Engineering Chemistry (DI01000071)

Winter 2024 Exam Solutions

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Date of Exam: 09 January 2025

Exam Overview

Exam Details

Subject:	Engineering Chemistry
Code:	DI01000071
Date:	09-01-2025
Time:	10:30 AM – 01:00 PM
Marks:	70

Topics at a Glance

Q.2	Atomic structure, pH, Fuels
Q.3	Solutions, Bonding, Organics
Q.4	Corrosion, Lubrication, Cells
Q.5	Semiconductors, Polymers, Cells

Paper Structure

Q.1	14 Fill in blanks (1 mark each)
Q.2–5	(A) any 2 $\times$ 3 marks = 6 each
	(B) any 2 $\times$ 4 marks = 8 each

#	Key word	Ans	Option
1	Electronic config of $_{29}$Cu	**B**	$[Ar]4s^1 3d^{10}$
2	pH = ... − pOH	**C**	14
3	Pure Cu deposited on (electro-refining)	**B**	Cathode
4	Metal forming non-porous oxide	**B**	Mg
5	Peat is a ... fuel	**A**	Solid
6	Formula for calorific value	**C**	Dulong
7	Coal with highest moisture	**A**	Lignite

Quick Recall

- Cu: anomalous config — half-filled → fully filled 3d is extra stable
- pH + pOH = **14** at 25°C
- Electro-refining: pure metal at **cathode**
- **Mg** forms dense, non-porous MgO layer
- Peat: lowest-grade **solid** fuel, 80–90% moisture
- **Dulong's** formula: $CV = 33800C + 144000(H - O/8) + 9400S$ kJ/kg

Q.1 — Fill in the Blanks (8–14) [14 marks]

#	Key word	Ans	Option
8	Unit of viscosity	C	Poise
9	Flash point of lubricant	A	High
10	Oil + water mixture	B	Emulsion
11	Phenol-formaldehyde polymer	C	Bakelite
12	Used for vulcanisation	B	S
13	Biodegradable polymer	C	PHBV
14	Unit of EMF	C	Volt

Quick Recall

- Viscosity unit: **Poise** (CGS); SI unit: Pa·s
- Flash point must be **High** — safe at operating temp
- Oil + water emulsified = **Emulsion**
- **Bakelite** = phenol + formaldehyde (thermosetting)
- **Sulfur** (S) cross-links rubber chains in vulcanization
- **PHBV** (polyhydroxybutyrate-co-valerate) — biodegrades naturally
- EMF measured in **Volt** (V)

Q.2(A)(1) — Importance of pH in Various Fields [3 marks]

Field	pH Value	Significance
Agriculture	6.0 – 7.0	Optimal soil pH for crop growth; outside this range nutrients are unavailable
Medicine	Blood: 7.35 – 7.45	Slight deviation causes acidosis/alkalosis; enzymes need specific pH
Water Treatment	6.5 – 8.5	Safe drinking water range; extreme pH indicates contamination
Food Industry	3 – 5 (acidic)	Acidic pH (vinegar, citric acid) inhibits microbial growth
Industry	Controlled	Electroplating, dyeing, paper industries depend on precise pH control

Q.2(A)(2) — Definitions: Buffer, Half-cell, Faraday's First Law [3 marks]

Buffer Solution

A solution that **resists change in pH** when a small amount of acid or base is added.

Example: CH_3COOH + CH_3COONa (acidic buffer, pH 3.5–5.5)

Importance: Controls pH in biological systems, industrial processes.

Half-Cell

A **single electrode** in contact with a solution of its ions constitutes one half of an electrochemical cell.

Example: Zn rod in $ZnSO_4$ solution is a half-cell (Zn^{2+}/Zn).

Two half-cells connected = a complete galvanic cell.

Faraday's First Law

The **mass of a substance** deposited or dissolved at an electrode is **directly proportional** to the quantity of electricity (charge) passed through the electrolyte.

$$m = \frac{Q \cdot M}{n \cdot F} = \frac{I \cdot t \cdot M}{n \cdot F}$$

Q.2(A)(3) — Factors Affecting Rate of Corrosion [3 marks]

Physical/Environmental Factors

1. **Temperature** — Higher temperature increases ion mobility and reaction rate, accelerating corrosion.
2. **Humidity/Moisture** — Water acts as electrolyte; no moisture = no electrochemical corrosion.
3. **Presence of electrolytes** — Salt ($NaCl$) in water greatly increases corrosion rate by improving conductivity.

Metal/Chemical Factors

4. **Nature of metal** — More active (electropositive) metals corrode faster; impurities create local galvanic cells.
5. **pH of environment** — Acidic conditions ($pH < 7$) dissolve the oxide film and accelerate corrosion.
6. **Galvanic series position** — Greater EMF difference between two metals in contact $\rightarrow$ faster anodic corrosion.

Q.2(B)(1) — Orbits vs Orbitals [4 marks]

Point	Orbit	Orbital
Definition	Fixed circular/elliptical path of electron around nucleus (Bohr model)	Region in 3D space where probability of finding an electron is $\geq 90\%$
Nature	Well-defined, fixed path	Probability cloud / diffuse region
Shape	Circular or elliptical; 2D (flat)	Various 3D shapes: s (sphere), p (dumbbell), d, f
Heisenberg UP	Violates Uncertainty Principle (gives exact position and momentum)	Based on Uncertainty Principle
Max electrons	$2n^2$ (where n = orbit number)	Maximum 2 electrons per orbital
Concept	Bohr atomic model (1913)	Quantum mechanical model (Schrödinger, 1926)

Q.2(B)(2) — Classification of Fuels [4 marks]

Based on Source (Origin)

1. **Natural fuels** — Occur in nature without processing.
   Examples: Wood, coal, petroleum, natural gas
2. **Artificial (Derived) fuels** — Obtained by processing natural fuels.
   Examples: Coke, charcoal, LPG, kerosene, producer gas

Based on Physical State

1. **Solid fuels** — Coal, wood, coke, charcoal, peat
2. **Liquid fuels** — Petrol, diesel, kerosene, alcohol, fuel oil
3. **Gaseous fuels** — Natural gas, LPG, CNG, hydrogen, producer gas

Note

Gaseous fuels have highest calorific value per unit mass and cleanest combustion among the three types.

Q.2(B)(3) — Bio-Diesel [4 marks]

Definition & Production

Biodiesel is a renewable fuel derived from vegetable oils, animal fats, or waste cooking oil through **transesterification**.

Reaction:

$$\text{Vegetable oil} + CH_3OH \xrightarrow{\text{NaOH}} \text{FAME} + \text{Glycerol}$$

FAME = Fatty Acid Methyl Ester (= Biodiesel)

Blends

B5: 5% biodiesel + 95% diesel **B20**: 20% biodiesel
B100: Pure biodiesel

Four Important Points

1. **Renewable** — Made from plant/animal sources that can be replenished.
2. **Biodegradable** — Breaks down naturally in the environment.
3. **Low emissions** — Reduces CO, HC, and particulate emissions; higher flash point.
4. **No engine modification** — Can be used in existing diesel engines directly or as blend.

Q.3(A)(1) — Solute, Solvent and Solution [3 marks]

Solution

A **homogeneous mixture** of two or more substances that is uniform throughout.

Properties:

- Uniform composition
- Single phase
- Particles < 1 nm

Example: Saltwater, sugar in water

Solvent

The component present in **larger quantity** that **dissolves** the solute.

Properties:

- Larger amount
- Determines phase of solution
- "Like dissolves like"

Example: Water in saltwater

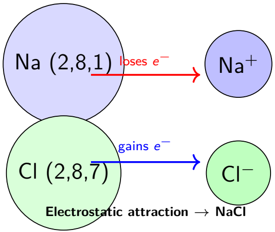
Solute

The component present in **smaller quantity** that gets **dissolved** in the solvent.

Properties:

- Smaller amount
- Can be solid, liquid or gas
- Distributed uniformly

Example: Salt (NaCl) in saltwater



Formation of Electrovalent (Ionic) Bond

An electrovalent bond is formed by the **complete transfer of electrons** from a metal atom to a non-metal atom, resulting in oppositely charged ions held together by electrostatic attraction.

In NaCl:

- Na: [2,8,1] → loses 1 electron → Na^+ [2,8]
- Cl: [2,8,7] → gains 1 electron → Cl^- [2,8,8]
- Electrostatic attraction: $Na^+ + Cl^- \longrightarrow NaCl$

Na: Group 1, loses 1e; Cl: Group 17, gains 1e. Both achieve noble gas configuration.

Q.3(A)(3) — Octane Number for Gasoline [3 marks]

Definition

Octane number (or octane rating) measures the **resistance of gasoline (petrol) to knocking** (pre-ignition) in a petrol engine.

Higher octane number = better anti-knock property = can withstand more compression before igniting.

Reference Fuels

iso-Octane (2,2,4-trimethylpentane): ON = 100
n-Heptane: ON = 0

Octane number = % iso-octane in a mixture with n-heptane having the same knock resistance as the test fuel.

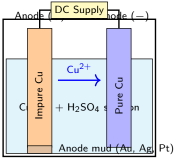
Significance

- Regular petrol: ON 87–88
- Premium petrol: ON 91–93
- High-performance engines require higher ON fuel
- Branched-chain and aromatic compounds have higher ON
- n-paraffins have low ON; branched/cyclic have high ON

Improvement

Tetraethyl lead (TEL) was used as anti-knock additive; now replaced by MTBE, ethanol.

Q.3(B)(1) — Electrorefining of Impure Copper (1/2) [4 marks]



Principle & Setup

Electrorefining purifies impure metal using electrolysis.

Anode:	Impure copper
Cathode:	Pure copper (thin sheet)
Electrolyte:	$CuSO_4 + H_2SO_4$ solution

Key Points

- Impure Cu **anode dissolves**; pure Cu at cathode
- Zn, Fe dissolve but **don't deposit** at cathode
- Au, Ag, Pt $\rightarrow$ **anode mud** (by-product)
- Final purity $\geq$ **99.99%** Cu

Q.3(B)(1) — Electrorefining of Impure Copper (2/2) [4 marks]

Chemical Reactions

At Anode (dissolution):

$$Cu \longrightarrow Cu^{2+} + 2\,e^-$$

At Cathode (deposition):

$$Cu^{2+} + 2\,e^- \longrightarrow Cu$$

Advantages

- Very high purity ($\geq 99.99\%$) copper obtained
- Noble metals (Au, Ag, Pt) recovered from anode mud
- Continuous process, easy to scale up
- Used for electrical grade copper (wires, cables)

Note

Active impurity ions (Zn^{2+}, Fe^{2+}) stay in solution and are removed by periodically replacing the electrolyte.

Preparation (Dehydration of Ethanol)

Reagents: Ethanol + Conc. H_2SO_4, 170°C

$$C_2H_5OH \xrightarrow[\Delta]{H2SO4} CH_2{=}CH_2 + H_2O$$

Alternative: Dehydration over Al_2O_3 at 360°C; or cracking of ethane: $C_2H_6 \xrightarrow{\Delta} CH_2{=}CH_2 + H_2$

Note

Ethene (ethylene, $CH_2{=}CH_2$) is the simplest alkene, containing one C=C double bond. It is an important petrochemical feedstock.

Properties

1. **Colorless gas** with a faint sweet odor; slightly lighter than air.
2. **Flammable** — burns with a slightly luminous flame: $C_2H_4 + 3\,O_2 \longrightarrow 2\,CO_2 + 2\,H_2O$

Uses

1. **Manufacture of polyethylene** (LDPE/HDPE) by addition polymerization.
2. **Production of ethanol, styrene, ethylene oxide** and other important chemicals.

Q.3(B)(3) — Preparation of Buna-S Rubber [4 marks]

Preparation (Copolymerization)

Full name: Butadiene-Styrene Rubber (SBR/GRS)

Monomers: 1,3-Butadiene (75%) + Styrene (25%)

Method: Emulsion polymerization (free radical mechanism)

$$nCH_2{=}CH{-}CH{=}CH_2 + nC_6H_5{-}CH{=}CH_2 \xrightarrow{\text{Na, emulsion}} \text{Buna-S (SBR)}$$

Buna = Butadiene + Na (sodium catalyst); *S* = Styrene

Properties

1. **Good abrasion and wear resistance** — better than natural rubber for tyre use.
2. **Higher heat resistance** than natural rubber; maintains properties at moderate temperatures.

Uses

1. **Automobile tyres** — most widely used synthetic rubber for this application.
2. **Shoe soles, conveyor belts, hoses** and other industrial rubber goods.

Q.4(A)(1) — Metal Cladding for Corrosion Prevention [3 marks]

Definition & Method

Metal cladding (bimetallism) is the process of permanently bonding a thin layer of a **corrosion-resistant metal** over a base metal to protect it from corrosion.

Methods of cladding:

1. **Hot rolling** — both metals rolled together under pressure at high temp.
2. **Pressure bonding** — metals pressed together using hydraulic pressure.
3. **Explosion bonding** — shock wave pressure joins metals.

Examples

- **Alclad** — Aluminium alloy core + pure Al outer layer (aircraft)
- **Copper-clad steel** — for coins and electrical contacts
- **Stainless steel-clad steel** — for chemical vessels
- **Lead-clad steel** — for acid storage equipment

Advantage

Combines **mechanical strength** of base metal with **corrosion resistance** of cladding metal — cost-effective protection.

Q.4(A)(2) — Waterline Corrosion [3 marks]

Definition

Waterline corrosion (differential aeration) occurs at the water surface due to different dissolved O_2 concentrations:

At waterline: high O_2 → **Cathode** (protected)
Below waterline: low O_2 → **Anode** (corrodes)

Chemical Reactions

Anode:

$$Fe \longrightarrow Fe^{2+} + 2\,e^-$$

Cathode:

$$O_2 + 2\,H_2O + 4\,e^- \longrightarrow 4\,OH^-$$

Rust formed:

$$Fe^{2+} + 2\,OH^- \longrightarrow Fe(OH)_2$$

$$4\,Fe(OH)_2 + O_2 \longrightarrow 2\,Fe_2O_3 \cdot H_2O$$

Q.4(A)(3) — Working Principle of Solar Cells [3 marks]

Principle

A **solar cell** converts sunlight to electricity using the **photovoltaic effect** at a **p-n junction** semiconductor (silicon).

Working Steps

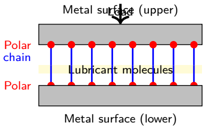
1. Photons hit p-n junction → **electron-hole pairs** created.
2. Built-in field **separates**: e^- to n-side, holes to p-side.
3. Connecting a load → **current flows** through the circuit.

Structure

n-type layer:	Donor-doped Si
p-type layer:	Acceptor-doped Si
p-n junction:	Charge separation zone
Electrodes:	Metal contacts (top/bottom)
Cell voltage:	$\approx$ 0.5 V per cell

Multiple cells connected in **series** (more voltage) or **parallel** (more current) form a solar panel.

Q.4(B)(1) — Boundary Lubrication [4 marks]



Definition

Boundary lubrication occurs when the load is **heavy** or speed is **slow** — a full fluid film cannot form. A thin **mono-molecular layer** adsorbed on surfaces prevents metal-to-metal contact.

Mechanism

- **Polar end** (–COOH, –OH) adsorbs onto metal surface
- **Non-polar tail** stands erect (cushion layer)
- Mono-layer prevents metal contact; reduces wear

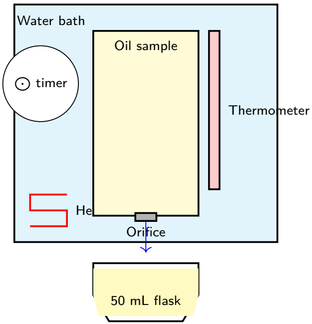
Q.4(B)(2) — Redwood Viscometer [4 marks]

Construction & Working

1. Oil sample placed in **inner cylinder**; heated by surrounding water bath to desired temperature.
2. When temperature stabilizes, the **stopper (plug) is removed** from the orifice at the bottom.
3. Oil flows through the calibrated orifice into a **50 mL measuring flask**.
4. Time (in seconds) for exactly **50 mL** of oil to collect is measured using a stopwatch.
5. This time (in **Redwood seconds**) represents the **kinematic viscosity** of the oil.

Types

Redwood No. 1: For thin/light oils (normal range).
Redwood No. 2: For heavy/thick oils.



Q.4(B)(3) — Definitions: Semiconductor, Insulator, Elastomer, Addition Polymerization [4 marks]

Semiconductor

A material with **electrical conductivity between a conductor and an insulator**, which increases with temperature or doping.

Example: Silicon (Si), Germanium (Ge), GaAs

Elastomer

A **polymer material** that shows **elastic behavior** — it can be stretched to several times its original length and returns to its original shape when the force is removed.

Example: Natural rubber, neoprene, silicone rubber

Insulating Material

A material with **very high electrical resistance** that prevents the flow of electric current.

Example: Rubber, glass, porcelain, PVC, mica, dry wood

Addition Polymerization

A type of polymerization in which monomers containing **C=C double bonds add to each other** repeatedly without elimination of any small molecule.

Example: $n CH_2{=}CH_2 \longrightarrow [-CH_2-CH_2-]_n$ (polyethylene)

Q.5(A)(1) — pH and pOH of 0.004 M HCl [3 marks]

Given

Concentration of HCl $= 0.004\,\text{M} = 4 \times 10^{-3}\,\text{M}$

$\log 4 = 0.6021$ (given)

Theory

HCl is a **strong acid** — fully dissociates:

$HCl \longrightarrow H^+ + Cl^-$

$[H^+] = [HCl] = 4 \times 10^{-3}\,\text{M}$

$\text{pH} = -\log[H^+]$ and $\text{pOH} = 14 - \text{pH}$

Solution

Step 1: Find pH

$$\begin{aligned}\text{pH} &= -\log(4 \times 10^{-3}) \\ &= -(\log 4 + \log 10^{-3}) \\ &= -(0.6021 - 3) \\ &= -(-2.3979)\end{aligned}$$

$$\boxed{\text{pH}}\boxed{= 2.40}$$

Step 2: Find pOH

$$\text{pOH} = 14 - \text{pH} = 14 - 2.40$$

$$\boxed{\text{pOH}}\boxed{= 11.60}$$

Since $\text{pH} = 2.40 < 7$, the solution is **acidic**.

Q.5(A)(2) — Extrinsic Semiconductors [3 marks]

Definition

Extrinsic semiconductors are **impure semiconductors** obtained by adding controlled amounts of impurity atoms (**dopants**) to a pure semiconductor to increase conductivity.

Process: Doping — adding impurities to Si or Ge lattice.
Types: n-type and p-type

n-type Semiconductor

Doped with **pentavalent** (Group 15) impurity (P, As, Sb).
Extra electron from impurity atom becomes a free electron.
Majority carriers: Electrons (e^-)
Example: Si doped with Phosphorus (P)

p-type Semiconductor

Doped with **trivalent** (Group 13) impurity (B, Al, In).
Missing electron creates a **hole** in the lattice.
Majority carriers: Holes (h^+)
Example: Si doped with Boron (B)

Q.5(A)(3) — Thermoplastic vs Thermosetting Polymers [3 marks]

Point	Thermoplastic Polymers	Thermosetting Polymers
Effect of heat	**Softens** on heating; can be reshaped repeatedly	**Decomposes** or chars on strong heating; cannot be reshaped
Structure	Linear or branched chain; weak inter-chain forces	3D cross-linked network; strong covalent bonds
Recyclability	**Can be recycled** and remoulded multiple times	**Cannot be recycled**; moulded only once
Strength	Moderate hardness; less rigid	**Hard and rigid**; higher mechanical strength
Examples	PVC, Polyethylene, Polystyrene, Nylon	Bakelite, Epoxy resin, Melamine, Urea-formaldehyde

Q.5(B)(1) — Hydrogen Bond and Its Types [4 marks]

Definition

A **hydrogen bond** is a weak electrostatic attractive force between a hydrogen atom **covalently bonded to an electronegative atom** (N, O, F) and another electronegative atom nearby.

Represented as: X–H...Y (where X, Y $=$ N, O, or F)

Strength: 10–40 kJ/mol (weaker than covalent, stronger than van der Waals)

Significance

H-bonds give water its high boiling point (100°C), hold DNA strands together, and stabilize protein structures (α-helix, β-sheet).

Type 1 — Intermolecular H-Bond

H-bond between **different molecules**.

Examples:

- Water: H_2O...H_2O (O–H...O)
- HF: HF...HF (F–H...F)
- Ethanol: C_2H_5OH...C_2H_5OH

Effect: Higher boiling point, higher surface tension.

Type 2 — Intramolecular H-Bond

H-bond **within the same molecule**.

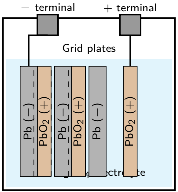
Example: *o*-nitrophenol (chelation)

Effect: Lower boiling point than intermolecular; reduces solubility in water.

Q.5(B)(2) — Primary Cell vs Secondary Cell [4 marks]

Point	Primary Cell	Secondary Cell
Recharging	**Cannot** be recharged; discarded after use	**Can be recharged** many times by passing current
Reactions	Electrode reactions are **irreversible**	Electrode reactions are **reversible**
Energy	Chemical energy stored during manufacture is used up	Energy restored by charging from external electrical source
Life span	Short — single use only	Long — hundreds or thousands of charge-discharge cycles
Examples	Dry cell (Leclanché), Mercury cell, Alkaline cell	Lead-acid battery, Ni-Cd, Li-ion, Ni-MH

Q.5(B)(3) — Lead-Acid Storage Cell: Construction & Working (1/2) [4 marks]



Construction

Neg. plate (−):	Spongy lead (Pb)
Pos. plate (+):	Lead dioxide (PbO_2)
Electrolyte:	Dil. H_2SO_4 (SG 1.28)
EMF per cell:	≈ 2 V
Car battery:	6 cells = 12 V

Discharge

Anode: $Pb + SO_4^{2-} \longrightarrow PbSO_4 + 2\,e^-$

Cathode: $PbO_2 + 4\,H^+ + SO_4^{2-} + 2\,e^- \longrightarrow PbSO_4 + 2\,H_2O$

Overall: $Pb + PbO_2 + 2\,H_2SO_4 \longrightarrow 2\,PbSO_4 + 2\,H_2O$

Q.5(B)(3) — Lead-Acid Storage Cell: Charging & Characteristics (2/2) [4 marks]

Charging Reactions (reversal)

Anode ($PbSO_4 \rightarrow PbO_2$):

$$PbSO_4 + 2\,H_2O \longrightarrow PbO_2 + 4\,H^+ + SO_4{}^{2-} + 2\,e^-$$

Cathode ($PbSO_4 \rightarrow Pb$):

$$PbSO_4 + 2\,e^- \longrightarrow Pb + SO_4{}^{2-}$$

Overall:

$$2\,PbSO_4 + 2\,H_2O \longrightarrow Pb + PbO_2 + 2\,H_2SO_4$$

Key Characteristics

- **Rechargeable** — can be charged thousands of times.
- **Acid density indicator:** During discharge, H_2SO_4 is consumed, reducing density; restored on charging.
- **Applications:** Car batteries, inverters, UPS, emergency lighting.
- **Disadvantage:** Heavy (lead), acid corrosive; requires maintenance (water top-up).

Memory Aid

Discharge: Both plates become $PbSO_4$; acid weakens.
Charge: Plates restored to Pb and PbO_2; acid strengthens.

Summary — Winter 2024 Solutions

Q	Topic	Marks
Q.1 (1–14)	Fill in the Blanks (MCQ)	14
Q.2(A)(1)	Importance of pH	3
Q.2(A)(2)	Buffer, Half-cell, Faraday's law	3
Q.2(A)(3)	Factors affecting corrosion rate	3
Q.2(B)(1)	Orbits vs Orbitals	4
Q.2(B)(2)	Classification of fuels	4
Q.2(B)(3)	Bio-diesel	4
Q.3(A)(1)	Solute, solvent, solution	3
Q.3(A)(2)	Electrovalent bond in NaCl	3
Q.3(A)(3)	Octane number for gasoline	3
Q.3(B)(1)	Electrorefining of Cu + diagram	4
Q.3(B)(2)	Preparation of ethene	4
Q.3(B)(3)	Preparation of Buna-S rubber	4

Q	Topic	Marks
Q.4(A)(1)	Metal cladding	3
Q.4(A)(2)	Waterline corrosion + diagram	3
Q.4(A)(3)	Solar cell principle	3
Q.4(B)(1)	Boundary lubrication + diagram	4
Q.4(B)(2)	Redwood viscometer + diagram	4
Q.4(B)(3)	Definitions: SC, Insulator, Elastomer	4
Q.5(A)(1)	pH and pOH of 0.004 M HCl	3
Q.5(A)(2)	Extrinsic semiconductors	3
Q.5(A)(3)	Thermoplastic vs Thermosetting	3
Q.5(B)(1)	Hydrogen bond and types	4
Q.5(B)(2)	Primary vs Secondary cell	4
Q.5(B)(3)	Lead-acid storage cell + diagram	4