**CY3151- ENGINEERING CHEMISTRY**

**PART – B**

**UNIT I – WATER AND ITS TREATMENT**

**1. What are sludge and scale in boilers? How are they formed? Suggest any two methods to prevent their formation.**

**[April/May 2015]**

**Sludge:**

* Sludge is a soft, loose, and non-adherent precipitate formed in the cooler parts of the boiler.
* It consists mainly of salts like MgCl₂, MgSO₄, CaCl₂ which are more soluble in hot water and less soluble in cooler areas.

**Scale:**

* Scale is a hard, adherent deposit that sticks firmly to the inner walls of the boiler.
* It is mainly formed due to salts like CaCO₃, CaSO₄, and silica which become less soluble at high temperatures.

**Formation of Scale and Sludge:**

* **Calcium bicarbonate:**

Ca(HCO3)2→CaCO3↓+H2O+CO2\text{Ca(HCO}\_3)\_2 \-> \text{CaCO}\_3 \ + \text{H}\_2O + \text{CO}\_2

* **Calcium sulfate:**

CaSO4↓(less soluble at high temperatures)\text{CaSO}\_4 \downarrow \quad (\text{less soluble at high temperatures})

* **Magnesium salts:**

MgCl2+2H2O→Mg(OH)2↓+2HCl\text{MgCl}\_2 + 2\text{H}\_2O \rightarrow \text{Mg(OH)}\_2 \downarrow + 2\text{HCl}

**Problems caused:**

* Decrease in heat transfer.
* Boiler overheating and possible explosions.
* Wastage of fuel.

**Prevention methods (any two):**

1. **External Treatment:**
   * Lime-soda, zeolite, or ion exchange processes remove hardness before water enters the boiler.
2. **Internal Treatment:**
   * Phosphate or carbonate conditioning converts scale-forming salts into sludge which can be removed by blowdown.

**Diagram:**

| Boiler Tube |

|-------------|

| Scale | ← Hard deposits at high temp

|-------------|

| Sludge | ← Soft deposits at low temp

**2. Explain the caustic embrittlement in detail.**

**[Nov/Dec 2015]**

**Definition:**

* Caustic embrittlement is a type of boiler corrosion that makes boiler metal brittle due to the formation of sodium hydroxide (NaOH).

**Cause:**

* During water softening using sodium carbonate:

Na2CO3+H2O→2NaOH+CO2\text{Na}\_2\text{CO}\_3 + \text{H}\_2\text{O} \rightarrow 2\text{NaOH} + \text{CO}\_2

* The NaOH formed seeps into hairline cracks and reacts with boiler metal (iron):

Fe+2NaOH→Na2FeO2+H2↑\text{Fe} + 2\text{NaOH} \rightarrow \text{Na}\_2\text{FeO}\_2 + \text{H}\_2 ↑

**Consequences:**

* Formation of sodium ferroate (Na₂FeO₂) weakens the metal.
* Leads to brittle fractures in high-stress regions.

**Prevention:**

1. Use sodium phosphate instead of sodium carbonate for softening.
2. Add tannin/lignin to block small cracks.
3. Control NaOH concentration within safe limits.

**Diagram:**

Boiler Metal → Crack → NaOH enters → Reacts with Fe → Forms brittle layer

**3. What is meant by boiler corrosion? How can it be minimized?**

**[Nov/Dec 2015]**

**Definition:**

* Boiler corrosion is the gradual destruction of boiler metal by chemical or electrochemical reaction with water or steam.

**Causes:**

1. **Dissolved Oxygen:**

4Fe+3O2+6H2O→4Fe(OH)34\text{Fe} + 3\text{O}\_2 + 6\text{H}\_2O \rightarrow 4\text{Fe(OH)}\_3

1. **Dissolved CO₂:**

CO2+H2O→H2CO3(Carbonic Acid)\text{CO}\_2 + \text{H}\_2O \rightarrow \text{H}\_2\text{CO}\_3 \quad (\text{Carbonic Acid})

1. **Acidic Water or salts like MgCl₂**

**Prevention:**

1. **Mechanical deaeration:** Use of deaerators to remove O₂ and CO₂.
2. **Chemical treatment:** Adding hydrazine (N₂H₄), sodium sulfite (Na₂SO₃).

Na2SO3+O2→Na2SO4\text{Na}\_2\text{SO}\_3 + \text{O}\_2 \rightarrow \text{Na}\_2\text{SO}\_4 N2H4+O2→N2+2H2O\text{N}\_2\text{H}\_4 + \text{O}\_2 \rightarrow \text{N}\_2 + 2\text{H}\_2\text{O}

**Diagram:**

Corrosion Site → Water + O₂/CO₂ → Rust (Fe(OH)₃) formation → Metal degradation

**4. What is reverse osmosis? How is it useful for desalination of brackish water? Explain with a diagram.**

**[April/May 2015, Nov/Dec 2015, May 2016, April/May 2023]**

**Definition:**

* Reverse osmosis (RO) is a process where water is forced through a semi-permeable membrane from a region of high solute concentration to low solute concentration by applying external pressure.

**Principle:**

* Opposite of natural osmosis. Applied pressure > osmotic pressure.

**Process:**

* Brackish water is passed through a semi-permeable membrane under pressure.
* The membrane allows only water to pass, rejecting salts and impurities.

**Applications:**

* Desalination of seawater.
* Purification of drinking water.
* Removal of heavy metals, fluorides, nitrates.

**Diagram:**

[ Brackish Water ] → | Membrane | → [ Pure Water ]

↑ ↓

Pressure Reject salts

**5. Discuss the process of demineralization of water using ion exchange resins.**

**[AU June 2010, June 2012, April/May 2013, May 2016, April/May 2023]**

**Definition:**

* Demineralization is the complete removal of all dissolved salts from water using ion exchange resins.

**Types of Resins:**

1. **Cation exchange resin (RH⁺):**
   * Exchanges H⁺ ions with metal cations.

Ca2++2RH→R2Ca+2H+\text{Ca}^{2+} + 2\text{RH} \rightarrow \text{R}\_2\text{Ca} + 2\text{H}^+

1. **Anion exchange resin (ROH):**
   * Exchanges OH⁻ with anions.

Cl−+ROH→RCl+OH−\text{Cl}^- + \text{ROH} \rightarrow \text{RCl} + \text{OH}^-

**Overall Reaction:**

CaCl2+RH+ROH→R2Ca+RCl+H2O\text{CaCl}\_2 + \text{RH} + \text{ROH} \rightarrow \text{R}\_2\text{Ca} + \text{RCl} + \text{H}\_2\text{O}

**Advantages:**

* Produces very pure water.
* No sludge formation.
* Suitable for high-pressure boilers.

**Regeneration:**

* **Cation resin:** Regenerated with dilute HCl or H₂SO₄.
* **Anion resin:** Regenerated with dilute NaOH.

**Diagram:**

Raw Water → [Cation Resin] → [H⁺ form] → [Anion Resin] → [OH⁻ form] → Pure Water

**UNIT-2 NANOCHEMISTRY**

### ****1. Explain the size dependent properties of nanomaterials.**[AU CEG Dec 2012, June 2014]**

**Size-dependent properties:** When materials are reduced to the nanoscale (1–100 nm), their properties change drastically due to:

* **Increased Surface Area to Volume Ratio**
* **Quantum Confinement Effect**

**Key Properties Affected:**

1. **Optical Properties:**
   * Color and absorption change.
   * Eg: Gold appears red at nano-size.
2. **Mechanical Properties:**
   * Hardness and strength increase.
3. **Electrical Properties:**
   * Conductivity may increase or decrease.
   * Eg: Carbon nanotubes have high conductivity.
4. **Magnetic Properties:**
   * Superparamagnetism in iron oxide nanoparticles.

**Diagram:**

arduino

↓ Particle size → ↑ Surface area → Enhanced reactivity

### ****2. Write an informative note on the properties of nanomaterials.****

**[AU CEG June 2013]**

**Salient Properties of Nanomaterials:**

1. **Mechanical:**
   * High strength, hardness (e.g., nanocrystalline metals).
2. **Optical:**
   * Quantum dots show size-dependent color.
3. **Electrical:**
   * Enhanced or tunable conductivity.
4. **Magnetic:**
   * Nano Fe exhibits superparamagnetism.
5. **Thermal:**
   * High heat resistance and thermal conductivity.
6. **Chemical:**
   * High catalytic activity due to more reactive surface atoms.

**Diagram:**  
Use bar chart to show change in properties vs. particle size.

### ****3. Discuss laser ablation and CVD techniques for the synthesis of nanomaterials.****

**[AU CEG June 2013, Jan 2015, April/May 2023]**

**(i) Laser Ablation:**

* A high-energy laser beam is focused on a solid target in vacuum/gas.
* Target evaporates, forming nanoparticles in the gas phase.

**Steps:**

1. Laser hits target.
2. Atoms vaporize.
3. Cool down and condense into nanoparticles.

**Advantages:**

* High purity.
* Good control of size.

**Diagram:**

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[Laser] → [Target Material] → Vapor → Nanoparticles

**(ii) Chemical Vapor Deposition (CVD):**

* A gas mixture reacts on a heated substrate to deposit a solid nanomaterial layer.

**Steps:**

1. Gas precursors flow into chamber.
2. Substrate heated to initiate chemical reaction.
3. Nanomaterials form on substrate.

**Example:**

* Carbon Nanotube synthesis using methane and Fe catalyst.

**Diagram:**Gas → Reactor → Heated Substrate → Nano Film Deposits

### ****4. What are nanomaterials? Write any four methods of preparation of nanomaterials.****

**[AU CEG Dec 2011]**

**Definition:**

* Nanomaterials have dimensions between 1–100 nm, showing unique properties.

**Four Synthesis Methods:**

1. **Sol-Gel Method** – Liquid-phase synthesis.
2. **Laser Ablation** – Uses high-energy laser.
3. **CVD** – Gas phase deposition.
4. **Ball Milling** – Mechanical size reduction.

**Alternate Answer: Types of Synthesis**  
**[AU Jan 2014, June 2014]**

**(a) Top-Down Approach:**

* Breaking bulk material to nanosize.
* Eg: Ball milling, lithography.

**(b) Bottom-Up Approach:**

* Building from atoms/molecules.
* Eg: Sol-gel, CVD, self-assembly.

### ****5. Explain the preparation of nanomaterials by:****

#### ****i) Sol-Gel Process****

* A wet-chemical technique.
* Metal alkoxides/hydroxides → Sol → Gel → Drying → Calcination → Nanoparticles.

**Steps:**

1. Hydrolysis
2. Condensation
3. Gelation
4. Drying & Calcination

**Advantages:**

* Low temperature.
* High purity.

**Diagram:**

nginx

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Solution → Sol → Gel → Dry → Nanoparticles

#### ****ii) Electrospinning****

* Produces nanofibers using high-voltage electric field.

**Steps:**

1. Polymer solution loaded in syringe.
2. High voltage applied → jet forms.
3. Jet stretches and dries into nanofiber.

**Used for:**

* Tissue engineering, drug delivery.

**Diagram:**Syringe → Electric Field → Jet → Collector with nanofibers

**UNIT-III PHASE RULE AND COMPOSITES**

**1. What is Phase Rule? Explain the terms involved.**

**Phase Rule Equation:**

F=C−P+2F = C - P + 2F=C−P+2

**Where:**

* **F** = Degrees of freedom (number of variables that can be changed independently)
* **C** = Number of components (independent chemical substances)
* **P** = Number of phases (distinct physical forms like solid, liquid, gas)

**Types of Systems:**

* **Invariant (F=0):** No variable can be changed
* **Monovariant (F=1):** One variable can be changed
* **Bivariant (F=2):** Two variables can be changed

**2. Explain one component water system with a neat phase diagram.**

**Component:** Water (H₂O)  
**Phases:** Ice (Solid), Water (Liquid), Vapour (Gas)

**Triple Point:** All three phases coexist at equilibrium (F = 0)  
**Curves:**

* Ice ⇌ Water (Fusion curve)
* Ice ⇌ Vapour (Sublimation curve)
* Water ⇌ Vapour (Vaporization curve)

📌 *Draw P-T phase diagram showing the triple point and curves*

**3. Write a note on simple eutectic system (Pb-Ag) with diagram.**

* Two-component system: Lead (Pb) and Silver (Ag)
* **Eutectic Point:** Lowest temperature where both solids crystallize together
* **Regions:**
  + Solid Pb
  + Solid Ag
  + Liquid
  + Mixtures of solid and liquid

**At eutectic point:**  
C = 2, P = 3, F = 0 (Condensed Phase Rule: F=C−P+1F = C - P + 1F=C−P+1)

📌 *Draw Temperature vs Composition diagram showing eutectic point*

**4. Mention the limitations of the Phase Rule.**

* Only for equilibrium systems
* Not applicable to open systems
* Ignores gravitational/electrical/magnetic fields
* Doesn’t consider rate of reactions
* Can’t handle chemical reactions altering components
* Assumes pure substances and perfect systems

**5. What is condensed Phase Rule? What is the number of Degrees of Freedom at Eutectic Point for a 2-component system?**

**Condensed Phase Rule:**

F=C−P+1F = C - P + 1F=C−P+1

Used when pressure is constant and gas phase is absent.

**At Eutectic Point:**

* C = 2 (e.g., Pb and Ag)
* P = 3 (solid Pb, solid Ag, and liquid)

F=2−3+1=0F = 2 - 3 + 1 = 0F=2−3+1=0

→ System is **invariant**

**UNIT-IV FUELS AND COMBUSTION**

### ****1. What is meant by proximate analysis of coal? What are the quantities estimated in this analysis and their significance. (A.U APRIL-MAY-2015)****

**Proximate analysis** is a method used to determine the **percentage composition** of four basic constituents in coal. It gives a quick idea about the fuel quality and combustion characteristics.

**Quantities Estimated:**

1. **Moisture**
   * Water present in coal (free or combined).
   * **Significance:** Affects heating value; high moisture reduces calorific value and increases transport cost.
2. **Volatile Matter**
   * Materials that get vaporized when coal is heated in absence of air.
   * **Significance:** High volatile matter increases flame length and ease of ignition.
3. **Ash**
   * Non-combustible residue left after burning coal.
   * **Significance:** High ash causes clinker formation, reduces furnace efficiency.
4. **Fixed Carbon**
   * The solid residue left after removal of moisture and volatile matter.
   * **Significance:** Responsible for the generation of heat and acts as the main combustible material.

### ****2. Describe the ultimate analysis of coal. (A.U JUNE-2014)****

**Ultimate analysis** determines the **elemental composition** of coal: Carbon, Hydrogen, Nitrogen, Sulphur, and Oxygen.

**Constituents Estimated:**

1. **Carbon (C):**
   * Main element providing heat.
   * Higher C = higher calorific value.
2. **Hydrogen (H):**
   * Combines with O₂ to form water, releasing heat.
   * Increases flame temperature.
3. **Nitrogen (N):**
   * Inert, does not aid combustion.
   * Too much nitrogen reduces calorific value.
4. **Sulphur (S):**
   * Burns to SO₂ → causes air pollution and corrosion.
   * Controlled to reduce acid rain.
5. **Oxygen (O):**
   * Decreases heating value as it indicates partially oxidized carbon.

### ****3. Differentiate between Proximate and Ultimate Analysis. (JAN-2016)****

| **Aspect** | **Proximate Analysis** | **Ultimate Analysis** |
| --- | --- | --- |
| Purpose | Physical composition | Elemental composition |
| Constituents Estimated | Moisture, volatile matter, ash, fixed carbon | C, H, N, S, O |
| Use | Grading coal, combustion behavior | Designing combustion systems, pollution analysis |
| Simplicity | Simple and quick | Complex and detailed |
| Equipment Required | Basic furnace and balance | Advanced analytical instruments |

### ****4. What is proximate analysis? (A.U JUNE 2016)****

**Proximate analysis** is a basic technique to determine four important properties of coal: **moisture, volatile matter, ash, and fixed carbon.**

* It helps in **grading coal**, estimating **combustion efficiency**, and selecting the right fuel for **industrial purposes.**

### ****5. What is metallurgical coke? How is it superior to coal? Describe any one method of manufacturing metallurgical coke. (A.U APRIL-MAY-2015, APRIL/MAY 2023)****

**Metallurgical coke** is a porous, carbon-rich, strong, and hard material obtained by **destructive distillation of coking coal** in the absence of air.

**Superiority over coal:**

* Higher **calorific value**
* **Stronger and porous**, ideal for use in blast furnaces
* Burns with **no smoke**
* **No impurities** like moisture or volatile matter

### ****Method of Manufacturing:****

#### ****Otto-Hoffmann Byproduct Oven Method**** (Most common industrial method)

**Process:**

1. **Coal is charged** into narrow silica chambers in the absence of air.
2. Heated to ~1200°C for 12–20 hours.
3. **Volatile by-products** (tar, ammonia, benzene, etc.) are collected and condensed.
4. After carbonization, coke is pushed out and cooled using **wet quenching or dry cooling.**

**Advantages:**

* Produces **high-quality coke**
* Recovers valuable **by-products**
* Used in **steel industries** and **metallurgy**

**UNIT – V- ENERGY SOURCES AND STORAGE DEVICES**

### 1) ****Explain the components and their functions of a nuclear reactor with a neat diagram. Give the working of a light water nuclear power plant.**** (AU June 2009, May 2015, May 2017)

#### Components and Functions of a Nuclear Reactor:

A nuclear reactor consists of the following key components:

* **Fuel Rods**: These contain fissile material such as uranium-235 or plutonium-239. These materials undergo nuclear fission, releasing energy in the form of heat.
* **Moderator**: Usually made of water, heavy water, or graphite, the moderator slows down the fast neutrons produced during fission, allowing them to sustain the chain reaction.
* **Control Rods**: Made from materials that absorb neutrons (such as boron or cadmium), control rods are used to regulate the rate of the nuclear reaction. They can be inserted into or withdrawn from the reactor core to control the reaction.
* **Coolant**: The coolant (usually water, gas, or liquid metal) removes heat from the reactor core and transfers it to the steam generator. It also helps to maintain the temperature and pressure within safe limits.
* **Reactor Pressure Vessel (RPV)**: A thick-walled container that houses the reactor core, it provides structural integrity and contains the pressurized coolant.
* **Containment Structure**: This is a thick concrete shell designed to prevent the escape of radioactive materials in case of an accident.
* **Steam Generator**: In a nuclear power plant, the steam generator uses the heat from the coolant to convert water into steam, which is used to drive the turbine.

#### Working of a Light Water Nuclear Power Plant:

In a light water nuclear power plant, the nuclear fission process takes place in the reactor core. The heat produced by fission is transferred to the coolant (light water) circulating through the core. The coolant removes the heat and is pumped to a heat exchanger or steam generator, where it heats a secondary loop of water to produce steam. The steam then drives a turbine connected to a generator, producing electricity. After passing through the turbine, the steam is condensed back into water in a cooling tower and returned to the system.

**2) What is a photovoltaic cell? Explain the principle and working of a solar cell with a neat diagram. (AU Jan 2010, Dec 2014, May 2015)**

#### Photovoltaic Cell:

A photovoltaic cell, commonly known as a solar cell, is a semiconductor device that converts light energy directly into electrical energy through the photovoltaic effect.

#### Principle of Solar Cell:

The principle of a solar cell is based on the photovoltaic effect, where light energy (usually from the sun) is absorbed by semiconductor materials like silicon. This absorption of light causes the electrons in the material to become excited and move, creating electron-hole pairs. The movement of these electrons generates an electric current.

#### Working of a Solar Cell:

* **Absorption of Light**: When sunlight strikes the surface of the solar cell, it excites the electrons in the semiconductor material (usually silicon).
* **Generation of Electron-Hole Pairs**: The energy from the sunlight causes electrons to be knocked loose from their atoms, creating electron-hole pairs.
* **Electric Field**: The solar cell has a built-in electric field created by the junction of two types of silicon: p-type (positive) and n-type (negative). The electric field pushes the electrons towards the n-type side and the holes towards the p-type side.
* **Flow of Current**: This movement of electrons creates an electric current that can be extracted by attaching metal contacts on the surface of the solar cell.

**3) How is wind energy harnessed? What are its advantages and limitations? (AU May 2015, Jan 2016, May 2016)**

#### Harnessing Wind Energy:

Wind energy is harnessed using wind turbines that convert the kinetic energy of the wind into mechanical energy, which is then converted into electricity.

* **Wind Turbine**: A wind turbine consists of blades that capture the wind's kinetic energy. The blades are connected to a rotor that spins when wind blows.
* **Generator**: The spinning rotor turns the generator, converting mechanical energy into electrical energy.
* **Transmission System**: The generated electricity is transmitted through wires to the grid or stored in batteries.

#### Advantages:

* **Renewable Energy Source**: Wind is a renewable, inexhaustible source of energy.
* **Environmentally Friendly**: Wind energy generation produces no harmful emissions, making it environmentally friendly.
* **Low Operating Costs**: Once installed, wind turbines have low maintenance and operating costs.

#### Limitations:

* **Intermittency**: Wind energy generation is dependent on wind speed, which is not always consistent.
* **Noise Pollution**: Wind turbines can produce noise, which can be a nuisance in certain areas.
* **Aesthetic Concerns**: Some people find the appearance of wind turbines in the landscape unattractive.

### 4) ****What are lead accumulators? Explain the construction and functioning of a lead-acid battery.**** (AU Dec 2014, June 2015, May 2016, April/May 2023)

#### Lead Accumulators (Lead-Acid Batteries):

Lead-acid batteries are rechargeable electrochemical batteries commonly used in vehicles and backup power systems. They consist of lead dioxide (PbO2) as the positive electrode, sponge lead (Pb) as the negative electrode, and a sulfuric acid (H2SO4) solution as the electrolyte.

#### Construction:

* **Positive Plate (Lead Dioxide, PbO2)**: The positive electrode is made of lead dioxide.
* **Negative Plate (Sponge Lead, Pb)**: The negative electrode is made of sponge lead.
* **Electrolyte**: The electrolyte is a dilute sulfuric acid solution (H2SO4).
* **Separator**: A porous separator is used to prevent the direct contact of the positive and negative plates while allowing the flow of ions.

#### Functioning:

During discharge:

* The lead dioxide (PbO2) on the positive plate reacts with the sulfuric acid (H2SO4) to form lead sulfate (PbSO4) and water.
* The sponge lead (Pb) on the negative plate also reacts with the sulfuric acid to form lead sulfate (PbSO4).
* This reaction generates electricity as electrons flow from the negative to the positive plate through the external circuit.

During charging:

* The battery is connected to an external power source, which reverses the chemical reactions, converting lead sulfate (PbSO4) back into lead dioxide (PbO2) and sponge lead (Pb) at the respective plates.

### 5) ****What is a fuel cell? Explain the working of a hydrogen-oxygen fuel cell.**** (AU Dec 2014, Jan 2016, May 2016, May 2017)

#### Fuel Cell:

A fuel cell is an electrochemical device that converts the chemical energy of a fuel (usually hydrogen) and an oxidant (usually oxygen) directly into electricity, heat, and water, through a chemical reaction.

#### Working of Hydrogen-Oxygen Fuel Cell:

* **Anode (Hydrogen Side)**: At the anode, hydrogen gas (H2) is supplied. Hydrogen molecules are split into protons (H+) and electrons (e-) by a catalyst.
* **Cathode (Oxygen Side)**: Oxygen gas (O2) is supplied to the cathode. The electrons travel through an external circuit to create an electric current.
* **Electrolyte**: The electrolyte allows only the protons (H+) to pass through to the cathode while blocking the electrons.
* **Reaction**: At the cathode, the protons combine with the oxygen and the electrons (which travel through the external circuit) to form water (H2O).

The overall reaction is: 2H2+O2→2H2O+Electricity2H\_2 + O\_2 \rightarrow 2H\_2O + \text{Electricity}2H2​+O2​→2H2​O+Electricity

#### Advantages of Fuel Cells:

* **High Efficiency**: Fuel cells are highly efficient in converting chemical energy to electrical energy.
* **Environmentally Friendly**: The only byproduct is water, making it a clean energy source.
* **Quiet Operation**: Unlike combustion engines, fuel cells operate silently.

#### Limitations:

* **Cost**: Fuel cells are expensive due to the use of precious metals like platinum as catalysts.
* **Storage of Hydrogen**: Storing hydrogen gas requires high pressure or cryogenic temperatures, making it challenging to store and transport.