

MAGNETIC EFFECT OF ELECTRIC CURRENT

- Electricity and magnetism were discovered separately, and for long time they were treated as two different things, without any interrelation. Then, in early 19th century, scientists like **Oersted**, Faraday and Ampere showed that there was a definite relationship between electricity and magnetism.

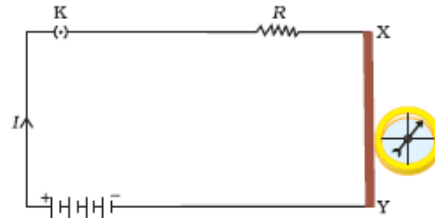


Figure 13.1
Compass needle is deflected on passing an electric current through a metallic conductor

Activity 13.1. When the current passes through a copper wire, it deflects the magnetic needle of the compass. This is because the current carrying copper wire behaves like a magnet. This shows that electricity and magnetism are linked together.

- Now we know that an electric current carrying wire behaves like a magnet. Alike any other magnet, it also produce magnetic field around it. This constitutes the magnetic effect of electric current.

MAGNET, MAGNETIC FIELD AND MAGNETIC FIELD LINES

- Magnet:** A magnet is an object which attracts pieces of iron, steel, nickel and cobalt. A magnet shows some unique properties-
 - It has two poles near its end. North Pole and South Pole.
 - If a magnet is suspended freely its North Pole points towards north direction and South Pole points towards south direction (as seen in compass).
 - Like magnetic poles repel each other whereas unlike magnetic poles attracts each other.
- Magnetic field:** The space around a magnet in which the magnetic forces can be detected is called magnetic field.

Activity 13.2. When some iron filings are sprinkled uniformly around a bar magnet placed on a card, and then tapped the card gently. The iron filings experience a force and arrange themselves in a regular pattern and give a rough picture of the pattern of magnetic field. The lines along which the iron filings align themselves represent magnetic field lines. (It gives only shape of magnetic field and field lines.)

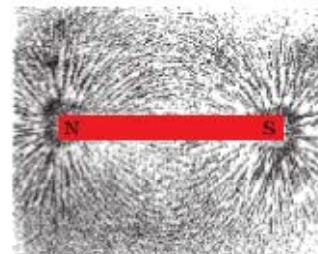


Figure 13.2
Iron filings near the bar magnet align themselves along the field lines.

- **Magnetic Field Lines:** The lines drawn in a magnetic field along with a north magnetic pole of a magnet would move is called Magnetic Field Lines or Magnetic Line of forces.

Activity 13.3. When a compass is placed near the north pole of a bar magnet, then the north pole of the compass needle point away from the north pole of the bar magnet and south pole of compass needle point towards the north pole of bar magnet, mark the two ends of the needle.

Now, if we move the compass needle to a new position such that its South Pole occupies the position previously occupied by the North Pole and proceed step by step till we reach the south pole of the magnet. If we join the points marked on the paper by a smooth curve. This curve will represent a field line. (It gives both shape and direction of the magnetic field and field lines.)



Figure 13.3
Drawing a magnetic field line with the help of a compass needle

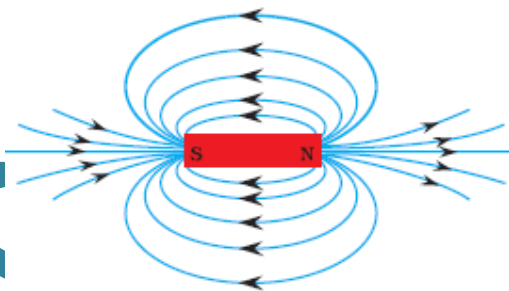


Figure 13.4
Field lines around a bar magnet

- Magnetic field is a quantity that has both direction and magnitude. And the direction of the magnetic field is the direction in which north pole of the compass needle moves inside it.
- **Properties of the Magnetic Field Lines:**
 1. The magnetic field lines originate from North Pole and end at its south pole. Inside the magnet, the direction of field lines is from its south pole to its north pole. Thus the magnetic field lines are closed curves.
 2. The magnetic field lines are closer to one another near the poles of a magnet but they are widely separated at other places. The degree of closeness of the field lines indicates the relative strength of the magnetic field.
 3. The magnetic field lines can never cross one another. If they did, the compass needle would point towards two directions, which is not possible.

MAGNETIC FIELD DUE TO A CURRENT CARRYING CONDUCTOR

- The magnetic effect of current was discovered by Oersted in 1820. It was concluded after extensive research that “a current flowing in a wire always gives rise to a magnetic field around it.

Activity 13.4. When a straight copper wire is connected to cells and plug key in series and a compass needle placed parallel to the straight wire. Now if the current flows from north to south direction, the north pole of compass needle would move towards the east and if we change the direction of current, the magnetic needle would move in opposite direction. (SNOW Rule.)

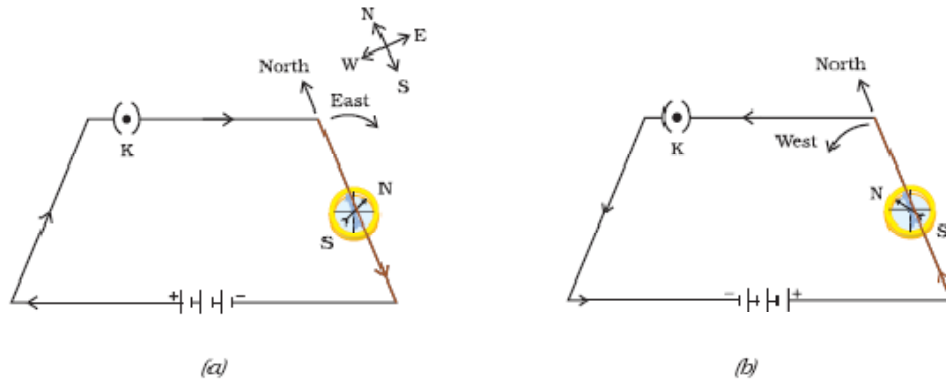


Figure 13.5 A simple electric circuit in which a straight copper wire is placed parallel to and over a compass needle. The deflection in the needle becomes opposite when the direction of the current is reversed.

MAGNETIC FIELD DUE TO CURRENT THROUGH STRAIGHT CONDUCTOR

- The magnetic field lines around a straight conductor carrying current are concentric circles whose centre lies on the wire.

Activity 13.5. A thick copper wire is taken and inserted through the centre of a rectangular cardboard. The vertical copper wire is now connected with a battery, a rheostat, an ammeter and a plug key in series.

After sprinkling the iron filings on the cardboard and then tapping it, the iron filings align themselves showing a pattern of concentric circles around the copper wire representing the magnetic field lines.

The direction of magnetic field can be detected by placing a compass needle over a circle. The direction of the north pole of compass needle would give the direction of the field lines.

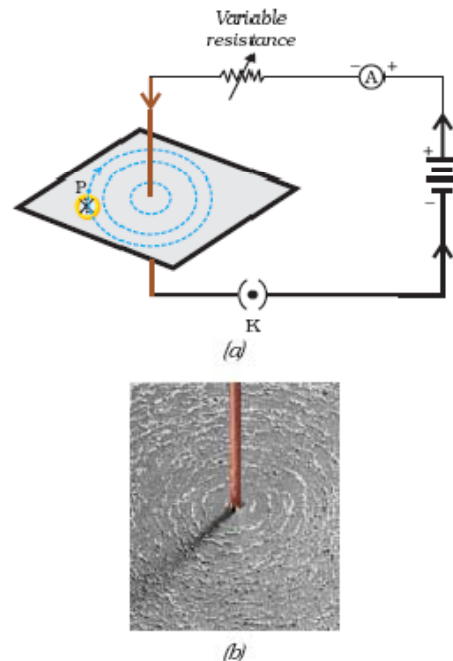


Figure 13.6
 (a) A pattern of concentric circles indicating the field lines of a magnetic field around a straight conducting wire. The arrows in the circles show the direction of the field lines.
 (b) A close up of the pattern obtained.

- Two factors mainly affect the magnitude of magnetic field produced by straight current carrying conductor-
 1. **Current:** magnitude of the magnetic field produced at a given point increases as the current through the wire increases. (Compass needle shows more deflection.)
 2. **Distance:** the magnetic field produced by a given current in the conductor decreases as the distance from it increases. (Compass needle shows less deflection.) Due to which the concentric circles around the straight conductor become larger and larger as we move away from it.

MAXWELL'S RIGHT HAND THUMB RULE

- If a straight current-carrying conductor is held in the right hand in such a way that the thumb is stretched along the direction of the current, the direction in which the fingers are curled will give the direction of magnetic field produced by the current.

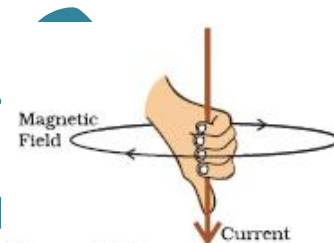


Figure 13.7
Right-hand thumb rule

MAGNETIC FIELD DUE TO CURRENT THROUGH A CIRCULAR LOOP

- The magnetic field lines are in the form of concentric circles near the both segments of current carrying loop. As we move away, the concentric circles become bigger and bigger. At the centre of the circular loop, the magnetic field lines are straight.

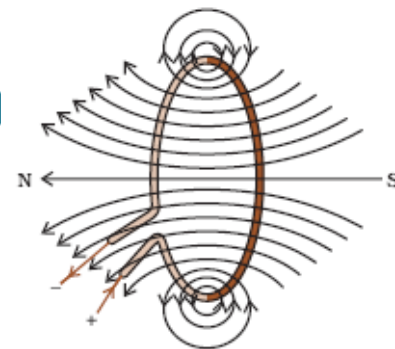


Figure 13.8
Magnetic field lines of the field produced by a current-carrying circular loop

Activity 13.6. A circular coil having large number of turns is inserted through a rectangular cardboard having two holes. The coil has been connected in series with a battery, a key and a rheostat.

After sprinkling the iron filings and tapping the board few times, the iron filings align themselves showing the concentric rings around the two segments of loop and straight line at the centre of the circular loop.

- By applying right-hand thumb rule, it can be seen that each segment of circular loop carrying current produces magnetic field lines in the same direction within the loop.
- The strength of magnetic field produced by a circular loop carrying current depends upon-

1. **Current flowing through the loop:** Greater the current, more will be the magnetic field strength.
2. **Radius of the loop:** Larger the radius of the loop, weaker will be the magnetic field strength.
3. **Number of turns in the loop:** Magnetic field strength will increase by n times, if we increase the n number of turns in the loop. This is because the current in the each loop flow in the same direction and magnetic field produced by each turn of circular coil then just adds up.

- The strength of magnetic field produced by a current carrying circular coil or loop can be increased:
 1. by increasing the current flowing through the coil,
 2. by decreasing the radius of the loop, and
 3. by increasing the number of turns of wire in the coil.

MAGNETIC FIELD DUE TO CURRENT IN A SOLENOID

- **Solenoid:** A coil of many circulated turns of insulated copper wire wrapped closely in the shape of a cylinder is called a solenoid.
- The magnetic field produced by a current carrying solenoid is similar to the magnetic field produced by a bar magnet.
- One end of solenoid behaves as magnetic North Pole, while other behaves as the South Pole. It can be detected by placing North Pole of a bar magnet near one end of solenoid. If it attracts the bar magnet then this end of solenoid will be South Pole and if repels, it will be North Pole. Because, unlike poles attract and like poles attract each other.
- The field lines inside the solenoid is in the form of parallel straight lines, which indicates that the magnetic field is uniform inside the solenoid.
- The strength of magnetic field produced by a current carrying solenoid depends on:
 1. **The number of turns in the solenoid.** Larger the number of turns in the solenoid, greater will be the strength of magnetic field.
 2. **The strength of current in the solenoid.** Larger the current passed through solenoid, stronger will be the magnetic field produced.
 3. **Nature of Core Material used in solenoid.** The use of soft iron rod as core in a solenoid produces the strongest magnetic field.

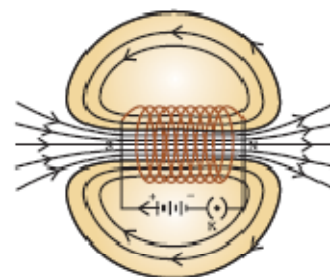


Figure 13.10
Field lines of the magnetic field through and around a current carrying solenoid.

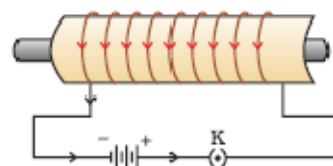


Figure 13.11
A current-carrying solenoid coil is used to magnetise steel rod inside it – an electromagnet.

ELECTROMAGNET

- When a piece of magnetic material, like soft iron is placed inside a solenoid, the soft iron magnetises due to effect of strong magnetic field of solenoid and called as electromagnet.
- The core or magnetic material to be placed inside the solenoid must be of soft iron because soft iron demagnetize when current in the solenoid is switched off.
- If steel is used at the place of soft iron, the steel does not demagnetize when the current is stopped and it become permanent magnet.
- Factors affecting the strength of an Electromagnet:-
 1. **The number of turns in the coil.** Strength of electromagnet increases with the increase in the number of turns in the coil.
 2. **The current flowing in the coil.** Increased current in the electromagnet increases its strength.
 3. **Air gap between its poles.** Magnetic strength of an electro magnet increases if we decrease the air gap between the two poles, i.e. if we bring the two poles near to each other.
 4. **Nature of Core Material used.** The use of soft iron rod as core produces the strongest magnetic field.
- Differences between an electromagnet and a permanent magnet:-

Electromagnet	Permanent magnet
1. It is a temporary magnet. It can be demagnetise easily, when switched off.	1. It is a permanent magnet. It cannot be demagnetise easily.
2. It produces very strong magnetic force.	2. It produces comparatively weaker magnetic force.
3. The strength of electromagnet can be changed by changing the number of turns in its coil or by changing the current passing through it.	3. The strength of a permanent magnet cannot be changed.
4. The north-south polarity of an electromagnet can be changed by changing the direction of current in its coil.	4. The polarity of permanent magnet is fixed and cannot be changed.

- Permanent magnets made up of ordinary sleet are not so strong, so Carbon Steel, Chromium Steel, Cobalt Steel, Tungsten Steel and Alnico are used to make strong permanent magnets.

FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

- **Oersted's** experiment shows that a current carrying conductor produces a magnetic field and exerts a force on a magnet present nearby.
- **Ampere** suggested that the magnet must also exert an equal and opposite force on the current carrying conductor.
- **Faraday** (in 1821) discovered that “when a current carrying conductor is placed in a magnetic field, a mechanical force is exerted on the conductor which can make the conductor move.”

Activity 13.7. When a small aluminium rod carrying current is suspended between the two poles of horse-shoe magnet. It is observed that the rod is displaced in one direction. Reversing the direction of current in the aluminium rod leads to displacement in opposite direction. Even the interchanging of two poles of the magnet leads to reversal of the force acting on the current carrying rod and displaced in opposite direction.

Activity 13.7

- Take a small aluminium rod AB (of about 5 cm). Using two connecting wires suspend it horizontally from a stand, as shown in Fig. 13.12.
- Place a strong horse-shoe magnet in such a way that the rod lies between the two poles with the magnetic field directed upwards. For this put the north pole of the magnet vertically below and south pole vertically above the aluminium rod (Fig. 13.12).
- Connect the aluminium rod in series with a battery, a key and a rheostat.
- Now pass a current through the aluminium rod from end B to end A.
- What do you observe? It is observed that the rod is displaced towards the left. You will notice that the rod gets displaced.
- Reverse the direction of current flowing through the rod and observe the direction of its displacement. It is now towards the right. Why does the rod get displaced?

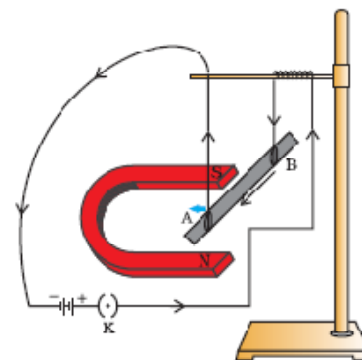


Figure 13.12
A current-carrying rod, AB, experiences a force perpendicular to its length and the magnetic field.

- Direction of magnetic force on the conductor depends upon two factors:
 - direction of the current, and
 - direction of the magnetic field.

Reversal of anyone of the above two factors will lead to reversal of direction of magnetic force.

- The maximum force is exerted on a current carrying conductor only when it is perpendicular to the direction of magnetic field. No force acts on a current carrying conductor when it is parallel to the magnetic field.

FLEMING'S LEFT-HAND RULE FOR THE DIRECTION OF FORCE

- If the thumb, the forefinger and the central finger of the left hand are stretched at right angles to each other, such that the forefinger points in the direction of magnetic field and the central finger in the direction of flow of current. Then the thumb will point in the direction of motion or the force acting on the conductor.
- The devices which use current-carrying conductors and magnetic fields includes electric motor, electric generator, microphone, loudspeaker, and current detecting and measuring instrument such as ammeter and galvanometer, etc.

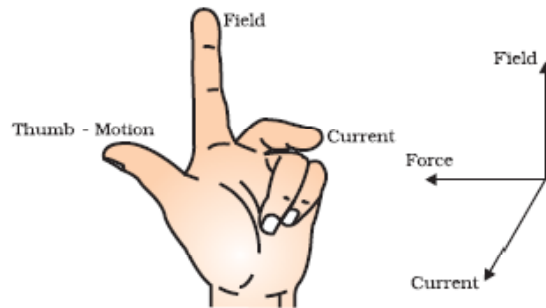


Figure 13.13
Fleming's left-hand rule

ELECTRIC MOTOR

- An electric motor is a device that converts electrical energy into mechanical energy.
- It is used as an important component in electric fans, refrigerators, mixers, washing machines, computers, MP3 players, etc.

PRINCIPLE OF A MOTOR

- A motor works on the principle that when a rectangular coil is placed in a magnetic field and current is passed through it, a force acts on the coil which rotates it continuously.

ELECTROMAGNETIC INDUCTION

- An electric current can produce magnetism, but can magnetism or magnets produce electric current? Michael Faraday in 1831, discovered that how a moving magnet can be used to generate electric current.
- The production of electricity from magnetism is called electromagnetic induction and the current produced by this process is called induced current.

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Activity 13.8. When north pole of a strong bar magnet is moved near a coil of wire, which is already connected to a galvanometer, the needle of galvanometer deflects towards one side. And when the north pole is moved away from the coil, the needle deflects in opposite direction.

Now, when the magnet is kept stationary and coil is moved near the north pole, needle of galvanometer shows same deflection and when the coil is moved away from north pole the needle shows deflection in opposite direction.

Even, if the polarity of magnet is changed to north to south the galvanometer deflects in opposite direction.

When the coil and magnet both are stationary, there is no deflection in galvanometer.

ELECTROMAGNETIC INDUCTION

- The phenomenon in which an electric current is induced in a circuit *due to a change in the magnetic field or the motion of the circuit in a magnetic field* is called electromagnetic induction.
- Motion of a magnet with respect to the coil produces an induced potential difference, which sets up an induced electric current in the circuit.
- The condition necessary for the production of electric current by electromagnetic induction is that there must be a relative motion between the coil of wire and magnet.
- Direction of induced current in any circuit can be reversed if-
 - Direction of motion of coil of wire is reversed.
 - Direction of magnetic field is reversed (by reversing the positions of the poles of the magnet).
- Electromagnetic induction can also be observed by using two conductors, where a changing magnetic field in a conductor induces a current in another conductor.

Activity 13.9. Two coils of insulated copper wire are wound over a single non conducting cylindrical roll. Where coil-1 is connected to a battery and coil-2 with galvanometer. Now, if coil-1 is switched on, the needle of galvanometer jump to one side and quickly returns back to zero, indicating a momentary current in coil-2.

If the coil-1 is switched off, the needle of galvanometer moves to the opposite direction and quickly returns to zero, this shows the current flowing in opposite direction in coil-2.

As soon as the current in coil-1 reaches either a steady value or zero, the galvanometer in coil-2 shows no deflection.

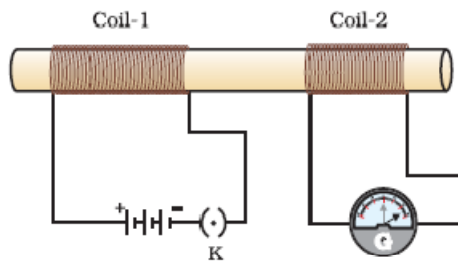
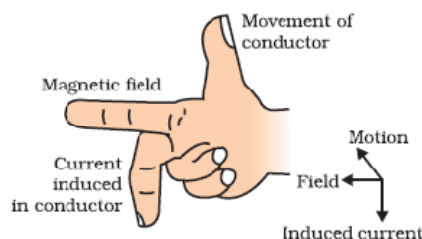


Figure 13.17
Current is induced in coil-2 when current in coil-1 is changed

- Deflection in the galvanometer of coil-2 occurs due to change in magnetic field around it, which is produced by the current in the coil-1. As the current in the coil-1 changes (starting or stopping), the magnetic field associated with it also changes. Thus the magnetic field around the coil-2 also change, which is the cause of induced electric current in it.
- The induced current is highest when the direction of motion of the coil is at right angles to the magnetic field.

FLEMING'S RIGHT-HAND RULE FOR THE DIRECTION OF INDUCED CURRENT

- If the thumb, the forefinger and the central finger of the right hand are stretched at right angles to each other such that the forefinger points in the direction of magnetic field and the thumb in the direction of motion of conductor. Then the central finger will point in the direction of induced current in the conductor.



ELECTRIC GENERATOR

- An electric generator is a device that converts mechanical energy into electrical energy.
- A small generator is called a Dynamo, e.g. bicycle dynamo.

PRINCIPLE OF A GENERATOR

- Electric generators are based upon the principle of electromagnetic induction i.e. when a conductor or a coil moved in a magnetic field, current is induced in the conductor or the coil.
- Electric generators are of two type:
 - Alternating Current Generator (A. C. Generator or Alternators)
 - Direct Current Generator (D. C. Generator)

DIRECT CURRENT AND ALTERNATING CURRENT

- **Direct Current or DC** always flows in one direction only. The positive (+) and negative (-) polarity of a direct current is fixed.
- Dry cells, dry cell battery, car battery and DC generator are some sources of DC.
- **Alternating current or AC** reverses direction after equal interval of time. The positive (+) and negative (-) polarity of an alternating current is not fixed.
- In India AC changes its direction after every $1/100$ seconds, that is, the frequency of AC is 50 Hz.
- Power house generator, car alternators and bicycle dynamo are some sources of AC.
- An important advantage of AC over DC is that AC can be transmitted over long distances without much loss of electrical energy.

DOMESTIC ELECTRIC CIRCUITS

- Electricity is generated at power station and brought to our homes by two thick wires fixed over overhead electric poles or by underground cables.
- From the electric poles or underground cables, we receive supply of electric power through a main supply.
- One of the wires in this supply is called **live wire** or positive (with red insulation cover) while another is called **neutral wire** or negative (with black insulation cover).
- Live wire has high potential of 220 volts whereas neutral wire has zero potential. Thus is **potential difference of 220 volts** is maintains in the supply.
- There is no harm if someone touches the neutral wire but if someone touches the live wire he will get an electric shock.
- The both wire enter into a box fitted in our house, where a main fuse (of 50 A rating) is put on the live wire and then connected to an electricity meter.

- Now the both wire are connected to a main switch. After the main switch there is another fuse on the live wire called consumer's fuse.
 - Now these wires are ready to supply electricity to separate circuits within the house. Usually there are two separate circuit present in our house:-
- (i) **Power circuit:** it is of 15 A current rating having 15 A fuses. It is used for the appliances with higher power ratings such as geysers, air coolers, AC, etc.

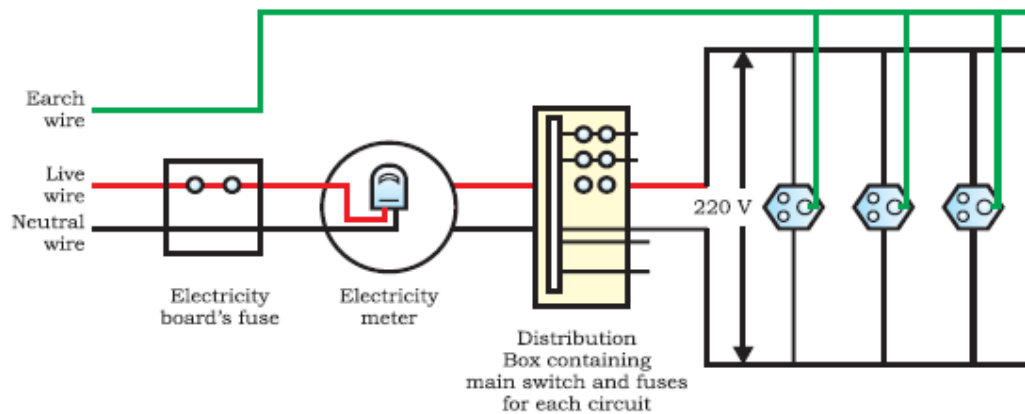


Figure 13.20 A schematic diagram of one of the common domestic circuits

- (ii) **Lightening circuit:** it is of 5 A current rating having 5 A fuses. It is used for the bulb, fan, tube light, etc.
- Along with live and neutral wire, a third wire also goes in the rooms. This wire is called **earth wire** which has insulation of green colour.
 - One end of earth wire is connected to a metal plate deep in the earth near the house. And another end is connected to such electrical appliances which have metallic body, thus provides a low resistance conducting path for the current. It always keeps the metallic case at zero potential of earth, if connected.
 - **Earth wire is used as safety measure.** If there is any leakage of electric current to the metallic body of appliance the current goes down to the earth through the earth wire and the user may not get a severe electric shock, if he touches the metallic case.
 - **All the electrical appliances are connected in parallel across the live and the neutral wire.** The parallel connection has some advantages:
 - (i) If one of the appliances is switched off, or gets fused, there is no effect on the other application and they keep on operating.
 - (ii) The same voltage or potential difference of the main line is available for all the electrical appliances.
 - (iii) The overall resistance of the household circuit is reduced due to which the current from the power supply is high.

- **Electric fuse is the most important safety device.** It is used for protecting the circuit due to short-circuiting or overloading of the circuits. It is connected in series in the circuit.

- **Overloading:** It occurs when the current in the circuit increase abruptly. It leads to excessive heating of the wire and even electric fire. Overloading may be arise in a circuit when-
 - (i) Live wire and neutral wire come into direct contact because of faulty and torn insulation. This is called short-circuiting. In such situation, current in the circuit become very large and heat the wire dangerously high.
 - (ii) When too many appliances are connected to a single socket, which increase the current flowing through the circuit.
 - (iii) There is accidental hike in the supply voltage.

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