# GUJARAT TECHNOLOGICAL UNIVERSITY
**BE- SEMESTER–1 PAPER SOLUTION – WINTER 2024**

## Subject Name & Code:
## Chemistry- B01000031

**Marks**

**Q.1** **(a)** Explain de Broglie's concept in wave mechanics. **03**

---

**Answer:**
**De Broglie's Concept in Wave Mechanics**
In 1924, **Louis de Broglie** proposed that **every moving particle** has **wave-like properties** in addition to its particle nature. This concept laid the foundation for **wave mechanics** and quantum theory.
He introduced the idea that a particle such as an **electron** can behave like a **wave**, and the wavelength (λ) associated with a moving particle is given by:

$$\lambda = h/\ mv$$

Where:
- $\lambda$ = wavelength of the particle
- h= Planck's constant ($6.626 \times 10^{-34}$ Js)
- m = mass of the particle (kg)
- v = velocity of the particle (m/s)

This relation is called the **de Broglie wavelength**.

---

**Significance:**
- It supports the **duality of matter**, i.e., matter exhibits both **particle and wave** behavior.
- It was later confirmed by **electron diffraction experiments** (Davisson-Germer experiment).
- It is essential in understanding **quantum mechanics** and explains the behavior of **subatomic particles**.

**(b)** Explain the types of hybridization with the molecular shapes of the following compounds: $CH_4$ and $C_2H_4$. **04**

---

**Answer:**
**1. Methane ($CH_4$):**
**Hybridization: $sp^3$**
- In methane, the central atom **carbon (C)** has 4 valence electrons.
- It forms 4 single covalent bonds with 4 hydrogen atoms.
- To accommodate these 4 bonds, carbon undergoes **$sp^3$ hybridization**, where one s and three p orbitals mix to form **four equivalent $sp^3$ hybrid orbitals**.

**Molecular Shape:**
- The geometry is **tetrahedral**.
- Bond angle = **109.5°**.

**Diagram:**

**2. Ethene ($C_2H_4$):**
**Hybridization: $sp^2$**

- In ethene, each carbon atom is bonded to **two hydrogen atoms** and **one carbon atom**.
- Each carbon forms **three sigma (σ) bonds** and one **pi (π) bond** between the two carbon atoms.
- Carbon undergoes **$sp^2$ hybridization** (one s and two p orbitals combine), leaving one unhybridized p-orbital for π-bond formation.

**Molecular Shape:**

- The geometry around each carbon is **trigonal planar**.
- Bond angle = **120°**.

**Diagram:**

**Summary Table:**

| **Compound** | **Hybridization** | **Molecular Shape** | **Bond Angle** |
|---|---|---|---|
| $CH_4$ | $sp^3$ | Tetrahedral | 109.5° |
| $C_2H_4$ | $sp^2$ | Trigonal Planar | 120° |

**(c)** Discuss caustic embrittlement in boilers. Why does caustic embrittlement occur in boilers, and how can it be prevented? **07**

---

**Answer:**
**Caustic Embrittlement – Definition:**
Caustic embrittlement is a **type of boiler corrosion** caused by the accumulation of **highly concentrated caustic alkali (NaOH)** in certain parts of the boiler, especially at **high-stress areas like rivets, joints, and bends**. This leads to the **cracking of boiler metal**, reducing its strength and causing boiler failure.

---

**Cause / Mechanism of Caustic Embrittlement:**

- During **boiler water treatment**, **sodium carbonate ($Na_2CO_3$)** is commonly used to soften water.
- In high-temperature and high-pressure conditions inside the boiler, sodium carbonate hydrolyzes as follows:

$$Na2CO3+H2O \rightarrow 2NaOH+CO2$$

- The **NaOH formed** is carried by boiler water and tends to concentrate in narrow cracks and crevices where the water can evaporate.
- This concentrated **NaOH reacts with boiler metal (usually iron)** and forms **sodium ferrate**, leading to localized corrosion and metal weakening:

$$Fe+2NaOH \rightarrow Na2FeO2+H2$$

- This process causes **intergranular cracking**, especially at stressed portions of the boiler, leading to **embrittlement**.

---

**Consequences:**

- Formation of fine cracks in the boiler metal.
- Leakage and failure in riveted joints or welds.
- Sudden rupture of the boiler under operating pressure.

---

**Prevention of Caustic Embrittlement:**

1. **Use of Sodium Phosphate Instead of Sodium Carbonate:**
   - Phosphates do not decompose into NaOH, hence they are safer.
2. **Addition of Tannins or Lignins:**
   - These substances block hairline cracks and prevent NaOH from entering stressed areas.
3. **Addition of $Na_2SO_4$ (Sodium Sulfate):**
   - It competes with NaOH and reduces its concentration in stressed areas.
4. **Controlled Use of $Na_2CO_3$:**
   - Avoid excess use of sodium carbonate in water softening.
5. **Regular Boiler Inspection:**
   - Ensures early detection of cracks or corrosion.

---

✅ **Summary Table:**

| **Aspect** | **Details** |
|---|---|
| Definition | Boiler corrosion due to localized concentration of I |
| Cause | Decomposition of $Na_2CO_3$ into NaOH at high pressu temperature |
| Affected Areas | Rivets, joints, welds – stressed areas |
| Consequence | Cracking of boiler metal, rupture |
| Prevention | Use of phosphate, tannin/lignin, $Na_2SO_4$, regular m |

**Q.2 (a)** **03**

Define the following terms:

1. Octane Number
2. Fullerenes
3. Corrosion

---

**Answer:**

**1. Octane Number:**

Octane number is a measure of the **anti-knocking property** of petrol (gasoline) in internal combustion engines.
It indicates the ability of the fuel to resist **engine knocking** (premature ignition).
It is defined by comparing the fuel's knocking tendency with a reference fuel mixture of **iso-octane (high anti-knock, rating 100)** and **n-heptane (high knocking, rating 0)**.

For example: A fuel with an octane number of 87 behaves like a mixture of 87% iso-octane and 13% n-heptane.

---

**2. Fullerenes:**

Fullerenes are a class of **allotropes of carbon** in which carbon atoms are arranged in the form of a **hollow sphere, ellipsoid, or tube**.

The most common fullerene is **$C_{60}$**, also known as **Buckminsterfullerene**, which has a structure similar to a **soccer ball**.

Fullerenes have unique properties and are used in **nanotechnology, electronics, and materials science**.

---

**3. Corrosion:**

Corrosion is the **gradual destruction or deterioration of metals** by **chemical or electrochemical reactions** with their environment.

The most common example is the **rusting of iron** when it reacts with oxygen and moisture to form **iron oxide**.

Corrosion leads to material loss, structural failure, and economic damage.

**(b)** Compare scale formation and sludge formation in boilers. **04**

---

**Answer:**

| **Point of Comparison** | **Scale Formation** | **Sludge Formation** |
|---|---|---|
| **1. Definition** | Scales are **hard, adherent deposits** formed on the inner boiler walls. | Sludges are **soft, loose, and non-adherent** precipitates formed in boiler water. |
| **2. Nature** | Hard, dense, and tightly sticking to the surface. | Soft, loose, and can be easily removed by blowdown. |
| **3. Formation Location** | Usually forms in **high temperature** zones like boiler walls and tubes. | Generally forms in **low temperature** zones or at bends where water flow is slow. |
| **4. Causes** | Caused by **precipitation of salts** like $CaSO_4$, $CaCO_3$ due to high temperature. | Caused by **precipitation of salts** like $MgCl_2$, $MgCO_3$, which are more soluble in hot water. |
| **5. Effects** | Decreases heat transfer efficiency, may lead to **overheating and bursting**. | Reduces boiler efficiency slightly, but can be removed easily. |
| **6. Removal** | **Mechanical or chemical cleaning** is required. | Can be **removed by blowdown operation** (regular drainage). |

---

**Conclusion:**

Both scale and sludge are undesirable in boilers. However, scales are more dangerous due to their hard nature and difficulty of removal, whereas sludges are relatively easy to remove.

**(c)** Explain the deionization method used for softening of water with appropriate diagrams. **07**

---

**Answer:**
**Deionization (Demineralization) Method:**
**Definition:**
Deionization (or demineralization) is a **process of removing all dissolved salts (both cations and anions)** from water by using **ion-exchange resins**. The resulting water is called **deionized water** or **demineralized water**, which is very pure and free from hardness.

---

**Principle:**
This method is based on **ion-exchange process**, where:

- **Cation exchange resins** remove **positive ions ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, etc.)**
- **Anion exchange resins** remove **negative ions ($Cl^{-}$, $SO_4^{2-}$, $HCO_3^{-}$, etc.)**

---

**Process:**

1. **Cation Exchange Unit:**
    - Water first passes through a **cation exchange column** containing **acidic resins** like R-H.
    - These resins exchange $H^{+}$ ions for cations in the water:

$$2\text{R-H} + \text{Ca}^{2+} \rightarrow \text{R}_2\text{-Ca} + 2\text{H}^{+}$$

2. **Anion Exchange Unit:**
    - The water then passes through an **anion exchange column** containing **basic resins** like R-OH.
    - These resins exchange $OH^{-}$ ions for anions:

$$\text{R-OH} + \text{Cl}^{-} \rightarrow \text{R-Cl} + \text{OH}^{-}$$

3. **Formation of Pure Water:**
    - The $H^{+}$ and $OH^{-}$ ions released during ion exchange combine to form pure water:

H++OH−→H2O

---

**Diagram:**

**Regeneration:**

- **Cation Resin:** Regenerated using **dilute HCl or $H_2SO_4$**.
- **Anion Resin:** Regenerated using **dilute NaOH**.

---

**Advantages:**

- Produces **very pure water** suitable for **high-pressure boilers**, labs, and industries.
- Removes **both temporary and permanent hardness**.

---

**Limitations:**

- Expensive equipment and chemicals.

- Needs skilled operation and regular regeneration.

---

**Conclusion:**
Deionization is an effective method for water softening where extremely pure water is required, especially in **power plants, pharmaceutical industries, and laboratories**.

**OR**

**(c)** Discuss the manufacturing of acetic acid through fermentation with appropriate diagrams. **07**

---

**Answer:**
**Introduction:**
Acetic acid ($CH_3COOH$) is a **colorless, sour-tasting, and pungent-smelling organic acid**, widely used in **food preservation (vinegar)** and **chemical industries**. It can be produced by **oxidation of ethanol** using **aerobic fermentation** carried out by **Acetobacter bacteria**.

---

**Fermentation Process for Acetic Acid:**
**Principle:**
Ethanol is **oxidized to acetic acid** in the presence of **Acetobacter aceti** under aerobic conditions:

$$C_2H_5OH + O_2 \xrightarrow{\text{Acetobacter}} CH_3COOH + H_2O$$

---

**Raw Materials Required:**
- **Dilute ethanol solution** (source: fermented molasses, fruit juices, etc.)
- **Acetobacter bacteria culture**
- **Air or oxygen** (for oxidation)
- **Fermentation tank**

---

**Manufacturing Methods:**
Two main fermentation methods are used:

---

**1. Orleans Process (Traditional):**
- Wooden barrels are filled with dilute wine or ethanol.
- Holes are provided for air circulation.
- The surface is inoculated with **Acetobacter aceti**.
- The bacteria slowly oxidize ethanol to acetic acid over **several weeks**.

**Limitations:** Very **slow**, used mainly for **vinegar production**.

---

**2. Quick Vinegar Process (Modern method):**
- Uses **fermentation towers** packed with wood shavings, charcoal, or plastic balls.
- Dilute alcohol (10–15%) is trickled from the top of the tower.
- Air is blown **from the bottom**.
- The medium is inoculated with **Acetobacter aceti**.
- As the solution trickles down, ethanol is oxidized to acetic

acid by the bacteria.

---

**Diagram:**

**Recovery:**
- The outflow is collected and distilled to concentrate acetic acid.

---

**Advantages of Fermentation Method:**
- Eco-friendly.
- Uses renewable raw materials.
- Used for **food-grade acetic acid** (vinegar).

---

**Limitations:**
- Slower than synthetic methods.
- Requires sterile and controlled conditions.

---

**Conclusion:**
Acetic acid is manufactured through microbial fermentation by oxidizing ethanol in the presence of oxygen and **Acetobacter bacteria**. The **Quick Vinegar Process** is the most widely used modern method due to its efficiency and shorter time cycle.

**Q.3** **(a)** What is meant by the mobile phase and stationary phase in liquid chromatography? **03**

---

**Answer:**
**Liquid Chromatography** is a technique used for the **separation of components** in a mixture based on their **differential affinity** toward two phases: the **mobile phase** and the **stationary phase**.

**1. Mobile Phase:**
The **mobile phase** is a **liquid solvent** or a mixture of solvents that flows through the chromatographic column.
It carries the sample mixture along the stationary phase.
The mobile phase is responsible for **transporting the components** of the mixture and helps in their **separation** based on their solubility and interaction.

**Example:** Water, methanol, or acetonitrile in High-Performance Liquid Chromatography (HPLC).

**2. Stationary Phase:**
The **stationary phase** is the **solid** or **liquid supported on a solid** that remains fixed inside the chromatographic column.
It interacts with the components of the sample mixture and **retards their movement** based on their **adsorption or partition** behavior.
Different components travel at different speeds due to their varying interactions with the stationary phase, leading to separation.

**Example:** Silica gel, alumina, or polymer resins coated inside the column.

**(b)** Differentiate between internal and external treatment for water softening. **04**

---

**Answer:**
Water used in boilers must be free from hardness-causing salts to avoid problems like **scale and sludge formation**. The methods to remove or reduce hardness are categorized as:

| Sr. No. | Internal Treatment | External Treatment |
|---|---|---|
| 1. | Treatment is done **inside the boiler** itself. | Treatment is done **outside the boiler** before water enters. |
| 2. | Chemicals are added to water **within the boiler** to react with impurities. | Water is **softened or purified in a separate unit**. |
| 3. | It **does not remove** hardness salts, but converts them into non-adherent sludge. | It **removes hardness salts** before feeding water into the boiler. |
| 4. | Suitable for **low-pressure boilers**. | Suitable for **high-pressure boilers**. |
| 5. | Common methods: Colloidal conditioning, carbonate conditioning, phosphate conditioning. | Common methods: Lime-soda process, zeolite process, ion-exchange process. |

---

**Conclusion:**

- **Internal treatment** is used when external treatment is not feasible or for low-pressure applications.
- **External treatment** is preferred for better efficiency, especially in **high-pressure boilers**, as it prevents scale formation completely.

**(c)** Explain electrochemical theory of corrosion with appropriate diagrams. **07**

---

**Answer:**
**Electrochemical theory of corrosion** explains how metals corrode in the presence of **electrolyte solutions** (e.g., water with dissolved ions) by forming **electrochemical cells** on the metal surface.

---

**1. Basic Concept:**
When a metal (like iron) is exposed to an electrolyte (like moist

air or water), some areas of the metal act as **anodes** and others as **cathodes**.

- **At the anode (oxidation):**

$$Fe \rightarrow Fe2++2e-$$

Iron atoms lose electrons and go into solution as iron ions.

- **At the cathode (reduction):**
  In **acidic medium**:

$$2H++2e- \rightarrow H2\uparrow$$

In **neutral/alkaline medium** (like moist air with dissolved oxygen):

$$O2+2H2O+4e- \rightarrow 4OH-$$

---

**2. Formation of Rust (in case of iron):**

- The $Fe^{2+}$ **ions** from the anode react with $OH^-$ **ions** from the cathode region:

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

- Further oxidation:

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$$

- $Fe(OH)_3$ dehydrates to form $Fe_2O_3 \cdot xH_2O$, commonly known as **rust**.

---

**3. Diagram:**

**4. Conditions for Electrochemical Corrosion:**

- Presence of **electrolyte** (moisture or water with ions)
- **Electrically connected anodic and cathodic areas**
- **Oxygen** or other oxidizing agent availability

---

**Conclusion:**
Electrochemical corrosion is a redox process involving **simultaneous oxidation and reduction** reactions. The **metal loses electrons at anodic areas** and gets corroded, while reduction happens at the **cathodic areas**.

**OR**

**Q.3** **(a)** State the products formed by the action of the enzyme invertase and zymase on cane sugar under suitable fermentation conditions, along with the reactions. **03**

---

**Answer:**
When cane sugar (**sucrose**) undergoes fermentation, two main enzymes act in sequence: **invertase** and **zymase**.

---

**1. Action of Invertase:**
**Invertase** hydrolyzes **sucrose** (cane sugar) into two simple sugars:

$$\mathrm{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{\text{invertase}} \mathrm{C_6H_{12}O_6} + \mathrm{C_6H_{12}O_6}$$

**Sucrose + Water → Glucose + Fructose**

**2. Action of Zymase:**
**Zymase** (from yeast) then ferments both **glucose and fructose** into **ethanol** and **carbon dioxide**:

$$C_6H_{12}O_6 \xrightarrow{\text{zymase}} 2C_2H_5OH + 2CO_2$$

**Glucose/Fructose → Ethanol + Carbon dioxide**

**Final Products:**

- **Ethanol ($C_2H_5OH$)**
- **Carbon dioxide ($CO_2$)**

These are the main products formed by the fermentation of cane sugar under the action of **invertase and zymase**.

**(b)** Compare hard acids and bases with soft acids and bases. **04**

**Answer:**
The classification of acids and bases as **hard** or **soft** is based on the **HSAB (Hard and Soft Acids and Bases) principle** proposed by Pearson.

| **Criteria** | **Hard Acids and Bases** | **Soft Acids and Bases** |
|---|---|---|
| **Polarity** | Small in size and highly polarizing | Larger in size and easily polarizable |
| **Charge density** | High | Low |
| **Preferred interaction** | Prefer to bind with hard species (ionic interactions) | Prefer to bind with soft species (covalent interactions) |
| **Bonding nature** | Mostly ionic | Mostly covalent |
| **Examples (Acids)** | $H^+$, $Li^+$, $Al^{3+}$, $Fe^{3+}$, $Ca^{2+}$ | $Ag^+$, $Hg^{2+}$, $Pt^{2+}$, $Pd^{2+}$ |
| **Examples (Bases)** | $OH^-$, $F^-$, $NH_3$, $H_2O$ | $I^-$, $S^{2-}$, R–SH, R–S–R |

**Key Principle (HSAB Rule):**
*Hard acids prefer to react with hard bases, and soft acids prefer to react with soft bases.*

**(c)** What do you mean by spectroscopy? Explain the principle of NMR spectroscopy. **07**

**Answer:**
**1. Spectroscopy – Definition:**
**Spectroscopy** is the branch of science that deals with the study of the interaction between **matter** and **electromagnetic**

**radiation**. It is used to determine the **structure**, **composition**, and **physical properties** of substances.
In spectroscopy, when matter is exposed to electromagnetic radiation, it either **absorbs** or **emits** energy. By analyzing this interaction, we can identify molecular structure, atomic bonding, and functional groups.

---

**2. Principle of NMR (Nuclear Magnetic Resonance) Spectroscopy:**
**NMR spectroscopy** is a powerful analytical technique used to determine the **structure of organic compounds** by studying **magnetic properties of atomic nuclei**.
**Basic Principle:**

- Certain nuclei (such as $^{1}\mathbf{H}$, $^{13}\mathbf{C}$) possess a property called **spin**.
- These spinning nuclei generate a **magnetic moment** and behave like tiny magnets.
- In an external **strong magnetic field**, these nuclear magnets align either **with** or **against** the field.
- When radiofrequency (RF) radiation is applied, the nuclei absorb this energy and move from the **lower energy state** to the **higher energy state** (resonance).
- When they return to the original state, they emit **electromagnetic signals**.
- These emitted signals are detected and recorded as an **NMR spectrum**.

---

**3. Working Diagram:**

**4. Applications of NMR Spectroscopy:**

- Identification of **organic compounds**
- Determination of **molecular structure**
- Study of **isomerism** and **functional groups**
- In **biochemistry**, to analyze proteins and nucleic acids

**Q.4** **(a)** Briefly explain thin-layer chromatography. **03**

---

**Answer:**
**Thin-Layer Chromatography (TLC)** is a simple, fast, and effective **separation technique** used to identify and analyze components in a mixture.

---

**Principle:**
TLC works on the principle of **adsorption** and **differential migration**. Different components of a mixture move at different rates on the TLC plate due to differences in their **affinities** towards the **stationary phase** and **solubility** in the **mobile phase**.

---

**Apparatus:**

1. **TLC plate:** A glass or plastic plate coated with a thin layer of adsorbent (usually silica gel or alumina) – this is the **stationary phase**.
2. **Solvent:** Acts as the **mobile phase**.
3. **Developing chamber:** Contains the solvent to allow upward movement.
4. **Sample mixture:** To be analyzed.

---

**Procedure:**

1. A small spot of the sample is applied near the bottom of the TLC plate.
2. The plate is placed in a chamber with a small amount of solvent (mobile phase).
3. The solvent rises up the plate by capillary action, carrying the components of the mixture with it.
4. Different components move to different heights based on their interaction with the stationary and mobile phases.
5. The spots are visualized using UV light or iodine vapors.

---

**Rf Value:**
The **Retention factor (Rf)** is calculated using:

$$Rf = \frac{\text{Distance travelled by the solute}}{\text{Distance travelled by the solvent front}}$$

---

**Applications:**

- Identification of **organic compounds**
- Monitoring **reaction progress**
- Checking **purity** of samples

**(b)** Discuss the applications of nanomaterials. **04**

---

**Answer:**
**Nanomaterials** are materials that have structural components with at least one dimension less than 100 nanometers. Due to their unique physical and chemical properties like **large surface area**, **high strength**, **chemical reactivity**, and **optical behavior**, nanomaterials find a wide range of applications.

---

**Applications of Nanomaterials:**

1. **Electronics:**
    - Used in the development of **nanochips**, **transistors**, and **quantum dots** for **high-speed computing** and **miniaturized electronic devices**.
2. **Medical field:**
    - Used in **drug delivery systems** where drugs are delivered directly to the target cells.
    - Employed in **cancer treatment**, **diagnostics**, and **imaging** (e.g., gold nanoparticles, silver nanoparticles).
3. **Energy Sector:**
    - Applied in **solar cells** to improve efficiency.
    - Used in **fuel cells** and **hydrogen storage systems**.
    - Nanomaterials enhance **battery performance** and **energy storage devices**.
4. **Environmental Applications:**
    - Used for **water purification** and **air filtration** due to their excellent adsorption properties.
    - Useful in **pollution control** and **catalytic converters**.
5. **Textile Industry:**
    - Nanoparticles are used to make **waterproof**, **wrinkle-resistant**, and **antibacterial fabrics**.
6. **Automobile and Aerospace:**
    - Used in manufacturing **lightweight**, **strong**, and **durable** components.
    - Improves fuel efficiency and reduces emissions.
7. **Cosmetics and Sunscreens:**
    - Nanoparticles like **ZnO** and **$TiO_2$** are used in **sunscreens** for better UV protection without leaving white residue.

---

**Conclusion:**
Nanomaterials play a crucial role in modern technology due to their **versatility** and **enhanced properties**, making them vital in various industries.

**(c)** Explain the principle and working of lithium batteries, including the reactions occurring in them. Reflect how they are better than other types of batteries. **07**

---

**Answer:**

**1. Principle of Lithium Batteries:**

Lithium batteries operate on the principle of **electrochemical redox reactions**, where **lithium ions ($Li^+$)** move from the anode to the cathode during **discharge**, and back from cathode to anode during **charging**.

---

**2. Construction of Lithium Battery:**

- **Anode (Negative Electrode):** Lithium metal or lithium intercalated graphite ($LiC_6$)
- **Cathode (Positive Electrode):** Lithium metal oxide (e.g., $LiCoO_2$)
- **Electrolyte:** Lithium salt (e.g., $LiPF_6$) in an organic solvent (e.g., ethylene carbonate)
- **Separator:** A porous membrane allowing ion flow but preventing short circuits.

---

**3. Working of Lithium Battery:**

**(A) During Discharge:**

- Lithium ions move from the **anode** to the **cathode** through the **electrolyte**.
- Electrons flow through the external circuit providing electrical energy.

**Reactions:**

- **Anode (oxidation):**
  LiC6→Li++e−+C6
- **Cathode (reduction):**
  Li++e−+CoO2→LiCoO2

**(B) During Charging:**

- Lithium ions move back from **cathode** to **anode**, and electrons return through the external power source.

---

**4. Advantages of Lithium Batteries over Other Types:**

| Feature | Lithium Battery | Other Batteries (e.g., Ni-Cd, Lead-acid) |
|---|---|---|
| **Energy Density** | High | Low to Moderate |
| **Weight** | Light | Heavy |
| **Self-discharge Rate** | Low | Higher |
| **Cycle Life** | Long | Shorter |
| **Memory Effect** | No | Present in Ni-Cd |

| | | |
|---|---|---|
| **Environmental Impact** | Less toxic | Lead & cadmium are hazardous |

---

**5. Applications:**

- **Smartphones, laptops, and tablets**
- **Electric vehicles (EVs)**
- **Medical devices**
- **Solar energy storage systems**

---

**Conclusion:**
Lithium batteries are efficient, reliable, and environmentally better than conventional batteries. Their **high energy density**, **long life**, and **low maintenance** make them suitable for modern technology.

**OR**

**Q.4** **(a)** List the applications of IR spectroscopy. **03**

---

**Answer:**
**Infrared (IR) spectroscopy** is a powerful analytical technique used to identify and study chemical substances based on the absorption of infrared light by molecules. The applications of IR spectroscopy are as follows:

---

**1. Identification of Functional Groups:**

- IR spectroscopy helps in identifying the presence of functional groups like **–OH**, **–$NH_2$**, **C=O**, **C=C**, **C–H**, etc., in organic compounds by analyzing their characteristic absorption bands.

---

**2. Determination of Molecular Structure:**

- It provides information about the **molecular structure**, **bond strength**, and **bond type** (single, double, triple) by analyzing vibrational frequencies.

---

**3. Purity Testing of Compounds:**

- It is used to check the **purity** of a compound. The presence of **extra peaks** indicates **impurities** in the sample.

---

**4. Qualitative and Quantitative Analysis:**

- IR spectroscopy can be used for both **qualitative identification** and **quantitative estimation** of compounds, especially in pharmaceuticals and chemicals.

---

**5. Study of Hydrogen Bonding:**

- It helps to detect **inter- and intra-molecular hydrogen bonding** by observing shifts in the –OH and –NH stretching frequencies.

**6. Monitoring Chemical Reactions:**

- IR spectra can be recorded over time to monitor the **progress of chemical reactions** by observing the disappearance or appearance of characteristic peaks.

**7. Applications in Polymer and Material Science:**

- Used to study **polymers, plastics, fibers**, and **composite materials** to determine composition and structural changes.

**Conclusion:**
IR spectroscopy is a valuable tool in **organic chemistry**, **pharmaceuticals**, **environmental analysis**, and **material science** due to its ability to quickly and accurately analyze molecular vibrations and structures.

**(b)** What are inhibitors? Provide two examples. **04**

**Answer:**
**Inhibitors** are chemical substances that **slow down or prevent** the rate of a **chemical reaction** without themselves undergoing any permanent chemical change.
In the context of corrosion, an inhibitor is a substance that, when added in small concentrations to an environment, **reduces the corrosion rate** of metals or alloys.

**Definition:**
*An inhibitor is a substance that decreases the rate of a chemical reaction or prevents undesirable reactions such as corrosion, oxidation, or polymer degradation.*

**Types of Inhibitors (optional for extra detail):**

- **Anodic Inhibitors**: Reduce the anodic reaction.
- **Cathodic Inhibitors**: Slow down the cathodic reaction.
- **Mixed Inhibitors**: Affect both anodic and cathodic processes.

**Examples:**

1. **Sodium Chromate ($Na_2CrO_4$):**
   Used as an anodic inhibitor in boilers to reduce metal corrosion.
2. **Triethanolamine (TEA):**
   Commonly used in cooling systems as an organic corrosion inhibitor.

**Conclusion:**
Inhibitors are widely used in industries to **protect metals**, extend the **life of equipment**, and **control reaction rates**, especially in processes involving **corrosion**, **polymerization**, or **combustion**.

**(c)** Analyze the structure of a bomb calorimeter and explain whether its design is suitable for measuring the calorific value. **07**

---

**Answer:**
**Bomb Calorimeter: Structure and Suitability**
A **bomb calorimeter** is a device used to **measure the calorific value** (heat of combustion) of a fuel or substance. It works on the principle of measuring the **temperature rise** in a known quantity of water due to combustion of a **known mass of fuel** in a constant-volume vessel.

---

**1. Structure of Bomb Calorimeter:**
The major components are:

1. **Bomb (Combustion Chamber):**
   - A strong, sealed steel container that resists high pressure.
   - Contains the **fuel sample** in a crucible and **oxygen gas** at high pressure.
2. **Crucible:**
   - Holds the sample of the fuel to be tested.
3. **Ignition Electrodes:**
   - An electrically heated wire is used to ignite the fuel sample.
4. **Water Jacket (Calorimeter Vessel):**
   - Surrounds the bomb and contains a known quantity of water to absorb the released heat.
5. **Stirrer:**
   - Ensures uniform distribution of heat in the water.
6. **Thermometer or Temperature Sensor:**
   - Records the temperature change accurately.
7. **Insulated Container:**
   - Prevents loss of heat to surroundings.

---

**2. Working Principle:**

- The sample is placed inside the bomb and filled with oxygen.
- The bomb is placed in the calorimeter filled with water.
- On ignition, the fuel burns completely.
- The heat released is transferred to the surrounding water.
- The rise in water temperature is measured.
- From this, the **calorific value (in kcal/kg or kJ/g)** is calculated using:

$$\text{Calorific Value} = \frac{(W + w)(T_2 - T_1)}{m}$$

Where:

- W = mass of water
- w = water equivalent of calorimeter
- T2−T1 = rise in temperature

- m = mass of fuel burned

---

**3. Suitability of Design for Measuring Calorific Value:**
The design of a bomb calorimeter is highly suitable due to the following reasons:

- **Closed System:** Prevents heat loss, ensuring accurate measurement.
- **High-Pressure Resistance:** The bomb can handle the pressure from combustion gases.
- **Efficient Heat Transfer:** Direct contact between the bomb and surrounding water allows precise heat absorption measurement.
- **Oxygen Supply:** Ensures complete combustion of fuel.
- **Precision Instruments:** Sensitive thermometers allow accurate temperature readings.

---

**Conclusion:**
The **bomb calorimeter** is a **well-designed and highly accurate instrument** for determining the **calorific value of fuels**. Its structure minimizes heat losses and ensures complete combustion, making it ideal for laboratory and industrial applications.

**Q.5** **(a)** Illustrate the uses of steel as an alloy with examples. **03**

---

**Answer:**
**Steel** is an important **ferrous alloy** primarily composed of **iron and carbon**, and often includes other elements like chromium, nickel, manganese, molybdenum, and vanadium to improve its mechanical and chemical properties.

---

**Uses of Steel as an Alloy:**

1. **Structural Applications:**
   - **Mild Steel** (low carbon content) is used in **construction of buildings, bridges, and pipelines** due to its strength and ductility.
2. **Tool Manufacturing:**
   - **High Carbon Steel** is used for making **cutting tools, chisels, and blades** because of its hardness and wear resistance.
3. **Automobile Industry:**
   - **Alloy Steel** containing **nickel and chromium** is used in **automobile bodies, engine parts, and gears** due to its toughness and corrosion resistance.
4. **Stainless Steel:**
   - Contains **at least 10.5% chromium**; used for **kitchen utensils, surgical instruments, chemical tanks**, etc., because of its high corrosion resistance and luster.
5. **Electrical Applications:**

- **Silicon Steel** is used in the **cores of transformers and electrical motors** due to its magnetic properties.

---

**Examples of Steel Alloys:**

| Type of Steel | Alloying Elements | Typical Use |
|---|---|---|
| Stainless Steel | Iron, Chromium, Nickel | Utensils, surgical tools |
| High-Speed Steel | Iron, Carbon, Tungsten | Cutting and drilling tools |
| Tool Steel | Iron, Carbon, Vanadium | Dies, molds, punches |

---

**Conclusion:**
Steel, due to its versatility and ability to be alloyed with various elements, is used extensively in construction, machinery, transportation, and domestic applications.

**(b)** Write about Heisenberg's Uncertainty Principle. **04**

---

**Answer:**
**Heisenberg's Uncertainty Principle** is a fundamental concept in **quantum mechanics** introduced by the German physicist **Werner Heisenberg in 1927**. It states that:
**"It is impossible to determine simultaneously and precisely both the position and momentum (or velocity) of a moving microscopic particle, such as an electron."**

---

**Mathematical Expression:**

$$\Delta x \cdot \Delta p \geq \frac{h}{4\pi}$$

Where:
- $\Delta x$ = uncertainty in position
- $\Delta p$ = uncertainty in momentum (mass × velocity)
- $h$ = Planck's constant (6.626×10−34 Js)

---

**Explanation:**
This principle is significant in understanding the behavior of **subatomic particles** like **electrons**. The more accurately we try to measure the **position** of an electron, the **less accurately** we can determine its **momentum**, and vice versa.
This is not due to limitations of measurement instruments, but a fundamental property of nature at the quantum level.

---

**Significance:**
1. It disproves the classical idea that particles like electrons can have precisely defined position and momentum at the same

time.
2. It explains why **electrons do not exist in fixed orbits** around the nucleus, as suggested by Bohr's model.
3. It supports the concept of **electron clouds or orbitals** instead of fixed paths.

---

**Conclusion:**
Heisenberg's Uncertainty Principle is essential for understanding the **dual nature of matter** and the limitations in studying **microscopic particles**, forming the basis of **quantum mechanics**.

**(c)** Discuss the "Top-Down" and "Bottom-Up" approaches for synthesizing a nanomaterial. **07**

---

**Answer:**
Nanomaterials can be synthesized using two fundamental approaches: **Top-Down** and **Bottom-Up**. These techniques are based on how the nanostructures are built or reduced to the nanometer scale.

---

**1. Top-Down Approach:**
**Definition:**
In this method, **bulk materials** are **broken down** into smaller particles until they reach the **nanoscale**.
**Key Features:**
- It starts with a **large structure** and reduces its size.
- Physical or mechanical methods are typically used.

**Techniques involved:**
- **Mechanical Milling:** High-energy ball milling to reduce material size.
- **Lithography:** Patterning using UV light or electron beams.
- **Etching and Grinding:** Removal of material layer by layer.

**Advantages:**
- Suitable for **mass production**.
- Compatible with existing **microfabrication** processes.

**Limitations:**
- Difficult to control **shape and size** at the nanoscale.
- May introduce **defects** in the crystal structure.

---

**2. Bottom-Up Approach:**
**Definition:**
This method builds **nanomaterials atom-by-atom or molecule-by-molecule**, assembling them into desired nanostructures.
**Key Features:**
- Mimics **natural biological processes** (like DNA synthesis).
- Results in **more precise control** over size, shape, and structure.

**Techniques involved:**

- **Sol-Gel Process**
- **Chemical Vapor Deposition (CVD)**
- **Self-Assembly**
- **Precipitation**

**Advantages:**

- Better **control over structure and purity**.
- Generates fewer **defects**.
- More suitable for creating **functional nanomaterials** (e.g., quantum dots, nanotubes).

**Limitations:**

- More complex and **time-consuming**.
- Requires precise **environmental control** (temperature, pH, etc.).

---

**Comparison Table:**

| Aspect | Top-Down Approach | Bottom-Up Approach |
|---|---|---|
| Starting Material | Bulk Material | Atoms or Molecules |
| Size Control | Difficult | Precise |
| Purity of Product | Lower (due to defects) | Higher |
| Equipment | Mechanical or Lithographic Tools | Chemical and Biological Tools |
| Cost | Lower (for bulk production) | Higher (for lab synthesis) |
| Examples | Ball milling, Lithography | Sol-Gel, CVD, Self-assembly |

---

**Conclusion:**
Both **Top-Down** and **Bottom-Up** approaches are essential for nanomaterial synthesis. The choice of method depends on the desired properties, applications, and scale of production. In general, **bottom-up techniques offer better control**, while **top-down methods are scalable** for industrial applications.

**OR**

**Q.5** **(a)** Explain the sacrificial protection method for preventing metal corrosion with suitable diagrams. **03**

---

**Answer:**
**Sacrificial protection** is a method of preventing corrosion of a metal (usually iron or steel) by **connecting it to a more reactive metal**. The more reactive metal acts as a **sacrificial anode** and **corrodes instead of the protected metal**.

---

**Principle:**

- The metal to be protected is connected to a **more electropositive (active)** metal like **zinc, magnesium, or aluminum**.
- The **more active metal oxidizes (loses electrons)** and **sacrifices itself**.
- The **less active metal (iron/steel)** remains protected as it becomes the **cathode** in the electrochemical cell and does not corrode.

---

**Example:**

- **Zinc coating** on iron (as in galvanization).
- **Magnesium rods** attached to underground water pipes or ship hulls.

---

**Diagram:**

---

**Reaction:**

- **At Magnesium (anode):**
  $Mg \rightarrow Mg^{2+} + 2e^{-}$ *(Oxidation, corrodes)*
- **At Iron (cathode):**
  No corrosion occurs as electrons are supplied by Mg.

---

**Conclusion:**
Sacrificial protection is an effective and widely used corrosion prevention technique in pipelines, ship hulls, underground structures, etc., because it is **simple, economical, and reliable**.

**(b)** Discuss carbon nanotubes and nanowires in detail. **04**

---

**Answer:**
**1. Carbon Nanotubes (CNTs):**
**Definition:**
Carbon nanotubes are cylindrical nanostructures made from rolled-up sheets of **graphene** (a single layer of carbon atoms arranged in a hexagonal lattice).
**Types of CNTs:**

- **Single-walled carbon nanotubes (SWCNTs):** Consist of a single graphene cylinder.
- **Multi-walled carbon nanotubes (MWCNTs):** Consist of multiple concentric graphene cylinders.

**Properties:**

- High electrical and thermal conductivity.
- Excellent mechanical strength.
- High surface area.

**Applications:**

- Used in **nanoelectronics**, **composite materials**, **drug delivery**, and **energy storage devices**.

**2. Nanowires:**
**Definition:**
Nanowires are **one-dimensional nanostructures** with a diameter in the nanometer range and length much longer than the diameter.
**Materials Used:**

- Metals (e.g., Au, Ag)
- Semiconductors (e.g., Si, GaN)
- Oxides (e.g., ZnO, $TiO_2$)

**Properties:**

- High aspect ratio.
- Quantum confinement effects.
- Good electrical and optical properties.

**Applications:**

- Used in **transistors**, **solar cells**, **sensors**, and **nano-devices**.

---

**Conclusion:**
Both carbon nanotubes and nanowires are essential building blocks in **nanotechnology** due to their **unique physical, electrical, and mechanical properties**. Their applications are revolutionizing fields such as **electronics, medicine, and materials science**.

**(c)** Explain the refining of petroleum with the help of suitable diagrams. **07**

---

**Answer:**
**Refining of Petroleum:**
Petroleum, also known as **crude oil**, is a complex mixture of **hydrocarbons** along with small amounts of impurities like sulfur, nitrogen, and oxygen compounds. Refining is the process of separating this mixture into useful components.

---

**Main Steps in Petroleum Refining:**
**1. Separation (Physical Processes):**
This is done by a method called **fractional distillation**.

---

**Fractional Distillation of Petroleum:**

- Crude oil is first **heated** to about **400°C** in a furnace.
- It is then fed into a **fractionating column**, which is a tall vertical tower fitted with **trays at various heights**.
- The column is **hot at the bottom** and **cooler at the top**.
- Different hydrocarbon components (called **fractions**) condense at different heights depending on their **boiling points**.

---

**Diagram: Fractionating Column**

**2. Conversion (Chemical Processes):**
To increase the yield of desired products like petrol, various chemical processes are applied:

- **Cracking:** Breaking large hydrocarbons into smaller ones.
- **Reforming:** Rearranging molecules to improve fuel quality.
- **Polymerization and Alkylation:** Combining smaller units into larger ones.

---

**3. Purification:**
The fractions are treated to remove impurities like **sulfur** to reduce air pollution. Common methods include:

- **Desulfurization**
- **Washing with chemical agents**
- **Catalytic treatment**

---

**Conclusion:**
Petroleum refining is essential to obtain various useful fuels and products from crude oil. The **fractional distillation method** plays a key role in this process, and is supported by conversion and purification techniques to meet the modern demands of fuel and chemicals.

***********************