

THERMAL AND CHEMICAL EFFECTS OF ELECTRIC CURRENT

We have seen that an electric current through a resistor increases its thermal energy. Also, there are other situations in which an electric current can produce or absorb thermal energy. All these are termed as thermal effects of electric current. We shall study them in sections (33.1) to (33.6). The chemical effects, such as electrolysis, are discussed in sections (33.7) onwards.

33.1 JOULE'S LAWS OF HEATING

When there is an electric current in a resistor, the thermal energy of the resistor increases. If the potential difference between the ends of a resistor is V and a current i passes through it, the work done by the electric field on the free electrons in time t is

$$\begin{aligned} W &= (\text{potential difference}) \times (\text{charge}) \\ &= V(it) \\ &= (iR)(it) = i^2 Rt. \end{aligned} \quad \dots (33.1)$$

The work by the field is converted into thermal energy of the resistor through the collisions with the lattice. This thermal energy is generally referred to as the *heat produced in the resistor* and is denoted by H . (Strictly speaking, this energy is not heat as it does not correspond to any temperature difference. Because of the increased thermal energy, the temperature of the resistor may rise. It may then transfer "heat" to the surrounding.) It follows from equation (33.1) that

(a) *the heat produced in a given resistor in a given time is proportional to the square of the current in it, i.e.,*

$$H \propto i^2$$

(b) *the heat produced in a given resistor by a given current is proportional to the time for which the current exists in it, i.e.,*

$$H \propto t$$

(c) *the heat produced in a resistor by a given current in a given time is proportional to its resistance,*

i.e.,

$$H \propto R.$$

The heating effects of an electric current were studied by James Prescott Joule and he arrived at the three laws stated above. These are thus known as *Joule's laws*.

Example 33.1

Find the heat developed in each of the three resistors shown in figure (33.1) in 1 minute.

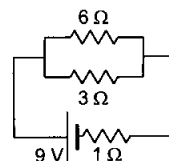


Figure 33.1

Solution : The equivalent resistance of $6\ \Omega$ and $3\ \Omega$ resistors is

$$\frac{(6\ \Omega) \times (3\ \Omega)}{6\ \Omega + 3\ \Omega} = 2\ \Omega.$$

This is connected in series with the $1\ \Omega$ resistor. The equivalent resistance of the circuit is

$$R = 2\ \Omega + 1\ \Omega = 3\ \Omega.$$

The current through the battery is

$$i = \frac{9\ \text{V}}{3\ \Omega} = 3\ \text{A}.$$

The current through the $1\ \Omega$ resistor is, therefore, $3\ \text{A}$. The heat developed in this resistor is

$$\begin{aligned} H &= i^2 Rt \\ &= (3\ \text{A})^2 \times (1\ \Omega) \times (60\ \text{s}) = 540\ \text{J}. \end{aligned}$$

The current through the $6\ \Omega$ resistor is

$$(3\ \text{A}) \times \frac{3\ \Omega}{6\ \Omega + 3\ \Omega} = 1\ \text{A}.$$

The heat developed in it

$$= (1\ \text{A})^2 \times (6\ \Omega) \times (60\ \text{s}) = 360\ \text{J}.$$

The current through the $3\ \Omega$ resistor is $3\text{ A} - 1\text{ A} = 2\text{ A}$.

The heat developed in it

$$= (2\text{ A})^2 \times (3\ \Omega) \times (60\text{ s}) = 720\text{ J}.$$

33.2 VERIFICATION OF JOULE'S LAWS

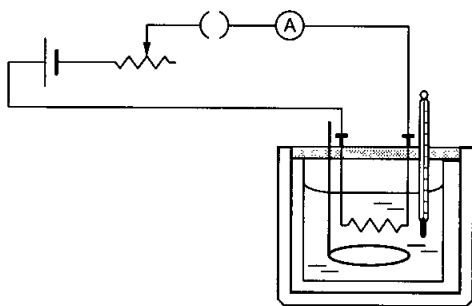


Figure 33.2

Figure (33.2) shows the apparatus and the connections. K-oil is taken in a copper calorimeter provided with a nonconducting lid and a stirrer. A resistor is dipped in the oil. It is joined to the external circuit through the leads coming out of the lid of the calorimeter. A thermometer is provided to measure the temperature of the oil. The calorimeter is called *Joule's calorimeter*.

$$H \propto i^2$$

The external circuit consists of a battery, a rheostat and a plug key in series with the resistor. An ammeter is also connected in the circuit to measure the current. The temperature θ_1 of the K-oil is noted. The plug key is closed to pass a constant current through the circuit for a known time t . The value of the current i_1 is measured by the ammeter. The liquid is stirred continuously and the final temperature θ_2 is noted. Thus, the rise in temperature $\Delta\theta_1 = \theta_2 - \theta_1$ is calculated.

The system is allowed to cool down to room temperature. The resistance of the rheostat is changed and the key is closed. The current i_2 is measured by the ammeter and is passed for the same time t . The rise in temperature $\Delta\theta_2$ is found as above.

The heat produced in the resistor is used to increase the temperature of the K-oil. Thus, the heat produced is proportional to the rise in temperature. It is found that

$$\frac{\Delta\theta_1}{\Delta\theta_2} = \frac{i_1^2}{i_2^2}.$$

This shows that $\Delta\theta \propto i^2$

$$\text{or, } H \propto i^2.$$

$$H \propto t$$

The arrangement described above can also be used to verify the second law, $H \propto t$. A current i is passed through the resistor and the temperature is noted at regular time intervals. It is found that the temperature rises uniformly, i.e., it increases by equal amounts in equal times. This shows that equal amounts of heat are produced in equal time intervals. Thus, the heat produced is proportional to the time.

$$H \propto R$$

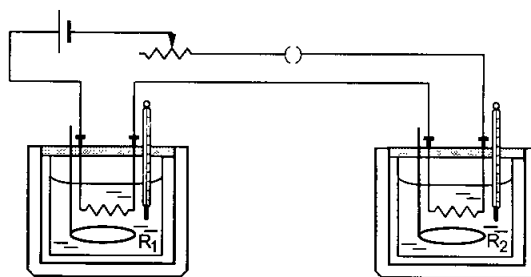


Figure 33.3

To verify this law, two Joule's calorimeters are taken (figure 33.3). Equal amounts of K-oil are taken in the two calorimeters. Different resistances R_1 and R_2 are dipped in the K-oil and the two are joined in series. The system is connected to a battery, a rheostat and a plug key. The initial temperatures of the two calorimeters are noted and a current is passed for some time. The temperatures of the two calorimeters are noted at the end. Let $\Delta\theta_1$ be the rise in the temperature of the first calorimeter and $\Delta\theta_2$ be the rise in the temperature of the second calorimeter. The heat produced in each resistor is proportional to the rise in the temperature of the corresponding calorimeter. It is found that

$$\frac{\Delta\theta_1}{\Delta\theta_2} = \frac{R_1}{R_2}$$

or,

$$\Delta\theta \propto R$$

or,

$$H \propto R.$$

33.3 SEEBECK EFFECT



Figure 33.4

Figure (33.4) shows two metallic strips, made of different metals and joined at the ends to form a loop. If the junctions are kept at different temperatures, there is an electric current in the loop. This effect is called the *Seebeck effect* and the emf developed is called the *Seebeck emf* or *thermo-emf*.

The magnitude and the direction of the emf depend on the metals and the temperatures of the hot and

cold junctions. Such a combination of two metals is called a *thermocouple*.

Thermoelectric Series

For given temperatures of hot and cold junctions, the direction of the current in a thermocouple depends on the metals chosen. Metals are arranged in a particular sequence which may be used to predict the direction of the current in the temperature range 0°C to 100°C . This sequence known as the *thermoelectric series*, is as follows:

antimony, nichrome, iron, zinc, copper, gold, silver, lead, aluminium, mercury, platinum-rhodium, platinum, nickel, costantan, bismuth.

At the cold junction, the current is *from* the metal coming earlier in the series *to* the metal coming latter in the series. For example, in a copper-iron thermocouple, the current will be from iron to copper at the cold junction. Also, the series gives an idea of the relative magnitude of emf for different thermocouples. Farther apart two metals lie in the series, larger is the emf produced.

Neutral and Inversion Temperature

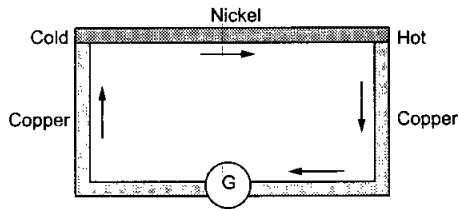


Figure 33.5

Figure (33.5) shows a copper-nickel thermocouple. A sensitive galvanometer is connected in series to measure the current. Suppose one of the junctions is kept at a fixed low temperature 0°C and the other is gradually heated. There will be a current in the circuit as shown in the figure. At the cold junction it is from copper to nickel and at the hot junction it is from nickel to copper. As the temperature of the hot junction is gradually increased, the magnitude of the current increases till the temperature becomes nearly 390°C . After this, the current decreases till the temperature of the hot junction becomes 780°C . At this temperature the current becomes zero. If the hot junction is heated further, the direction of the current is reversed and the magnitude increases.

If the cold junction of the copper-nickel thermocouple is not at 0°C but say at 10°C , the current will be again maximum when the hot junction is at 390°C . But the inversion of the direction of the current will take place at 770°C instead of 780°C . As the current is proportional to the emf developed, the above

observations also indicate the behaviour of the thermo-emf.

Copper and nickel were taken above only as an example. The behaviour of any other thermocouple will be, in general, similar. The numeric values will, of course, be different. Also even for a copper-nickel thermocouple, the neutral temperature depends on the purity, heat treatment, etc., of the metals.

The temperature of the hot junction at which the thermo-emf is maximum is called the *neutral temperature* and the temperature at which the thermo-emf changes its sign (current reverses) is called the *inversion temperature*. If θ_c , θ_n and θ_i denote the temperature of the cold junction, the neutral temperature and the inversion temperature respectively, we have

$$\theta_n - \theta_c = \theta_i - \theta_n. \quad \dots (33.2)$$

At this stage, let us explain the sign convention. The thermo-emf developed in a thermocouple of metals *A* and *B* is denoted by \mathcal{E}_{AB} and is taken to be positive if the direction of the current is from *A* to *B* at the hot junction.

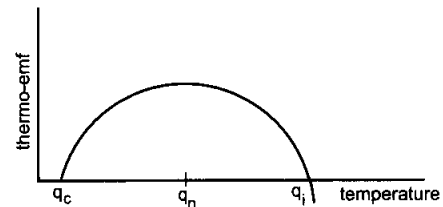


Figure 33.6

Figure (33.6) shows graphically the variation in thermo-emf as the temperature of the hot junction changes. If the cold junction is at 0°C and the hot junction at θ (in Celsius), the thermo-emf depends on the temperature as

$$\mathcal{E}_{AB} = a_{AB}\theta + \frac{1}{2} b_{AB}\theta^2 \quad \dots (33.3)$$

where a_{AB} and b_{AB} are constants for the pair of metals *A* and *B*.

This gives

$$\frac{d\mathcal{E}_{AB}}{d\theta} = a_{AB} + b_{AB}\theta. \quad \dots (33.4)$$

The quantity $\frac{d\mathcal{E}_{AB}}{d\theta}$ is called *thermoelectric power* at temperature θ .

The emf is maximum when $\frac{d\mathcal{E}_{AB}}{d\theta} = 0$ or, $\theta = -\frac{a_{AB}}{b_{AB}}$.

This is the neutral temperature. The emf becomes zero at $\theta = -2a_{AB}/b_{AB}$. This is the inversion temperature.

Example 33.2

The cold junction of a thermocouple is maintained at 10°C . No thermo-emf is developed when the hot junction is maintained at 530°C . Find the neutral temperature.

Solution : Clearly, 530°C is the inversion temperature θ_i of the couple. If θ_n be the neutral temperature and θ_c be the temperature of the cold junction,

$$\theta_i - \theta_n = \theta_n - \theta_c$$

$$\text{or, } \theta_n = \frac{\theta_i + \theta_c}{2} = \frac{530^\circ\text{C} + 10^\circ\text{C}}{2} = 270^\circ\text{C}.$$

Table (33.1) gives the values of a and b for some of the metals with lead. Note that there is no neutral temperature or inversion temperature above 0°C for the thermocouple if a and b have the same sign.

Table 33.1 : Coefficients a and b for thermocouples

| Metal with lead (Pb) | a $\mu\text{V}^\circ\text{C}^{-1}$ | b $\mu\text{V}^\circ\text{C}^{-2}$ |
|----------------------|---|---|
| Aluminium | -0.47 | 0.003 |
| Bismuth | -43.7 | -0.47 |
| Copper | 2.76 | 0.012 |
| Gold | 2.90 | 0.0093 |
| Iron | 16.6 | -0.030 |
| Nickel | 19.1 | -0.030 |
| Platinum | -1.79 | -0.035 |
| Silver | 2.50 | 0.012 |
| Steel | 10.8 | -0.016 |

Law of Intermediate Metal

Suppose \mathcal{E}_{AB} = thermo-emf between metals A and B

\mathcal{E}_{AC} = thermo-emf between metals A and C

and \mathcal{E}_{BC} = thermo-emf between metals B and C .

Also, suppose the temperatures of the cold junctions are the same in the three cases and the temperatures of the hot junctions are also the same in the three cases.

$$\text{Then, } \mathcal{E}_{AB} = \mathcal{E}_{AC} - \mathcal{E}_{BC}. \quad \dots (33.5)$$

This law is known as the *law of intermediate metal*.

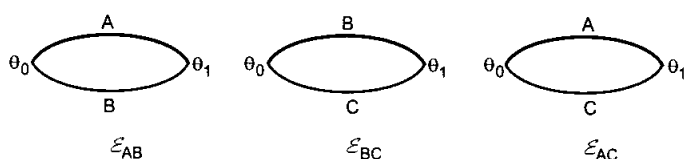


Figure 33.7

We have,

$$\mathcal{E}_{AB} = a_{AB}\theta + \frac{1}{2} b_{AB}\theta^2$$

$$\mathcal{E}_{BC} = a_{BC}\theta + \frac{1}{2} b_{BC}\theta^2$$

$$\mathcal{E}_{AC} = a_{AC}\theta + \frac{1}{2} b_{AC}\theta^2.$$

Equation (33.5) gives

$$a_{AB} = a_{AC} - a_{BC} \text{ and } b_{AB} = b_{AC} - b_{BC}.$$

Table (33.1) may, therefore, be used to find the values of a and b for any pair of metals listed.

Example 33.3

Using table (33.1), find a and b coefficients for a copper-iron thermocouple.

Solution :

$$a_{Cu, Fe} = a_{Cu, Pb} - a_{Fe, Pb}$$

$$= 2.76 \mu\text{V}^\circ\text{C}^{-1} - 16.6 \mu\text{V}^\circ\text{C}^{-1} = -13.8 \mu\text{V}^\circ\text{C}^{-1}.$$

$$b_{Cu, Fe} = b_{Cu, Pb} - b_{Fe, Pb}$$

$$= 0.012 \mu\text{V}^\circ\text{C}^{-2} + 0.030 \mu\text{V}^\circ\text{C}^{-2} = 0.042 \mu\text{V}^\circ\text{C}^{-2}.$$

Law of Intermediate Temperatures

Let $\mathcal{E}_{\theta_1, \theta_2}$ denote the thermo-emf of a given thermocouple when the temperatures of the junctions are maintained at θ_1 and θ_2 . Then,

$$\mathcal{E}_{\theta_1, \theta_2} = \mathcal{E}_{\theta_1, \theta_3} + \mathcal{E}_{\theta_3, \theta_2}. \quad \dots (33.6)$$

This is known as the *law of intermediate temperature*.

The two laws given by equations (33.5) and (33.6) show that we can include any metal wire or a galvanometer, etc. in the thermocouple circuit without changing the emf in the circuit.

33.4 PELTIER EFFECT

Suppose the two junctions of a thermocouple are initially at the same temperature and an electric current is passed through the circuit by using an external battery. It is observed that heat is produced at one junction and is absorbed at the other. Thus, one junction is warmed up and the other is cooled down due to the currents through the junctions. It is reverse of the Seebeck effect and is called the *Peltier effect*. If the direction of the current is reversed, the cooling and warming are also reversed. This means, the junction which was originally warmed up, now cools down and vice-versa. The heat absorbed or liberated at the junction is proportional to the charge passed through the junction. If an amount ΔH of heat is produced or absorbed when a charge ΔQ is passed through the junction, we define *Peltier emf* as

$$\Pi_{AB} = \frac{\Delta H}{\Delta Q} = \frac{\text{Peltier heat}}{\text{charge transferred}}.$$

The Peltier emf Π_{AB} across a junction of two metals A and B is taken as positive if heat is absorbed by the junction when there is an electric current from A to B through the junction. When two different metals are joined at a point, this much emf is developed across the junction.

The heat developed in Peltier effect should not be confused with the Joule heat when a current is passed through a resistor. Joule heat always warms up the resistor whatever be the direction of the current. But one has both Peltier heating and Peltier cooling of the junction depending on the direction of the current.

Another difference is that the Peltier heat in a given time is proportional to the current through the junction whereas the Joule heat is proportional to the square of the current,

$$H_{\text{Peltier}} \propto i, \quad H_{\text{Joule}} \propto i^2.$$

Also, the Peltier heating or cooling is observed only at a junction, whereas the Joule heating is throughout the resistor.

33.5 THOMSON EFFECT

If a metallic wire has a nonuniform temperature and a current is passed through it, heat may be absorbed or produced in different sections of the wire. This heat is over and above the Joule heat $i^2 R t$ and is called the *Thomson heat*. The effect itself is called the *Thomson effect*.

Thomson heat, produced or absorbed in a small section of a given wire, is proportional to the charge passed through the section and the temperature difference between the ends of the section.

If a charge ΔQ is passed through a small section of the wire having a temperature difference ΔT between the ends, the Thomson heat is

$$\Delta H = \sigma(\Delta Q)(\Delta T)$$

where σ is a constant for a given metal at a given temperature. The quantity

$$\sigma \Delta T = \frac{\Delta H}{\Delta Q} = \frac{\text{Thomson heat}}{\text{charge transferred}}$$

is called the *Thomson emf*.

In fact, this much amount of emf is produced when the ends of the section of the wire are maintained at different temperatures.

The constant σ is called the *Thomson coefficient*. It is taken to be positive if heat is absorbed when a current is passed from the low-temperature end to the high-temperature end. Copper, silver, zinc, antimony, cadmium, etc., have positive σ . Iron, cobalt, nickel, bismuth, platinum, etc., have negative σ . In these metals heat is absorbed when current is passed from hotter end to the colder end. In lead, σ is almost zero.

33.6 EXPLANATION OF SEEBECK, PELTIER AND THOMSON EFFECTS

The density of free electrons is different in different metals. When two different metals are joined to form a junction, the electrons tend to diffuse from the side with higher concentration to the side with lower concentration. This produces an emf across the junction. This emf is the Peltier emf. If a current is forced through the junction, positive or negative work is done on the charge carriers depending on the direction of the current. Accordingly, thermal energy is either produced or absorbed.

If the temperature of a metal piece is not uniform everywhere, density of free electrons varies inside the metal. The electrons tend to diffuse from the higher-concentration regions to the lower-concentration regions. This gives rise to an emf between the hot and the cold parts of the metal. This emf is the Thomson emf. If a current is forced through a wire having nonuniform temperature, positive or negative work is done on the charge carriers depending on the direction of the current. Accordingly, thermal energy is either produced or absorbed.

The density of free electrons in a metal depends on the temperature. Hence, the Peltier emf developed across a junction depends on the temperature of the junction. In a thermocouple, there are two junctions. If these junctions are maintained at the same temperature, the Peltier emf's developed across the two junctions balance each other and there is no net Peltier emf in the loop. If the junctions are at different temperatures, the emf's developed across the junctions are different and there is a net Peltier emf in the loop. Also, when the junctions of a thermocouple are kept at different temperatures, each of the two metal pieces has nonuniform temperature. Thus, a Thomson emf is developed across its ends. The emf's are different for the two metals and hence there is a net Thomson emf in the loop because of this effect. The actual emf developed in a thermocouple loop is the algebraic sum of the net Peltier emf and the net Thomson emf developed in the loop.

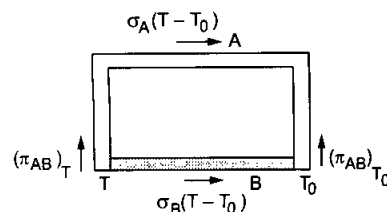


Figure 33.8

Referring to figure (33.8), we can write the thermo-emf \mathcal{E}_{AB} in the loop as

$$\mathcal{E}_{AB} = (\Pi_{AB})_T - (\Pi_{AB})_{T_0} + (T - T_0)(\sigma_A - \sigma_B). \quad \dots (33.6)$$

Thus, Seebeck emf is a combination of two Peltier emf's and two Thomson emf's.

33.7 ELECTROLYSIS

Several liquids are found to be good conductors of electricity. Solutions of inorganic salts in water, dilute acids and bases are examples of conducting liquids. Such a liquid is called an *electrolyte* and the vessel with the electrolyte is called an *electrolytic cell*. The mechanism of electric conduction in electrolytes is quite different from that in metals. Let us understand the process with a specific example.

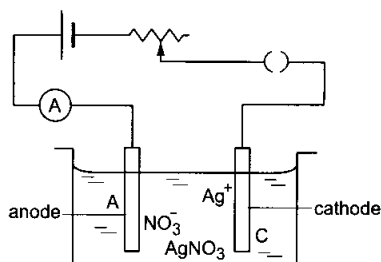
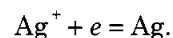


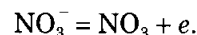
Figure 33.9

Let us take a solution of silver nitrate (AgNO_3) in an electrolytic cell and immerse two silver rods in it (figure 33.9). Electric current is passed through the solution by connecting the rods to an external battery. The current enters the solution through the rod A, called the *anode* and it leaves the solution through the rod C, called the *cathode*. These rods are collectively called *electrodes*. We find that as time passes, silver gets deposited on the cathode C and an equal amount of silver is removed from the anode A.

A fraction of the molecules of the dissolved AgNO_3 are separated in two parts, Ag^+ and NO_3^- , each of which has electric charge. These are called *ions*. An ion with positive charge is called *cation* and an ion with negative charge is called *anion*. Here Ag^+ is the cation and NO_3^- is the anion. These ions move freely in the solution. When a battery is connected to the electrodes, electric field is produced in the solution from the anode towards the cathode. Thus, the cations move towards the cathode and the anions move towards the anode. The ions give up their charges at the electrodes and the substance making up the ions is *liberated*. The liberated substance may get deposited on the electrodes or may take part in some secondary chemical reaction. In case of AgNO_3 , the Ag^+ ions (cation) move to the cathode, the charge is given up there and the silver atoms are deposited on the cathode. In fact an Ag^+ ion receives an electron from the cathode to become neutral Ag atom,



The NO_3^- ion (anion) moves to the anode and gives its extra electron to it. The NO_3^- ion is converted to NO_3 ,



The NO_3 so formed reacts with a silver atom of the anode to form AgNO_3 which gets dissolved in the solution. This way, silver is continuously removed from the anode and deposited on the cathode with the concentration of the electrolyte remaining unchanged. The movement of cations (positive charge) towards the cathode and anions (negative charge) towards the anode make the current in the electrolyte.

The electron given up by an anion to the anode is passed through the battery back to the cathode which has supplied one electron to the cation. This way, the potential difference between the electrodes is maintained. Also, the number of electrons passed through the battery is equal to the number of electrons absorbed or released at each electrode. In other words, the charge passed through the circuit is equal to the charge released at each electrode.

When a current passes through an electrolyte, chemical changes occur in the electrolyte and substances are liberated at the electrodes. This process is called *electrolysis*.

33.8 FARADAY'S LAWS OF ELECTROLYSIS

After systematically studying electrolysis, Faraday discovered two laws:

(a) The mass of a substance liberated at an electrode is proportional to the charge passing through the electrolyte.

(b) The mass of a substance liberated at an electrode by a given amount of charge is proportional to the chemical equivalent of the substance.

If an electric current i is passed through an electrolyte for a time t , the amount of charge passed is $Q = it$. According to the first law, the amount of the substance liberated at an electrode is

$$m \propto Q \quad \dots (i)$$

$$\text{or,} \quad m \propto it$$

$$\text{or,} \quad m = Zit \quad \dots (33.7)$$

where Z is a constant for the substance being liberated. The constant Z is called the *electrochemical equivalent* (ECE) of the substance. The SI unit of ECE is kilogram coulomb⁻¹ written as kg C^{-1} .

The chemical equivalent of a substance is equal to its relative atomic mass divided by its valency. Relative atomic mass of a substance is the ratio of the

mass of its atom to the $\frac{1}{12}$ of the mass of a ^{12}C atom. The relative atomic mass of silver is 108 and its valency is 1. Thus, the chemical equivalent of silver is 108. The relative atomic mass and valency of copper are 63.5 and 2 respectively. The chemical equivalent is, therefore, 31.75. For oxygen, the chemical equivalent is $16/2 = 8$.

If E denotes the chemical equivalent of a substance being liberated at an electrode, from the second law,

$$m \propto E.$$

Combining with (i) it gives

$$m \propto EQ.$$

$$\text{or, } m = \frac{1}{K} EQ \quad \dots (33.8)$$

where K is a universal constant having the value $9.6485 \times 10^7 \text{ C kg}^{-1}$.

Example 33.4

Calculate the electric current required to deposit 0.972 g of chromium in three hours. ECE of chromium is 0.00018 g C^{-1} .

Solution : We have

$$m = Zit$$

$$\text{or, } 0.972 \text{ g} = (0.00018 \text{ g C}^{-1}) i (3 \times 3600 \text{ s})$$

$$\text{or, } i = \frac{0.972}{0.00018 \times 3 \times 3600} \text{ A} = 0.50 \text{ A}.$$

Verification of Faraday's Laws

1st law

An electrolytic cell is connected to a battery, a rheostat, a key and an ammeter in series as in figure (33.9). The cathode is cleaned, dried, weighed and then inserted in the electrolytic cell. A constant current i_1 is passed for a measured time t . The current is measured by the ammeter. Slight adjustment of the rheostat may be necessary to keep the current constant. The cathode is taken out, washed without rubbing in gently-flowing water and is dried. It is weighed again and the mass m_1 of the deposit is obtained. The cathode is reinserted in the cell and the rheostat position is changed. This allows a different current i_2 when the circuit is completed. This current is passed for the same time t and the mass m_2 of the deposit is obtained. It is found that

$$\frac{m_1}{m_2} = \frac{i_1}{i_2}.$$

$$\text{Thus, } m \propto i. \quad \dots (i)$$

Similarly, two experiments are done with the same current but for different times t_1 and t_2 . If the masses

of the deposits are m_1' and m_2' respectively, it is found that

$$\frac{m_1'}{m_2'} = \frac{t_1}{t_2}$$

$$\text{or, } m \propto t. \quad \dots (ii)$$

From (i) and (ii),

$$m \propto it$$

$$\text{or, } m \propto Q.$$

So, the first law is verified.

2nd law

To verify the second law, one can take two electrolytic cells containing different electrolytes. To be specific, one may contain CuSO_4 solution with copper electrodes and the other AgNO_3 solution with silver electrodes. The electrodes are connected in series with an external circuit as shown in figure (33.10). This arrangement ensures that the currents in the two cells are the same.

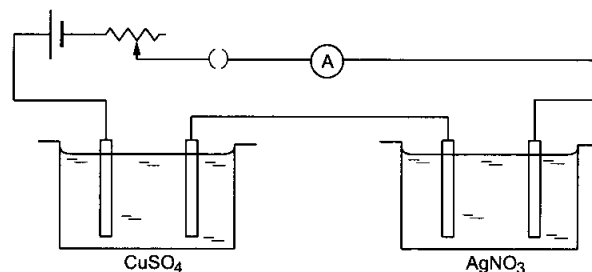


Figure 33.10

The cathodes are cleaned, dried, weighed and then inserted in the respective cells. The current is passed for some time and then the cathodes are taken out. They are washed without rubbing in gently-flowing water, dried and weighed. Thus, the masses of the deposits are obtained. If m_1 and m_2 are the masses of copper and silver deposited, it is found that

$$\frac{m_1}{m_2} = \frac{E_1}{E_2}$$

where E_1 and E_2 are the chemical equivalents of copper and silver respectively. So, the second law is verified.

Faraday's Laws and Ionic Theory

Faraday's laws of electrolysis can be easily understood in terms of the ionic character for the conduction in an electrolyte. Suppose a substance of valency v is liberated at an electrode. Its ion will carry a positive or a negative charge of magnitude ve . To neutralise this ion, the battery has to supply or take up a charge ve . If the total charge passing through the battery is Q , the number of ions neutralised is

$$N = \frac{Q}{ve}.$$

Suppose, the relative atomic mass of the substance is A . Now $1/12$ of the mass of a ^{12}C atom is one atomic mass unit (amu) and has the value 1.6605×10^{-27} kg. Let us denote this quantity as m_u . The mass of an atom of the substance is then

$$m_a = A m_u.$$

This can also be taken as the mass of an ion because the difference in ionic mass and atomic mass is negligible. The mass of the N ions neutralised at the electrode is

$$\begin{aligned} m &= N A m_u \\ &= \frac{Q}{ve} A m_u. \end{aligned}$$

But $\frac{A}{v}$ is the chemical equivalent E , so that

$$m = \frac{1}{e/m_u} EQ.$$

Thus, $m \propto Q$ and $m \propto E$ which are Faraday's laws. The constant

$$\begin{aligned} \frac{e}{m_u} &= K = \frac{1.6022 \times 10^{-19} \text{ C}}{1.6605 \times 10^{-27} \text{ kg}} \\ &= 9.6485 \times 10^7 \text{ C kg}^{-1} \end{aligned}$$

as mentioned earlier.

The Unit "faraday" and Faraday Constant

The charge of 1 mole of electrons is called 1 faraday. So faraday is a unit of charge and its relation with coulomb is

$$\begin{aligned} 1 \text{ faraday} &= (1.6022 \times 10^{-19} \text{ C}) \times (6.022 \times 10^{23}) \\ &= 96485 \text{ C}. \end{aligned}$$

The quantity *charge per mole of electrons* is called Faraday constant and is denoted by the symbol F . Thus,

$$\begin{aligned} F &= 96485 \text{ C mol}^{-1} \\ &= 1 \text{ faraday mol}^{-1}. \end{aligned}$$

Suppose, 1 faraday of charge is passed through an electrolyte. The amount of electrons taken up or supplied at an electrode is 1 mole. Since each ion takes up or gives up v electrons, the amount of ions liberated is $\frac{1}{v}$ moles. The mass of 1 mole of the substance is A gram (A = relative atomic mass), so that the mass of these ions is $\frac{A}{v}$ gram = E gram. The amount E gram of a substance is called 1 gram-equivalent of this substance. So, 1 faraday of charge liberates one gram-equivalent of any substance in electrolysis.

33.9 VOLTAMETER OR COULOMBMETER

An electrolytic cell can be used to measure electric currents or amounts of charge. The current to be

measured is passed through the electrolytic cell for a known time t . If the mass deposited in time t is m and the electrochemical equivalent of the material is Z ,

$$m = Zit$$

$$\text{or, } i = \frac{m}{Zt}.$$

The charge passed is $it = m/Z$.

When an electrolytic cell is used to measure electric current it is called a *voltameter* or a *coulombmeter*. Quite often, the word voltameter is used to mean just the electrolytic cell whatever be its use.

A copper voltameter may be used for routine laboratory measurements. The electrolyte is CuSO_4 solution in water in the ratio of about 1 : 4 by weight. A copper plate placed in the middle serves as the cathode and two connected copper plates on the two sides of the cathode are used as the anode. In this arrangement, shown schematically in figure (33.11), both sides of the cathode plate receive the deposit.

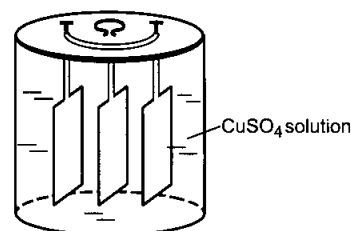


Figure 33.11

A silver voltameter (figure 33.12) is used when high accuracy is needed. The electrolyte is silver nitrate solution in water in the ratio of 1 : 5 to 1 : 6. The solution is taken in a platinum cup. The cup itself acts as the cathode. The anode is made of a silver rod placed in the middle. A porcelain cup which is porous to the electrolyte surrounds the anode. This prevents the impurities in the anode to reach the cathode.

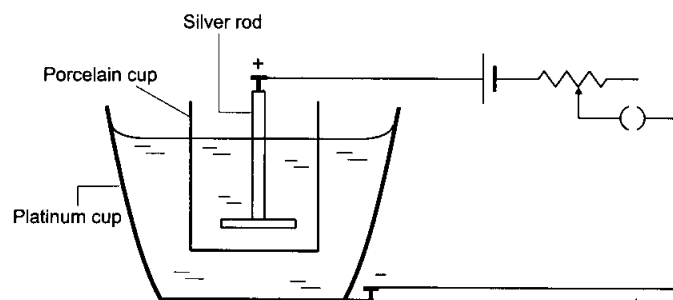


Figure 33.12

Because of the high accuracy attainable, silver voltameters are used in laboratories for standardization purposes.

33.10 PRIMARY AND SECONDARY CELLS

When a metal electrode is dipped in an electrolyte, negative or positive ions tend to go from the electrolyte to the electrode. Thus, an emf is produced between the electrolyte and the electrode. If two electrodes of different metals are dipped in an electrolyte, the emf's produced at the two electrodes are different and there is a net emf between the electrodes. This forms a *voltaic cell*, also called simply a *cell*. The electrode at higher potential is called the *positive electrode* and that at lower potential is called the *negative electrode*. Terminals connected to these electrodes are called positive and negative terminals respectively. This is the basic theory of a voltaic cell in which electrolysis is used to produce an emf between two terminals.

A cell is called *primary* if it is used only for discharge. The current leaves the cell at the positive terminal, goes through the external circuit and enters the cell at the negative terminal. A *secondary* cell on the other hand can be discharged as well as charged; the current can go both ways in the cell.

33.11 PRIMARY CELLS

Daniell Cell

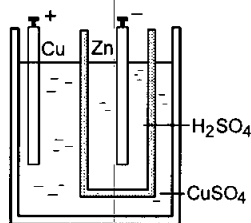


Figure 33.13

In the simplest form, a Daniell cell consists of a zinc electrode in a dilute H_2SO_4 solution and a copper electrode in CuSO_4 solution. The two solutions are separated by a porous cup which allows any gas to pass through, but generally prevents the liquids to mix. The zinc surface is amalgamated to avoid the local effects of impurities.

The H_2SO_4 solution consists of H^+ ions and SO_4^{--} ions. The SO_4^{--} ions move to the zinc electrode to form ZnSO_4 . Negative charge is given up to the zinc electrode in the process. The H^+ ions move out through the porous cup. These H^+ ions combine with the SO_4^{--} ions in the CuSO_4 solution to form H_2SO_4 . The Cu^{++} ions in the outer vessel move towards the copper electrode. Copper is deposited on the copper electrode and positive charge is given up to this electrode in the process. This arrangement prevents hydrogen from

collecting near the anode. Any hydrogen collected near the anode may stop the function of the cell. This problem is called the *polarization* of the cell.

Because of the chemical actions described, the positive charge is accumulated on the copper electrode and negative charge on the zinc electrode. Thus an emf is produced. The zinc electrode works as the negative electrode and the copper electrode works as the positive electrode.

Daniel cell is used when a continuous current is needed. The emf of a Daniell cell is around 1.09 V and its internal resistance is around 1 Ω .

Leclanche Cell

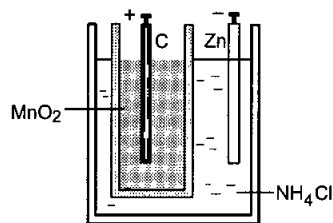


Figure 33.14

A Leclanche cell has a carbon and a zinc electrode in a solution of NH_4Cl . The carbon electrode is packed in a porous cup containing MnO_2 . The zinc electrode forms the negative terminal and the carbon forms the positive terminal. When a current passes through the cell, the Cl^- ions combine with zinc and the NH_4^+ ions move towards the carbon electrode. The NH_4^+ separates into ammonia (NH_3) and hydrogen (H^+). The H^+ ion enters the porous cup. The positive charge is given to the carbon electrode. The hydrogen reacts with MnO_2 present there to form Mn_2O_3 and water. Thus, MnO_2 prevents hydrogen from collecting on the anode which could otherwise stop the cell's function.

The depolarizing action (absorbing hydrogen in some chemical reaction) is quite slow in Leclanche cell. Thus, if the cell is used continuously, hydrogen starts collecting at the carbon electrode and the cell is not able to supply enough current. Thus, the cell is used when intermittent currents are needed. Its emf is about 1.5 V.

Dry Cell

This is a special kind of Leclanche cell in which both NH_4Cl and MnO_2 are prepared in the form of a paste. The paste is contained in a zinc container which itself works as the negative electrode. The whole system is sealed so that the paste does not dry up. The internal resistance of a dry cell is very small, of the order of 0.1 Ω .

33.12 SECONDARY CELL : LEAD ACCUMULATOR

In a secondary cell, one can pass current in both directions. When current leaves the cell at the positive terminal and enters the cell at the negative terminal, the cell is discharged. This is the normal working of the cell. Chemical energy is converted into electrical energy in this case. If the cell is connected to some other source of larger emf, current may enter the cell at the positive terminal and leave it at the negative terminal. The electric energy is then converted into chemical energy and the cell gets charged. The most commonly used secondary cell is a lead accumulator.

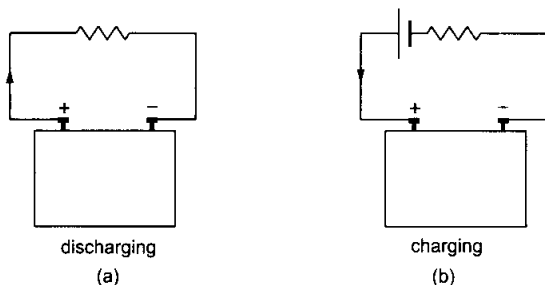
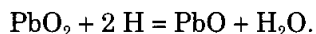


Figure 33.15

Lead Accumulator

In principle, a lead accumulator consists of electrodes made of PbO_2 and of Pb immersed in dilute sulphuric acid (H_2SO_4). The specific gravity of the solution should be between 1.20 and 1.28. PbO_2 acts as the positive electrode and Pb as the negative electrode. While discharging, the SO_4^{--} ions move towards the Pb electrode, give up the negative charge and form PbSO_4 there (figure 33.16a). The H^+ ions move to the PbO_2 electrode, give up the positive charge and reduce PbO_2 to PbO ,



The PbO so formed reacts with the H_2SO_4 to form PbSO_4 and water.



Thus, PbSO_4 is formed at both the electrodes. As the sulphuric acid is used up in discharging, the specific gravity of the acid decreases. When the specific gravity falls to 1.15, the cell is considered to be fully

discharged and any further current drawn from it may permanently damage the electrodes.

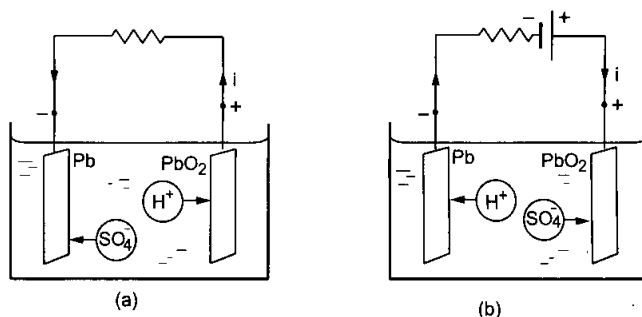
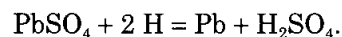
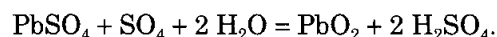


Figure 33.16

The charging process is reverse of discharging. A current is forced from the positive to the negative electrode inside the cell. The H^+ ions move towards the negative electrode and react with the PbSO_4 present there (which was formed during discharging).



At the positive electrode, the reaction is



Thus, the PbSO_4 deposited at the two electrodes is dissolved, Pb is deposited at the negative electrode and PbO_2 at the positive electrode. This restores the capacity of the cell to provide current. The emf of a lead accumulator is about 2.05 V when fully charged. In the discharged condition, the emf may fall to 1.8 V.

A practical lead accumulator contains several plates of lead connected together to form the negative electrode and several plates of lead peroxide connected together to form the positive electrode. This increases the capacity of the accumulator. These plates are separated from each other by insulating separators.

For commercial use, several such cells are connected in series and assembled together in one case. A six volt battery is obtained by connecting three such cells and a twelve volt battery is obtained by connecting six such cells.

The capacity of an accumulator is measured in ampere-hour. Thus, a 100 ampere-hour accumulator can supply 20 A current for 5 hours or 10 A current for 10 hours.

Worked Out Examples

1. A current of 30 A is registered when the terminals of a dry cell of emf 1.5 volts are connected through an ammeter. Neglecting the meter resistance, find the amount of heat produced in the battery in 10 seconds.

Solution : The current in the circuit will be

$$i = \frac{\mathcal{E}}{r}$$

$$\text{or, } 30 \text{ A} = \frac{1.5 \text{ V}}{r} \text{ giving } r = 0.05 \Omega.$$

The amount of heat produced in the battery

$$= i^2 r t = (30 \text{ A})^2 \times (0.05 \Omega) \times 10 \text{ s} = 450 \text{ J}.$$

2. A room heater is rated 500 W, 220 V. (a) Find the resistance of its coil. (b) If the supply voltage drops to 200 V, what will be the power consumed? (c) If an electric bulb rated 100 W, 220 V is connected in series with this heater, what will be the power consumed by the heater and by the bulb when the supply is at 220 V?

Solution :

(a) The power consumed by a coil of resistance R when connected across a supply V is

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

The resistance of the heater coil is, therefore,

$$R = \frac{(220 \text{ V})^2}{500 \text{ W}} = 96.8 \Omega.$$

(b) If the supply voltage drops to 200 V, the power consumed will be

$$P = \frac{V^2}{R} = \frac{(200 \text{ V})^2}{96.8 \Omega} = 413 \text{ W}.$$

(c) The resistance of the 100 W, 220 V bulb is

$$R = \frac{(220 \text{ V})^2}{100 \text{ W}} = 484 \Omega.$$

If this is connected in series with the heater of 96.8Ω , the current i will be

$$i = \frac{220 \text{ V}}{484 \Omega + 96.8 \Omega} = 0.379 \text{ A}.$$

Thus, the power consumed by the heater

$$= i^2 \times 96.8 \Omega = 0.144 \times 96.8 \text{ W} = 13.9 \text{ W}$$

and that by the bulb

$$= i^2 \times 484 \Omega = 69.7 \text{ W}.$$

3. A battery of emf \mathcal{E} and internal resistance r is used in a circuit with a variable external resistance R . Find the value of R for which the power consumed in R is maximum.

Solution : The current in the resistance R is

$$i = \frac{\mathcal{E}}{r + R}.$$

The power consumed in R is

$$P = i^2 R = \frac{\mathcal{E}^2 R}{(r + R)^2}.$$

It is maximum when $\frac{dP}{dR} = 0$. We have

$$\frac{dP}{dR} = \mathcal{E}^2 \left[\frac{(r + R)^2 - 2R(r + R)}{(r + R)^4} \right].$$

It is zero when

$$(r + R)^2 = 2R(r + R)$$

or,

$$R = r.$$

4. The junctions of a Ni-Cu thermocouple are maintained at 0°C and 100°C . Calculate the Seebeck emf produced

in the loop. $a_{\text{Ni, Cu}} = 16.3 \times 10^{-6} \text{ V}^\circ\text{C}^{-1}$ and $b_{\text{Ni, Cu}} = -0.042 \times 10^{-6} \text{ V}^\circ\text{C}^{-2}$.

Solution :

$$\mathcal{E}_{\text{Ni, Cu}} = a_{\text{Ni, Cu}} \theta + \frac{1}{2} b_{\text{Ni, Cu}} \theta^2$$

$$= (16.3 \times 10^{-6} \times 100) \text{ V} + \frac{1}{2} (-0.042 \times 10^{-6} \times 10^4) \text{ V}$$

$$= 1.42 \times 10^{-3} \text{ V}.$$

5. Find the neutral and inversion temperatures for Ni-Cu thermocouple with the cold junction at 0°C . Use data from previous example.

Solution : The neutral temperature is

$$\theta_n = -\frac{a}{b}$$

$$= \frac{16.3 \times 10^{-6}}{0.042 \times 10^{-6}} ^\circ\text{C} = 388^\circ\text{C}.$$

The inversion temperature is double the neutral temperature, i.e., 776°C .

6. An electric current of 0.4 A is passed through a silver voltameter for half an hour. Find the amount of silver deposited on the cathode. ECE of silver = $1.12 \times 10^{-6} \text{ kg C}^{-1}$.

Solution : Using the formula $m = Zit$, the mass of silver deposited

$$= (1.12 \times 10^{-6} \text{ kg C}^{-1}) (0.4 \text{ A}) (30 \times 60 \text{ s})$$

$$= 8.06 \times 10^{-4} \text{ kg} = 0.806 \text{ g}.$$

7. A silver and a copper voltameter are connected in series with a 12.0 V battery of negligible resistance. It is found that 0.806 g of silver is deposited in half an hour. Find (a) the mass of the copper deposited and (b) the energy supplied by the battery. ECE of silver = $1.12 \times 10^{-6} \text{ kg C}^{-1}$ and that of copper = $6.6 \times 10^{-7} \text{ kg C}^{-1}$.

Solution :

(a) For silver voltameter, the formula $m = Zit$ gives

$$0.806 \text{ g} = (1.12 \times 10^{-6} \text{ kg C}^{-1}) i (30 \times 60 \text{ s})$$

or,

$$i = 0.4 \text{ A}.$$

As the two voltameters are connected in series, the same current passes through the copper voltameter. The mass of copper deposited is

$$m = Zit$$

$$= (6.6 \times 10^{-7} \text{ kg C}^{-1}) (0.4 \text{ A}) (30 \times 60 \text{ s})$$

$$= 4.75 \times 10^{-4} \text{ kg} = 0.475 \text{ g}.$$

This could also be obtained by using $\frac{m_1}{m_2} = \frac{Z_1}{Z_2}$ for series circuit.

(b) Energy supplied by the battery = Vit

$$= (12 \text{ V}) (0.4 \text{ A}) (30 \times 60 \text{ s}) = 8.64 \text{ kJ}.$$

8. A current of 1 A is passed through a dilute solution of sulphuric acid for some time to liberate 1 g of oxygen. How much hydrogen is liberated during this period? How long was the current passed? Faraday constant = 96500 C mol^{-1} .

Solution : The relative atomic mass of oxygen = 16 and its valency = 2 so that the chemical equivalent $E = \frac{16}{2} = 8$.
Chemical equivalent of hydrogen = 1.

$$\frac{m_{\text{oxygen}}}{m_{\text{hydrogen}}} = \frac{E_{\text{oxygen}}}{E_{\text{hydrogen}}} = \frac{8}{1}$$

$$\text{or, } m_{\text{hydrogen}} = \frac{m_{\text{oxygen}}}{8} = \frac{1 \text{ g}}{8} = 0.125 \text{ g}.$$

We have, 1 g of oxygen = $\frac{1}{8}$ gram-equivalent.

The charge needed to liberate $\frac{1}{8}$ gram-equivalent

$$= \frac{1}{8} \text{ faraday} \\ = \frac{96500}{8} \text{ C} \approx 1.2 \times 10^4 \text{ C}.$$

As the current is 1 A, the time taken is

$$t = \frac{Q}{i} = \frac{1.2 \times 10^4 \text{ C}}{1 \text{ A}} \\ = 1.2 \times 10^4 \text{ s} \\ = 3 \text{ hours } 20 \text{ minutes}.$$

□

QUESTIONS FOR SHORT ANSWER

1. If a constant potential difference is applied across a bulb, the current slightly decreases as time passes and then becomes constant. Explain.
2. Two unequal resistances R_1 and R_2 are connected across two identical batteries of emf \mathcal{E} and internal resistance r (figure 33-Q1). Can the thermal energies developed in R_1 and R_2 be equal in a given time. If yes, what will be the condition?
3. When a current passes through a resistor, its temperature increases. Is it an adiabatic process?
4. Apply the first law of thermodynamics to a resistor carrying a current i . Identify which of the quantities ΔQ , ΔU and ΔW are zero, which are positive and which are negative.
5. Do all the thermocouples have a neutral temperature?
6. Is inversion temperature always double of the neutral temperature? Does the unit of temperature have an effect in deciding this question?
7. Is neutral temperature always the arithmetic mean of the inversion temperature and the temperature of the cold junction? Does the unit of temperature have an effect in deciding this question?
8. Do the electrodes in an electrolytic cell have fixed polarity like a battery?
9. As temperature increases, the viscosity of liquids decreases considerably. Will this decrease the resistance of an electrolyte as the temperature increases?

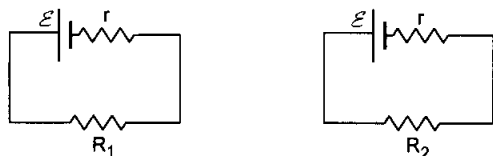


Figure 33-Q1

OBJECTIVE I

1. Which of the following plots may represent the thermal energy produced in a resistor in a given time as a function of the electric current?
2. A constant current i is passed through a resistor. Taking the temperature coefficient of resistance into account, indicate which of the plots shown in figure (33-Q3) best

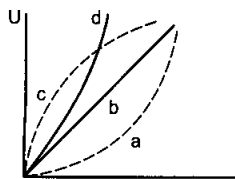


Figure 33-Q2

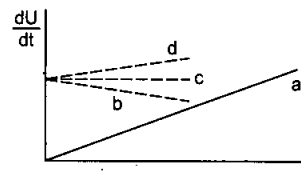


Figure 33-Q3

represents the rate of production of thermal energy in the resistor.

3. Consider the following statements regarding a thermocouple.

(A) The neutral temperature does not depend on the temperature of the cold junction.

(B) The inversion temperature does not depend on the temperature of the cold junction.

- (a) Both A and B are correct.
 (b) A is correct but B is wrong.
 (c) B is correct but A is wrong.
 (d) Both A and B are wrong.

4. The heat developed in a system is proportional to the current through it.

- (a) It cannot be Thomson heat.
 (b) It cannot be Peltier heat.
 (c) It cannot be Joule heat.
 (d) It can be any of the three heats mentioned above.

5. Consider the following two statements.

- (A) Free-electron density is different in different metals.
 (B) Free-electron density in a metal depends on temperature.

Seebeck effect is caused

(a) due to both A and B

(b) due to A but not due to B

(c) due to B but not due to A

(d) neither due to A nor due to B.

6. Consider the statements A and B in the previous question. Peltier effect is caused

(a) due to both A and B

(b) due to A but not due to B

(c) due to B but not due to A

(d) neither due to A nor due to B.

7. Consider the statements A and B in question 5. Thomson effect is caused

(a) due to both A and B

(b) due to A but not due to B

(c) due to B but not due to A

(d) neither due to A nor due to B.

8. Faraday constant

(a) depends on the amount of the electrolyte

(b) depends on the current in the electrolyte

(c) is a universal constant

(d) depends on the amount of charge passed through the electrolyte.

OBJECTIVE II

1. Two resistors having equal resistances are joined in series and a current is passed through the combination. Neglect any variation in resistance as the temperature changes. In a given time interval,

- (a) equal amounts of thermal energy must be produced in the resistors
 (b) unequal amounts of thermal energy may be produced
 (c) the temperature must rise equally in the resistors
 (d) the temperature may rise equally in the resistors.

2. A copper strip AB and an iron strip AC are joined at A . The junction A is maintained at 0°C and the free ends B and C are maintained at 100°C . There is a potential difference between

- (a) the two ends of the copper strip
 (b) the copper end and the iron end at the junction
 (c) the two ends of the iron strip
 (d) the free ends B and C .

3. The constants a and b for the pair silver-lead are $2.50 \mu\text{V}^\circ\text{C}^{-1}$ and $0.012 \mu\text{V}^\circ\text{C}^{-2}$ respectively. For a silver-lead thermocouple with colder junction at 0°C ,

(a) there will be no neutral temperature

(b) there will be no inversion temperature

(c) there will not be any thermo-emf even if the junctions are kept at different temperatures

(d) there will be no current in the thermocouple even if the junctions are kept at different temperatures.

4. An electrolysis experiment is stopped and the battery terminals are reversed.

(a) The electrolysis will stop.

(b) The rate of liberation of material at the electrodes will increase.

(c) The rate of liberation of material will remain the same.

(d) Heat will be produced at a greater rate.

5. The electrochemical equivalent of a material depends on

(a) the nature of the material

(b) the current through the electrolyte containing the material

(c) the amount of charge passed through the electrolyte

(d) the amount of this material present in the electrolyte.

EXERCISES

1. An electric current of 2.0 A passes through a wire of resistance 25Ω . How much heat will be developed in 1 minute?
2. A coil of resistance 100Ω is connected across a battery of emf 6.0 V . Assume that the heat developed in the coil is used to raise its temperature. If the heat capacity of

the coil is 4.0 J K^{-1} , how long will it take to raise the temperature of the coil by 15°C ?

3. The specification on a heater coil is 250 V , 500 W . Calculate the resistance of the coil. What will be the resistance of a coil of 1000 W to operate at the same voltage?

4. A heater coil is to be constructed with a nichrome wire ($\rho = 1.0 \times 10^{-6} \Omega\text{m}$) which can operate at 500 W when connected to a 250 V supply. (a) What would be the resistance of the coil? (b) If the cross-sectional area of the wire is 0.5 mm^2 , what length of the wire will be needed? (c) If the radius of each turn is 4.0 mm, how many turns will be there in the coil?
5. A bulb with rating 250 V, 100 W is connected to a power supply of 220 V situated 10 m away using a copper wire of area of cross section 5 mm^2 . How much power will be consumed by the connecting wires? Resistivity of copper $= 1.7 \times 10^{-8} \Omega\text{m}$.
6. An electric bulb, when connected across a power supply of 220 V, consumes a power of 60 W. If the supply drops to 180 V, what will be the power consumed? If the supply is suddenly increased to 240 V, what will be the power consumed?
7. A servo voltage stabiliser restricts the voltage output to $220 \text{ V} \pm 1\%$. If an electric bulb rated at 220 V, 100 W is connected to it, what will be the minimum and maximum power consumed by it?
8. An electric bulb marked 220 V, 100 W will get fused if it is made to consume 150 W or more. What voltage fluctuation will the bulb withstand?
9. An immersion heater rated 1000 W, 220 V is used to heat 0.01 m^3 of water. Assuming that the power is supplied at 220 V and 60% of the power supplied is used to heat the water, how long will it take to increase the temperature of the water from 15°C to 40°C ?
10. An electric kettle used to prepare tea, takes 2 minutes to boil 4 cups of water (1 cup contains 200 cc of water) if the room temperature is 25°C . (a) If the cost of power consumption is Re 1.00 per unit (1 unit = 1000 watt-hour), calculate the cost of boiling 4 cups of water. (b) What will be the corresponding cost if the room temperature drops to 5°C ?
11. The coil of an electric bulb takes 40 watts to start glowing. If more than 40 W is supplied, 60% of the extra power is converted into light and the remaining into heat. The bulb consumes 100 W at 220 V. Find the percentage drop in the light intensity at a point if the supply voltage changes from 220 V to 200 V.
12. The 2.0Ω resistor shown in figure (33-E1) is dipped into a calorimeter containing water. The heat capacity of the calorimeter together with water is 2000 J K^{-1} . (a) If the circuit is active for 15 minutes, what would be the rise in the temperature of the water? (b) Suppose the 6.0Ω resistor gets burnt. What would be the rise in the temperature of the water in the next 15 minutes?
13. The temperatures of the junctions of a bismuth–silver thermocouple are maintained at 0°C and 0.001°C . Find the thermo-emf (Seebeck emf) developed. For bismuth–silver, $a = -46 \times 10^{-6} \text{ V}^\circ\text{C}^{-1}$ and $b = -0.48 \times 10^{-6} \text{ V}^\circ\text{C}^{-2}$.
14. Find the thermo-emf developed in a copper–silver thermocouple when the junctions are kept at 0°C and 40°C . Use the data in table (33.1).
15. Find the neutral temperature and inversion temperature of copper–iron thermocouple if the reference junction is kept at 0°C . Use the data in table (33.1).
16. Find the charge required to flow through an electrolyte to liberate one atom of (a) a monovalent material and (b) a divalent material.
17. Find the amount of silver liberated at cathode if 0.500 A of current is passed through AgNO_3 electrolyte for 1 hour. Atomic weight of silver is 107.9 g mol^{-1} .
18. An electroplating unit plates 3.0 g of silver on a brass plate in 3.0 minutes. Find the current used by the unit. The electrochemical equivalent of silver is $1.12 \times 10^{-6} \text{ kg C}^{-1}$.
19. Find the time required to liberate 1.0 litre of hydrogen at STP in an electrolytic cell by a current of 5.0 A .
20. Two voltmeters, one having a solution of silver salt and the other of a trivalent-metal salt, are connected in series and a current of 2 A is maintained for 1.50 hours. It is found that 1.00 g of the trivalent metal is deposited. (a) What is the atomic weight of the trivalent metal? (b) How much silver is deposited during this period? Atomic weight of silver is 107.9 g mol^{-1} .
21. A brass plate having surface area 200 cm^2 on one side is electroplated with 0.10 mm thick silver layers on both sides using a 15 A current. Find the time taken to do the job. The specific gravity of silver is 10.5 and its atomic weight is 107.9 g mol^{-1} .
22. Figure (33-E2) shows an electrolyte of AgCl through which a current is passed. It is observed that 2.68 g of silver is deposited in 10 minutes on the cathode. Find the heat developed in the 20Ω resistor during this period. Atomic weight of silver is 107.9 g mol^{-1} .

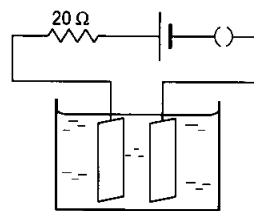


Figure 33-E2

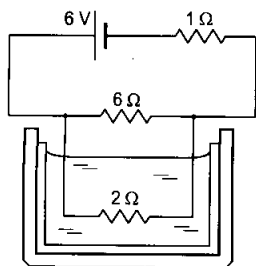


Figure 33-E1

23. The potential difference across the terminals of a battery of emf 12 V and internal resistance 2Ω drops to 10 V when it is connected to a silver voltameter. Find the silver deposited at the cathode in half an hour. Atomic weight of silver is 107.9 g mol^{-1} .
24. A plate of area 10 cm^2 is to be electroplated with copper (density 9000 kg m^{-3}) to a thickness of 10 micrometres on both sides, using a cell of 12 V . Calculate the energy spent by the cell in the process of deposition. If this

energy is used to heat 100 g of water, calculate the rise in the temperature of the water. ECE of copper

$= 3 \times 10^{-7} \text{ kg C}^{-1}$ and specific heat capacity of water
 $= 4200 \text{ J kg}^{-1} \text{ K}^{-1}$.

□

ANSWERS

OBJECTIVE I

1. (a) 2. (d) 3. (b) 4. (c) 5. (a) 6. (b)
 7. (c) 8. (c)

OBJECTIVE II

1. (a), (d) 2. all 3. (a), (b)
 4. (c) 5. (a)

EXERCISES

1. $6.0 \times 10^3 \text{ J}$
 2. 2.8 min
 3. 125 Ω , 62.5 Ω
 4. (a) 125 Ω (b) 62.5 m (c) ≈ 2500 turns
 5. 8.4 mW
 6. 40 W, 71 W
 7. 98 W, 102 W

8. up to 270 V
 9. 29 minutes
 10. (a) 7 paise (b) 9 paise
 11. 29%
 12. (a) 2.9°C (b) 3.6°C
 13. $-4.6 \times 10^{-8} \text{ V}$
 14. $1.04 \times 10^{-5} \text{ V}$
 15. 330°C, 659°C
 16. (a) $1.6 \times 10^{-19} \text{ C}$ (b) $3.2 \times 10^{-19} \text{ C}$
 17. 2.01 g
 18. 15 A
 19. 29 minutes
 20. (a) 26.8 g mol⁻¹ (b) 12.1 g
 21. 42 minutes
 22. 190 kJ
 23. 2 g
 24. 7.2 kJ, 17 K

□