The University of Zambia
School of Natural Sciences
Department of Physics

PHY2231: Properties of Matter and Thermodynamics

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Learning outcomes

At the end of the chapter, students must be able to:

1. Demonstrate an understanding of the basic concepts of mechanical properties of matter and thermal physics.
2. Demonstrate an understanding of the laws of thermodynamics and of properties of gases.

Prescribed reading material

1. Newman F.H and V. H. L Searle V.H.L, "The General Properties of Matter", Edward Arnold, 1965. ISBN: 13:978-071312119365.
2. Zemansky M.W and Dittman R. H, "Heat and Thermodynamics", McGraw Hill, 1981. ISBN: 13:978-0071223041.
3. Mathur D.S, "Elements of Properties of Matter", S.CHAND & Company, New Delhi, India, 2006. ISBN: 81-219-0815-9.

Recommended reading material

1. Mathur D.S, "Mechanics" S. CHAND & Company, New Delhi, India, 2009.ISBN: 81-219-0599-0.
2. Brij L. and Subrahmanyam N, "Properties of Matter", S.CHAND & Company, New Delhi, India, 2004.ISBN: 81-219-0280-0.

3. Brij L. Subrahmanyam N and Hemne P.S., "Heat Thermodynamics and Statistical Physics", S. CHAND & Company, New Delhi, India, 2007. ISBN: 81-219-2831-3.

4. Sears F.W and Salinger G.L, "Thermodynamics, Kinetic Theory, and Statistical Thermodynamics", 3rd Ed, Narosa Publishing House, New Delhi, India, 1998. ISBN: 81-85015.

1 Introduction

Properties of matter and Thermodynamics is a course aimed at introducing learners to the fundamental properties and behaviour of matter. You may recall from your previous science classes that matter can exist in 3 forms, namely solid, liquid, and gaseous states. This course is divided into 3 main subjects: *Elasticity*, which deals with behaviour of matter in solid form when subjected to external forces, *Surface Tension & Viscosity*, which focusses on the properties and behaviour of matter in liquid form, and *Heat & Thermodynamics*, which focusses on thermal properties of matter. This course is useful to those studying physics, chemistry, biology, geology, geography, engineering, and in general anyone in STEM.

2 Elasticity

2.1 Deformation of solids

- The action of forces applied on a rigid body produces a change in size and shape. This is referred to as *deformation* and the force causing the deformation is called the *deforming force*.
- The amount and type of deformation on a solid object depends on several factors, such as the magnitude of the deforming force, how the force is applied, and the material the solid is made of.
- Provided the elastic limit is not exceeded the deformation is proportional to the force producing it. This is called **Hooke's Law** and is the basis of the theory of elasticity.
- Solid deformation can be classified into:
  1. *Elastic deformation*, refers to temporary (non-permanent) deformation of a solid such that its original shape or size is recoverable (or self-reversing) once the deforming force is removed, e.g. springs, rubber, etc. A solid that completely recovers its original shape and size once the deforming force is removed is said to be *perfectly elastic*. No real solids are perfectly elastic.
  2. *Plastic deformation*, refers to a permanent deformation of a solid without fracture under the action of a sustained deforming force. If a solid completely retains its altered shape and size it is said to be *perfectly plastic*. No real solid is perfectly plastic.
- Real solids undergo a mixture of both elastic and plastic deformation.
- What really happens inside a solid when it is subjected to a deforming force?
  - Before a deforming force is applied on the solid, the solid is at equilibrium, i.e. it has a specific interatomic distance to maintain its shape and size.
  - For an increase in length or volume of the solid to occur, there has to be increase in the relative distance between the atoms of the solid without causing the solid to fracture.

  - For a change in shape or size to occur, the applied deforming force displaces some atoms more relative to others.

- According to Newton's third law of motion: For every action (force), there is an equal but opposite reaction. So, a solid being acted upon by a deforming force of a given magnitude will internally develop an equal but opposite reaction force (known as the *restoring force*) in trying to maintain its preferred equilibrium state.
- Due to this restoring force created internally in a solid as a result of the applied deforming force, solids tend to regain their original length, volume, shape or size.
- This tendency of deformed solids to regain their original length, volume or shape upon removal of the deforming force is called *elasticity*.

2.2 Stress & Strain

2.2.1 Stress

- A force which deforms a body is called *Stress*. Stress is the applied force (or deforming force) per unit area of the body, i.e.

$$\sigma = \frac{F}{A}, \tag{1}$$

where F is the deforming force = restoring force in N, A is the cross section area of a body in m^2, and σ is stress in N/m^2, which is the same as the unit of pressure Pascal (Pa), i.e. $1\ N/m^2 = 1\ Pa$.

2.2.2 Strain

- The change in the dimension of a body (or deformation) produced by an applied force is called *Strain*. It depends on the nature of the force.
- Strain refers to the ratio of the amount of deformation (e.g. increase in length, volume or change in shape) of a solid to the original dimensions (length, volume or shape) of the solid.
- For a rod or a wire, strain can be defined as the extension per unit length.

$$\text{Strain} = \frac{\text{Extension}}{\text{Original length}},$$

$$\varepsilon = \frac{\Delta l}{l_o} = \frac{l - l_o}{l_o}, \tag{2}$$

where $\Delta = l - l_o$ is the extension in meters, l is the full length of the deformed rod or wire, and l_o is its original length.

** Another way to state Hooke's Law is to say that, provided the elastic limit of a body is not exceeded, strain is directly proportional to stress.

$$\frac{\text{stress}}{\text{strain}} = \text{constant}$$

The constant of proportionality is called the *elastic modulus* or *modulus of elasticity*.

- The relationship between stress and strain can be demonstrated by plotting stress vs strain. Such a graph is called the stress-strain diagram. Consider a wire clamped or fixed on one end and gradually loaded with weights on the other end until it breaks. The stress-strain graph is as shown in Figure 1.

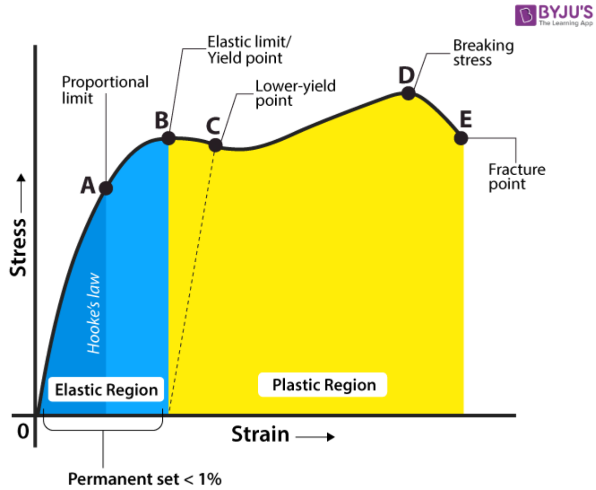

Figure 1: The stress-strain graph.

- OA: strain $\propto$ stress, i.e. obeys Hooke's Law upto A. On removal of stress the wire regains its original length represented by O.
- AB: immediately the elastic limit A is crossed the strain increases more rapidly than stress. In this region the wire experiences a mix of plastic and elastic deformation hence it does not regain its original length if unloaded. Thus, there remains a residual strain called permanent set.
- Beyond point B, for small or no increase in stress, there is a large increase in strain. BC is an irregular wave line referred to as yielding. The two points are called upper and lower yield points,respectively. The corresponding stress is called yielding stress. B is called the lower yield point and C is called the upper yield point. The correspoing stress is called yielding stress. Yielding ceases at C
- Beyond C the wire begins to thin down as the deformation is purely plastic. Its cross section decreases uniformly with extension upto D but the volume remains constant. The maximum load (force) divided by the cross section area is called the tensile strength or the ultimate strength of the wire.
- Beyond D, the extension on the wire continues increasing even without addition load or even if the load is reduced, this is called flowing down or plastic flow. The wire breaks down at E, also known as the breaking point of a wire.

Exercise 1: Consider the 2 rods, shown in Figure 2, with same original length $l_o = 1\ m$, and are made of the same material but have radii 5 cm and 10 cm, respectively. If the increase in lengths are 5 cm and 2 cm respectively when they are are stretched by the same force, $F = 420\ N$, calculate Stress and Strain in both of these rods.

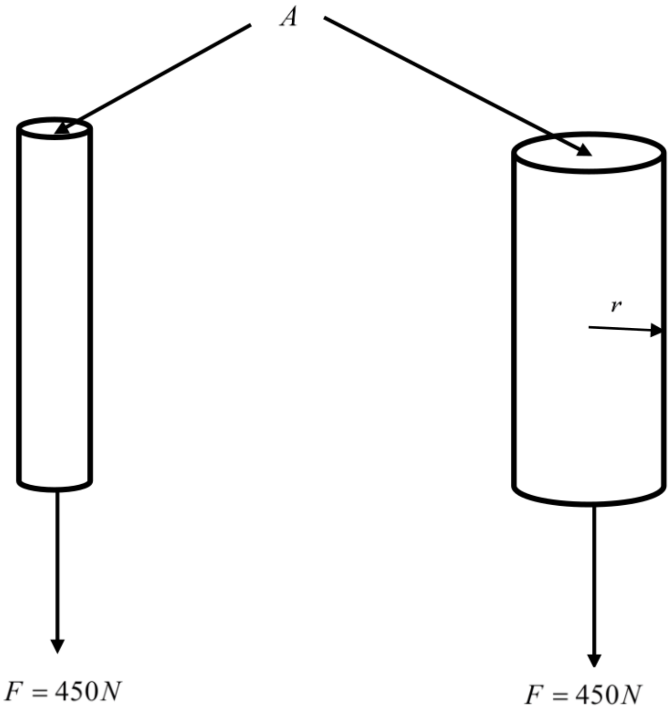

Figure 2: Illustration of 2 rods with different radii.