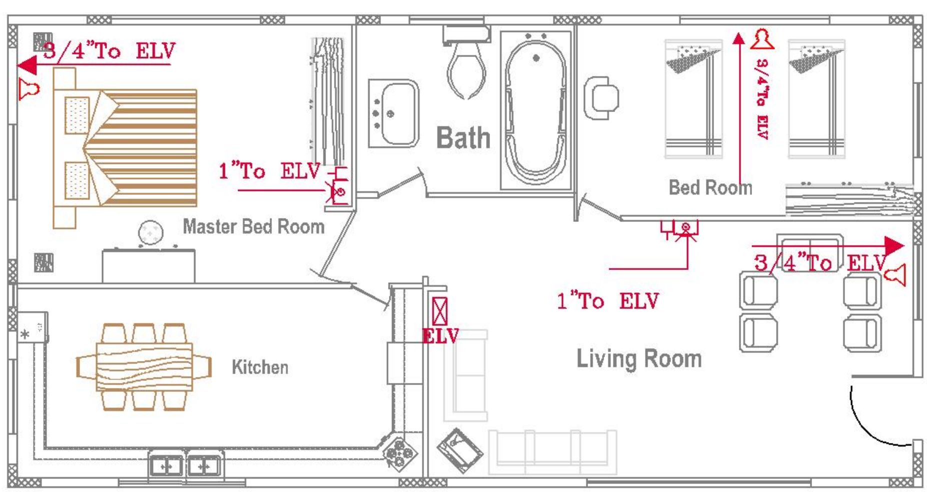
2. ***Low Voltage:*** is defined as any voltage not exceeding 1000Vac or 1500Vdc between conductors; or **600Vac** or 900Vdc between conductors and earth.



- ELV includes Telephone systems, TV and Satellite systems, Data systems, Fire Alarm systems, Security systems, Call or Emergency systems…
- Every TV, Data, Telephone, or any other ELV system has a power socket outlet next to its socket outlet or location.
- An example of Extra Low Voltage Plan is shown in the Figure below.

Table of Symbols

E.L.V	Extra Low Voltage Board
▼	Telephone Socket
	Satelite Socket
	Television Socket
	Data Socket

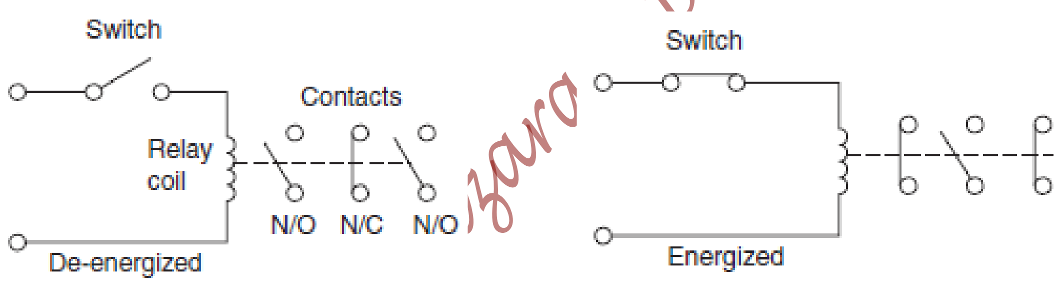


PART III

Extra Low Voltage Systems

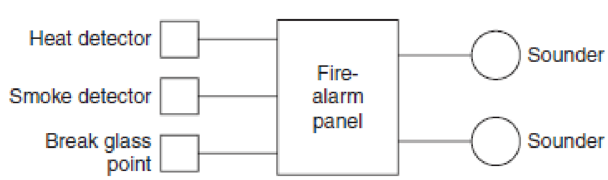
- These systems operate by a voltage up to 50Vac or 120Vdc.
- The operating voltage may be supplied by a transformer whose primary is fed from 220V mains, hence they need a power Socket outlet.
- Many of Extra Low Voltage systems rely on using relays

A Relay: is an electromagnetic switch which causes pairs of contacts to make or break, when energized. It has normally open (NO) and/or normally closed (NC) contacts.



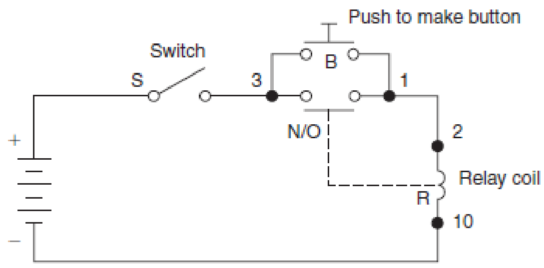
A Schematic (Block) Diagram

A Schematic (Block) Diagram shows how the system functions; relay contacts, switches and accessories are shown on a diagram in a position most convenient for drawing and understanding, e.g. the Figure below shows a block diagram of a Fire Alarm System.

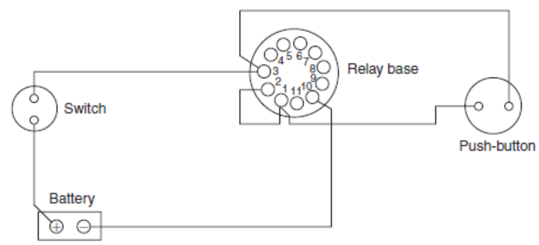


A Wiring (Assembling) Diagram

It shows how the system is to be wired; all components of the circuit should be shown in their correct places.



a) Simple Diagram of a hold-on circuit

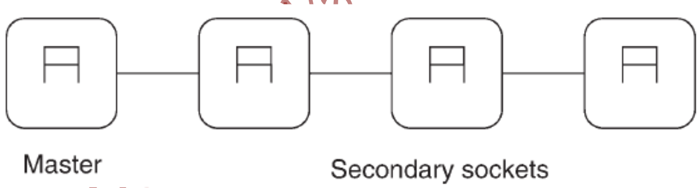


b) Wiring Diagram of a hold-on circuit

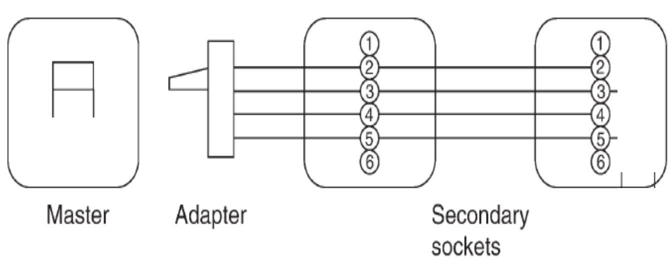
I) Telephone Systems

The following points should be taken into consideration:

1) All sockets are connected in parallel.
2) Usually there are a Master socket and Secondary sockets (or extension)



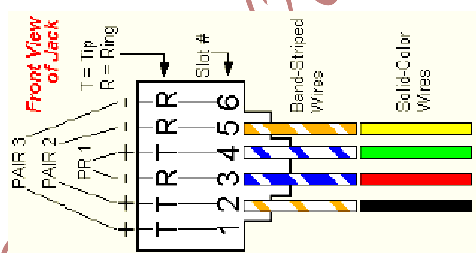
3) The Master socket: is the first socket in any installation and contains components to:
   a) Allow telephone to be removed without causing problems at the exchange.
   b) Stop surges on the line such as lightning strikes
   c) Stop (prevent) the telephone from making partial ringing noises when dialing
4) Connection to the Master socket is made by the use of an adapter plug and extension cable



5) The number of Secondary sockets is unlimited. But the number of telephones or ringing devices connected at any time is limited to 4; otherwise they may not ring or work.

6) A Registered Jack socket (**RJ-11**) is used for telephone systems. The Figure below shows a **standard phone jack diagram (RJ-11)**. It shows the front view of the female wall jack. This color scheme is used with standard 2-pair phone cables. The slot numbers next to the Tip and Ring indicators are usually marked on the jack. Standard 2-pair wiring color codes are shown in the table below:

1st Pair	Tip (+), slot 4 Ring (-), slot 3	WHITE/BLUE (Green) BLUE/WHITE (Red)
2nd Pair	Tip (+), slot 2 Ring (-), slot 5	WHITE/(Brown) ORANGE (Black) Brown (ORANGE)/WHITE (Yellow)



Cables and Wiring

The cable used is of twisted pairs and ranges from 4 cores (2 pairs; 1 pair is used and the other is spare) to 40 cores, e.g.: 4X0.5 mm^2, 8X0.5 mm^2, 10X0.5 mm^2, 12X0.5 mm^2, 16X0.5 mm^2….

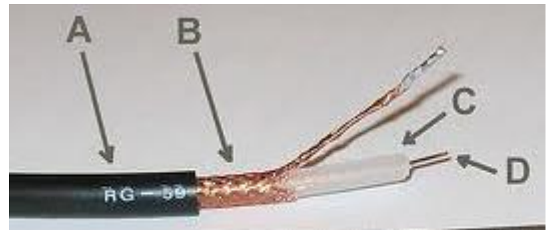
The maximum length of the cable between the Master and first Secondary socket is 50m, and overall cable length is 100m.

Internal Phones and Intercom:

- The cable size used depends on the number of extensions or intercoms. It ranges from 2 X 4 X 0.5mm^2, 2 X 8 X 0.5mm^2, 2 X 16 X 0.5 mm^2…
- The operator and all extensions are connected to the telephone switch (مقسم)
- The wiring diagram of an intercom depends on the manufacture's layout

II) Television (TV) Systems

- Coaxial cables are used.
- A Coaxial cable consists of an outer plastic sheath (A), woven copper shield (B) to protect against Electromagnetic Interference (EMI), inner dielectric insulator (C), and a copper core (D). It carries radio frequency signals with a low level of loss from one location to another.



- A coaxial cable runs from the Satellite dish or Antenna to the Extra Low Voltage Distribution Board.
- A mixer is used to connect the signals from satellite collectors (sources or ports) and to send them via a main coaxial cable to the Extra Low Voltage Distribution Board. The mixer is called DiSEqC switch, which stands for **Digital Satellite Equipment Control**; e.g. DiSEqC 1.0: for 4 satellite sources, DiSEqC 1.1: for 16 satellite sources.

- A splitter is used to split the signal, coming from the main coaxial cable, between TV sockets installed in different locations, e.g. 4-way splitter (5 to 1,000 MHz).

- Proper coaxial cable connecters or joints, a variety of which is shown in the Figure next, should be used as needed.

III) Data Systems

A- Data delivery:

Data is delivered to homes and other facilities by:

1) Asynchronous Data

- Asymmetric Digital Subscriber Line (ADSL) is delivered using telephone cables.
- ADSL modem can be installed wherever there is a telephone point.
- A filter should be used at every point where a phone is plugged.

2) Cable modem: is installed wherever there is a TV outlet Socket.

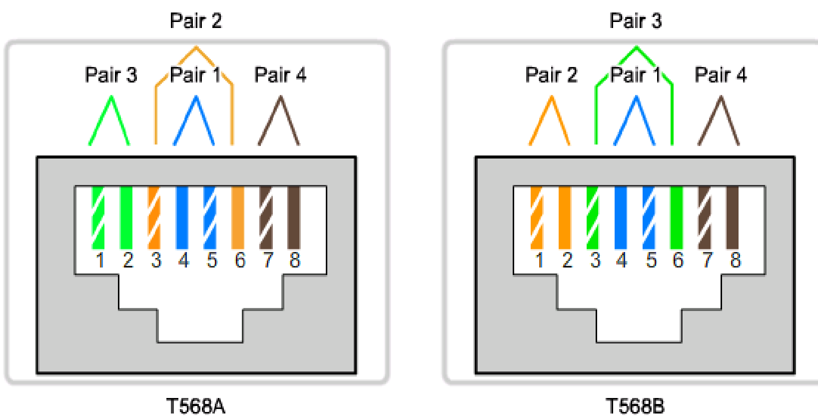
3) Fiber: The fiber terminates by Optical Network Termination Unit (ONT) with a data port connected to it. Recently, this method is growing in use.

B- Data Networking (Cabling)

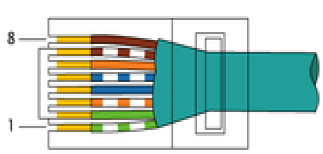
- The data service is extended by using Local Area Networking (LAN) cabling.
- The cable used for LAN is similar to phone cable, but of much higher quality category: Cat 5 or Cat 6.
- If a single computers is used, then an Ethernet cable (speed could reach 100Gbits/s) is used to connect the PC and the modem.
- Each data outlet is connected individually (uninterrupted) to a patch panel next to the modem.
- Wireless data transmission is growing and replacing wired systems.
- A Registered Jack socket (**RJ-45**) is used as internet (data) port, it uses 8 conductors (8P8C: 8 Positions 8 Conductors).
- Ethernet cables are connected and installed according to different wiring conventions. This means that the individual wires in the cable have to be connected in different orders to different sets of pins in the RJ-45 connectors. The table next page differentiates between the different conventions used:

Straight-through, Crossover, and Rollover Cable Types

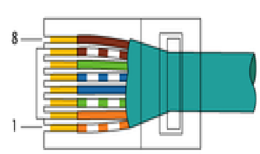
Cable Type	Standard	Application
Ethernet Straight-through	Both ends T568A or both ends T568B	Connecting a network host to a network device such as a switch or hub.
Ethernet Crossover	One end T568A, other end T568B	Connecting two network hosts. Connecting two network intermediary devices (switch to switch, or router to router).
Rollover	Cisco proprietary	Connect a workstation serial port to a router console port, using an adapter.



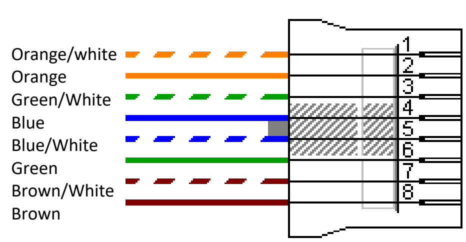
Connectors are frequently terminated using the **T568A** (<u>TIA/EIA-568-A</u>) or **T568B** (<u>TIA/EIA-568-B</u>) pin/pair assignments, depending on whether they are straight or cross connection. The Figures below show male and female (RJ45) wiring. Comparing the male terminals of the Figures below, it is clear that the copper connections and pairing are the same, the only difference is that the orange and green pairs (colors) are swapped. Note that the female connector or socket is of EIA/TIA 568B type.



EIA/TIA-568A



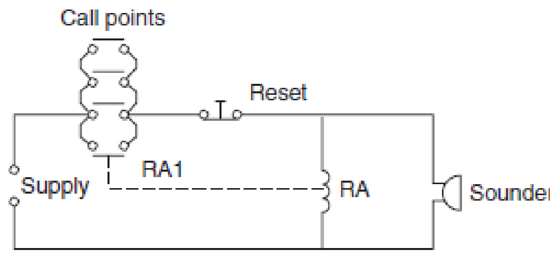
EIA/TIA-568B



IV) Fire Alarm Systems

Open Circuit System: all call points (sensors and detectors) are wired in parallel such that the operation of any one will operate the relay coil and a sounder (bell or siren); the Figure below shows the connection of such a system.

Reset button: resets all sounders



The hold on facility ensures that the sounder is not interrupted if an attempt is made to return the activated call point to its original off position.

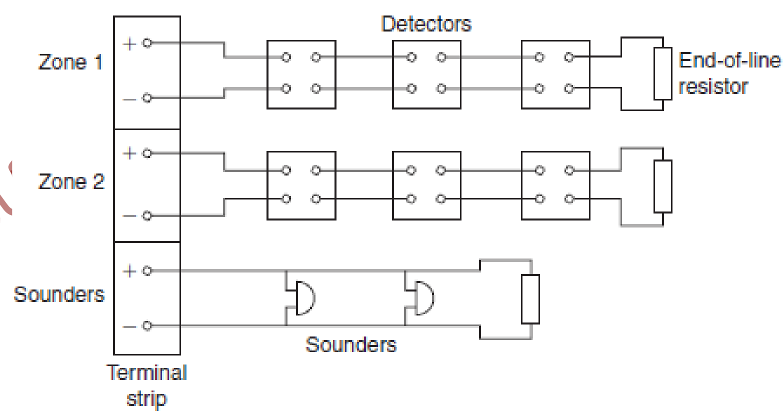
The call points are normally open contacts, and examples of these are:

1) Heat detectors

2) Smoke detectors

3) Break glass points

The Figure next shows the wiring of call points and sounders within a Fire Alarm System



Notes:

- The DC voltages used could be 12, 24, or 48V; Backup batteries are needed.
- Zone indication lamps are used.
- Conventional Fire Alarm Systems are wired on open circuit basis, with a two wire system looped from one detector to the next, terminating across an End Off Line Resistor (EOLR).
- EOLR provides a circuit's cable monitoring facility; the EOLR is of a sufficiently high value to prevent operation of the alarm.
- The controller sees either full load voltage, no load voltage or reduced voltage "the controller is looking for a known resistance".
- The cable used to link the sensors is usually FP200 or Fire tuff (both of which are fire retardant)
- Modern systems are addressable where all call points are connected with a loop cable; the call points of every zone are connected in parallel, and the loop cable starts and terminates at the control panel (no need for EOLR).

V) Security Alarm Systems – Intruder Alarm Systems - Burglar Alarm Systems

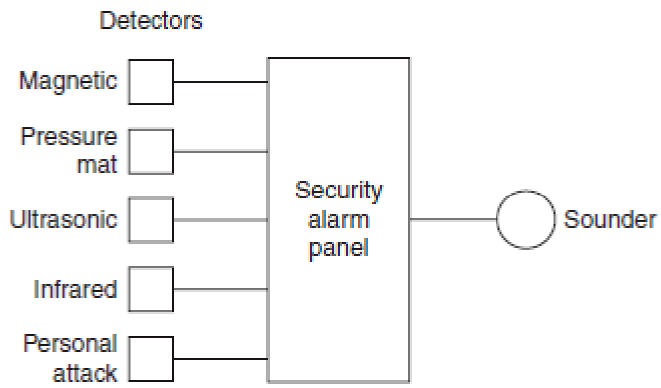
Such systems can be classified into two types:

1) Hard wired system: it is more reliable

2) Wireless system:

- Attractive from installation point of view – no cables or wires to be run
- Stray radio frequencies unrelated to the system may cause nuisance operation (malfunction)!!

A Block Diagram of a Security Alarm System:



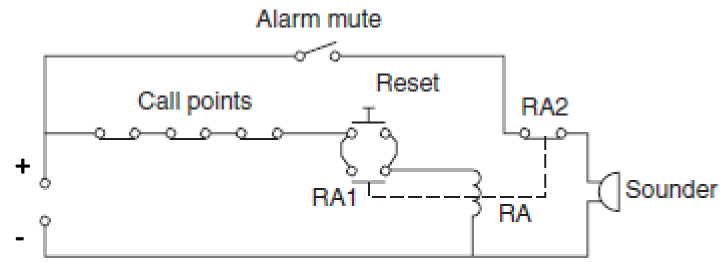
Call points (sensors or detectors):

A) A Magnetic sensor: It is a pair of contacts held closed by the proximity of a magnet. It requires no supply. The unit housing the contacts is installed in door or window frame and the magnet is installed in the moving parts.

B) A Passive Infrared (PIR) sensor: It reacts to body heat and movement and require a permanent DC power supply (e.g. 9V) from the control panel as well a battery backup. It is used to protect areas from intrusion from several directions.

C) An Ultrasonic sensor (transceiver): It generates high frequency sound waves and evaluates the echo which is received by the sensor. It calculates the time interval between sending the signal and receiving the echo to determine the distance of an object.

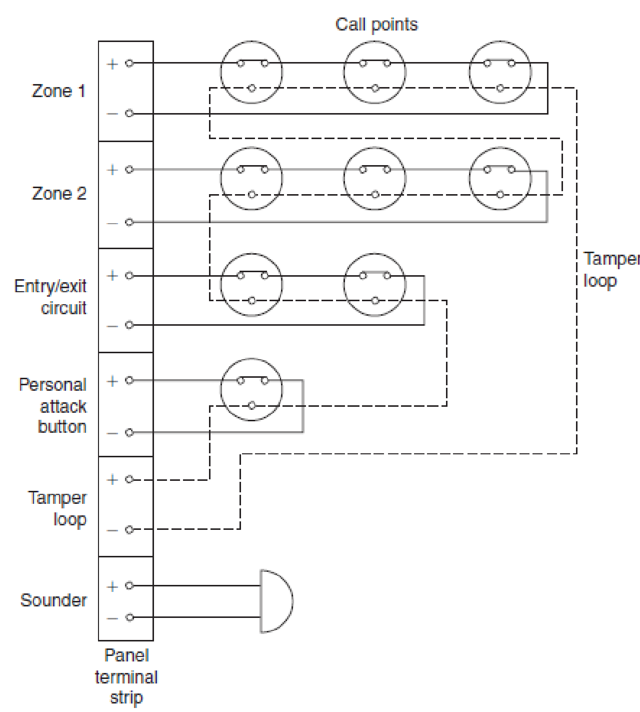
Closed Circuit System: All call points are wired in series, as shown below, the operation of the reset button energizes relay RA. Normally Closed contacts of call points are used.



Principle of Operation:

1. When the rest button is pressed, the system holds-on via RA_1 (Normally Open Contacts), then the alarm mute switch is closed to setup the system.
2. An interruption of the supply to RA coil, by operating any of call points, will de-energize the relay, opening RA_1 and closing RA_2 (Normally Closed Contacts) actuating the alarm sounder/s.
3. The system can be reset or cancelled only by the reset button.
4. The closed circuit system is self-monitoring such that any malfunction of the relay or break in a call point wiring will cause the operation of the system as if a call point has been activated.

Notes:



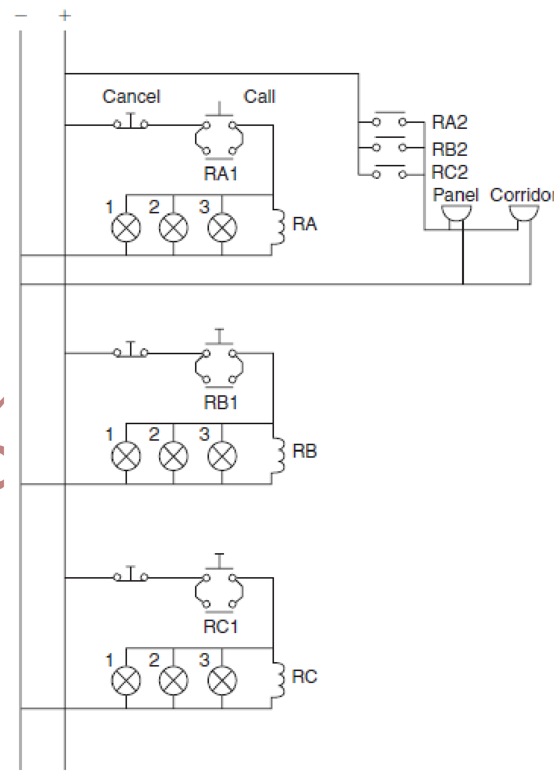
- The entry/exit circuit is confined to front and/or back doors.
- The facility exists to alter time delay between setting the system and exiting, and between entering and switching off the system. This adjustment is made inside the control panel.
- The system has back up batteries with charging facility.
- ***Tamper loop:*** is a continuous conductor wired to a terminal in each detector (call point) of the system. Any interruption will activate the system.
- The cable linking sensors and detectors depends on the system, but it is usually multi-core PVC sheathed and insulated with stranded conductors, typically 7/0.2; i.e. seven strands of 0.2mm^2 wires.

VI) Call and Emergency Systems

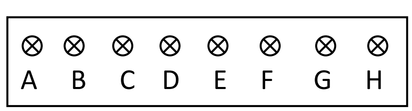
Types**: A) Nurse Call Systems:** use push buttons, indicator lamps, and buzzers

B) Wireless Call Systems: e.g. pager and beeper system used in hospitals and restaurants

A) Nurse Call System



- It is more popular than the wireless type.
- The Figure next shows the arrangement of a Nurse Call system for 3 rooms.
- Each room is equipped with:
  1. a call button
  2. reassurance light
  3. cancel button
- Outside the room is an indicator light
- At strategic points in the building there are zone buzzers.
- Centrally located a Display panel which incorporates a buzzer and an indication of which room is calling.
- Every call activates a buzzer and 3 lamps:
  1. Lamp 1: reassurance light indicator (in room)
  2. Lamp 2: outside room light indicator
  3. Lamp 3: display panel light indicator
- RA_1, RA_2, RB_1, RB_2, RC_1 & RC_2: normally open contacts
- The cancel button is located in room to ensure that the staff visits the patients in question
- An example of a display panel is shown below, where the alphabets indicate room numbers.



- Cables and wires used in wired call systems are similar to those used in security; flexible cords.

B) Wireless Call Systems

The system consists of:

A) **Calling buttons**: a service is requested by a push button!

B) **Pager:** receives the signal from calling buttons, each may receive more than 200 calling button signals.

C) **Page server**: to transmit signal between calling buttons and pagers, coverage range of some systems could reach a 3000m or several floors

D) **Dispatch controller**: is used to dispatch calling requests to pagers, it is operated by a receptionist or a supervisor.

PART IV

Illumination and Light Sources Characteristics

Definitions:

A Luminary (Luminaire):
It is any device that includes a lamp holder, the means of electrification and support for that device.

Luminous Intensity (I):

It is the measure of the power of a light source or brightness, and is measured in candela (Cd).

Luminous Flux (F):

It is a measure of the flow or amount of light emitted from a source. It is measured in Lumen (Lm).

Illuminance or Illumination (E):

It is a measure of the amount of light falling on a surface, it is measured in Lux or Lumen/m^2

$$E = \frac{luminous\ (F)}{Area}$$

Luminous Efficacy (K):

It is a ratio of Luminous flux to electrical input power; it could be thought of as "efficiency" of a light source. It is measured in Lumen/Watt (Lm/W).

Maintenance Factor (MF)

It is the loss of light due to collection of dirt and ageing, it should not fall below 0.8. It has no units!

Coefficient of Utilization (CU)
The amount of useful light reaching a working plane will depend or the lamp output, reflectors and/or diffusers used, position of lamp, color of walls and ceiling.

Example # 1:

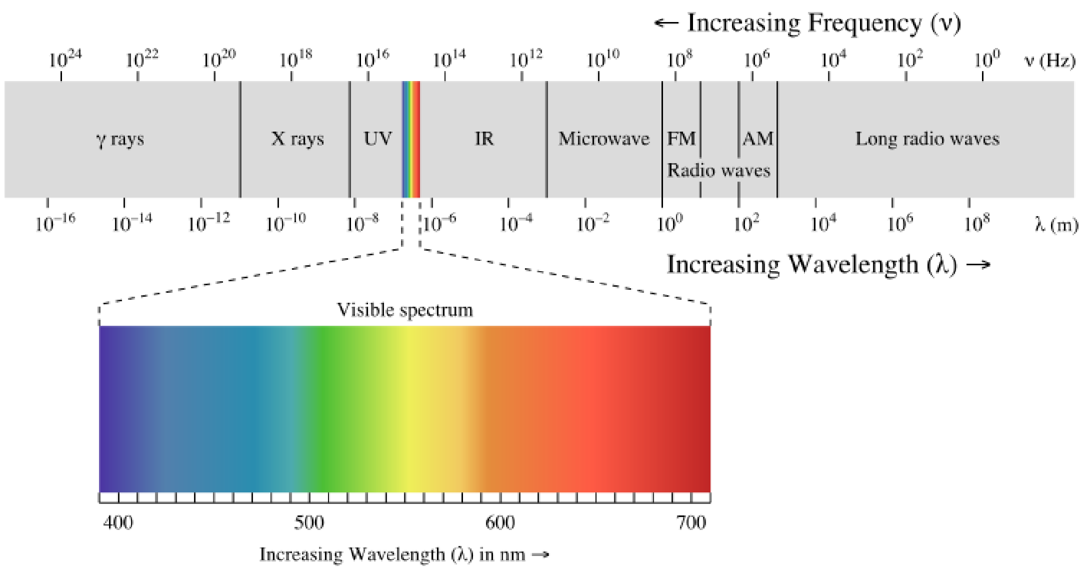
A new 80W Fluorescent lamp with a lumen output of 5700Lm. After 3 or 4 months, the output would have fallen and settled at around 5200 Lm, then find Maintenance Factor (MF)?

$$MF = \frac{5200}{5700} = 0.9;$$

Regular cleaning improves Maintenance Factor.

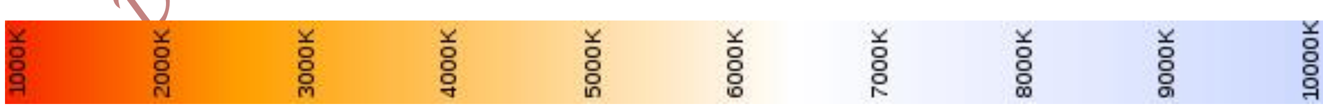
Visible Light

The wavelength of visible light is in the range: 380nm to 770nm.



<u>Color Temperature Code (Scale):</u>

The color temperature scale is expressed as the colors that a black body radiator (a block of iron that won't melt) exhibits when heated to extreme temperatures. The Figure below shows the colors when the black body is heated up to the shown temperatures in Kelvins.



<u>Color Rendering Index (CRI)</u>

It describes the quality of light on a scale of 0 (horrible) to 100 (perfect; natural light). It expresses how accurate the light renders objects' colors.

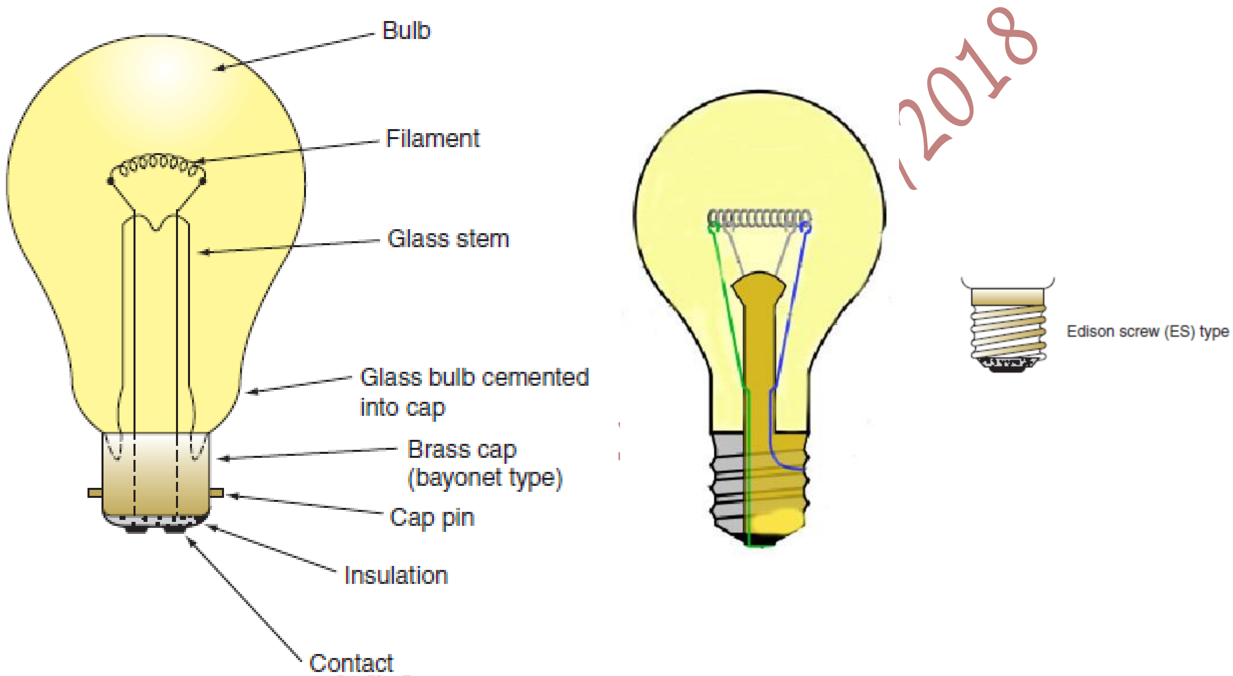
Types of Luminaries

The main types are:

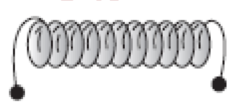
A) Incandescent Lamps and **B)** Discharge Lighting

A-1) Standard Incandescent Lamps or Tungsten- Filament Lamps

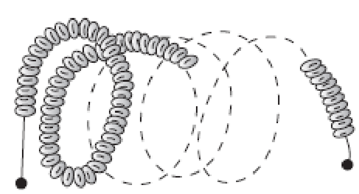
The Figures below show the basic components of a Tungsten Filament lamp (light bulb or globe).



The Tungsten Filament is either single (Figure (a)) or double (coiled coil) (Figure (b)), as shown below:



(a) A single coil



b) A double (coiled) coil

The Efficacy of gas filled lamps is increased by using coiled coil Filament, as it has a thicker Filament which reduces the heat loss due to convection currents in the gas.

Standard Incandescent (Filament) Lamp types:

They are Vacuum and gas filled.

I) Vacuum type:

The filament operates in a vacuum in the glass bulb. It has a poor Efficacy as it can only operate up to around 2000C°. Though, old light bulbs were of vacuum type, some modern ones are manufactured based on vacuum technology.

II) Gas–Filled Type:

- The bulb is filled with an inert gas such Argon and Nitrogen, Krypton or Xenon, this enables the operating temperature of the Filament to reach 2500C°. The glass bulb of a general service lamp can reach temperatures between 200 and 260 °C.
- The Efficacy increases and the bulb is so bright that it is given an opaque coating internally.
- The Efficacy of a Tungsten lamp depends on the age and size of lamp; it tends to be around 12Lm/W for 100W lamp (Efficacy ranges from 5 to 20Lm/W).
- The color light tends to be mostly Red and Yellow (the Color Temperature Code is 2700°K; warm color) and is used in situations that do not require high level of illumination.
- Color Rendering Index (CRI) is 100 (great).
- Approximately, more than two thirds of the power consumed by an incandescent light bulb is emitted as heat, rather than as visible light (wave length: 380nm to 770nm).
- Life time is 750hrs-1,000hrs (1000hr=1 year; based on an average of 3 operating hours per day)
- Any mounting position is possible, also instantaneous on/off operation.
- Other lamps of filament type include tabular stripe light, oven lamps, infrared heating lamps, spot and floodlight, and Tungsten–Halogen lamps.

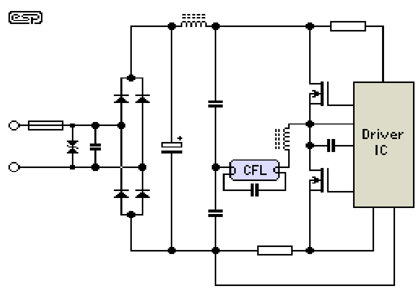
A-2) Tungsten Halogen Lamp

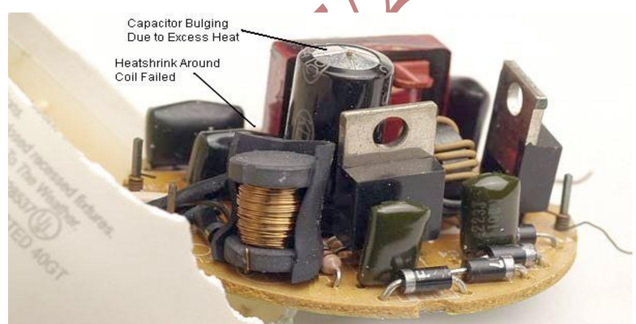
It is another type of Incandescent lamps, but it contains Halogen gas.

- Efficacy: 15 to 25Lm/W (a bit higher than Standard lamps)
- Life time is 2,000hrs-10,000hrs
- Color Rendering Index (CRI) is 100 (great).
- The Color Temperature Code is 3000°K (slightly whiter and cooler color).
- Any mounting position is possible.
- More expensive than standard Incandescent lamps
- Dimming is possible for both types (standard Incandescent and Halogen lamps).

B) Discharge Lighting (High Intensity Discharge (HID))

- This type of lighting relies on the ionization of a gas to produce light. High voltages are present in these types.
- Ballasts are necessary to start the operation of the Discharge Lighting (or High Intensity Discharge (HID) Lamps), and to limit the current flow. They are two types:
  1. **Magnetic:** consists of the coil, a starter, and capacitors.
  2. **Electronic:** more energy efficient, quieter, and reduce Lamp flickering; no humming or buzzing! An example of the equivalent circuit of an Electronic Ballast is shown left Figure below, also a photo of an electronic ballast is shown on the right Figure.

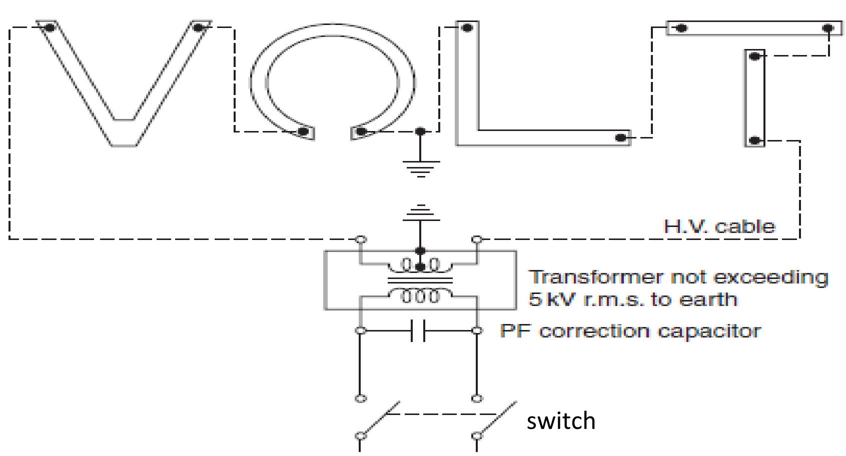




- Examples of Discharge Lamps: decorative neon signs (tubes), Fluorescent lighting, and Mercury and Sodium-vapor lamps used for street lighting.

B-1) Neon Tubes

- A Neon tube describes any gas-filled tube.
- The tube is filled with various gases (including: Helium, Nitrogen, Neon, Argon, and/or Carbon Dioxide) to give different colors. A basic circuit of cold–cathode neon–sign installation is shown in the Figure below.
- Life time: 20,000-40,000hrs!

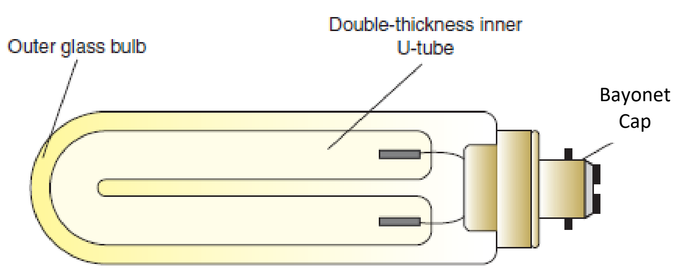


B-2) Sodium Vapor Lamps

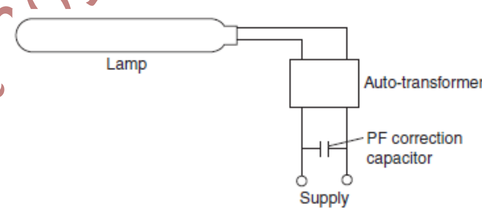
They are low pressure and high pressure lamps.

B-2-a) Low Pressure Sodium Lamp

- It consists of a U-shaped double thickness glass tube.
- The inner wall is of low–silica glass, which withstands attack by hot Sodium.
- Inside the tube is a quantity of solid Sodium and a small amount of Neon gas (this helps starting discharge process).
- The outer glass envelope stops too much heat loss from inner tube.



a) Low pressure Sodium Vapor type SOX



b) The control circuit

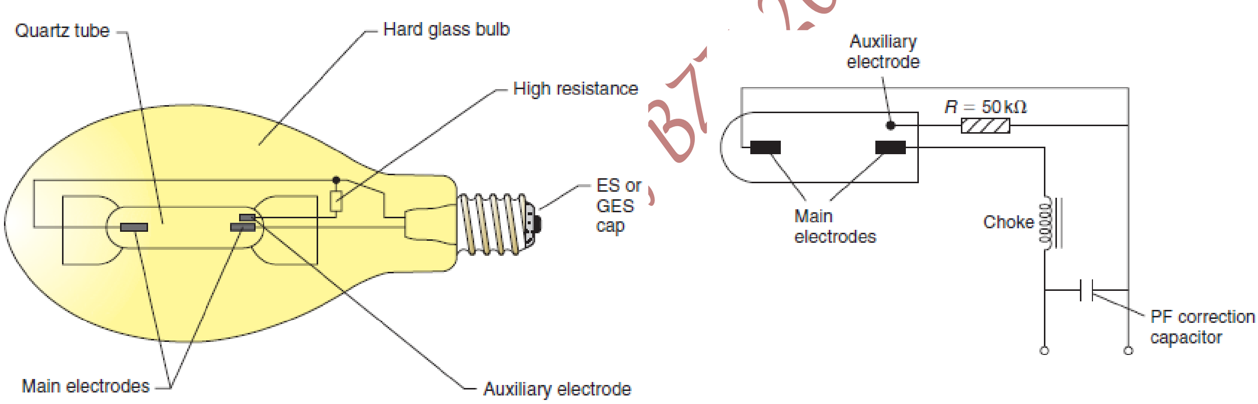
- The output of the transformer could reach 480V
- The power factor of lamp and transformer could be as low as 0.3 lagging. Hence, a power factor correction capacitor is needed.
- The recommended burning position of the lamp is **horizontal $\pm$ 20** to ensure that hot Sodium does not collect at one end of the tube in sufficient quantities to attack and damage it.
- The light output is **pure Yellow** which distorts the surrounding colors, hence it is only useful for **street lighting**.
- Low Pressure Sodium Lamps are of two types:
  - **a)** SOH: is the old type and has an Efficacy of 70Lm/W.
  - **b)** SOX: is the modern type, and has a high Efficacy of 140Lm/W for 90W lamp.
- Life time is 18,000hrs

B-2-b) High Pressure Sodium Lamps

- The discharge tube is made of compressed Aluminum Oxide, which is capable of withstanding the intense chemical activity of the Sodium vapor at high pressure and temperature.
- The Efficacy is about 100 Lm/W.
- The lamp may be mounted in **any position**.
- The color is Golden White → little surrounding color distortion; it is used in shopping centers, car parks, sports grounds…

B-3) Mercury Vapor Lamp

B-3-I) High Pressure Mercury–Vapor Lamp



a) High Pressure Mercury Vapor lamp   b) Control circuit

(GES: Goliath Edison Screw)

- ✓ *The **Quartz tube*** contains Mercury at high pressure and a little Argon gas to assist starting.
- ✓ *An **Auxiliary electrode*** is used for starting the discharge; noting that initial discharge occurs in Argon gas between Auxiliary and the nearby Main electrode, causing the Main electrode to heat up starting the Main discharge between the two Main electrodes.

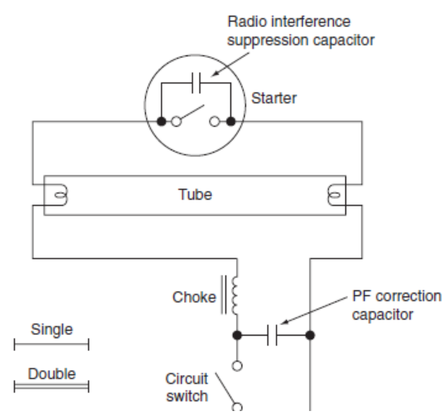
- ✓ **High Pressure Mercury lamps are of two types**:

  a) ***MB type**: standard mercury–vapor (older)*
  - Any mounting position
  - Efficacy ~ 40 Lm/W
  - Color: Blue–Green

  b) ***MBF type***: standard mercury–vapor (more modern)
  - It has Fluorescent Phosphor coating on the inside of hard glass bulb.
  - Any mounting position is possible
  - Efficacy ~ 50Lm/W
  - Used for Industrial and street lighting, commercial and display lighting
  - Color: Blue–Green
  - Life time is 12,000hrs
  - CRI: 30-50 (bad)

In general, High Pressure Mercury Lamps are not used in any new constructions because of the poor color and low energy efficiency.

B-3-II) Low Pressure Mercury–Vapor Lamp



- ❖ It is more popularly known as a Fluorescent lamp.
- ❖ It consists of a glass tube, a choke, and a starter, as shown in the Figure next:
- ❖ Glass tube is filled with Mercury vapor at low pressure and a little of Argon to assist starting.
  - The interior of the tube is coated in Fluorescent Phosphor.
  - Each end of the tube has an oxide coated Filament.
  - Discharge takes place when a high voltage is applied across the tube.

Operation of Fluorescent lamps

a) When the main switch is closed, the circuit is closed via the starter contacts.

b) The filaments become warm and the oxide coated filaments emit electrons and gas ionizes at the ends of the tube (this helps main ionization).

c) The starter contacts separate, and the choke is open circuited causing a high voltage to appear across the open contacts; the inductive energy is released in the form of an arc, and the energy dissipates via the gas.

d) When the gas is fully ionized, the choke limits the current to a predetermined value.

e) The light emitted, which is ultraviolet, is made visible by the Fluorescent powder coating (the color depends on the mixture of Phosphor minerals; powder).

Notes:

1. A Fluorescent lamp consumes ~1/7th power of the Incandescent lamps for the same amount of light.
2. A Power Factor (PF) correction capacitor is needed. If only real power rating (P) is given and no information about the Power Factor (PF) is given, and to be able to calculate the current rating, the PF is assumed to be 0.555 lagging or VA = 1.8XP; *i.e.* S= 1.8XP; for 80W lamp→ VA= 1.8 (80) = 144VA.
3. The switch should be deigned to have a current rating twice the steady state current of the inductive load (lamp).
4. Radio interference suppression capacitor is located in the starter.
5. The white tube has the highest Efficacy (amongst other tube colors), which is around 70Lm/W.
6. CRI: 70-90 (moderate to good)
7. Life time: 10-30yrs
8. Fluorescent and HID products are labeled with 3 digit code expressing CRI and Color Temperature Code; e.g. Fxxxx-835: means CRI= 8X10= 80, Color Temperature Code: 35X100= 3500°K (cool!)

Compact Fluorescent Lamps (CFLs)

They are other types of Fluorescent lamps, some of which are shown in the Figure below. Many of these are commonly known as PLs, which stands for Plug-in Lamps (or Philips Lamps)!

Table # 1 shows a comparison between a Standard Incandescent Lamp and a Compact Fluorescent Lamp (CFL).

Table # 1: A Comparison between a Standard Incandescent and a Compact Fluorescent Lamp (CFL)

Standard Incandescent Lamp	***Compact Fluorescent Lamp (CFL)***
X Low efficacy	✓ *High efficacy*
X Short life time	✓ *Long life time*
X Low efficiency	✓ *High efficiency*
✓ *Low price (~US$ 0.5)*	*X Higher price (~US$ 3-4)*
✓ *Comfortable to eye (CRI: 100)*	*X Less comfortable to eye (CRI: ~70-90)*
✓ *Unity power factor*	*X Low power factor (as low as 0.55 lag)*

Example # 2:

It is required to illuminate a room with a luminous flux of 900Lm. Two options are available:

The first is using Incandescent lamp with the following specifications:

60W, 900Lm, life time of 1000hour, and unit price is US$ 0.5.

The second option is using a Compact Fluorescent lamp of the following specifications:

15W, 900Lm, life time of 10,000hour, and unit price is US$ 4.

a) Compare the total cost of illuminating the room for 10,000 hours, assuming that the price of every kWH is 15 cent (US$ 0.15/kWH).

b) What would be the savings if CFL is used?

c) What would be the Hourly Energy saving if CFL is used?

d) What would be the payback period if CFL is to replace the Incandescent lamp?

Solution:

a) For option # 1:

The total cost = the capital cost + running cost

Total $cost_1$= 0.5$X10 + 10000Hr X (60W/1000W/kW) X 0.15$/kWH

Total $cost_1$= US$ 95

For option # 2:

The total cost = the capital cost + running cost

Total $cost_2$= 4$ + 10000Hr X (15W/1000W/kW) X 0.15$

Total $cost_2$= US$ 26.5

b) Savings = 95- 26.5 = US$ 68.5

c) Hourly Energy saving = ((60-15)/1000) X 0.15 = US$ 0.00675

d) The payback period = Investment in Replacement/hourly saving

= 4 / 0.00675 = 592.6 Hr

If the lamp is used 5 hours a day, then the payback period = 119 day; 4 months!

B-4) Metal Halide Lamps

B-4-a) Standard Metal Halide Lamps

- Metal Halide Lamps use Rare Earth Metal Salts and Mercury vapor at high pressure and temperature.
- They are compact, efficient, available in many sizes, and powerful; power rating could reach kilo Watts.
- Color temperature: 3700(cool) to 4100°K (slightly Greenish)
- CRI: 65-70
- They require ballasts as the igniter requires high voltages 1kV-5kV.
- They are typically used in table lamps to huge lamps for lighting stadiums, sports areas, parking lots, landscape lighting, and building floodlighting.

B-4-b) Ceramic Metal Halide Lamps

- They are the latest Metal Halide lamps.
- CRI: 80 to 95
- Efficacy: 65-115 Lm/W
- Color Temperature: 3000°K (warm) or 20000°K (Blue).
- They can be used for interior lighting, such as down lighting, display lighting, and wall washing lighting (washing walls with colored light), as well as for exterior lighting.

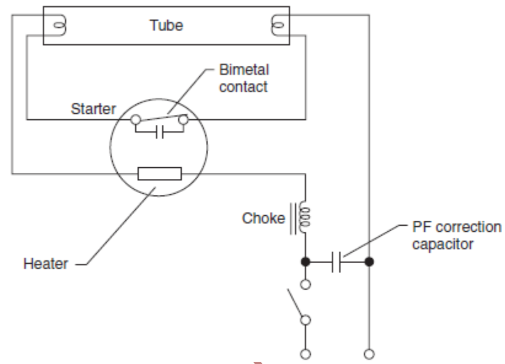
C) Light Emitting Diode (LED) Sources:

- They are at the cutting Edge of Technology.
- Efficacy: ~50Lm/W, however it is improving rapidly and could reach more than 100Lm/W in new street light sources.
- Color code: 2800-5000°K
- CRI: 70-80 (moderate to good)
- They need Ballasts and transformers to provide needed voltages
- Instantaneous on/off operation
- Dimming is possible
- Life time 50-100yrs!
- Application: in Exit and Traffic signs, wall washer lights (washing walls with colored light), besides application in street lighting is spreading.

__**Types of Starters for Fluorescent Tubes**__

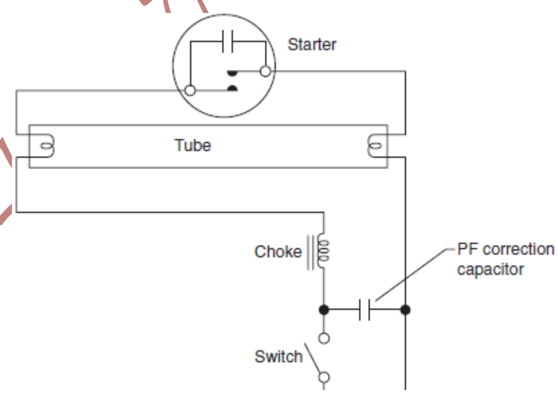
They are Thermal, Glow, or Quick starters.

1) A Thermal Starter



- It consists of two contacts one is bimetallic (Normally closed) and a heater.
- The heater when energized causes the contacts to part and the choke open circuits to initiate discharge in the tube.

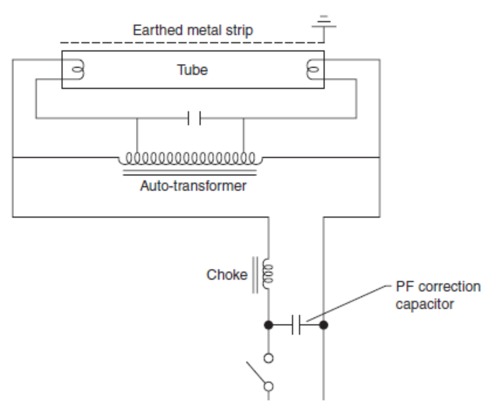
2) A Glow Starter



- A Glow starter is the most popular.
- Its compromises a pair of open contacts (bimetallic) enclosed in a sealed glass bulb filled with Helium gas.
- The assembly is housed in a metal or plastic canister.
- ***__Operation:__***

  When the supply is connected, the Helium gas ionizes and heats up causing the contacts to close energizing the tube Filaments. As the contacts have closed, the discharge in Helium ceases, contacts cool and part, open circuiting the choke and tube discharge takes place.

3) A Quick Start (Instant Starter)



Starting is achieved by the use of an auto-transformer and an earthed metal stripe in close proximity to the tube.

__**Operation**__

- When the main supply is switched on, the main voltage appears a cross the tube and the small part of the winding at each end of the transformer energizes the Filaments, which heat up.
- The difference in potential between the electrodes and the earthed stripe causes ionization, which spreads along the tube.

Common Light Levels (Illumination) Outdoors

Condition	Illumination	
	Foot Candela (ftCd)	***(Lux or Lumen/m²)***
Sunlight	10,000	107,527
Full Daylight	1,000	10,752
Overcast Day	100	1,075
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	.1	1.08
Full Moon	.01	.108
Quarter Moon	.001	.0108
Starlight	.0001	.0011
Overcast Night	.00001	.0001

Recommended Light Levels (Illumination) Indoors

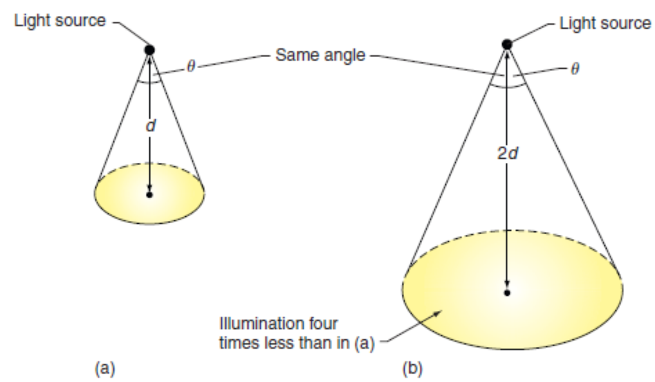
The light level is commonly in the range *500 - 1000 Lux*; depending on activity.

Activity	Illumination *(Lux or Lumen/m²)*
Public areas with dark surroundings	20 - 50
Simple orientation for short visits	50 - 100
Working areas where visual tasks are only occasionally performed	100 - 150
Warehouses, Homes, Theaters, Archives	150
Easy Office Work, Classes, corridors	250
Normal Office Work, PC Work, Study Library, Groceries, Show Rooms, Laboratories	**500**
Supermarkets, Mechanical Workshops, Office Landscapes	750
Normal Drawing Work, Detailed Mechanical Workshops, Operation Theatres	1,000
Detailed Drawing Work, Very Detailed Mechanical Works	1500 - 2000
Performance of visual tasks of low contrast and very small size for prolonged periods of time	2000 - 5000
Performance of very prolonged and exacting visual tasks	5000 - 10000
Performance of very special visual tasks of extremely low contrast and small size	10000 - 20000

Calculation of Lighting Requirements

A) Inverse Square Law:

The illumination at a surface from a luminary positioned vertically above it is directly proportional to the light luminous intensity and inversely proportional to the distance squared.



$$\text{Illuminance } E \text{ (lux)} = \frac{\text{luminous intensity (cd)}}{d^2}$$

$$E = \frac{I}{d^2}$$

Example # 3:

A light source of 900 candelas is situated 3m above a working surface.

a) Calculate the illuminance directly below the source.

b) What would be the luminance if the lamp were moved to a position 4m from the surface?

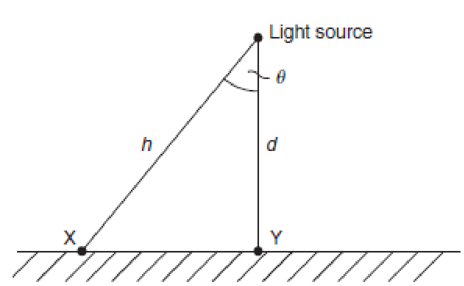
Solution:

a) $E = \frac{I}{d^2} = \frac{900}{3^2} = 100$ Lux

b) $E = \frac{I}{d^2} = \frac{900}{4^2} = 65.25$ Lux

B) Cosine Rule:

The Illuminance at a point (x) which is not directly below the light source is directly proportional to Luminous Intensity (I) and cos θ, and inversely proportional to the vertical distance squared.



$$E_X = \frac{I \times \cos^3 \theta}{d^2}$$

Where I is the Luminous intensity (Cd).

Example # 4:

A 250W sodium–vapor street lamp emits a light of 22500Cd and is situated 5m above the road. Calculate the Illuminance (E): **a)** directly below the lamp **b)** at a horizontal distance of 6m along the road

Solution: a) Illumination at y:

$$E_y = \frac{\text{luminous intensity (cd)}}{d^2}$$

$$E_y = \frac{I}{d^2} = \frac{22500}{5^2}$$

E_y= 900 Lux or Lumen/m^2

b) $\theta = \tan^{-1}\frac{6}{5} = \tan^{-1} 1.2 \rightarrow \theta = 50.2^0$ Cos 50.2 = 0.64

Illuminance at X is

$$E_x = \frac{I\cos^3\theta}{d^2} = \frac{22\,500 \times 0.64^3}{25} = 236 \text{ Lux (Lx)}$$

Example # 5:

A work area at bench level is to be illuminated to a value of 300Lux, using 85W single Fluorescent fittings having an efficacy of 80 Lumens/Watt. If the work area is 10mx8m, the MF=0.8 and CU is 0.6, then calculate the number of fittings required.

Solution:

Luminous Flux = $\text{Total lumens } (F) \text{ required} = \frac{E\text{ (lx)} \times \text{area}}{\text{MF} \times \text{CU}}$

$$F = \frac{300 \times 10 \times 8}{0.8 \times 0.6}$$

$$= 50\,000 \text{ lm}$$

Since the efficacy is 80 Lm/W

$\rightarrow$ Total power required = $\frac{50000}{80}$ = 625W

Since each lamp is 85W

$\rightarrow$ Number of lamps = $\frac{625}{85}$ = 8 lamps

PART V

Conductors, Cables and Insulating Materials

Cables:

- A cable comprises two parts: the conductor or conductors and the sheathing and insulation.
- Cables range from very small single core (wire), used in electronic circuits to huge oil or gas filled cables used in high voltage transmission systems. The oil is used for insulation and also for cooling.
- The price of installing a power grid using underground cables could reach 4-6 times the cost of installing overhead transmission lines of similar capacity.
- The price of the oil-filled cables could reach 12 times that of a normal transmission line.

Conductors:

A conductor is the conductive portion of a cable, which consists of a single wire or group of wires in contact with each other. A comparison between different elements according to their resistivity is shown in Table # 1.

Table # 1: *Resistivity of Commonly Used Elements*

	Material	Symbol	Resistivity at 20°C (μΩ cm)	Atomic number
Lowest resistivity	Silver	Ag	1.58	47
	Copper	Cu	1.72	29
	Gold	Au	2.36	79
	Aluminum	AL	2.6	13
Highest resistivity	Tungsten	W	5.6	74

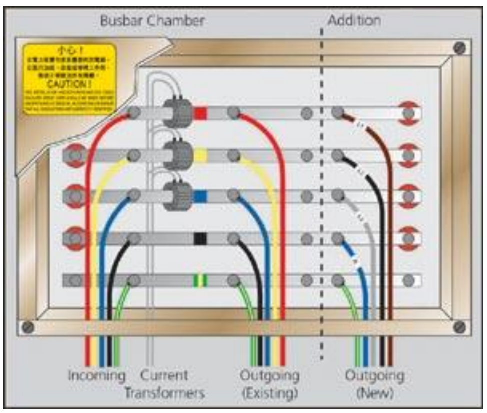
- Silver and gold are expensive to be used in conductors
- Copper is a plentiful mineral of low resistivity making it a suitable conductor, hence it is widespread in manufacturing cables and conductors.
- Aluminum is also cheap and is used in manufacturing conductors.
- Tungsten has a high resistivity and is used mainly in heating elements and light bulb filaments.

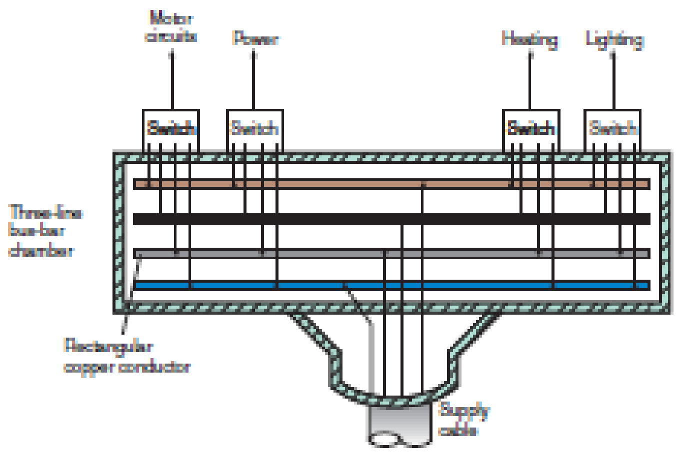
Conductors' Construction

1) **Solid Conductors**

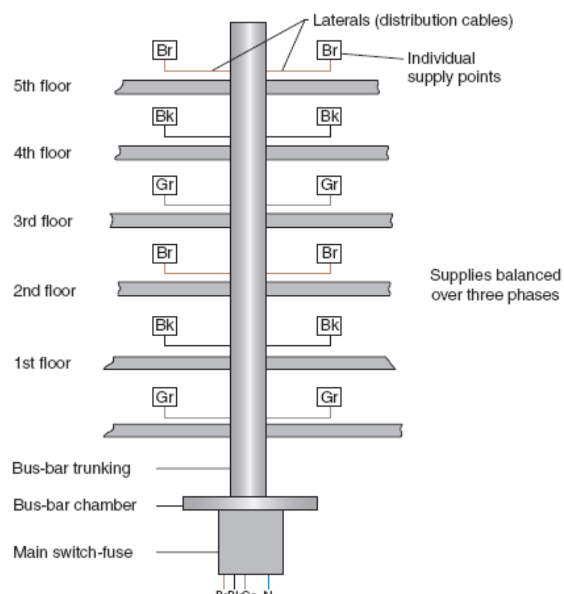
   They are either circular or rectangular in cross section and are used for fixed wiring.

   A) ***Rectangular Conductors*** are called Bus-Bars and are used in main Distribution Boards. The figures below show two Bus–Bar chambers arrangements.





   B) ***Circular Conductors*** are restricted mainly to cable cores up to 6mm^2. Although, cross sectional area of up to 25mm^2 are sometimes used in trunks, from the ground floor to the top floor of a block of flats, to provide a supply point for each floor; these conductors are called rizers (risers).

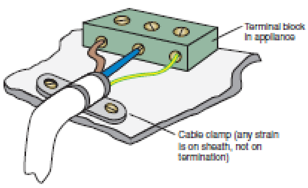


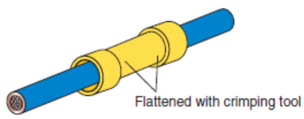
2) **Stranded Conductors**

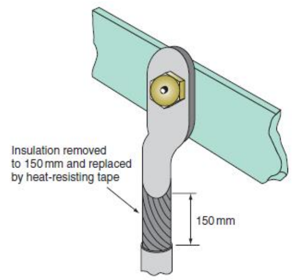
   They are used in both fixed wiring cables and flexible cords (flexible cables not exceeding 4mm^2). The number of strands depends on the cross sectional area; e.g. cables up to 25mm^2 have 7 strands. Flexible cords have many fine strands.

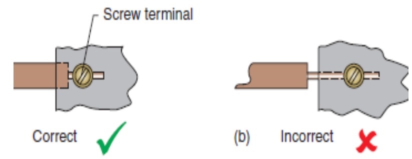
Joints and Termination:

When conductors are joined together or to a Bus–Bar an effective joint or termination must be used; e.g. cable shoe (Lug termination), or screw terminal connection (proper peeling must be made, refer to the right figure below). Cable cord grip might be needed, as shown in the left Figure below.









Wires

Wires or singles are single-core cables of Poly Vinyl Chloride (PVC)-insulation and are used when installations are to be run in trunks or conduits. They are of various cross sectional areas and colors, and are mainly used in lighting, extra low voltage and power circuits. Table # 2 shows the wires' cross sectional areas, the recommended protective Fuse or Miniature Circuit Breaker (MCB) current ratings (Ampacity), and typical application circuits. On the other hand, Table # 3 shows the color code for flexible cords and singles used in domestic wiring.

Table # 2: *Wires Cross Sectional Areas, Protection Fuse or MCB Rating, and Typical Applications*

Wire's cross sectional area [mm^2]	**Rated current of protection Fuse or Miniature Circuit Breaker [A]**	**Application**
0.5	4	Extra low voltage circuits
1.5	10	Lighting circuits
2.5	16	Power circuits
4	20	Heavy heating and cooking loads
6	32	Main supply for single phase loads
10	40	In three phase circuits

Table # 3: *Color Code for Wiring Circuits*

Wires' colors	Application
Brown or Red	Phase or the Line conductor
Blue or Black	Neutral conductor
Yellow with Green stripes	Earth/Ground
Violet, Green, Brown with Black stripes, Brown with Orange stripes, or any other colors	Strapper or Traveler conductors

Terminal Blocks

Terminal blocks are used to connect single core cables (wires) together. They are usually supplied in 12-way lengths as shown in the Figure next. But, they can be cut into smaller blocks with a sharp knife or large wire cutters. They are sometimes called 'chocolate blocks' because of the way they can be easily cut to size.

Table # 4 shows the standard colors for conductors' insulators used in cables and single cores. More details about the wires and cables and their current ratings can be obtained from standard tables; an example is shown in Table # 5 for single core wires of 650V rating.

Table # 4: *Standard Colors of Conductors' Insulators*

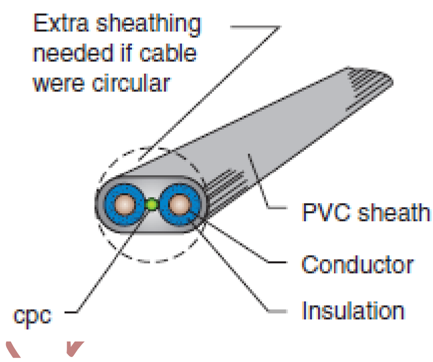
$1mm^2$ to $4mm^2$	Red, Yellow, Blue, Black, Orange, White, Pink, Violet, Brown, Grey, Green and Green / Yellow
$6mm^2$ to $25mm^2$	Red, Yellow, Blue, Black, Orange, White, Brown, Green and Green / Yellow
$35mm^2$ to $400mm^2$	Red, Yellow, Blue, Black, Green and Green / Yellow

Table # 5: *Specifications of Single Core Wires (650V Rating)*

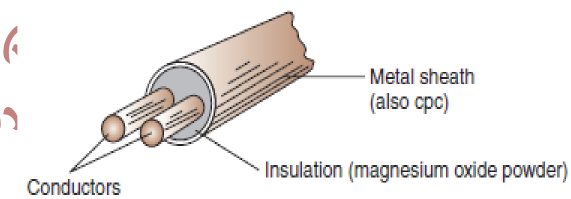
				Unsheathed Cables		Sheathed Cables			Current Rating Amp	
Cond. Area Sq. mm	Conductor Construction No./ Dia	Max. DC Conductor Resistance at 20°C in ohm / km		Insulation thickness	Overall Diameter	Insulation thickness	Sheath thickness	Overall Diameter		
		Copper	Aluminum	Nominal mm	Approx mm	Nominal mm	Nominal mm	Approx mm	Copper	Aluminum
1	01/01/12	17.7	-	0.7	2.6	0.6	0.8	4.1	10	8
1.5	01/01/38	11.9	19.7	0.7	2.9	0.6	0.8	4.4	13	10
2.5	01/01/78	7.14	11.8	0.8	3.5	0.7	0.8	5	20	15
4	01/02/24	4.47	7.39	0.8	4	0 8	0.9	5.85	26	20
6	01/02/76	2.97	4.91	0.8	4.5	0.8	0 9	6.4	35	27
10	01/3.55 Al	01/08/09	2.94	1	5.7	1	0.9	7.55	44	34
	7/1.35 Cu	-	-	-	6.2	-	-	8.05	45	35
16	07/01/70	1.13	1.87	1	7.2	1	1	9.3	55	43
25	07/02/14	0.71	1.18	1.2	8.9	1.2	1.1	11.2	75	58
35	07/02/50	0.51	0.85	1.2	10	1.2	1.1	12.3	90	70
50	07/3.00	0.38	0.63	1.4	11.9	1.4	1.2	14.4	120	92
	19/1.78	-	-	-	11.9	1.4	1.2	14.4	120	92
70	19/2.14	0.26	0.44	1.4	13.6	-	-	-	150	116
95	19/2.50	0.19	0.31	1.6	15.8	-	-	-	175	135
120	02/03/37	0.15	0.25	1.6	17.5	-	-	-	200	155
150	02/24/37	0.12	0.2	1.8	19.4	-	-	-	230	175
185	37/2.50	0.1	0.16	2	21.7	-	-	-	265	205

Sheathing and Insulation

- All conductors have some type of insulation and/or sheathing except bare conductors; e.g. Bus-Bars and bare Risers (Rizers).
- *Old cables* were insulated with rubber, with an outer sheathing of lead, cotton or rubber. These cables are no longer manufactured.
- *Modern cables* are insulated with Poly Vinyl Chloride (PVC), and some have the sheath also of PVC, as shown in the Figure next.

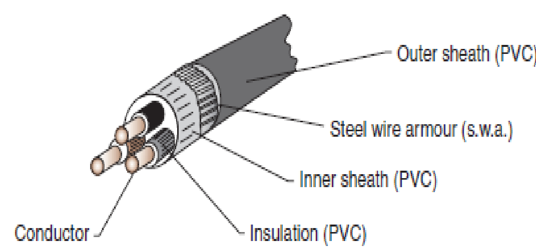


- CPC: stands for Circuit Protective Conductor and is used as a ground conductor.
- Other types of cables are Mineral–Insulated Metal–Sheathed (m.i.m.s.), as shown in the Figure next. The most popular type has copper conductors and copper sheath (m.i.c.s.). It may have PVC overall covering, very strong and long-lasting type.



Twin-core m.i.m.s. cable.

- In ***Armoured cables*** the inner PVC sheath is in turn sheathed in strands of steel wire and an overall PVC sheath is fitted. Armouring protect the insulated conductor from mechanical damage.



- **XLPE Cables** (Cross Linked Poly Ethylene cables) is another type of cables; named after the insulation type.

Minimum Bending Radius of Cables:

The minimum bending radius of a cable is directly proportional to the cable diameter; an example of the recommended minimum bending radius is specified in the Table # 6.

Table # 6: *The Minimum Bending Radius of Cables*

Cable Diameter	**Minimum Bending Radius**
Up to 10mm	*3 x overall diameter*
10mm to 25mm	*4 x overall diameter*
Above 25mm	*6 x overall diameter*

Plastic Materials (Polymers)

The uses of plastic materials (Polymers) in electrical engineering are widespread; they are used in cable insulation, plug tops, socket outlets, motor and transformer winding insulation. Polymers are of two types:

1) **Thermoplastic Polymers**

   - They soften on heating and solidify to their original state on cooling.
   - Repeated heating and cooling causes no damage.

2) **Thermosetting Polymers**

   - They become fluid when heated and change permanently to a solid state when cooled.
   - Further heating may cause the polymer to disintegrate.

Poly Vinyl Chloride (PVC)

Is a Thermoplastic polymer and is used in conduits and cable insulation. It has the following properties:

1) It has high tensile strength.
2) It can be bent by hand if warmed.
3) It has high electrical resistance.
4) It is weather resistant.
5) It does not crack under stress at normal temperatures.
6) It has a low flammability.
7) It is a self–extinguishing when source of heat is removed.

Phenol – Formaldehydes: are Thermosetting polymers and are used with other compounds to manufacture plug tops, and socket outlets.

XLPE Cable

XLPE Cables: Cross linked Poly Ethylene cables; named after the insulation material.

In general, there are two semi-conductive layers in a high voltage cable. One is between the actual conductors and the XLPE. The other semi-conductive is on outside of the XLPE insulation underneath the concentric neutral.

Comparison between PVC and XLPE Cables

PVC and XLPE are two materials used as insulation. XLPE has got more capacity to hold on incase of high temperature. XLPE will not deteriorate its insulating property until it reaches 90 degree Celsius. It will not suddenly lose its insulating property if the temperature jumps just above 90. But, the overall life of the cable will be reduced. PVC can withstand temperatures only up to 70 degree Celsius.

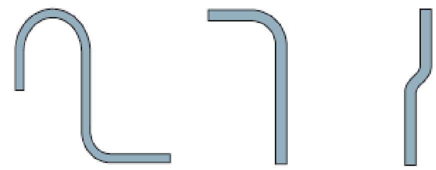
PVC is cheaper than XPLE, hence it finds its place in the market today.

PVC is a Thermoplastic polymers where as XLPE is Thermosetting polymer.

Conduits

A conduit is a tube or pipe in which conductors are run. It replaces the PVC sheathing of a cable providing mechanical protection for the insulated conductors.

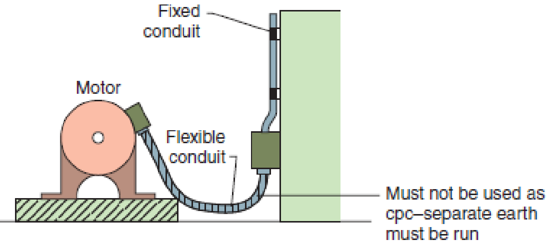
Type of conduits:



Conduit bends.

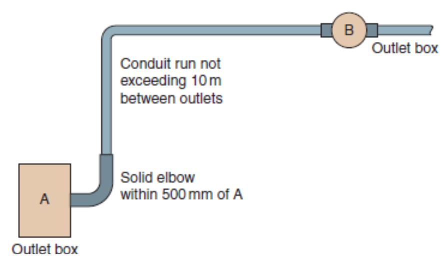
A) Metal Conduit

1. They are used in low voltage installations
2. They are used in flameproof installations.
3. They are expensive!
4. Flexible (metal) conduit is used when a rigid conduit is supplying machinery to prevent vibration from affecting the rigid conduit.

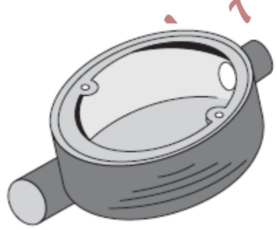


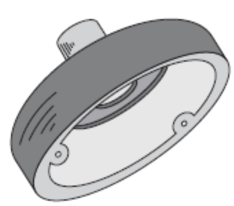
B) Non-metallic (PVC) Conduit

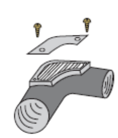
PVC conduits are suitable for domestic, light industrial premises, or offices installations.

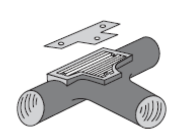


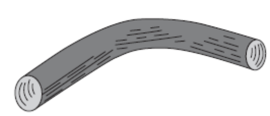
Some conduit accessories are shown in the Figures below:


Straight-through box

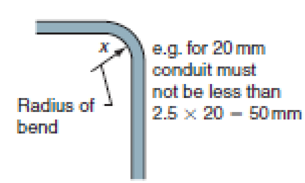

Back-entry box (useful for light fittings)


Inspection elbow


Inspection tee

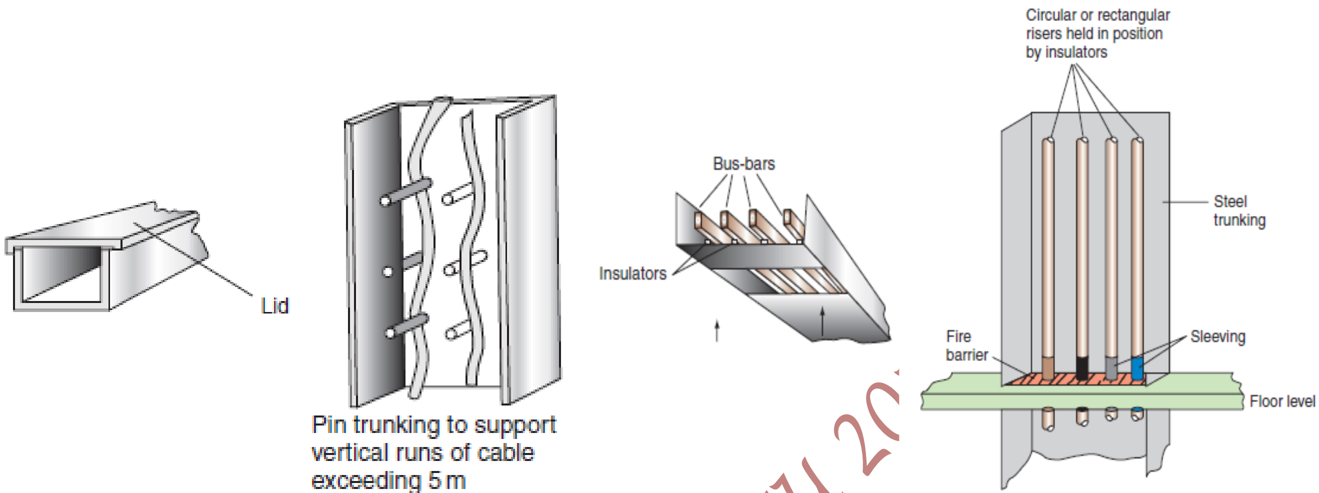

Non-inspection bend (90°)

Note: when a conduit is bent, the radius of any bend must not be less than 2.5 times the outside diameter of the conduit, as illustrated in the Figure next.



Trunks

A Trunk is a larger and more accessible conduit system; ordinary wiring trunks and bus–bar trunks. Examples of trunks are shown in the Figures below:



Bus-bar trunking.

Trunk are of two types:

1) **PVC Trunks**
   They are used in domestic and office premises. They are referred to as channeling.

2) **Metal Trunks**
   They are used in engineering premises; they allow a large number of cables to be drawn into one system.

Notes:

- The number of cables drawn in a conduit may be obtained from tables.
- However, the occupancy of cables within a conduit should not exceed 40% (40% of space is for cables and 60% for air).
- In trunking, the cables may occupy up to 45% of the space. For example, 8 single core cables of $2.5mm^2$ need at least 20mm conduit to be run within.

PART VI

Human Body and Earthing Systems

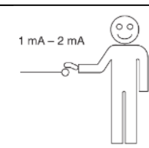
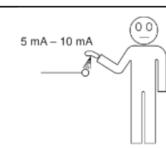
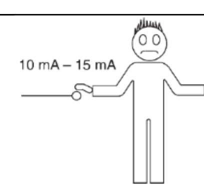
Electricity and Human Body:

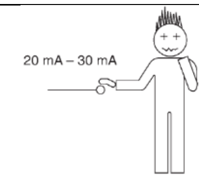
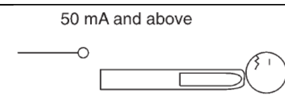
The human body resistivity varies not only between individuals, but between values for each person. Depending whether the body is dry, moist or wet, the resistance value measured between hands or between hands and feet is in the range 250 to 10,000Ω. Table # 1 shows the body resistance and corresponding fault currents under different conditions. Various levels of shock current and their effects on the body are shown in Table # 2.

Table # 1: *Body Resistance under Different Conditions*

Condition	Resistance	Current at 230V
Dry with shoes	> 3000Ω	76mA
Dry	1500Ω	153mA
Wet	500Ω	460mA
Body ½ immersed	250Ω	920mA

Table # 2: *Various Levels of Shock Current and Their Effects on the Body*

Current [mA]	Effect	Illustrated effects
1 - 2	Perception level, no harmful effects	
5	Throw-off level, painful sensation	
10 - 15	Muscular contraction begin, cannot let go	

20 - 30	**Impaired Breathing**	
50 and above	**Ventricular Fibrillation and death** (considered lethal level)	

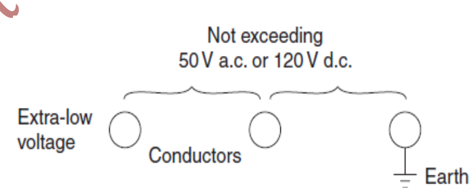
Since 50mA is considered lethal, and the person's body resistance can be as low as 1000Ω, the voltage required to cause this current to flow is:

$$V = IR$$

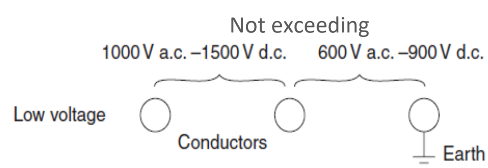
$$V = 1000 \times (50 \times 10^{-3}) = 50V!$$

Voltage Bands:

3. *Extra Low Voltage:* not exceeding 50Vac or 120Vdc, between conductors or conductors and earth.

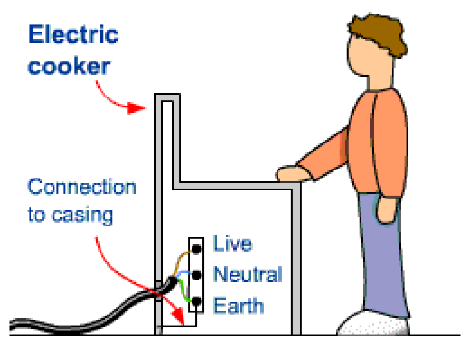


4. *Low Voltage:* not exceeding 1000Vac or 1500Vdc between conductors; or 600Vac or 900Vdc between conductors and earth.



The Need for Earthing Systems:

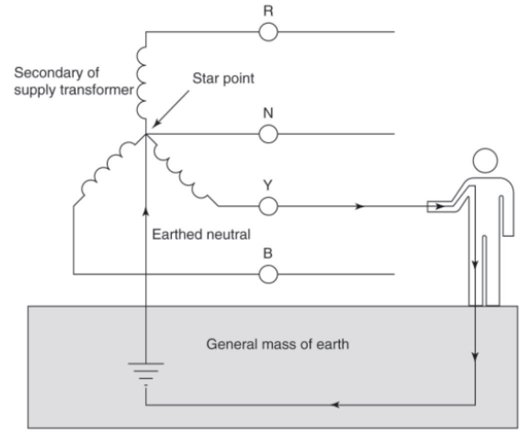
1. To ensure that the fault current can return to source in a controlled manner
2. To ensure that persons are not exposed to unsafe potentials under steady state or fault conditions
3. To ensure voltage (potential difference) does not rise with respect to earth on faulty equipment
4. To help protection systems detect and isolate faults



Earthing Systems and Bonding:

In many power systems, the secondary side of the distribution transformer is Y-connected and has its neutral (star point) connected to the general mass of earth; the neutral is maintained at or about 0V.

Persons or livestock in contact with a live conductor and earth are at risk of electric shock.



Shock current flows through person, through mass of earth to star point through yellow phase winding back to person

Notes:

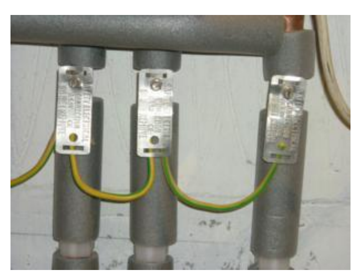
- The lethal level of shock current passing through person is 50mA.
- The earth mass is not a good conductor unless it is very wet!

Faraday's Cage:

Michael Faraday (1791-1867) placed himself in a cage made of conducting material and insulated from the floor. He charged the cage to a high voltage and he found that he could move freely touching any place within the cage with no adverse effect. He created an equipotential zone.

In correctly bonded installations, we live and/or work in Faraday's cages.

Earthed Equipotential Bonding:



All metallic parts are joined together (bonded) and connected to earth, this ensures that all the metal works are in a healthy situation and are at/or near zero volts. Under faulty conditions all metal works will rise to the same potential. Examples of metal works: conduits, trunks, and the metal cases of apparatus.

Methods of Making a Connection to Earth

1. Plates
2. Tapes
3. Rods or Electrodes

1. Plates:

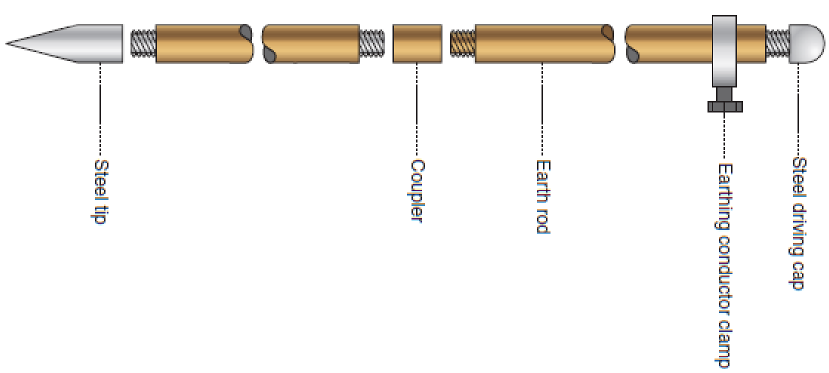
The plates are made of steel or other type of metal covered with copper or a conducting material. The plates are manufactured such that they are corrosion resistance, shock resistance and are of different areas and thickness (area is 1 or 2 meters square, while thickness is 2-8mm). The plate is buried at a sufficient depth to be effective, and considerable excavation is necessary.

2. Tapes:

Tapes are used in earthing large electricity substation and buildings. The tape of a conductive material and different sizes (e.g. 3X25mm, 3X30mm, 3X50mm…) is laid in trenches in a mesh formation over the whole site. Welding with structural steel of the foundations of a building enhances the earth connection. The tape is assembled to earth bus-bar in the Main Distribution Board using special screws.

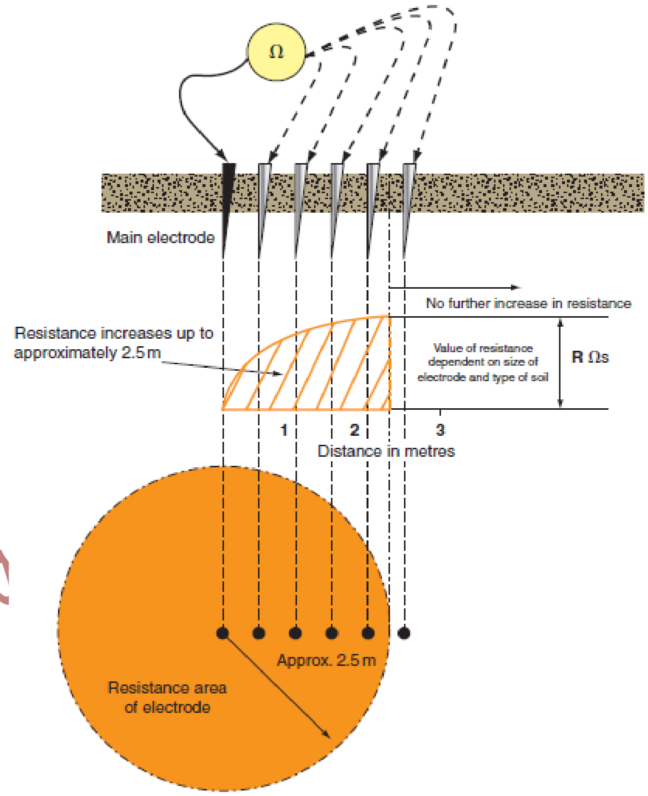
3. Rods or Electrodes:

These are made of solid copper or copper clad carbon-steel, the latter is used for larger diameter rods. The rod is 1.5 to 2m long and 16-19 mm diameter. The rod has a steel cap to protect the rode when driven in, a steel driving tip, and a clamp for connectors to an earth tape or conductor. It is very common method for earthing. The figures below show example of electrode; the figure on the right shows that the electrode is not properly installed.

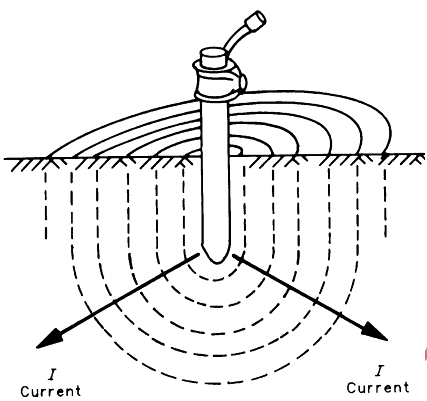


Earth Electrode Resistance:

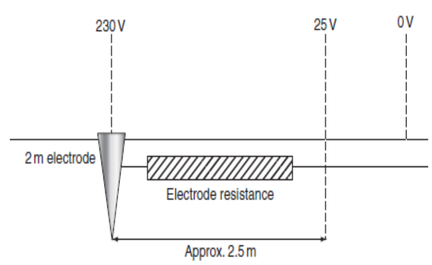
If an electrode is placed in the earth and the resistance between the electrode and points at increasingly larger distances from it were measured, then the resistance will increase with distance until a point is reached (~2.5m to 3m); a maximum resistance is reached.



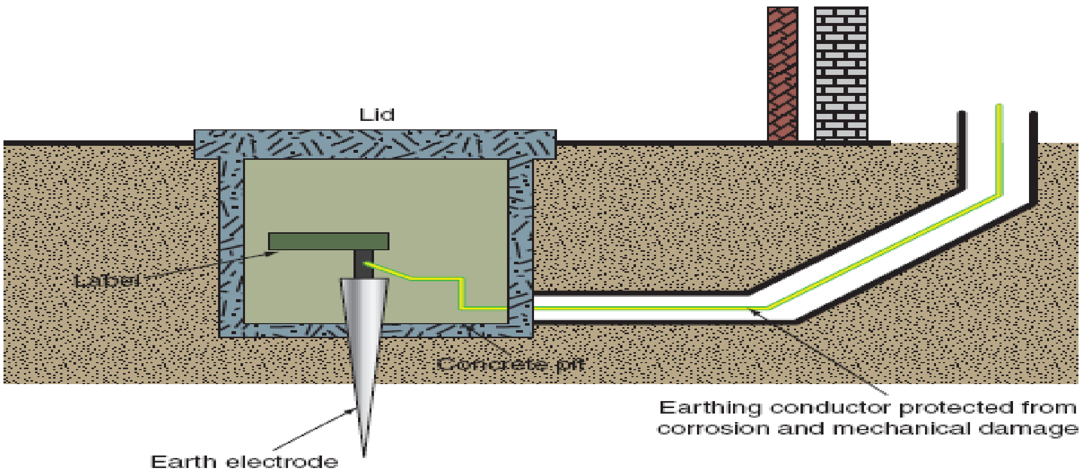
The maximum resistance is known as the electrode resistance.



For 2m electrode, with its top at ground level, 80% to 90% of the voltage appearing at the electrode under fault conditions is dropped across the first 2.5 to 3m. This is dangerous as the hind and the forelegs of an animal can be inside and outside the resistance area; 25V can be lethal.



Hence, the whole of electrode must be buried well below the ground level. A special manhole (60X60cm and 15-30cm depth, which has a lid) may be prepared to accommodate and protect the electrode from corrosion, mechanical forces or soil erosion, also to provide safety for livestock and persons during a fault occurrence. A typical Manhole is shown in the Figure next page.



Electrode Resistance:

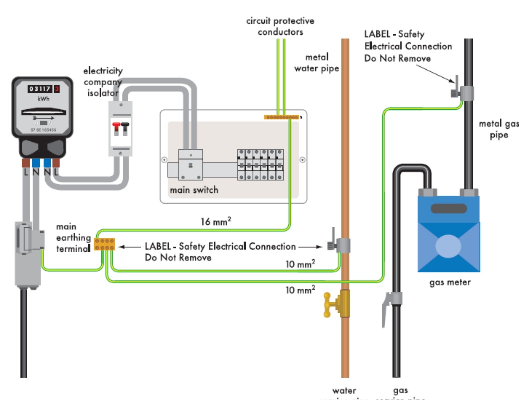
The electrode resistance depends on the length and cross sectional area of the electrode, number of electrodes and connection's configuration, and also the type of soil. Table # 3 below shows typical resistivity values in ohm-meter for different soil types. The resistivity is a measure of the resistance between the opposite sides of a cube of soil with a side dimension of 1 meter.

Table # 3: *The Resistivity of Different Soil Types in Ohm-meter*

Type	Ohm-m
Garden Soil	5 to 50
Clay	10 to 100
Sand	250 to 500
Rock	1,000 to 10,000

The resistivity may be reduced by:

1. Moisturizing the soil
2. Addition of earthing powder, some mineral compounds, coal, Ferrous or iron powder, salts, Magnesium Sulfate, etc…
3. Connecting more than one electrode in parallel or in a ring configuration enhances the earthing. The distance between electrodes must be at least twice the electrode length.
4. Earthing is enhanced by bonding earth conductors to gas, oil, water pipes, and structural steel works (this method should be supplementary).



Earthing Systems:

The following letters are used in earthing systems according to IEC and IEE regulations:

T: Terre (a French word for Earth); direct connection to Earth

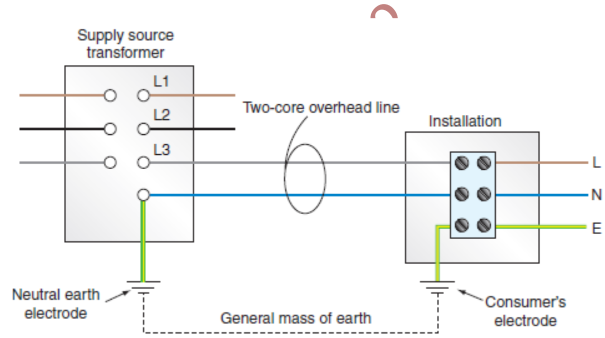
N: Neutral

C: Combined

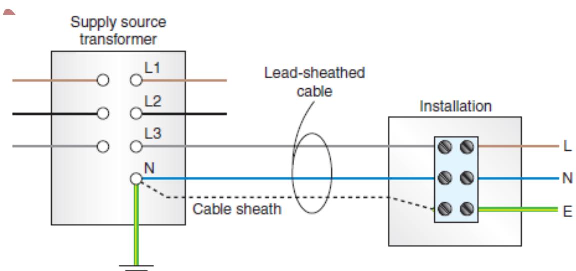
S: Separate

Classification of Earthing Systems:

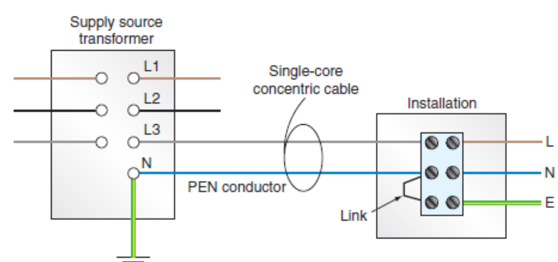
1) A **'TT System'**: The Star or the Neutral point of the supply (secondary of distribution transformer) is directly connected to earth, and the earthing of consumer's installations is directly connected to earth. The mass of the earth is the return path (problems with earth impedance). *This system is implemented in rural areas, and also in JDECo.*

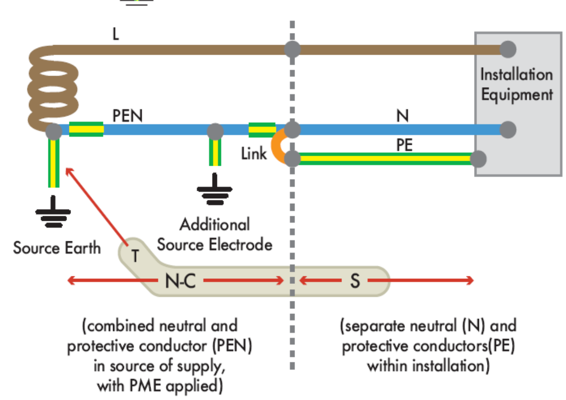


2) A **'TN-S System'**: The Star (Neutral) point of the supply transformer is connected to earth. The outer metallic sheaths of the distribution cable, and the service cable, are connected to a Star point. Hence, there are separate (S) metallic earth and neutral conductors. It is more expensive! *This system is implemented in older homes in the UK, and also in Nablus electricity network!*

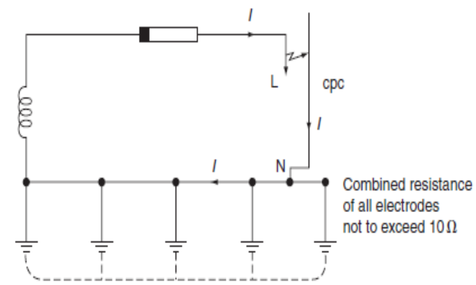


3) A **'TN-C-S System'**: is also known as Protective Multiple Earthing (PME). The neutral (Star) point is connected to earth and to the metal sheaths of distribution and service cables. The outer cable sheath is used as a neutral conductor; i.e. combined (C) earth and neutral (Protective Earth Neutral (PEN)). However, inside consumer's premises, the system has separate (S) earth and neutral conductors. *Implemented in most modern homes in UK and Europe*.



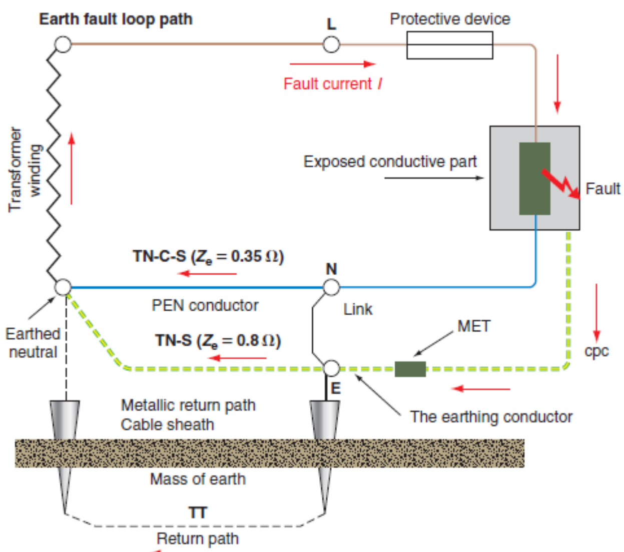


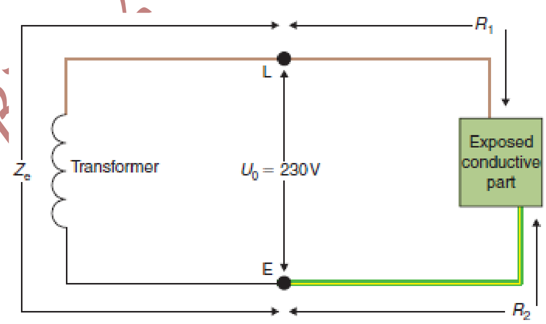
In TN-C-S or PME system, the neutral is earthed at many points (multiple) across its length to keep it at earth potential. Otherwise, a fault to Neutral in one installation could cause a shock risk in all the other installations connected to that system.



Earth Fault Loop Impedance:

The speed of operation of the protection is important and depends on the magnitude of fault current, which in turn will depend on the impedance of the earth fault loop path. The Figures below show the circuit diagram of a fault at one of the phases; the equivalent circuit is shown in the right figure.





The total loop impedance (Zs):

$$Z_s = Z_e + R_1 + R_2$$

Where, Z_e is the impedance of external installations; transformer, distribution and service cables

R_1 is the resistance of the phase conductor

R_2 is the resistance of the Circuit Protective Conductor (CPC)

The fault current, I:

$$I = V_{oc}/Z_s \quad ;$$

Where, V_{oc}: open circuit voltage, 220V-230V

Determining the Value of the Total Loop Impedance (Z_s):

When a building is still in drawing stage, the impedance of the external installations Z_e can be determined by one of the following methods:

a) From the data (if available) of supply transformer, the main distribution cable and the proposed service cable.

b) By measuring it (using a phase-to-earth loop impedance tester) from the supply intake position of an adjacent building having a service cable of a similar size and length to that proposed.

c) Using the maximum likely values of Z_e accepted by the Electricity Regulating Authorities; for example, the maximum likely values according to IEE regulations are:

For 'TT system' is 21Ω

For 'TN-S system' is 0.8Ω

For 'TN-C-S system' is 0.35Ω

Method '**a)**' is difficult except if detailed data is available, whilst method **c)** may result in pessimistically large cable size. Method '**b)**' will give a closer and more realistic estimation of Z_e.

The value of R_1 and R_2 are determined from tables, which give values of resistance per meter at a given temperature; e.g. 20°C. However, for PVC sheathed cables, the conductor operating temperature is usually 70°C. Thus a factor of 1.2 is used to find the actual values or R_1 and R_2. Table # 4 shows typical values of a copper-conductor resistance of various lengths and cross sectional areas at 20°C.

***Table # 4:** The Resistance in Ohms (Ω) of Copper Conductors at* 20°C

CSA (mm^2)	Length (m)									
	5	10	15	20	25	30	35	40	45	50
1	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.82	0.9
1.5	0.06	0.12	0.18	0.24	0.3	0.36	0.43	0.48	0.55	0.6
2.5	0.04	0.07	0.11	0.15	0.19	0.22	0.26	0.03	0.33	0.37
4	0.023	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.21	0.23
6	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.13	0.14	0.16
10	0.01	0.02	0.03	0.04	0.05	0.06	0.063	0.07	0.08	0.09
16	0.006	0.01	0.02	0.023	0.03	0.034	0.04	0.05	0.05	0.06
25	0.004	0.007	0.01	0.015	0.02	0.022	0.026	0.03	0.033	0.04
35	0.003	0.005	0.008	0.01	0.013	0.016	0.019	0.02	0.024	0.03

The selection of Circuit Protective Conductor (CPC) cross sectional area depends on the area of the phase conductor and is usually chosen as shown in Table # 5 (according to IEE Regulations):

Table # 5: *CPC Cross Sectional Area Compared to That of Phase Conductor*

Phase Conductor Cross Sectional Area (mm^2)	CPC Cross Sectional Area (mm^2)
$A_{Ph} < 16$	$A_{cpc} = A_{Ph}$
$16 < A_{Ph} < 35$	$A_{cpc} = 16$
$35 < A_{Ph}$	$A_{cpc} = A_{Ph}/2$

Notes:

- The neutral conductor cross sectional area is almost the same as that of the CPC.
- The protection (Earth Leakage or Residual Current Device) should have a rated residual current (I_n) not exceeding 30mA and an operating time not exceeding 40 ms at 5 I_n.
- The product of the electrode resistance and the operating current of EL or RCD should not exceed 50V.
- The fault current should operate the Earth Leakage or Residual Current Device (EL or RCD) within appropriate time.
- The main switch gears (Distribution Board (DB)) should be accessible at all times.

PART VII

Faults, Protection and Protective Devices

1) Faults and Protection

I) Protection Against an Electric Shock

The electric shock may be received by a direct contact or indirect contact with live parts.

I.a) Protection Against Direct Contact

Direct Contact: the contact of a person or livestock with live parts, which may result in an electric shock.

- The live parts must not be accessible to touch by persons and livestock.

Methods of Minimizing the Danger of Direct Contact:

1) Covering the live part/s by insulation, which can only be removed by destruction; e.g. cable insulation.

2) Placing the live part/s behind a barrier or an enclosure locked with a key or screws.

3) Placing obstacles to prevent unintentional approach to/or contact with live parts. This method must only be used where skilled persons are working.

4) Placing out of Arms' reach: for example, the high level of the bare conductors of travelling cranes.

5) By using a Residual Current Device (RCD) or Earth Leakage (EL): this is not permitted as the sole means of protection; also one of the other methods should be applied.

- The RCD has a rated residual operating current ($I_{\Delta n}$) $\leq$ 30mA, and an operating time not exceeding 40ms at 150mA.
- Note that Residual Current Circuit Breaker (RCCB), Residual Circuit Breaker (RCB), Residual Current Device (RCD), or Earth Leakage (EL) are all names of the same device.

I.b)Protection Against Indirect Contact

Indirect Contact: the contact of persons or livestock with exposed conductive part(s) made live by a fault.

Methods of Protection Against Indirect Contact:

1) Earthed Equipotential Bonding

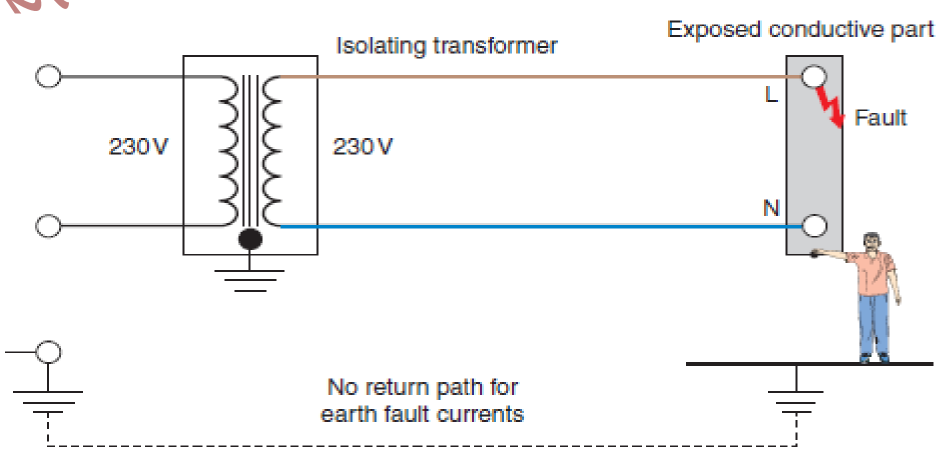
- All metallic frames or parts of appliances must be connected to ground and also RCD(s) must be used.
- The fault loop impedance Z_s (= $Z_e + R_1 + R_2$) must be very low (though it depends on climatic conditions; wet or dry).
- For TT system: the product of the operating current of the RCD or EL and the loop impedance (Z_s) should not exceed **50V**.

2) Non-Conducting Location

- It is the area in which the floor, walls, and ceiling are insulated.
- In such an area, there must be no earth conductors; also the socket outlets must not have earth connection.
- However, it must not be possible to touch two conductive parts, simultaneously.

3) Electrical Separation

- This method relies on a supply from a safety source such as isolating transformer, which has no earth connection on the secondary side, as shown in the Figure below.
- However, no an inadvertent connection to earth or interconnection with other circuits must be made.



II) Protection Against Over-Current:

Over-current is any current greater than the rated current of a circuit. It may damage circuit conductors or equipments. Over-current occurs either by:

II.A) Overload:

Overload currents are currents occurring in a healthy circuit, which are greater than the rated values. They are caused by faulty appliances or by surges due to starting motors. Circuit Breakers, Fuses, or Overload heaters and relays may be used for protection against overload currents.

II.B) Short Circuit:

A short circuit current is the current that flows when a "dead short" occurs between live conductors (phase to neutral for single and three phase systems, or phase to phase in a three phase system). When a short circuit occurs, the current may, for a fraction of a second, reach hundreds or even thousands of Amperes.

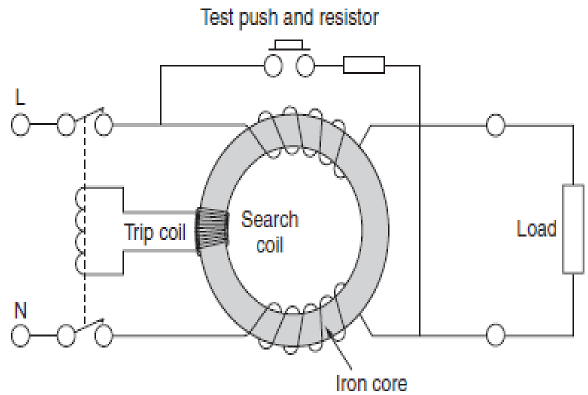
Fuses, Circuit Breakers (CBs), or Miniature Circuit Breakers (MCBs) are used for protection against over-currents (overload or short-circuit currents).

2) Protective Devices

2.1) Residual Current Device (RCD) or Earth leakage (EL)

It is also known as Residual Current Circuit Breaker (RCCB) or Residual Current Breaker (RCB). A photo of a single phase RCD is shown in the left Figure below, whilst the right Figure below shows a three-phase RCD.

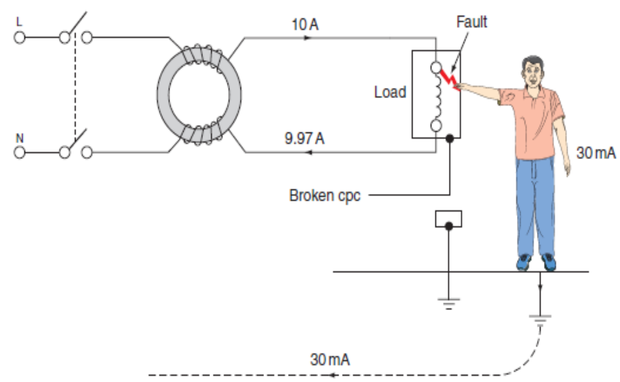
The construction of a single–phase RCD is shown in the Figure next. It has the phase and the neutral connected directly to and out of it. It detects any leakage current by comparing the current in the phase with that in the neutral. Typically, it operates when the difference between both currents (called residual operating current, $\mathbf{I_{\Delta n}}$) exceeds 30mA. The RCD operates in not more than 40ms at a fault current of 150mA. It has a Test button **[T]** to have the functionally of the device checked periodically.



Principle of Operation of an RCD

a) In a healthy circuit the same current passes through the phase coil, the load, and back through the neutral coil. Hence the magnetic effects of phase and neutral currents cancel out.

b) In a faulty circuit, either a phase to earth or a neutral to earth fault, the phase and the neutral currents are no longer equal (they are out-of-balance). Therefore, a residual magnetism is produced in the core, which induces a voltage in the search coil, which in turn drives a current through the trip coil, causing operation of the tripping mechanism.



- In some RCDs, out-of balance current as low as 5mA to 30mA will be detected.
- The Test button creates an out-of-balance condition, which operates (trips) the RCD. It is used to check whether the device is in working order or not.
- Note that the **phase to neutral fault** appears as a load, and hence the RCD **will not operate** for this fault.

The three-phase RCD has four inputs and four outputs. The four inputs are the three phase lines and the Neutral, whilst the four outputs are the three phase load terminals and the Neutral. It compares the current sum in the three lines (phases) with the value of the Neutral current. If the sum of the currents in the three lines is equal to the Neutral current, no fault is recorded. If there is a difference between the current sum in the three lines and the Neutral current, this difference or residual current will be detected using a magnetic field mechanism. Besides, when the difference exceeds a threshold value (30mA, 100mA or 300mA …), the RCD will trip isolating the main source from the load, and consequently preventing more damage to the system or Shock Risks.

Nuisance Tripping:

Certain appliances such as cookers, water heaters, and freezers tend to have, by the nature of their construction and use, some leakage currents to earth. This may cause the operation of an RCD protecting an entire installation. Sometimes this problem is also faced in particular factories.

This problem (Nuisance tipping) can be overcome by:

1. Using split-load consumer units, where socket outlet circuits are protected by a 30mA RCD, leaving all other circuits controlled by a normal main switch, which disconnects them within 0.4s in the case of an earth fault.
2. A better method, especially in TT systems, is the use of 100mA RCD for protecting circuits other than socket outlets.
3. Modern development in MCB and RCD make it easy to protect any individual circuit with a combined MCB/RCD device ➔ Hence, no need for split–load boards.

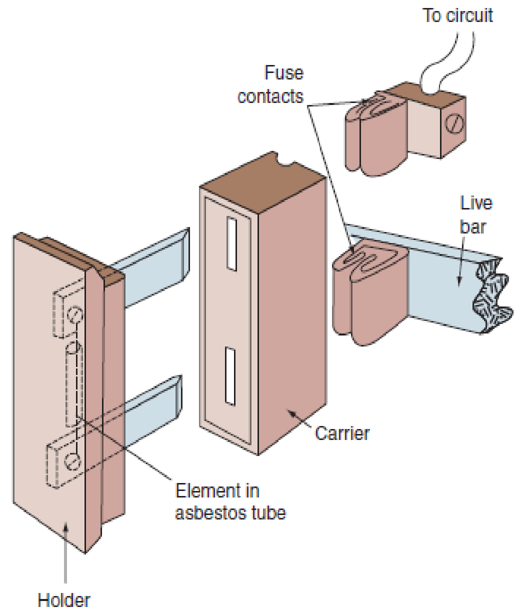
2.2) Fuses:

A Fuse: is a device which carries a metal element, usually tinned Copper, that will melt and break the circuit when an excessive current flows; it acts as a sacrificial device to provide over-current protection. Thus, it forms the weakest link in a circuit and protects the circuit conductors from damage. There are many different types, ratings and sizes of Fuses.

Fuses Types:

- **A)** Rewirable (Renewable) or semi-enclosed Fuse
- **B)** Cartridge Fuse and Fuse link
- **C)** High-Rupturing-Capacity Fuse

2.2.A.) Rewirable (Renewable) Fuse:



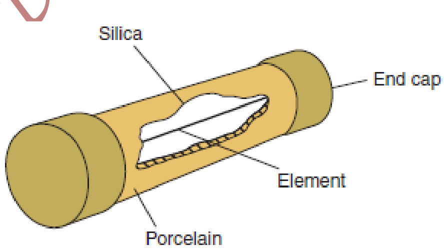
- It is cheap and easy to repair, which makes it very popular in domestic Installations.
- It consists of a Fuse holder, a Fuse element, and a Fuse carrier. The holder and carrier are made of Porcelain or Bakelite (An early Plastic material). The Figure next shows a typical Rewirable Fuse assembly.
- The circuit for which this type of Fuse is designed has a color code marked on the Fuse holder as follows: Green: 45A, Red: 30A, Yellow: 20A, Blue: 15A, and White: 5A.
- This type of Fuses is slow and is not accurate.

Disadvantages of Rewirable Fuses:

1. Wrong size of Fuse wire (element) may be used when it is repaired.
2. The element may become weak after long usage and may break under normal conditions.
3. Normal starting current surges (of motors) are seen by the Fuse as overload, and will, therefore, break the circuit.
4. The Fuse holder and carrier may become damaged as a result of arcing in the event of a heavy overload or short circuit.

2.2.B.) Cartridge Fuse

- It consists of a porcelain or glass tube with metal and caps to which the element is attached.
- The Fuse is filled with Silica. The left Figure below shows the main components of a Cartridge Fuse, whilst the right Figure shows samples of this type of Fuse.

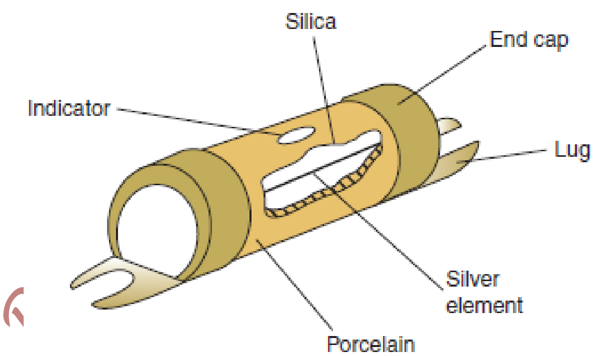


- These Fuses are found in modern plug tops, some Distribution Boards, and equipments.
- They are more expensive to replace!

Advantages of Cartridge Fuses over Rewirable Fuses:

- **a)** They do not deteriorate.
- **b)** They are accurate in breaking at rated values.
- **c)** They do not arc when interrupting faults.

2.2.C) High-Rupturing Capacity (HRC) Fuse



- It is a sophisticated variation of the cartridge Fuse and is normally found protecting motor circuits and industrial installations.
- It consists of a porcelain body filled with Silica, a Silver element, lug type and caps. Silica quenches the arc and prevents any restriking across the element gaps. Silica also changes color from blue to pink when wet; replacement is needed.
- It has an indicating element which shows when the Fuse has blown.
- It is very fast acting and can discriminate between a starting surge current and an over load current.

2.3) Miniature Circuit Breaker (MCB)

- It is connected in series with the line. It protects the circuit against overload and short circuit currents.
- The Nominal current rating (**I_n**) is defined as the current that can be carried indefinitely by the device.
- A CB disconnects the circuit if the current is greater than the rated value by a certain factor (Fusing Factor).
- A Miniature Circuit Breaker (MCB) is a term used to describe a Circuit Breaker (CB), whose voltage rating is less than 1000V, or/and current rating is less than 100A.

- The commonly-available preferred values for the Nominal current ratings are: 6A, 8A, 10A, 13A, 16A, 20A, 25A, 32A, 40A, 50A, 63A, 80A, 100A. The Nominal current rating is marked clearly on the MCB housing.

A Three-phase Circuit Breaker has three inputs and three outputs. The three inputs are the three phase lines, whilst the three outputs are the three phase feeders or load terminals. Some breakers have a common node for the neutral line. It operates if the current in any line exceeded the pre-set value; the breaker will interrupt the current flow and the source will be isolated from the load.

Miniature Circuit Breakers (MCBs) differ according to their purpose, rating and functionality. In general, **MCBs have two elements**:

1. A **thermal (bimetallic)** mechanism for overload protection
2. An **electromagnetic** mechanism for short circuit protection

Advantages of MCBs compared to Fuses:

a. They can be rest after being operated.
b. They are very accurate (tripping current) and fast. Hence, they provide a high degree of discrimination.

The protective device (Fuse or MCB) is characterized a Fusing Factor, a Nominal Current Rating (**I_n**), and an Operating Current (**I_2**).

Fusing Factor (FF):

It is a measure of the circuit breaking or fusing performance of the protective devices. It is a figure when multiplied by the Nominal current rating will indicate the Operating current value. Typical values of Fusing Factor for Fuses and MCBs are listed in Table # 1. Thus, the Fusing Factor is defined as:

$$Fusing\ Factor\ (FF) = \frac{Operating\ Current}{Nominal\ Current} = \frac{I_2}{I_n}$$

Nominal Current Rating (I_n): is the maximum current which a protective device (a Fuse or an MCB) can sustain (carry indefinitely) without blowing (or tripping).

Operating Current (I_2): is the minimum current causing a Fuse to blow or a Circuit Breaker to trip.

Example # 1: A 5A Fuse blows only when a 9A current flows, what is the Fusing Factor?

Solution: $Fusing\ Factor\ (FF) = \frac{Operating\ Current}{Nominal\ Current} = \frac{I_2}{I_n}$

$$FF = \frac{9}{5} = 1.8$$

Table # 1: *Typical Values of Fusing Factor for Fuses and MCBs*

Protective Device Type	Fusing Factor
Rewirable Fuse	1.8
Cartridge Fuse	1.25 to 1.75
HRC Fuse	1.25 (maximum)
Miniature Circuit Breakers (MCBs)	1.5 (maximum)

In general, if not given, a Fusing Factor of 1.45 is assumed.

Breaking Capacity of Fuses and Miniature Circuit Breakers

When a short circuit occurs, the current may for a fraction of a second, reach hundreds or even thousands of Amperes. The protective device must be able to break or make the high (short circuit) current without damage to its surroundings by arcing, overheating or scattering of hot particles. According to IEC, the MCB is assigned I_{cu} (for industrial) or I_{cn} (for domestic) to indicate the rated ultimate short circuit breaking capacity, which is normally given in kA_{rms}. For example, according to British standards, the breaking capacity of MCBs is indicated by an “M” number; i.e. M3-3KA, M6-6KA, M9-9KA; in other regulations it is given by a number only; e.g. 6000.

- In high current three-phase Circuit Breakers, the breaking capacity could reach hundreds of thousands of Amperes.
- In some types of Fuses and Circuit Breakers, the breaking capacity is in the range of hundreds of MVA; e.g. 750MVA, or even much higher.

Fuse and Miniature Circuit Breaker Operation:

Recall the definition of:

The Nominal Current Rating (I_n): the value of current that can be carried indefinitely by the protective device.

The Operating Current (I_2): the value of current that will cause operation of the protective device ($I_2 > I_n$).

$$\boldsymbol{I_2 = Fusing\ Factor\ \times I_n}$$

Typically, the Fusing Factor for Fuses and MCBs ~ 1.45

Coordination:

IEE Regulations require coordination between conductors and protection when an over-current (over load or short circuit) occurs by taking into account the following points:

1. I_n is greater than or equal to Design current of the circuit (I_b); ($I_n > I_b$)
2. I_n is less than or equal to the lowest Current-Carrying Capacity (I_z) of any conductor ($\boldsymbol{I_n \le I_z}$)
3. The operating current of the device (I_2) is less than or equal to $1.45I_z$ ($\boldsymbol{I_2 \le 1.45I_z}$)

These conditions ($\boldsymbol{I_b \le I_n \le I_z\ and\ I_2 \le 1.45I_z}$) will ensure that the cable insulation is undamaged when an over-current (overload or short circuit) occurs.

Example # 2: The Nominal current (I_n) of a protective device is 10A, the Fusing Factor is 1.45 and the cable current-carrying capacity (I_z) is also 10A.

a) Does the design comply with IEE Regulations?

b) If a Rewirable Fuse was used with a Fusing Factor of 2, then what would be its Nominal Current to make the design comply with IEE Regulations?

Solution:

a) Since I_n= 10A = I_z, then Condition # 2 is satisfied.

Since the Fusing Factor is 1.45, then the Operating Current of the device is:

$I_2 = 1.45I_n = 14.5A$, which equals 1.45X cable rating ($\boldsymbol{1.45I_z}$); Condition # 3 is satisfied.

∴ Since no information is given about the circuit Design Current, the design complies with IEE Regulations.

b) To satisfy Condition # 3, the Operating current of the Fuse (I_2) should be less than or equal to 1.45Xcable rating; $I_2 = 14.5A$

But, $$\boldsymbol{I_2 = Fusing\ FactorX\ I_n}$$

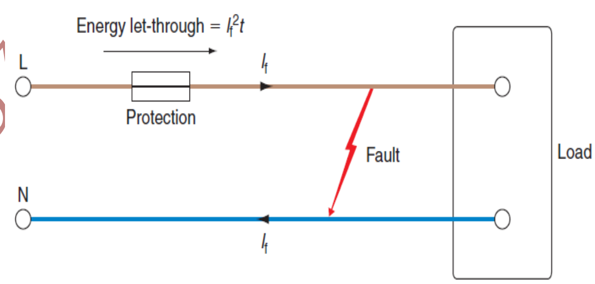
$$I_n = \frac{14.5}{2} = 7.25A$$

∴ Choose the Nominal Current of the Fuse to be 7.25A.

With I_n = 7.25A, which is less than I_z (=10A), Condition # 2 is also satisfied; the design is in compliance with IEE Regulations!

Operation of a Fuse or an MCB under a Short Circuit

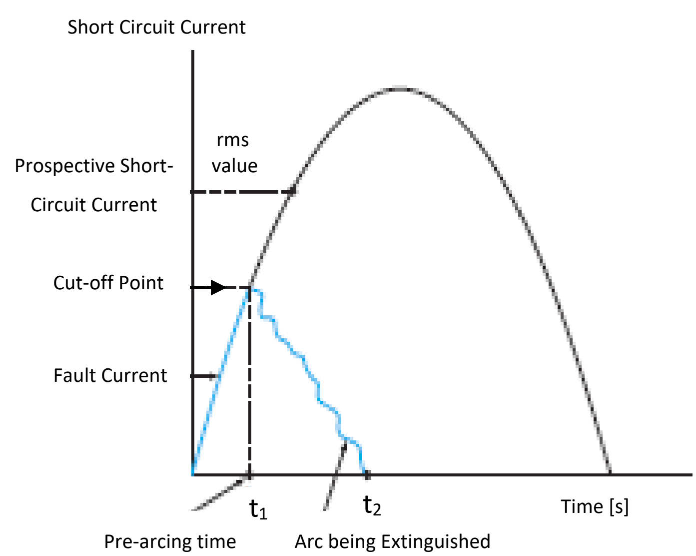
The current increases during a short circuit as shown in the Figure next (during half a cycle).



The prospective short circuit current is the rms value of the current = $\frac{I_p}{\sqrt{2}}$; I_p is the maximum current.

The Pre-arcing time (t_1): is the time taken to reach cut-off point and interrupt the short circuit current, and an Arc is formed.

- After the current has been cut off, it falls to zero as the Arc is being extinguished.



The Total Disconnection time (t_2): is the total time taken to disconnect the fault.

Pre-arcing Let-through Energy $(I_f{}^2\, t_1)$: is the energy passing through the protective device to the load during t_1(I_f the short circuit current in Amperes).

The Total Let-through Energy $(I_f{}^2 t_2)$: is the total energy from start of a fault to disconnection of the fault.

- The type of a cable and its cross sectional area dictate the maximum disconnection time of a fault.
- For faults up to 5s duration, the Total Let-through Energy must be less than the Heat Energy a cable withstands;

$$I_f^{\,2}\, t \le k^2 A^2 \,,$$

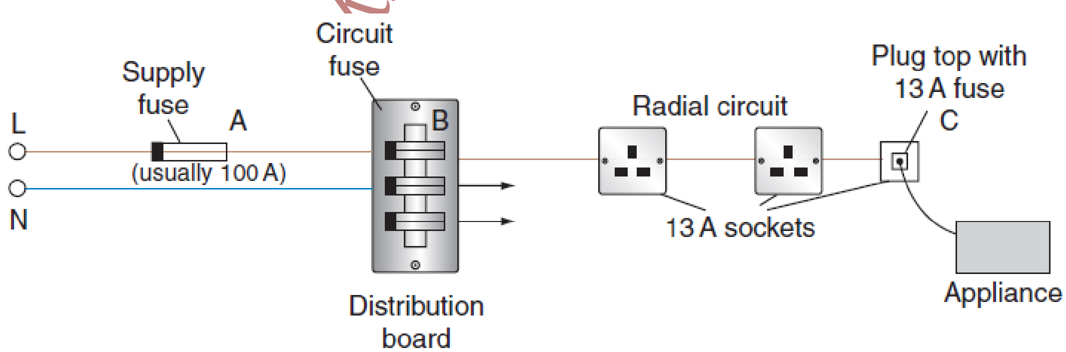
The maximum disconnection time in seconds is:

$$t = \frac{k^2 A^2}{I_f^2}$$

Where, ***k*** is a factor which depends on cable's material, temperature and properties and can be calculated or obtained from tables, whilst ***A*** is the cross sectional area of cable [mm^2].

Discrimination:

Where several protective devices (Fuses or Circuit Breakers) are connected in series at the various levels of a power distribution system, it is desirable to blow (trip) only the Fuse (or other protective device) electrically closest to the fault; in the Figure below Fuse 'C' should blow not 'B' nor 'A'.



Discrimination: is the arrangement of protective devices to protect the correct part of the circuit.

Discrimination between Fuses (or protective device) is achieved if the Total Let-through Energy of the minor Fuse (or protective device) does not exceed the Pre-arcing Let-through Energy of the major Fuse (or protective device). Table # 2 shows the I_f^2t Energy of Fuses.

Inspecting Table # 2 yields:

- A 2A Fuse will discriminate with a 4A Fuse
- A 4A Fuse will discriminate with a 6A Fuse
- A 6A Fuse will **NOT** discriminate with a 10A Fuse
- A 10A Fuse will discriminate with a 16A Fuse

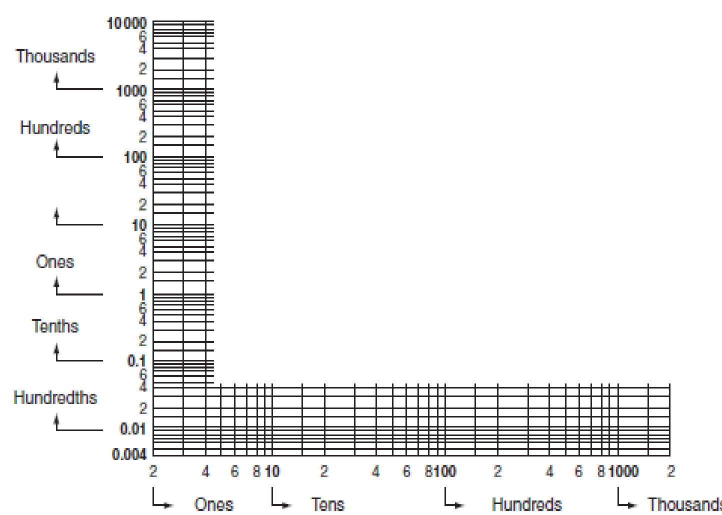
All other Fuses will not discriminate with the next highest Fuse, and in some cases, several sizes higher are needed; for example, a 250A Fuse will only discriminate with a 400A Fuse.

Table # 2: I_f^2t Energy of Fuses

Rating (A)	I_f^2t Pre-arcing	I_f^2t Total at 400 V
2	0.9	1.7
4	4	12
6	16	59
10	56	170
16	190	580
20	310	810
25	630	1700
32	1200	2800
40	2000	6000
50	3600	11000
63	6500	14000
80	13000	36000
100	24000	66000
125	34000	120000
160	80000	260000
200	140000	400000
250	230000	560000
315	360000	920000
350	550000	1300000
400	800000	2300000
450	700000	1400000
500	900000	1800000
630	2200000	4500000
700	2500000	5000000
800	4300000	10000000

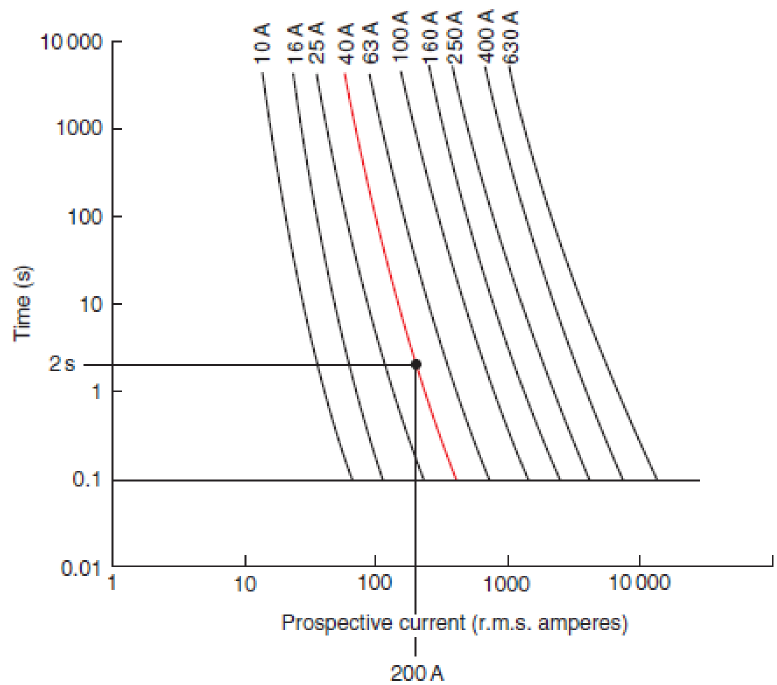
Time-Current Characteristic of MCB and Fuses

The time-current curves describe the disconnection time of a Fuse or a Circuit Breaker versus the fault current. Since they cover a wide time scale (e.g. 0.004s to 10000s) and a wide range of currents (e.g. 2A to 1200A), it is difficult to draw the scale on equal divisions. Therefore, a logarithmic (log-log) scale is used, as shown in the Figure next.



Time-Current Characteristic of Fuses

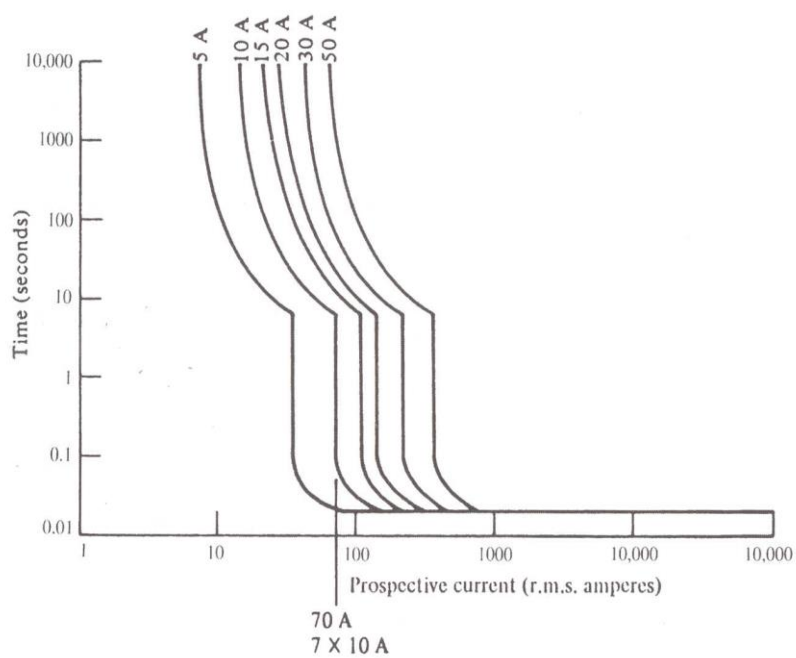
- An example of time-current curves for Fuses is shown in the Figure next.
- For example, A 200A fault current causes a 40A-Fuse to disconnect in 2s.



Time-Current Characteristic of MCB

The time-current curves of many MCB consist of two parts, as shown in the Figure next. That is because MCBs provide protection against overload and short circuit currents. Each of which is performed by a different part of the MCB.

- The overload current is dealt with by a bimetallic mechanism.
- The short circuit current is dealt with by an electromagnetic mechanism.
- For disconnection times less than 20ms the manufacturer should be consulted.



Miniature Circuit Breaker Classifications:

According to IEC regulations, the Miniature Circuit Breaker (MCB) class determines the value of overload current compared to Nominal (rated) current to operate instantaneously. The MCB is labeled with the Nominal (rated) current in Amperes, but without the unit symbol "A". Instead, the Ampere figure is preceded by a letter "B", "C" or "D" that indicates the instantaneous (operating) tripping current, that is the minimum value of current that causes the MCB to trip without intentional time delay (i.e., in less than 100 ms), expressed in terms of I_n. Table # 3 lists the classes of MCB against the value of the operating currents according to IEC, whilst Table # 4 lists the classes of MCB against the value of the overload currents according to British Standards.

Table # 3: *Classes of MCB against the Value of the Operating Current According to IEC Regulations*

Class (Type)	Operating (Instantaneous Tripping) current
B	above 3 I_n up to and including 5 I_n
C	above 5 I_n up to and including 10 I_n
D	above 10 I_n up to and including 20 I_n
K	above 8 I_n up to and including 12 I_n For the protection of loads that cause frequent short duration (approximately 400ms to 2s) current peaks in normal operation
Z	above 2 I_n up to and including 3 I_n for periods in the order of tens of seconds. For the protection of loads such as semiconductor devices or measuring circuits using current transformers

Table # 4: *Classes of MCB against the Value of Overload Current According to British Standards*

Class (Type)	$I_{overload}/I_{rated}$
1	4 times
2	7 times
3	10 times
B and C	5 times

Application Categories of Fuses

According to IEC 60269, the application category of Fuses is a two-digit code; e.g. gG:

- The first letter is ***a*** if the Fuse is for **short-circuit protection only**; an *associated* device must provide overload protection.
- The first letter is ***g*** if the Fuse is intended to operate even with currents as low as those that cause it to blow in one hour. These are considered ***general-purpose*** Fuses for protection of wires.

The second letter indicates the type of equipment or system to be protected by the Fuse:

- D – North American time-delay Fuses for motor circuits
- G – General purpose protection of wires and cables
- M – Motors
- N – Conductors sized to North American practice
- PV – Solar Photovoltaic Arrays
- R, S – Rectifiers or Semiconductors
- Tr – Transformers

Any Fuse built according IEC 60269 standard and carrying the same application category (for example, gG or aM) will have similar electrical characteristics, time-current characteristics, power dissipation as any other, even if the Fuses are made in the packages standardized to the earlier national standards. Fuses of the same application category can be substituted for each other provided the voltage rating of the circuit does not exceed the Fuse rating.

PART VIII

Electrical Circuits' Design

Domestic Loadings:

In designing any electric circuit, knowledge of the expected loads is very essential. Typical loadings of domestic apparatus and appliances are listed in Table # 1.

Table # 1: *Typical Loadings of Domestic Appliances*

Appliance	Loading [Watt]
Incandescent Lamps; e.g. Tungsten	25, 40, 60, 75, 100, 150
Fluorescent Lamps	20, 30, 36, 40, 65, 75, 85
Fire and Heaters	500 - 3000
Water Heater	750 - 3000
Dish Washers	3000
Washing Machines	3000
Spin Driers	300 - 500
Tumble Driers	2000 - 3000
Refrigerators	300 - 400
Cookers	6000 - 8000
Portable appliances; e.g. Adopters, Iron, Kettles, Vacuum Cleaners…	10 - 3000

Diversity:

The size of a cable or accessory is not necessarily determined by the total power rating of all the current-consuming devices connected to it; it depends on the **Diversity Factor**.

Diversity Factor:

It is the percentage of the connected load which is likely to be operating at any time. It helps in **reducing the cable size and current demand from mains**; the cable size of the final circuit (closest to the load) is not affected. Also, the distribution board is designed to supply the whole load without applying diversity. Table # 2 represents a guide for Diversity Factor of particular electric circuits.

Table # 2: *A Guide for Diversity Factor of Electric Circuits*

Circuit Type	Percentage Diversity
Lighting	66%
Cooking Appliances	The first 10A of the cooker load + 30% of the remainder (+ 5A if the cooker has a socket outlet)
Instantaneous Water Heaters (showers)	100% of the full load of first and second largest appliances + 25% of full load of remaining appliances
Water-Heaters Thermostatically Controlled	No diversity; stay as they are
Ring and Radial Circuits to Socket-Outlet/s	100% of full load of largest circuit + 40% of full load of all other circuits

Circuits Types

I) Fluorescent and Discharge Lighting Circuits:

- If only the real power rating is known and no information about power factor is given, a factor of 1.8 is used when calculating current ratings; i.e. the power factor is assumed to be 0.555.
- For an inductive load, the switch must be designed to withstand twice the rated current.

II) Water Heaters:

Types: **1)** Large storage type (140 liters)

2) Open Outlets type (10 - 12 liters/minute) used for small quantities of instant hot water

Notes:

a. Heaters over 15 liters/minute are recommended to have their own circuits.

b. Heaters should be connected effectively to ground, and the inlet and outlets pipes must be made of metal.

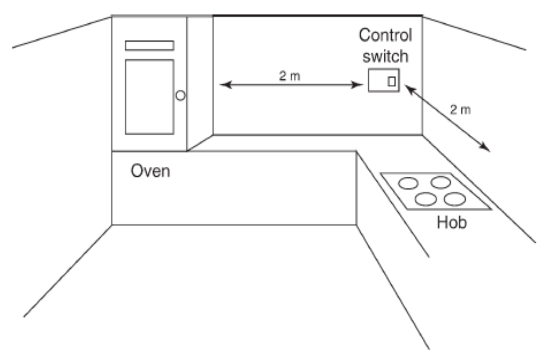
c. The heater must be supplied from a double–pole single-throw switch with indicator lamp.

III) Cooker Circuits:

Hob, Microwave, Oven, Grill, Toaster ...

Notes:

- Diversity is applied to calculate the assumed current demand, as it is rare to have every cooking or heating element working at once.
- All the assumed currents are added together to size **the main incoming tails**.
- If the assumed current demand is in the range 15A $< I' <$ 50A, two or more cooking appliances may be fed from the same circuit.
- Every cooker must have a control switch within 2m. If there is more than one cooker in the same room, one switch is sufficient for two cookers (as shown in the Figure next).



Example # 1:

What is the current rating of an 80W, 230V Fluorescent lamp?

Solution:

Since no value for power factor is given, the power factor is assumed to be 0.555 or a factor of 1.8 is used to calculate the apparent power as:

$$I_b = \frac{Rated\ Power\ (Watt)}{Volts\ \ X\ PF} \qquad \rightarrow \quad I_b = \frac{80}{230} \times 1.8 = 0.63A$$

Example # 2:

For an 8kW, 230V cooker, calculate its assumed demand current using diversity.

Solution:

The rated current is:

$$I_b = \frac{8000}{230} = 35A$$

The assumed demand current after applying diversity is:

$$I' = 10A + 30\% \text{ X } (35 - 10) = 17.5A$$

Note that this current is less than the current rating of $4mm^2$ conductor. However, the size of the cable next to load should be based on the cooker's maximum (rated) current; more than $6mm^2$.

Example # 3:

The full load rating of a 230V cooker is 11.5kW, calculate the assumed demand current using diversity if the cooker circuit has a socket outlet.

Solution:

The rated current (I) is:

$$I_b = \frac{Rated\ Power\ (Watt)}{Volts\ \ X\ PF} \quad \rightarrow \quad I_b = \frac{11.5 \text{ X } 10^3}{230\ (1)} = 50A$$

The assumed current demand is:

$$I' = 10A + 30\%\ (50 - 10) + 5$$

$$= 10 + 12 + 5 = 27A$$

Circuit Design:

- Conductors and the current-carrying components of accessories (switches, Fuses, MCBs, socket outlets and plugs) must be large enough to carry the maximum current, which the connected apparatus can cause to flow, without overheating or being overstressed.
- Conductors and accessories are rated in terms of the current in Amperes.
- This size of a conductor and/or an accessory depends on the Design (rated) Current (I_b).

Design Procedure:

1. Determine the Design (Rated) Current (I_b)
2. Select the Nominal Current Rating (setting) of the protection (I_n)
3. Select relevant Correction Factors (CF_s)
4. Divide I_n by relevant Correction Factors CF_s to give Tabulated Current-Carrying Capacity of the cable (I_t).
5. Choose a cable size that suits (I_t)
6. Check the Cable Voltage Drop (V_C)
7. Check the Shock Risk constraints
8. Check for the Thermal constraints

1. Design (Rated) Current (I_b):

It is the consumption (rated) current of the apparatus in Amperes.

For a single phase load ➔ $I_b = \dfrac{\text{Rated Power }(Watt)}{Vrated\ X\ PF}$

For a three-phase load ➔ $I_b = \dfrac{\text{Rated Power (Watt)}}{\sqrt{3}\ X\ Vline\ X\ PF}$

Where V_{rated} is the rms value of the phase voltage, whilst V_{line} is the rms value of the line-to-line voltage, and PF is the Power Factor.

If the appliance has moving parts (motors), then I_b is divided by the efficiency; for example, for a single phase load:

$$I_b = \frac{\text{Rated Output Power (Watts)}}{Vrated\ X\ PF\ X\ efficiency}$$

Example # 4:

For a 1kW and 230V electric fire, what is the Design Current?

Solution:

$$I_b = \frac{1000}{230} = 4.35\text{A}$$

2. **Nominal Current Rating (Setting) for Protection (I_n):**

   The Nominal Current Rating (Setting) for the protective Device (I_n) is the maximum current, which a protective device (a Fuse or an MCB) can sustain (carry indefinitely) without blowing (or tripping). It is taken from IEC or IEE Regulation tables or from manufacturer charts. However, the following condition must be satisfied:

$$I_n \geq I_b$$

3. **Selection of Correction Factor (CF):**

   The rise in cable temperature due to other influences (aside from current) such as: high Ambient Temperature, cables grouped together closely, uncleared over currents (due to having high values of Fusing Factors), and contact with thermal insulation derate cable current-carrying capacity or conversely increase cable size. The corresponding Correction Factors are: C_a, C_g, C_f, or C_i, respectively.

   These Correction Factors are obtained from tables. However, approximate values of these factors are: $C_a \cong$ 0.87 to 0.97, $C_f \cong 0.725$, $C_i \cong$ 0.89 to 0.55 and $C_i \cong 0.5$ if totally insulated. C_g depends on number and the size ratio of grouped cables within a conduit.

4. **The Tabulated Current-Carrying Capacity of a Cable(I_t):**

   It is obtained by dividing I_n by the relevant Correction Factors;

$$I_t \geq \frac{I_n}{Relevant\ CFs};$$

Select $I_n = I_b$ if the circuit is not likely to be overloaded.

5. Voltage Drop:

The Voltage Drop in a cable (V_C) depends on the cable's resistance and length, and the Design Current (I_b). The resistance of copper conductors of various lengths is shown again in Table # 3. However, the Voltage Drop should not exceed 4%; i.e.

- For a single phase system, 220V, the maximum allowed Voltage Drop in the cable, V_C = 8.8V.
- For a three-phase system, 380V, the maximum allowed Voltage Drop in the cable, V_C = 15.2V.

The load voltage at the end of the cable (V_L) then is:

$$V_L = V - V_c$$

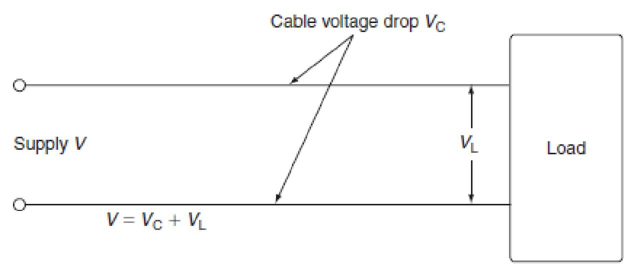


Table # 3: *The Resistance in Ohms (Ω) of Copper Conductors at* 20°c

CSA (mm^2)	Length (m)									
	5	10	15	20	25	30	35	40	45	50
1	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.82	0.9
1.5	0.06	0.12	0.18	0.24	0.3	0.36	0.43	0.48	0.55	0.6
2.5	0.04	0.07	0.11	0.15	0.19	0.22	0.26	0.03	0.33	0.37
4	0.023	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.21	0.23
6	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.13	0.14	0.16
10	0.01	0.02	0.03	0.04	0.05	0.06	0.063	0.07	0.08	0.09
16	0.006	0.01	0.02	0.023	0.03	0.034	0.04	0.05	0.05	0.06
25	0.004	0.007	0.01	0.015	0.02	0.022	0.026	0.03	0.033	0.04
35	0.003	0.005	0.008	0.01	0.013	0.016	0.019	0.02	0.024	0.03

Example # 5:

a) What is the Voltage Drop in a circuit supplied by a two-core copper cable of *16mm²* and 25m long, if the Design Current is 33A?

b) What is the maximum allowed length of the *16mm²* cable for the same load?

Solution: **a)** From Table # 3, the resistance of 25m of *16mm²* conductor is 0.03Ω, therefore the Voltage Drop in the cable (phase and neutral conductors) is:

$$V_C = 2\ X\ 0.03\ X\ 33 = 1.98V$$

b) Since the maximum allowed Voltage Drop (V_C) is 8.8V, then:

$$V_C = 8.8 = 2\ X\ R_C\ X\ 33$$

R_C = 0.1333Ω

From Table # 3, the $16mm^2$ conductor resistance is approximately 0.001Ω/m, therefore, the length of the cable is:

$$\therefore\ L = \frac{R_C}{\frac{Ohm}{meter}}$$

$$L = \frac{0.1333}{0.001} = 133.3m;$$

Other constraints must be checked, as they may not permit such a length!

6. Shock Risk:

The actual loop impedance Z_s ($Z_s = Z_e + R_1 + R_2$) should not exceed the allowed values in IEC tables (or any other adopted Regulations), to ensure that circuits feeding socket outlets and bathrooms (portable appliances) will be disconnected in the event of an earth fault in **less than 0.4s**, and that fixed equipments will be disconnected in **less than 5s**.

- These times are based on the probable chances of someone being in contact with exposed conductive part(s) at the precise moment that a fault develops.
- Besides, these times do not indicate the duration that a person can be in contact with a fault.

7. Thermal Constraints:

The size of Circuit Protective Conductor (CPC) is selected according to the adopted Regulations, or using an Adiabatic Equation. For Example, IEE Regulation recommendations relate the phase and CPC conductor sizes as shown in Table # 4.

Table # 4: *CPC Cross Sectional Area Compared to that of Phase Conductor*

Phase Conductor Cross Sectional Area (mm^2)	**CPC Cross Sectional Area (mm^2)**
$A_{Ph} < 16$	$A_{cpc} = A_{Ph}$
$16 < A_{Ph} < 35$	$A_{cpc} = 16$
$35 < A_{Ph}$	$A_{cpc} = A_{Ph}/2$

Using adiabatic equation, the minimum CPC cross sectional area ***A*** is:

$$\boldsymbol{A = \frac{\sqrt{I^2\, t}}{k}}$$

Where, **I**: the earth fault current and

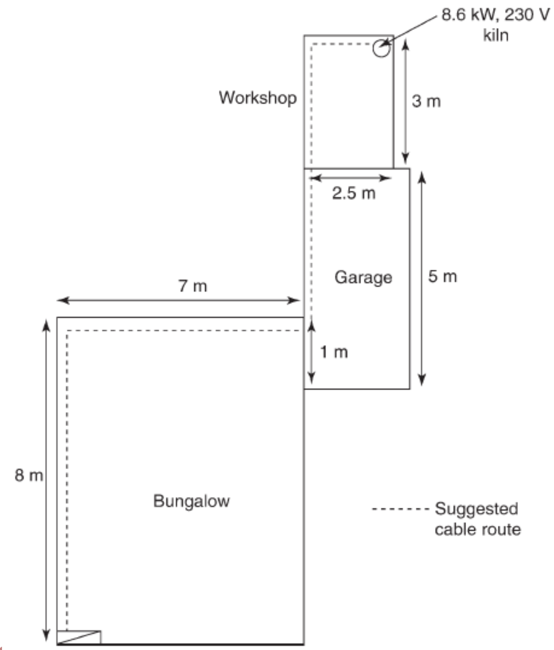
$$\boldsymbol{I = \frac{Voc}{Z_s}}$$

t: is the disconnection time of a Fuse or an MCB (can be obtained from corresponding curves)

k: is a factor obtained from Regulations' tables and is dependent on the cable's material, temperature, properties and insulation.

A Worked Design Example (Extra Reading):

A consumer lives in bungalow with a detached garage and workshop, a site drawing of which is shown in the Figure next.



The building method is traditional British brick and timber. The mains intake position is at high level and comprises an 80A main Fuse, an 80A rated kWH meter, and a six-way 80A consumer unit housing MCBs as follows:

Ring socket circuit	30A
Lighting circuit	5A
Immersion heater circuit	15A
Cooker circuit	30A
Shower circuit	30A
Spare way	----

The cooker is rated at 30A, with no socket in the cooker unit. The main tails are 16mm^2 double-insulated PVC, with a 6mm^2 earthing conductor.

The earthing system is TN-S with external loop impedance Z_e of 0.3Ω. The prospective short circuit current at the origin has been measured as 800A.

The roof space is insulated to full depth of the ceiling joints and the temperature of the roof is not expected to exceed over 40°C.

The consumer wishes to convert the workshop into a pottery room and install an 8.6kW/230V electric Kiln. **The Deign procedure is as follows**:

A- Assessment of General Characteristics

The present maximum demand currents, applying diversity, is:

Ring socket circuit	30A
Lighting circuit (66% of 5A)	3.3A
Immersion heater circuit	15A
Cooker (10A + 30% of 20A)	16A
Shower	30A
Total	**94.3A**

Reference to IEE regulations, the exiting main tails cable is too small (refer to conductors current capacity (Ampacity) tables) and should be uprated. Also, the consumer unit should be capable of carrying the full load of installation without application of diversity. So, the addition of 8.6 kW of load is not possible with the present arrangement.

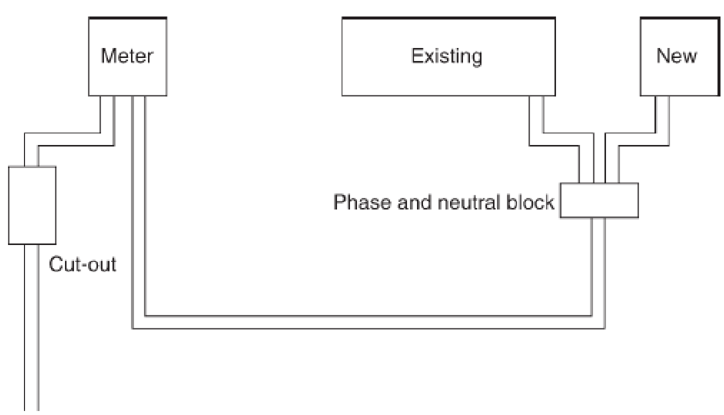
The design current of the Kiln is:

$$I = \frac{8600}{230} = 37.4A \text{ (no diversity is applicable)}$$

The maximum demand current is:

$$I = 94.3 + 37.4A = 134.7A$$

Since the existing arrangement is not satisfactory, it is sensible to disconnect, say, the shower circuit, and supply it and the new Kiln circuit via a new consumer unit as shown in the Figure below.



B) Sizing Main Tails

1) The new load on the existing consumer unit will be the old load minus the shower load:

94.3 – 30 = 64.3A

Reference to conductor current-capacity tables reveals that $16mm^2$ is not okay (use $25mm^2$)!

2) The load on the new consumer unit will be the Kiln plus the shower load:

37.4 + 30 = 67.4A

A $25mm^2$ cable size is needed.

3) The total load is 64.3 + 67.4 = 131.7A ➡ needs a cable of $70mm^2$ for the main tails

4) The earthing conductor size will be $35mm^2$.

C) Sizing the Kiln Circuit Cable

1) Design Current:

$$I_b = \frac{P}{V} = \frac{8600}{230} = 37.4A$$

2) Nominal Current:

The Nominal Current of protective device depends on protective device. According to IEE Regulations:

BS 88: 40A, BS 3036: 45A, BS 1361: 45A, MCB: 50A.

3) Correction Factors:

From Regulation tables:

C_a: 0.87 or 0.94 if the Fuse is BS 3036

C_g: not applicable

C_f: 0.725 if only the Fuse is BS 3036

C_i: 0.5 if the cable is totally surrounded in thermal insulation

4) Tabulated Current-Carrying Capacity of a Cable

The Current-Carrying Capacity depends on protection type and is shown in Table # 5.

Table # 5: *Current-Carrying Capacity of a Cable*

	BS 88 40A	BS 1361 45A	BS 3036 45A	MCB 50A
Surrounded by thermal insulation	40/(0.5 X 0.87) = 92A	45/(0.5 X 0.87) = 103.4A	45/(0.5 X 0.94 X0.725)= 132A	50/(0.95 X 0.87) = 115A
Not touching	40/0.87 = 46A	45/0.87 = 51.7A	45/(0.94 X 0.725) = 66 A	50/0.87 = 57.5A

The cable size is based on the Tabulated Current-Carrying Capacity, as shown in Table # 6 (According to IEE Regulations).

Table # 6: *Cable Size Associated with Protection Type*

	BS 88	BS 1361	BS 3036	MCB
Cable size with thermal insulation	25 mm^2	25 mm^2	35 mm^2	35 mm^2
Cable size without thermal insulation	6 mm^2	10 mm^2	16 mm^2	10 mm^2
Cable size with half thermal insulation	10 mm^2	16 mm^2	25 mm^2	25 mm^2

It is clear that BS 88 Fuse gives the smallest cable size if the cable is kept clear of thermal insulation; i.e. $6mm^2$. However, this value is very optimistic, and a larger cable size is needed!!

5) Voltage Drop:

The length of the cable according to the site drawing is 24.5m.

For a $6mm^2$ cable and 24.5m long the resistance is 0.08Ω (obtained from Table # 3).

⇨ The cable voltage drop is:

$$V_C = 2\ X\ R_C\ X\ I_b = 2\ (0.08)(37.4) = 5.984V$$

To improve the efficiency, use a $10mm^2$ cable;

$$V_C = 2\ X\ R_C\ X\ I_b = 2\ (0.05)(37.4) = 3.74V$$

6) Shock Risk

The CPC associated with a $10mm^2$ cable is $4mm^2$ the total loop impedance is:

$$Z_s = Z_e + \frac{(R_1 + R_2)\ X\ 1\ X\ 1.2}{1000}$$

$$= 0.3 + \frac{6.44\ X\ 24.5\ X\ 1.2}{1000} = 0.489\Omega$$

Notes:

- $R_1 + R_2$ = 6.44Ω, are tabulated values
- 1.2: is the multiplier which takes into account the conductor resistance at its operating temperature.
- The value of Z_s must be compared to the appropriate type of protective recommended according to regulations or standards.

According to IEE regulations, CB must be a type B.

7) Thermal Constraints :

To check whether the $4mm^2$ CPC withstands damage under earth fault conditions, calculate the fault current as:

$$I = \frac{V_{OC}}{Zs}$$

The open circuit voltage (V_{oc}) is taken to be 240V (not 230V),

$$I = \frac{240}{0.489} = 490A$$

The disconnection time for each type of protection is obtained from the relevant curves in IEE regulations as follows:

40A BS 88	0.05s
45A BS 1361	0.18s
50A CB type B	0.01s

From regulations, the factor k = 115 (for a twin cable), applying the adiabatic equation:

$$A = \frac{\sqrt{I^2 t}}{k}$$

For each type of protection, the following minimum sizes of CPC are obtained:

40A BS 88	$0.9mm^2$
45A BS 1361	$1.7mm^2$
50A CB type B	$0.47mm^2$

$4mm^2$ CPC is of adequate size!

PART IX

Instruments, Inspection, and Testing of Electrical Installations

A) Instruments:

In order to fulfill the basic requirements for testing according to any Regulation (IEE, IEC, or National Regulations), the following instruments are needed:

1. A Continuity Tester (low ohms)
2. An Insulation Resistance Tester (high ohms)
3. Proprietary Test Instrument
4. A Loop Impedance Tester
5. A Prospective Short-Circuit Current (PSCC) Tester
6. An RCD Tester
7. An Approved Test Lamp or Voltage Indicator

1. A Continuity Tester

It is a Low-Reading Ohmmeter in the range of 2 – 0.005Ω or even less. A Continuity Tester should have a no-load source voltage of between 4V and 24V, and be capable of delivering an AC or DC short-circuit current of not less than 200mA. It should have a resolution (i.e. a detectable difference in resistance) of at least 0.05mΩ.

Bells, buzzers and simple multimeters will all indicate whether or not a circuit is continuous, but will not show the difference between the resistance of, say, a 10m length of 10.0mm^2 conductor and a 10m length of 1.0mm^2 conductor.

2. An Insulation Resistance Tester

An Insulation Resistance Tester is a High-Reading Ohmmeter (called Megger) measures values ranging from fractions of Mega Ohms up to infinity. It must be capable of delivering 1mA when the required test voltage is applied across the minimum acceptable value of insulation resistance.

Consequently, an instrument selected for use on a low voltage system should be capable of delivering 1mA at 250V across a resistance of 0.25MΩ.

3. A Loop Impedance Tester

It is basically a Special Ohmmeter whose range is 0 – 2000Ω used to measure the impedance of a loop. This instrument functions by **creating**, in effect, **an earth fault for a brief moment**, and is connected to the circuit via a plug or by 'flying leads' connected separately to phase, neutral and earth.

The instrument should only allow an earth fault to exist for a maximum of 40ms and a resolution of 0.01 Ohms is adequate for circuits up to 50A. Above this circuit rating, the Ohmic values become too small to give such an accuracy using a standard instrument and a more specialized equipment may be required.

The Earth Electrode Resistance has any value ranging from fractions of Ohms to hundreds of Ohms, and is measured by using a Special Ohmmeter; either **Proprietary Test Instrument** or a **Loop Impedance Tester**.

4. A PSCC Tester

Its name stands for a Prospective-Short Circuit-Current Tester. It is normally one half of a dual; Loop Impedance/PSCC tester. This instrument measures the Prospective Short Circuit Current (phase-neutral fault current) at the point of measurement using the flying leads. Its current range is 2 – 20kA.

5. An RCD Tester

It is usually connected by the use of a plug, although flying leads are needed for non-socket-outlet circuits. This instrument allows a range of **out-of-balance currents** to flow through the Residual Current Device (RCD) to cause its operation within specified time limits.

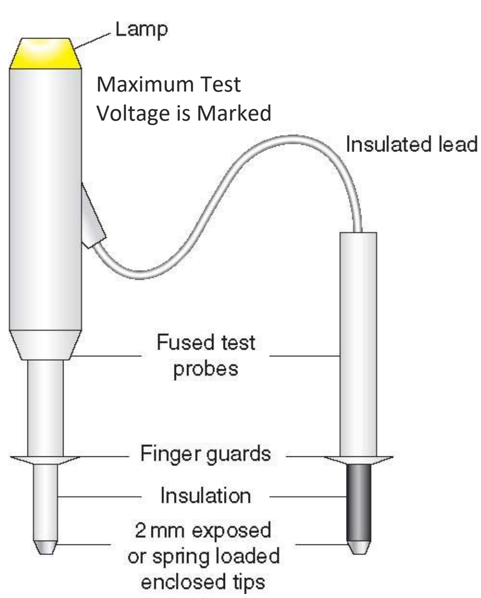
The test instrument should not be operated for longer than 2s and it should have a 10% accuracy across the full range of test currents. The current range of the tester is 5 – 500mA.

6. An Approved Test Lamp or Voltage Indicator

A typical Approved Test Lamp is shown in the Figure below. A flexible cord with a lamp attached is not an approved device, nor for that matter is the 'testascope' or 'neon screw-driver', which encourages the passage of current, at low voltage, through the body!

The Approved Test Lamp has the following characteristics:

- The leads should be adequately insulated and, ideally, fused.
- The leads should be easily distinguished from each other by color.
- The leads should be flexible and sufficiently long for their purpose.
- The probes should incorporate finger barriers to prevent accidental contact with live parts.
- The probes should be insulated and have a maximum of 2mm of exposed metal, but preferably have spring-loaded enclosed tips.



B) Inspection:

Certain information such as General Characteristics', Design procedure, Drawings, Diagrams, Charts and similar information relating to the installation must be available to the verifier.

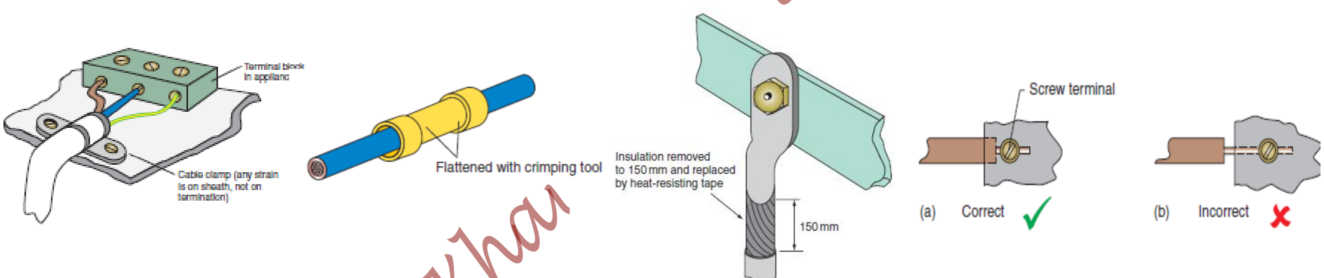
A sequence of inspections must be conducted, prior testing, for any installation; some of these are:

1. Diagrams

Are diagrams, instructions and similar information relating to the installation available?

2. Connection of Conductors

Are terminations electrically and mechanically sound, and whether insulation and sheathing is removed only to a minimum to allow satisfactory termination? **Is there any loose connection?**



3. Identification of Conductors

Are conductors correctly identified in accordance with Regulations and Standards; color, size and type?

4. Labeling

Are all protective devices, switches (where necessary) and terminals of conductors correctly labeled? Is numbering used in Distribution Boards?

5. Routing of Cables

Are cables installed in such a way that account is taken of external influences such as mechanical damage, corrosion, heat, etc.?

6. **Conductor Selection**

Are conductors selected for Current-Carrying Capacity and Voltage Drop in accordance with the design requirements?

7. **Connection of Single Pole Devices**

Are single pole protective and switching devices connected in the live conductor only?

8. **Protection against Shock**

What methods have been used to provide protection against an electric shock?

9. **Isolation and Switching**

Are there correctly located and installed appropriate devices for isolation and switching?

10. **Protective Devices**

Are protective devices, monitoring devices, and meters correctly chosen and set to ensure fault protection against indirect contact and/or overcurrent?

11. **Access**

Are all means of access to switches, switchgears, and equipments adequate?

12. **Notices and Signs**

Are danger notices and warning signs present? For example, warning signs are needed in the case of presence of bare live conductors (Bus-bars or Rizers) or buried underground cables.

13. **Thermal Effects**

Are fire barriers present where required, and protection against thermal effects provided?

14. **Accessories and Equipments**

Are all accessories and equipments correctly connected?

C) Testing:

C.1) Testing Continuity of Protective Conductors

All protective conductors, including main and supplementary protective bonding conductors must be tested for continuity using a Low-Resistance Ohmmeter. Each measured value, should be compared with the relevant value for the length and size of a particular conductor. Such values are shown in Table # 1.

***Table # 1**: Resistance (Ω) of Copper Conductors at 20°C*

CSA (mm^2)	Length (m)									
	5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
1	0.09	0.18	0.27	0.36	0.45	0.54	0.63	0.72	0.82	0.9
1.5	0.06	0.12	0.18	0.24	0.3	0.36	0.43	0.48	0.55	0.6
2.5	0.04	0.07	0.11	0.15	0.19	0.22	0.26	0.03	0.33	0.37
4	0.023	0.05	0.07	0.09	0.12	0.14	0.16	0.18	0.21	0.23
6	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.13	0.14	0.16
10	0.01	0.02	0.03	0.04	0.05	0.06	0.063	0.07	0.08	0.09
16	0.006	0.01	0.02	0.023	0.03	0.034	0.04	0.05	0.05	0.06
25	0.004	0.007	0.01	0.015	0.02	0.022	0.026	0.03	0.033	0.04
35	0.003	0.005	0.008	0.01	0.013	0.016	0.019	0.02	0.024	0.03

Where a supplementary protective bonding conductor has been installed between **simultaneously accessible** exposed and extraneous conductive parts, because circuit disconnection times cannot be met, then the resistance (*R*) of the conductor must be equal to or less than $50/I_a$.

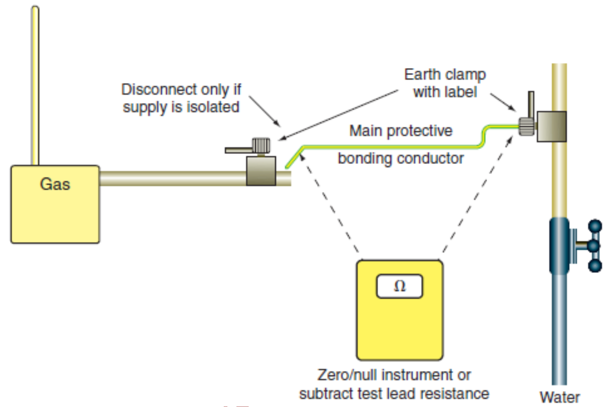
Hence, $R \leq \frac{50}{I_a}$, where 50 is the voltage above which exposed metalwork should not rise, and I_a is the minimum current causing operation of the circuit protective device within 5s.

For example, suppose a 45A BS 3036 Fuse protects a cooker circuit, the disconnection time for the circuit cannot be met, and hence a supplementary bonding conductor has been installed between the cooker case and an adjacent central heating radiator. The *R* of the protective conductor should not be greater than $50/I_a$, and I_a in this case is 145A (obtained from IEE Regulation figures); that is,

$$R = 50/145 = 0.34\Omega$$

Conducting a Continuity Test:

To conduct a test to establish continuity of main or supplementary bonding conductors, just connect the leads from a Low-Resistance Ohmmeter (Continuity Tester) to the ends of the bonding conductor, as shown in the Figure next. One end should be disconnected from its bonding clamp, or else the measurements may include the resistance of parallel paths of other earthed metalworks. Also, remember to zero the instrument first or, if this facility is not available, record the resistance of the test leads so that this value can be subtracted from the test reading later on.



The continuity of Circuit Protective Conductors (CPC's) may be established in the same way, but a second method is preferred, as the results of this second test indicate the value of (R_1 + R_2) for the circuit in question.

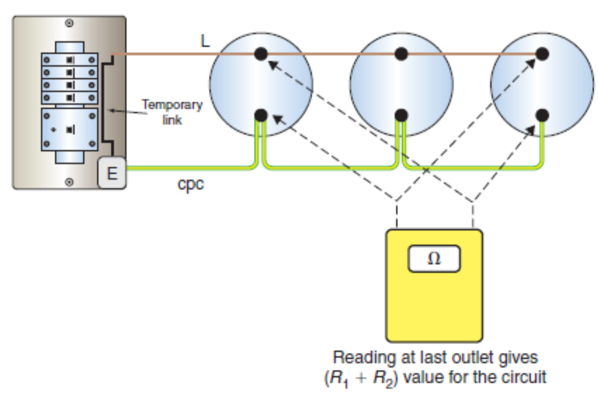
The test is conducted in the following manner (This procedure is shown in the Figure below):

1. Ensure that the installation is disconnected from the supply

2. Temporarily link together the line conductor and CPC of the circuit concerned in the Distribution Board (DB) or consumer unit.

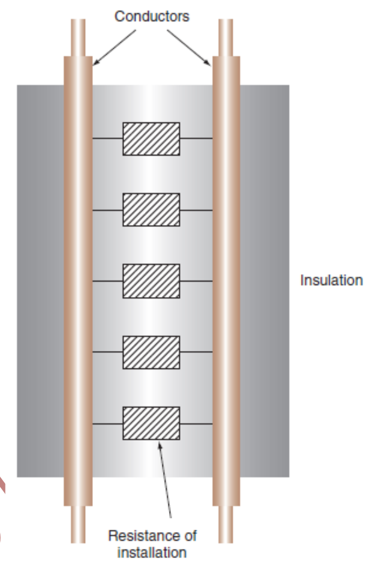
3. Test between line and CPC at **each** outlet in the circuit. A reading indicates continuity.

4. Record the test result obtained at the furthest point in the circuit. This value is (R_1 + R_2) for the circuit.



C.2) Testing Insulation Resistance

This is probably the most used and yet the most abused test among all. Affectionately known as 'meggering', an **Insulation Resistance Test** is performed to ensure that the insulation of conductors, accessories and equipments is in a healthy condition, and will prevent dangerous leakage currents between conductors, as well as between conductors and earth. It also indicates whether any short circuit exists.



Insulation resistance is the resistance measured between conductors and is made up of countless millions of resistances in parallel, as shown in the Figure next.

The more resistances there are in parallel, the **lower** the overall resistance would be, and as a consequence, the longer a cable is, the lower is the insulation resistance. In addition to the fact that almost all installation circuits are also wired in parallel, it becomes apparent that tests on large installations may give, if measured as a whole, pessimistically low values, even if there are no faults.

Under these circumstances, it is usual to break down such large installations into smaller sections, such as floor by floor, distribution circuit by distribution circuit, etc. This also helps to minimize disruption in the case of periodic testing.

The Test Procedure is as follows:

1) Disconnect all items of equipment such as capacitors and indicator lamps as these are likely to give misleading results. Remove any items of equipment likely to be damaged by the test, such as dimmer switches, electronic timers, etc. Remove all lamps and accessories and disconnect fluorescent and discharge fittings. Ensure that the **installation is disconnected from the supply**, all Fuses are in place, and MCB's and switches are in the 'on' position. In some instances it may be impracticable to remove lamps, etc. and in this case the local switch controlling such equipment may be left in the 'off' position.

2) Join together all live conductors of the supply and test between this joint and earth. Alternatively, test between each live conductor and earth in turn.

3) Test between line (live) and neutral. For three-phase systems, join together all lines and test between this joint and the neutral. Then test between each of the lines. Alternatively, test between each of the live conductors in turn. Installations incorporating two-way lighting systems should be tested twice with the two-way switches in alternative positions.

Table # 2 shows the test voltages and the minimum values of insulation resistance for various types of circuits.

Table # 2: *Minimum Values of Insulation Resistance*

System	Test Voltage (d.c.)	Minimum Insulation Resistance (MΩ)
ELV	250V	0.25
LV up to 500 V	500V	0.50
Over 500 V	1000V	1.00

If a value of less than 2MΩ is recorded, it may indicate a situation where a fault is developing (though it complies with permissible values).

Note: Many manufacturers provide **Insulation Tester** and **Continuity Tester** in one instrument.

C.3) Testing Earth Electrode Resistance

In a T-T system, the general mass of earth is relied upon for a return path under earth fault. Connection to earth is made by an electrode, usually of the rod type, tape or plate.

In order to determine the resistance of the earth return path, it is necessary to measure the resistance that the electrode has with earth. If the measurements were taken at increasingly longer distances from the electrode, an increase in resistance would be noticed up to about 2.5 – 3m from the rod, after which no further increase in resistance would be noticed.

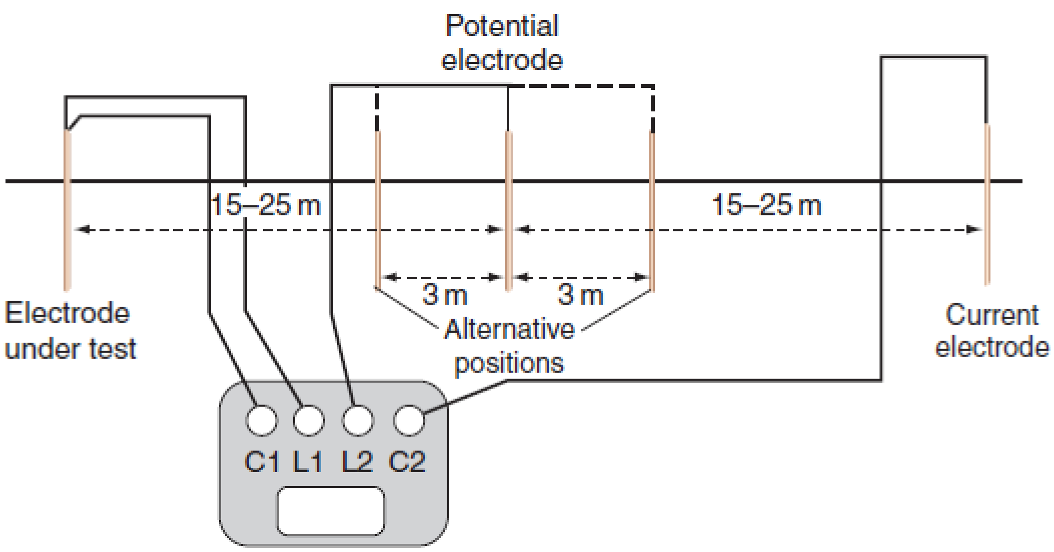
The maximum resistance recorded is known as the Electrode Resistance, and the area that extends 2.5 – 3m beyond the electrode is known as the Earth Electrode Resistance Area.

There are two methods of making the measurement; one using a **Proprietary Test Instrument**, and the other using a **Loop Impedance Tester**. The use of any method depends on the type of protection employed.

Method 1: For Protection by an Overcurrent Device:

The test procedure is as follows:

1. Temporarily, disconnect the earthing conductor to the Electrode under test.
2. Place the Current electrode (C2) away from the electrode under test, approximately 10 times its length; i.e. a 30m distance for a 3m-rod.
3. Place the Potential electrode(L2) midway.
4. Connect the **Proprietary Test Instrument** as shown in the Figure below.



5. Record the resistance value
6. Move the Potential electrode approximately 3m on either side of the mid position, and record these two readings
7. Take an average of these three readings; this is the Earth Electrode Resistance.
8. Determine the maximum deviation or difference of this average from the three readings
9. Express the deviation as a percentage of the average reading
10. To obtain the accuracy of measurements, multiply the percentage deviation by a factor 1.2.
11. The accuracy of the measurements is acceptable if it is within 5%.

Example # 1: If three readings obtained from an Earth Electrode Resistance test were 181, 185 and 179Ω, then what would be the value of the Electrode Resistance, and would the accuracy of the measurement be acceptable?

Solution:

$$\text{Average Value} = \frac{181 + 185 + 179}{3} = 181.67\Omega$$

Maximum deviation = 185 - 181.67 = 3.3

$$\text{Deviation as percentage of the Average} = \frac{3.3}{181.67}\, X\ 100\% = 1.83\%$$

Measurement Accuracy = 1.83% X 1.2 = 2.2% (which is acceptable)

For TT systems, the result of this test will indicate compliance if the product of the electrode resistance and the operating current of the overcurrent device does not exceed 50V.

Method 2: For Protection by an RCD:

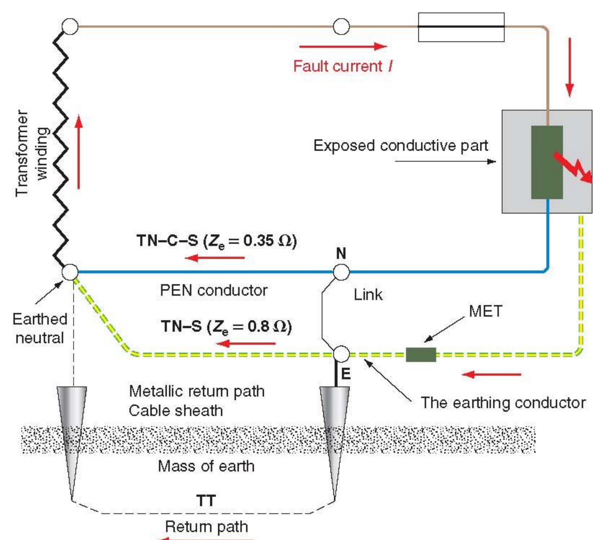
This test is conducted using a Loop Impedance Tester. In this case, an earth fault loop impedance test is carried out between the incoming line terminal and the electrode – a standard test for Z_e.

The value obtained is added to the CPC resistance of the protected circuits and this value is multiplied by the operating current of the RCD. The resulting value should not exceed 50V. If it does, then Method 1 should be used to check the actual value of the electrode resistance.

C.4) Testing Earth Fault Loop Impedance

The test is achieved by a Special Ohmmeter or Loop Impedance Tester. Earth fault loop impedance has been discussed in previous lectures. The main components of the earth fault loop path are, as shown in the Figure next:

1. The CPC
2. The main earthing conductor and earthing terminal
3. The return path via the earth for TT systems, and the



metallic return path in the case TN-S or TN-C-S systems. In the latter case, the metallic return is the Protective Earthed Neutral (PEN) conductor.

4. The earthed Neutral of the supply Transformer
5. The transformer windings
6. The phase conductor back to the point of fault

Overcurrent protective devices must, under earth fault conditions, disconnect fast enough to reduce the risk of electric shock. This is achieved if the actual value of the earth fault loop impedance does not exceed the tabulated maximum values given in Regulations.

The purpose of the test, therefore, is to determine the actual value of the loop impedance (Z_s) for comparison with those maximum values, and it is conducted as follows:

a. Ensure that all main equipotential bonding is in place.

b. Connect the Loop Impedance Tester by the 'flying leads' to **the line, the neutral, and earth** terminals at the **remote end** of the circuit being under test. (If a neutral is not available, e.g. in the case of a three-phase motor, connect the neutral probe to earth.)

c. Press to test and record the value indicated (Z_S)

Account must be taken to ambient temperature at the test time as well as the conductor maximum operating temperature, which affect the conductor resistance. A correction factor is needed!

Instead of worrying about the correction factor and using appropriate formulas, which is time consuming and is not commonly used, a rule of thumb may be applied, which simply requires the measured value of Z_S does not exceed 0.8 of the appropriate tabulated value. Table # 3 gives the 0.8 values of the tabulated loop impedance for direct comparison with measured values.

Table # 3: *Values of Loop Impedance for Comparison with Test Readings*

Protection	Disconnection Time		5 A	6 A	10 A	15 A	16 A	20 A	25 A	30 A	32 A	40 A	45 A	50 A	60 A	63 A	80 A	100 A	125 A	160 A
BS 3036 fuse	0.4s	Z_s max	7.6	–	–	2.04	–	1.41	–	0.87	–	–	–	–	–	–	–	–	–	–
	5s	Z_s max	14.16	–	–	4.2	–	3.06	–	2.11	–	–	1.27	–	0.89	–	–	0.42	–	–
BS 88 fuse	0.4s	Z_s max	–	6.82	4.09	–	2.16	1.42	1.15	–	0.83	–	–	–	–	–	–	–	–	–
	5s	Z_s max	–	10.8	5.94	–	3.33	2.32	1.84	–	1.47	1.08	–	0.83	–	0.67	0.45	0.33	0.26	0.2
BS 1361 fuse	0.4s	Z_s max	8.36	–	–	2.62	–	1.36	–	0.92	–	–	–	–	–	–	–	–	–	–
	5s	Z_s max	13.12	–	–	4	–	2.24	–	1.47	–	–	0.79	–	0.56	–	0.4	0.29	–	–
BS 1362 fuses	0.4s	Z_s max	(3 A) 13.12			(13 A) 1.9	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	5s	Z_s max	(3 A) 18.56			(13 A) 3.06	–	–	–	–	–	–	–	–	–	–	–	–	–	–
BS 3871 MCB Type 1	0.4 & 5s	Z_s max	9.2	7.6	4.6	3.06	2.87	2.3	1.84	1.53	1.44	1.15	1.02	0.92	–	0.73	–	–	–	–
BS 3871 MCB Type 2	0.4 & 5s	Z_s max	5.25	4.37	2.62	1.75	1.64	1.31	1.05	0.87	0.82	0.67	0.58	0.52	–	0.42	–	–	–	–
BS 3871 MCB Type 3	0.4 & 5s	Z_s max	3.68	3	1.84	1.22	1.15	0.92	0.74	0.61	0.57	0.46	0.41	0.37	–	0.29	–	–	–	–
BS EN 60898 CB Type B	0.4 & 5s	Z_s max	(3 A) 12.26	6.13	3.68	–	2.3	1.84	1.47	–	1.15	0.92		0.74	–	0.58	0.46	0.37	0.3	–
BS EN 60898 CB Type C	0.4 & 5s	Z_s max		3.06	1.84		1.15	0.92	0.75	–	0.57	0.46		0.37	–	0.288	0.23	0.18	0.15	–
BS EN 60898 CB Type D	0.4 & 5s	Z_s max		1.54	0.92		0.57	0.46	0.37	–	0.288	0.23		0.18	–	0.14	0.12	0.09	0.07	–

C.5) RCD/RCCB Operation

Where RCDs/RCCBs are fitted, it is essential that they operate within set parameters. The RCD testers used are designed to do just this, and the basic tests required are as follows:

1- Set the test instrument to the rating of the RCD.

2- Set the test instrument to half rated trip.

3- Operate the instrument and the RCD should not trip.

4- Set the instrument to deliver the full rated tripping current of the RCD.

5- Operate the instrument and the RCD should trip out in the required time.

6- For 30mA RCDs used for additional protection, set the instrument to five times the tripping current.

7- Operate the instrument and the RCD should trip out in no more than 40ms.

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