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ELECTRICITY AND CHEMICAL REACTIONS

WHAT WE HAVE LEARNT

- When electricity is passed through acidified water, it decomposes to form hydrogen and oxygen.
- Reactions which either absorb or liberate electrical energy are called electrochemical reactions.
- Like charges repel while unlike charges attract.
- Ionic compounds are formed as a result of the electrostatic force of attraction between oppositely charged ions.
- Oxidation is the process of losing of electron (s) and reduction is the gaining of electron(s).
- The electrical conductivity of metals is due to the presence of free electrons in them.
- Flow of electricity can take place only when there is a potential difference between the ends of the conductor.

ELECTRICITY AND CHEMICAL REACTIONS

You have understood through many examples that the properties of an element or a compound are associated with its atomic structure. Physical and chemical properties can be explained on the basis of atomic structure. This is why scientists study atomic structure in physics and in chemistry. Therefore both in Physics and Chemistry scientists study atomic structure. You know that electricity is the flow of electrons and that when electrons are gained or lost, the chemical structure of a substance changes. Hence, how chemical reactions and electricity are related is a separate field of study in chemistry.

Whether a substance conducts or resists electricity is related to its atomic structure. The response of chemicals to electricity is studied in chemistry. Electricity is used in large and small industries and in the manufacture of many chemicals and it is of importance to chemistry.

As electricity is a flow of electrons, it can decompose substances, cause chemical reactions and influence the rate of reactions. You also know that electrons are released in many chemical reactions. Electricity can be produced from such reactions when they are controlled suitably.

Electrochemistry is the study of reactions between electricity and chemical substances.

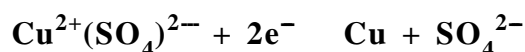
You have come across instances of chemical changes producing electrical energy and vice versa. Electrochemistry deals with reactions in which electrical energy and chemical energy are mutually transformed. Electrochemical cells are set-up arrangements where this energy conversion takes place.

Galvanic cells

Observe the changes that happen to copper sulphate solution in which a zinc strip is immersed.

Do you see any change in the colour of copper sulphate solution? Why?

Notice the reaction which takes place here.



Here, can you find which reaction is oxidation and which reaction is reduction.

Now, immerse Zn strip in ZnSO_4 solution and a Cu strip in CuSO_4 solution. Observe the changes the solutions undergo.

Conduct the following experiment. Take ZnSO_4 solution in a beaker and immerse a Zn strip in it. In another beaker take CuSO_4 solution and immerse a Cu strip in it. Connect the electrodes with a voltmeter through a conductor (figure 4.1).

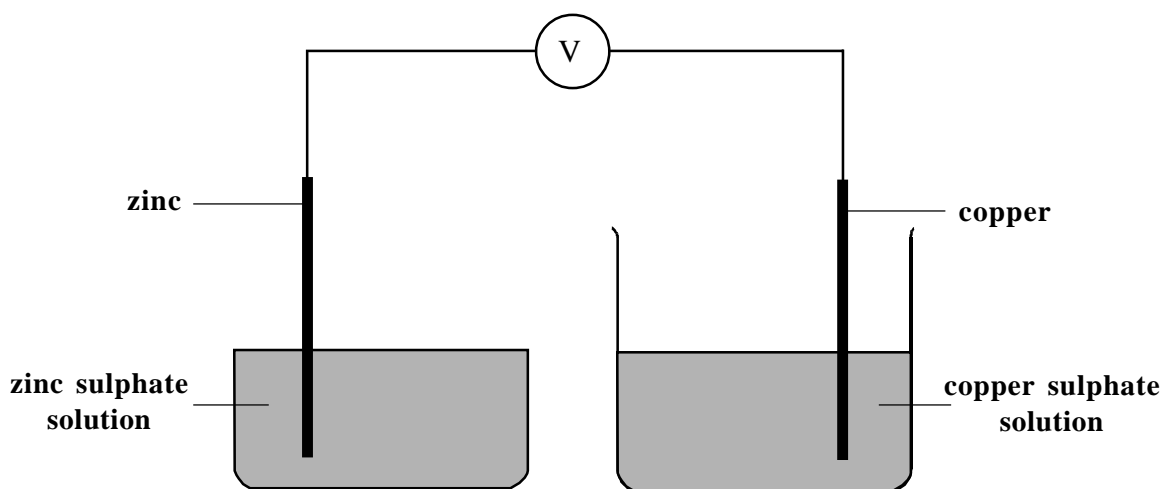
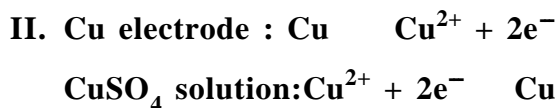
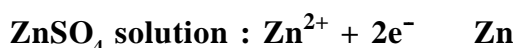
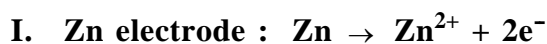


Figure 4.1

Does electricity flow for long?

Now, cut a strip of filter paper and soak it in a solution of potassium nitrate. Using the soaked filter paper, connect the two solutions as shown in figure 4.2. Is there a continuous flow of electricity now? Can you explain the reason?

When a metal is immersed in a solution of its own ion, it displays a tendency to form ions by losing electrons. At the same time, metal ions in the solution show the tendency to form metal atom by accepting the electrons. This can be represented by the following equations.



Examine the changes that occur at Zn electrode and in ZnSO_4 solution. How many electrons shall the Zn atom lose to become Zn^{2+} ions? It is by giving two electrons to the electrode that each Zn atom dissolves. At the same time Zn^{2+} ions have the tendency to become Zn atom. Due to the opposing

tendencies, an electrical potential develops at the place where the electrons from the Zn electrode join an equal number of Zn^{2+} that arrive at that place. This is called electrode potential and is indicated by the letter E.

Similarly, what happens when Cu electrode is immersed in CuSO_4 solution?

- the changes that happen in Cu electrode
- the changes that take place in CuSO_4 solution
- the consequences of the changes that take place in the electrode and the solution

Discuss the above and record your inferences in the science diary.

To represent the potential of zinc electrode we write $E_{\text{Zn}^{2+}/\text{Zn}}$ and for that of Cu electrode, we write $E_{\text{Cu}^{2+}/\text{Cu}}$. Write down the representation of the potential of silver electrode.

You know that for electric flow to take place when zinc and copper are connected, their electrode potentials must be different.

Notice the direction of flow of electrons, given in figure 4.2, when Zn and Cu are connected.

How can you ensure a continuous flow of electrons?

It is clear that such an electric current is produced as a result of the chemical changes that take place in each of the electrodes and their solutions?

Galvanic cells are instruments that convert chemical energy into electrical energy.

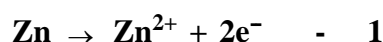
Anode and Cathode

What components are needed to build a Galvanic cell that provides electricity continuously? Make a list.

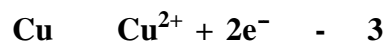
Cell 1

From which electrode to which electrode does the electrons flow in a Zn-Cu cell when the electrodes are connected through an external circuit?

Electrons go from Zn electrode dipped in ZnSO_4 solution to Cu electrode dipped in CuSO_4 solution. For electron flow to occur, which of the following reaction should take place in Zn electrode?



If so, then, which of the following reactions must take place in the copper electrode which accepts electrons?



If expressed in relation to oxidation - reduction hypothesis, when electricity is produced in a galvanic cell, it can be said that oxidation takes place on the side of zinc electrode and reduction takes place on the side of copper electrode.

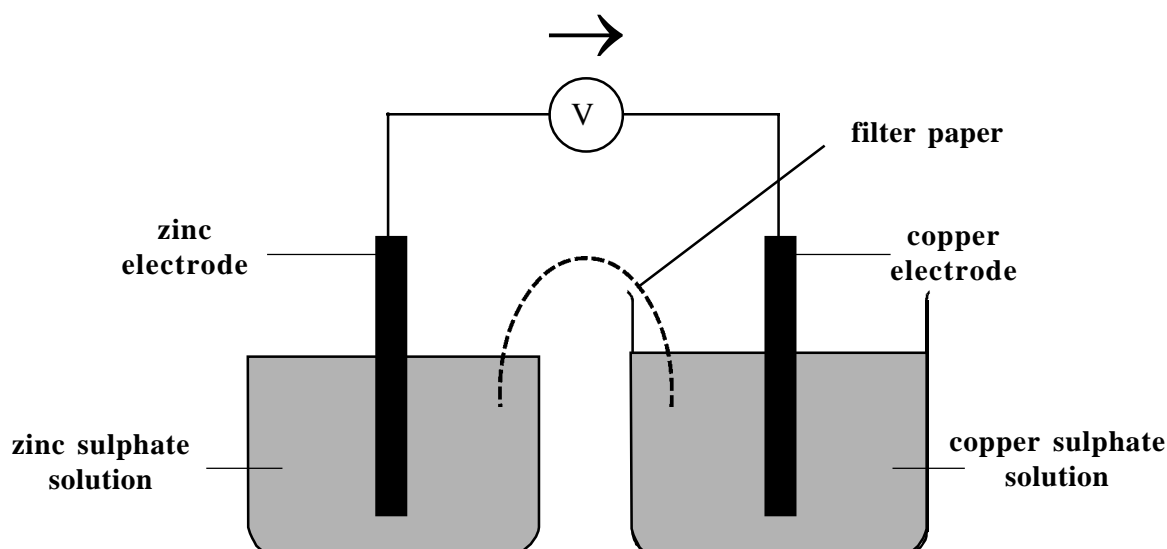


Figure 4.2 (cell 1)

The electrode at which oxidation takes place is called the anode and the one at which reduction takes place is called the cathode.

Identify the anode and cathode in a Zn-Cu cell.

Cell 2

Notice the direction of flow of electron in the cell given below. (Figure 4.3). Chemical

Solutions



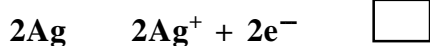
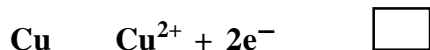
In this cell which is the anode and which is the cathode? The anode, cathode and the reactions that take place in the electrodes of cell 1 and cell 2 are given in table 4.1 below.

	Anode	Cathode	Chemical reaction	
			Anode	Cathode
Cell 1 Fig. 4.2	Zn	Cu	Zn $\text{Zn}^{2+} + 2\text{e}^{-}$	$\text{Cu}^{2+} + 2\text{e}^{-}$ Cu
Cell 2 Fig 4.3	Cu	Ag	Cu $\text{Cu}^{2+} + 2\text{e}^{-}$	$\text{Ag}^{+} + 1\text{e}^{-}$ Ag

Table 4.1

reactions that take place in the metals and solutions are also given below. When electricity is produced, which of the following reactions take place in each electrode? Record your answer in respective boxes.

Metals



Here, Cu in cell 1 functions as cathode where as in cell 2, Cu functions as the anode. That is, any electrode can act as either anode or cathode according to the nature of the electrode to which the former is connected.

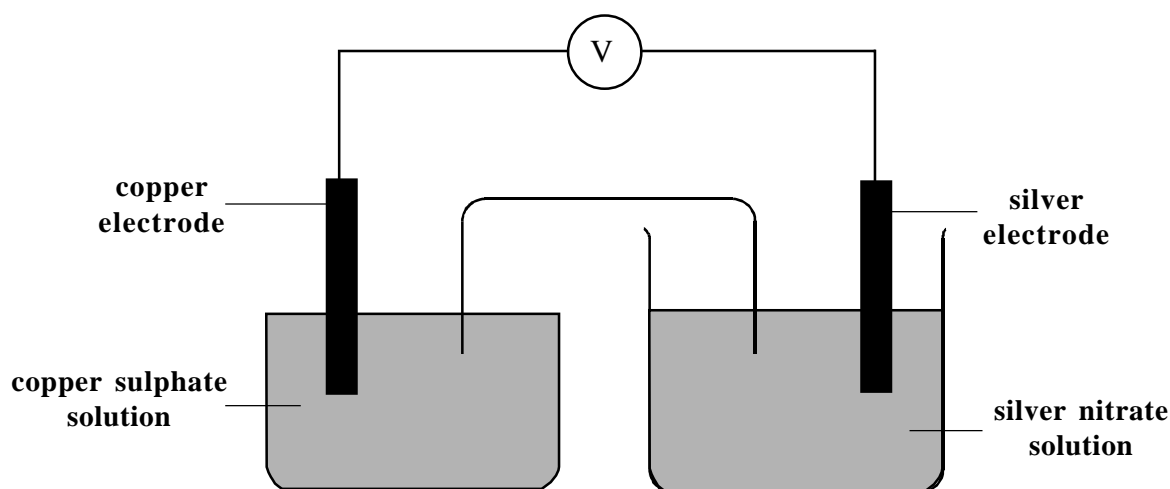


Figure 4.3 (cell 2)

Cell e.m.f.

You know that electric current can be generated only if there is a difference between the potentials of two electrodes. The potential difference between two electrodes is termed as the cell e.m.f. (cell electromotive force).

$$\text{e.m.f.} = E_2 - E_1$$

Where E_1, E_2 are the electrode potentials.

So, if the e.m.f. of a cell is to be formed, it is enough to note the Volt meter reading. But the potential of each electrode cannot be measured. To measure this, the Standard Hydrogen Electrode - SHE is taken as the reference. The electrode potential of SHE is taken as 'zero' at 298 K, one atm pressure and a concentration of 1 molar (1 M) H^+ solution. To find the electrode potential of any particular electrode, it is enough to measure the e.m.f. of the cell obtained by connecting that electrode with a standard hydrogen electrode.

Let us see how the potentials are measured by taking SHE as reference. The given electrode is connected with a standard

hydrogen electrode through a voltmeter. (e.m.f. = the difference between the electrode potential and SHE potential = electrode potential). The reading of voltmeter will be the electrode potential. This is called the standard electrode potential. This can be represented by the letter E^0 . Its unit is Volt (V).

For example, if the voltmeter reading obtained by connecting Zn electrode immersed in $ZnSO_4$ solution with a SHE is 0.76, the electrode potential of Zn electrode () can be taken as 0.76 V.

The value of the electrode potential that we get here can be either positive or negative. It depends on the chemical reactions that take place at the hydrogen electrode. If the reaction at hydrogen electrode is oxidation, this value will be positive and if it is reduction, the value will be negative.

The reaction at hydrogen electrode, the voltmeter reading and the electrode potential of certain electrodes when they are connected with standard hydrogen electrode are given in the table below. Fill in the blanks.

Electrode	Reaction at the hydrogen electrode	Volt meter reading	Electrode potential
Zn^{2+}/Zn	Reduction	0.76	-- 0.76
Cu^{2+}/Cu	Oxidation	0.34	+0.34
Ag^+/Ag	0.80	+0.80
Al^{3+}/Al	-- 1.66
Mg^{2+}/Mg	Reduction	2.52

Table 4.2

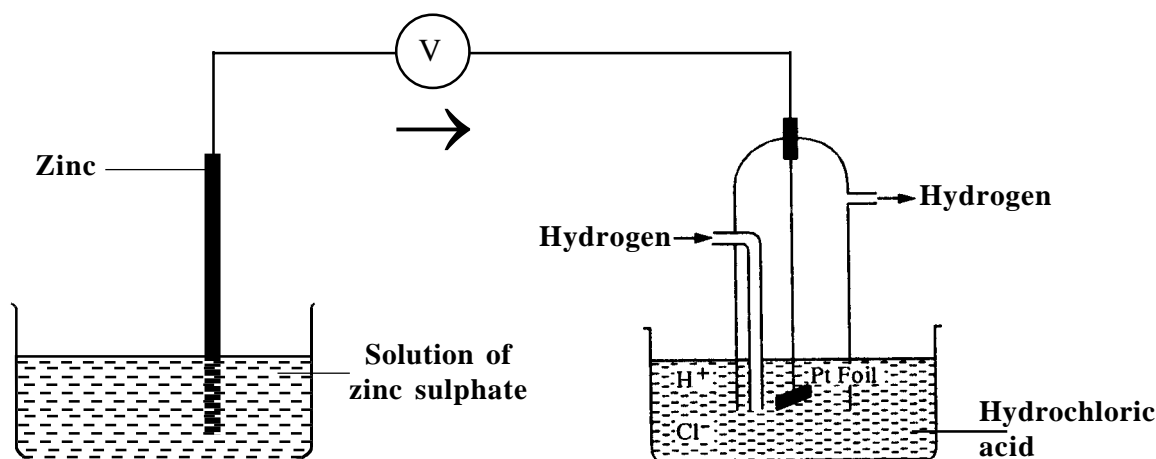


Figure 4.4

In which of the two electrodes of an electrochemical cell, oxidation or reduction takes place is decided by the value of the electrode potential. Oxidation takes place (anode) at the electrode which has a low potential and reduction (cathode) at the electrode which has a high potential.

Find the anode and cathode of any four cells that can be made with the metal electrodes given in table 4.2 and write the electrode reactions. You know that the cell e.m.f. is the difference between the electrode potentials.

Cell e.m.f. = the greater electrode potential minus the smaller electrode potential.

For example, the electrode potential of copper is +0.34 V and that of zinc is -0.76 V. The e.m.f. of the cell made by coupling copper and zinc under standard conditions is denoted as E^0 cell. Then,

$$\begin{aligned} E^0_{\text{cell}} &= E^0_{\text{Cu}^{2+}/\text{Cu}} - E^0_{\text{Zn}^{2+}/\text{Zn}} \\ &= (+0.34 \text{ V}) - (-0.76 \text{ V}) \\ &= +1.1 \text{ V} \end{aligned}$$

Do you now understand that the cell e.m.f. will always be positive?

$$E^0_{\text{Cu}^{2+}/\text{Cu}} = +0.34 \text{ V}$$

$$E^0_{\text{Ag}^+/\text{Ag}} = +0.80 \text{ V}$$

Find the e.m.f. of the cell made by coupling these two.

If the electrode potentials are known, can we make cells of required e.m.f.? If the electrode potentials of electrodes are found out, using the hydrogen electrode and recorded in a table form it will be useful to make cells of required e.m.f.

The series in which electrodes are arranged according to electrode potential in the standard state is called electrochemical series (table 4.3).

Electrochemical Series

Electrode	Electrode potential (V)
Li^+/Li	-3.04
K^+/K	-2.92
Ca^{2+}/Ca	-2.87
Na^+/Na	-2.71
Mg^{2+}/Mg	-2.52
Al^{3+}/Al	-1.66
Zn^{2+}/Zn	-0.76
Fe^{2+}/Fe	-0.44
Ni^{2+}/Ni	-0.28
Sn^{2+}/Sn	-0.15
Pb^{2+}/Pb	-0.13
$\text{H}^+/\frac{1}{2}\text{H}_2$	0.00
Cu^{2+}/Cu	+0.34
I / I^-	+0.53
Ag^+/Ag	+0.80
Hg^{2+}/Hg	+0.92
Cl / Cl^-	+1.35
Au^{3+}/Au	+1.50
F / F^-	+2.87

Table 4.3

Electrolysis

Let us now see how the flow of electricity causes chemical reactions. You have prepared hydrogen and oxygen by passing electricity through water to which a little acid is added. Here the decomposition of water into its component elements is caused by electricity.

Similarly, let us see what happens when electricity is passed through molten sodium chloride.

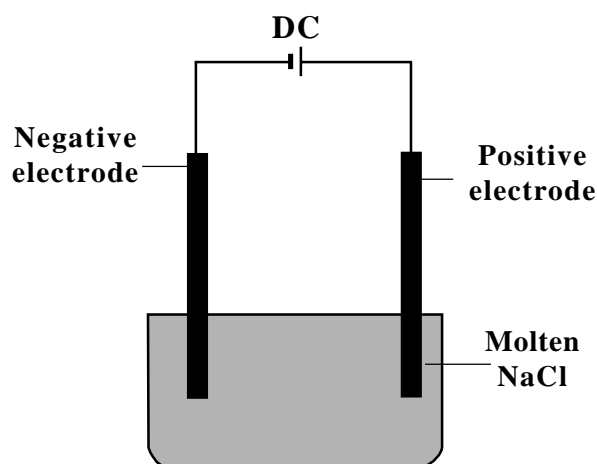


Figure 4.5

Figure 4.5 is the arrangement for passing electricity through molten sodium chloride.

When electricity is passed, sodium chloride decomposes as shown under

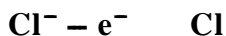


- Is there a possibility for the movement of positive and negative ions towards the electrodes?
- Towards which electrode will Na^+ ions move? Why?
- Which is the ion that move towards positive electrode?
- See how Na^+ ions become sodium atom

$$\text{Na}^+ + 1e^- \rightarrow \text{Na}$$

Is this oxidation or reduction?

- From which electrode do the Na^+ ions get the required electrons?
- What happens when Cl^- ions lose an electron?



Why do Cl atoms form chlorine molecules?

Is it possible to decompose all substances by passing electricity through them? Among NaCl solution, acidified water, kerosene and glucose solution, which ones will pass electricity? Can you explain this on the basis of the method of chemical bonding in these?

Compounds that decompose into oppositely charged particles while in aqueous solution or in molten state are called electrolytes. The decomposition of an electrolyte into its ions by the passage of electricity is called electrolysis.

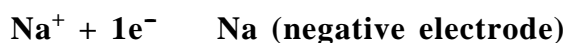
The solutions of ionic compounds are electrolytes. Can you explain why?

The aqueous solution of polar compounds undergo electrolytic decomposition. Why? Non-polar compounds do not conduct electricity. Why?

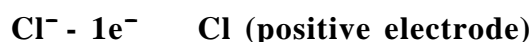
Separate the following compounds into ionic, polar and non-polar. From among them, can you identify the electrolytes?

CuSO₄, HCl, H₂SO₄, KCl, KNO₃, NH₄Cl, kerosene oil, petrol

In the electrolysis of molten sodium chloride, you saw that sodium and chlorine are deposited at the negative and positive electrodes respectively.



Is this reaction oxidation or reduction?



Here, it is loss of electron, i.e., oxidation.

You know that the electrode at which oxidation takes place is called anode and the electrode at which reduction takes place is called cathode. So out of these negative and positive electrodes, identify which is cathode and which is anode.

In the electrolysis of the following electrolytes can you find out the elements deposited at cathode and anode?

Electrolyte	Cathode	Anode
molten NaCl	Na	Cl ₂
molten KBr		
H ₂ O		
molten CaCl ₂		

Table 4.4

Electrolysis of aqueous solutions

Allow electricity to pass through aqueous solution of sodium chloride. Identify the gases that are formed at the two electrodes. The chemical decomposition is as follows:



Two kinds of positive ions and two kinds of negative ions are formed here.

- Which ions will move towards the cathode?
- Towards which electrodes will Cl⁻ and OH⁻ ions move?
- Will the oxidation and reduction tendencies of the two ions that reach a particular electrode be the same? Why?

- Between Na^+ and H^+ ions, which one has a greater tendency to get reduced? Find out from the electrochemical series.
- Out of Cl^- and OH^- ions, if Cl^- ion has a greater tendency to get oxidised; write the reaction at the anode.

Now you can tell why hydrogen and chlorine are deposited during the electrolysis of aqueous sodium chloride solution.

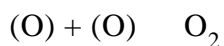
Can you predict the electrolytic products of CuSO_4 solution?



- Between Cu^{2+} and H^+ ions, which one has a greater reduction tendency?
- OH^- ion has greater tendency to get oxidised than SO_4^{2-} ions. Hence the following reaction occurs at the anode.



As 'OH' groups are not stable, they combine to form water and oxygen atom. Two oxygen atoms join to form O_2 gas.



Faraday's law of electrolysis

You found that substances are deposited at anode and cathode as a result of electrolysis. Is there any relation between the mass of substance deposited and the quantity of electricity that is passed through the electrolyte?

Given in the table below are the results observed when electricity is passed through copper sulphate solution.

Sl. No.	Quantity of current passed (Coulomb)	Amount of copper deposited (g)
1	5400	1.78
2	13500	4.45
3	27000	8.90

What is the relation between quantity of electricity and the mass of copper? When the quantity of electricity is increased, the amount of copper deposited also increases. i.e., they are directly proportional.

The above relationship was first stated by Faraday. Hence it is known as Faraday's law of electrolysis.

If 'q' is the quantity of electricity and 'm', the mass of substance deposited then the above relation can be mathematically expressed as $m \propto q$

$$m = \text{a constant } q$$

$$= z \quad q$$

'z' is the amount of substance deposited when one coulomb electricity is allowed to pass through.

- When 9650 coulomb current was passed through copper sulphate solution, 3.18 g copper was deposited. What is the 'z' value of copper?

$$\text{Quantity of electricity (q)} = 9650 \text{ coulomb}$$

$$\text{Mass of copper (m)} = 3.18 \text{ g}$$

$$m = zq$$

$$z = \frac{3.18}{9650}$$

$$= 0.0003295 \text{ g/coulomb}$$

- The 'z' value of an element is 0.00025 g/coulomb. How much element is deposited when 500 coulomb electricity is passed through?

SUMMARY

- Electrochemical cell is a device in which chemical energy is converted to electrical energy and electrical energy into chemical energy.
- The electrode potential of an element is the tendency of an element to lose or gain electrons when it is in contact with a solution containing its own ion.
- Single electrode potential cannot be measured. But potential difference between two points can be measured.
- The hydrogen electrode under the standard conditions (1 atm pressure, 1 M concentration, 298 K) is called standard hydrogen electrode (SHE). Electrode potential of SHE is arbitrarily fixed as zero.
- The electrode potential of other electrodes can be calculated by taking SHE as reference electrode.
- The e.m.f. of a cell is the difference between the electrode potentials of the electrodes.
- The electrode at which oxidation takes place is anode and that at which reduction takes place is cathode.
- The arrangement of elements in the ascending order of their reduction potential is called the electrochemical series.
- Electrolytes are substances that decompose into oppositely charged ions, while in molten state or in solution and conduct electricity.
- The mass of substances deposited at the electrodes will be directly proportional to the quantity of electricity that is passed through the electrolyte. This is the Faraday's law of electrolysis.

MORE ACTIVITIES FOR YOU

- The electrodes A, B, C, D and E have potentials -2.78 , -1.75 , -0.81 , $+0.34$, $+0.80$ respectively. Find out the anode, cathode and cell e.m.f. of the cells formed by the following pairs of electrodes.
(a) A - C (b) B - D (c) C - E (d) A - D
- If a solution containing chloride and fluoride ions is subjected to electrolysis, which ion will change into element? Why?
- Electrolysis is a redox reaction. Explain.
- Find out the practical applications of electrolysis.
- Find out which cells are used in calculator, watch etc.
- When copper sulphate solution is electrolysed using Pt electrodes, oxygen is given out at the anode. Explain the reaction that occurs here.
- When the various electrodes in the table given below are connected through external circuit, find out at which electrodes do oxidation and reduction take place, on the basis of electrochemical series.

Electrodes connected through external circuit	Oxidation	Reduction
Zn electrode - Fe electrode		
Ni electrode - Sn electrode		
Al electrode - Cu electrode		

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