BAL BHARATI PUBLIC SCHOOL PITAMPURA

SESSION 2020-21 CLASS 12 PHYSICS

Chapter–3 NCERT *Current Electricity* PART 3

INSTRUCTIONS

In this lecture we are going to do the following topics

Temperature dependence of resistance. Electrical energy and power,

Internal resistance of a cell, potential difference and emf of a cell, combination of cells in series and in parallel

Kindly do the assignment in your physics registers. It is very important to attempt the numericals simultaneously .

Main points of the chapter

Temperature dependence of resistance

The value of a resistor changes with changing temperature, but this is not as we might expect, mainly due to a change in the dimensions of the component as it expands or contracts.

The reasons for these changes in resistivity can be explained by considering the flow of current through the material.

Heating a metal makes the atoms inside it vibrate. Higher the temperature, the more violently do the atoms vibrate.

In a conductor, which already has a large number of free electrons flowing through it, the vibration of the atoms causes many collisions between the free electrons and the bound electrons. Hence average time between two consecutive collisions decreases and therefore resistance as well as resistivity increases from the formulae

$$R = \frac{ml}{nA\tau e^2}$$

$$\rho = \frac{m}{n\tau e^2}$$

Each collision results in expenditure of some energy from the free electron and this energy is given out as heat. The more the atoms jostle around in the material the more collisions are caused and hence the greater the resistance to current flow.

We can write an equation for the effect on resistance when temperature of a material is increased.

Let R_1 be the resistance of a wire at a temperature T_1. Let the temperature be increased to T_2 and the new resistance be R_2, then

$$\boldsymbol{R_2 = R_1(1 + \alpha(T_2 - T_1))}$$

Where $\boldsymbol{\alpha}$ is called temperature coefficient of resistance of the given material. It can be represented by the formula

$$\boldsymbol{\alpha = \frac{(R_2 - R_1)}{(T_2 - T_1)\,R_1}}$$

It is measured in $°C^{-1}$.

In a material where the resistance increases with temperature is said to have a positive temperature coefficient of resistance.

In a material where the resistance decreases with temperature is said to have a negative temperature coefficient of resistance.

In general, conductors have a positive temperature coefficient of resistance. Whereas insulators have a negative temperature coefficient of resistance.

The value of$\boldsymbol{\alpha}$ varies also with temperature ranges. In use, resistors made from such materials will have only very slight increases in resistivity and resistance as temperature increases.

Graphical interpretation of resistivity

Variation of resistivity of different materials with temperature can be shown graphically.

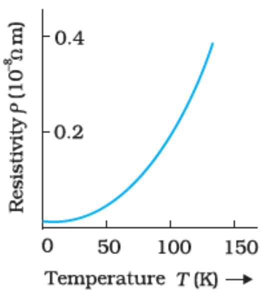


FIGURE 3.9 Resistivity ρ_T of copper as a function of temperature *T*.

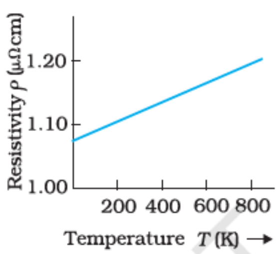


FIGURE 3.10 Resistivity ρ_T of nichrome as a function of absolute temperature *T*.

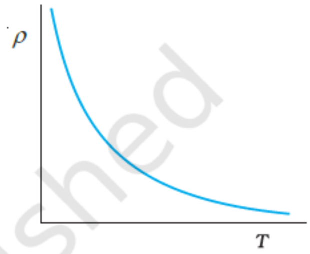


FIGURE 3.11 Temperature dependence of resistivity for a typical semiconductor.

For good conductors like metals the resistivity increase as shown with temperature.

Effect of temperature on resistance of an insulator

In an insulator however, there is a slightly different situation. There are so few free electrons that hardly any current can flow. Almost all the electrons are tightly bound within their particular atom.

Heating an insulating material vibrates the atoms, and if we heated sufficiently the atoms vibrate violently enough to actually shake some of their captive electrons free, creating free electrons to become carriers of current.

Therefore at high temperatures the resistance of an insulator can fall, and in some insulating materials, quite dramatically.
Commonly used insulators like glass, plastic etc only exhibit a marked drop in their resistivity at very high temperatures. They remain good insulators over a wide range.

Know more about effect of temperature on resistance at

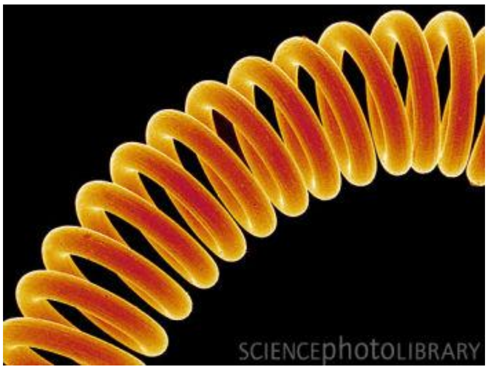
http://www.allaboutcircuits.com/vol_1/chpt_12/6.html

http://ed.fnal.gov/pdf/erlab.pdf

Electrical energy

Let us do an activity

Take a copper wire .Connect it across a dry cell. You will find that the wire immediately becomes hot. Why?



Heat is produced in the copper wire because of the collisions between the moving free electrons and the relatively stationary atoms of the conductor material. As a result, heating increases rapidly with increase of current flow, since a greater rate of flow results in more collision.

Let us now derive an expression for this electrical energy.

Consider a conductor PQ in which a current I is flowing from P to Q.

The electric potential at P and Q are denoted by V_P and V_Q. Since current is flowing from P to Q

We have, however, seen earlier that on the average, charge carriers do not move with acceleration but with a steady drift velocity.

This is because of the collisions with ions and atoms during motion. During collisions, the energy gained by the charges thus is shared with the atoms.

The atoms vibrate more vigorously, i.e., the conductor heats up.

Thus,in an actual conductor, an amount of energy dissipated as heat in the conductor during the time interval Δt is,

$$\Delta W = I V \Delta t$$

The energy dissipated per unit time is the power dissipated

$P = \frac{\Delta W}{\Delta t}$ and we have,

$$P = I V$$

Using Ohm's law $V = IR$, we get

$$P = I^2 R = \frac{V^2}{R} = VI$$

as the power loss ("ohmic loss") in a conductor of resistance R carrying a current I. It is this power which heats up, for example, the coil of an electric kettle and gives out heat to boil water.

JOULES LAW

Joule had experimentally proved that when a current of I amperes passes through a circuit of resistance R ohms for a time of t seconds then the heat produced is given by the relation.

$H = I^2Rt$ joules

The above relation is known as the *Joule's law of heating*.
It states that the heat produced is proportional to

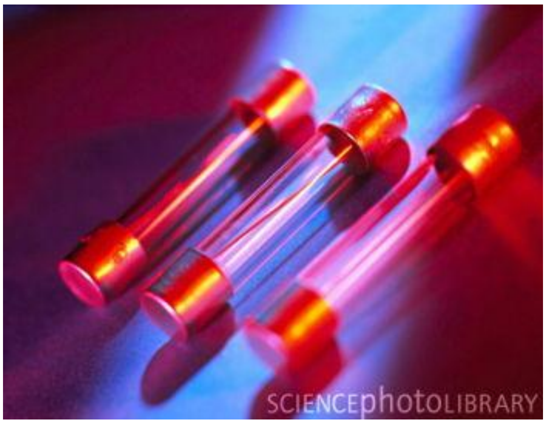
1. Square of the current I.
2. Resistance of the circuit R.
3. The time t during which the current flows through the circuit.

Applications of Joule's law

1 All heating devices like a electric toaster, geyser, iron, heater, kettle, immersion rods etc produce heat as per Joule' law of heating.

2 In a household circuit all appliances are connected in parallel so each device receives the same potential difference across it.

3 Transportation of electricity from one place to another is done at high voltages and low currents (this is done with help of a device called transformer which you will study later in this year).The advantage is that the I^2R loss is reduced as the current is decreased. However this is done for alternating currents only!



4 The fuse wire is another example of heating effect of current .The fuse wire is made of an alloy of tin, lead and .It is connected in series to an appliance or the entire household circuit. If the current in the circuit exceeds a particular value the heat produced in the fuse wire melts the wire and breaks the circuit before damage is done to the electrical appliances.

Solved example

An electric bulb has a rating of 220 V and 100 Watts. How much electrical energy is dissipated in 20 minutes by this bulb when it is connected across a potential difference of 220V? Also calculate the resistance of the bulb.

Let us first understand what is meant by 220V and 100 W . It is called power rating of any electrical appliance. It means that if the device is connected across a potential difference of 220V ,it will consume/deliver a power of 100W. It automatically implies that if it were to be connected to a smaller potential difference ,it would deliver lesser power!

$Here\ P = 100W\ and\ V = 220V$

Using

$$P = I^2 R = \frac{V^2}{R} = VI$$

$$R = \frac{V^2}{P} = \frac{220^2}{100} = 484\Omega$$

$$E = \frac{V^2 t}{R}$$

$$E = \frac{220^2 \times 20 \times 60}{484} = 120000\, J$$

SOLVED EXAMPLE

An electric bulb has a power rating of 220 V and 60 W. How much power will it deliver if it is operated at 110V?

$$Here\ P = 60W\ and\ V = 220V$$

Using

$$P = I^2 R = \frac{V^2}{R} = VI$$

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

$$R = \frac{220^2}{60} = 806.6\Omega$$

$$P\ new = \frac{V^2(new)}{R}$$

$$Pnew = \frac{110^2}{806.6} = 15.1\, W$$

Solved example

Two bulbs of power ratings 100 W,200V and 50 W,200 V are connected in series across a potential difference of 200 V. How much power is associated with each bulb? Also calculate the potential difference across each bulb.

Let us first calculate the resistance of each bulb

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

First bulb

$$R = \frac{200^2}{100} = 400\Omega$$

Second bulb

$$R = \frac{200^2}{50} = 800\Omega$$

Net resistance of the circuit is 400+800=1200Ω

Current flowing $I = \frac{200}{1200} = \frac{1}{6}$ *Ampere*

So power associated with first bulb is given by

$$P = I^2 R = \frac{1}{6} \times \frac{1}{6} \times 800 = 22.22W$$

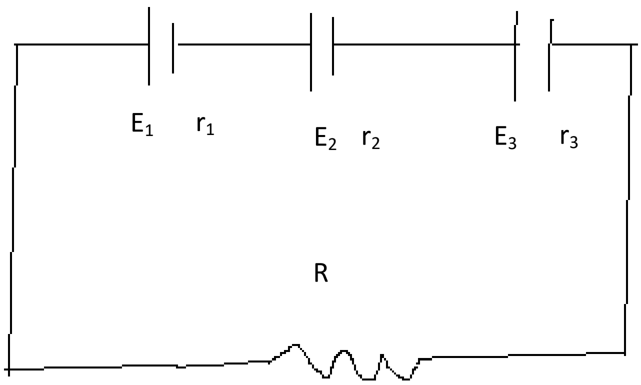
Power associated with second bulb is given by

$$P = I^2 R = \frac{1}{6} \times \frac{1}{6} \times 400 = 11.11W$$

Similarly Potential difference across first bulb is

$$V = \frac{1}{6} \times 800 = 133.33\, V$$

Let us now derive expressions for EMF in series and parallel like we did for resistances.



Let E_1, E_2 *and* E_3 be the EMF’s of the three cells in series .Let their internal resistances be r_1, $r_2$and r_3.Let I be the current flowing in the circuit through all the cells. Let V_1, V_2 *and* V_3 be the terminal potential differences across the three cells.

In series the potential differences are added so.

$$V_{net=}V_1+V_2+V_3$$

Substituting in

$$V = E - Ir$$

$$V_{net=}(E_1 - Ir_1) + (E_2 - Ir_2) + (E_3 - Ir_3)$$

$$V_{net=}(E_1+E_2+E_3) - I(r_1+r_2+r_3)$$

Again comparing with

$$Veq = Eeq - Ireq$$

$Enet = E_1+E_2+E_3$

And req $is\ given\ by\ r_1 + r_2 + r_3$.

So if a number of cells are connected in series the net EMF of the combination is given by the algebraic sum of the individual EMF's.

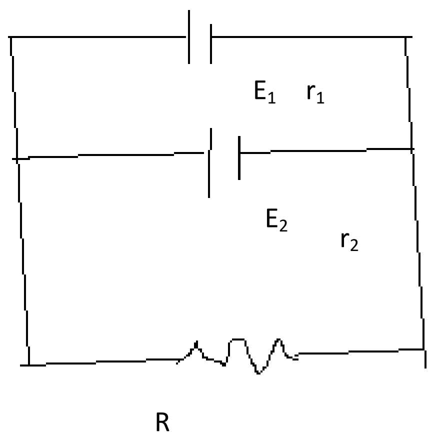
The equivalent resistance is obtained by adding the individual resistances.

If you have several cells of EMF 1.5 V, how would you connect them to get a equivalent EMF of 12 V?

A student is asked to connect five cells of 2 V EMF in series with each other. By mistake, he connects the terminals of one cell in reverse. What will be the equivalent EMF of the combination?

Cells in parallel

Let $E_1\ and\ E_2$ be the EMF's of the two cells in parallel .Let their internal resistances be r_1, $and\ r_2$.Let V be the terminal potential difference across them. Let $I_1\ and\ I_2$ be the currents flowing through the two cells.



Since potential difference remains same in parallel, terminal potential difference is same for all the cells.

$$V = E_1 - I_1 r_1 = E_2 - I_2 r_2$$

Net current $I = I_1 + I_2$

$$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

Or

$$I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Multiplying and dividing the equation with $\frac{r_1 r_2}{r_1 + r_2}$

$$I\frac{r_1 r_2}{r_1 + r_2} = \frac{E_1 + E_2}{r_1 + r_2} - V$$

Or

$$V = \frac{E_1 + E_2}{r_1 + r_2} - I\frac{r_1 r_2}{r_1 + r_2}$$

Comparing with

$$V = E - Ir$$

$$Eeq = \frac{E_1 + E_2}{r_1 + r_2}$$

And

$req = \frac{r_1 r_2}{r_1 + r_2}$

In other words

$$\frac{Eeq}{req} = \frac{E_1}{r_1} + \frac{E_2}{r_2}$$

To conclude if the two cells have the same EMF then in parallel, the net EMF is equal to the EMF of either cell. If they have different EMF's their equivalent is given by

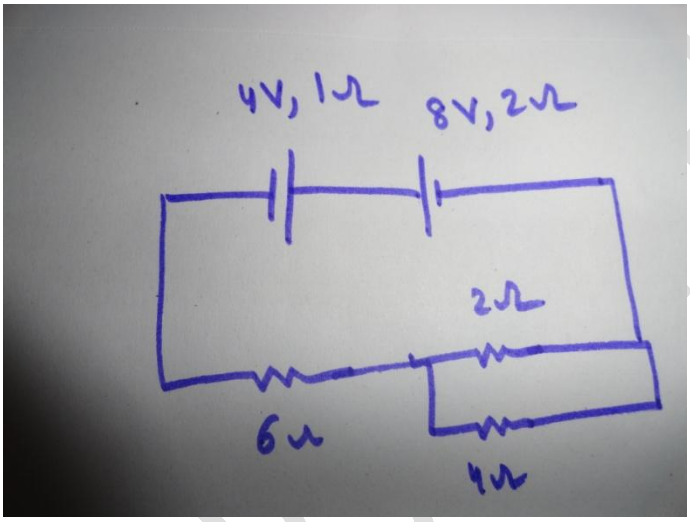
$$Eeq = \frac{E_1 + E_2}{r_1 + r_2}$$

Charging a cell

We charge a cell by connecting it in series to a battery of a larger potential difference. Now for the cell being charged, the current is being sent through the cell in opposite direction as compared to the current direction if the cell were supplying current. Hence for the cell being charged the terminal potential difference is greater than the EMF and is given by $V = E + Ir$

SOLVED EXAMPLE

In the given circuit diagram, calculate current flowing through each cell and terminal potential difference across each cell.



Here the 4 V and 8 V cell oppose each other,so net EMF available is 4V.

Equivalent resistance of the circuit is $9\Omega + \frac{4}{3} = \frac{31}{3}\Omega$

Hence current is $I = \frac{12}{31}$ A

For the 4 V cell $V = E + Ir$

$$V = 4 + \frac{12}{31} = 4.38\,V$$

For the 8 V cell $V = E - Ir$

$$V = 8 - \frac{24}{31} = 7.22\ V$$

SOLVED EXAMPLE

A storage battery of EMF 10.0 V and internal resistance 1 Ω is being charged by a 100 V dc supply using a series resistor of 17 Ω. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?

Using$I = \frac{100-10}{18} = \frac{90}{18} = 5A$

For the battery being charged

$$V = E + Ir$$

$$V = 10 + 5 = 15\ V$$

The high resistance is supposed to limit the current and hence limit the heating los which may occur.

Know more about cells in series and parallel at

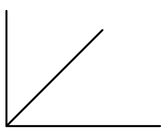
http://www.physicsclassroom.com/class/circuits/u9l4e.cfm

ASSIGNMENT
Student worksheet 4

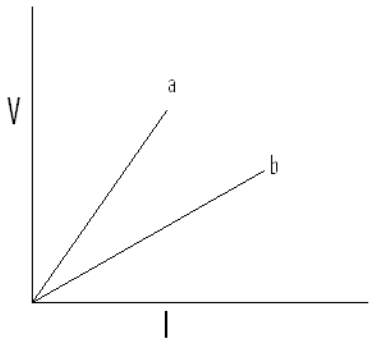
1 Let us say you have to prepare standard resistances. Which material will you choose for the same?

2 What should be the criterion to select a material for making element of a toaster?

3 V-I characteristic curve for a metal conductor is a straight line Will the graph remain a straight line for very high values of current? Explain your answer.



4 V-I graph for metallic wire at two different temperature ‘a’ and ‘b’ is shown . Which of the two temperatures is higher and why?



5 I have an electric kettle which boils water in 15 minutes. If I want the same amount of water to boil in 10 minutes, what changes are required in the length of the heating element?

6 Two wires of copper and iron of equal lengths and areas of cross-sections are taken. If they are connected (1) in series (2) in parallel to a constant voltage supply. Which wire will produce more heat in each case? Justify**.**

7 What should be the criterion (at least two)for selecting a material for making a heating element of a electric iron**.**

8 Which will have more resistance a 100W, 220 V bulb or a 1000W,220 V heater? Why?

9 If two household light bulbs rated 60 W and 100W are connected in series to household power, which will be brighter**?**

10 Boosting a car using someone else's battery for cold weather starting requires the combination of two batteries. Are these batteries connected in series or parallel? Explain.

11 Six lead-acid type of secondary cells each of EMF 2.0 V and internal resistance 0.01 Ω are joined in series to provide a supply to a resistance of 8 Ω. What are the current drawn from the supply and its terminal voltage?

12 Two bulbs of 60W,110V and 100W,110 V are connected in series with a 220 V d.c supply. Will any of the bulbs fuse? What will happen if they were both connected in parallel to the same supply?

13 A cell of EMF 2 V and internal resistance one ohm is charged by a battery of 12 V and negligible internal resistance through a series resistance of 20 Ω. Calculate Charging current ,Potential difference across the cell during charging,Power supplied by the charging battery,Power lost as heat.