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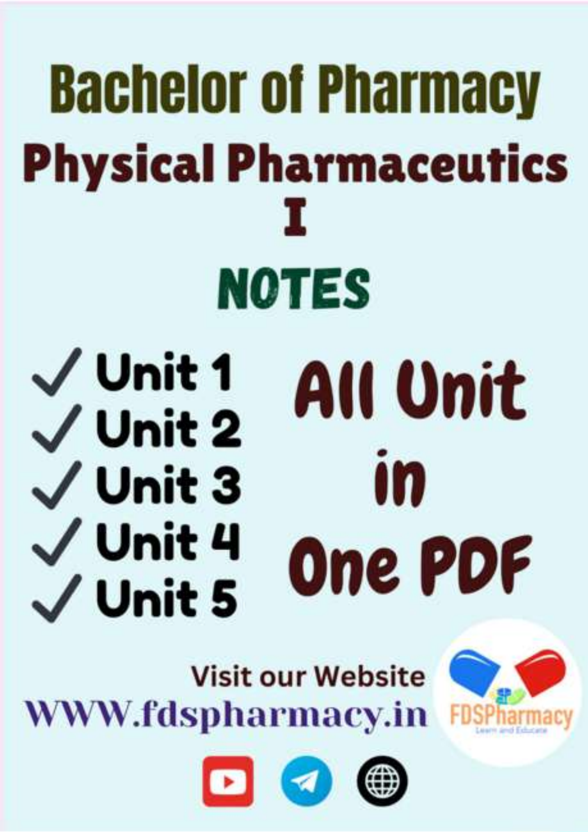

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PHYSICAL PHARMACEUTICS - I

UNIT 3

TOPIC :

- **Surface and interfacial phenomenon :** Liquid interface, surface & interfacial tensions, surface free energy, measurement of surface & interfacial tensions, spreading coefficient, adsorption at liquid interfaces, surface active agents, HLB Scale, solubilisation, detergency, adsorption at solid interface.

Surface & Interface

Interface

- An interface is the boundary present at the junction of two different phases.
- Depending on the nature of the two phases (solid, liquid, or gas), different types of interfaces can exist.

Types of Interfaces

1. **Solid–Solid Interface**
   (e.g., grain boundaries in metals)
2. **Solid–Liquid Interface**
   (e.g., a solid immersed in water)
3. **Liquid–Liquid Interface**
   (e.g., oil and water)
4. **Solid–Gas Interface**
   (e.g., surface of a metal exposed to air)
5. **Liquid–Gas Interface**
   (e.g., water surface exposed to air)

Surface

- A surface refers specifically to the boundary between a gas and a liquid or a gas and a solid.
- In simple terms, it is the outermost layer or boundary of a liquid or solid in contact with a gas (usually air).

Surface Tension

- Surface tension is the tensile force acting at the surface of a liquid, which tends to minimize its surface area.
- Molecules inside the bulk of a liquid are surrounded equally by other molecules, resulting in no net force.
- However, molecules at the surface experience unequal attraction—they are pulled inward by the bulk molecules but not outward (since there's air above).
- This inward cohesive force causes the surface to behave like a stretched elastic sheet, minimizing surface area.

Definition

- Surface tension is defined as the force acting along the surface of a liquid at right angles to a line of unit length.
- Alternatively, it is the tendency of the surface of a liquid to contract and acquire the least possible surface area.

Symbol and Unit

- Denoted by: γ (gamma)
- SI Unit: N/m (Newton per meter)
- CGS Unit: dyne/cm

Interfacial Tension

- Interfacial tension is defined as the force per unit length that exists at the interface between two immiscible liquids (e.g., oil and water).
- It is caused by unequal attractive forces between molecules at the boundary of the two phases.

Key Points

- Unit: Newton per meter (N/m)
- Interfacial tension is similar in concept to surface tension, but it occurs between two liquids, not between a liquid and gas.
- Interfacial tension is generally lower than surface tension, because:
    - Adhesive forces (attraction between dissimilar molecules) exist at the interface.
    - Greater the adhesive force, lower will be the interfacial tension.

Types of Intermolecular Forces

There are mainly two types of intermolecular forces relevant to surface and interfacial phenomena:

1. Cohesive Forces

- These are the intermolecular forces of attraction between similar molecules.
  (Example: Water–Water, Oil–Oil)
- These forces are responsible for surface tension and maintaining the integrity of each individual phase.

2. Adhesive Forces

- These are the intermolecular forces of attraction between dissimilar molecules.
  (Example: Water–Oil, Water–Glass)
- These forces play a major role in reducing interfacial tension.
- Strong adhesive forces can lead to better mixing or wetting between phases.

Surface Free Energy

- Surface Free Energy is the work required to increase the surface area of a liquid by 1 square meter.
- It represents the energy needed to overcome surface tension and create new surface.

Unit: Joules per square meter (J/m^2)
Since 1 N/m = 1 J/m^2, it has the same numerical value as surface tension.

Conceptual Understanding

- A liquid naturally tries to minimize its surface area due to surface tension.
- If we expand the surface, work must be done against surface tension.
- This work is stored as surface free energy.

Estimation of Surface Free Energy (Soap Film Method)

Experimental Setup

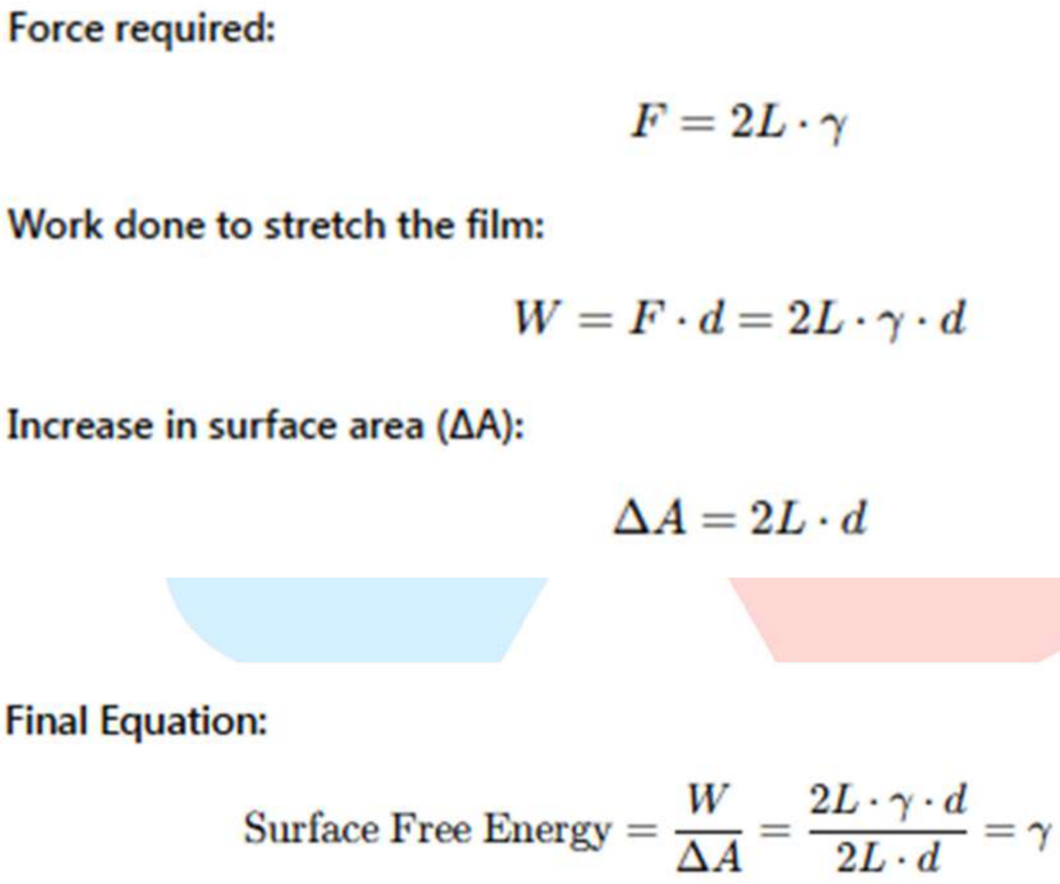
- Consider a rectangular wire frame: ABCD.
- The side AD is movable and has a length L.
- A soap film is formed across the frame.
- Since the soap film has two surfaces (top and bottom), surface tension acts on both sides.

Process

- A force F is applied to pull the movable wire AD outward to a new position A'D′ by a distance d.

Now

- Total length under surface tension = **2 × L** (for both surfaces)
- Surface tension = **γ** (gamma)



Force required:

$$F = 2L \cdot \gamma$$

Work done to stretch the film:

$$W = F \cdot d = 2L \cdot \gamma \cdot d$$

Increase in surface area (ΔA):

$$\Delta A = 2L \cdot d$$

Final Equation:

$$\text{Surface Free Energy} = \frac{W}{\Delta A} = \frac{2L \cdot \gamma \cdot d}{2L \cdot d} = \gamma$$

Therefore,
Surface Free Energy = Surface Tension (γ)
(but units differ: J/m² vs N/m, though numerically equal)

Measurement of Surface and Interfacial Tension

- Surface and interfacial tensions can be measured by various experimental methods. These methods help determine the tensile force acting at liquid interfaces, which is important in formulating emulsions, suspensions, and dosage forms.
- There are several methods used to measure surface and interfacial tension. The most common ones include:

1. Capillary Rise Method
2. Drop Weight Method
3. Drop Count Method
4. Wilhelmy Plate Method
5. Du Noüy Ring Method

1. Capillary Rise Method

Principle

When a narrow capillary tube is dipped vertically into a liquid, the liquid rises inside the tube to a certain height.
This rise occurs due to the adhesive force between the liquid and the glass surface of the capillary.

- Adhesive force pulls the liquid upward.
- Cohesive force holds the liquid together.
- The rise continues until the upward surface tension force is balanced by the downward gravitational force (weight of liquid column).

Calculation of Surface Tension

Let:

- γ = surface tension (N/m)
- r = radius of the capillary tube (m)
- h = height of liquid rise in the capillary (m)
- ρ = density of the liquid (kg/m^3)
- g = acceleration due to gravity ($9.8\ m/s^2$)
- θ = contact angle (for water on glass, $\theta \approx 0°$)

Upward Force (due to surface tension):

$$F_{\text{up}} = 2\pi r \cdot \gamma \cdot \cos\theta$$

(Since $\theta \approx 0^\circ$, $\cos\theta = 1$)

$$F_{\text{up}} = 2\pi r\gamma$$

Downward Force (due to weight of liquid column):

$$F_{\text{down}} = \text{mass} \times g = \rho \cdot (\pi r^2 h) \cdot g$$

Equating Upward and Downward Forces:

$$2\pi r\gamma = \rho g \pi r^2 h$$

Simplifying:

$$\gamma = \frac{\rho g r h}{2}$$

Final Formula:

$$\boxed{\gamma = \frac{\rho g r h}{2}}$$

This is the formula used to calculate surface tension using the Capillary Rise Method.

2. Drop Weight Method

(Using a **Stalagmometer**)

Principle

- → The Drop Weight Method is a comparative technique used to determine the surface tension of an unknown liquid by comparing it with a standard liquid of known surface tension.
- → It is based on the fact that the weight of a drop falling from a capillary tube is directly proportional to its surface tension.
- → A stalagmometer (a special type of glass dropper) is used in this method.

Apparatus

- Stalagmometer – a narrow glass tube with two marks (A and B) and a fine capillary tip at the bottom.
- Standard liquid (e.g., water or ethanol)
- Test liquid

Procedure

1. Fill the stalagmometer with the standard liquid up to mark A.
2. Allow the liquid to fall slowly through the capillary tip and count or weigh approximately 20–30 drops that fall between marks A and B.
3. Calculate the average weight of one drop of standard liquid.
4. Repeat the same steps with the test liquid.
5. Use the weights of individual drops to calculate surface tension.

Forces Acting on the Drop

When a drop forms at the tip of the stalagmometer:

- ➢ **Downward force**: Weight of the drop = mg

- **Upward force**: Surface tension γ acts along the circumference of the capillary
- At the point when the drop detaches:
- Weight of the drop=Force due to surface tension⇒$mg=2\pi r\gamma$
- (But in practice, we use a comparative formula instead.)

Comparative Calculation Formula:

Let:

- m_1= weight of 1 drop of test liquid
- m_2 = weight of 1 drop of standard liquid
- γ_1 = surface tension of test liquid
- γ_2 = surface tension of standard liquid

$$\boxed{\gamma_1 = \frac{m_1}{m_2} \cdot \gamma_2}$$

3. DROP COUNT METHOD

(Also called: Stalagmometric Drop Number Method)

Principle

- The Drop Count Method is similar to the Drop Weight Method, but instead of weighing the drops, we count the number of drops of both standard and test liquids that fall from a stalagmometer for a fixed volume.
- Surface tension is inversely proportional to the number of drops formed.
- Fewer drops = heavier drops = higher surface tension.

Apparatus

- **Stalagmometer**
- Standard liquid (with known surface tension)
- Test liquid
- Beaker, stopwatch, and drop counter

Procedure

1. Fill the stalagmometer with a known volume (say 1 mL) of standard liquid.
2. Allow the liquid to fall drop by drop and count the number of drops formed between two marks.
3. Repeat the same with the test liquid, using the same volume.
4. Note the densities of both liquids (ρ_1 and ρ_2).
5. Use the following formula to calculate the surface tension of the test liquid.

Formula:

Let:

- $\gamma1$= Surface tension of test liquid
- $\gamma2$ = Surface tension of standard liquid
- $\rho1$ = Density of test liquid
- $\rho2$= Density of standard liquid
- n1 = Number of drops of test liquid
- n2= Number of drops of standard liquid

$$\boxed{\gamma_1 = \gamma_2 \cdot \frac{\rho_1 \cdot n_2}{\rho_2 \cdot n_1}}$$

4. WILHELMY PLATE METHOD

(For measurement of Surface and Interfacial Tension)

Principle

This method uses the force of adhesion between a liquid and a thin vertical plate (usually of platinum or glass) to calculate surface or interfacial tension.

- When the plate is immersed in a liquid, it experiences a downward force due to surface tension.
- A torsion balance is used to measure this force, which is directly related to the surface or interfacial tension.

Apparatus

- Thin rectangular Wilhelmy plate (platinum/glass/mica)
- Torsion balance or microbalance
- Beaker containing the test liquid

Procedure

1. The clean and dry plate is vertically suspended using a torsion balance.
2. The plate is slowly lowered until it just touches the surface of the liquid.
3. The liquid wets the plate and pulls it downward due to surface tension.
4. The downward force (F) is measured by the torsion balance.
5. This force is then used to calculate the surface tension.

Conditions

- The plate must be completely wetted by the liquid (contact angle ≈ 0°).
- If not completely wetted, a correction factor must be used.

Formula

$$\boxed{\gamma = \frac{F}{2(L + d)}}$$

Where:

- γ = Surface or Interfacial Tension (dyne/cm or N/m)
- F = Force measured by torsion balance (dynes or Newtons)
- L = Length of the plate (cm)
- d = Thickness (or width) of the plate (cm)
- 2(L+d) = Total perimeter in contact with the liquid (assuming both sides are wetted)

5. DU NOUY RING METHOD

(Also known as Ring Detachment Method or Du Noüy Tensiometer)

Principle

This method is based on the force required to detach a platinum-iridium ring from the surface of a liquid.

- The ring is first immersed just below the surface of the liquid.
- Then, a force is applied upward to detach the ring.
- The maximum force recorded just before detachment is used to calculate the surface tension.

Apparatus

- Du Noüy Tensiometer
- Platinum-iridium ring (precisely made and clean)
- Beaker containing test liquid
- Balance or force-measuring device

Procedure

1. The clean ring is submerged horizontally just below the surface of the liquid.
2. Slowly, the ring is pulled upward using a torsion or force balance.
3. As the ring rises, a film of liquid clings to it.
4. The maximum force (F) required to detach the ring is measured.
5. This force is used to compute the surface tension.

Formula

$$\boxed{\gamma = \frac{F}{2\pi R} \times f}$$

Where:

- γ = Surface tension (dyne/cm or N/m)
- F = Measured force (dynes or Newtons)
- R = Radius of the ring (cm)
- f = Correction factor (accounts for liquid adhesion, ring size, shape, etc.)

Spreading Coefficient

➢ The spreading coefficient (S) measures the ability of one liquid to spread over another. It is particularly relevant when a drop of liquid (like oleic acid) is placed on the surface of another liquid (like water) and forms a thin film.

Spreading:

- Spreading occurs when a liquid spontaneously forms a film over another liquid surface.
- This occurs only if the adhesive forces (between two liquids) are greater than the cohesive forces (within the spreading liquid).

Formula for Spreading Coefficient:

$$\boxed{S = W_A - W_C}$$

Where:

- SSS = Spreading Coefficient
- WAW_AWA = Work of Adhesion
- WCW_CWC = Work of Cohesion

Work of Cohesion (W_C)

- It is the energy required to separate molecules of a pure liquid from each other to form two surfaces.
- For a liquid with surface tension γL,

$$W_C = 2\gamma_L$$

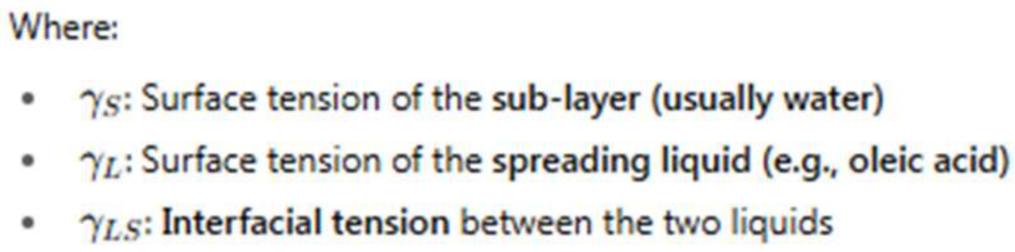
Work of Adhesion (W_A)

- It is the energy required to separate two immiscible liquids (like oil and water) into two interfaces.
- For two liquids with surface tensions γS and γL , and interfacial tension γLS,

$$W_A = \gamma_S + \gamma_L - \gamma_{LS}$$

Therefore, the Spreading Coefficient becomes:

$$\boxed{S = \gamma_S - (\gamma_L + \gamma_{LS})}$$



Where:

- γ_S: Surface tension of the **sub-layer (usually water)**
- γ_L: Surface tension of the **spreading liquid (e.g., oleic acid)**
- γ_{LS}: **Interfacial tension between the two liquids**

Condition for Spreading:

- **If S>0 :** Spreading occurs spontaneously
- **If S<0 :** Spreading will not occur

Applications of Spreading Coefficient in Pharmacy:

1. **Formulation of Creams and Lotions**
    - Proper spreading ensures uniform application and better absorption of active ingredients.
2. **Emulsion Stability**
    - Aids in predicting phase separation and helps in selecting emulsifying agents.
3. **Tablet Cooling and Coating**
    - Ensures uniform film coating during tablet manufacturing.

Adsorption at Liquid Surfaces

- Adsorption at liquid surfaces refers to the accumulation or adhesion of molecules or ions at the surface (interface) of a liquid.
  It is a surface phenomenon, unlike absorption which occurs throughout the bulk of the material.

Types of Adsorption:

There are **two main types** of adsorption at liquid surfaces:

1. Positive Adsorption

- In positive adsorption, the solute molecules accumulate at the surface of the liquid.
- This leads to a higher concentration of the solute at the surface than in the bulk of the liquid.

Effects of Positive Adsorption:

- Surface tension decreases
- Surface free energy decreases

Example: Adsorption of organic solutes (like alcohol or soap) on the surface of water.

2. Negative Adsorption

- In negative adsorption, the solute molecules prefer to remain in the bulk of the liquid rather than accumulating at the surface.
- This results in a lower concentration of solute at the surface compared to the bulk.

Effects of Negative Adsorption:

- Surface tension increases
- Surface free energy increases

Example: Adsorption of inorganic electrolytes like NaCl in water (they stay in the bulk phase).

Applications in Pharmacy:

1. **Formulation of emulsions and suspensions**
    - Surface-active agents (surfactants) lower surface tension via positive adsorption.
2. **Drug solubility enhancement**
    - Surfactants help increase drug solubility by adsorbing at interfaces.
3. **Controlled drug release**
    - Adsorption principles are used in drug delivery systems like micelles, liposomes, and colloids.

Surface Active Agents (Surfactants)

- Surface Active Agents, also called Surfactants, are compounds that lower the surface tension of a liquid or reduce the interfacial tension between two immiscible liquids (like oil and water).

  They are amphiphilic, meaning they contain both:
    - Hydrophilic group – water-loving (polar)
    - Hydrophobic group – water-hating (non-polar)

Structure

Group	Nature
Hydrophilic	Polar, water soluble
Hydrophobic	Non-polar, oil soluble

When surfactants are added to water:

- The hydrophilic head interacts with water.
- The hydrophobic tail avoids water and aggregates to form micelles.

Micelle Formation

- A micelle is an aggregate of surfactant molecules formed in aqueous solution above a certain concentration.
- In a micelle:
    - Hydrophobic tails face inward (core)
    - Hydrophilic heads face outward towards water

Critical Micelle Concentration (CMC)

- The minimum concentration of surfactant above which micelles start forming is called the Critical Micelle Concentration.

Core of the Micelle

- The hydrophobic center of the micelle is called the core, which can trap oily or lipophilic drugs.

Types of Surfactants

Surfactants are classified based on the **nature of the charge** on their hydrophilic head:

1. Anionic Surfactants

- Carry a negative charge on the hydrophilic head.
- Most commonly used in industrial applications.
- **Examples:**
    - Soaps of alkali metals (e.g., sodium stearate)
    - Alkyl sulfates
- **Properties:**
    - Unpleasant taste
    - Irritant to mucous membranes
    - Not suitable for internal use

2. Cationic Surfactants

- Carry a positive charge on the hydrophilic head.
- Often used as antiseptics or disinfectants.
- **Examples:**
    - Cetrimide
    - Benzalkonium chloride
- **Properties:**
    - More expensive than anionic surfactants
    - Used externally for cleaning wounds, surgical equipment, etc.

3. Ampholytic (Zwitterionic) Surfactants

- Contain both positive and negative charges depending on the pH of the environment:
    - At low pH: act as cationic
    - At high pH: act as anionic
    - At neutral pH: act as zwitterion (both charges)
- **Applications:**
    - Cosmetics, shampoos, toothpaste, and mild skin cleansers

4. Non-Ionic Surfactants

- Do not ionize in aqueous solution.
- The hydrophilic part contains non-dissociable groups (e.g., -OH, ether groups).
- **Properties:**
  - Stable across a wide pH range
  - Less irritant
  - Pharmaceutically important
- **Examples:**
  - Glycerol
  - Polyoxyethylene ethers
  - Polysorbates (e.g., Tween 80)

Applications of Surfactants in Pharmacy:

- Emulsification – Forming emulsions (oil in water or water in oil)
- Wetting Agents – Improving spreadability of creams/ointments
- Solubilization – Enhancing solubility of poorly soluble drugs
- Suspension Stabilizers – Preventing particle aggregation
- Disinfectants and Antiseptics – (e.g., benzalkonium chloride)
- Foaming Agents – In soaps, toothpaste, shampoos
- Drug Delivery – Micelles and liposomes for targeted delivery

HLB SCALE

(Hydrophilic-Lipophilic Balance)

→ The HLB scale is a numerical system used to classify surfactants based on the balance between their hydrophilic (water-loving) and lipophilic (oil-loving) portions.

History

- Introduced by William C. Griffin in 1949.
- Used to predict the function and application of surfactants in emulsions and other formulations.

HLB Value Range

- The HLB values range from 1 to 20.
- Low HLB (1–10) → Lipophilic (oil-loving)
- High HLB (10–20) → Hydrophilic (water-loving)

HLB Value	Nature of Surfactant
1–3	Anti-foaming agents
3–8	**W/O emulsifying agents**
7–9	Wetting and spreading agents
8–16	**O/W emulsifying agents**
13–16	Detergents
16–20	Solubilizing agents

Interpretation

HLB Value	Behavior/Use
< 10	Lipophilic surfactants (for W/O emulsions)
> 10	Hydrophilic surfactants (for O/W emulsions)

Determination of HLB Value:

Method 1: Griffin’s Method (for non-ionic surfactants)

$$\boxed{HLB = \frac{E + P}{5}}$$

Where:

- E = weight % of ethylene oxide in the molecule
- P = weight % of polyhydric alcohol group

Method 2: Davies' Method (based on saponification and acid value)

$$\boxed{HLB = 20 \times \left(\frac{S}{A}\right)}$$

Where:

- S = Saponification value
- A = Acid value

Applications of HLB System

1. **Pharmaceutical Formulations**
   - Creams, lotions, and emulsions based on desired oil/water system.
2. **Cosmetic Industry**
   - To choose appropriate emulsifiers for skin and hair products.
3. **Food Industry**
   - In making stable food emulsions (e.g., margarine, mayonnaise).
4. **Agriculture**
   - Helps formulate herbicides, fungicides, and pesticides.
5. **Detergents & Cleansers**
   - Choosing surfactants based on whether foaming or solubilizing is desired.
6. **Solubilization of Drugs**
   - Higher HLB surfactants are used to solubilize poorly water-soluble drugs.

Limitations of the HLB System

1. **Temperature Sensitivity:**
   - It doesn’t account for changes in emulsion stability due to temperature.
2. **Surfactant Concentration Ignored:**
   - The HLB value doesn’t indicate the optimal concentration required.
3. **Multiple Surfactants in a Formula:**
   - It doesn't define stability of complex formulations with mixed surfactants.
4. **No Polarity Index:**
   - It lacks a scale for the degree of polarity of hydrophilic or lipophilic groups.

SOLUBILIZATION

- Solubilization is defined as the process of increasing the solubility of a poorly water-soluble substance using surface active agents (surfactants).
- It allows drugs that are not easily dissolved in water to become soluble by incorporating them into micelles.

Mechanism of Solubilization

- Surfactants in aqueous solution form micelles above a certain concentration known as the Critical Micelle Concentration (CMC).
- The drug molecules are entrapped within these micelles, making them appear soluble in water.

Micelle Structure

- Hydrophobic (non-polar) drugs are solubilized in the core of the micelle (formed by the hydrophobic tails).
- Hydrophilic (polar) drugs can get adsorbed onto the micelle surface (near the hydrophilic heads).

Steps Involved

1. Surfactant molecules align at the air-water or oil-water interface.
2. Above CMC, they aggregate to form micelles.
3. Poorly soluble drug molecules get entrapped inside or adsorbed onto micelles.
4. This increases the apparent solubility of the drug.

Types of Solubilization:

Type of Solubilization	Based On
Aqueous Solubilization	Use of surfactants in water to solubilize hydrophobic drugs
Co-solvent Solubilization	Addition of water-miscible solvents (e.g., ethanol, propylene glycol)

Factors Affecting Solubilization

1. Type of surfactant
2. Concentration of surfactant
3. Temperature
4. pH of the medium
5. Nature of solute (drug)

Importance / Applications of Solubilization

1. Pharmaceutical Industry
   - Enhances solubility and bioavailability of poorly water-soluble drugs.
2. Formulation Development
   - Used in injectables, syrups, suspensions, and topical products.
3. Cosmetic Industry
   - Helps in preparing clear shampoos, lotions, and creams.
4. Food Industry
   - Used to incorporate oil-soluble flavors and vitamins into aqueous systems.
5. Drug Delivery Systems
   - Forms the basis for micellar drug delivery, liposomes, and nanoemulsions.

Advantages of Solubilization

- Improves dissolution rate
- Enhances absorption and bioavailability
- Reduces dose size and side effects
- Allows formulation of clear solutions

Detergency

- Detergency is defined as the phenomenon of removing dirt, grease, or foreign particles from solid surfaces (such as fabric, skin, metal, or glass) with the help of surfactants.
- It involves both the removal and prevention of redeposition of dirt.

Mechanism of Detergency

1. Surfactants lower the surface tension of water, allowing it to spread and penetrate more easily into dirty surfaces.
2. They reduce the adhesion forces between the dirt and the surface, making it easier to dislodge the dirt.
3. The hydrophobic tail of the surfactant attaches to the oily or greasy dirt.
4. The hydrophilic head interacts with water, helping to lift and suspend the dirt particles.
5. After removal, surfactant molecules adsorb onto the dirt particles, imparting a charge (usually negative), which:
    - Prevents re-agglomeration
    - Keeps the dirt suspended in the cleaning solution
    - Prevents redeposition onto the cleaned surface

Role of Surfactants in Detergency

- **Wetting agents:** Help water spread and reach the dirt
- **Emulsifiers:** Help solubilize oils and greases
- **Dispersants:** Prevent dirt particles from settling back
- **Foaming agents:** Improve scrubbing and cleaning feel (in some cases)

Applications of Detergency

1. **Household Cleaning**
    - Detergents in soaps, dishwashing liquids, laundry powders
2. **Industrial Cleaning**
    - Cleaning of machinery, surfaces, and instruments
3. **Food Industry**
    - Cleaning of utensils, food processing equipment
4. **Pharmaceutical and Hospital Settings**
    - Cleaning of surgical tools, hospital floors, and surfaces
5. **Personal Hygiene**
    - Shampoos, body washes, and facial cleansers rely on detergent action

Examples of Detergents

- **Anionic surfactants:** Sodium lauryl sulfate (SLS), used in shampoos and toothpaste
- **Non-ionic surfactants:** Used in pharmaceutical and cosmetic formulations due to mildness
- **Cationic surfactants:** Benzalkonium chloride, used in disinfectants

Adsorption at Solid Interface

- Adsorption at solid interface is a surface phenomenon where molecules (adsorbate) from a gas or liquid accumulate on the surface of a solid (adsorbent), forming a molecular or atomic layer.
- It occurs due to intermolecular forces (van der Waals forces or chemical bonds) between the solid surface and the adsorbed species.

Types of Adsorption at Solid Interfaces

1. **Physical Adsorption (Physisorption)**
    - Involves weak van der Waals forces
    - Reversible in nature
    - Multilayer adsorption possible
    - Low heat of adsorption (20–40 kJ/mol)
    - Increases at low temperature and high pressure
    - Example: Adsorption of gases like N_2, H_2 on activated charcoal
2. **Chemical Adsorption (Chemisorption)**
    - Involves chemical bond formation between adsorbent and adsorbate
    - Irreversible process
    - Monolayer adsorption only
    - High heat of adsorption (80–400 kJ/mol)
    - Increases at high temperature
    - Example: Adsorption of O_2 on metal surfaces

Factors Affecting Adsorption at Solid Interface

1. **Nature of Adsorbent** (porosity, surface area)
2. **Nature of Adsorbate** (molecular size, polarity)
3. **Temperature** – Physisorption ↓ with temp, Chemisorption ↑ with temp
4. **Pressure** – Higher pressure favors physisorption (in gases)
5. **Surface Area** – Greater surface area = more adsorption
6. **Concentration** – Higher solute concentration increases adsorption

Applications in Pharmacy

- ✓ Activated charcoal for poisoning and toxin removal
- ✓ Tablet formulation – adsorption of flavors and colors
- ✓ Controlled drug delivery – adsorption onto carriers
- ✓ Chromatography – based on differential adsorption
- ✓ Taste masking – drug adsorbed onto inert carrier
- ✓ Filtration – removal of impurities by adsorption