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PHYSICAL PHARMACEUTICS - II

UNIT 2

TOPIC :

- **Deformation of solids :** Plastic and elastic deformation, Heckel equation, Stress, Strain, Elastic Modulus

Deformation of Solids

- Deformation is the process by which a solid material changes its shape, size, or both when an external force (stress) is applied.
- The internal structure of the solid resists the applied force, but if the force is strong enough → deformation occurs.
- Deformation may be:
  - **Temporary (elastic)** → reversible
  - **Permanent (plastic)** → irreversible

Types of Deformation

1. **Elastic Deformation** → Temporary, reversible change.
2. **Plastic Deformation** → Permanent, irreversible change.

Forces Involved in Deformation

1. **Tensile Force** → Stretches the material.
2. **Compressive Force** → Compresses or shortens the material.
3. **Shear Force** → Causes sliding of parallel layers.
4. **Torsional Force** → Twisting force.

Elastic Deformation

- A type of deformation where a material temporarily changes shape or size under an applied force but returns to its original shape once the force is removed.
- It is a reversible process.

Characteristics

- **Reversible** → No permanent change.
- **Instantaneous** → Occurs as soon as stress is applied and removed.
- **Occurs within the elastic limit** of the material.
- **Obeys Hooke's Law**.

Hooke's Law

"Within the elastic limit, stress applied on a body is directly proportional to the strain produced in it."

$$\text{Stress} \propto \text{Strain} \quad \text{or} \quad \frac{\text{Stress}}{\text{Strain}} = E$$

Where:

- **Stress** = Force / Area
- **Strain** = Change in length / Original length
- E = Young's modulus (measure of stiffness)

Elastic Limit

- The maximum stress a material can withstand without permanent deformation.
- Beyond this point → plastic deformation begins.

Examples of Elastic Materials

- Rubber
- Human skin
- Pharmaceutical polymers (used in tablets, films, capsules)

Plastic Deformation

Plastic deformation is the permanent change in the shape or size of a solid material when the applied stress exceeds the elastic limit.

- The material does not return to its original shape after removal of stress.
- It is an irreversible process.
- Occurs due to slipping or repositioning of atoms/molecules within the material's structure.

Characteristics of Plastic Deformation

1. **Irreversible** → Permanent deformation occurs.
2. **Does not obey Hooke's Law** (stress $\propto$ strain no longer valid).
3. Involves dislocation movement and structural rearrangement at molecular/atomic level.
4. Occurs at higher stress levels (beyond elastic limit).
5. Leads to strain hardening (material becomes harder and less ductile).

Examples

- Bending of an aluminium rod.
- Denting of a car body.
- Plastic flow in metals.
- Permanent deformation of polymer films.

Heckel's Equation

- Heckel's equation is used to analyze the compressibility of powders during tablet compression.
- It relates the applied pressure to the relative density of the material as it gets compressed into a tablet.

Equation

$$\ln\left(\frac{1}{1-\rho_r}\right) = K \cdot P + A$$

Where:

- ρr = Relative density of the powder (ratio of apparent density to true density)
- P = Applied pressure
- K = Slope of the curve → related to **plasticity** of the material
- A = Constant → related to **particle rearrangement** in the early stages of compression

Interpretation

- Initial stage → particle rearrangement (controlled by A)
- Later stage → plastic/elastic deformation and bonding (controlled by K)
- High K value = material undergoes greater plastic deformation
- Low K value = material resists deformation (brittle behavior)

Applications in Pharmacy

1. To study compressibility of powders.
2. To compare behavior of different drugs and excipients under compression.
3. To optimize tablet formulations (binder concentration, lubricant effect, etc.).
4. To predict tablet strength and porosity.
5. To relate laboratory compression studies to actual compression in tablet machines.

Stress

- Stress is defined as the force applied per unit area on a body.

$$\text{Stress }(\sigma) = \frac{\text{Force (F)}}{\text{Area (A)}}$$

- Unit: N/m^2 (Pascal, Pa)
- Symbol: σ

Explanation

- When an external force is applied to a material, it tends to deform.
- The internal resistance offered by the material to oppose this deformation is called stress.
- Stress is directly proportional to the applied force and inversely proportional to the area.

Types of Stress

1. **Tensile Stress**
   - Produced when a force pulls or stretches the material.
   - Example: Stretching a rubber band.
2. **Compressive Stress**
   - Produced when a force pushes or compresses the material.
   - Example: Pressing a spring.
3. **Shear Stress**
   - Produced when the force acts parallel to the surface, causing layers of the material to slide over each other.
   - Example: Using scissors on paper.
4. **Torsional Stress** *(sometimes separately considered)*
   - Produced when a twisting force (torque) is applied.
   - Example: Twisting a screwdriver shaft.

Strain

- Strain is the deformation (change in shape or size) produced in a material when stress is applied.

$$\text{Strain } (\varepsilon) = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

- **Key Features**:
  - It is a dimensionless quantity (no unit).
  - Represented by ε (epsilon).
  - It only measures the relative change, not the absolute size.

Types of Strain

1. **Tensile Strain**
   - Produced when a material is stretched under tensile stress.
   - Example: Stretching of a rubber band, elongation of capsule shells.
2. **Compressive Strain**
   - Produced when a material is compressed, leading to a reduction in length or volume.
   - Example: Compression of powders during tablet manufacturing.
3. **Shear Strain**
   - Produced when a material undergoes angular deformation due to shear stress.
   - Example: Flow of ointments and gels when rubbed on skin.

Applications of Strain in Pharmacy

1. **Tablet Compression**
    - Powders undergo compressive strain during compaction, helping in understanding hardness and friability.
2. **Capsule and Film Testing**
    - Tensile strain studies help to evaluate the elasticity and brittleness of gelatin capsules and polymeric films.
3. **Biodegradable Implants**
    - Strain analysis ensures implants and sutures can withstand body stresses without breaking.
4. **Topical Formulations**
    - Shear strain explains the spreadability of creams and gels during application.
5. **Controlled Release Systems**
    - Polymeric matrices in transdermal patches or implants are tested under strain to avoid rupture and dose dumping.
6. **Packaging Materials**
    - Strain testing checks whether blister packs, vials, or bottles expand or deform under pressure or heat.

Elastic Modulus

- Elastic modulus is a measure of stiffness of a material. It quantifies how much a material resists deformation when stress is applied within its elastic limit.

$$E = \frac{\text{Stress}}{\text{Strain}}$$

- **Key Points**:
  - High modulus (stif … deformation.
  - Low modulus (flexi… → deforms easily.
  - Elastic modulus is determined only in the elastic region (where Hooke's law is valid).

Types of Elastic Modulus

Type	Applied Force	Change in	Explanation / Formula
Young's Modulus (E)	Tensile / Compressive force	**Length**	$E = \frac{\text{Tensile Stress}}{\text{Tensile Strain}}$
Shear Modulus (G)	Shear force	**Shape**	$G = \frac{\text{Shear Stress}}{\text{Shear Strain}}$
Bulk Modulus (K)	Uniform pressure	**Volume**	$K = -\frac{\text{Pressure}}{\text{Volumetric Strain}}$

Examples in Pharmacy

1. **Young's Modulus**
   - Used to test tablet hardness and brittleness.
   - Determines flexibility of polymeric films, capsules, and coatings.
2. **Shear Modulus**
   - Explains flow and spreadability of creams, gels, and ointments under shear force.
   - Important in powder flow studies during manufacturing.
3. **Bulk Modulus**
   - Relevant in solution compressibility studies.
   - Helps in designing aerosols and injectable formulations (pressure-sensitive)