Physics

10

Power and Energy of Electric Appliances

We use electric energy to do various jobs in our daily lives conveniently. On all these occasions we convert electric energy into another form of energy to suit our requirements. This energy conversion takes place in various electric appliances. The instruments used for these energy conversions are known as electric appliances. The main forms of energy conversions that take place in some electric appliances used in daily life are given in the Figure 10.1.

Figure 10.1 - The main form of energy conversion in some electric appliances

For extra knowledge

In some electric appliances, after the first energy conversion, another energy conversion also takes place and we use that energy. As an example, in a filament bulb, electric energy is initially converted into heat which increases the temperature of the filament resulting in the emission of light. In fluorescent lights electric energy is first converted into ultraviolet radiation which is next converted into visible light.

10.1 Power output of an electric appliance

We know that power is the work done in a unit time.

Just like in mechanical work, power is the rate of doing work in work done by electricity too. **That is, power is the work done in a unit time or the energy consumed in a unit time**.

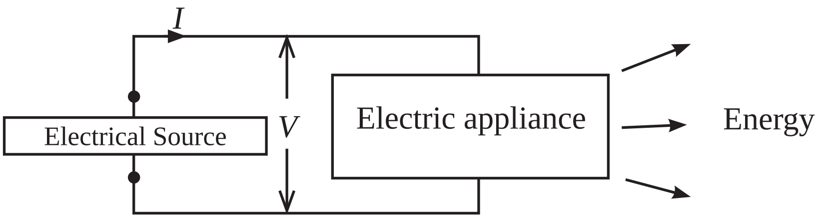


Figure 10.2 - An electric appliance operating with a potential difference *V* and drawing a current *I*

Therefore the rate of energy consumption P by an electric appliance operated with a voltage V and drawing a current I is given by the following equation.

$$\text{Power} = \text{voltage} \times \text{current}$$
$$P = VI$$

When the voltage, V is measured in Volts (V) and the current, I in Amperes (A) the power, P is given in Watts (W).

Example 1

When a filament bulb is connected across a voltage difference of 12 V, a current of 2 A flows through it. What is the power of the bulb?

$$\text{Power} \quad P = VI$$
$$= 12 \times 2 \text{ W}$$
$$P = 24 \text{ W}$$

Power of the bulb is 24 W.

Example 2

An electric oven operates under a 230 V power supply. If it has a power output of 2000 W, find the current drawn when the oven is working.

$$P = VI$$
$$\therefore 2000 = 230 \times I$$
$$\therefore I = \frac{2000}{230} = 8.69 \text{ A}$$

The current drawn by the oven is 8.69 A.

In the heating coils (heating element) of electric ovens, the energy consumed is converted only into heat. In some other appliances, part of the electric energy is converted into heat due to their internal resistance, while the remaining part is converted into other forms of energy.

10.2 Electric energy consumed by electric appliances

Power is the rate of consumption of energy or the energy consumed in a unit time by an electric appliance. Therefore, the total energy consumed by an electric appliance depends on the time duration that it operates.

If the energy consumed during a unit time interval is P, the total amount of electric energy consumed in a time t is Pt. If the total energy consumed is E,

$$E = Pt$$

When P is measured in Watts (W) and the time t in seconds (s), the electrical energy E is given in Joules (J).

Since $P = VI$, substituting VI for P,

$$E = Pt = VIt$$

$$\text{Total Energy} = \text{voltage} \times \text{current} \times \text{time}$$
$$E = VIt$$

In order to find the energy consumed by an electric appliance, the relation $E = VIt$ can also be used.

Example 1

The power of the head light of a motor car is 50 W. Find the energy consumed when this lamp is operated for $1\frac{1}{2}$ hours.

$$E = Pt$$
$$E = 50 \times 1.5 \times 60 \times 60 \text{ J}$$
$$E = 270\,000 \text{ J}$$

The amount of energy consumed is 270 000 J.

Example 2

A 6 V bicycle electric bulb draws a current 0.6 A. What is the power consumed in lighting this bulb for five minutes?

$$E = VIt$$
$$E = 6 \times 0.6 \times 5 \times 60$$
$$E = 1080 \text{ J}$$

Total electric energy consumed is 1080 J.

10.3 Efficiency of electric appliances and conserving power

In many instances, the same purpose can be achieved using various different appliances. In order to get illumination we can use filament bulbs, LED bulbs, fluorescent light tubes or CFL lights (compact fluorescent lights). Choosing a more efficient appliance helps us to save energy. A few different types of bulbs giving the same illumination, their power output and life times are given in Table 10.1 below.

Table 10.1 – Power and life times of various types of bulbs

Light source	Power	Life time
Filament bulbs	60 W	1200 h
Fluorescent tubes	22 W	3000 h
CFL bulbs	11 ~ 13 W	8000 h
LED lights	6 ~ 8 W	50 000 h

According to Table 10.1, it is advantageous to use LED bulbs as light sources. However, the use of LED bulbs in Sri Lanka is limited due to their high initial cost.

Similarly, the efficiencies of cookers used to prepare food are different from one to another due to varying amounts of heat wastage. Old cookers that use heating coils are the lowest in efficiency. Emersion heater is highly efficient for heating water. The reason is that, all the heat generated in the heater is transferred to water when using it. Heaters which contains hot plates such as rice cooker is more efficient because heat loss is less from them. Although microwave ovens cannot be used to cook all types of food, they are very efficient since they produce heat inside the food items. In addition to these, induction cookers with high efficiencies are now available in the market. In these devices, the variable magnetic field emitted by the cooker generates heat only at the bottom of the cooking utensil.

For extra knowledge

The power consumption of television sets that use LCD screens is lower than that of the old televisions that use cathode ray tubes. LCD television sets that use LED lights to illuminate the screen have a very low power consumption and are known as LED televisions in the market.

Similarly, it is more efficient to use table fans to cool houses than ceiling fans. Using the most efficient device suitable for a particular purpose whenever possible would help to minimize the future energy crisis.

If 40% of the energy supplied to a certain electric appliance is lost as heat, then only 60% of the energy would be used for the expected purpose. This means that the efficiency of the electric appliance is 60%. We should try to minimize the loss of electric energy as heat and get the maximum out of the electric energy supplied for a particular purpose. Ironing all clothes required for a week in one occasion is more efficient because it saves electricity used in the initial heating of the iron. All the unwanted lights of the home should be switched off. Also, you have to use more efficient bulbs such as CFL and LED bulbs.

Assignment 10.1

Prepare a list of electric devices used in households and indicate their power usage against them (You may use the specification labels pasted on the device or the instruction sheet provided with the device to do this. Get assistance from an adult when this is not possible.)

10.4 Home Electric Circuits

Electric energy required to operate home electric appliances is obtained from the national electric grid. Electric energy generated by electric power stations are raised to high voltages such as 132 kV or 220 kV using step-up transformers and distributed throughout the island. In distribution sub-centres, these high voltages are lowered to voltages such as 33 kV or 11 kV and ultimately they are lowered down to 230 V before supplying to households. Electricity provided to houses is in the form of an alternating current with a frequency of 50 Hz.

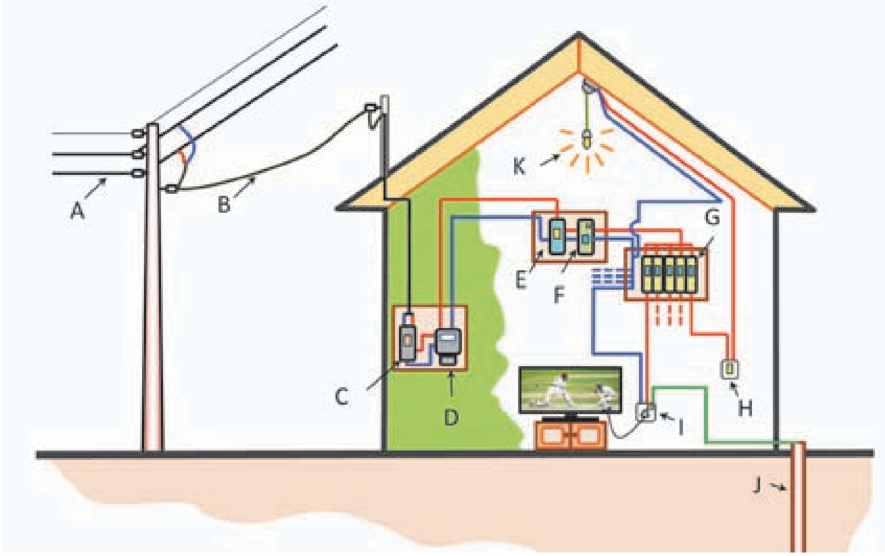


Figure 10.3 – A house connected to the electric grid

A – Distribution wire
B – Supply cable
C – Overload circuit breaker (or Service fuse)
D – Electric meter
E – Isolator (or Main fuse with main switch)
F – Residual current circuit breaker or trip switch (RCCB)
G – miniature circuit breakers or fuses (MCB)
H – Switch
I – plug socket
J – Earth wire
K – Light bulb

Electricity is supplied to houses using a service cable consisting of two wires known as the live wire and the neutral wire. The current flowing through these two wires is provided to the electric appliances through a circuit inside the house.

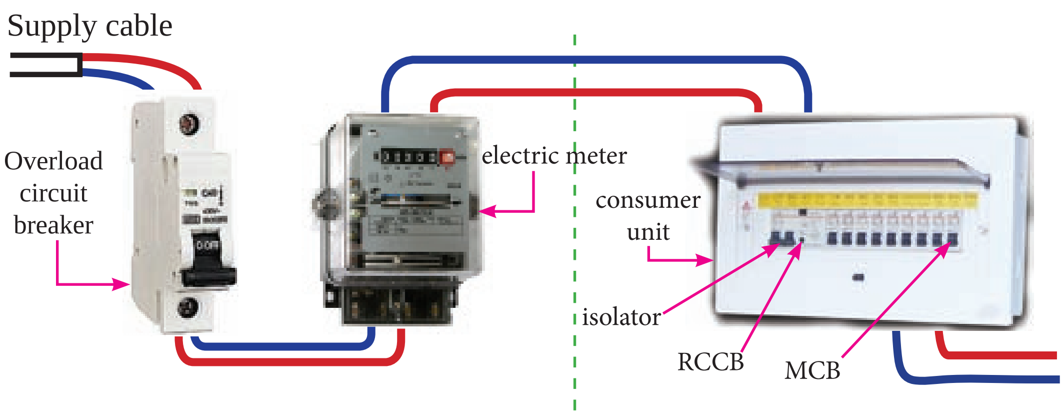


Figure 10.4

Figure 10.5 shows a diagram of a domestic electric circuit.

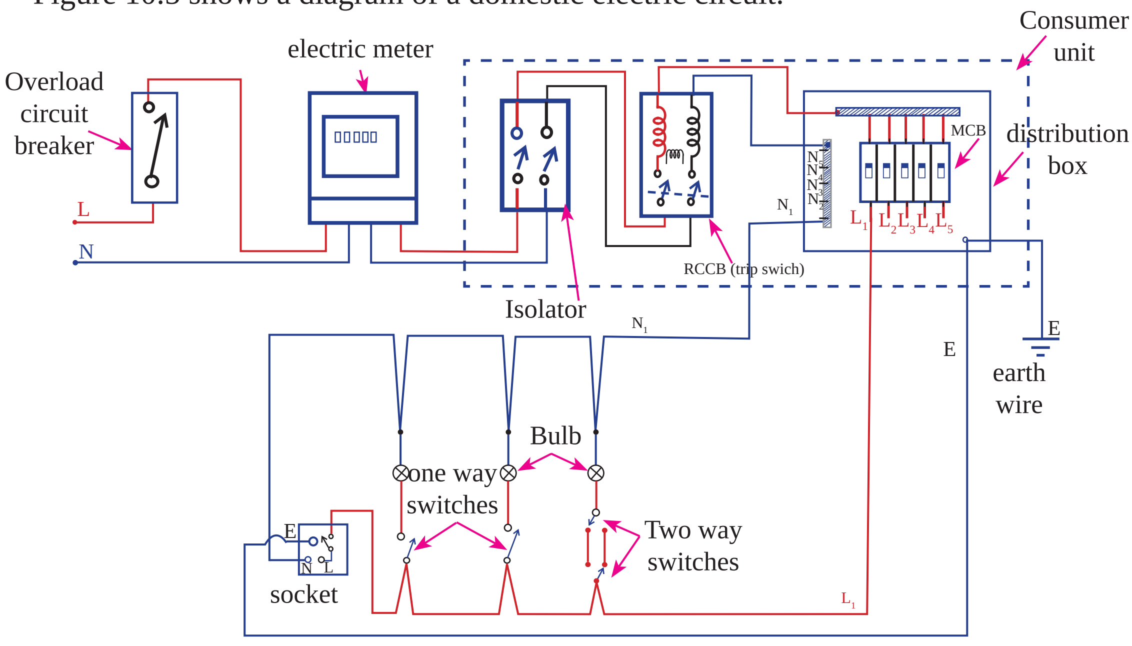


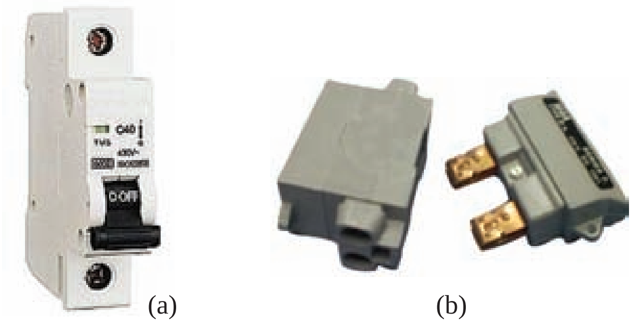
Figure 10.5 – Arrangement of a domestic electric circuit

10.4.1 Components of a Domestic Electric Circuit

- **Overload circuit breaker (or Service fuse)**

Electricity supplied to household first passes through a fuse connected to the live cable. This fuse is arranged to allow the passage of a maximum current of about 40 A. If a larger current passes through it, the circuit breaker disconnects power to the house. When that happens, the power can be reconnected by moving the lever up, manually. In older houses, a fuse, is used instead of a circuit breaker. When a current above the limit passes through the fuse wire which is made of an alloy consisting of lead and tin, it heats up and melts disconnecting the power supply. The fuse wire is inserted in a ceramic tube or a ceramic mount.

Only the live wire is disconnected by the overload circuit breaker or the service fuse. Figure 10.6(a) shows a overload circuit breaker and Figure 10.6(b) shows a service fuse.



(a) (b)

Figure 10.6 - (a) Overload circuit breaker (b) Service fuse

- ## Electricity Meter

Consumers are billed according to the amount of electricity they consume. The meter records the electric energy in kilowatt hours (kW h). The live and neutral wires coming through the over load circuit breaker or service fuse are next connected to the electricity meter. These two wires coming from the electricity meter are next connected to the main switch. An electricity meter is shown in Figure 10.7.

Figure 10.7 - An electricity meter

Overload circuit breaker and the electricity meter are properties belonging to the service provider (electricity board or electricity company) and any problem with these items should be solved by informing the service provider.

- ## Isolator (or Main Switch with Main Fuse)

All items in the domestic circuit beyond the isolator belong to the consumer. After passing through the electric meter, the live wire passes through an isolator that allows the passage of a maximum current of 30 A. Isolator acts as a 30 A high current circuit breaker too. In any instance, by the lowering of the switch levers, it can be disconnected the home hold circuit from power mains (L and N).

In older domestic electrical circuits, a main switch consisting of a 30 A fuse and a dipole switch was used in place of the isolator. The isolator is capable of disconnecting both the live and the neutral wires. Such switches are known as **dual pole switches**. Disconnecting the domestic circuit for any repair purpose can be done by turning off the isolator. Figure 10.8(a) shows the outward appearance of an isolator and Figure 10.8(b) shows the circuit diagram of a main switch.

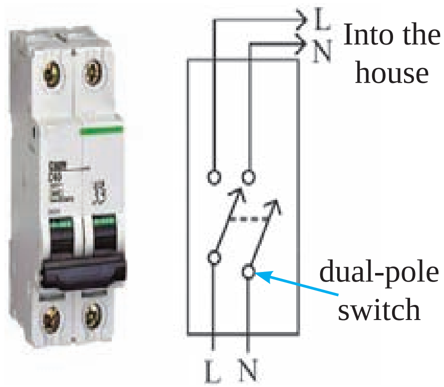


Figure 10.8 (a) - The external view of an isolator and circuit diagram of a isolator

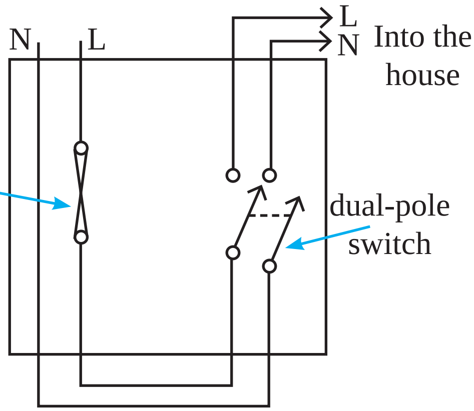
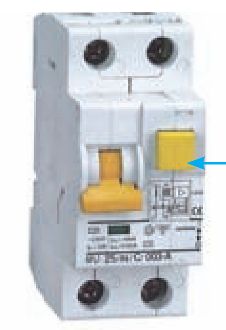


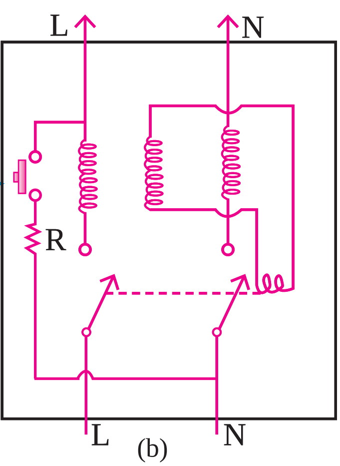
Figure 10.8 (b) - circuit diagram of a main switch

- ## Residual Current Circuit Breaker - RCCB (or Trip Switch)

After the isolator, the live wire and the neutral wire are connected to a RCCB or a tripped switch. The purpose of connecting to a RCCB is to protect the residents from electric shocks. When there is a current leak to the metal caring of an appliance or to the ground the circuit is automatically disconnect by the RCCB. The RCCB too is a dual pole switch. Outward appearance of a RCCB is shown in Figure 10.9(a) and circuit diagram of a RCCB is shown in Figure 10.9(b).


(a)

Test button



(b)

Figure 10.9 – (a) Outward appearance of a RCCB (b) circuit diagram of a RCCB

In a normal switch the switch is on when the lever is turned down. But in this switch it become on when the lever arm is raised.

• Distribution Box

Electricity is distributed for consumption in the household through the distribution box. Electricity is distributed inside the house through lighting circuits and plug circuits. Adequate current to light bulbs in ordinary rooms is supplied by lighting circuits. The maximum current supplied to a lighting circuit is limited to 6 A. Plug circuits are connected to places such as the kitchen that have devices like electric heaters and electric ovens that consume a large amount of electricity. Plug circuits allow the consumption of current upto about 13 A.

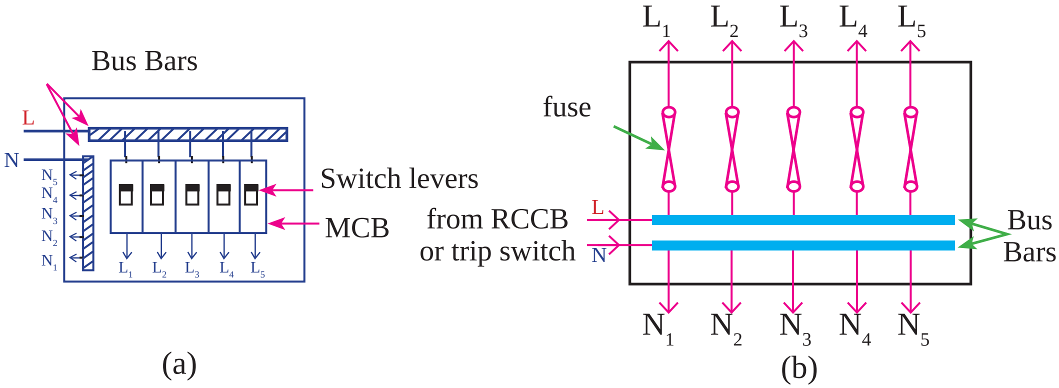
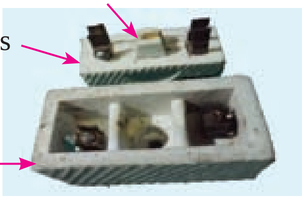


Figure 10.10 – (a) Circuit diagram of a distribution box with MCBs
(b) Circuit diagram of a distribution box with fuses

• Miniature circuit breakers (MCB) and fuses

Miniature circuit breakers (MCB) supplying electricity are connected to each circuit inside the distribution box. When a current larger than the maximum current that can pass through the circuit is drawn, miniature circuit breakers automatically get disconnected and the lever shifts down to the off position. Because of this, the electricity supply gets disconnected only in these circuits and not to the whole household. For lamp circuits, MCBs which can conduct a current of 6 A are used. For socket circuits, MCBs which can conduct a current of 13 A are used.

While bulbs and two 6 A plugs can be connected to a lighting circuit, only plugs can be connected to plug circuits. Figure 10.11 shows the outward appearance of a fuse mount and a miniature circuit breaker.



(a) A fuse

(b) An MCB

Figure 10.11 – Outward appearance of a fuse and an MCB

MCBs can be mounted in specially designed distribution boxes. MCBs provide protection against electric shorts and resulting fires due to heated cables only. Since the fuse or the MCB does not operate when a person gets an electric shock, they do not provide any protection to people.

In older domestic circuits, fuses were used instead of MCB. In lighting circuits, 5 A fuses were used instead of 6 A MCBs. Instead of 13 A MCBs, 15 A fuses were used. The use of fuses has declined because replacing fuse wires of blown fuses is inconvenient. When MCBs or fuses are connected, they must always be connected to the live wire.

In modern domestic circuit, isolator, RCCB and the distribution box are included in the same units called **consumer units**. A consumer unit is shown in figure 10.12.

Figure 10.12 - A consumer unit

For extra knowledge

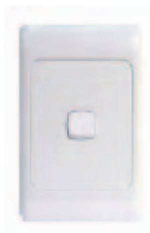
One of the two cables providing electricity to households is earthed near the step down transformer that distributes electricity to the house. Then a potential difference of 230 V is established between the other cable and the earth. Earthed cable maintains a zero potential (Earth is assumed to be at a zero potential).

Now if a person standing on the ground touches the cable that is not grounded, he would receive an electric shock due to the 230 V potential difference across his body (An electric shock is the damage caused to the body by passing an electric current through the body). A 50 mA current passing through the body is considered a major electric shock while a 100 mA current can cause death. Since touching the ungrounded cable causes electric shocks, this cable is known as the "live" cable. Since touching the grounded cable from the ground does not give rise to a potential difference across the body, this cable is known as the neutral cable.

One cable is made to be a live cable in this manner since it is essential for the operation of the RCCB that protects the household from accidents related to electric shocks. If the live wire gets grounded anywhere inside the house, the RCCB automatically disconnects the electricity supply to the house by detecting the large current passing through it. The RCCB operates from electromagnetic induction and if a current of about 35 mA passes through the switch to ground, it automatically turns off. In addition to this, a flow of about 30 A into the house (short circuit) the RCCB operates and disconnects the electricity supply to the house. Although the RCCB sometimes disconnects the electricity supply when there is lightning activity, its protection from lightning damage is not assured.

• Switches and Plug sockets

Switches used to turn on or off power to electric bulbs are major components in domestic circuits. Switches are available as single units or as units consisting of several switches on the same board. Switches are connected to the circuit so as to enable the turning on or off of each bulb separately.



A single switch

Four switches

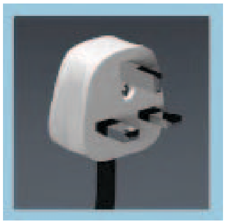
Figure 10. 13 – Switches

Another important component in a domestic circuit is the plug socket. The live cable, the neutral cable and the separately grounded earth cable are connected to these circuit elements. The larger terminal of a three-pin plug socket is connected to the external metal cover of an electric appliance and it connects to the earth wire in the domestic circuit when plugged on. This connection is essential in order to get protection from electric shocks by turning off the trip switch. For some of the modern

Figure 10.14 – A plug socket with switch

electric equipment having a plastic cover that does not leak electricity, two-pin plugs can be used. Two-pin plug sockets are not connected to the earth wire.

Two pin plugs



A three pin plug

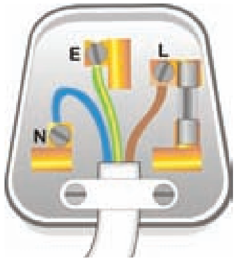


Figure 10.15 – Plugs and plug sockets

- **Connecting Wires**

Copper wires with suitable cross-sectional areas are used as connecting wires for carrying currents. Single cables with a 1 mm^2 cross-sectional area (1.13 mm diameter) are used in order to carry 5 A or 6 A currents while cables consisting of seven wires with a 1.5 mm^2 effective cross-sectional area are used for 15 A or 13 A plug circuits.

A brown PVC cover is used to identify the live wire while a blue PVC cover is used to identify the neutral wire. Previously red and black covers were used to identify live and neutral wires respectively. Green covers are used for the earth wire.

10.4.2 Domestic Electric Circuit

Each bulb and each plug in a domestic circuit is connected in parallel to one another. All switches should be connected to the live wire. Therefore touching a bulb circuit when the switch is in the off position does not cause electric shocks.

Plug circuits are connected using cables that can withstand a current of 13 A. Only plugs are connected in these circuits and this type of circuits are often used in kitchens.

Sometimes plug circuits are connected as ring circuits. Such a ring circuit is shown in Figure 10.16. Cables with smaller diameters can be used in such circuits since each plug receives current through two wires.

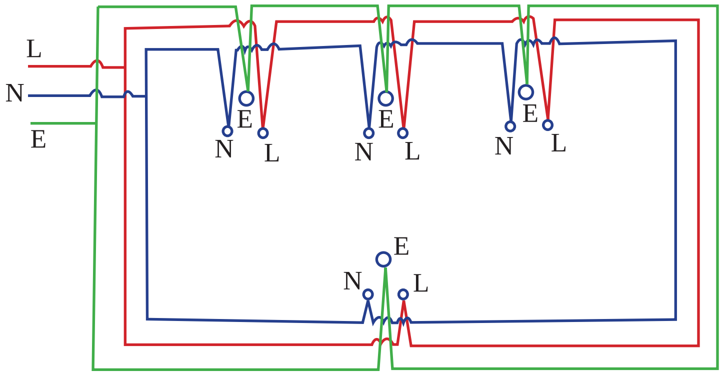


Figure 10.16 – A loop circuit

10.4.3 Protective Measures in Domestic Circuits

Basically there are two protective measures in domestic electric circuits. These are the residual current circuit breaker and the fuse or MCB's.

- **Residual current circuit breaker - RCCB (or Trip Switch)**

In case of a current leakage in the electric appliances or an electric shock, the RCCB disconnects the power supply to the whole house hold. In addition to this, the RCCB also disconnects power if a current greater than 30 A flows through the circuit. This prevents fire arising from over- heated main cables.

- **Fuses or MCB's**

These electrical components prevent large currents flowing through domestic circuits. Fuses or MCB's do not provide protection from accidents due to current leaks or electric shocks.

If there is a power disconnection due to any of the above reasons, the overload circuit breaker should be opened (turned OFF) first. Next, the lever of the RCCB or that of the MCB should be turned upwards (to the ON position) and then close (turn ON) the overload circuit breaker again. If the power supply gets disconnected again, the circuit should be repaired by an electrician.

Further to the above, it is very important to follow the following precautionary measures for safety.

- Only fuses appropriate for 6 A and 13 A currents should be used.
- Many electric appliances that draw a total current exceeding the capacity of the plug socket should not be connected to the plug socket through a multi-plug.
- Only plugs suitable for a plug socket should be inserted into a plug socket. Wires should not be inserted into a plug socket.

- When using an electric iron for ironing clothes, rubber slippers or a rubber carpet underneath the feet should be used. It is good to use a mat in front of a refrigerator for safety.
- Tasks such as changing burnt bulbs in bathrooms should not be done without turning off the overload circuit breaker or the main switch.
- When electric appliances are not in use, their plugs should be disconnected from the socket.
- If there are strong lightning strikes, radio receivers and television sets should be unplugged as much as possible. In such cases it is advisable to refrain from using any unessential electric devices. (RCCBs do not protect the domestic circuit from thunder).
- Electric devices should not be used when the body is wet. Electric switches must not be turned on or off with wet hands.
- During a power failure, switches of electric appliances should not be turned on.
- In case of a fire, the domestic power supply should be disconnected using the overload circuit breaker.
- All maintenance work and installing power extensions should be done by a trained electrician.
- The functioning of the RCCB should be checked every few days by pressing the test button.

10.5 Measuring Electric Energy in kilowatt hours

- **Commercial unit of measuring electric energy**

Electric energy is measured in kilowatt hours by the domestic electricity meter. One kilowatt hour is the amount of electric energy consumed during one hour by an electric appliance with a power consumption of 1 kW. Although energy is usually measured in Joules, when the consumption is high, energy in Joules gives a large numerical value. Because of this, kilowatt hours (kW h) is used as the measuring unit of electricity. The energy consumed in a second by a device with a 1 Watt power is equal to one Watt second (W s) or one Joule (J).

$$\therefore\ 1\text{ kW h} = 1\text{ kW} \times 1\text{ h}$$
$$= 1000\text{ W} \times 1 \times 60 \times 60\text{ s}$$

$$\mathbf{1\ kW\ h = 3\ 600\ 000\ J = 3.6 \times 10^6\ J}$$

This shows that 1 kW h has a large numerical value in Joules.

When the power of domestic electric appliances and the number of hours they are used are known, the amount of electricity consumed by these devices can be easily calculated.

$$\text{Number of kW h} = \frac{\text{number of Watts}}{1000} \times \text{number of hours}$$

Example 1

If four bulbs, each having a power of 100 W are used for 3 hours and 5 bulbs, each with a power of 60 W are used for 4 hours daily, find the electricity consumption during a month.

Energy consumed by 4 bulbs of 100 W power } $= 100 \times 4 \times 3$ W h

Energy consumed by 5 bulbs of 60 W power } $= 60 \times 5 \times 4$ W h

Total energy consumed by all bulbs in a month $= (100 \times 12 + 60 \times 20) \times 30$ W h

Total energy consumed during a month $= (1200 + 1200) \times 30$ W h

$= \frac{2400 \times 30}{1000}$ kW h

Total electricity consumed during a month = 72 kWh

Therefore, a total of 72 kW h of electricity is consumed during a month.

Summary

- The power of an electric appliance is the amount of electric energy consumed by it in a unit time.
- When a current I passes through an electric device due to a potential difference V, its power P is given by $P = VI$
- Electric energy E consumed by an electric device over a time period t is given by $E = VIt$
- Domestic electricity meter measures electric energy in kilowatt hours (kW h).
- One kilowatt hour is the energy consumed during one hour by an electric device that has a power of one kW.

  1 kW h = 3 600 000 J

Exercise 10.1

(1) The power of an electric water pump is 750 W.

(a) Calculate the current drawn by the motor, if it is connected to a 230 V supply.

(b) State one type of energy, other than the kinetic energy, generated when the motor is operating.

(2) Specifications of a flash light bulb are given as 2.5 V and 0.3 A.

(a) What is the power of this bulb?

(b) If the efficiency of emitting light from this bulbs is 42% what will happen to the remaining 58%?

(3) The power of the two head lamps of a motor vehicle is 50 W each. There are other two lamps in the rear with 10 W each. If all these bulbs are lighted up for 1/2 h, calculate the quantity of electrical energy spent.

(4) The current flowing through a motor cycle bulb when it is connected to 12 V battery is 2 A. How much electrical energy is spent if this current is flowing for 15 minutes?

(5) (a) Name two instruments that are used in a domestic circuit for the protection of residents.

(b) Mention what is the type of protection provided by each of them.

(c) Explain what is to be done to protect electric equipment in a house when lightning occurs.

(6) (a) Consumers are charged money for the electricity used in houses. What is the unit of electrical energy which is used to make electric bills?

(b) Calculate the amount of energy in Joules equivalent to one commercial unit of electricity.

(c) If the first 60 units are charged at a rate of Rs. 7.50 per unit and the next 30 units are charged Rs. 10.00 per unit, how much will be the electricity bill of a house where the electricity usage is 75 units in a month?

(7) (a) The power of a water heater in a home is 1500 W. This is used for half an hour daily. Three 40 W bulbs are used for 3 hours daily. Two bulbs of 60 W are lighted for 2 hours daily. Calculate the number of units used up in one day.

(b) If electricity is charged according to the above rates given in the question 6 (c), what should be the monthly electricity bill.

(8) (a) A hot plate or immersion heater can be used to heat water. Which one is more efficient out of these two?
(b) Give the reason for this.
(c) What is the reason for using three pin plugs instead of two pin plugs for immersion heaters?
(d) When an electrical appliance is switched on the electrical circuit was disconnected. Give two reasons due to which this can happen.

Technical terms

Power	- ක්ෂමතාව	- வலு
Efficiency	- කාර්යක්ෂමතාව	- திறன்
Hot plate	- තාපන ඵලක	- வெப்பத் தட்டு
Immersion heater	- ගිල්ලුම තාපකය	- அமிழ்ப்பு வெப்பமாக்கி
Microwave oven	- ක්ෂුද්‍ර තරංග උදුන	- நுணுக்கலைக் கனலி
Induction cooker	- ප්‍රේරක උදුන	- தூண்டற் சமைகலன்
Live	- සජීවී	- உயிர்
Neutral	- උදාසීන	- நொதுமல்
Fuse	- විලායකය	- உருகி
Residual current circuit breaker (RCCB) or Trip Switch	- ශේෂ ධරා පරිපථ බිඳිනය හෝ පැන්නුම් ස්විච්චය	- இடறு ஆளி / எச்சமான மின் சுற்றுடைப்பான்
Distribution box	- විබෙදුම් පෙට්ටිය	- பரப்பற் பெட்டி
Miniature circuit breaker (MCB)	- සිඟිති පරිපථ බිඳිනය	- சிறு சுற்றுடைப்பான்
Plug socket	- කෙවෙනිය	- குதை
Plug	- පේනුව	- செருகி
Overload circuit breaker	- අධිධාරා පරිපථ බිඳිනය	- பளு சுற்றுடைப்பான்
Isolator	- වෙන්කරණය	- பிரதான ஆளியும் பிரதான உருகியும்