CHAPTER

1

Electricity

Electricity is an important source of energy in the modern times. Electricity is used in our homes, in industry and in transport. For example, electricity is used in our homes for lighting, operating fans and heating purposes (see Figure 1). In industry, electricity is used to run various types of machines, and in transport sector electricity is being used to pull electric trains. In this chapter, we will discuss electric potential, electric current, electric power and the heating effect of electric current. In order to understand electricity, we should first know something about the electric charges. These are discussed below.

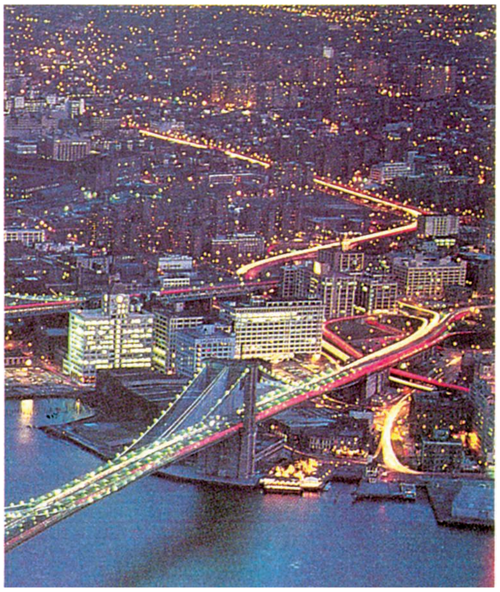


Figure 1. Can you imagine life without electricity ? What would this city look like at night if there was no electricity ?

If we bring a plastic comb near some very tiny pieces of paper, it will not have any effect on them. If, however, the comb is first rubbed with dry hair and then brought near the tiny pieces of paper, we find that the comb now attracts the pieces of paper towards itself. These observations are explained by saying that initially the comb is electrically neutral so it has no effect on the tiny pieces of paper. When the comb is rubbed with dry hair, then it gets electric charge. This electrically charged comb exerts an electric force on the tiny pieces of paper and attracts them. Similarly, a glass rod rubbed with silk cloth ; and an ebonite rod rubbed with woollen cloth also acquire the ability to attract small pieces of paper and are said to have electric charge.

Types of Electric Charges

It has been found by experiments that there are two types of electric charges : *positive* charges and *negative* charges. By convention, the charge acquired by a glass rod (rubbed with a silk cloth) is called positive charge and the charge acquired by an ebonite rod (rubbed with a woollen cloth) is called negative charge. An important property of electric charges is that :

(*i*) **Opposite charges (or Unlike charges) attract each other.** For example, a positive charge attracts a negative charge.

(*ii*) **Similar charges (or Like charges) repel each other.** For example, a positive charge repels a positive charge; and a negative charge repels a negative charge.

The SI unit of electric charge is coulomb which is denoted by the letter **C.** We can define this unit of charge as follows : One coulomb is that quantity of electric charge which exerts a force of 9×10^9 newtons on an equal charge placed at a distance of 1 metre from it. We now know that all the matter contains positively charged particles called *protons* and negatively charged particles called *electrons.* A proton possesses a positive charge of 1.6×10^{-19} C whereas **an electron possesses a negative charge of 1.6×10^{-19} C.** It is obvious that the unit of electric charge called 'coulomb' is much *bigger* than the charge of a proton or an electron. This point will become more clear from the following example.

Sample Problem. Calculate the number of electrons constituting one coulomb of charge.

(NCERT Book Question)

Solution. We know that the charge of an electron is 1.6×10^{-19} coulomb (or 1.6×10^{-19} C).

Now, If charge is 1.6×10^{-19} C, No. of electrons = 1

So, If charge is 1 C, then No. of electrons $= \frac{1}{1.6 \times 10^{-19}} \times 1$

$$= \frac{10^{19}}{1.6}$$

$$= \frac{10}{1.6} \times 10^{18}$$

$$= 6.25 \times 10^{18}$$

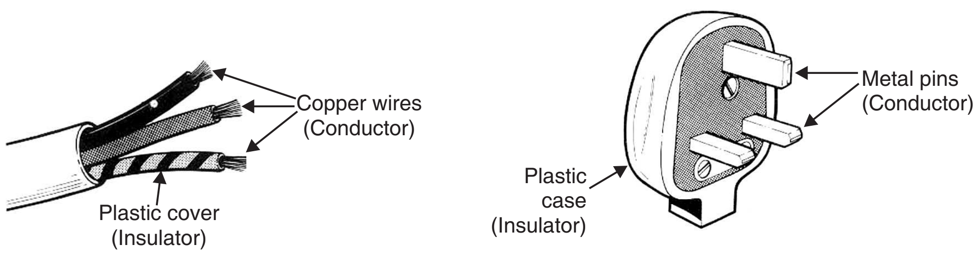
Thus, 6.25×10^{18} electrons taken together constitute 1 coulomb of charge.

The above example tells us that **the SI unit of electric charge 'coulomb' (C) is equivalent to the charge contained in 6.25×10^{18} electrons.** Thus, coulomb is a very big unit of electric charge.

Conductors and Insulators

In some substances, the electric charges can flow easily while in others they cannot. So, all the substances can be divided mainly into two electrical categories : conductors and insulators.

Those substances through which electric charges can flow, are called conductors. But the flow of electric charges is called electricity, so we can also say that : **Those substances through which electricity can flow are called conductors.** All the metals like silver, copper and aluminium, etc., are conductors (see Figure 2). The metal alloys such as nichrome, manganin and constantan (which are used for making heating elements of electrical appliances) are also conductors but their electrical conductivity is much less than that of pure metals. Carbon, in the form of graphite, is also a conductor. The human body is a fairly good conductor.



(*a*) An electric cable containing three insulated copper wires

(*b*) A three-pin plug

Figure 2. Conductors and insulators.

Those substances through which electric charges cannot flow, are called insulators. In other words : **Those substances through which electricity cannot flow are called insulators.** Glass, ebonite, rubber, most plastics, paper, dry wood, cotton, mica, bakelite, porcelain, and dry air, are all insulators because they do not allow electric charges (or electricity) to flow through them (see Figure 2). In the case of charged insulators like glass, ebonite, etc., the electric charges remain bound to them, and do not move away.

We have just seen that some of the substances are conductors whereas others are insulators. We will now explain the reason for this difference in their behaviour.

All the conductors (like metals) have some electrons which are loosely held by the nuclei of their atoms. These electrons are called "free electrons" and can move from one atom to another atom throughout the conductor. **The presence of "free electrons" in a substance makes it a conductor (of electricity).**

The electrons present in insulators are strongly held by the nuclei of their atoms. Since there are "no free electrons" in an insulator which can move from one atom to another, an insulator does not allow electric charges (or electricity) to flow through it.

Electricity can be classified into two parts :

1. Static electricity, and
2. Current electricity.

In static electricity, the electric charges remain at *rest* (or *stationary*), they do not move. The charge acquired by a glass rod rubbed with a silk cloth and the charge acquired by an ebonite rod rubbed with a woollen cloth are the examples of static electricity. The lightning which we see in the sky during the rainy season also involves static electricity. In current electricity, the electric charges are in *motion* (and produce an electric current). The electricity which we use in our homes is the current electricity (see Figure 3). In this chapter, we will discuss only current electricity in detail. So, when we talk of electricity in these discussions, it will actually mean current electricity.

Figure 3. The electricity which we use in our homes is current electricity.

Electric Potential

When a small positive test charge is placed in the electric field due to another charge, it experiences a force. So, work has to be done on the positive test charge to move it against this force of repulsion. **The electric potential (or potential) at a point in an electric field is defined as the work done in moving a unit positive charge from infinity to that point.** Potential is denoted by the symbol V and its unit is volt. A potential of 1 volt at a point means that 1 joule of work is done in moving 1 unit positive charge from infinity to that point. Since the unit of charge is coulomb, so we can also say that : A potential of 1 volt at a point means that 1 joule of work is done in moving 1 coulomb of positive charge from infinity to that point. A more common term used in electricity is, however, potential difference which we will discuss now.

Potential Difference

The *difference in electric potential* between two points is known as *potential difference.* **The potential difference between two points in an electric circuit is defined as the amount of work done in moving a unit charge from one point to the other point.** That is :

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Quantity of charge moved}}$$

If W joules of work has to be done to move Q coulombs of charge from one point to the other point, then the potential difference V between the two points is given by the formula :

$$\text{Potential difference,} \quad V = \frac{W}{Q}$$

where W = work done

and Q = quantity of charge moved

The SI unit of potential difference is volt which is denoted by the letter **V**. The potential difference is also sometimes written in symbols as p.d.

The potential difference between two points is said to be 1 volt if 1 joule of work is done in moving 1 coulomb of electric charge from one point to the other.

$$\text{Thus,} \quad 1 \text{ volt} = \frac{1 \text{ joule}}{1 \text{ coulomb}}$$

$$\text{or} \quad 1\text{ V} = \frac{1\text{ J}}{1\text{ C}}$$

$$\text{or} \quad 1\text{ V} = 1\text{ J C}^{-1}$$

The potential difference is measured by means of an instrument called voltmeter (see Figure 4). The voltmeter is always connected in *parallel* across the two points where the potential difference is to be measured. For example, in Figure 5 we have a conductor *AB* such as a resistance wire (which is the part of a circuit), and we want to measure the potential difference across its ends. So, one end of the voltmeter *V* is connected to the point *A* and the other end to the point *B*. We can read the value of the potential difference in volts on the dial of the voltmeter. **A voltmeter has a high resistance** so that it takes a negligible current from the circuit. The term "volt" gives rise to the word "voltage". **Voltage is the other name for potential difference**. We will now solve some problems based on potential difference.

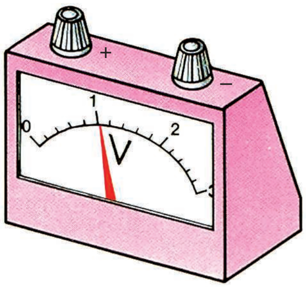


Figure 4. This is a voltmeter.

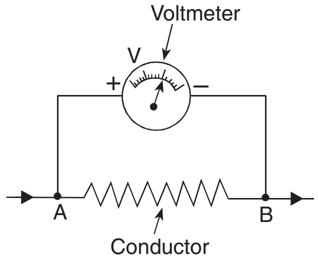


Figure 5. A voltmeter connected in parallel with conductor AB to measure the potential difference across its ends.

Sample Problem 1. How much work is done in moving a charge of 2 coulombs from a point at 118 volts to a point at 128 volts ?

Solution. We know that :

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

$$\text{or} \quad V = \frac{W}{Q}$$

Here, Potential difference, $V = 128 - 118$

$= 10$ volts

Work done, W = ? (To be calculated)

And, Charge moved, Q = 2 coulombs

Putting these values in the above formula, we get :

$$10 = \frac{W}{2}$$

or $W = 10 \times 2$

Thus, Work done, $W = 20$ joules

Sample Problem 2. How much energy is given to each coulomb of charge passing through a 6 V battery ?

(NCERT Book Question)

Solution. The term 'each coulomb' means 'every 1 coulomb', so the charge here is 1 coulomb. The potential difference is 6 volts. We have to find out the energy. This energy will be equal to the work done. Now,

$$\text{Potential difference} = \frac{\text{Work done}}{\text{Charge moved}}$$

$$\text{or} \qquad V = \frac{W}{Q}$$

$$6 = \frac{W}{1}$$

$$\text{So,} \qquad \text{Work done, } W = 6 \times 1 \text{ joules}$$

$$= 6 \text{ J}$$

Since the work done on each coulomb of charge is 6 joules, therefore, the energy given to each coulomb of charge is also 6 joules.

Before we go further and discuss electric current, **please answer the following questions :**

Very Short Answer Type Questions

1. By what other name is the unit joule/coulomb called ?

2. Which of the following statements correctly defines a volt ?

(*a*) a volt is a joule per ampere.

(*b*) a volt is a joule per coulomb.

3. (*a*) What do the letters p.d. stand for ?

(*b*) Which device is used to measure p.d. ?

4. What is meant by saying that the electric potential at a point is 1 volt ?

5. How much work is done when one coulomb charge moves against a potential difference of 1 volt ?

6. What is the SI unit of potential difference ?

7. How much work is done in moving a charge of 2 C across two points having a potential difference of 12 V ?

8. What is the unit of electric charge ?

9. Define one coulomb charge.

10. Fill in the following blanks with suitable words :

(*a*) Potential difference is measured in ....by using a ....placed in..............across a component.

(*b*) Copper is a good...............Plastic is an..................

Short Answer Type Questions

11. What is meant by conductors and insulators ? Give two examples of conductors and two of insulators.

12. Which of the following are conductors and which are insulators ?

Sulphur, Silver, Copper, Cotton, Aluminium, Air, Nichrome, Graphite, Paper, Porcelain, Mercury, Mica, Bakelite, Polythene, Manganin.

13. What do you understand by the term "electric potential" ? (or potential) at a point ? What is the unit of electric potential ?

14. (*a*) State the relation between potential difference, work done and charge moved.

(*b*) Calculate the work done in moving a charge of 4 coulombs from a point at 220 volts to another point at 230 volts.

15. (*a*) Name a device that helps to measure the potential difference across a conductor.

(*b*) How much energy is transferred by a 12 V power supply to each coulomb of charge which it moves around a circuit ?

Long Answer Type Question

16. (*a*) What do you understand by the term "potential difference" ?

(*b*) What is meant by saying that the potential difference between two points is 1 volt ?

(*c*) What is the potential difference between the terminals of a battery if 250 joules of work is required to transfer 20 coulombs of charge from one terminal of battery to the other ?

(*d*) What is a voltmeter ? How is a voltmeter connected in the circuit to measure the potential difference between two points. Explain with the help of a diagram.

(*e*) State whether a voltmeter has a high resistance or a low resistance. Give reason for your answer.

Multiple Choice Questions (MCQs)

17. The work done in moving a unit charge across two points in an electric circuit is a measure of :

(*a*) current (*b*) potential difference (*c*) resistance (*d*) power

18. The device used for measuring potential difference is known as :

(*a*) potentiometer (*b*) ammeter (*c*) galvanometer (*d*) voltmeter

19. Which of the following units could be used to measure electric charge ?

(*a*) ampere (*b*) joule (*c*) volt (*d*) coulomb

20. The unit for measuring potential difference is :

(*a*) watt (*b*) ohm (*c*) volt (*d*) kWh

21. One coulomb charge is equivalent to the charge contained in :

(*a*) 2.6×10^{19} electrons (*b*) 6.2×10^{19} electrons

(*c*) 2.65×10^{18} electrons (*d*) 6.25×10^{18} electrons

Questions Based on High Order Thinking Skills (HOTS)

22. Three 2 V cells are connected in series and used as a battery in a circuit.

(*a*) What is the p.d. at the terminals of the battery ?

(*b*) How many joules of electrical energy does 1 C gain on passing through (*i*) one cell (*ii*) all three cells ?

23. The atoms of copper contain electrons and the atoms of rubber also contain electrons. Then why does copper conduct electricity but rubber does not conduct electricity ?

ANSWERS

1. Volt **2.** (*b*) **5.** 1 J **7.** 24 J **10.** (*a*) volts ; voltmeter ; parallel (*b*) conductor ; insulator
14. (*b*) 40 J **15.** (*b*) 12 J **16.** (*c*) 12.5 V **17.** (*b*) **18.** (*d*) **19.** (*d*) **20.** (*c*) **21.** (*d*)
22. (*a*) 6 V (*b*) (*i*) 2 J (*ii*) 6 J

ELECTRIC CURRENT

When two charged bodies at different electric potentials are connected by a metal wire, then electric charges will flow from the body at higher potential to the one at lower potential (till they both acquire the same potential). This flow of charges in the metal wire constitutes an electric current. **It is the potential difference between the ends of the wire which makes the electric charges (or current) to flow in the wire.** We now know that the electric charges whose flow in a metal wire constitutes electric current are the negative charges called *electrons*. Keeping this in mind, we can now define electric current as follows.

The electric current is a flow of electric charges (called electrons) in a conductor such as a metal wire. *The magnitude of electric current in a conductor is the amount of electric charge passing through a given point of the conductor in one second.* If a charge of Q coulombs flows through a conductor in time t seconds, then the magnitude I of the electric current flowing through it is given by :

$$\text{Current,} \quad I = \frac{Q}{t}$$

The SI unit of electric current is ampere which is denoted by the letter **A.** We can use the above formula to obtain the definition of the unit of current called '*ampere*'. If we put charge Q = 1 coulomb and time t = 1 second in the above formula, then current I becomes 1 ampere. This gives us the following definition of ampere : **When 1 coulomb of charge flows through any cross-section of a conductor in 1 second, the electric current flowing through it is said to be 1 ampere.** That is,

$$1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

$$\text{or} \qquad 1 \text{ A} = \frac{1 \text{ C}}{1 \text{ s}}$$

Sometimes, however, a smaller unit of current called "milliampere" is also used, which is denoted by mA.

$$1 \text{ milliampere} = \frac{1}{1000} \text{ ampere}$$

$$\text{or} \qquad 1 \text{ mA} = \frac{1}{1000} \text{ A}$$

$$\text{or} \qquad 1 \text{ mA} = 10^{-3} \text{ A}$$

Thus, the small quantities of current are expressed in the unit of milliampere, mA (1 mA = 10^{-3} A). The very small quantities of current are expressed in a still smaller unit of current called microampere, μA (1 μA = 10^{-6} A).

Current is measured by an instrument called ammeter (see Figure 6). The ammeter is always connected in *series* with the circuit in which the current is to be measured. For example, if we want to find out the current flowing through a conductor *BC* (such as a resistance wire), then we should connect the ammeter *A* in series with the conductor *BC* as shown in Figure 7. Since the entire current passes through the ammeter, therefore, **an ammeter should have very low resistance** so that it may not change the value of the current flowing in the circuit. Let us solve one problem now.

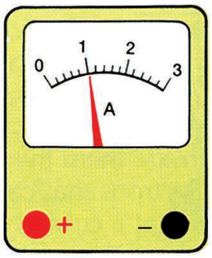


Figure 6. This is an ammeter.

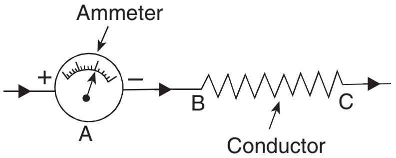


Figure 7. An ammeter connected in series with a conductor BC to measure the current passing through it.

Sample Problem. An electric bulb draws a current of 0.25 A for 20 minutes. Calculate the amount of electric charge that flows through the circuit.

Solution. Here, Current, I = 0.25 A

Charge, Q = ? (To be calculated)

And Time, t = 20 minutes

= 20 × 60 seconds

= 1200 s

We know that, $I = \frac{Q}{t}$

So, $0.25 = \frac{Q}{1200}$

$Q = 0.25 \times 1200$ C

$Q = 300$ C

Thus, the amount of electric charge that flows through the circuit is 300 coulombs.

How to Get a Continuous Flow of Electric Current

We have just studied that it is due to the potential difference between two points that an electric current flows between them. **The simplest way to maintain a potential difference between the two ends of a conductor so as to get a continuous flow of current is to connect the conductor between the terminals of a cell or a battery.** Due to the chemical reactions going on inside the cell or battery, a potential difference is maintained between its terminals. And this potential difference drives the current in a circuit in which the cell or battery is connected. For example, a single dry cell has a potential difference of 1.5 volts between its two terminals (+ terminal and – terminal). So, when a dry cell is connected to a torch bulb through copper connecting wires, then its potential difference causes the electric current to flow through the copper wires and the bulb, due to which the bulb lights up (see Figure 8). In order to maintain current in the external circuit, the cell has to expend the chemical energy which is stored in it. Please note that the torch bulb used in the circuit shown in Figure 8 is actually a kind of 'conductor'. We can also call it a resistor. It is clear from the above discussion that a common source of 'potential difference' or 'voltage' is a cell or a battery. It can make the current flow in a circuit.

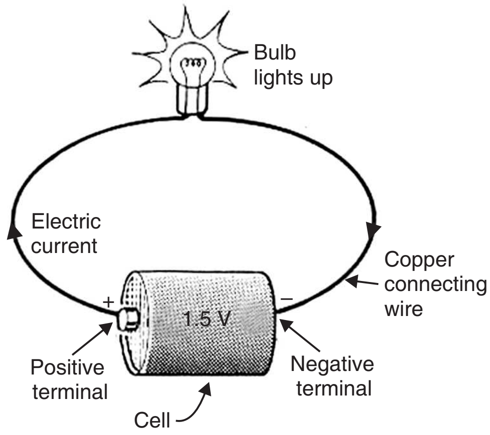


Figure 8. The potential difference between the two terminals of this cell causes electric current to flow through copper wires and the bulb.

Direction of Electric Current

When electricity was invented a long time back, it was known that there are two types of charges : positive charges and negative charges, but the electron had *not* been discovered at that time. So, electric current was considered to be a flow of positive charges and the direction of flow of the positive charges was taken to be the direction of electric current. Thus, **the conventional direction of electric current is from positive terminal of a cell (or battery) to the negative terminal, through the outer circuit.** So, in our circuit diagrams, we put the arrows on the connecting wires pointing from the positive terminal of the cell towards the negative terminal of the cell, to show the direction of conventional current (see Figure 8). *The actual flow of electrons (which constitute the current) is, however, from negative terminal to positive terminal of a cell, which is opposite to the direction of conventional current.*

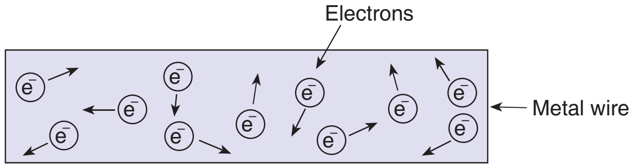


Figure 9. When no cell or battery is connected across a metal wire, the electrons in it flow at random in all directions (Please note that this is a highly magnified diagram of a metal wire).

How the Current Flows in a Wire

We know that **electric current is a flow of electrons in a metal wire (or conductor)** when a cell or battery is applied across its ends. A metal wire has plenty of free electrons in it.

(*i*) When the metal wire has not been connected to a source of electricity like a cell or a battery, then the electrons present in it move at random in all the directions between the atoms of the metal wire as shown in Figure 9.

(*ii*) When a source of electricity like a cell or a battery is connected between the ends of the metal wire, then an electric force acts on the electrons present in the wire. Since the electrons are negatively charged, they start moving from *negative* end to the *positive* end of the wire (see Figure 10). This flow of electrons constitutes the electric current in the wire.

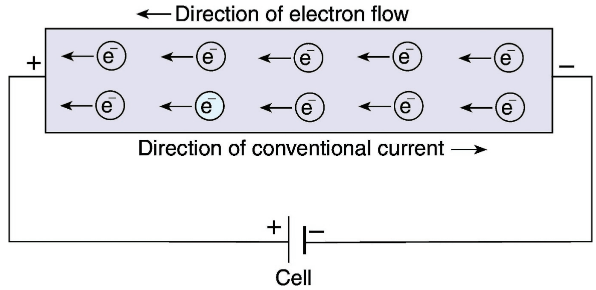
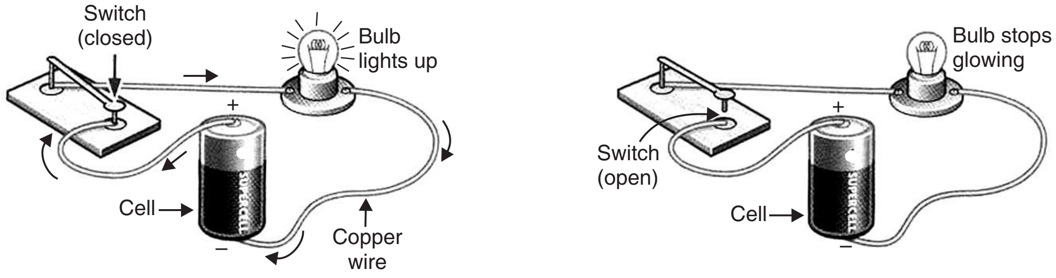


Figure 10. When a cell or battery is connected across a metal wire, the electrons in it flow towards positive terminal.

Electric Circuits

A cell (or battery) can make electrons move and electric current flow. But there must be a conducting path (like wires, bulb, etc.) between the two terminals of the cell through which electrons can move causing the electric current to flow. **A continuous conducting path consisting of wires and other resistances (like electric bulb, etc.) and a switch, between the two terminals of a cell or a battery along which an electric current flows, is called a circuit.** A simple electric circuit is shown in Figure 11(*a*).



(*a*) When the switch is closed, the circuit is complete and a current flows in it.

(*b*) When the switch is open, the circuit gets broken and no current flows in it.

Figure 11. The electric circuits showing actual components (like cell, bulb, switch, etc.).

In Figure 11(*a*) we have a cell having a positive terminal (+) and a negative terminal (–). The positive terminal of the cell is connected to one end of the bulb holder with a copper wire (called connecting wire) through a switch. The negative terminal of the cell is connected to the other end of bulb holder. In Figure 11(*a*) the switch is closed. So, the circuit in Figure 11(*a*) is complete and hence a current flows in this circuit. This current makes the bulb light up [see Figure 11(*a*)].

If we open the switch as shown in Figure 11(*b*), then a gap is created between the two ends of the connecting wire. Due to this, one terminal of the cell gets disconnected from the bulb and current stops flowing in the circuit. Thus, when the switch is open, the circuit breaks and no current flows through the bulb. The bulb stops glowing [see Figure 11(*b*)].

Symbols for Electrical Components (or Circuit Symbols)

In electric circuits, we have to show various electrical components such a cell, a battery, connecting wires, wire joints, fixed resistance, variable resistance, ammeter, voltmeter, galvanometer, an open switch, a closed switch, and an electric bulb (or lamp), etc. Now, to draw the electric circuits by making the *actual* sketches of the various electrical components is a difficult job and takes a lot of time. So, the scientists have devised some symbols for electrical components which are easy to draw. They are called electrical symbols or circuit symbols. The common electrical symbols for electrical components which are used in drawing circuit diagrams are given below :

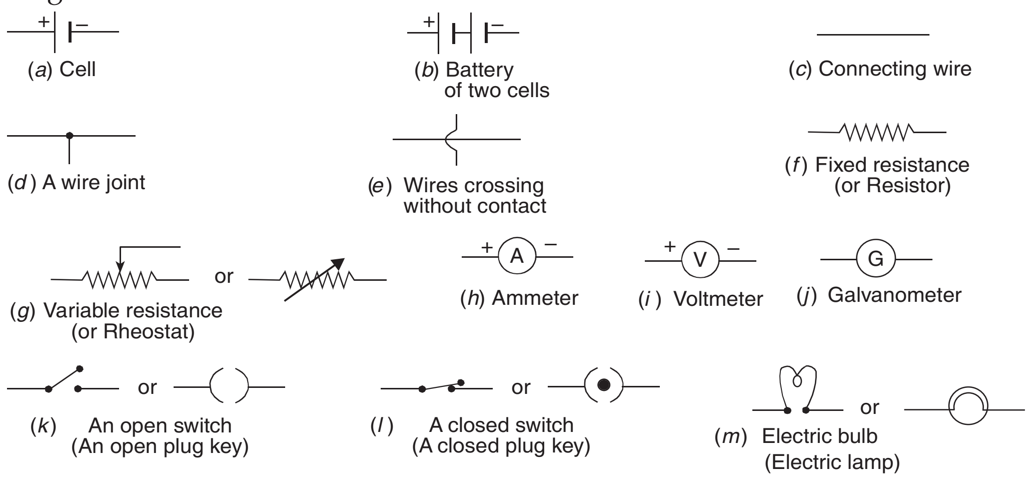


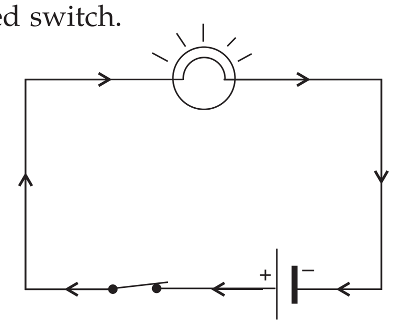
Figure 12. Electrical symbols (or circuit symbols).

The symbol for a single cell is shown in Figure 12(*a*). The symbol of a single cell consists of two parallel vertical lines, one thin and long and the other thick and short (having horizontal lines on the sides). The longer vertical line represents the positive terminal of the cell (so it is marked plus, +), whereas the shorter vertical line represents the negative terminal of the cell (so it is marked minus, –). **Battery is a combination of two (or more) cells connected in series.** In order to obtain a battery, the negative terminal of the first cell is joined with the positive terminal of the second cell, and so on. The symbol for a battery is shown in Figure 12(*b*). The battery shown in Figure 12(*b*) consists of two cells joined together in series. We can also draw the symbol for a battery having more than two cells in a similar way.

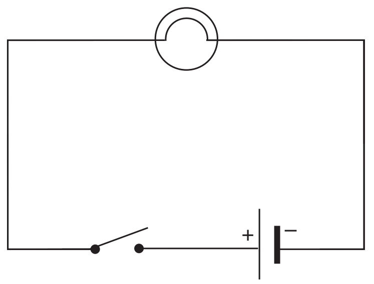
The resistance which can be changed as desired is called *variable* resistance. Variable resistance has two symbols shown in Figure 12(*g*). **Variable resistance is also known as rheostat.** Rheostat is a variable resistance which is usually operated by a sliding contact on a long coil (made of resistance wire). A rheostat is used to change the current in a circuit without changing the voltage source like the cell or battery. It can do so by changing the resistance of the circuit. The galvanometer is a current-detecting instrument (which we will come across in the next Chapter). The switch (or plug key) is a device for 'making' or 'breaking' an electric circuit. When the switch is open, then the circuit 'breaks' and no current flows in it [see Figure 12(*k*)]. But when the switch is closed, then the circuit is 'made' (or completed) and current flows in it [see Figure 12(*l*)].

Circuit Diagrams

Electrical circuits are represented by drawing circuit diagrams. **A diagram which indicates how different components in a circuit have been connected by using the electrical symbols for the components, is called a circuit diagram.** An electric circuit consisting of a cell, a bulb and a closed switch which was drawn in Figure 11(*a*) can be represented by drawing a circuit diagram shown in Figure 13(*a*). In the circuit diagram shown in Figure 13(*a*), a bulb has been connected to the two terminals of a cell by copper wires through a closed switch.



(*a*) This is the circuit diagram of the circuit shown in Figure 11(*a*).



(*b*) This is the circuit diagram of the circuit given in Figure 11(*b*).

Figure 13. Circuit diagrams drawn by using the electrical symbols of the various components.

The electric circuit consisting of a cell, a bulb and an open switch which was drawn in Figure 11(*b*) can be represented by drawing a circuit diagram shown in Figure 13(*b*). In the circuit diagram shown in Figure 13(*b*), a bulb has been connected to the two terminals of the cell by copper wires through an open switch.

The circuit shown in Figure 13(*a*) is complete (due to closed switch). Since there is no gap, therefore, current flows in this circuit and the bulb lights up. In this case, the electrons can move through the external circuit. These moving electrons form an electric current. The circuit given in Figure 13(*b*) is broken (due to a gap because of open switch), so no current flows in this circuit and bulb goes off. The electrons cannot flow in this circuit due to the gap produced by the open switch.

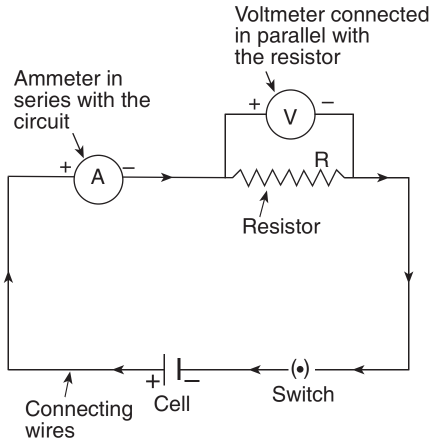


Figure 14. An electric circuit consisting of a cell, a resistor, an ammeter, a voltmeter and a switch (or plug key).

Another simple electric circuit has been shown in Figure 14. In this circuit, a resistor *R* has been connected to the two terminals of a cell through a switch. An ammeter *A* has been put in series with the resistor *R*. This is to measure current in the circuit. A voltmeter *V* has been connected across the ends of the resistor *R*, that is, voltmeter is connected in parallel with the resistor. This voltmeter is to measure potential difference (or voltage) across the ends of the resistor *R*. Before we go further and discuss Ohm's law, **please answer the following questions :**

Very Short Answer Type Questions

1. By what name is the physical quantity coulomb/second called ?
2. What is the flow of charge called ?
3. What actually travels through the wires when you switch on a light ?
4. Which particles constitute the electric current in a metallic conductor ?
5. (*a*) In which direction does conventional current flow around a circuit ?
(*b*) In which direction do electrons flow ?
6. Which of the following equation shows the correct relationship between electrical units ?
1 A = 1 C/s or 1 C = 1 A/s
7. What is the unit of electric current ?
8. (*a*) How many milliamperes are there in 1 ampere ?
(*b*) How many microamperes are there in 1 ampere ?
9. Which of the two is connected in series : ammeter or voltmeter ?
10. Compare how an ammeter and a voltmeter are connected in a circuit.
11. What do the following symbols mean in circuit diagrams ?

(*i*)  (*ii*) 

12. If 20 C of charge pass a point in a circuit in 1 s, what current is flowing ?
13. A current of 4 A flows around a circuit for 10 s. How much charge flows past a point in the circuit in this time ?
14. What is the current in a circuit if the charge passing each point is 20 C in 40 s ?
15. Fill in the following blanks with suitable words :
(*a*) A current is a flow of.................For this to happen there must be a ....circuit.
(*b*) Current is measured in..............using an..............placed in............in a circuit.

Short Answer Type Questions

16. (*a*) Name a device which helps to maintain potential difference across a conductor (say, a bulb).
(*b*) If a potential difference of 10 V causes a current of 2 A to flow for 1 minute, how much energy is transferred ?
17. (*a*) What is an electric current ? What makes an electric current flow in a wire ?
(*b*) Define the unit of electric current (or Define ampere).
18. What is an ammeter ? How is it connected in a circuit ? Draw a diagram to illustrate your answer.
19. (*a*) Write down the formula which relates electric charge, time and electric current.
(*b*) A radio set draws a current of 0.36 A for 15 minutes. Calculate the amount of electric charge that flows through the circuit.
20. Why should the resistance of :
(*a*) an ammeter be very small ?
(*b*) a voltmeter be very large ?
21. Draw circuit symbols for (*a*) fixed resistance (*b*) variable resistance (*c*) a cell (*d*) a battery of three cells (*e*) an open switch (*f*) a closed switch.
22. What is a circuit diagram ? Draw the labelled diagram of an electric circuit comprising of a cell, a resistor, an ammeter, a voltmeter and a closed switch (or closed plug key). Which of the two has a large resistance : an ammeter or a voltmeter ?
23. If the charge on an electron is 1.6×10^{-19} coulombs, how many electrons should pass through a conductor in 1 second to constitute 1 ampere current ?
24. The p.d. across a lamp is 12 V. How many joules of electrical energy are changed into heat and light when :
(*a*) a charge of 1 C passes through it ?

(*b*) a charge of 5 C passes through it ?
(*c*) a current of 2 A flows through it for 10 s ?

25. In 10 s, a charge of 25 C leaves a battery, and 200 J of energy are delivered to an outside circuit as a result.
(*a*) What is the p.d. across the battery ?
(*b*) What current flows from the battery ?

Long Answer Type Question

26. (*a*) Define electric current. What is the SI unit of electric current.
(*b*) One coulomb of charge flows through any cross-section of a conductor in 1 second. What is the current flowing through the conductor ?
(*c*) Which instrument is used to measure electric current ? How should it be connected in a circuit ?
(*d*) What is the conventional direction of the flow of electric current ? How does it differ from the direction of flow of electrons ?
(*e*) A flash of lightning carries 10 C of charge which flows for 0.01 s. What is the current ? If the voltage is 10 MV, what is the energy ?

Multiple Choice Questions (MCQs)

27. The other name of potential difference is :
(*a*) ampereage (*b*) wattage (*c*) voltage (*d*) potential energy

28. Which statement/statements is/are correct ?
1. An ammeter is connected in series in a circuit and a voltmeter is connected in parallel.
2. An ammeter has a high resistance.
3. A voltmeter has a low resistance.

(*a*) 1, 2, 3 (*b*) 1, 2 (*c*) 2, 3 (*d*) 1

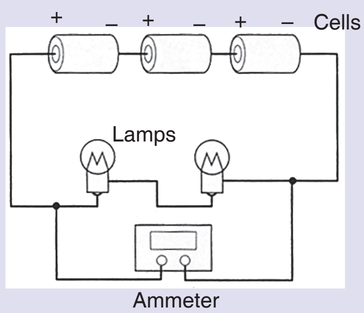
29. Which unit could be used to measure current ?
(*a*) Watt (*b*) Coulomb (*c*) Volt (*d*) Ampere

30. If the current through a floodlamp is 5 A, what charge passes in 10 seconds ?
(*a*) 0.5 C (*b*) 2 C (*c*) 5 C (*d*) 50 C

31. If the amount of electric charge passing through a conductor in 10 minutes is 300 C, the current flowing is :
(*a*) 30 A (*b*) 0.3 A (*c*) 0.5 A (*d*) 5 A

Questions Based on High Order Thinking Skills (HOTS)

32. A student made an electric circuit shown here to measure the current through two lamps.
(*a*) Are the lamps in series or parallel ?
(*b*) The student has made a mistake in this circuit. What is the mistake ?
(*c*) Draw a circuit diagram to show the correct way to connect the circuit. Use the proper circuit symbols in your diagram.



33. Draw a circuit diagram to show how 3 bulbs can be lit from a battery so that 2 bulbs are controlled by the same switch while the third bulb has its own switch.

34. An electric heater is connected to the 230 V mains supply. A current of 8 A flows through the heater.
(*a*) How much charge flows around the circuit each second ?
(*b*) How much energy is transferred to the heater each second ?

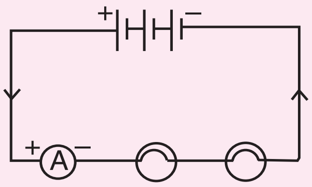
35. How many electrons are flowing per second past a point in a circuit in which there is a current of 5 amp ?

ANSWERS

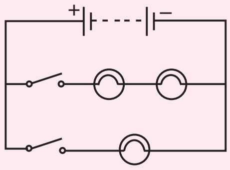
1. Ampere **2.** Electric current **3.** Electrons **4.** Electrons **6.** 1 A = 1 C/s **9.** Ammeter **11.** (*i*) Variable resistance (*ii*) Closed plug key **12.** 20 A **13.** 40 C **14.** 0.5 A **15.** (*a*) electrons ; closed (*b*) amperes ; ammeter ; series **16.** (*a*) Cell or Battery (*b*) 1200 J **19.** (*b*) 324 C **22.** See Figure 14 on page 10;

Voltmeter **23.** 6.25×10^{18} electrons **24.** (*a*) 12 J (*b*) 60 J (*c*) 240 J **25.** (*a*) 8 V (*b*) 2.5 A **26.** (*b*) 1 ampere (*e*) 1000 A ; 100 MJ (or 100,000,000 J) *Note.* M = Mega which means 1 million or 1000,000 **27.** (*c*) **28.** (*d*) **29.** (*d*) **30.** (*d*) **31.** (*c*) **32.** (*a*) In series (*b*) Ammeter is connected in parallel with the lamps. It should be connected in series.

(*c*)



33.



34. (*a*) 8 C (*b*) 1840 J **35.** 31.25×10^{18}

OHM'S LAW

Ohm's law gives a relationship between *current* and *potential difference*. According to Ohm's law : **At constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends.** If I is the current flowing through a conductor and V is the potential difference (or voltage) across its ends, then according to Ohm's law :

$$I \propto V \qquad \text{(At constant temp.)}$$

This can also be written as : $V \propto I$

or $V = R \times I$

where R is a constant called "resistance" of the conductor. The value of this constant depends on the nature, length, area of cross-section and temperature of the conductor. The above equation can also be written as :

$$\frac{V}{I} = R \qquad ...(1)$$

where V = Potential difference

I = Current

and R = Resistance (which is a constant)

The above equation is a mathematical expression of Ohm's law. Equation (1) can be written in words as follows :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{constant} \quad \text{(called resistance)}$$

We find that **the ratio of potential difference applied between the ends of a conductor and the current flowing through it is a constant quantity called resistance.**

We have just seen that : $\frac{V}{I} = R$

or $V = I \times R$

or $\frac{V}{R} = I$

So, Current, $I = \frac{V}{R}$

It is obvious from this relation that :

(*i*) **the current is directly proportional to potential difference,** and

(*ii*) **the current is inversely proportional to resistance.**

Since the current is directly proportional to the potential difference applied across the ends of a conductor, it means that **if the potential difference across the ends of a conductor is doubled, the current flowing through it also gets doubled,** and **if the potential difference is halved, the current also gets halved.** On the other hand, the current is inversely proportional to resistance. So, **if the resistance is doubled, the current gets halved,** and **if the resistance is halved, the current gets doubled.** Thus, the strength of an electric current in a given conductor depends on two factors :

(*i*) potential difference across the ends of the conductor, and

(*ii*) resistance of the conductor.

We will now discuss the electrical resistance of a conductor in detail.

Resistance of a Conductor

The electric current is a flow of electrons through a conductor. When the electrons move from one part of the conductor to the other part, they collide with other electrons and with the atoms and ions present in the body of the conductor. Due to these collisions, there is some obstruction or opposition to the flow of electron current through the conductor. **The property of a conductor due to which it opposes the flow of current through it is called resistance.** The resistance of a conductor is numerically equal to the ratio of potential difference across its ends to the current flowing through it. That is :

$$\text{Resistance} = \frac{\text{Potential difference}}{\text{Current}}$$

$$\text{or} \qquad R = \frac{V}{I}$$

The resistance of a conductor depends on length, thickness, nature of material and temperature, of the conductor. A long wire (or conductor) has more resistance and a short wire has less resistance. Again, a thick wire has less resistance whereas a thin wire has more resistance. Rise in temperature of a wire (or conductor) increases its resistance.

The SI unit of resistance is ohm which is denoted by the symbol omega, Ω. The unit of resistance ohm, can be defined by using Ohm's law as described below.

According to Ohm's law :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{Resistance} \quad \text{(A constant)}$$

$$\text{That is,} \qquad \frac{V}{I} = R$$

$$\text{So,} \qquad \text{Resistance, } R = \frac{V}{I}$$

Now, if the potential difference V is 1 volt and the current I is 1 ampere, then resistance R in the above equation becomes 1 ohm.

$$\text{That is,} \qquad 1 \text{ ohm} = \frac{1 \text{ volt}}{1 \text{ ampere}}$$

This gives us the following definition for ohm : **1 ohm is the resistance of a conductor such that when a potential difference of 1 volt is applied to its ends, a current of 1 ampere flows through it.** We can find out the resistance of a conductor by using Ohm's law equation $\frac{V}{I} = R.$ This will become more clear from the following examples.

Sample Problem 1. Potential difference between two points of a wire carrying 2 ampere current is 0.1 volt. Calculate the resistance between these points.

Solution. From Ohm's law we have :

$$\frac{\text{Potential difference}}{\text{Current}} = \text{Resistance}$$

$$\text{or} \qquad \frac{V}{I} = R$$

Here, Potential difference, V = 0.1 volt

Current, I = 2 amperes

And, Resistance, R = ? (To be calculated)

Putting these values in the above formula, we get :

$$\frac{0.1}{2} = R$$

$$0.05 = R$$

or Resistance, R = 0.05 ohm (or 0.05 Ω)

Sample Problem 2. A simple electric circuit has a 24 V battery and a resistor of 60 ohms. What will be the current in the circuit ? The resistance of the connecting wires is negligible.

Solution. In this case :

Potential difference, V = 24 volts

Resistance, R = 60 ohms

And, Current, I = ? (To be calculated)

Now, putting these values in the Ohm's law equation :

$$\frac{V}{I} = R$$

we get :
$$\frac{24}{I} = 60$$

So,
$$60\,I = 24$$

And,
$$I = \frac{24}{60} \text{ ampere}$$

$$I = 0.4 \text{ ampere} \quad (\text{or } 0.4 \text{ A})$$

Thus, the current flowing in the circuit is 0.4 ampere.

Sample Problem 3. An electric iron draws a current of 3.4 A from the 220 V supply line. What current will this electric iron draw when connected to 110 V supply line ?

Solution. First of all we will calculate the resistance of electric iron. Now, in the first case, the electric iron draws a current of 3.4 A from 220 V supply line. So,

Potential difference, V = 220 V

Current, I = 3.4 A

And, Resistance, R = ? (To be calculated)

Now,
$$\frac{V}{I} = R$$

So,
$$\frac{220}{3.4} = R$$

Resistance, R = 64.7 Ω

Thus, the resistance of electric iron is 64.7 ohms. This resistance will now be used to find out the current drawn when the electric iron is connected to 110 V supply line. So,

$$\frac{V}{I} = R$$

$$\frac{110}{I} = 64.7$$

$$\text{Current, } I = \frac{110}{64.7}$$

$$= 1.7 \text{ A}$$

Thus, the electric iron will draw a current of 1.7 amperes from 110 volt supply line.

Graph Between V and I

If a graph is drawn between the potential difference readings (*V*) and the corresponding current values (*I*), the graph is found to be a straight line passing through the origin (see Figure 15). A straight line graph can be obtained only if the two quantities are directly proportional to one another. Since the 'current-potential difference' graph is a straight line, we conclude that **current is directly proportional to the potential difference.** It is clear from the graph *OA* that as the potential difference *V* increases, the current *I* also increases, but the ratio $\frac{V}{I}$ remains constant. This constant is called resistance of the conductor. We will now solve one problem based on the graph between *V* and *I*.

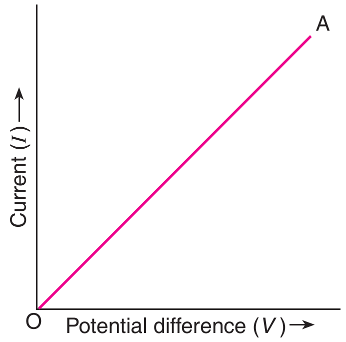


Figure 15. *V* – *I* graph for a metal conductor.

Sample Problem. The values of current *I* flowing through a coil for the corresponding values of the potential difference *V* across the coil are shown below :

I (amperes)	:	0.05	0.10	0.20	0.30	0.4
V (volts)	:	0.85	1.70	3.5	5.0	6.8

Plot a graph between *V* and *I* and calculate the resistance of the coil.

Solution. We take a graph paper and mark the potential difference (*V*) values of 1, 2, 3, 4, 5, 6 and 7 on the *x*-axis. The current (*I*) values of 0.1, 0.2, 0.3 and 0.4 are marked on the *y*-axis (see Figure 16).

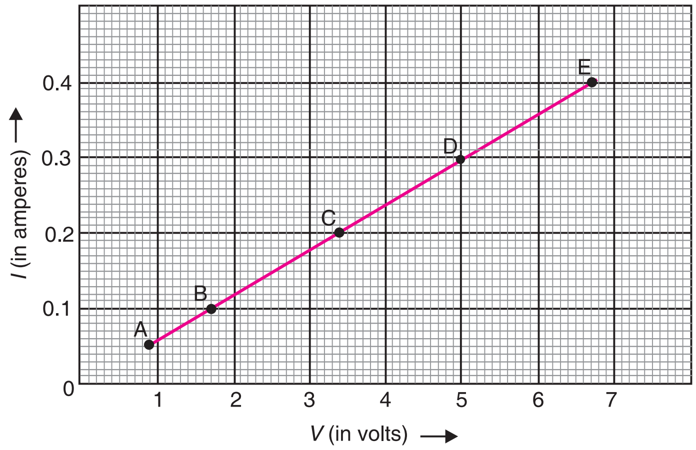


Figure 16.

(*i*) On plotting the first reading of 0.85 V on *x*-axis and 0.05 A on the *y*-axis, we get the point *A* on the graph paper (see Figure 16)

(*ii*) On plotting the second reading of 1.70 V on the *x*-axis and 0.10 A on the *y*-axis, we get a second point *B* on the graph paper.

(*iii*) On plotting the third reading of 3.5 V on the *x*-axis and 0.20 A on the *y*-axis, we get a third point *C* on the graph paper.

(*iv*) On plotting the fourth reading of 5.0 V on *x*-axis and 0.30 A on the *y*-axis, we get a fourth point *D* on the graph paper.

(*v*) And on plotting the fifth reading of 6.8 V on *x*-axis and 0.4 A on the *y*-axis, we get a fifth point *E* on the graph paper.

Let us now join all the five points *A, B, C, D* and *E*. In this way we get a straight-line graph between *V* and *I*. This straight-line graph shows that current (*I*) is directly proportional to the potential difference (*V*). And this conclusion proves Ohm's law.

Let us calculate the resistance now. If we look at the above graph, we find that at point *E*, potential difference (V) is 6.8 volts whereas the current (I) is 0.4 amperes. Now, we know that :

$$\text{Resistance,} \quad R = \frac{V}{I}$$

$$\text{So,} \quad R = \frac{6.8}{0.4}$$

$$R = 17 \text{ ohms}$$

Thus, the resistance is of 17 ohms.

Experiment to Verify Ohm's Law

If we can show that for a given conductor, say a piece of resistance wire (such as a nichrome wire), the ratio $\frac{\textit{potential difference}}{\textit{current}}$ is constant, then Ohm's law will get verified. Alternatively, we can draw a graph between the potential difference (V) and current (I), and if this graph is a straight line, even then Ohm's law gets verified. Let us see how this is done in the laboratory.

Suppose we have a piece of resistance wire R (which is the conductor here) (Figure 17), and we want to verify Ohm's law for it, that is, we want to show that the conductor R obeys Ohm's law. For this purpose we take a battery (B), a switch (S), a rheostat (Rh), an ammeter (A), a voltmeter (V) and some connecting wires. Using all these and the conductor R we make a circuit as shown in Figure 17.

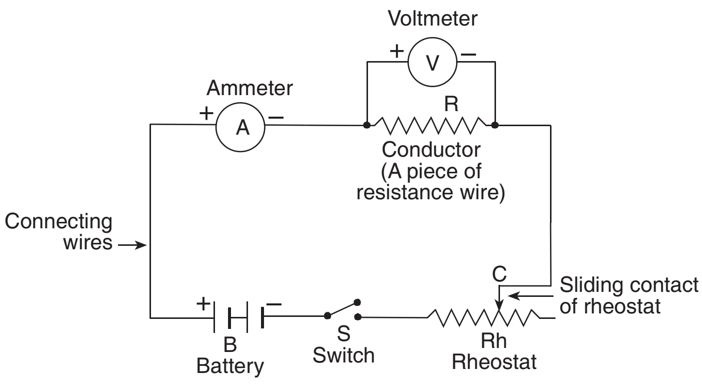


Figure17. Circuit to verify Ohm's law in the laboratory.

To start the experiment, the circuit is completed by pressing the switch S. On pressing the switch, a current starts flowing in the whole circuit including the conductor R. This current is shown by the ammeter. The rheostat Rh is initially so adjusted that a *small* current passes through the circuit. The ammeter reading is now noted. This reading gives us the current I flowing through the conductor R. The voltmeter reading is also noted which will give the potential difference V across the ends of the conductor. This gives us the first set of V and I readings. The current in the circuit is now *increased* step by step, by changing the position of the sliding contact C of the rheostat. The current values and the corresponding potential difference values are noted in all the cases. The ratio $\frac{\textit{potential difference}}{\textit{current}}$ or $\frac{V}{I}$ is calculated for all the readings. It is found that the ratio $\frac{V}{I}$ has constant value for all the observations. Since the ratio of potential difference and current, $\frac{V}{I}$ is constant, Ohm's law gets verified because this shows that the current is directly proportional to potential difference. The constant ratio $\frac{V}{I}$ gives us the resistance R of the conductor. So, this Ohm's law experiment can also be used to determine the resistance of a conductor. If a graph is drawn between potential difference readings and corresponding current readings, we will get a straight line graph showing that current is directly proportional to potential difference. This also verifies Ohm's law.

Good Conductors, Resistors and Insulators

On the basis of their electrical resistance, all the substances can be divided into three groups : Good conductors, Resistors and Insulators. **Those substances which have very low electrical resistance are called good conductors.** A good conductor allows the electricity to flow through it easily. Silver metal is the *best*

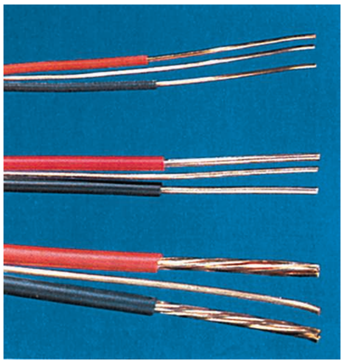


Figure 18. The electric wires are made of copper (good conductor). Their covering is made of plastic (insulator).

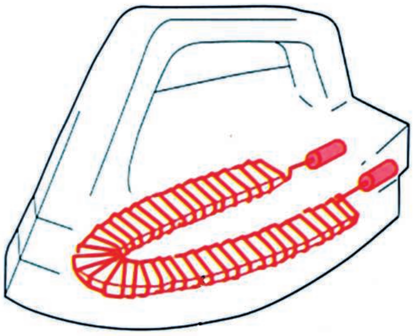


Figure 19. The heating element of electric iron is made of nichrome wire which is a resistor.

Figure 20. Rubber is an insulator. The electricians wear rubber gloves to protect themselves from electric shocks.

conductor of electricity. Copper and aluminium metals are also *good* conductors. Electric wires are made of copper or aluminium because they have very low electrical resistance (see Figure 18). **Those substances which have comparatively high electrical resistance, are called resistors.** The alloys like nichrome, manganin and constantan (or eureka), all have quite high resistances, so they are called resistors. Resistors are used to make those electrical devices where high resistance is required (see Figure 19). A resistor *reduces* the current in a circuit. **Those substances which have infinitely high electrical resistance are called insulators.** An insulator does not allow electricity to flow through it. Rubber is an excellent insulator. Electricians wear rubber handgloves while working with electricity because rubber is an insulator and protects them from electric shocks (see Figure 20). Wood is also a good insulator. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Name the law which relates the current in a conductor to the potential difference across its ends.

2. Name the unit of electrical resistance and give its symbol.

3. Name the physical quantity whose unit is "ohm".

4. What is the general name of the substances having infinitely high electrical resistance ?

5. Keeping the resistance constant, the potential difference applied across the ends of a component is halved. By how much does the current change ?

6. State the factors on which the strength of electric current flowing in a given conductor depends.

7. Which has less electrical resistance : a thin wire or a thick wire (of the same length and same material) ?

8. Keeping the potential difference constant, the resistance of a circuit is halved. By how much does the current change ?

9. A potential difference of 20 volts is applied across the ends of a resistance of 5 ohms. What current will flow in the resistance ?

10. A resistance of 20 ohms has a current of 2 amperes flowing in it. What potential difference is there between its ends ?

11. A current of 5 amperes flows through a wire whose ends are at a potential difference of 3 volts. Calculate the resistance of the wire.

12. Fill in the following blank with a suitable word :
Ohm's law states a relation between potential difference and ....

Short Answer Type Questions

13. Distinguish between good conductors, resistors and insulators. Name two good conductors, two resistors and two insulators.

14. Classify the following into good conductors, resistors and insulators :
Rubber, Mercury, Nichrome, Polythene, Aluminium, Wood, Manganin, Bakelite, Iron, Paper, Thermocol, Metal coin

15. What is Ohm's law ? Explain how it is used to define the unit of resistance.

16. (*a*) What is meant by the "resistance of a conductor" ? Write the relation between resistance, potential difference and current.

(*b*) When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Calculate the value of the resistance of the resistor.

17. (*a*) Define the unit of resistance (or Define the unit "ohm").

(*b*) What happens to the resistance as the conductor is made thinner ?

(*c*) Keeping the potential difference constant, the resistance of a circuit is doubled. By how much does the current change ?

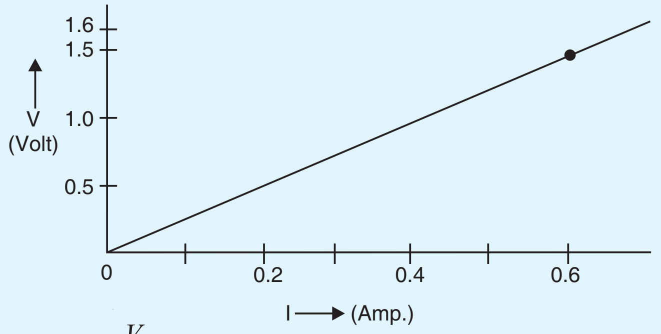
18. (*a*) Why do electricians wear rubber hand gloves while working with electricity ?

(*b*) What p.d. is needed to send a current of 6 A through an electrical appliance having a resistance of 40 Ω ?

19. An electric circuit consisting of a 0.5 m long nichrome wire XY, an ammeter, a voltmeter, four cells of 1.5 V each and a plug key was set up.

(*i*) Draw a diagram of this electric circuit to study the relation between the potential difference maintained between the points 'X' and 'Y' and the electric current flowing through XY.

(*ii*) Following graph was plotted between *V* and *I* values :



What would be the values of $\frac{V}{I}$ ratios when the potential difference is 0.8 V, 1.2 V and 1.6 V respectively ? What conclusion do you draw from these values ?

(*iii*) What is the resistance of the wire ?

Long Answer Type Question

20. (*a*) What is the ratio of potential difference and current known as ?

(*b*) The values of potential difference *V* applied across a resistor and the correponding values of current *I* flowing in the resistor are given below :

Potential difference, *V* (in volts)	:	2.5	5.0	10.0	15.0	20.0	25.0
Current, *I* (in amperes)	:	0.1	0.2	0.4	0.6	0.8	1.0

Plot a graph between *V* and *I*, and calculate the resistance of the resistor.

(*c*) Name the law which is illustrated by the above *V–I* graph.

(*d*) Write down the formula which states the relation between potential difference, current and resistance.

(*e*) The potential difference between the terminals of an electric iron is 240 V and the current is 5.0 A. What is the resistance of the electric iron ?

Multiple Choice Questions (MCQs)

21. The p.d. across a 3 Ω resistor is 6 V. The current flowing in the resistor will be :

(*a*) $\frac{1}{2}$ A (*b*) 1 A (*c*) 2 A (*d*) 6 A

22. A car headlight bulb working on a 12 V car battery draws a current of 0.5 A. The resistance of the light bulb is :

(*a*) 0.5 Ω (*b*) 6 Ω (*c*) 12 Ω (*d*) 24 Ω

23. An electrical appliance has a resistance of 25 Ω. When this electrical appliance is connected to a 230 V supply line, the current passing through it will be :

(*a*) 0.92 A (*b*) 2.9 A (*c*) 9.2 A (*d*) 92 A

24. When a 4 Ω resistor is connected across the terminals of a 12 V battery, the number of coulombs passing through the resistor per second is :

(*a*) 0.3 (*b*) 3 (*c*) 4 (*d*) 12

25. Ohm's law gives a relationship between :
(*a*) current and resistance
(*b*) resistance and potential difference
(*c*) potential difference and electric charge
(*d*) current and potential difference

26. The unit of electrical resistance is :
(*a*) ampere (*b*) volt (*c*) coulomb (*d*) ohm

27. The substance having infinitely high electrical resistance is called :
(*a*) conductor (*b*) resistor (*c*) superconductor (*d*) insulator

28. Keeping the potential difference constant, the resistance of a circuit is doubled. The current will become :
(*a*) double (*b*) half (*c*) one-fourth (*d*) four times

29. Keeping the p.d. constant, the resistance of a circuit is halved. The current will become :
(*a*) one-fourth (*b*) four times (*c*) half (*d*) double

Questions Based on High Order Thinking Skills (HOTS)

30. An electric room heater draws a current of 2.4 A from the 120 V supply line. What current will this room heater draw when connected to 240 V supply line ?

31. Name the electrical property of a material whose symbol is "omega".

32. The graph between V and I for a conductor is a straight line passing through the origin.
(*a*) Which law is illustrated by such a graph ?
(*b*) What should remain constant in a statement of this law ?

33. A p.d. of 10 V is needed to make a current of 0.02 A flow through a wire. What p.d. is needed to make a current of 250 mA flow through the same wire ?

34. A current of 200 mA flows through a 4 kΩ resistor. What is the p.d. across the resistor ?

ANSWERS

1. Ohm's law **3.** Electrical resistance **4.** Insulators **5.** Current becomes half **7.** Thick wire **8.** Current becomes double **9.** 4 A **10.** 40 V **11.** 0.6 Ω **12.** current **16.** (*b*) 4800 Ω **17.** (*c*) Current becomes half **18.** (*b*) 240 V **19.** (*ii*) 2.5, 2.5, 2.5 ; The ratio of potential difference applied to the wire and current passing through it is a constant (*iii*) 2.5 Ω **20.** (*a*) Resistance (*b*) 25 Ω (*c*) Ohm's law (*e*) 48 Ω **21.** (*c*) **22.** (*d*) **23.** (*c*) **24.** (*b*) **25.** (*d*) **26.** (*d*) **27.** (*d*) **28.** (*b*) **29.** (*d*) **30.** 4.8 A **31.** Resistance **32.** (*a*) Ohm's law (*b*) Temperature **33.** 125 V **34.** 800 V

FACTORS AFFECTING THE RESISTANCE OF A CONDUCTOR

The electrical resistance of a conductor (or a wire) depends on the following factors :
(*i*) length of the conductor,
(*ii*) area of cross-section of the conductor (or thickness of the conductor),
(*iii*) nature of the material of the conductor, and
(*iv*) temperature of the conductor.

We will now describe how the resistance depends on these factors.

1. Effect of Length of the Conductor

It has been found by experiments that on increasing the length of a wire, its resistance increases; and on decreasing the length of the wire, its resistance decreases. Actually, **the resistance of a conductor is directly proportional to its length.** That is,

Resistance, $R \propto l$ (where l is the length of conductor)

Since the resistance of a wire is directly proportional to its length, therefore, **when the length of a wire is doubled, its resistance also gets doubled;** and **if the length of a wire is halved, then its resistance also gets halved.** When we double the length of a wire, then this can be considered to be equivalent to two resistances joined in series, and their resultant resistance is the sum of the two resistances (which is double the original value). From this discussion we conclude that **a long wire (or long conductor) has more resistance,** and **a short wire has less resistance.**

2. Effect of Area of Cross-Section of the Conductor

It has been found by experiments that **the resistance of a conductor is inversely proportional to its area of cross-section.** That is,

Resistance, $R \propto \frac{1}{A}$ (where A is area of cross-section of conductor)

Since the resistance of a wire (or conductor) is inversely proportional to its area of cross-section, therefore, **when the area of cross-section of a wire is doubled, its resistance gets halved;** and **if the area of cross-section of wire is halved, then its resistance will get doubled.** We know that a thick wire has a greater area of cross-section whereas a thin wire has a smaller area of cross-section. This means that **a thick wire has less resistance,** and **a thin wire has more resistance.** A thick wire (having large area of cross-section) can be considered equivalent to a large number of thin wires connected in parallel. And we know that if we have two resistance wires connected in parallel, their resultant resistance is halved. So, doubling the area of cross-section of a wire will, therefore, halve the resistance. From the above discussion it is clear that to make resistance wires (or resistors) :

(*i*) short length of a thick wire is used for getting low resistance, and

(*ii*) long length of a thin wire is used for getting high resistance.

The thickness of a wire is usually represented by its diameter. It can be shown by calculations that **the resistance of a wire is inversely proportional to the square of its diameter.** Thus, when the diameter of a wire is doubled (made 2 times), its resistance becomes one-fourth $\left(\frac{1}{4}\right)$, and if the diameter of the wire is halved $\left(\text{made } \frac{1}{2}\right)$, then its resistance becomes four times (4 times). Similarly, if the diameter of a wire is tripled (made 3 times), then its resistance will become $\frac{1}{(3)^2}$ or $\frac{1}{9}$ th of its original value.

3. Effect of the Nature of Material of the Conductor

The electrical resistance of a conductor (say, a wire) depends on the nature of the material of which it is made. Some materials have low resistance whereas others have high resistance. For example, if we take two similar wires, having equal lengths and diameters, of copper metal and nichrome alloy, we will find that the resistance of nichrome wire is about 60 times more than that of the copper wire. This shows that the resistance of a conductor depends on the nature of the material of the conductor.

4. Effect of Temperature

It has been found that **the resistance of all pure metals increases on raising the temperature; and decreases on lowering the temperature.** But the resistance of alloys like manganin, constantan and nichrome is almost unaffected by temperature.

RESISTIVITY

It has been found by experiments that :

(*i*) The resistance of a given conductor is directly proportional to its length. That is :

$$R \propto l \quad \text{... (1)}$$

(*ii*) The resistance of a given conductor is inversely proportional to its area of cross-section. That is :

$$R \propto \frac{1}{A} \quad \text{... (2)}$$

By combining the relations (1) and (2), we get :

$$R \propto \frac{l}{A}$$

or

$$R = \frac{\rho \times l}{A} \quad \text{... (3)}$$

where ρ (rho) is a constant known as *resistivity* of the material of the conductor. Resistivity is also known as specific resistance.

From equation (3), it is clear that for a given conductor having a specified length l and area of cross-section A, the resistance R is directly proportional to its resistivity ρ. So, if we change the material of a conductor to one whose resistivity is two times, then the resistance will also become two times. And if we change the material of a conductor to one whose resistivity is three times, then the resistance will also become three times.

If we rearrange equation (3), we can write it as :

$$\text{Resistivity, } \rho = \frac{R \times A}{l} \qquad \text{..... (4)}$$

where R = resistance of the conductor

A = area of cross-section of the conductor

and l = length of the conductor

This formula for calculating the resistivity of the material of a conductor should be memorised because it will be used to solve numerical problems. By using this formula, we will now obtain the definition of resistivity. Let us take a conductor having a unit area of cross-section of 1 m^2 and a unit length of 1 m. So, putting $A = 1$ and $l = 1$ in equation (4), we get :

$$\text{Resistivity, } \rho = R$$

Thus, **the resistivity of a substance is numerically equal to the resistance of a rod of that substance which is 1 metre long and 1 square metre in cross-section.** Since the length is 1 metre and the area of cross-section is 1 square metre, so it becomes a 1 metre cube. So, we can also say that *the resistivity of a substance is equal to the resistance between the opposite faces of a 1 metre cube of the substance.* We will now find out the unit of resistivity.

We have just seen that :

$$\text{Resistivity, } \rho = \frac{R \times A}{l}$$

Now, to get the unit of resistivity ρ we should put the units of resistance R, area of cross-section A and length l in the above equation. We know that :

The unit of resistance R is ohm

The unit of area of cross-section A is $(\text{metre})^2$

And, The unit of length l is metre

So, putting these units in the above equation, we get :

$$\text{Unit of resistivity, } \rho = \frac{\text{ohm} \times (\text{metre})^2}{\text{metre}}$$

$$= \text{ohm–metre} \quad (\text{or } \Omega \text{ m})$$

Thus, **the SI unit of resistivity is ohm-metre** which is written in symbols as **Ω m.**

Please note that **the resistivity of a substance does not depend on its length or thickness. It depends on the nature of the substance and temperature.** The resistivity of a substance is its characteristic property. So, we can use the resistivity values to compare the resistances of two or more substances. Another point to be noted is that just as when we talk of resistance in the context of electricity, it actually means electrical resistance, in the same way, when we talk of *resistivity*, it actually means *electrical resistivity*. The resistivities of some of the common substances (or materials) are given on the next page.

Resistivities of Some Common Substances (at 20°C)

Category	*Substance (Material)*	*Resistivity*
Conductors :	***Metals***	
	1. Silver	1.60×10^{-8} Ω m
	2. Copper	1.69×10^{-8} Ω m
	3. Aluminium	2.63×10^{-8} Ω m
	4. Tungsten	5.20×10^{-8} Ω m
	5. Nickel	6.84×10^{-8} Ω m
	6. Iron	10.0×10^{-8} Ω m
	7. Chromium	12.9×10^{-8} Ω m
	8. Mercury	94.0×10^{-8} Ω m
	9. Manganese	184.0×10^{-8} Ω m
	Alloys	
	1. Manganin (Cu–Mn–Ni)	44×10^{-8} Ω m
	2. Constantan (Cu–Ni)	49×10^{-8} Ω m
	3. Nichrome (Ni–Cr–Mn–Fe)	110×10^{-8} Ω m
Semiconductors :	1. Germanium	0.6 Ω m
	2. Silicon	2300 Ω m
Insulators :	1. Glass	10^{10} to 10^{14} Ω m
	2. Paper (Dry)	10^{12} Ω m
	3. Diamond	10^{12} to 10^{13} Ω m
	4. Hard rubber	10^{13} to 10^{16} Ω m
	5. Ebonite	10^{15} to 10^{17} Ω m

From the above table we find that the resistivity of copper is 1.69×10^{-8} ohm-metre. Now, **by saying that the resistivity of copper is 1.69×10^{-8} ohm-metre, we mean that if we take a rod of copper metal 1 metre long and 1 square metre in area of cross-section, then its resistance will be 1.69×10^{-8} ohms.** Please note that a good conductor of electricity should have a low resistivity and a poor conductor of electricity will have a high resistivity. From the above table we find that of all the metals, silver has the lowest resistivity (of 1.60×10^{-8} Ω m), which means that silver offers the least resistance to the flow of current through it. Thus, **silver metal is the best conductor of electricity.** It is obvious that we should make electric wires of silver metal. But silver is a very costly metal. **We use copper and aluminium wires for the transmission of electricity because copper and aluminium have very low resistivities** (due to which they are very good conductors of electricity). From this discussion we conclude that *silver, copper* and *aluminium* are very good conductors of electricity.

The resistivities of alloys are much more higher than those of the pure metals (from which they are made). For example, the resistivity of manganin (which is an alloy of copper, manganese and nickel) is about 25 times more than that of copper; and the resistivity of constantan (which is an alloy of copper and nickel) is about 30 times more than that of copper metal. It is due to their high resistivities that manganin and constantan alloys are used to make resistance wires (or resistors) used in electronic appliances to reduce the current in an electrical circuit. Another alloy having a high resistivity is nichrome. This is an alloy of nickel, chromium, manganese and iron having a resistivity of about 60 times more than that of copper.

The heating elements (or heating coils) of electrical heating appliances such as electric iron and toaster, etc., are made of an alloy rather than a pure metal because (*i*) the resistivity of an alloy is much higher than that of pure metal, and (*ii*) an alloy does not undergo oxidation (or burn) easily even at high temperature, when it is red hot. For example, **nichrome alloy is used for making the heating elements of electrical appliances** such as electric iron, toaster, electric kettle, room heaters, water heaters (geysers), and hair dryers, etc., because :

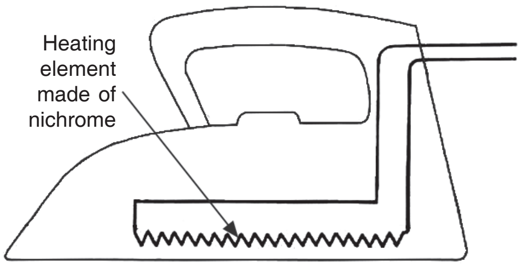


Figure 21. An electric iron.

(*i*) **nichrome has very high resistivity** (due to which the heating element made of nichrome has a high resistance and produces a lot of heat on passing current).

(*ii*) **nichrome does not undergo oxidation (or burn) easily even at high temperature.** Due to this nichrome wire can be kept red-hot without burning or breaking in air.

The resistivity of conductors (like metals) is very low. The resistivity of most of the metals increases with temperature. On the other hand, the resistivity of insulators like ebonite, glass and diamond is very high and does not change with temperature. **The resistivity of semi-conductors like silicon and germanium is in-between those of conductors and insulators,** and decreases on increasing the temperature. Semi-conductors are proving to be of great practical importance because of their marked change in conducting properties with temperature, impurity, concentration, etc. Semi-conductors are used for making solar cells and transistors. We will now solve some problems based on resistivity.

Sample Problem 1. A copper wire of length 2 m and area of cross-section 1.7×10^{-6} m^2 has a resistance of 2×10^{-2} ohms. Calculate the resistivity of copper.

Solution. The formula for resistivity is :

$$\text{Resistivity, } \rho = \frac{R \times A}{l}$$

Here, Resistance, $R = 2 \times 10^{-2}\ \Omega$

Area of cross-section, $A = 1.7 \times 10^{-6}$ m^2

And, Length, $l = 2$ m

So, putting these values in the above formula, we get :

$$\rho = \frac{2 \times 10^{-2} \times 1.7 \times 10^{-6}}{2}$$

$$= 1.7 \times 10^{-8}\ \Omega\text{ m}$$

Thus, the resistivity of copper is 1.7×10^{-8} ohm-metre.

Sample Problem 2. A copper wire has a diameter of 0.5 mm and resistivity of $1.6 \times 10^{-8}\ \Omega$ m.

(*a*) What will be the length of this wire to make its resistance 10 Ω ?

(*b*) How much does the resistance change if the diameter is doubled ? **(NCERT Book Question)**

Solution. (*a*) First of all we will calculate the area of cross-section of the copper wire. Here the diameter of copper wire is 0.5 mm, so its radius (r) will be $\frac{0.5}{2}$ mm or 0.25 mm. This radius of 0.25 mm will be equal to $\frac{0.25}{1000}$ m or 0.25×10^{-3} m. Thus, the radius r of this copper wire is 0.25×10^{-3} m. We will now find out the area of cross-section of the copper wire by using this value of the radius. So,

Area of cross-section of wire, $A = \pi r^2$

$$= \frac{22}{7} \times (0.25 \times 10^{-3})^2$$

$$= 0.1964 \times 10^{-6} \text{ m}^2$$

Resistivity, $\rho = 1.6 \times 10^{-8}\ \Omega$ m

Resistance, $R = 10\ \Omega$

And, Length, $l = ?$ (To be calculated)

Now, putting these values in the formula :

$$\rho = \frac{R \times A}{l}$$

We get : $$1.6 \times 10^{-8} = \frac{10 \times 0.1964 \times 10^{-6}}{l}$$

So, $$l = \frac{10 \times 0.1964 \times 10^{-6}}{1.6 \times 10^{-8}}$$

$$l = \frac{1964}{16}$$

$$l = 122.7 \text{ m}$$

Thus, the length of copper wire required to make 10 Ω resistance will be 122.7 metres.

(*b*) The resistance of a wire is *inversely* proportional to the square of its diameter. So, when the diameter of the wire is doubled (that is, made 2 times), then its resistance will become $\left(\frac{1}{2}\right)^2$ or $\frac{1}{4}$ (one-fourth).

Sample Problem 3. A 6 Ω resistance wire is doubled up by folding. Calculate the new resistance of the wire.

Solution. Suppose the length of 6 Ω resistance wire is l, its area of cross-section is A and its resistivity is ρ. Then :

$$R = \frac{\rho \times l}{A}$$

or $$6 = \frac{\rho \times l}{A} \quad \text{... (1)}$$

Now, when this wire is doubled up by folding, then its length will become half, that is, the length will become $\frac{l}{2}$. But on doubling the wire by folding, its area of cross-section will become double, that is, the area of cross-section will become $2A$. Suppose the new resistance of the doubled up wire (or folded wire) is R. So,

$$R = \frac{\rho \times l}{2 \times 2A}$$

or $$R = \frac{\rho \times l}{4A} \quad \text{... (2)}$$

Now, dividing equation (2) by equation (1), we get :

$$\frac{R}{6} = \frac{\rho \times l \times A}{4A \times \rho \times l}$$

or $$\frac{R}{6} = \frac{1}{4}$$

$$4R = 6$$

$$R = \frac{6}{4}$$

$$R = 1.5\ \Omega$$

Thus, the new resistance of the doubled up wire is 1.5 Ω.

Before we go further and study the combination of resistances (or resistors) in series and parallel, **please answer the following questions :**

Very Short Answer Type Questions

1. What happens to the resistance as the conductor is made thicker ?

2. If the length of a wire is doubled by taking more of wire, what happens to its resistance ?

3. On what factors does the resistance of a conductor depend ?

4. Name the material which is the best conductor of electricity.

5. Which among iron and mercury is a better conductor of electricity ?

6. Why are copper and aluminium wires usually used for electricity transmission ?

7. Name the material which is used for making the heating element of an electric iron.

8. What is nichrome ? State its one use.

9. Give two reasons why nichrome alloy is used for making the heating elements of electrical appliances.

10. Why are the coils of electric irons and electric toasters made of an alloy rather than a pure metal ?

11. Which has more resistance :

(*a*) a long piece of nichrome wire or a short one ?

(*b*) a thick piece of nichrome wire or a thin piece ?

12. (*a*) How does the resistance of a pure metal change if its temperature decreases ?

(*b*) How does the presence of impurities in a metal affect its resistance ?

13. Fill in the following blanks with suitable words :

Resistance is measured in............ The resistance of a wire increases as the length.........; as the temperature............ ; and as the cross-sectional area............

Short Answer Type Questions

14. (*a*) What do you understand by the "resistivity" of a substance ?

(*b*) A wire is 1.0 m long, 0.2 mm in diameter and has a resistance of 10 Ω. Calculate the resistivity of its material ?

15. (*a*) Write down an expression for the resistance of a metallic wire in terms of the resistivity.

(*b*) What will be the resistance of a metal wire of length 2 metres and area of cross-section 1.55×10^{-6} m^2, if the resistivity of the metal be 2.8×10^{-8} Ω m ?

16. (*a*) Give two examples of substances which are good conductors of electricity. Why do you think they are good conductors of electricity ?

(*b*) Calculate the resistance of a copper wire 1.0 km long and 0.50 mm diameter if the resistivity of copper is 1.7×10^{-8} Ωm.

17. Will current flow more easily through a thick wire or a thin wire of the same material when connected to the same source ? Give reason for your answer.

18. How does the resistance of a conductor depend on :

(*a*) length of the conductor ?

(*b*) area of cross-section of the conductor ?

(*c*) temperature of the conductor ?

19. (*a*) Give one example to show how the resistance depends on the nature of material of the conductor.

(*b*) Calculate the resistance of an aluminium cable of length 10 km and diameter 2.0 mm if the resistivity of aluminium is 2.7×10^{-8} Ωm.

20. What would be the effect on the resistance of a metal wire of :

(*a*) increasing its length ?

(*b*) increasing its diameter ?

(*c*) increasing its temperature ?

21. How does the resistance of a wire vary with its :

(*a*) area of cross-section ?

(*b*) diameter ?

22. How does the resistance of a wire change when :
(*i*) its length is tripled ?
(*ii*) its diameter is tripled ?
(*iii*) its material is changed to one whose resistivity is three times ?

23. Calculate the area of cross-section of a wire if its length is 1.0 m, its resistance is 23 Ω and the resistivity of the material of the wire is 1.84×10^{-6} Ω m.

Long Answer Type Question

24. (*a*) Define resistivity. Write an expression for the resistivity of a substance. Give the meaning of each symbol which occurs in it.
(*b*) State the SI unit of resistivity.
(*c*) Distinguish between resistance and resistivity.
(*d*) Name two factors on which the resistivity of a substance depends and two factors on which it does not depend.
(*e*) The resistance of a metal wire of length 1 m is 26 Ω at 20°C. If the diameter of the wire is 0.3 mm, what will be the resistivity of the metal at that temperature ?

Multiple Choice Questions (MCQs)

25. The resistance of a wire of length 300 m and cross-section area 1.0 mm^2 made of material of resistivity 1.0×10^{-7} Ωm is :
(*a*) 2 Ω (*b*) 3 Ω (*c*) 20 Ω (*d*) 30 Ω

26. When the diameter of a wire is doubled, its resistance becomes :
(*a*) double (*b*) four times (*c*) one-half (*d*) one-fourth

27. If the resistance of a certain copper wire is 1 Ω, then the resistance of a similar nichrome wire will be about :
(*a*) 25 Ω (*b*) 30 Ω (*c*) 60 Ω (*d*) 45 Ω

28. If the diameter of a resistance wire is halved, then its resistance becomes :
(*a*) four times (*b*) half (*c*) one-fourth (*d*) two times

29. The resistivity of a certain material is 0.6 Ω m. The material is most likely to be :
(*a*) an insulator (*b*) a superconductor (*c*) a conductor (*d*) a semiconductor

30. When the area of cross-section of a conductor is doubled, its resistance becomes :
(*a*) double (*b*) half (*c*) four times (*d*) one-fourth

31. The resistivity of copper metal depends on only one of the following factors. This factor is :
(*a*) length (*b*) thickness (*c*) temperature (*d*) area of cross-section

32. If the area of cross-section of a resistance wire is halved, then its resistance becomes :
(*a*) one-half (*b*) 2 times (*c*) one-fourth (*d*) 4 times

Questions Based on High Order Thinking Skills (HOTS)

33. A piece of wire of resistance 20 Ω is drawn out so that its length is increased to twice its original length. Calculate the resistance of the wire in the new situation.

34. The electrical resistivities of three materials P, Q and R are given below :

P	2.3×10^{3} Ω m
Q	2.63×10^{-8} Ω m
R	1.0×10^{15} Ω m

Which material will you use for making (*a*) electric wires (*b*) handle for soldering iron, and (*c*) solar cells ? Give reasons for your choices.

35. The electrical resistivities of four materials A, B, C and D are given below :

A	110×10^{-8} Ω m
B	1.0×10^{10} Ω m
C	10.0×10^{-8} Ω m
D	2.3×10^{3} Ω m

Which material is : (*a*) good conductor (*b*) resistor (*c*) insulator, and (*d*) semiconductor ?

36. The electrical resistivities of five substances A, B, C, D and E are given below :

A	5.20×10^{-8} Ω m

B	110×10^{-8} Ω m
C	2.60×10^{-8} Ω m
D	10.0×10^{-8} Ω m
E	1.70×10^{-8} Ω m

(*a*) Which substance is the best conductor of electricity ? Why ?
(*b*) Which one is a better conductor : A or C ? Why ?
(*c*) Which substance would you advise to be used for making heating elements of electric irons ? Why ?
(*d*) Which two substances should be used for making electric wires ? Why ?

ANSWERS

1. Resistance decreases **2.** Resistance gets doubled **5.** Iron **7.** Nichrome **11.** (*a*) Long piece of nichrome wire (*b*) Thin piece of nichrome wire **12.** (*a*) Resistance decreases (*b*) Resistance increases **13.** Ohms ; increases ; increases ; decreases **14.** (*b*) 31.4×10^{-8} Ωm **15.** (*b*) 0.036 Ω **16.** (*b*) 86.5 Ω **17.** Thick wire ; Lesser electrical resistance **19.** (*b*) 86 Ω **22.** (*i*) Resistance becomes 3 times (*ii*) Resistance becomes $\frac{1}{9}$ th. (*iii*) Resistance becomes 3 times **23.** 8.0×10^{-8} m^2 **24.** (*e*) 1.84×10^{-8} Ωm, **25.** (*d*) **26.** (*d*) **27.** (*c*) **28.** (*a*) **29.** (*d*) **30.** (*b*) **31.** (*c*) **32.** (*b*) **33.** 80 Ω (*Hint*. In the new situation, length becomes $2l$ and area of cross-section becomes $\frac{A}{2}$) **34.** (*a*) Q ; Very low resistivity (*b*) R ; Very high resistivity (*c*) P; Semiconductor **35.** (*a*) C (*b*) A (*c*) B (*d*) D **36.** (*a*) E ; Least electrical resistivity (*b*) C ; Lesser electrical resistivity (*c*) B ; High electrical resistivity (*d*) C and E ; Low electrical resistivities

COMBINATION OF RESISTANCES (OR RESISTORS)

Apart from potential difference, current in a circuit depends on resistance of the circuit. So, in the electrical circuits of radio, television and other similar things, it is usually necessary to combine two or more resistances to get the required current in the circuit. We can combine the resistances lengthwise (called series) or we can put the resistances parallel to one another. Thus, **the resistances can be combined in two ways : (*i*) in series, and (*ii*) in parallel.** If we want to *increase* the total resistance, then the individual resistances are connected in *series*, and if we want to *decrease* the resistance, then the individual resistances are connected in *parallel*. We will study these two cases in detail, one by one.

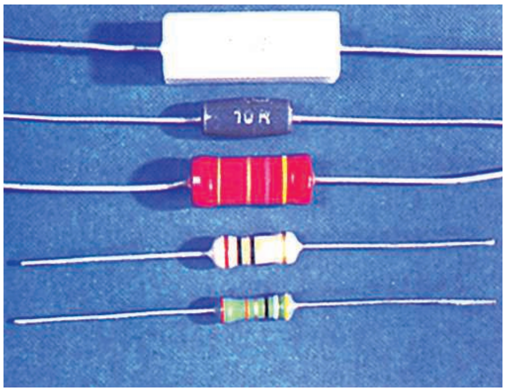


Figure 22. This picture shows some of the resistances (or resistors) . These can be connected in series or parallel combinations.

When two (or more) resistances are connected end to end consecutively, they are said to be connected in series. Figure 23 shows two resistances R_1 and R_2 which are connected in series. On the other hand, **when two (or more) resistances are connected between the same two points, they are said to be connected in parallel** (because they become parallel to one another). In Figure 24, the two resistances R_1 and R_2 are connected in parallel arrangement between the same two points A and B. In the above examples, we have shown only two resistances (or resistors) connected in series and parallel combinations. We can, however, connect any number of resistors in these two arrangements.

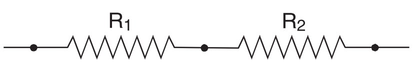


Figure 23. Two resistances (R_1 and R_2) connected in series.

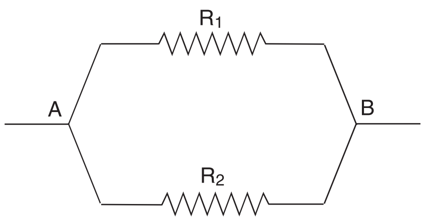


Figure 24. Two resistances (R_1 and R_2) connected in parallel.

RESISTANCES (OR RESISTORS) IN SERIES

The combined resistance (or resultant resistance) of a number of resistances or resistors connected in series is calculated by using the law of combination of resistances in series. According to the law of combination of resistances in series : **The combined resistance of any number of resistances connected in series is equal to the sum of the individual resistances.** For example, if a number of resistances R_1, R_2, R_3 ...... etc., are connected in series, then their combined resistance R is given by : $R = R_1 + R_2 + R_3 + ...$

Suppose that a resistance R_1 of 2 ohms and another resistance R_2 of 4 ohms are connected in series and we want to find out their combined resistance R.

We know that : $R = R_1 + R_2$

So, $R = 2 + 4$

And, Combined resistance, $R = 6$ ohms

Thus, if we join two resistances of 2 ohms and 4 ohms in series, then their combined resistance (or resultant resistance) will be 6 ohms which is equal to the sum of the individual resistances. Before we derive the formula for the resultant resistance of a number of resistances connected in series, we should keep in mind that :

(*i*) When a number of resistances connected in series are joined to the terminals of a battery, then each resistance has a different potential difference across its ends (which depends on the value of resistance). But the total potential difference across the ends of all the resistances in series is equal to the voltage of the battery. Thus, when a number of resistances are connected in series, then the sum of the potential differences across all the resistances is equal to the voltage of the battery applied.

(*ii*) When a number of resistances are connected in series, then the same current flows through each resistance (which is equal to the current flowing in the whole circuit).

1. Resultant Resistance of Two Resistances Connected in Series

We will now derive a formula for calculating the combined resistance (equivalent resistance or resultant resistance) of two resistances connected in series.

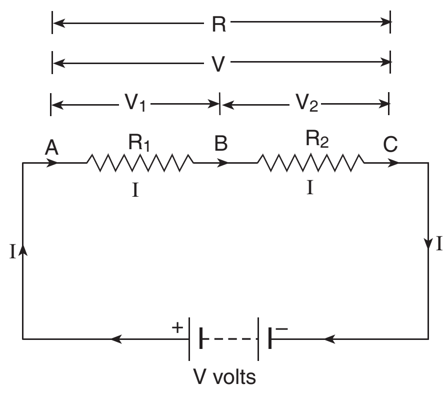


Figure 25.

Figure 25 shows two resistances R_1 and R_2 connected in series. A battery of V volts has been applied to the ends of this series combination. Now, suppose the potential difference across the resistance R_1 is V_1 and the potential difference across the resistance R_2 is V_2. We have applied a battery of voltage V, so the total potential difference across the two resistances should be equal to the voltage of the battery.

That is : $V = V_1 + V_2$ ... (1)

We have just seen that the total potential difference due to battery is V. Now, suppose the total resistance of the combination be R, and the current flowing through the whole circuit be I. So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

or $V = I \times R$ ... (2)

Since the same current I flows through both the resistances R_1 and R_2 connected in series, so by applying Ohm's law to both the resistances separately, we will get :

$V_1 = I \times R_1$ ... (3)

and $V_2 = I \times R_2$ ... (4)

Now, putting the values of V, V_1 and V_2 from equations (2), (3) and (4) in equation (1), we get :

$$I \times R = I \times R_1 + I \times R_2$$
or $$I \times R = I \times (R_1 + R_2)$$

Cancelling I from both sides, we get :

Resultant resistance (combined resistance or equivalent resistance),

$$R = R_1 + R_2$$

2. Resultant Resistance of Three Resistances Connected in Series

Figure 26 shows three resistances R_1, R_2 and R_3 connected in series. A battery of V volts has been applied to the ends of this series combination of resistances. Now, suppose the potential difference across the resistance R_1 is V_1, the potential difference across the resistance R_2 is V_2 and that across resistance R_3 is V_3. We have applied a battery of voltage V, so the total potential difference across the three resistances should be equal to the voltage of the battery applied. That is,

$$V = V_1 + V_2 + V_3 \quad \text{... (1)}$$

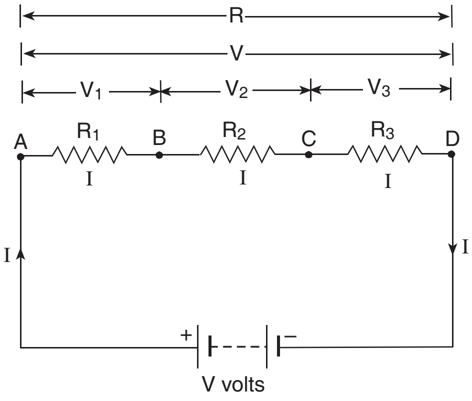


Figure 26.

We have just seen that the total potential difference due to battery is V. Now, let the total resistance (or resultant resistance) of the combination be R. The current flowing through the whole circuit is I. So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$
or $$V = I \times R \quad \text{... (2)}$$

Since the same current I flows through all the resistances R_1, R_2 and R_3 in series, so by applying Ohm's law to each resistance separately, we will get :

$$V_1 = I \times R_1 \quad \text{... (3)}$$
$$V_2 = I \times R_2 \quad \text{... (4)}$$
and $$V_3 = I \times R_3 \quad \text{... (5)}$$

Putting these values of V, V_1, V_2 and V_3 in equation (1), we get :

$$I \times R = I \times R_1 + I \times R_2 + I \times R_3$$
or $$I \times R = I \times (R_1 + R_2 + R_3)$$

Cancelling I from both sides, we get :

$$R = R_1 + R_2 + R_3$$

Thus, if three resistors R_1, R_2, and R_3 are connected in series then their total resistance R is given by the formula :

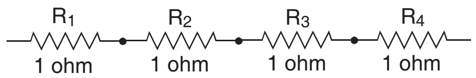
$$R = R_1 + R_2 + R_3$$

Similarly, if there are four resistors R_1, R_2, R_3 and R_4 connected in series, then their resultant resistance R is given by the formula : $R = R_1 + R_2 + R_3 + R_4$ and so on.

We will now solve some problems based on the combination of resistances in series.

Sample Problem 1. If four resistances, each of value 1 ohm, are connected in series, what will be the resultant resistance ?

Solution. Here we have four resistances, each of 1 ohm, connected in series. These are shown in the Figure below.



Now, if we have four resistances R_1, R_2, R_3 and R_4 connected in series, then their resultant resistance R is given by : $R = R_1 + R_2 + R_3 + R_4$

Here $R_1 = 1\ \Omega$, $R_2 = 1\ \Omega$, $R_3 = 1\ \Omega$, $R_4 = 1\ \Omega$

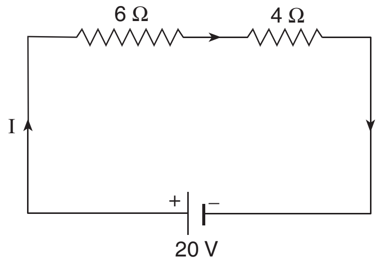
So, Resultant resistance, $R = 1 + 1 + 1 + 1$

or $R = 4\ \Omega$

Thus, the resultant resistance is equal to 4 ohms.

We will now solve some problems by applying Ohm's law to the circuits having resistances in series.

Sample Problem 2. A resistance of 6 ohms is connected in series with another resistance of 4 ohms. A potential difference of 20 volts is applied across the combination. Calculate the current through the circuit and potential difference across the 6 ohm resistance.



Solution. The first step in solving such problems based on current electricity is to draw a proper circuit diagram. For example, in this problem we have two resistances of 6 ohms and 4 ohms which are connected in series. So, first of all we have to draw these two resistances on paper as shown in Figure alongside. Now, a potential difference of 20 volts has been applied across this combination of resistances. So, we draw a cell or a battery of 20 volts and complete the circuit as shown in Figure alongside. Suppose the current flowing in the circuit is I amperes.

We will now find out the value of current I flowing through the circuit. To do this we should know the total resistance R of the circuit. Here we have two resistances of 6 Ω and 4 Ω connected in series. So,

Total resistance, $R = R_1 + R_2$

$R = 6 + 4$

$R = 10$ ohms

Now, Total resistance, $R = 10$ ohms

Potential difference, $V = 20$ volts

and, Current in the circuit, $I = ?$ (To be calculated)

So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

So that, $$\frac{20}{I} = 10$$

And, $$10\,I = 20$$

$$I = \frac{20}{10}$$

So, Current, $I = 2$ amperes (or 2 A)

Thus, the current flowing through the circuit is 2 amperes.

The second part of this problem is to find out the potential difference across the ends of the 6 ohm resistance. To do this we will have to apply Ohm's law to this resistance only. We know that the current flowing through the 6 ohm resistance will also be 2 amperes. Now,

Potential difference (across 6 Ω resistance), $V = ?$ (To be calculated)

Current (through 6 Ω resistance), $I = 2$ amperes

And, Resistance, $R = 6$ ohms

So, applying Ohm's law to the 6 Ω resistance only, we get :

$$\frac{V}{I} = R$$

or $$\frac{V}{2} = 6$$

So, Potential difference, V = 12 volts

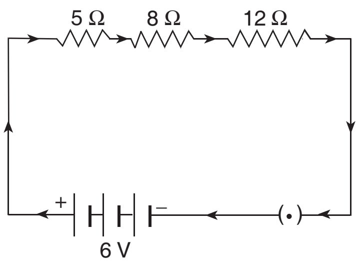
Thus, the potential difference across the 6 ohm resistance is 12 volts.

Here is an exercise for you. Find out the potential difference across the 4 ohm resistance yourself. The answer will be 8 volts. Remember that the same current of 2 amperes flows through the 4 ohm resistance.

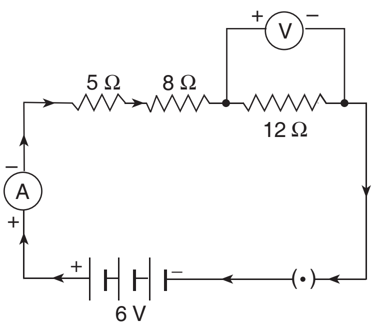
Sample Problem 3. (*a*) Draw the diagram of a circuit consisting of a battery of three cells of 2 V each, a 5 Ω resistor, an 8 Ω resistor and a 12 Ω resistor, and a plug key, all connected in series.

(*b*) Redraw the above circuit putting an ammeter to measure the current through the resistors and a voltmeter to measure the potential difference across the 12 Ω resistor. What would be the readings in the ammeter and the voltmeter ? **(NCERT Book Question)**

Solution. (*a*) In this problem, we have a battery of 3 cells of 2 V each, so the total potential difference (or voltage) of the battery will be 3 × 2 = 6 V. The circuit consisting of a battery of three cells of 2 V each (having a voltage of 6 V), resistors of 5 Ω, 8 Ω, 12 Ω and a plug key, all connected in series is given in Figure alongside.



(*b*) The above circuit can be redrawn by including an ammeter in the main circuit and a voltmeter across the 12 Ω resistor, as shown in Figure alongside. Please note that the ammeter has been put in series with the circuit but the voltmeter has been put in parallel with the 12 Ω resistor. We will now calculate the current reading in the ammeter and potential difference reading in the voltmeter.



(*i*) Calculation of current flowing in the circuit. The three resistors of 5 Ω, 8 Ω and 12 Ω are connected in series. So,

Total resistance, R = 5 + 8 + 12

= 25 Ω

Potential difference, V = 6 V

And, Current, I = ? (To be calculated)

Now, $$\frac{V}{I} = R$$

So, $$\frac{6}{I} = 25$$

$$25\,I = 6$$

$$I = \frac{6}{25}$$

$$I = 0.24 \text{ A}$$

Now, since the current in the circuit is 0.24 amperes, therefore, the ammeter will show a reading of 0.24 A.

(*ii*) Calculation of potential difference across 12 Ω resistor. We have just calculated that a current of 0.24 A flows in the circuit. The same current of 0.24 A also flows through the 12 Ω resistor which is connected in series. Now, for the 12 Ω resistor :

Current, I = 0.24 A (Calculated above)

Resistance, R = 12 Ω (Given)

And, Potential difference, V = ? (To be calculated)

We know that, $$\frac{V}{I} = R$$

So, $\frac{V}{0.24} = 12$

And $V = 0.24 \times 12$

$V = 2.88$ V

Thus, the potential difference across the 12 Ω resistor is 2.88 volts. So, the voltmeter will show a reading of 2.88 V.

RESISTANCES (OR RESISTORS) IN PARALLEL

The combined resistance (or resultant resistance) of a number of resistances or resistors connected in parallel can be calculated by using the law of combination of resistances in parallel. According to the law of combination of resistances in parallel : **The reciprocal of the combined resistance of a number of resistances connected in parallel is equal to the sum of the reciprocals of all the individual resistances.** For example, if a number of resistances, R_1, R_2, R_3 ...... etc., are connected in parallel, then their combined resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$$

Suppose that a resistance R_1 of 6 ohms and another resistance R_2 of 12 ohms are connected in parallel and we want to find out their combined resistance R.

We know that : $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$$= \frac{1}{6} + \frac{1}{12}$$

$$= \frac{2+1}{12}$$

$$= \frac{3}{12}$$

Now, $\frac{1}{R} = \frac{1}{4}$

So, Combined resistance, $R = 4$ ohms

This means that if we join two resistances of 6 ohms and 12 ohms in parallel then their combined resistance is only 4 ohms which is less than either of the two individual resistances (of 6 ohms and 12 ohms). Thus, **when a number of resistances are connected in parallel then their combined resistance is less than the smallest individual resistance.** This is due to the fact that when we have two or more resistances joined parallel to one another, then the same current gets additional paths to flow and the overall resistance decreases. Before we derive a formula for the resultant resistance of a number of resistances connected in parallel, we should keep in mind that :

(*i*) When a number of resistances are connected in parallel, then the potential difference across each resistance is the same which is equal to the voltage of the battery applied.

(*ii*) When a number of resistances connected in parallel are joined to the two terminals of a battery, then different amounts of current flow through each resistance (which depends on the value of resistance). But the current flowing through all the individual parallel resistances, taken together, is equal to the current flowing in the circuit as a whole. Thus, when a number of resistances are connected in parallel, then the sum of the currents flowing through all the resistances is equal to the total current flowing in the circuit.

1. Combined Resistance of Two Resistances Connected in Parallel

We will now derive a formula for calculating the combined resistance (resultant resistance or equivalent resistance) of two resistors connected in parallel. In Figure 27, two resistances R_1 and R_2 are connected parallel to one another between the same two points A and B. A battery of V volts has been applied across the ends of this combination. In this case the potential difference across the ends of both the resistances will be the same. And it will be equal to the voltage of the battery used. The current flowing through the two resistances in parallel is, however, not the same.

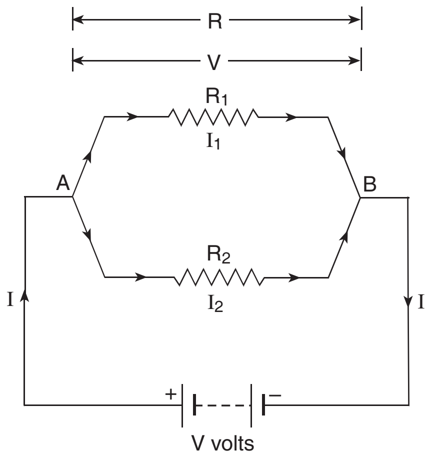


Figure 27.

Suppose the total current flowing in the circuit is I, then the current passing through resistance R_1 will be I_1 and the current passing through the resistance R_2 will be I_2 (see Figure 27). It is obvious that :

$$\text{Total current, } I = I_1 + I_2 \qquad \text{... (1)}$$

Suppose the resultant resistance of this parallel combination is R. Then by applying Ohm's law to the whole circuit, we get :

$$I = \frac{V}{R} \qquad \text{... (2)}$$

Since the potential difference V across both the resistances R_1 and R_2 in parallel is the same, so by applying Ohm's law to each resistance separately, we get :

$$I_1 = \frac{V}{R_1} \qquad \text{... (3)}$$

and $$I_2 = \frac{V}{R_2} \qquad \text{... (4)}$$

Now, putting the values of I, I_1 and I_2 from equations (2), (3) and (4) in equation (1), we get :

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

or $$V\left[\frac{1}{R}\right] = V\left[\frac{1}{R_1} + \frac{1}{R_2}\right]$$

Cancelling V from both sides, we get :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

Thus, if two resistances R_1 and R_2 are connected in parallel, then their resultant resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

2. Combined Resistance of Three Resistances Connected in Parallel

In Figure 28, three resistances R_1, R_2 and R_3 are connected parallel to one another between the same two points A and B. A battery of V volts has been applied across the ends of this combination. In this case the potential difference across the ends of all the three resistances will be the same. And it will be equal to the voltage of the battery used. The current flowing through the three resistances connected in parallel is, however, not the same. Suppose the total current flowing through the circuit is I, then the current passing

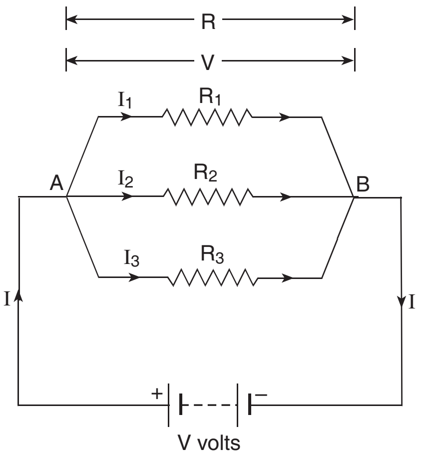


Figure 28.

through resistance R_1 will be I_1, the current passing through resistance R_2 will be I_2, and that through R_3 will be I_3 (see Figure 28). It is obvious that :

Total current, $I = I_1 + I_2 + I_3$ ... (1)

Suppose the resultant resistance of this combination is R. Then, by applying Ohm's law to the whole circuit, we get :

$$I = \frac{V}{R} \quad \text{... (2)}$$

Since the potential difference V across all the three resistances R_1, R_2 and R_3 in parallel is the same, so by applying Ohm's law to each resistance separately, we get :

$$I_1 = \frac{V}{R_1} \quad \text{... (3)}$$

$$I_2 = \frac{V}{R_2} \quad \text{... (4)}$$

and $$I_3 = \frac{V}{R_3} \quad \text{... (5)}$$

Putting these values of I, I_1, I_2 and I_3 in equation (1), we get :

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or $$V\ \frac{1}{R} = V\ \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Cancelling V from both sides, we get :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Thus, if three resistances R_1, R_2 and R_3 are connected in parallel, then their resultant resistance R is given by the formula :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Similarly, when four resistances R_1, R_2, R_3 and R_4 are connected in parallel, then their resultant resistance R is given by the formula :

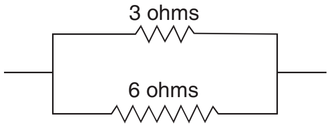
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} \text{ and so on}$$

Let us solve some problems now.

Sample Problem 1. Calculate the equivalent resistance when two resistances of 3 ohms and 6 ohms are connected in parallel.

Solution. Here we have two resistances of 3 ohms and 6 ohms which are connected in parallel. This arrangement is shown in Figure given below. Now, we want to find out their equivalent resistance or resultant resistance. We know that when two resistances R_1 and R_2 are connected in parallel, then their equivalent resistance R is given by :

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$



Here, $R_1 = 3$ ohms

and, $R_2 = 6$ ohms

So, $$\frac{1}{R} = \frac{1}{3} + \frac{1}{6}$$

or $$\frac{1}{R} = \frac{2+1}{6}$$

or $$\frac{1}{R} = \frac{3}{6}$$

or $$\frac{1}{R} = \frac{1}{2}$$

and $$R = 2\ \Omega$$

Thus, the equivalent resistance is 2 ohms.

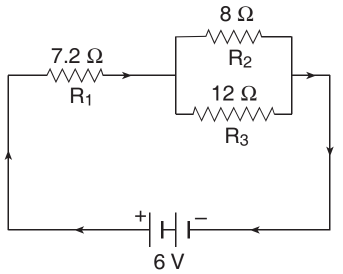
So far we have studied the combination of resistances in series and parallel separately. Many times, however, the practical electrical circuits involve the combination of resistances in series as well as in parallel in the same circuit. **We will now solve a problem in which the resistances are connected in series as well as in parallel in the same circuit.**

Sample Problem 2. In the circuit diagram given alongside, find :

(*i*) total resistance of the circuit,

(*ii*) total current flowing in the circuit, and

(*iii*) the potential difference across R_1



Solution. In this problem the resistances are connected in series as well as in parallel combination. For example, the two resistances R_2 and R_3 are in parallel combination to each other but, taken together, they are in series combination with the resistance R_1.

(*i*) **Calculation of Total Resistance.** We will now find out the total resistance of the circuit. For doing this, let us first calculate the resultant resistance R of R_2 and R_3 which are connected in parallel.

Now, $$\frac{1}{R} = \frac{1}{R_2} + \frac{1}{R_3}$$

Here, $$R_2 = 8\ \Omega$$

and, $$R_3 = 12\ \Omega$$

So, $$\frac{1}{R} = \frac{1}{8} + \frac{1}{12}$$

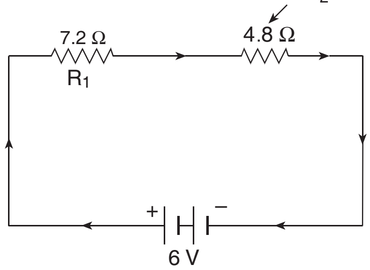
or $$\frac{1}{R} = \frac{3+2}{24}$$

$$\frac{1}{R} = \frac{5}{24}$$

$$R = \frac{24}{5}$$

and $$R = 4.8 \text{ ohms}$$

Thus, the two resistances of 8 ohms and 12 ohms connected in parallel are equal to a single resistance of 4.8 ohms. It is obvious that in the above given diagram, we can replace the two resistances R_2 and R_3 by a single resistance of 4.8 ohms. We can now draw another circuit diagram for this problem by showing a single resistance of 4.8 ohms in place of two parallel resistances. Such a circuit diagram is given alongside.



It is clear from this diagram that now we have two resistances of 7.2 ohms and 4.8 ohms which are connected in series. So,

$$\text{Total resistance} = 7.2 + 4.8$$
$$= 12 \text{ ohms}$$

Thus, the total resistance of the circuit is 12 ohms.

(*ii*) **Calculation of Total Current.** The battery shown in the given circuit is of 6 volts. So,

Total potential difference, $V = 6$ volts

Total current, $I = ?$ (To be calculated)

and Total resistance, $R = 12$ ohms (Calculated above)

So, applying Ohm's law to the whole circuit, we get :

$$\frac{V}{I} = R$$

or $$\frac{6}{I} = 12$$

or $$12\,I = 6$$

or $$I = \frac{6}{12}$$

$$I = \frac{1}{2}$$

So, Total current, $I = 0.5$ ampere (or 0.5 A)

Thus, the total current flowing in the circuit is 0.5 ampere. It should be noted that the same current flows through all the parts of a series circuit. So, the current flowing through the resistance R_1 is also 0.5 ampere.

(*iii*) **Calculation of Potential Difference Across R_1.** We have now to find out the potential difference across the resistance R_1 of 7.2 ohms.

Now,Potential difference across $R_1 = ?$ (To be calculated)

Current through $R_1 = 0.5$ ampere

And, Resistance of $R_1 = 7.2$ ohms

Applying Ohm's law to the resistance R_1 only, we get :

$$\frac{V}{I} = R$$

or $$\frac{V}{0.5} = 7.2$$

or $$V = 7.2 \times 0.5$$

or $$V = 3.6 \text{ volts}$$

Thus, the potential difference across the ends of the resistance R_1 is 3.6 volts.

Before we go further and discuss the advantages and disadvantages of series and parallel circuits, **please answer the following questions and problems yourself :**

Very Short Answer Type Questions

1. Give the law of combination of resistances in series.
2. If five resistances, each of value 0.2 ohm, are connected in series, what will be the resultant resistance ?
3. State the law of combination of resistances in parallel.
4. If 3 resistances of 3 ohm each are connected in parallel, what will be their total resistance ?
5. How should the two resistances of 2 ohms each be connected so as to produce an equivalent resistance of 1 ohm ?
6. Two resistances X and Y are connected turn by turn : (*i*) in parallel, and (*ii*) in series. In which case the resultant resistance will be less than either of the individual resistances ?
7. What possible values of resultant resistance one can get by combining two resistances, one of value 2 ohm and the other 6 ohm ?

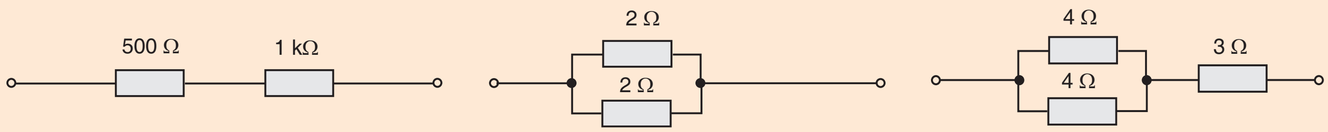
8. Show how you would connect two 4 ohm resistors to produce a combined resistance of (*a*) 2 ohms (*b*) 8 ohms.

9. Which of the following resistor arrangement, A or B, has the lower combined resistance ?

(A) (B)

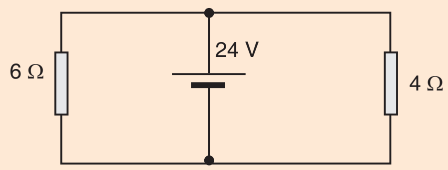
10. A wire that has resistance R is cut into two equal pieces. The two parts are joined in parallel. What is the resistance of the combination ?

11. Calculate the combined resistance in each case :



(*a*) (*b*) (*c*)

12. Find the current in each resistor in the circuit shown below :



Short Answer Type Questions

13. Explain with diagrams what is meant by the "series combination" and "parallel combination" of resistances. In which case the resultant resistance is : (*i*) less, and (*ii*) more, than either of the individual resistances ?

14. A battery of 9 V is connected in series with resistors of 0.2 Ω, 0.3 Ω, 0.4 Ω, 0.5 Ω and 12 Ω. How much current would flow through the 12 Ω resistor ?

15. An electric bulb of resistance 20 Ω and a resistance wire of 4 Ω are connected in series with a 6 V battery. Draw the circuit diagram and calculate :

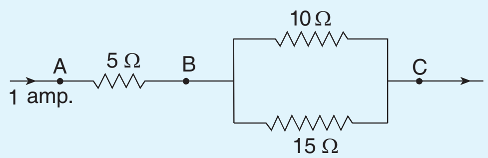
(*a*) total resistance of the circuit.

(*b*) current through the circuit.

(*c*) potential difference across the electric bulb.

(*d*) potential difference across the resistance wire.

16. Three resistors are connected as shown in the diagram.



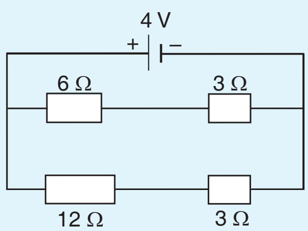
Through the resistor 5 ohm, a current of 1 ampere is flowing.

(*i*) What is the current through the other two resistors ?

(*ii*) What is the p.d. across *AB* and across *AC* ?

(*iii*) What is the total resistance ?

17. For the circuit shown in the diagram below :



What is the value of :

(*i*) current through 6 Ω resistor ?

(*ii*) potential difference across 12 Ω resistor ?

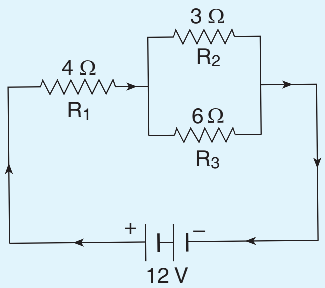
18. Two resistors, with resistances 5 Ω and 10 Ω respectively are to be connected to a battery of emf 6 V so as to obtain :

(*i*) minimum current flowing (*ii*) maximum current flowing

(*a*) How will you connect the resistances in each case ?

(*b*) Calculate the strength of the total current in the circuit in the two cases.

19. The circuit diagram given below shows the combination of three resistors R_1, R_2 and R_3 :

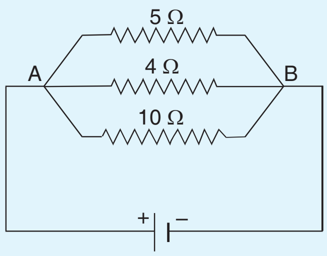


Find : (*i*) total resistance of the circuit.

(*ii*) total current flowing in the circuit.

(*iii*) the potential difference across R_1.

20. In the circuit diagram given below, the current flowing across 5 ohm resistor is 1 amp. Find the current flowing through the other two resistors.



21. A resistor has a resistance of 176 ohms. How many of these resistors should be connected in parallel so that their combination draws a current of 5 amperes from a 220 volt supply line ?

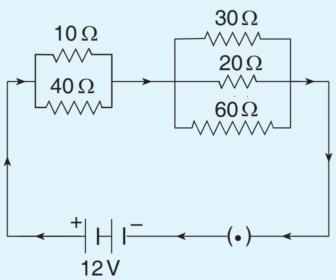
22. An electric heater which is connected to a 220 V supply line has two resistance coils *A* and *B* of 24 Ω resistance each. These coils can be used separately (one at a time), in series or in parallel. Calculate the current drawn when :

(*a*) only one coil *A* is used.

(*b*) coils *A* and *B* are used in series.

(*c*) coils *A* and *B* are used in parallel.

23. In the circuit diagram given below five resistances of 10 Ω, 40 Ω, 30 Ω, 20 Ω and 60 Ω are connected as shown to a 12 V battery.

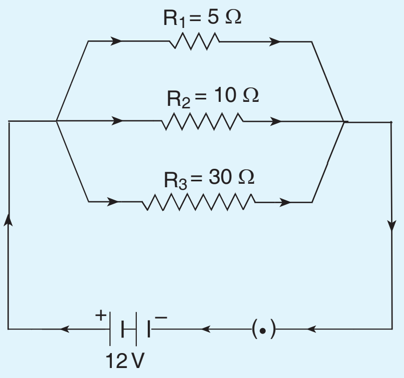


Calculate :

(*a*) total resistance in the circuit.

(*b*) total current flowing in the circuit.

24. In the circuit diagram given below, three resistors R_1, R_2, and R_3 of 5 Ω, 10 Ω and 30 Ω, respectively are connected as shown.



Calculate :

(*a*) current through each resistor.

(*b*) total current in the circuit.

(*c*) total resistance in the circuit.

25. A p.d. of 4 V is applied to two resistors of 6 Ω and 2 Ω connected in series. Calculate :

(*a*) the combined resistance

(*b*) the current flowing

(*c*) the p.d. across the 6 Ω resistor

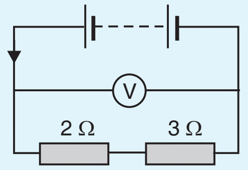
26. A p.d. of 6 V is applied to two resistors of 3 Ω and 6 Ω connected in parallel. Calculate :

(*a*) the combined resistance

(*b*) the current flowing in the main circuit

(*c*) the current flowing in the 3 Ω resistor.

27. In the circuit shown below, the voltmeter reads 10 V.



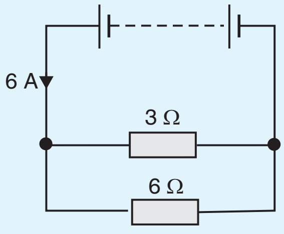
(*a*) What is the combined resistance ?

(*b*) What current flows ?

(*c*) What is the p.d. across 2 Ω resistor ?

(*d*) What is the p.d. across 3 Ω resistor ?

28. In the circuit given below :



(*a*) What is the combined resistance ?

(*b*) What is the p.d. across the combined resistance ?

(*c*) What is the p.d. across the 3 Ω resistor ?

(*d*) What is the current in the 3 Ω resistor ?

(*e*) What is the current in the 6 Ω resistor ?

29. A 5 V battery is connected to two 20 Ω resistors which are joined together in series.

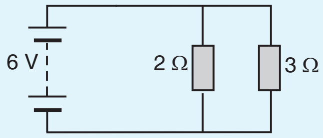
(*a*) Draw a circuit diagram to represent this. Add an arrow to indicate the direction of conventional current flow in the circuit.

(*b*) What is the effective resistance of the two resistors ?

(*c*) Calculate the current that flows from the battery.

(*d*) What is the p.d. across each resistor ?

30. The figure given below shows an electric circuit in which current flows from a 6 V battery through two resistors.



(*a*) Are the resistors connected in series with each other or in parallel ?

(*b*) For each resistor, state the p.d. across it.

(*c*) The current flowing from the battery is shared between the two resistors. Which resistor will have bigger share of the current ?

(*d*) Calculate the effective resistance of the two resistors.

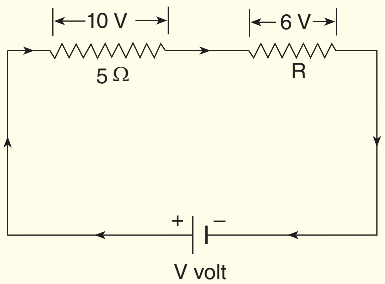
(*e*) Calculate the current that flows from the battery.

31. A 4 Ω coil and a 2 Ω coil are connected in parallel. What is their combined resistance ? A total current of 3 A passes through the coils. What current passes through the 2 Ω coil ?

Long Answer Type Questions

32. (*a*) With the help of a circuit diagram, deduce the equivalent resistance of two resistances connected in series.

(*b*) Two resistances are connected in series as shown in the diagram :



(*i*) What is the current through the 5 ohm resistance ?

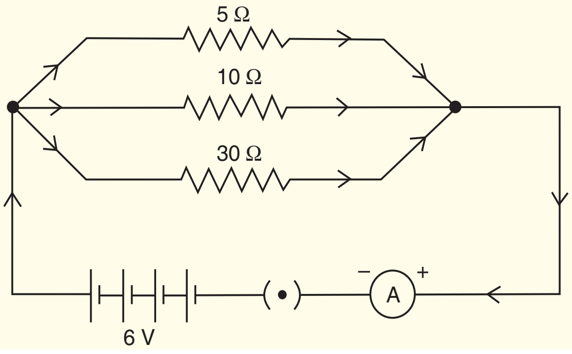
(*ii*) What is the current through *R* ?

(*iii*) What is the value of *R* ?

(*iv*) What is the value of *V* ?

33. (*a*) With the help of a diagram, derive the formula for the resultant resistance of three resistors connected in series.

(*b*) For the circuit shown in the diagram given below :



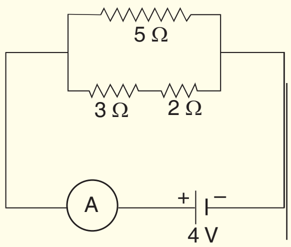
Calculate :

(*i*) the value of current through each resistor.
(*ii*) the total current in the circuit.
(*iii*) the total effective resistance of the circuit.

34. (*a*) With the help of a circuit diagram, obtain the relation for the equivalent resistance of two resistances connected in parallel.

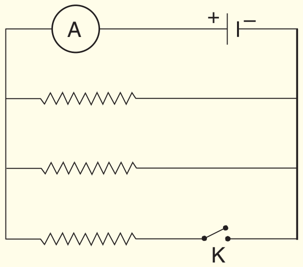
(*b*) In the circuit diagram shown below, find :

(*i*) Total resistance.
(*ii*) Current shown by the ammeter *A*



35. (*a*) Explain with the help of a labelled circuit diagram, how you will find the resistance of a combination of three resistors of resistances R_1, R_2 and R_3 joined in parallel.

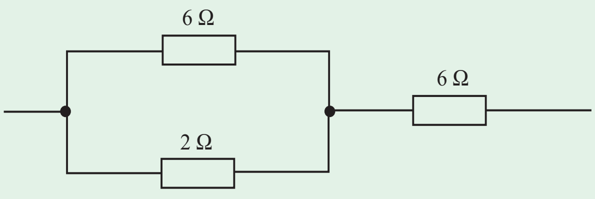
(*b*) In the diagram shown below, the cell and the ammeter both have negligible resistance. The resistors are identical.



With the switch *K* open, the ammeter reads 0.6 A. What will be the ammeter reading when the switch is closed ?

Multiple Choice Questions (MCQs)

36. The figure given below shows three resistors :



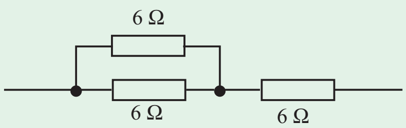
Their combined resistance is :

(*a*) $1\frac{5}{7}$ Ω (*b*) 14 Ω (*c*) $6\frac{2}{3}$ Ω (*d*) $7\frac{1}{2}$ Ω

37. If two resistors of 25 Ω and 15 Ω are joined together in series and then placed in parallel with a 40 Ω resistor, the effective resistance of the combination is :

(*a*) 0.1 Ω (*b*) 10 Ω (*c*) 20 Ω (*d*) 40 Ω

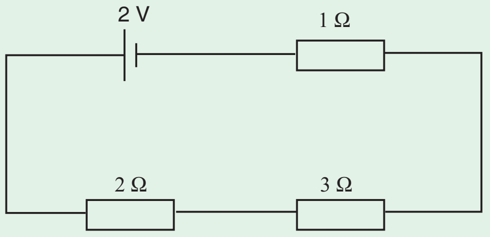
38. The diagram below shows part of a circuit :



If this arrangement of three resistors was to be replaced by a single resistor, its resistance should be :

(*a*) 9 Ω (*b*) 4 Ω (*c*) 6 Ω (*d*) 18 Ω

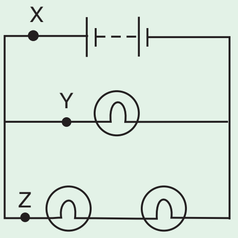
39. In the circuit shown below :



The potential difference across the 3 Ω resistor is :

(*a*) $\frac{1}{9}$ V (*b*) $\frac{1}{2}$ V (*c*) 1 V (*d*) 2 V

40. A battery and three lamps are connected as shown :



Which of the following statements about the currents at X, Y and Z is correct ?

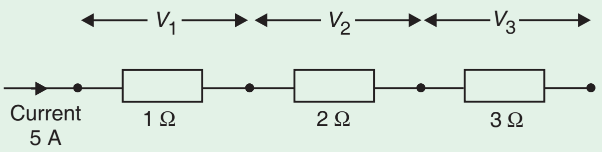
(*a*) The current at Z is greater than that at Y.

(*b*) The current at Y is greater than that at Z.

(*c*) The current at X equals the current at Y.

(*d*) The current at X equals the current at Z.

41. V_1, V_2 and V_3 are the p.ds. across the 1 Ω , 2 Ω and 3 Ω resistors in the following diagram, and the current is 5 A.



Which one of the columns (*a*) to (*d*) shows the correct values of V_1 , V_2 and V_3 measured in volts ?

	V_1	V_2	V_3
(*a*)	1.0	2.0	3.0
(*b*)	5.0	10.0	15.0
(*c*)	5.0	2.5	1.6
(*d*)	4.0	3.0	2.0

42. A wire of resistance R_1 is cut into five equal pieces. These five pieces of wire are then connected in parallel. If the resultant resistance of this combination be R_2, then the ratio $\frac{R_1}{R_2}$ is :

(*a*) $\frac{1}{25}$ (*b*) $\frac{1}{5}$ (*c*) 5 (*d*) 25

Questions Based on High Order Thinking Skills (HOTS)

43. Show with the help of diagrams, how you would connect three resistors each of resistance 6 Ω, so that the combination has resistance of (*i*) 9 Ω (*ii*) 4 Ω.

44. Two resistances when connected in parallel give resultant value of 2 ohm; when connected in series the value becomes 9 ohm. Calculate the value of each resistance.

45. A resistor of 8 ohms is connected in parallel with another resistor *X*. The resultant resistance of the combination is 4.8 ohms. What is the value of the resistor *X* ?

46. You are given three resistances of 1, 2 and 3 ohms. Show by diagrams, how with the help of these resistances you can get :

(*i*) 6 Ω (*ii*) $\frac{6}{11}$ Ω (*iii*) 1.5 Ω

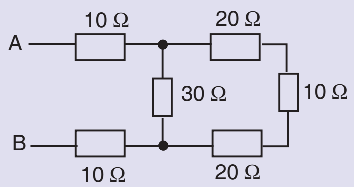
47. How will you connect three resistors of 2 Ω, 3 Ω and 5 Ω respectively so as to obtain a resultant resistance of 2.5 Ω ? Draw the diagram to show the arrangement.

48. How will you connect three resistors of resistances 2 Ω, 3 Ω and 6 Ω to obtain a total resistance of : (*a*) 4 Ω, and (*b*) 1 Ω ?

49. What is (*a*) highest, and (*b*) lowest, resistance which can be obtained by combining four resistors having the following resistances ?

4 Ω, 8 Ω, 12 Ω, 24 Ω

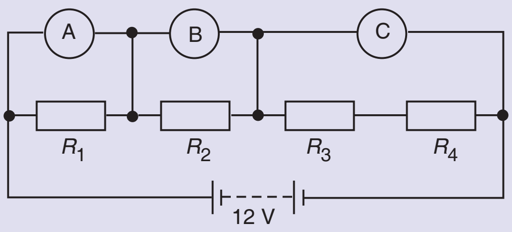
50. What is the resistance between A and B in the figure given below ?



51. You are given one hundred 1 Ω resistors. What is the smallest and largest resistance you can make in a circuit using these ?

52. You are supplied with a number of 100 Ω resistors. How could you combine some of these resistors to make a 250 Ω resistor ?

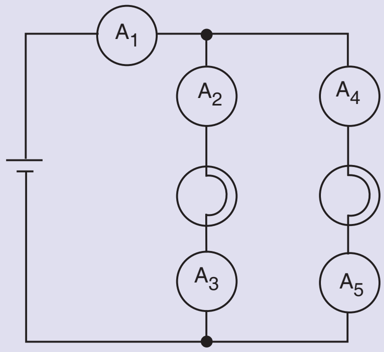
53. The resistors R_1, R_2, R_3 and R_4 in the figure given below are all equal in value.



What would you expect the voltmeters A, B and C to read assuming that the connecting wires in the circuit have negligible resistance ?

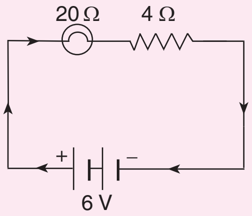
54. Four resistances of 16 ohms each are connected in parallel. Four such combinations are connected in series. What is the total resistance ?

55. If the lamps are both the same in the figure given below and if A_1 reads 0.50 A, what do A_2, A_3, A_4 and A_5 read ?



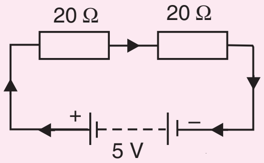
ANSWERS

2. 1 ohm **4.** 1 ohm **5.** In parallel **6.** In parallel **7.** 8 Ω ; 1.5 Ω **8.** (*a*) In parallel (*b*) In series **9.** B **10.** $\frac{R}{4}$ **11.** (*a*) 1500 Ω (*b*) 1 Ω (*c*) 5 Ω **12.** Current in 6 Ω resistor = 4 A ; Current in 4 Ω resistor = 6 A. **13.** (*i*) Parallel combination (*ii*) Series combination **14.** 0.67 A

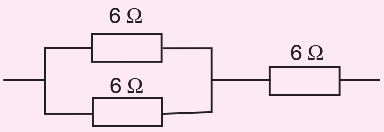
15. 

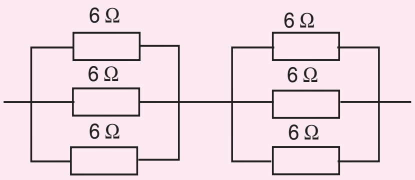
(*a*) 24 Ω (*b*) 0.25 A (*c*) 5 V (*d*) 1 V **16.** (*i*) 0.6 A ; 0.4 A (*ii*) 5 V ; 11 V (*iii*) 11 Ω

17. (*i*) 0.44 A (*ii*) 3.2 V **18.** (*a*) For minimum current flowing : In series ; For maximum current flowing : In parallel (*b*) 0.4 A ; 1.8 A **19.** (*i*) 6 Ω (*ii*) 2 A (*iii*) 8 V **20.** 1.25 A ; 0.5 A **21.** 4 resistors **22.** (*a*) 9.2 A (*b*) 4.6 A (*c*) 18.3 A **23.** (*a*) 18 Ω (*b*) 0.67 A **24.** (*a*) 2.4 A ; 1.2 A ; 0.4 A (*b*) 4 A (*c*) 3 Ω **25.** (*a*) 8 Ω (*b*) 0.5 A (*c*) 3 V **26.** (*a*) 2 Ω (*b*) 3 A (*c*) 2 A **27.** (*a*) 5 Ω (*b*) 2 A (*c*) 4 V (*d*) 6 V **28.** (*a*) 2 Ω (*b*) 12 V (*c*) 12 V (*d*) 4 A (*e*) 2 A

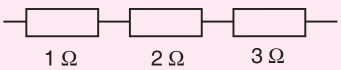
29. (*a*) 

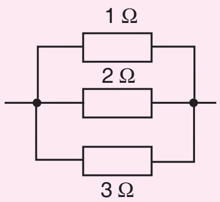
(*b*) 40 Ω (*c*) 0.125 A (*d*) 2.5 V **30.** (*a*) Parallel (*b*) 6 V (*c*) 2 Ω resistor (*d*) 1.2 Ω (*e*) 5 A **31.** $\frac{4}{3}$ Ω ; 2 A **32.** (*b*) (*i*) 2 A (*ii*) 2 A (*iii*) 3 Ω (*iv*) 16 V **33.** (*b*) (*i*) Current through 5 Ω resistor = 1.2 A ; Current through 10 Ω resistor = 0.6 A ; Current through 30 Ω resistor = 0.2 A (*ii*) 2 A (*iii*) 3 Ω **34.** (*b*) (*i*) 2.5 Ω (*ii*) 1.6 A **35.** (*b*) 0.9 A **36.** (*d*) **37.** (*c*) **38.** (*a*) **39.** (*c*) **40.** (*b*) **41.** (*b*) **42.** (*d*) *Hint.* Resistance of one piece of wire will be $\frac{R_1}{5}$. And $\frac{1}{R_2} = \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} + \frac{5}{R_1} = \frac{25}{R_1}$

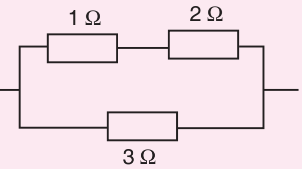
43. (*i*) 

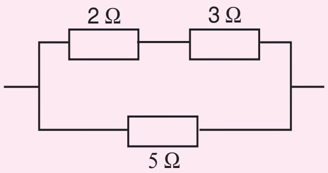
(*ii*) 

44. 3 Ω and 6 Ω

45. 12 Ω **46.** (*i*) 

(*ii*) 

(*iii*) 

47. 

48. (*a*) Connect 2 Ω resistor in series with a parallel combination of 3 Ω and 6 Ω resistors (*b*) Connect 2 Ω , 3 Ω and 6 Ω resistors in parallel **49.** (*a*) 48 Ω (*b*) 2 Ω **50.** 38.75 Ω **51.** 0.01 Ω ; 100 Ω **52.** Combine two 100 Ω resistors in series with a parallel combination of two 100 Ω resistors **53.** A = 3 V ; B = 3 V; C = 6 V **54.** 16 Ω **55.** All read 0.25 A.

DOMESTIC ELECTRIC CIRCUITS : SERIES OR PARALLEL

When designing an electric circuit, we should consider whether a series circuit or a parallel circuit is better for the intended use. For example, if we want to connect (or join) a large number of electric bulbs (say, hundreds or thousands of electric bulbs) for decorating buildings and trees as during festivals such as *Diwali* or marriage functions, then the series circuit is *better* because all the bulbs connected in series can be controlled with just one switch (see Figure 29). A series circuit is also safer because the current in it is smaller. But there is a problem in this series lighting circuit. This is because if one bulb gets fused (or blows off), then the circuit breaks and all the bulbs are turned off. An electrician has to spend a lot of time in locating the fused bulb from among hundreds of bulbs, so as to replace it and restore the lighting.

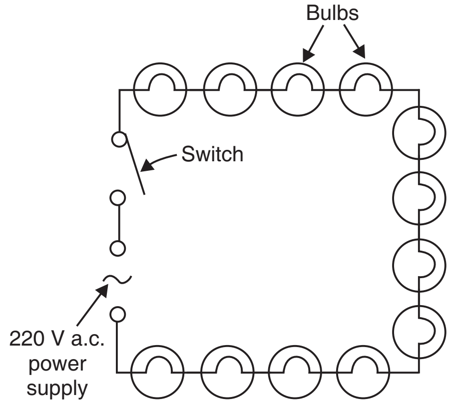


Figure 29. The electric bulbs for decoration are usually connected in series circuit with the 220 volt a.c. (alternating current) power supply line (The circuit symbol for alternating current or a.c. supply is —○ ∼ ○—). Please note that all the bulbs have just one switch.

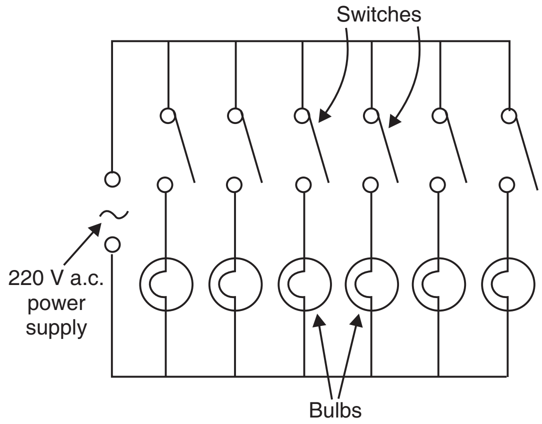


Figure 30. The electric bulbs in a house are connected in parallel circuit with the 220 volt a.c. power supply line. Please note that all the bulbs have separate switches (Just like bulbs, all other appliances like fan, TV, fridge, electric iron, etc., are also connected in parallel in a similar way).

The parallel electric circuit is *better* for connecting bulbs (and other electrical appliances) in a house because then we can have separate switches for each bulb (or electrical appliance) and hence operate it separately (see Figure 30). In addition to having ease of operation, parallel domestic circuits (or household circuits) have many other advantages over the series circuits. We will first give the disadvantages of the series electric circuits for domestic purposes and then the advantages of the parallel electric circuits.

Disadvantages of Series Circuits for Domestic Wiring

The arrangement of lights and various other electrical appliances in series circuit is not used in domestic wiring because of the following disadvantages :

1. In series circuit, if one electrical appliance stops working due to some defect, then all other appliances also stop working (because the whole circuit is broken). For example, if a number of bulbs are connected in series and just one bulb gets fused (or blows off), then all other bulbs will also stop glowing.

2. In series circuit, all the electrical appliances have only one switch due to which they cannot be turned on or off separately. For example, all the bulbs connected in series have only one switch due to which all the bulbs can be switched on or switched off together and not separately.

Figure 31. Christmas tree bulbs are usually wired in series.

3. In series circuit, the appliances do not get the same voltage (220 V) as that of the power supply line because the voltage is shared by all the appliances. The appliances get less voltage and hence do not work properly. For example, all the bulbs connected in series do not get the same voltage of 220 volts of the power supply line. They get less voltage and hence glow less brightly.

4. In the series connection of electrical appliances, the overall resistance of the circuit increases too much due to which the current from the power supply is low. Moreover, the same current flows throughout a series circuit due to which all the appliances of different power ratings cannot draw sufficient current for their proper working.

Advantages of Parallel Circuits in Domestic Wiring

The arrangement of lights and various other electrical appliances in parallel circuits is used in domestic wiring because of the following advantages :

1. In parallel circuits, if one electrical appliance stops working due to some defect, then all other appliances keep working normally. For example, if a number of bulbs are connected in parallel circuits and one bulb gets fused (or blows out), then all the remaining bulbs will keep glowing.

2. In parallel circuits, each electrical appliance has its own switch due to which it can be turned on or turned off independently, without affecting other appliances. For example, all the bulbs joined in parallel circuits in a house have separate switches due to which we can switch on or switch off any bulb as required, without affecting other bulbs in the house.

3. In parallel circuits, each electrical appliance gets the same voltage (220 V) as that of the power supply line. Due to this, all the appliances will work properly. For example, all the bulbs connected in parallel circuits get the same voltage of 220 volts of the power supply line and hence glow very brightly.

4. In the parallel connection of electrical appliances, the overall resistance of the household circuit is reduced due to which the current from the power supply is high. Every appliance can, therefore, draw the required amount of current. For example, in parallel circuits, even the high power rating appliances like electric irons, water heaters and air-conditioners, etc., can draw the high current needed for their proper functioning.

We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. Are the lights in your house wired in series ?

2. What happens to the other bulbs in a series circuit if one bulb blows off ?

3. What happens to the other bulbs in a parallel circuit if one bulb blows off ?

4. Which type of circuit, series or parallel, is preferred while connecting a large number of bulbs :

(*a*) for decorating a hotel building from outside ?

(*b*) for lighting inside the rooms of the hotel ?

5. Draw a circuit diagram to show how two 4 V electric lamps can be lit brightly from two 2 V cells.

Short Answer Type Questions

6. Why is a series arrangement not used for connecting domestic electrical appliances in a circuit ?

7. Give three reasons why different electrical appliances in a domestic circuit are connected in parallel.

8. Ten bulbs are connected in a series circuit to a power supply line. Ten identical bulbs are connected in a parallel circuit to an identical power supply line.

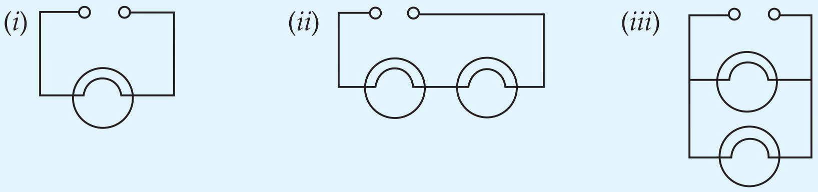
(*a*) Which circuit would have the highest voltage across each bulb ?

(*b*) In which circuit would the bulbs be brighter ?

(*c*) In which circuit, if one bulb blows out, all others will stop glowing ?

(*d*) Which circuit would have less current in it ?

9. Consider the circuits given below :



(*a*) In which circuit are the lamps dimmest ?

(*b*) In which circuit or circuits are the lamps of equal brightness to the lamps in circuit (*i*) ?

(*c*) Which circuit gives out the maximum light ?

10. If you were going to connect two light bulbs to one battery, would you use a series or a parallel arrangement ? Why ? Which arrangement takes more current from the battery ?

Long Answer Type Question

11. (*a*) Which is the better way to connect lights and other electrical appliances in domestic wiring : series circuits or parallel circuits ? Why ?

(*b*) Christmas tree lamps are usually wired in series. What happens if one lamp breaks ?

(*c*) An electrician has wired a house in such a way that if a lamp gets fused in one room of the house, all the lamps in other rooms of the house stop working. What is the defect in the wiring ?

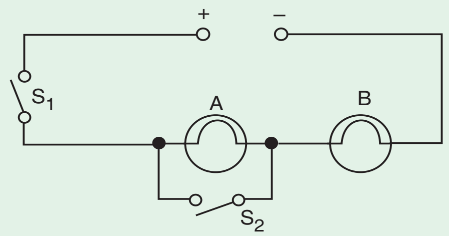
(*d*) Draw a circuit diagram showing two electric lamps connected in parallel together with a cell and a switch that works both lamps. Mark an Ⓐ on your diagram to show where an ammeter should be placed to measure the current.

Multiple Choice Questions (MCQs)

12. The lamps in a household circuit are connected in parallel because :

(*a*) this way they require less current
(*b*) if one lamp fails the others remain lit
(*c*) this way they require less power
(*d*) if one lamp fails the others also fail

13. Using the circuit given below, state which of the following statement is correct ?



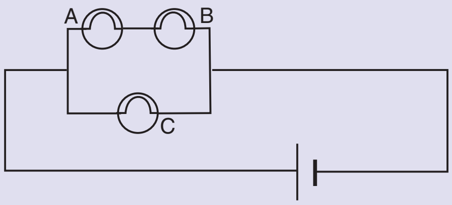
(*a*) When S_1 and S_2 are closed, lamps A and B are lit.
(*b*) With S_1 open and S_2 closed, A is lit and B is not lit.
(*c*) With S_2 open and S_1 closed A and B are lit.
(*d*) With S_1 closed and S_2 open, lamp A remains lit even if lamp B gets fused.

Questions Based on High Order Thinking Skills (HOTS)

14. (*a*) Draw a circuit diagram showing two lamps, one cell and a switch connected in series.

(*b*) How can you change the brightness of the lamps ?

15. Consider the circuit given below where A, B and C are three identical light bulbs of constant resistance.



(*a*) List the bulbs in order of increasing brightness.
(*b*) If C burns out, what will be the brightness of A now compared with before ?
(*c*) If B burns out instead, what will be the brightness of A and C compared with before ?

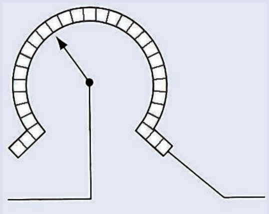
16. How do you think the brightness of two lamps arranged in parallel compares with the brightness of two lamps arranged in series (both arrangements having one cell) ?

17. If current flows through two lamps arranged :

(*a*) in series,
(*b*) in parallel,

and the filament of one lamps breaks, what happens to the other lamp ? Explain your answer.

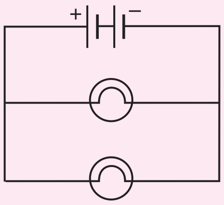
18. The figure below shows a variable resistor in a dimmer switch.



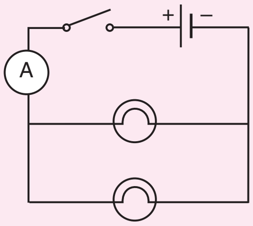
How would you turn the switch to make the lights : (*a*) brighter, and (*b*) dimmer ? Explain your answer.

ANSWERS

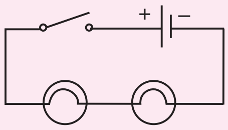
1. No **2.** All other bulbs stop glowing **3.** All other bulbs keep glowing **4.** (*a*) Series circuit (*b*) Parallel circuit **5.**



8. (*a*) Parallel circuit (*b*) Parallel circuit (*c*) Series circuit (*d*) Series circuit
9. (*a*) Circuit (*ii*) (*b*) Circuit (*iii*) (*c*) Circuit (*iii*) **10.** Parallel arrangement ; Series arrangement
11. (*a*) Parallel circuit (*b*) All other lamps stop glowing (*c*) All the lamps have been connected in series (*d*)



12. (*b*) **13.** (*c*) **14.** (*a*)



(*b*) Connect the lamps in parallel

15. (*a*) A and B are the same ; C is brighter (*b*) The same (*c*) A goes out ; C remains the same **16.** The brightness of two lamps arranged in parallel is much more than those arranged in series
17. (*a*) In series : The other lamp stops glowing (*b*) In parallel : The other lamp keeps glowing
18. (*a*) Turn the switch to right side (*b*) Turn the switch to left side.

ELECTRIC POWER

When an electric current flows through a conductor, electrical energy is used up and we say that the current is doing work. We know that the rate of doing work is called power, so **electric power is the electrical work done per unit time.** That is,

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

or

$$P = \frac{W}{t}$$

Unit of Power

We have calculated the power by dividing work done by time taken. Now, the unit of work is "joule" and that of time is "second". So, the unit of power is "joules per second". This unit of power is called watt. Thus, **the SI unit of electric power is watt** which is denoted by the letter W. **The power of 1 watt is a rate of working of 1 joule per second.** That is,

$$1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

Actually, watt is a small unit, therefore, a bigger unit of electric power called kilowatt is used for commercial purposes. It is obvious that :

$$1 \text{ kilowatt} = 1000 \text{ watts}$$

or $$1 \text{ kW} = 1000 \text{ W}$$

It should be noted that the symbol for watt is W and that for kilowatt is kW. When work is done, an equal amount of energy is consumed. So, we can also say that **electric power is the rate at which electrical energy is consumed.** In other words, *electric power is the electrical energy consumed per second.* We can now write down another definition of watt based on electrical energy. **When an electrical appliance consumes electrical energy at the rate of 1 joule per second, its power is said to be 1 watt.** We have just given two definitions of electric power, one by using the term 'work' and another by using the term 'energy'. We can combine these two definitions and say that : **The rate at which electrical work is done or the rate at which electrical energy is consumed, is called electric power.**

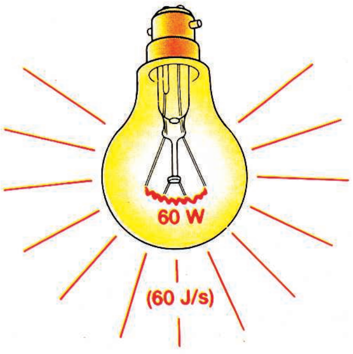


Figure 32. This electric bulb consumes electric energy at the rate of 60 joules per second, so its power is 60 watts.

Formula for Calculating Electric Power

We know that :

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}}$$

or $$P = \frac{W}{t} \quad \dots (1)$$

We have already studied that the work done W by current I when it flows for time t under a potential difference V is given by :

$$W = V \times I \times t \text{ joules}$$

Putting this value of W in equation (1), we get :

$$P = \frac{V \times I \times t}{t} \text{ joules per second}$$

or $$P = V \times I \text{ joules per second}$$

or Power, $$\mathbf{P = V \times I} \text{ watts}$$

where V = Potential difference (or Voltage) in volts

and I = Current in amperes

Thus, the power in watts is found by multiplying the potential difference in volts by the current in amperes. We can write down the above formula for electric power in words as follows :

Electric power = Potential difference × Current

Since the potential difference is also known by the name of voltage, we can also say that :

Electric power = Voltage × Current

It is clear from the above discussion that in electric circuits, **the power expended in heating a resistor or turning a motor depends upon the potential difference between the terminals of the device and the electric current passing through it.**

We can also use the formula $P = V \times I$ for defining the unit of power called 'watt' in another way as described below.

Power, $$P = V \times I \text{ watts}$$

Now, if an electrical device is operated at a potential difference of 1 volt and the device carries a current of 1 ampere, then power becomes 1 watt. That is :

$$1 \text{ watt} = 1 \text{ volt} \times 1 \text{ ampere}$$

or $$1 \text{ W} = 1 \text{ V} \times 1 \text{ A}$$

or $$1 \text{ W} = 1 \text{ V A}$$

This gives us another definition of the unit of power called 'watt'. We can now say that : One watt is the power consumed by an electrical device which when operated at a potential difference (or voltage) of 1 volt carries a current of 1 ampere.

Some Other Formulae for Calculating Electric Power

We have just obtained a formula for calculating electric power, which is :

$$P = V \times I$$

This formula can be used when both, the potential difference (or voltage) V and the current I are known to us. Sometimes, however, they do not give us V and I. We are given either voltage V and resistance R or current I and resistance R. In that case we have to take the help of Ohm's law. This will become clear from the following discussion.

(*i*) Power P in terms of I and R. We have just seen that :

$$P = V \times I \quad \text{... (1)}$$

Now, from Ohm's law we have, $\frac{V}{I} = R$

or $V = I \times R$ ... (2)

Putting this value of V in equation (1), we get :

$$P = I \times R \times I$$

or Power, $\boldsymbol{P = I^2 \times R}$

where I = Current

and R = Resistance

This formula is to be used for calculating electric power when only current I and resistance R are known to us.

(*ii*) Power P in terms of V and R. We know that :

$$P = V \times I \quad \text{... (1)}$$

Also, from Ohm's law we have, $\frac{V}{I} = R$

or $V = I \times R$

or $I = \frac{V}{R}$ ... (2)

Putting this value of I in equation (1), we get :

$$P = V \times \frac{V}{R}$$

or Power, $\boldsymbol{P = \frac{V^2}{R}}$ ... (3)

where V = Potential difference (or Voltage)

and R = Resistance

This formula is to be used for calculating power when voltage V and resistance R are known to us.

It is clear from equation (3) that **power is inversely proportional to the resistance.** Thus, the resistance of high power devices is smaller than the low power ones. For example, the resistance of 100 watt (220 volt) bulb is smaller than that of a 60 watt (220 volt) bulb (see Figure 33). We have now three formulae for calculating electric power. These are :

First formula for power : $\boldsymbol{P = V \times I}$

Second formula for power : $\boldsymbol{P = I^2 \times R}$

Figure 33. The bulb on left side has higher resistance, so its power is less. It glows less brightly. The bulb on right side has less resistance, so its power is more. It glows much more brightly.

Third formula for power : $P = \dfrac{V^2}{R}$

These three formulae should be memorized because they will be used to solve numerical problems. Before we solve the problems based on electric power, it is very important to know the meaning of 'power-voltage' rating of electrical appliances.

Power-Voltage Rating of Electrical Appliances

Every electrical appliance like an electric bulb, radio or fan has a label or engraved plate on it which tells us the voltage (to be applied) and the electrical power consumed by it. For example, if we look at a particular bulb in our home, it may have the figures 100 W – 220 V written on it. Now, 100 W means that this bulb has a power consumption of 100 watts and 220 V means that it is to be used on a voltage of 220 volts. The power rating of an electrical appliance tells us the rate at which electrical energy is consumed by the appliance. For example, **a power rating of 100 watts on the bulb means that it will consume electrical energy at the rate of 100 joules per second.** If we know the power P and voltage V of an electrical appliance, then we can very easily find out the current I drawn by it. This can be done by using the formula : $P = V \times I$. The usual power-voltage ratings of some of the common household electrical appliances and the current drawn by them are given below.

Power-Voltage Ratings of Some Electrical Appliances and the Current Drawn by Them

Electrical appliance	*Usual power*	*Usual voltage*	*Current drawn*
1. Tube light	40 W	220 V	0.18 A
2. Electric bulb (or Lamp)	60 W	220 V	0.27 A
3. Radio set	80 W	220 V	0.36 A
4. Electric fan	100 W	220 V	0.45 A
5. T.V. set	120 W	220 V	0.54 A
6. Refrigerator	150 W	220 V	0.68 A
7. Electric iron	750 W	220 V	3.4 A
8. Electric heater	1000 W	220 V	4.5 A
9. Immersion heater	1500 W	220 V	6.8 A
10. Washing machine	3000 W	220 V	13.6 A

(*a*) An electric bulb may have power of 15 W, 40 W, 60 W, 100 W or more

(*b*) The usual power of a TV set is about 120 W

(*c*) An electric iron has a power of 750 W or more

(*d*) An electric heater may have power of 1000 W or 2000 W, etc.

(*e*) The usual power of a washing machine is 3000 W (or 3 kW)

Figure 34. Different electrical appliances have different power ratings.

Let us solve some problems now.

Sample Problem 1. What will be the current drawn by an electric bulb of 40 W when it is connected to a source of 220 V ?

Solution. In this case we have been given power P and voltage V, so the formula to be used for calculating the current will be :

$$P = V \times I$$

Here, Power, $P = 40$ watts

Voltage, $V = 220$ volts

And, Current, $I = ?$ (To be calculated)

Now, putting these values in the above formula, we get :

$$40 = 220 \times I$$

$$I = \frac{40}{220}$$

$$= \frac{2}{11}$$

Thus, Current, $I = 0.18$ ampere

Sample Problem 2. An electric bulb is rated 220 V and 100 W. When it is operated on 110 V, the power consumed will be :

(*a*) 100 W (*b*) 75 W (*c*) 50 W (*d*) 25 W **(NCERT Book Question)**

Solution. ***In the first case :***

Power, $P = 100$ W

Potential difference, $V = 220$ V

And, Resistance, $R = ?$ (To be calculated)

Now, $P = \frac{V^2}{R}$

So, $100 = \frac{(220)^2}{R}$

And $R = \frac{220 \times 220}{100} = 484\ \Omega$

This resistance of 484 Ω of the bulb will remain unchanged.

In the second case :

Power, $P = ?$ (To be calculated)

Potential difference, $V = 110$ V

And, Resistance, $R = 484\ \Omega$ (Calculated above)

Now, $P = \frac{V^2}{R}$

$$P = \frac{(110)^2}{484} = \frac{110 \times 110}{484} = 25 \text{ W}$$

Thus, the correct answer is : (*d*) 25 W.

Sample Problem 3. Which of the following does not represent electrical power in a circuit ?

(*a*) I^2R (*b*) IR^2 (*c*) VI (*d*) $\frac{V^2}{R}$ **(NCERT Book Question)**

Answer. (*b*) IR^2

An Important Formula for Calculating Electrical Energy

We will now derive a formula for calculating electrical energy in terms of power and time. We have already studied that :

$$\text{Electric power} = \frac{\text{Work done by electric current}}{\text{Time taken}}$$

Now, according to the law of conservation of energy,

Work done by electric current = Electric energy consumed

So, we can now write down the above relation as :

$$\text{Power} = \frac{\text{Electrical energy}}{\text{Time}}$$

or **Electrical energy = Power × Time**

or $E = P \times t$

It is obvious that **the electrical energy consumed by an electrical appliance is given by the product of its power rating and the time for which it is used.** From this we conclude that *the electrical energy consumed by an electrical appliance depends on two factors :* (*i*) *power rating of the appliance, and* (*ii*) *time for which the appliance is used.* We should memorize the above formula for calculating electrical energy because it will be used in solving numerical problems.

In the formula : *Electrical energy = Power × Time,* if we take the power in 'watts'and time in 'hours' then the unit of electrical energy becomes 'Watt-hour' (Wh). **One watt-hour is the amount of electrical energy consumed when an electrical appliance of 1 watt power is used for 1 hour.** We will now describe the commercial unit (or trade unit) of electrical energy called kilowatt-hour.

COMMERCIAL UNIT OF ELECTRICAL ENERGY : KILOWATT-HOUR

The SI unit of electrical energy is joule and we know that *"1 joule is the amount of electrical energy consumed when an appliance of 1 watt power is used for 1 second".* Actually, joule represents a very small quantity of energy and, therefore, it is inconvenient to use where a large quantity of energy is involved. So, for commercial purposes we use a bigger unit of electrical energy which is called "kilowatt-hour". **One kilowatt-hour is the amount of electrical energy consumed when an electrical appliance having a power rating of 1 kilowatt is used for 1 hour.** Since a kilowatt means 1000 watts, so we can also say that *one kilowatt-hour is the amount of electrical energy consumed when an electrical appliance of 1000 watts is used for 1 hour.* In other words, one kilowatt-hour is the energy dissipated by a current at the rate of 1000 watts for 1 hour. From this discussion we conclude that **the commercial unit of electrical energy is kilowatt-hour** which is written in short form as kWh.

Relation between kilowatt-hour and joule

1 kilowatt-hour is the amount of energy consumed at the rate of 1 kilowatt for 1 hour. That is,

1 kilowatt-hour = 1 kilowatt for 1 hour

or 1 kilowatt-hour = 1000 watts for 1 hour ... (1)

But : $1 \text{ watt} = \frac{1 \text{ joule}}{1 \text{ second}}$

So, equation (1) can be rewritten as :

$$1 \text{ kilowatt-hour} = 1000 \frac{\text{joules}}{\text{seconds}} \text{ for 1 hour}$$

And, 1 hour = 60 × 60 seconds

So, $$1 \text{ kilowatt-hour} = 1000 \frac{\text{joules}}{\text{seconds}} \times 60 \times 60 \text{ seconds}$$

or **1 kilowatt-hour = 36,00,000 joules (or 3.6 × 10^6 J)**

From this discussion we conclude that **1 kilowatt-hour is equal to 3.6×10^6 joules of electrical energy.** It should be noted that watt or kilowatt is the unit of electrical power but kilowatt-hour is the unit of electrical energy. Let us solve some problems now.

Sample Problem 1. A radio set of 60 watts runs for 50 hours. How much electrical energy is consumed ?

Solution. We know that :

Electrical energy = Power × Time

or $E = P \times t$ ... (1)

We want to calculate the electrical energy in kilowatt-hours, so first we should convert the power of 60 watts into kilowatts by dividing it by 1000. That is :

$$\text{Power, } P = 60 \text{ watts} = \frac{60}{1000} \text{ kilowatt} = 0.06 \text{ kilowatt}$$

And, Time, t = 50 hours

Now, putting $P = 0.06$ kW and, $t = 50$ hours in equation (1), we get :

$$\text{Electrical energy, } E = 0.06 \times 50 = 3 \text{ kilowatt-hours} \quad (\text{or } 3 \text{ kWh})$$

Thus, electrical energy consumed is 3 kilowatt-hours.

Note. In the above problem we have calculated the electrical energy consumed in the commercial unit of energy 'kilowatt-hour' (kWh). We can also convert this electrical energy into SI unit of energy called joule by using the relation between kilowatt-hour and joule. Now,

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

So, $$3 \text{ kWh} = 3.6 \times 10^6 \times 3 \text{ J} = 10.8 \times 10^6 \text{ J} \quad (\text{or } 10.8 \times 10^6 \text{ joules})$$

Sample Problem 2. A current of 4 A flows through a 12 V car headlight bulb for 10 minutes. How much energy transfer occurs during this time ?

Solution. Energy = Power × Time

or $E = P \times t$ ... (1)

First of all we should calculate power P by using the current of 4 A and voltage of 12 V.

Now, $P = V \times I$

So, $P = 12 \times 4$

or, Power, P = 48 watts

$$= \frac{48}{1000} \text{ kilowatts}$$

Thus, Power, P = 0.048 kW

And, Time, t = 10 minutes

$$= \frac{10}{60} \text{ hours} = \frac{1}{6} \text{ hours}$$

Now, putting $P = 0.048$ kW and, $t = \frac{1}{6}$ hours in equation (1), we get :

$$E = 0.048 \times \frac{1}{6} = 0.008 \text{ kWh}$$

Thus, the energy transferred is 0.008 kilowatt-hour.

Sample Problem 3. Calculate the energy transferred by a 5 A current flowing through a resistor of 2 ohms for 30 minutes.

Solution. We will first calculate the power by using the given values of current and resistance. This can be done by using the formula :

$$P = I^2 \times R$$

Here, Current, $I = 5$ amperes

And, Resistance, $R = 2$ ohms

So, Power, $P = (5)^2 \times 2$

$= 25 \times 2$

$= 50$ watts

$= \dfrac{50}{1000}$ kilowatts

Thus, Power, $P = 0.05$ kW ... (1)

And, Time, $t = 30$ minutes

$= \dfrac{30}{60}$ hours

$= \dfrac{1}{2}$ hours

$= 0.5$ hours ... (2)

Now, Energy, $E = P \times t$

$= 0.05 \times 0.5$

Energy, $E = 0.025$ kWh

In the above given sample problems, we have calculated the electrical energy in the commercial unit of "kilowatt-hour". Please calculate the energy in "joules" yourself.

How to Calculate the Cost of Electrical Energy Consumed

Kilowatt-hour is the "unit" of electrical energy for which we pay to the Electricity Supply Department of our City. One unit of electricity costs anything from rupees 3 to rupees 5 (or even more). The rates vary from place to place and keep on changing from time to time. Now, **by saying that 1 unit of electricity costs say, 3 rupees, we mean that 1 kilowatt-hour of electrical energy costs 3 rupees.** The electricity meter in our homes measures the electrical energy consumed by us in kilowatt-hours (see Figure 35). Now, we use different electrical appliances in our homes. We use electric bulbs, tube-lights, fans, electric iron, radio, T.V., and refrigerator, etc. All these household electrical appliances consume electrical energy at different rates. Our electricity bill depends on the total electrical energy consumed by our appliances over a given period of time, say a month. We will now describe **how the cost of electricity consumed is calculated**. Since the electricity is sold in units of kilowatt-hour, so first we should convert the power consumed in watts into kilowatts by dividing the total watts by 1000. The kilowatts are then converted into kilowatt-hours by multiplying the kilowatts by the number of hours for which the appliance has been used. This gives us the total electrical energy consumed in kilowatt-hours. In other words, this gives us the total number of "units" of electricity consumed. Knowing the cost of 1 unit of electricity, we can find out the total cost. This will become more clear from the following examples.

Figure 35. This is a domestic electricity meter. The reading in this meter shows the number of kilowatt-hours (or units) that have been used. The reading from this electricity meter is used to prepare our monthly electricity bill.

Sample Problem 1. A refrigerator having a power rating of 350 W operates for 10 hours a day. Calculate the cost of electrical energy to operate it for a month of 30 days. The rate of electrical energy is Rs. 3.40 per kWh.

Solution. Electrical energy, $E = P \times t$

Here, Power, $P = 350$ W

$= \frac{350}{1000}$ kW

$= 0.35$ kW

And, Time, $t = 10 \times 30$ hours

$= 300$ h

Now, putting these values of P and t in the formula,

$E = P \times t$

We get : $E = 0.35 \times 300$ kWh

$= 105$ kWh

Thus, the electrical energy consumed by the refrigerator in a month of 30 days is 105 kilowatt-hours.

Now, Cost of 1 kWh of electricity = Rs. 3.40

So, Cost of 105 kWh of electricity = Rs. 3.40 × 105

= Rs. 357

Sample Problem 2. A bulb is rated at 200 V-100 W. What is its resistance ? Five such bulbs burn for 4 hours. What is the electrical energy consumed ? Calculate the cost if the rate is ₹ 4.60 per unit.

Solution. (*a*) **Calculation of Resistance.** Here we know the voltage and power of the bulb. So, the resistance can be calculated by using the formula :

$$P = \frac{V^2}{R}$$

Here, Power, $P = 100$ watts

Voltage, $V = 200$ volts

And, Resistance, $R = ?$ (To be calculated)

Now, putting these values in the above formula, we get :

$$100 = \frac{(200)^2}{R}$$

$$100\,R = 40000$$

And, $R = \frac{40000}{100}$

$= 400$ ohms

(*b*) **Calculation of Electrical Energy Consumed.** The electrical energy consumed in kilowatt-hours can be calculated by using the formula :

$E = P \times t$

Here, Power, $P = 100$ watts

$= \frac{100}{1000}$ kilowatt

$= 0.1$ kilowatt ... (1)

And, Time, $t = 4$ hours ... (2)

So, Energy consumed by 1 bulb $= 0.1 \times 4$

$= 0.4$ kilowatt-hours

And,Energy consumed by 5 bulbs $= 0.4 \times 5$

$= 2$ kilowatt-hours (or 2 kWh)

Thus, the total electrical energy consumed is "2 kilowatt-hours" or "2 units".

(*c*) **Calculation of Cost of Electrical Energy.** We have been given that :

Cost of 1 unit of electricity = ₹ 4.60

So, Cost of 2 units of electricity = ₹ 4.60 × 2

= ₹ 9.20

Sample Problem 3. An electric heater draws a current of 10 A from a 220 V supply. What is the cost of using the heater for 5 hours everyday for 30 days if the cost of 1 unit (1 kWh) is ₹ 5.20 ?

Solution. In this problem, first of all we have to calculate the power of the heater by using the given values of current and voltage. This can be done by using the formula :

$$P = V \times I$$

Here, Voltage (or p.d.), V = 220 V

And, Current, I = 10 A

So, Power, P = 220 × 10 W

= 2200 W

$= \frac{2200}{1000}$ kW

= 2.2 kW ... (1)

Now, Electric energy consumed, $E = P \times t$

Here, Power, P = 2.2 kW

And, Time, t = 5 h

So, Electric energy consumed in 1 day = 2.2 × 5

= 11 kWh

And, Electric energy consumed in 30 days = 11 × 30

= 330 kWh (or 330 units) ... (2)

Now, Cost of 1 unit of electricity = ₹ 5.20

So, Cost of 330 units of electricity = ₹ 5.20 × 330

= ₹ 1716

Before we go further and discuss the heating effect of electric current, **please answer the following questions :**

Very Short Answer Type Questions

1. State two factors on which the electrical energy consumed by an electrical appliance depends.
2. Which one has a higher electrical resistance : a 100 watt bulb or a 60 watt bulb ?
3. Name the commercial unit of electric energy.
4. An electric bulb is rated at 220 V, 100 W. What is its resistance ?
5. What is the SI unit of (*i*) electric energy, and (*ii*) electric power ?
6. Name the quantity whose unit is (*i*) kilowatt, and (*ii*) kilowatt-hour.
7. Which quantity has the unit of watt ?
8. What is the meaning of the symbol kWh ? Which quantity does it represent ?
9. If the potential difference between the end of a wire of fixed resistance is doubled, by how much does the electric power increase ?
10. An electric lamp is labelled 12 V, 36 W. This indicates that it should be used with a 12 V supply. What other information does the label provide ?
11. What current will be taken by a 920 W appliance if the supply voltage is 230 V ?

Short Answer Type Questions

12. Define watt. Write down an equation linking watts, volts and amperes.
13. Define watt-hour. How many joules are equal to 1 watt-hour ?
14. How much energy is consumed when a current of 5 amperes flows through the filament (or element) of a heater having resistance of 100 ohms for two hours ? Express it in joules.
15. An electric bulb is connected to a 220 V power supply line. If the bulb draws a current of 0.5 A, calculate the power of the bulb.
16. In which of the following cases more electrical energy is consumed per hour ?
(*i*) A current of 1 ampere passed through a resistance of 300 ohms.
(*ii*) A current of 2 amperes passed through a resistance of 100 ohms.
17. An electric kettle rated at 220 V, 2.2 kW, works for 3 hours. Find the energy consumed and the current drawn.

18. In a house two 60 W electric bulbs are lighted for 4 hours, and three 100 W bulbs for 5 hours everyday. Calculate the electric energy consumed in 30 days.

19. A bulb is rated as 250 V; 0.4 A. Find its : (*i*) power, and (*ii*) resistance.

20. For a heater rated at 4 kW and 220 V, calculate :
(*a*) the current,
(*b*) the resistance of the heater,
(*c*) the energy consumed in 2 hours, and
(*d*) the cost if 1 kWh is priced at ₹ 4.60.

21. An electric motor takes 5 amperes current from a 220 volt supply line. Calculate the power of the motor and electrical energy consumed by it in 2 hours.

22. Which uses more energy : a 250 W TV set in 1 hour or a 1200 W toaster in 10 minutes ?

23. Calculate the power used in the 2 Ω resistor in each of the following circuits :
(*i*) a 6 V battery in series with 1 Ω and 2 Ω resistors.
(*ii*) a 4 V battery in parallel with 12 Ω and 2 Ω resistors.

24. Two lamps, one rated 40 W at 220 V and the other 60 W at 220 V, are connected in parallel to the electric supply at 220 V.
(*a*) Draw a circuit diagram to show the connections.
(*b*) Calculate the current drawn from the electric supply.
(*c*) Calculate the total energy consumed by the two lamps together when they operate for one hour.

25. An electric kettle connected to the 230 V mains supply draws a current of 10 A. Calculate :
(*a*) the power of the kettle.
(*b*) the energy transferred in 1 minute.

26. A 2 kW heater, a 200 W TV and three 100 W lamps are all switched on from 6 p.m. to 10 p.m. What is the total cost at Rs. 5.50 per kWh ?

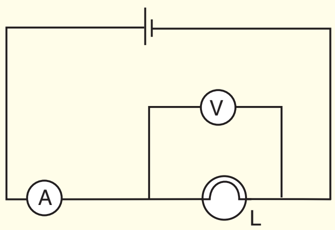
27. What is the maximum power in kilowatts of the appliance that can be connected safely to a 13 A ; 230 V mains socket ?

28. An electric fan runs from the 230 V mains. The current flowing through it is 0.4 A. At what rate is electrical energy transferred by the fan ?

Long Answer Type Question

29. (*a*) What is meant by "electric power" ? Write the formula for electric power in terms of potential difference and current.

(*b*) The diagram below shows a circuit containing a lamp L, a voltmeter and an ammeter. The voltmeter reading is 3 V and the ammeter reading is 0.5 A.



(*i*) What is the resistance of the lamp ?
(*ii*) What is the power of the lamp ?

(*c*) Define kilowatt-hour. How many joules are there in one kilowatt-hour ?

(*d*) Calculate the cost of operating a heater of 500 W for 20 hours at the rate of ₹ 3.90 per unit.

Multiple Choice Questions (MCQs)

30. When an electric lamp is connected to 12 V battery, it draws a current of 0.5 A. The power of the lamp is :
(*a*) 0.5 W (*b*) 6 W (*c*) 12 W (*d*) 24 W

31. The unit for expressing electric power is :
(*a*) volt (*b*) joule (*c*) coulomb (*d*) watt

32. Which of the following is likely to be the correct wattage for an electric iron used in our homes ?
(*a*) 60 W (*b*) 250 W (*c*) 850 W (*d*) 2000 W

33. An electric heater is rated at 2 kW. Electrical energy costs ₹ 4 per kWh. What is the cost of using the heater for 3 hours ?

(*a*) ₹ 12 (*b*) ₹ 24 (*c*) ₹ 36 (*d*) ₹ 48

34. The SI unit of energy is :
(*a*) joule (*b*) coulomb (*c*) watt (*d*) ohm-metre

35. The commercial unit of energy is :
(*a*) watt (*b*) watt-hour (*c*) kilowatt-hour (*d*) kilo-joule

36. How much energy does a 100 W electric bulb transfer in 1 minute ?
(*a*) 100 J (*b*) 600 J (*c*) 3600 J (*d*) 6000 J

37. An electric kettle for use on a 230 V supply is rated at 3000 W. For safe working, the cable connected to it should be able to carry at least :
(*a*) 2 A (*b*) 5 A (*c*) 10 A (*d*) 15 A

38. How many joules of electrical energy are transferred per second by a 6 V ; 0.5 A lamp ?
(*a*) 30 J/s (*b*) 12 J/s (*c*) 0.83 J/s (*d*) 3 J/s

39. At a given time, a house is supplied with 100 A at 220 V. How many 75 W, 220 V light bulbs could be switched on in the house at the same time (if they are all connected in parallel) ?
(*a*) 93 (*b*) 193 (*c*) 293 (*d*) 393

40. If the potential difference between the ends of a fixed resistor is halved, the electric power will become :
(*a*) double (*b*) half (*c*) four times (*d*) one-fourth

Questions Based on High Order Thinking Skills (HOTS)

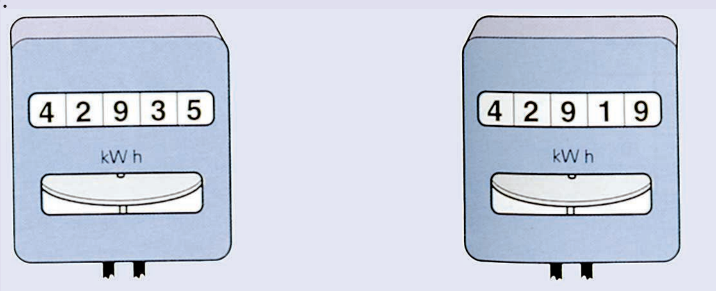
41. State whether an electric heater will consume more electrical energy or less electrical energy per second when the length of its heating element is reduced. Give reasons for your answer.

42. The table below shows the current in three different electrical appliances when connected to the 240 V mains supply :

Appliance	*Current*
Kettle	8.5 A
Lamp	0.4 A
Toaster	4.8 A

(*a*) Which appliance has the greatest electrical resistance ? How does the data show this ?
(*b*) The lamp is connected to the mains supply by using a thin, twin-cored cable consisting of live and neutral wires. State two reasons why this cable should not be used for connecting the kettle to the mains supply.
(*c*) Calculate the power rating of the kettle when it is operated from the 240 V mains supply.
(*d*) A man takes the kettle abroad where the mains supply is 120 V. What is the current in the kettle when it is operated from the 120 V supply ?

43. A boy noted the readings on his home's electricity meter on Sunday at 8 AM and again on Monday at 8 AM (see Figures below).



(*a*) What was the meter reading on Sunday ?
(*b*) What was the meter reading on Monday ?
(*c*) How many units of electricity have been used ?
(*d*) In how much time these units have been used ?
(*e*) If the rate is Rs. 5 per unit, what is the cost of electricity used during this time ?

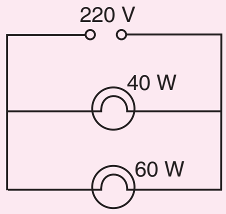
44. An electric bulb is rated as 10 W, 220 V. How many of these bulbs can be connected in parallel across the two wires of 220 V supply line if the maximum current which can be drawn is 5 A ?

45. Two exactly similar electric lamps are arranged (*i*) in parallel, and (*ii*) in series. If the parallel and series combination of lamps are connected to 220 V supply line one by one, what will be the ratio of electric power consumed by them ?

ANSWERS

2. 60 watt bulb **4.** 484 Ω **9.** Four times **10.** The electric lamp consumes energy at the rate of 36 J/s **11.** 4 A **14.** 18.0×10^6 J **15.** 110 W **16.** 2 A ; 100 Ω **17.** 6.6 kWh ; 10 A **18.** 59.4 kWh **19.** (*i*) 100 W (*ii*) 625 Ω **20.** (*a*) 18.18 A (*b*) 12.1 Ω (*c*) 8 kWh (*d*) ₹ 36.80 **21.** 1.1 kW ; 2.2 kWh **22.** TV set uses 0.25 kWh energy whereas toaster uses 0.20 kWh energy. So, TV uses more energy.

23. (*i*) 8 W (*ii*) 8 W **24.** (*a*)



(*b*) 0.45 A (*c*) 356.4 kJ **25.** (*a*) 2300 W or 2.3 kW (*b*) 1,38,000 J or 138 kJ **26.** Rs. 55.00 **27.** 2.99 kW **28.** 92 J/s **29.** (*b*) (*i*) 6 Ω (*ii*) 1.5 W (*d*) ₹ 39.00 **30.** (*b*) **31.** (*d*) **32.** (*c*) **33.** (*b*) **34.** (*a*) **35.** (*c*) **36.** (*d*) **37.** (*d*) **38.** (*d*) **39.** (*c*) **40.** (*d*)
41. More electrical energy ; Power is inversely proportional to resistance **42.** (*a*) Lamp ; Least current flowing in it (*b*) Large current drawn by kettle ; Earth connection needed (*c*) 2040 W (*d*) 4.25 A
43. (*a*) 42919 (*b*) 42935 (*c*) 16 units (*d*) 24 hours (*e*) Rs. 80 **44.** 110 bulbs **45.** 4 : 1

Effects Produced by Electric Current

An electric current can produce three important effects. These are : (1) Heating effect, (2) Magnetic effect, and (3) Chemical effect. We will now discuss the heating effect of current. The magnetic effect of current will be discussed in the next Chapter whereas the chemical effect of current will be described in higher classes.

HEATING EFFECT OF CURRENT

When an electric current is passed through a high resistance wire, like nichrome wire, the resistance wire becomes very hot and produces heat. This is called the heating effect of current. The heating effect of current is obtained by the transformation of electrical energy into heat energy. Just as mechanical energy used to overcome friction is converted into heat, in the same way, electrical energy is converted into heat energy when an electric current flows through a resistance wire. Thus, *the role of 'resistance' in electrical circuits is similar to the role of 'friction' in mechanics.* We will now derive a formula for calculating the heat produced when an electric current flows through a resistance wire.

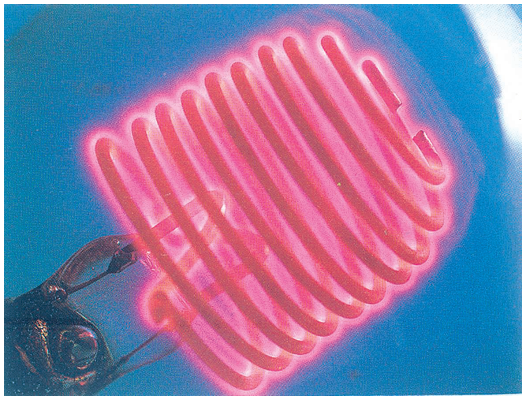


Figure 36. An electric current produces heating effect. This filament has become red-hot due to the heating effect of current.

Since a conductor, say a resistance wire, offers resistance to the flow of current, so work must be done by the current continuously to keep itself flowing. We will calculate the work done by a current I when it flows through a resistance R for time t. Now, when an electric charge Q moves against a potential difference V, the amount of work done is given by :

$$W = Q \times V \qquad \text{... (1)}$$

From the definition of current we know that :

$$\text{Current,} \quad I = \frac{Q}{t}$$

$$\text{So,} \quad Q = I \times t \qquad \text{... (2)}$$

And from Ohm's law, we have :

$$\frac{V}{I} = R$$

or $$\text{Potential difference, } V = I \times R \qquad \text{... (3)}$$

Now, putting $Q = I \times t$ and $V = I \times R$ in equation (1), we get :

$$W = I \times t \times I \times R$$

So, Work done, $W = I^2 \times R \times t$

Assuming that all the electrical work done or all the electrical energy consumed is converted into heat energy, we can write 'Heat produced' in place of 'Work done' in the above equation. Thus,

Heat produced, $\boldsymbol{H = I^2 \times R \times t}$ joules

This formula gives us the heat produced in joules when a current of I amperes flows in a wire of resistance R ohms for time t seconds. This is known as **Joule's law of heating.** According to Joule's law of heating given by the formula $H = I^2 \times R \times t$, it is clear that **the heat produced in a wire is directly proportional to :**

(*i*) square of current (I^2)
(*ii*) resistance of wire (R)
(*iii*) time (t), for which current is passed

(*a*) Since the heat produced is directly proportional to the square of current :

$$H \propto I^2$$

so, if we *double* the current, then the heat produced will become *four times*. And if we *halve* the current, then heat generated will become *one-fourth.*

(*b*) Since the heat produced in a wire is directly proportional to the resistance :

$$H \propto R$$

so, if we *double* the resistance, then heat produced will also get *doubled*. And if we *halve* the resistance, then the heat produced will also be *halved*. This means that **a given current will produce more heat in a high resistance wire than in a low resistance wire**.

We know that when two similar resistance wires are connected in series, then their combined resistance gets doubled but when they are connected in parallel then their combined resistance gets halved. So, **a given current will produce more heat per unit time if the two resistances are connected in series than when they are connected in parallel.**

(*c*) Since the heat produced in a wire is directly proportional to the time for which current flows :

$$H \propto t$$

so, if the current is passed through a wire for *double* the time, then the heat produced is *doubled*. And if the time is *halved*, the heat produced is also *halved*.

We will now solve some problems based on the heating effect of current. Please note that the formula : $H = I^2 \times R \times t$ for calculating the heat produced can be used only if the current I, resistance R and time t are known to us. In some cases, however, they give us the power P and time t only. In that case the heat energy is to be calculated by using the formula : $E = P \times t$.

It should be noted that **all the appliances which run on electricity do not convert all the electric energy into heat energy.** Only the electrical heating appliances convert most of the electric energy into heat energy. For example, when electric current is passed through an electric appliance such as a fan, then most of the electric energy is used up in running the fan (or turning the fan), only a very small amount of electric energy is converted into heat energy by a fan. Due to this, an electric fan becomes slightly warm when run continuously for a long time. On the other hand, when electric current is passed through an electrical heating appliance such as an electric heater, electric kettle, hair dryer, immersion rod or a geyser, then most of the electrical energy is converted into heat. All the electrical heating appliances have a 'heating element' or 'heating coil' made of high resistance wire (like nichrome wire) which helps in converting most of the electric energy into heat energy. We will now solve some problems based on the heating effect of current.

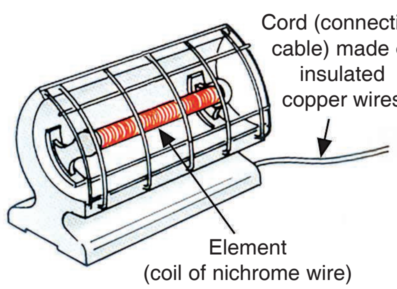


Figure 37. An electric room heater converts almost all the electrical energy into heat.

Sample Problem 1. A potential difference of 250 volts is applied across a resistance of 500 ohms in an electric iron. Calculate (*i*) current, and (*ii*) heat energy produced in joules in 10 seconds.

Solution. (*i*) **Calculation of Current.** The current can be calculated by using Ohm's law equation :

$$\frac{V}{I} = R$$

Here, Potential difference, $V = 250$ volts

Current, $I = ?$ (To be calculated)

Resistance, $R = 500$ ohms

Putting these values in the above formula, we get :

$$\frac{250}{I} = 500$$

So, $$I = \frac{250}{500}$$

$$= \frac{1}{2}$$

$$= 0.5 \text{ ampere}$$

Thus, the current flowing in the electric iron is 0.5 A.

(*ii*) **Calculation of Heat Energy.** The heat energy in joules can be calculated by using the formula :

$$H = I^2 \times R \times t$$

Here, Current, $I = 0.5$ A

Resistance, $R = 500\ \Omega$

And, Time, $t = 10$ s

Putting these values in the above formula, we get :

$$H = (0.5)^2 \times 500 \times 10$$

$$= 1250 \text{ joules}$$

Sample Problem 2. Calculate the heat produced when 96,000 coulombs of charge is transferred in 1 hour through a potential difference of 50 volts. **(NCERT Book Question)**

Solution. First of all we will calculate the current by using the values of charge and time. We know that :

$$\text{Current, } I = \frac{Q}{t}$$

$$I = \frac{96,000}{60 \times 60} \quad \text{(Because 1 h = 60 × 60 s)}$$

$$I = 26.67 \text{ A}$$

We will now calculate the resistance by using Ohm's law :

$$R = \frac{V}{I}$$

$$R = \frac{50}{26.67}$$

$$R = 1.87\ \Omega$$

$$\text{Heat produced, } H = I^2 \times R \times t$$

$$= (26.67)^2 \times 1.87 \times 60 \times 60$$

$$= 4788400 \text{ J}$$

$$= 4788.4 \text{ kJ}$$

Thus, the heat produced is 4788.4 kilojoules.

Sample Problem 3. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then in parallel in a circuit across the same potential difference. The ratio of heat produced in series and parallel combinations would be :

(*a*) 1 : 2 (*b*) 2 : 1 (*c*) 1 : 4 (*d*) 4 : 1 **(NCERT Book Question)**

Solution. Suppose the resistance of each one of the two wires is x.

(*i*) When the two resistance wires, each having a resistance x, are connected in series, then :

Combined resistance, $R_1 = 2x$

And, if the potential difference in the circuit is V, then applying Ohm's law :

$$\text{Current, } I_1 = \frac{V}{2x}$$

Suppose the heat produced with the series combination of wires is H_1. Then :

$$H_1 = I_1^2 \times R_1 \times t$$

or $$H_1 = \left(\frac{V}{2x}\right)^2 \times 2x \times t = \frac{V^2}{4x^2} \times 2x \times t$$

or $$H_1 = \frac{V^2 \times t}{2x} \quad \text{... (1)}$$

(*ii*) When the two resistance wires, each of resistance x, are connected in parallel, then :

Combined resistance, $R_2 = \frac{x}{2}$

And if the potential difference in the circuit is V, then applying Ohm 's law :

$$\text{Current, } I_2 = \frac{V \times 2}{x}$$

Suppose the heat produced with the parallel combination of wires is H_2. Then :

$$H_2 = I_2^2 \times R_2 \times t$$

or $$H_2 = \left(\frac{V \times 2}{x}\right)^2 \times \frac{x}{2} \times t = \frac{V^2 \times 4 \times x \times t}{x^2 \times 2}$$

or $$H_2 = \frac{V^2 \times 2 \times t}{x} \quad \text{... (2)}$$

Dividing equation (1) by equation (2), we get :

$$\frac{H_1}{H_2} = \frac{V^2 \times t \times x}{2x \times V^2 \times 2 \times t}$$

$$\frac{H_1}{H_2} = \frac{1}{4} \quad \text{or} \quad H_1 : H_2 = 1 : 4$$

Thus, the correct option is : (*c*) 1 : 4

Applications of the Heating Effect of Current

The important applications of the heating effect of electric current are given below :

1. The heating effect of current is utilised in the working of electrical heating appliances such as electric iron, electric kettle, electric toaster, electric oven, room heaters, water heaters (geysers), etc. All these heating appliances contain coils of high resistance wire made of nichrome alloy. When these appliances are connected to power supply by insulated copper wires then a large amount of heat is produced in the heating coils (because they have high resistance), but a negligible heat is produced in the connecting wires of copper (because copper has very, very low resistance). For example, the heating element (or coil) of an electric heater made of nichrome glows because it becomes red-hot due to the large amount of heat produced on passing current (because of its high resistance), but the cord or connecting cable of the electric heater made of copper does not glow because negligible heat is produced in it by passing current (because of its extremely low resistance). The temperature of the heating element (or heating coil) of an electrical heating device when it becomes red-hot and glows is about 900°C.

Figure 38. This is an electric iron.

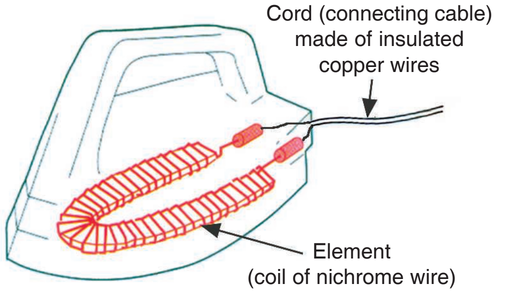


Figure 39. An electric iron works on the heating effect of current. When current is passed, its heating element made of nichrome wire becomes red-hot and produces heat.

2. The heating effect of electric current is utilised in electric bulbs (electric lamps) for producing light. When electric current passes through a very thin, high resistance tungsten filament of an electric bulb, the filament becomes white-hot and emits light. Please note that the same current flowing through the tungsten filament of an electric bulb produces enormous heat but almost negligible heat is produced in the connecting wires of copper. This is because of the fact that the fine tungsten filament has very high resistance whereas copper connecting wires have very low resistance.

Tungsten metal is used for making the filaments of electric bulbs because it has a very high melting point (of 3380°C). Due to its very high melting point, the tungsten filament can be kept white-hot without melting away. The other properties of tungsten which make it suitable for making filaments of electric bulbs are its *high flexibility* and *low rate of evaporation at high temperature.* Please note that when the tungsten filament of an electric bulb becomes white-hot and glows to emit light, then its temperature is about 2500°C !

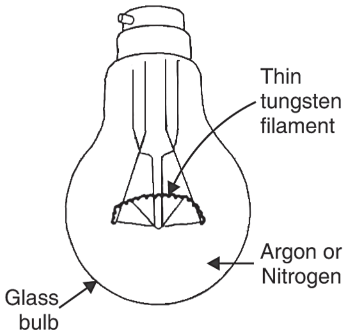


Figure 40. An electric bulb works on the heating effect of electric current. When current is passed, its filament becomes white-hot and produces heat and light.

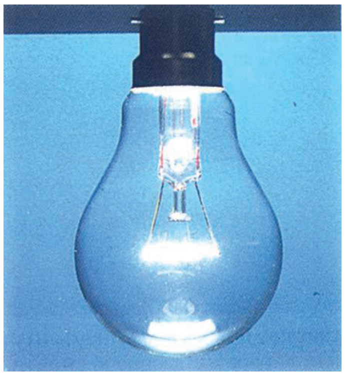


Figure 41. The glowing filament of this electric bulb is producing light and heat.

If air is present in an electric bulb, then the extremely hot tungsten filament would burn up quickly in the oxygen of air. So, **the electric bulb is filled with a chemically unreactive gas like argon or nitrogen (or a mixture of both).** The gases like argon and nitrogen do not react with the hot tungsten filament and hence prolong the life of the filament of the electric bulb. It should be noted that most of the electric power consumed by the filament of an electric bulb appears as heat (due to which the bulb becomes hot), only a small amount of electric power is converted into light. So, filament-type electric bulbs are not power efficient. On the other hand, tube-lights are much more power efficient, because they have no filaments.

3. The heating effect of electric current is utilised in electric fuse for protecting household wiring and electrical appliances. A fuse is a short length of a thin tin-plated copper wire having low melting point. The thin fuse wire has a *higher* resistance than the rest of the electric wiring in a house. So, when the current in a household electric circuit rises too much due to some reason, then the fuse wire gets heated too much, melts and breaks the circuit (due to which the current stops flowing). This prevents the fire in house (due to over-heating of wiring) and also prevents damage to various electrical appliances in the house due to excessive current flowing through them. Thus, an electric fuse is a very important application of the

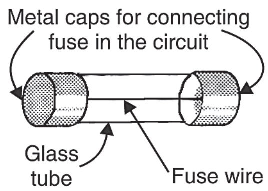


Figure 42. An electric fuse works on the heating effect of current. This diagram shows a fuse which is used to protect individual electrical appliances.

heating effect of current. We will discuss the electric fuse in more detail in the topic on domestic electric circuits in the next Chapter. We are now in a position to **answer the following questions :**

Very Short Answer Type Questions

1. How does the heat H produced by a current passing through a fixed resistance wire depend on the magnitude of current I ?

2. If the current passing through a conductor is doubled, what will be the change in heat produced ?

3. Name two effects produced by electric current.

4. Which effect of current is utilised in an electric light bulb ?

5. Which effect of current is utilised in the working of an electric fuse ?

6. Name two devices which work on the heating effect of electric current.

7. Name two gases which are filled in filament type electric light bulbs.

8. Explain why, filament type electric bulbs are not power efficient.

9. Why does the connecting cord of an electric heater not glow hot while the heating element does ?

Short Answer Type Questions

10. (*a*) Write down the formula for the heat produced when a current I is passed through a resistor R for time t.

(*b*) An electric iron of resistance 20 ohms draws a current of 5 amperes. Calculate the heat produced in 30 seconds.

11. State three factors on which the heat produced by an electric current depends. How does it depend on these factors ?

12. (*a*) State and explain Joule's law of heating.

(*b*) A resistance of 40 ohms and one of 60 ohms are arranged in series across 220 volt supply. Find the heat in joules produced by this combination of resistances in half a minute.

13. Why is an electric light bulb not filled with air ? Explain why argon or nitrogen is filled in an electric bulb.

14. Explain why, tungsten is used for making the filaments of electric bulbs.

15. Explain why, the current that makes the heater element very hot, only slightly warms the connecting wires leading to the heater.

16. When a current of 4.0 A passes through a certain resistor for 10 minutes, 2.88×10^4 J of heat are produced. Calculate :

(*a*) the power of the resistor.

(*b*) the voltage across the resistor.

17. A heating coil has a resistance of 200 Ω. At what rate will heat be produced in it when a current of 2.5 A flows through it ?

18. An electric heater of resistance 8 Ω takes a current of 15 A from the mains supply line. Calculate the rate at which heat is developed in the heater.

19. A resistance of 25 Ω is connected to a 12 V battery. Calculate the heat energy in joules generated per minute.

20. 100 joules of heat is produced per second in a 4 ohm resistor. What is the potential difference across the resistor ?

Long Answer Type Question

21. (*a*) Derive the expression for the heat produced due to a current 'I' flowing for a time interval 't' through a resistor 'R' having a potential difference 'V' across its ends. With which name is this relation known ?

(*b*) How much heat will an instrument of 12 W produce in one minute if it is connected to a battery of 12 V ?

(*c*) The current passing through a room heater has been halved. What will happen to the heat produced by it ?

(*d*) What is meant by the heating effect of current ? Give two applications of the heating effect of current.

(*e*) Name the material which is used for making the filaments of an electric bulb.

Multiple Choice Questions (MCQs)

22. The heat produced by passing an electric current through a fixed resistor is proportional to the square of :

(*a*) magnitude of resistance of the resistor
(*b*) temperature of the resistor
(*c*) magnitude of current
(*d*) time for which current is passed

23. The current passing through an electric kettle has been doubled. The heat produced will become :
(*a*) half (*b*) double (*c*) four times (*d*) one-fourth

24. An electric fuse works on the :
(*a*) chemical effect of current (*b*) magnetic effect of current
(*c*) lighting effect of current (*d*) heating effect of current

25. The elements of electrical heating devices are usually made of :
(*a*) tungsten (*b*) bronze (*c*) nichrome (*d*) argon

26. The heat produced in a wire of resistance '*x*' when a current '*y*' flows through it in time '*z*' is given by :
(*a*) $x^2 \times y \times z$ (*b*) $x \times z \times y^2$ (c) $y \times z^2 \times x$ (*d*) $y \times z \times x$

27. Which of the following characteristic is not suitable for a fuse wire ?
(*a*) thin and short (*b*) thick and short
(*c*) low melting point (*d*) higher resistance than rest of wiring

28. In a filament type light bulb, most of the electric power consumed appears as :
(*a*) visible light (*b*) infra-red-rays (*c*) ultraviolet rays (*d*) fluorescent light

29. Which of the following is the most likely temperature of the filament of an electric light bulb when it is working on the normal 220 V supply line ?
(*a*) 500°C (*b*) 1500°C (*c*) 2500°C (*d*) 4500°C

30. If the current flowing through a fixed resistor is halved, the heat produced in it will become :
(*a*) double (*b*) one-half (*c*) one-fourth (*d*) four times

Questions Based on High Order Thinking Skills (HOTS)

31. The electrical resistivities of four materials *P*, *Q*, *R* and *S* are given below :

P	6.84×10^{-8} Ωm
Q	1.70×10^{-8} Ωm
R	1.0×10^{15} Ωm
S	11.0×10^{-7} Ωm

Which material will you use for making : (*a*) heating element of electric iron (*b*) connecting wires of electric iron (*c*) covering of connecting wires ? Give reason for your choice in each case.

32. (*a*) How does the wire in the filament of a light bulb behave differently to the other wires in the circuit when the current flows ?
(*b*) What property of the filament wire accounts for this difference ?

33. Two exactly similar heating resistances are connected (*i*) in series, and (*ii*) in parallel, in two different circuits, one by one. If the same current is passed through both the combinations, is more heat obtained per minute when they are connected in series or when they are connected in parallel ? Give reason for your answer.

34. An electric iron is connected to the mains power supply of 220 V. When the electric iron is adjusted at 'minimum heating' it consumes a power of 360 W but at 'maximum heating' it takes a power of 840 W. Calculate the current and resistance in each case.

35. Which electric heating devices in your home do you think have resistors which control the flow of electricity ?

ANSWERS

2. Heat produced becomes four times **10.** (*b*) 15000 J **12.** (*b*) 14520 J **16.** (*a*) 48 W (*b*) 12 V **17.** 1250 J/s **18.** 1800 J **19.** 345.6 J **20.** 20 V **21.** (*b*) 720 J (*c*) Heat produced becomes one-fourth **22.** (*c*) **23.** (*c*) **24.** (*d*) **25.** (*c*) **26.** (*b*) **27.** (*b*) **28.** (*b*) **29.** (*c*) **30.** (*c*) **31.** (*a*) *S* ; Because it has high resistivity of 11.0×10^{-7} Ωm (It is actually nichrome) (*b*) *Q* ; Because it has very low resistivity of 1.70×10^{-8} Ω m (It is actually copper) (*c*) *R* ; Because it has very, very high resistivity of 1.0×10^{15} Ω m (It is actually rubber) **32.** (*a*) The filament wire becomes white hot whereas other wires in the circuit do not get heated much (*b*) High resistance of filament wire 33. In series **34.** 1.64 A ; 134.15 Ω ; 3.82 A , 57.60 Ω **35.** Electric iron ; Electric oven ; Water heater (Geyser) ; Room heater (Convector)