QUESTIONS

1. Judge the equivalent resistance when the following are connected in parallel – (a) 1 Ω and 10^6 Ω, (b) 1 Ω and 10^3 Ω, and 10^6 Ω.
2. An electric lamp of 100 Ω, a toaster of resistance 50 Ω, and a water filter of resistance 500 Ω are connected in parallel to a 220 V source. What is the resistance of an electric iron connected to the same source that takes as much current as all three appliances, and what is the current through it?
3. What are the advantages of connecting electrical devices in parallel with the battery instead of connecting them in series?
4. How can three resistors of resistances 2 Ω, 3 Ω, and 6 Ω be connected to give a total resistance of (a) 4 Ω, (b) 1 Ω?
5. What is (a) the highest, (b) the lowest total resistance that can be secured by combinations of four coils of resistance 4 Ω, 8 Ω, 12 Ω, 24 Ω?

1[redacted] CURRENT

We [redacted] of electrical energy. The ch[redacted]tential difference between its[redacted]tion to flow the current th[redacted]ected to the battery. We ha[redacted] the current, the source ha[redacted]this energy go? A part of th[redacted] may be consumed into us[redacted]electric fan). Rest of the so[redacted]aise the temperature of ga[redacted]. For example, an electric fa[redacted]er time etc. On the other ha[redacted]hat is, a configuration of re[redacted]e energy continually gets di[redacted]s known as the heating eff[redacted] devices such as electric he[redacted]

Consider a current *I* flowing through a resistor of resistance *R*. Let the potential difference across it be *V* (Fig. 12.13). Let *t* be the time during which a charge *Q* flows across. The work done in moving the charge *Q* through a potential difference *V* is *VQ*. Therefore, the source must supply energy equal to *VQ* in time *t*. Hence the power input to the circuit by the source is

$$P = V\frac{Q}{t} = VI \qquad (12.19)$$

Or the energy supplied to the circuit by the source in time *t* is $P \times t$, that is, *VIt*. What happens to this energy expended by the source? This energy gets dissipated in the resistor as heat. Thus for a steady current *I*, the amount of heat *H* produced in time *t* is

$$H = VIt \qquad (12.20)$$

Applying Ohm's law [Eq. (12.5)], we get

$$H = I^2 Rt \qquad (12.21)$$

This is known as Joule's law of heating. The law implies that heat produced in a resistor is (i) directly proportional to the square of current for a given resistance, (ii) directly proportional to resistance for a given current, and (iii) directly proportional to the time for which the current flows through the resistor. In practical situations, when an electric appliance is connected to a known voltage source, Eq. (12.21) is used after calculating the current through it, using the relation $I = V/R$.

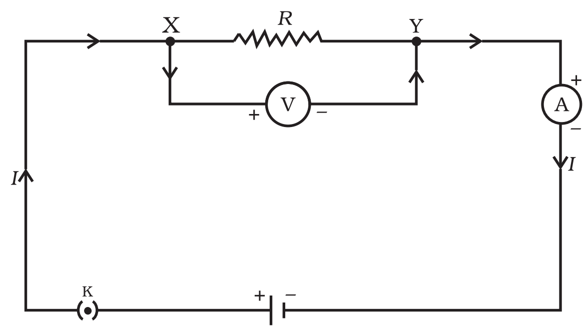

Figure 12.13
A steady current in a purely resistive electric circuit

Example 12.10

An electric iron consumes energy at a rate of 840 W when heating is at the maximum rate and 360 W when the heating is at the minimum. The voltage is 220 V. What are the current and the resistance in each case?

Solution

From Eq. (12.19), we know that the power input is

$P = VI$

Thus the current $I = P/V$

(a) When heating is at the maximum rate,
$I = 840\ \text{W}/220\ \text{V} = 3.82\ \text{A}$;
and the resistance of the electric iron is
$R = V/I = 220\ \text{V}/3.82\ \text{A} = 57.60\ \Omega$.

(b) When heating is at the minimum rate,
$I = 360\ \text{W}/220\ \text{V} = 1.64\ \text{A}$;
and the resistance of the electric iron is
$R = V/I = 220\ \text{V}/1.64\ \text{A} = 134.15\ \Omega$.

Example 12.11

100 J of heat is produced each second in a 4 Ω resistance. Find the potential difference across the resistor.

Solution

$H = 100\ \text{J},\ R = 4\ \Omega,\ t = 1\ \text{s},\ V = ?$

From Eq. (12.21) we have the current through the resistor as

$$I = \sqrt{(H/Rt)} = \sqrt{[100\ \text{J}/(4\ \Omega \times 1\ \text{s})]} = 5\ \text{A}$$

Thus the potential difference across the resistor, V [from Eq. (12.5)] is

$$V = IR = 5\ \text{A} \times 4\ \Omega = 20\ \text{V}.$$

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QUESTIONS

1. Why does the cord of an electric heater not glow while the heating element does?
2. Compute the heat generated while transferring 96000 coulomb of charge in one hour through a potential difference of 50 V.
3. An electric iron of resistance 20 Ω takes a current of 5 A. Calculate the heat developed in 30 s.

12.7.1 Practical Applications of Heating Effect of Electric Current

The generation of heat in a conductor is an inevitable consequence of electric current. In many cases, it is undesirable as it converts useful electrical energy into heat. In electric circuits, the unavoidable heating can increase the temperature of the components and alter their properties. However, heating effect of electric current has many useful applications. The electric laundry iron, electric toaster, electric oven, electric kettle and electric heater are some of the familiar devices based on Joule's heating.

The electric heating is also used to produce light, as in an electric bulb. Here, the filament must retain as much of the heat generated as is possible, so that it gets very hot and emits light. It must not melt at such high temperature. A strong metal with high melting point such as tungsten (melting point 3380°C) is used for making bulb filaments. The filament should be thermally isolated as much as possible, using insulating support, etc. The bulbs are usually filled with chemically inactive nitrogen and argon gases to prolong the life of filament. Most of the power consumed by the filament appears as heat, but a small part of it is in the form of light radiated.

Another common application of Joule's heating is the fuse used in electric circuits. It protects circuits and appliances by stopping the flow of any unduly high electric current. The fuse is placed in series with the device. It consists of a piece of wire made of a metal or an alloy of appropriate melting point, for example aluminium, copper, iron, lead etc. If a current larger than the specified value flows through the circuit, the temperature of the fuse wire increases. This melts the fuse wire and breaks the circuit. The fuse wire is usually encased in a cartridge of porcelain or similar material with metal ends. The fuses used for domestic purposes are rated as 1 A, 2 A, 3 A, 5 A, 10 A, etc. For an electric iron which consumes 1 kW electric power when operated at 220 V, a current of (1000/220) A, that is, 4.54 A will flow in the circuit. In this case, a 5 A fuse must be used.

12.8 ELECTRIC POWER

You have studied in your earlier Class that the rate of doing work is power. This is also the rate of consumption of energy.

Equation (12.21) gives the rate at which electric energy is dissipated or consumed in an electric circuit. This is also termed as electric power. The power P is given by

$$P = VI$$

Or $$P = I^2R = V^2/R \quad (12.22)$$

The SI unit of electric power is watt (W). It is the power consumed by a device that carries 1 A of current when operated at a potential difference of 1 V. Thus,

$$1 \text{ W} = 1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ V A} \quad (12.23)$$

The unit 'watt' is very small. Therefore, in actual practice we use a much larger unit called 'kilowatt'. It is equal to 1000 watts. Since electrical energy is the product of power and time, the unit of electric energy is, therefore, watt hour (W h). One watt hour is the energy consumed when 1 watt of power is used for 1 hour. The commercial unit of electric energy is kilowatt hour (kW h), commonly known as 'unit'.

$$1 \text{ kW h} = 1000 \text{ watt} \times 3600 \text{ second}$$
$$= 3.6 \times 10^6 \text{ watt second}$$
$$= 3.6 \times 10^6 \text{ joule (J)}$$

More to Know!

Many people think that electrons are consumed in an electric circuit. This is wrong! We pay the electricity board or electric company to provide energy to move electrons through the electric gadgets like electric bulb, fan and engines. We pay for the energy that we use.

Example 12.12

An electric bulb is connected to a 220 V generator. The current is 0.50 A. What is the power of the bulb?

Solution

$P = VI$

$= 220 \text{ V} \times 0.50 \text{ A}$

$= 110 \text{ J/s}$

$= 110 \text{ W}.$

Example 12.13

An electric refrigerator rated 400 W operates 8 hour/day. What is the cost of the energy to operate it for 30 days at Rs 3.00 per kW h?

Solution

The total energy consumed by the refrigerator in 30 days would be

400 W × 8.0 hour/day × 30 days = 96000 W h

= 96 kW h

Thus the cost of energy to operate the refrigerator for 30 days is

96 kW h × Rs 3.00 per kW h = Rs 288.00

QUESTIONS

1. What determines the rate at which energy is delivered by a current?
2. An electric motor takes 5 A from a 220 V line. Determine the power of the motor and the energy consumed in 2 h.

What you have learnt

- A stream of electrons moving through a conductor constitutes an electric current. Conventionally, the direction of current is taken opposite to the direction of flow of electrons.
- The SI unit of electric current is ampere.
- To set the electrons in motion in an electric circuit, we use a cell or a battery. A cell generates a potential difference across its terminals. It is measured in volts (V).
- Resistance is a property that resists the flow of electrons in a conductor. It controls the magnitude of the current. The SI unit of resistance is ohm (Ω).
- Ohm's law: The potential difference across the ends of a resistor is directly proportional to the current through it, provided its temperature remains the same.
- The resistance of a conductor depends directly on its length, inversely on its area of cross-section, and also on the material of the conductor.
- The equivalent resistance of several resistors in series is equal to the sum of their individual resistances.
- A set of resistors connected in parallel has an equivalent resistance R_p given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

- The electrical energy dissipated in a resistor is given by

$W = V \times I \times t$

- The unit of power is watt (W). One watt of power is consumed when 1 A of current flows at a potential difference of 1 V.
- The commercial unit of electrical energy is kilowatt hour (kWh).
1 kW h = 3,600,000 J = 3.6×10^6 J.

EXERCISES

1. A piece of wire of resistance R is cut into five equal parts. These parts are then connected in parallel. If the equivalent resistance of this combination is R', then the ratio R/R' is –

   (a) 1/25 (b) 1/5 (c) 5 (d) 25

2. Which of the following terms does not represent electrical power in a circuit?

   (a) I^2R (b) IR^2 (c) VI (d) V^2/R

3. 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

4. Two conducting wires of the same material and of equal lengths and equal diameters are first connected in series and then 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

5. How is a voltmeter connected in the circuit to measure the potential difference between two points?

6. A copper wire has diameter 0.5 mm and resistivity of 1.6×10^{-8} Ω m. What will be the length of this wire to make its resistance 10 Ω? How much does the resistance change if the diameter is doubled?

7. The values of current I flowing in a given resistor for the corresponding values of potential difference V across the resistor are given below –

I (amperes)	0.5	1.0	2.0	3.0	4.0
V (volts)	1.6	3.4	6.7	10.2	13.2

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

8. When a 12 V battery is connected across an unknown resistor, there is a current of 2.5 mA in the circuit. Find the value of the resistance of the resistor.

9. 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, respectively. How much current would flow through the 12 Ω resistor?

10. How many 176 Ω resistors (in parallel) are required to carry 5 A on a 220 V line?

11. Show how you would connect three resistors, each of resistance 6 Ω, so that the combination has a resistance of (i) 9 Ω, (ii) 4 Ω.

12. Several electric bulbs designed to be used on a 220 V electric supply line, are rated 10 W. How many lamps can be connected in parallel with each other across the two wires of 220 V line if the maximum allowable current is 5 A?

13. A hot plate of an electric oven connected to a 220 V line has two resistance coils A and B, each of 24 Ω resistance, which may be used separately, in series, or in parallel. What are the currents in the three cases?

14. Compare 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, and (ii) a 4 V battery in parallel with 12 Ω and 2 Ω resistors.

15. Two lamps, one rated 100 W at 220 V, and the other 60 W at 220 V, are connected in parallel to electric mains supply. What current is drawn from the line if the supply voltage is 220 V?
16. Which uses more energy, a 250 W TV set in 1 hr, or a 1200 W toaster in 10 minutes?
17. An electric heater of resistance 8 Ω draws 15 A from the service mains 2 hours. Calculate the rate at which heat is developed in the heater.
18. Explain the following.
    (a) Why is the tungsten used almost exclusively for filament of electric lamps?
    (b) Why are the conductors of electric heating devices, such as bread-toasters and electric irons, made of an alloy rather than a pure metal?
    (c) Why is the series arrangement not used for domestic circuits?
    (d) How does the resistance of a wire vary with its area of cross-section?
    (e) Why are copper and aluminium wires usually employed for electricity transmission?