

CHAPTER - 13

ELECTROCHEMISTRY

SYNOPSIS

1. Electrolytes and Electrolysis

A substance which decomposes as a result of the passage of electric current is called an **electrolyte** and phenomenon of decomposition by electricity is called **electrolysis**.

2. Electrolytic cell: The apparatus used to carry out electrolysis is known as electrolytic cell.

3. Faradays Laws of Electrolysis

I) First Law: The amount of the substance deposited or liberated at an electrode is directly proportional to the quantity of electricity passed through an electrolyte.

$$W \propto I \times t = I \times t \times Z = Q \times Z$$

I = Current strength in amp., t = time in secs., Q = Quantity of charge (coulombs)

Z is a constant known as Electrochemical equivalent

When $I = 1$ amp., $t = 1$ sec. then $Q = 1$ coulomb, then $w = z$. **Thus electrochemical equivalent is the amount of the substance deposited or liberated by 1 ampere current passing for 1 second (i.e. 1 coulomb, $1 \times t = Q$)**

II Second Law: When the same quantity of electricity is passed through different electrolytes, the amounts of the products obtained at the electrodes are directly proportional to their chemical equivalents or equivalent weights. Thus

4. One Faraday: $E \propto Z$; $E = FZ$. F = Known as Faraday

One Faraday is the quantity of charge carried by one mole of electrons.

$$1F = 1.6023 \times 10^{-19} \times 6.023 \times 10^{23} = 96500 \text{ Coulombs}$$

5. Amount of the substance m liberated or deposited at an electrode

$$m = \frac{\text{Eq. wt of the Sub.} \times I \times t}{96500} = \frac{\text{Eq. wt} \times Q}{96500}$$

6. Comparison of Electrolytic and Metallic conductors

Metallic conduction

- 1) due to movement of electrons
- 2) No transfer of matter
- 3) No change in chemical property

Electrolytic conductor

- due to movement of ions
- there is transfer of matter
- there is chemical change

4) decreases with increase of temperature increases with increase of temperature

7. **Factors affecting electrolytic conduction:** Inter ionic attraction, viscosity, temperature, solvation of ions etc.

8. **Ohm's Law:** The potential difference across the conductor is directly proportional to the current flowing through it.

Potential difference \propto current

$V \propto I$; $V = RI$; where R is a constant known as resistance of the conductor

$R = \frac{V}{I}$ units. Law is applicable to metallic as well as electrolytic conductors. R is expressed in Ohms. It is also designated as Ω .

9. **Resistance (R):** It offers obstruction to the passage of electric current. It is directly proportional to the length (l) and inversely proportional to the area of cross section (a) of the conductor.

$R \propto \frac{l}{a} = \rho \times \frac{l}{a}$ where ρ is constant, called **resistivity or specific resistance**

when $l = 1\text{cm}$ and $a = 1\text{cm}^2$ then $\rho = R$

10. **Specific Resistance (ρ):** The resistance offered by 1cm^3 of the conductor is known as specific

resistance. Units of $\rho = \frac{Ra}{l} = \frac{\text{Ohm} \times \text{cm}^2}{\text{cm}} = \text{Ohm cm}$ or $\Omega \text{ cm}$

11. **Conductance (C):** It is ease of flow of electric current through the conductor and reciprocal of resistance R.

$C = \frac{1}{R}$ units ohm^{-1} , mhos or Ω^{-1}

12. **Specific Conductivity (κ kappa):** It is the reciprocal of specific resistance

$\kappa = \frac{1}{\rho} = \frac{l}{Ra} = C \times \frac{l}{a} = C \times \text{cell constant} \left(\frac{l}{a} = \text{cell constant} \right)$

Hence specific conductivity κ (Kappa) = conductance \times cell constant

Units $\kappa = \text{Ohm}^{-1} \text{cm}^{-1} = \Omega^{-1} \text{cm}^{-1}$ ($\Omega^{-1} = \text{S}$ Seimens)

13. **Effect of dilution on conductance:** The number of current carrying particles or ions per ml decreases on dilution and specific conductivity, being the conductance of one centimetre cube of solution, decreases with dilution.

14. **Cell constant and its determination:** The quantity $\frac{l}{a}$ is known as cell constant. Its direct measurement is very difficult. It is measured by using standard solution of KCl whose conductivity is known at specific conductance of KCl solutions.

Hence cell constant = $\frac{\text{specific conductance}}{\text{measured conductance}}$

15. **Equivalent conductivity (Λ_{eq}):** The conductivity of all the ions produced when 1 gram equivalent of an electrolyte is dissolved in V ml of solution is known as equivalent conductivity.

16. **Relation between equivalent conductivity (Λ_m) and specific conductivity (κ)**

$\Lambda_{eq} = \kappa \times V = \kappa \cdot \frac{1000}{N}$ where V is the volume in cm³ or ml containing 1g eq. of the electrolyte

17. **Units of equivalent conductivity:** Ohm⁻¹ cm² eq⁻¹

18. **Effect of dilution on equivalent conductivity:** Since the degree of dissociation of the electrolyte increases with dilution, the equivalent conductivity also increases. The increase is more in case of weak electrolytes than strong electrolytes.

The equivalent conductivity increases and specific conductivity decreases

19. **Molar Conductivity (Λ_m):** The conductivity of all the ions produced when 1 mole of an electrolyte is dissolved in V ml of solution is known as molar conductivity.

20. **Relation between Molar conductivity (Λ_m) and specific conductivity (κ):**

$\Lambda_m = \kappa \cdot V = \kappa \cdot \frac{1000}{M}$ where V is the volume in cm³ or ml containing 1 mole of the electrolyte

Units of molar conductivity (Λ_m): ohm⁻¹ cm² mol⁻¹

Effect of dilution on Molar conductivity: Since the degree of dissociation of electrolyte increases with dilution, Λ_m also increases but less in case of strong electrolytes and more in case of weak electrolytes.

21. **Debye - Huckel Onsagar equation:** Relation between molar conductivity Λ_m at a particular concentration and molar conductivity at infinite dilution Λ_m^∞ is given by $\Lambda_m^c = \Lambda_m^\infty - b\sqrt{C}$ where b is constant. It depends upon nature of solvent and temperature.

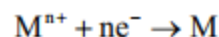
22. **Degree of dissociation (α):** For weak electrolytes is given by

$$\alpha = \frac{\Lambda_m^c}{\Lambda_m^\infty} = \frac{\text{Molar conductivity at a given concentration}}{\text{Molar conductivity at infinite dilution}}$$

23. **Kohlrausch's law:** At infinite dilution the molar conductivity of an electrolyte is the sum of the ionic conductivities of the cations and anions. e.g. for A_xB_y .

$$\Lambda_m^\infty(A_xB_y) = x\lambda_+^\infty + y\lambda_-^\infty$$

24. **Nernst Equation for Electrode Potential :** The relationship between the concentration of ions and electrode potential is given by Nernst equation.



$$E = E^0 + \frac{2.303RT}{nF} \log[M^{n+}] = E^0 + \frac{.059}{n} \log[M^{n+}]$$

- 25. Nernst equation for cell potential :** Consider a general cell reaction involving n electrons



$$E = E^0 + \frac{2.303RT}{nF} \log \frac{[A][B]}{[C][D]}$$

- 26. Nernst equation and equilibrium constant (K_c) :** When E_{cell} drops to zero the concentration of ions will be equilibrium concentrations. We have for general cell reaction.



$$E_{\text{cell}}^0 = \frac{2.303RT}{nF} \log K_c$$

According to Gibbs and Helmholtz, the decrease of free energy (ΔG) of the reaction occurring in the cell is equal to electrical energy

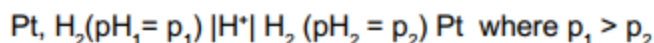
Hence $-\Delta G = nFE = \text{Electrical work done}$

The standard free energy and E_{cell}^0 are related as $\Delta G^0 = -nFE_{\text{cell}}^0$

- 27. Relationship between free energy change and equilibrium constant :** $\Delta G^0 = -2.303RT \log K_c$

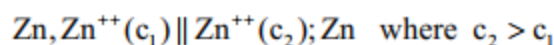
- 28. Concentration Cells :** They are of two types

(I) Electrode Concentration Cells : Two electrodes of different concentrations are dipped in the same solution of electrolyte e.g.



$$E_{\text{cell}} = \frac{2.303RT}{nF} \log \frac{p_1}{p_2}$$

(II) Electrolyte concentration cells : Electrodes are the same but electrolyte solutions have different concentrations eg.



$$E_{\text{cell}} = \frac{2.303}{nF} RT \log \frac{c_2}{c_1} = \frac{0.0591}{n} \log \frac{c_2}{c_1}$$

- 29. Some commercial cells and their types :** They are broadly classified into two groups.

(I) Primary cells : They cannot be recharged and used again/ Examples are

(a) Dry cell or Leclanche cell : Particulars are

Anode - Zinc Container

Cathode - graphite rod surrounded by MnO_2 powder

Electrolyte - paste of $\text{NH}_4\text{Cl} + \text{ZnCl}_2$

Cathode Reaction : $\text{MnO}_2 + \text{NH}_4^+ + \text{e}^- \rightarrow \text{MnO}(\text{OH}) + \text{NH}_3$

Anode reaction : $\text{Zn} - 2\text{e}^- \longrightarrow \text{Zn}^{2+}$

Overall reaction : $\text{Zn}^{2+} + 2\text{NH}_3 \rightarrow [\text{Zn}(\text{NH}_3)_2]^{2+}$

Cell potential : 1.25 to 1.5 V

(II) Secondary cells : Can be recharged and can be used again and again. Examples

(a) Lead Storage battery :

Anode - Spongy lead

Cathode - grid of lead packed with PbO_2

Electrolyte - 38% H_2SO_4 by mass

Anode Reaction : $\text{Pb} + \text{SO}_4^{2-} \rightarrow \text{PbSO}_4 + 2\text{e}^-$

Cathode Reaction : $\text{PbO}_2 + \text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^- \rightarrow \text{PbSO}_4 + 2\text{H}_2\text{O}$

Net Reaction : $\text{Pb} + \text{PbO}_2 + 4\text{H}^+ + 2\text{SO}_4^{2-} \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O}$

When recharged, the cell reactions are reversed

- 30. Fuel Cells** : They convert chemical energy into electrical energy. The reactants are continuously fed and products are removed.

(a) Hydrogen-Oxygen-Fuel Cell : Electrodes - made of porous graphite impregnated with catalyst (Pt, Ag or a metal oxide).

Electrolyte : Aqueous solution of KOH or NaOH

Oxygen and hydrogen are continuously fed into the cell.

Oxidation Half-cell Reaction: $\text{H}_2 + 2\text{OH}^- \rightarrow 2\text{H}_2\text{O} + 2\text{e}^-$

Reduction Half-cell Reaction: $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$

Net Reaction: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

EMF of the cell : 1 volt

- 31. Corrosion** : Slow formation of undesirable compounds such as oxides, sulphides or carbonates at the surface of metals by reaction with moisture and other atmospheric gases is known as corrosion.

Factors affecting corrosion :

(I) Reactivity of metals

(II) Presence of moisture and atmospheric gases like CO_2 , SO_2 etc

(III) Presence of impurities

(IV) Strains in the metal

(V) Presence of electrolyte

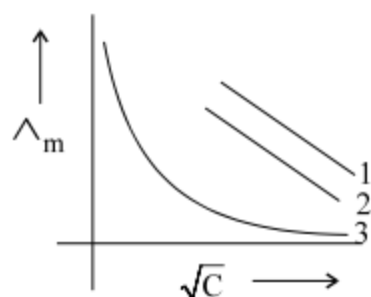
32. Prevention of corrosion :

- (I) Barrier protection : By painting, coating, electroplating
- (II) Sacrificial protection : By galvanization, Sheraridising
- (III) Electrical protection
- (IV) Use of anti-rust compounds

PART-I (JEE MAIN)**SECTION-I- Straight objective type questions**

- Which of the following statements is true for the Daniell cell?
 - Electrons flow from copper electrode to zinc electrode
 - Current flows from zinc electrode to copper electrode
 - Cations move towards copper electrode
 - Cations move towards zinc electrode
- The standard reduction potential for two half reactions are given below
 $\text{Zn}^{2+} + 2\text{e}^- \longrightarrow \text{Zn}; E^\circ = -0.76 \text{ V}$
 $\text{Fe}^{2+} + 2\text{e}^- \longrightarrow \text{Fe}; E^\circ = -0.44 \text{ V}$
 The emf for the cell reaction, $\text{Fe}^{2+} + \text{Zn} \rightarrow \text{Zn}^{2+} + \text{Fe}$ is
 1) -0.32 V 2) $+0.32 \text{ V}$ 3) $+1.17 \text{ V}$ 4) -1.17 V
- Consider the reaction, $\text{Zn(s)} + \text{Cl}_2(1 \text{ atm}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq})$. E°_{cell} for this cell is 2.12 V . To increase the cell potential,
 - $[\text{Zn}]$ should be decreased
 - $[\text{Zn}^{2+}]$ should be decreased
 - $[\text{Cl}^-]$ should be increased
 - P_{Cl_2} should be decreased
- Assertion:** For a cell reaction $\text{Zn(s)} + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{Cu(s)}$, at equilibrium, voltmeter gives zero reading.
Reason: At the equilibrium, there is no change in the concentration of Cu^{2+} and Zn^{2+} ions.
 Choose the correct option:
 - Both assertion and reason are true and reason is the correct explanation of assertion.
 - Both assertion and reason are true but reason is not the correct explanation of assertion.
 - Assertion is true but reason is false.
 - Assertion is false but reason is true.
- For a cell reaction involving a two-electron transfer, the standard emf of the cell is found to be 0.295 V at 25°C . The equilibrium constant of the reaction at 25°C will be
 - 1×10^{-10}
 - 29.5×10^{-2}
 - 10
 - 1×10^{10}

6. A graph of molar conductivity of three electrolytes (NaCl, HCl, NH_4OH) is plotted against \sqrt{C} . Identify the electrolytes (C = molar concentration)



- | | 1 | 2 | 3 |
|----|------------------------|------|------------------------|
| 1) | NaCl | HCl | NH_4OH |
| 2) | NH_4OH | NaCl | HCl |
| 3) | HCl | NaCl | NH_4OH |
| 4) | NH_4OH | HCl | NaCl |
7. Following limiting molar conductivities are given as

$$\Lambda_{m(\text{H}_2\text{SO}_4)}^0 = x \text{ Scm}^2 \text{mol}^{-1}$$

$$\Lambda_{m(\text{K}_2\text{SO}_4)}^0 = y \text{ Scm}^2 \text{mol}^{-1}$$

$$\Lambda_{m(\text{CH}_3\text{COOK})}^0 = z \text{ Scm}^2 \text{mol}^{-1}$$

$$\Lambda_m^0 (\text{in } \text{Scm}^2 \text{mol}^{-1}) \text{ for } \text{CH}_3\text{COOH} \text{ will be}$$

- 1) $x - y + 2z$ 2) $x + y - z$ 3) $x - y + z$ 4) $\frac{(x - y)}{2} + z$
8. The correct expression for dissociation constant of acetic acid in terms of molar conductivity is (C = molar concentration)

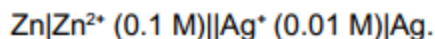
1) $K_a = \frac{C \Lambda_m^2}{\Lambda_m^0 - \Lambda_m}$ 2) $K_a = \frac{C (\Lambda_m^0)^2}{\Lambda_m (\Lambda_m^0 - \Lambda_m)}$ 3) $K_a = \frac{C \Lambda_m^2}{\Lambda_m^0 (\Lambda_m^0 - \Lambda_m)}$ 4) $K_a = \frac{C (\Lambda_m^0)^2}{\Lambda_m - \Lambda_m^0}$

9. Three faraday of electricity are passed through molten Al_2O_3 , aqueous solution of CuSO_4 and molten NaCl taken in different electrolytic cells. The amount of Al, Cu and Na deposited at the cathodes will be in the ratio of
- 1) 1 mole : 2 mole : 3 mole 2) 3 mole : 2 mole : 1 mole
 3) 1 mole : 1.5 mole : 3 mole 4) 1.5 mole : 2 mole : 3 mole

10. On electrolysis, in which of the following, O_2 would not be liberated at the anode?
- dilute H_2SO_4 with Pt electrodes
 - aqueous $AgNO_3$ solution with Pt electrodes
 - aqueous $CuCl_2$ solution with Pt electrodes
 - aqueous $CuSO_4$ with Pt electrodes
11. In a dry cell, at cathode, the oxidation state of manganese decreases from +x to +y. The value of x and y are respectively
- 4, 2
 - 6, 3
 - 4, 3
 - 3, 2
12. When lead storage battery is charged
- Lead dioxide dissolves
 - Sulphuric acid is regenerated
 - The lead electrode becomes coated with lead sulphate
 - The amount of sulphuric acid decreases

SECTION-II - Numerical Type Questions

13. EMF of the following cell at 298 K in V is $x \times 10^{-2}$.



The value of x is $\left[\text{Given : } E_{Zn^{2+}/Zn}^0 = -0.76V, E_{Ag^+/Ag}^0 = 0.80 V, \frac{2.303 RT}{F} = 0.059 \right]$

14. Given that the standard electrode potential of Cu^{2+}/Cu and Cu^+/Cu are 0.34 V and 0.522 V respectively. The standard potential of Cu^{2+}/Cu^+ is $\times 10^{-2}$ V
15. The resistance of conductivity cell containing 0.01 M KCl solution at 298 K is 1750Ω . If the conductivity of 0.01 M KCl solution at 298 K is $0.152 \times 10^{-3} S cm^{-1}$, then the cell constant of the conductivity cell is $\times 10^{-3} cm^{-1}$
16. The potential of a hydrogen electrode decreases by $x \times 10^{-2}$ V, when its solution initially at pH = 0 is neutralised to pH = 7. The value of x is $\left[\text{Given : } \frac{2.303 RT}{F} = 0.059, P_{H_2} = 1 \text{ bar} \right]$

PART-II (JEE ADVANCED)

Section-III - Only one option correct type

17. The specific conductance of a saturated solution of AgCl is $3.4 \times 10^{-6} S cm^{-1}$ at $25^\circ C$. If $\lambda(Ag^+) = 62.3 S cm^2 mol^{-1}$ and $\lambda(Cl^-) = 67.7 S cm^2 mol^{-1}$, solubility of AgCl at $25^\circ C$ will be
- $2.6 \times 10^{-5} M$
 - $1.7 \times 10^{-5} M$
 - $3.7 \times 10^{-5} M$
 - $3.7 \times 10^{-3} M$
18. When a concentrated solution of an electrolyte is diluted:
- its specific conductance decreases but equivalent conductance increases
 - its specific conductance increases but equivalent conductance decreases
 - both specific conductance and equivalent conductance increases
 - both specific conductance and equivalent conductance decreases

19. The emf of the cell $\text{Pt(s)} | \text{H}_2(\text{g}, 1 \text{ atm}) | \text{HA}(0.01 \text{ M}) || \text{HCl}(1 \text{ M}) | \text{H}_2(\text{g}, 1 \text{ atm}) | \text{Pt(s)}$ is 0.295 V. Dissociation constant of the acid HA would be
 A) 1×10^{-4} B) 1×10^{-6} C) 1×10^{-8} D) 1×10^{-5}
20. When a certain aqueous solution was electrolysed with Pt electrodes, the pH of the solution was found not to change. The solution would be that of :
 A) AgNO_3 B) NaCl C) CuSO_4 D) KNO_3
21. If reduction potential of Cu^{2+}/Cu couple is 0.1335 V in a saturated solution of $\text{Cu}(\text{OH})_2$, the pH of solution will be (Given : Standard reduction potential of Cu^{2+}/Cu couple is 0.34 V; K_{sp} of $\text{Cu}(\text{OH})_2$ is 1×10^{-19})
 A) 6 B) 8 C) 12 D) 11

Section IV - One or more option correct type

22. A blue colour can be observed in the solution when:
 A) Cu electrode is placed in AgNO_3 solution
 B) Cu electrode is placed in ZnSO_4 solution
 C) Cu electrode is placed in dil HNO_3
 D) Cu electrode is placed in NiSO_4 solution
23. Equal quantity of electricity is passed through three electrolytic cells containing aqueous solutions of FeSO_4 , $\text{Fe}_2(\text{SO}_4)_3$ and $\text{Fe}(\text{NO}_3)_3$ respectively. Regarding the electrolytic process, which of the following is/are correct? (Assume that only iron is reduced at the cathode).
 A) The amount of iron deposited in three cases are equal
 B) The amount of iron deposited in $\text{Fe}_2(\text{SO}_4)_3$ and $\text{Fe}(\text{NO}_3)_3$ are equal
 C) Same gas is evolved at anode in all three cases
 D) Amount of iron deposited in $\text{Fe}_2(\text{SO}_4)_3$ is double that in case of $\text{Fe}(\text{NO}_3)_3$
24. Select the correct relation(s) from the following

$$\begin{array}{ll} \text{A) } \Delta S^0 = \left(\frac{\partial E^0}{\partial T} \right)_P \times nF & \text{B) } \Delta S^0 = - \left(\frac{\partial E^0}{\partial T} \right)_P \times nF \\ \text{C) } \left(\frac{\partial E^0}{\partial T} \right)_P = \left(\frac{\partial \Delta S^0}{\partial T} \right)_P & \text{D) } E^0 = - \frac{\Delta H^0}{nF} + T \left(\frac{\partial E^0}{\partial T} \right)_P \end{array}$$

25. Which of the following statements is/are correct?

(Use: $E^0_{\text{Cu}^{2+}/\text{Cu}} = 0.34 \text{ V}$, $E^0_{\text{Sn}^{2+}/\text{Sn}} = -0.14 \text{ V}$ and $E^0_{\text{H}^+/\text{H}_2} = 0.0 \text{ V}$)

- A) Cu^{2+} ions can be reduced by H_2
 B) Cu can be oxidized by H^+
 C) Sn^{2+} ions can be reduced by H_2
 D) Sn can be oxidized by H^+

26. 2 amperes of current is passed for 16 min and 5 seconds through 1000 ml of 2 molar aqueous solution of CuSO_4 using Pt electrodes. Then
- A) 1.204×10^{22} electrons are passed through the cell
- B) 0.635 g of Cu is deposited at cathode
- C) 1.204×10^{23} electrons are passed through the cell
- D) 1.27 g of Cu is deposited at cathode

Section V - Numerical type questions

27. Conductivity of 0.02 M KCl at 25°C is $4 \times 10^{-3} \text{ ohm}^{-1} \text{ cm}^{-1}$. The resistance of this solution at 25° when measured with a particular cell was 200 ohms. The resistance of 0.01 M CuSO_4 at 25°C measured with the same cell was 8×10^3 ohms. What is molar conductivity of the copper sulphate solution (in $\text{ohm}^{-1} \text{ cm}^2 \text{ mol}^{-1}$) at 25°C ?
28. The cell potential for $\text{Zn} | \text{Zn}^{2+}_{(\text{aq})} || \text{Sn}^{2+} | \text{Sn}$ is 0.801 V at 298 K. The reaction quotient for the reaction is 10^{-2} . The number of electrons involved in the given electrochemical cell reaction is _____

$$\left(\text{given } E^0_{\text{Zn}^{2+}/\text{Zn}} = -0.763 \text{ V } E^0_{\text{Sn}^{2+}/\text{Sn}} = +0.008 \text{ V } \& \frac{2.303 RT}{F} = 0.06 \text{ V} \right)$$

Section-VI - Matrix match type

29. Match the following

Column-I (Reduction process)

I) 1 mole of MnO_4^- to Mn^{2+}

II) 1 mole of $\text{Cr}_2\text{O}_7^{2-}$ to Cr^{3+}

III) 1 mole of Sn^{4+} to Sn^{2+}

IV) 1 mole of Al^{3+} to Al

A) $\text{I} \rightarrow \text{R}; \text{II} \rightarrow \text{Q}; \text{III} \rightarrow \text{P}; \text{IV} \rightarrow \text{Q}$

C) $\text{I} \rightarrow \text{R}; \text{II} \rightarrow \text{S}; \text{III} \rightarrow \text{P}; \text{IV} \rightarrow \text{Q}$

Column-II (Charge required)

P) 193000 C

Q) 289500 C

R) 482500 C

S) 579000 C

B) $\text{I} \rightarrow \text{P}; \text{II} \rightarrow \text{Q}; \text{III} \rightarrow \text{R}; \text{IV} \rightarrow \text{S}$

D) $\text{I} \rightarrow \text{P}; \text{II} \rightarrow \text{S}; \text{III} \rightarrow \text{R}; \text{IV} \rightarrow \text{S}$

30. Match the following

Column-I (Cell)

I) $\text{Pt} | \text{H}_2(0.1 \text{ bar}) | \text{H}^+(0.1 \text{ M}) || \text{H}^+(1 \text{ M}) | \text{H}_2(1 \text{ bar}) | \text{Pt}$

II) $\text{Ag} | \text{AgCl} | \text{KCl} (0.1 \text{ M}) || \text{Ag}^+(0.01 \text{ M}) | \text{Ag}$

III) $\text{Cu} | \text{Cu}^{2+}(0.1 \text{ M}) || \text{Cu}^{2+}(0.01 \text{ M}) | \text{Cu}$

IV) $\text{Pt} | \text{Cl}_2(1 \text{ bar}) | \text{HCl}(0.1 \text{ M}) || \text{NaCl}(0.1 \text{ M}) | \text{Cl}_2(1 \text{ bar}) | \text{Pt}$

A) $\text{I} \rightarrow \text{PR}; \text{II} \rightarrow \text{PQR}; \text{III} \rightarrow \text{PS}; \text{IV} \rightarrow \text{S}$

B) $\text{I} \rightarrow \text{PQR}; \text{II} \rightarrow \text{PQR}; \text{III} \rightarrow \text{PS}; \text{IV} \rightarrow \text{PS}$

C) $\text{I} \rightarrow \text{PQ}; \text{II} \rightarrow \text{PQ}; \text{III} \rightarrow \text{PS}; \text{IV} \rightarrow \text{S}$

D) $\text{I} \rightarrow \text{PQR}; \text{II} \rightarrow \text{Q}; \text{III} \rightarrow \text{PS}; \text{IV} \rightarrow \text{PS}$

Column-II (Feature)

P) Concentration cell

Q) $E_{\text{cell}} > 0$

R) $E_{\text{cell}}^0 = 0$ but cell is working

S) Non working condition