According to the Latest Syllabus

Sanjiv®

Physics

Class-11 (Part-II)

For the Students of Rajasthan Board of Secondary Education

By

Dr. Shyam Prakash Pareek
Associate Professor
Department of Physics
S.S. Jain Subodh P.G. College, Jaipur

Dr. Meenal Bafna
Head of the Department,
Department of Physics
Agrawal P.G. College, Jaipur

Price : ₹ 440/-

Sanjiv Prakashan, Jaipur

- Publisher :
  Sanjiv Prakashan
  Dhamani Market, Chaura Rasta,
  Jaipur-3
  email : sanjeevprakashanjaipur@gmail.com
  website : www.sanjivprakashan.com

- Laser Typesetting :
  Sanjiv Prakashan (DTP Department), Jaipur

- Printer :
  Om Printers, Jaipur
  *****

❖ *Every effort has been made to remove the mistakes and omissions in this book. In case of any suggestion or any error found, send an email or post a letter to us at the following address :*

Email : sanjeevprakashanjaipur@gmail.com
Postal Address : Publication Department
Sanjiv Prakashan,
Dhamani Market, Chaura Rasta,
Jaipur-302003

❖ *Your suggestions shall be taken care of in our next edition.*

Preface

We are extremely pleased to present this book according to latest syllabus of NCERT. The book has been written in easy and simple language so that students may assimilate the subject easily. We hope that students will get benefitted from it and teachers will appreciate our efforts. In comparison to other books available in market, this book has many such features which make it a unique book :

1. Theoretical subject-material is given in adequate and accurate description along with pictures.
2. The latest syllabus of NCERT is followed thoroughly.
3. Complete solutions of all the questions given at the end of the chapter in the textbook are given in easy language.
4. Topic wise summary is also given in each chapter for the revision of the chapter.
5. In every chapter, all types of questions that can be asked in the exam (Objective, Fill in the blanks, Very short, Short, Numerical and Long answer type questions) are given.
6. At the end of every chapter, multiple choice questions asked in various competitive exams are also given with solutions.

Valuable suggestions received from subject experts, teachers and students have also been given appropriate place in the book.

We wholeheartedly bow to the Almighty God, whose continuous inspiration and blessings have made the writing of this book possible.

We express our heartfelt gratitude to the publisher – Mr. Pradeep Mittal and Manoj Mittal of Sanjiv Prakashan, all their staff, laser type center and printer for publishing this book in an attractive format on time and making it reach the hands of the students.

Although utmost care has been taken in publishing the book, human errors are still possible, hence, valuable suggestions are always welcome to make the book more useful.

In anticipation of cooperation!

Authors

Dr. Shyam Prakash Pareek

Dr. Meenal Bafna

Contents

MECHANICAL PROPERTIES OF SOLIDS

CHAPTER 8

Chapter Overview

8.1 Introduction

On stretching a rubber strip, we see that the length of the strip increases and as soon as the force is removed, its length decrease back to its initial length. Wires made of steel, gold, silver, copper etc. also increases in length when pulled and when the force is removed, they return to their original length.

Any external force applied on an object due to which shape or size or both of the object change is called deforming force. The bodies that come back to their original state completely when the external force is removed are called elastic bodies. This property of the body is called **elasticity**. **Therefore the property of a body, due to which it opposes the external force and when the external force is removed it come back again to its original state is called elasticity.**

8.1.1 Elastic and Plastic Bodies

The bodies that come back to their original state completely when the external force is removed are called perfectly elastic bodies. *e.g.* quartz, phosphor bronze etc. The bodies which remain in the deformed state even after the external force is removed are called plastic bodies. *e.g.* wax, wet clay etc. There is no such material in nature which is perfectly elastic. Substance or bodies can be considered completely elastic for a force up to a certain limit.

The elastic behaviour of materials plays an important role in engineering design. The elastic behaviour of a material determines how the material will be behave under tensile force. For example, while designing a building, knowledge of elastic properties of materials like steel, concrete, rubber etc. is essential. The same is true in the design of bridges, automobiles, rope ways etc. The questions for engineers are : Can we design an aeroplane structure that can bear the weight of 500 passengers which is very light but sufficiently strong? Can such artificial organs be made which is relatively light but stronger? Why is glass material brittle but material like brass are not brittle? Why is the shape of a railway track similar to the letter I of the English alphabet? In order to select the best materials and their design in all these special applications, it is very important to know now relatively simple kinds of forces or loads act to deform different solid bodies. In this chapter, we shall study the elastic behaviour and mechanical properties of solids which would answer many such questions.

8.2 Stress and Strain

An elastic object come back to its original state when the deforming force is removed. But in bodies this quality remain only up to a particular limit of deforming force. If we keep increasing the value of deforming force, then a state will come where when the force is removed, the body does not gain back its original state. For example, if a weight is hung at the lower end of a wire hanging from a rigid base, the wire increases in length. When the load is removed, the wire returns to its original length. If the suspended load is gradually increased, then a state is reached such that when the load is removed, the wire does not return to its original length but its length increases for ever. Thus, its elastic properties is destroyed. The maximum limit of the deforming force applied on a material within which the elastic property of the material exists is called **'Elastic limit'** of that material.

8.2.1 Stress

When external force is applied on a body it becomes deformed. But at the same time due to the property of elasticity an internal force is produced in the body which is equal to the external force but it is opposite in direction is called restoring force. **The internal restoring force acting per unit area of cross-section of the deformed body is called stress**.

In the equilibrium state the magnitude of restoring force is exactly equal but opposite to external force.

If A is the cross-section area of the body on which external force F is applied, then in equilibrium

$$\text{Stress} = \frac{\text{Restoring force}}{\text{Area of cross-section of the body}}$$

$$= \frac{\text{External force}}{\text{Area of cross-section of the body}} = \frac{F}{A}$$

The unit of stress is Newton/meter^2. Its dimensions are $[M^1L^{-1}T^{-2}]$. The stress produced in the body depends on what external force is applied on it. Therefore, on this basis there are three types of stress :

(i) Longitudinal stress (ii) Volume stress (iii) Shearing (tangential) stress.

(i) Longitudinal stress : When stress is applied perpendicular to the surface of the body, it is called longitudinal stress or the restoring froce acting per unit area of the body is called longitudinal stress. This type of stress produced due to deformation in the length or volume of the body. Longitudinals stress are of two types :

(a) Tensile stress (b) Compressive stress.

(a) Tensile stress : The longitudinal stress produced due to increase in the length or volume of the body is called tensile stress.

(b) Compression stress : The longitudinal stress produced due to decrease in the length of the body or volume of the body is called compression stress.

The restoring force acting per unit area of the body in its compressed state is called compressive stress.

(ii) Volume stress : When force of equal value is applied on each plane of the body, the volume of the body changes. The internal force per unit cross-sectional area that opposes the change in volume is called volume stress. Its value is equal to the external force applied on the unit area and it is opposite direction to the external force at every place.

(iii) Shearing stress : When the stress is parallel or tangential to the surface of the body, it is called shearing stress. Due to this, change in the shape of a body.

8.2.2 Strain

The change in the per unit size of the body due to external forces is called strain.

$$\text{Strain} = \frac{\text{Change in size of the body}}{\text{Original size of the body}}$$

The form of strain depends on the direction of the applied force. It is a ratio, hence it has no units and dimensions. Strains is of three types :

(i) Longitudinal strain
(ii) Volume strain
(iii) Shearing strain

(i) Longitudinal strain : The change produced per unit length of a body under the influence of external force is called longitudinal strain.

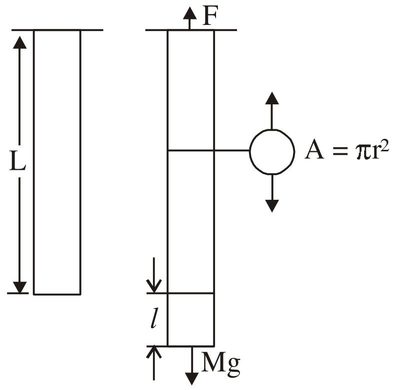


Fig. : A cylindrical body under the influence of tensile stress elongates by ΔL = *l*

Longitudinal strain

$$= \frac{\text{Change in the length of the body}}{\text{Original length of body}}$$

$$= \frac{l}{L} = \frac{\Delta L}{L}$$

Linear strain produced perpendicular to the direction of deforming force is called lateral strain.

For example : Stretching a wire along its length increase its length but its diameter decreases. The change per unit length perpendicular to the direction of force is called **lateral strain** *i.e.*

$$\text{Lateral strain} = \frac{\text{Change in the length perpendicular to direction of force}}{\text{Original length perpendicular to direction of force}}$$

(ii) Volume strain : The change produced unit volume of a body under the influence of an external body is called volume strain.

If the initial volume of the body is V and the change in volume is ΔV, then

$$\text{Volume strain} = \frac{\text{Change in the volume of body}}{\text{Original volume}}$$

$$= -\frac{\Delta V}{V}$$

Here, negative sign represents the decrease in the volume.

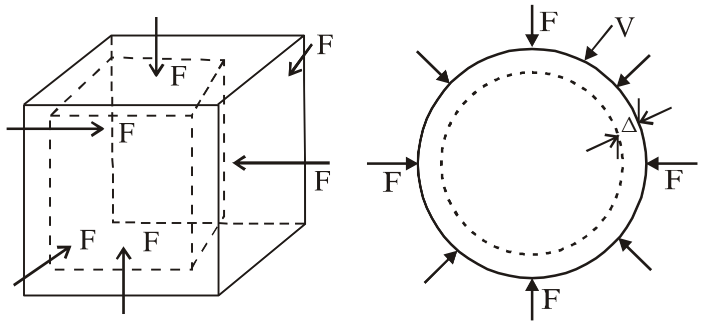


Fig. : Compression of the volume of a solid sphere ΔV under the influence of hydraulic stress.

(iii) Shearing strain : When one surface of the body is kept fixed and a tangential deforming force is applied on its opposite surface, then the shape of the body changes and there is no change in its volume or length then this strain is called shearing strain. This type of deformation occurs only in solids.

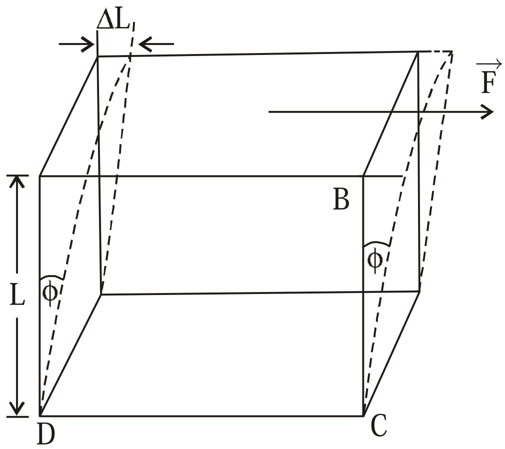


Fig. : Shearing shape

Shear angle or shear strain is shown in the figure by the angle φ.

Hence shearing strain $(\phi) = \frac{\Delta L}{L} = \tan\phi = \phi$

[Because the value of φ is very small, due to which $\tan\phi = \phi$]

8.3 Hooke's Law

According to this law, within the limit of elasticity the strain produced inside the material is proportional to the stress acting on the material. *i.e.*

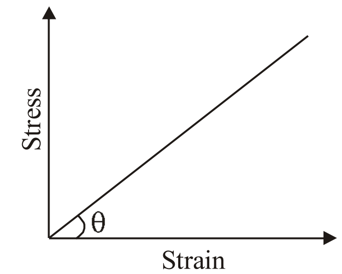
$$\text{Stress} \propto \text{Strain}$$

or $$\text{Stress} = \text{Constant (E)} \times \text{Strain}$$

$$\therefore \quad \text{Constant (E)} = \frac{\text{Stress}}{\text{Strain}}$$

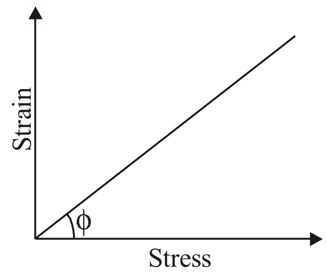
This constant (E) is called the modulus of elasticity. Its value depends on the physical states of material and its nature and not on stress and strain. The unit of E is Newton/m^2 and dimension $M^1L^{-1}T^{-2}$. Hooke's law is an Empirical law and most solid materials obey it. However, there are some materials which do not exhibit this linear relationship.

In the limit of elasticity, stress-strain graph is obtained as a straight line whose slope denotes the modulus of elasticity (E).



Slope tan θ = modulus of elasticity (E)

and



$$\text{Slope } (\tan \phi) = \frac{1}{\text{Modulus of elasticity (E)}}$$

8.4 Stress Strain Curve

According to Hooke's law, the stress produced in an object is directly proportional to the strain. But it has been observed that this proportionality is found only for small strains. To know the behaviour of a material under tensile stress, consider that a uniform cross-section area is suspended from a rigid base and the applied weight is slowly increased at its free end then length of wire goes on increasing. If we calculate the values of longitudinal stress and longitudinal strain from time to time while increasing the load and draw a graph between them, then it will be as follows :

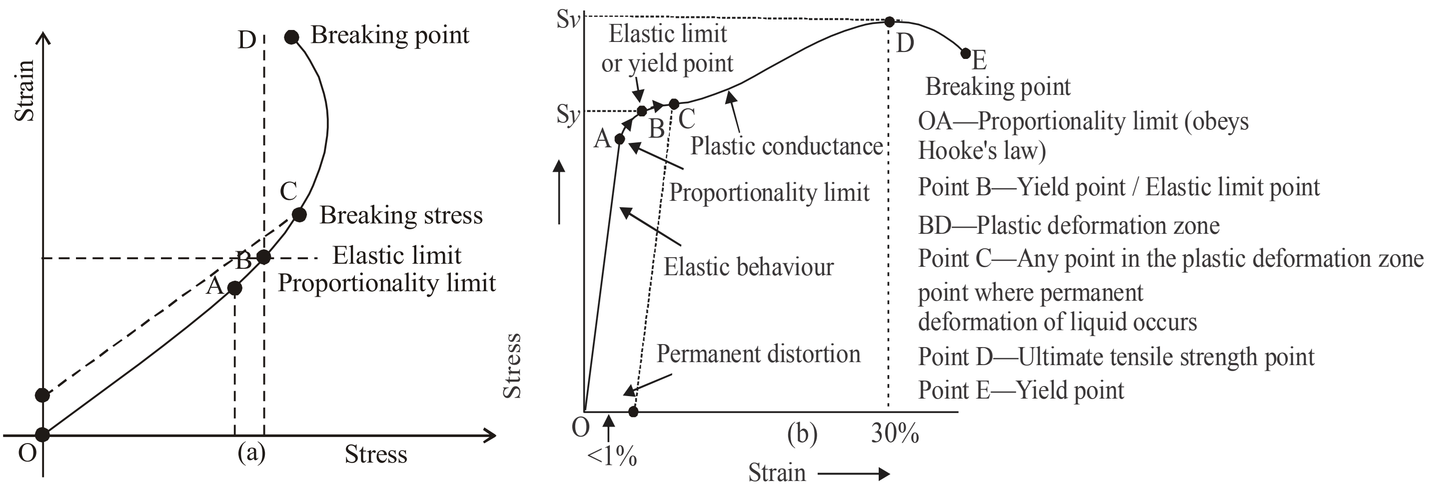


Fig. : Graphical representation of stress and strain

The starting part OA of the curve is a straight line therefore it is clear that the increases in the length of the wire till point A is directly proportional to the weight hung on it. The value of stress at point A is called **proportionality limit**.

After point A the graph starts becoming curved. This shows that by increasing the load on the wire, the increase in its length is not directly proportional to the load but becomes more than it, but the elastic property of the wire remains till point B. (*i.e.* when the load is removed, the wire comes back to its original length. The value of stress at point B is called **elastic limit**. The elastic limit is close to the **proportional limit**. The point in the curve B is called the **yield point** or **elastic limit** and the corresponding stress is called the **yield strength** of the material.

From point B onwards, when pressed towards the load hanging on the wire, the length increases very rapidly. In this condition, after the weight is removed, the wire does not return to its original length, but there is some permanent increases in its length. At point C the stress reaches its maximum value, which is called **'breaking stress'**. At this point the wire starts becoming thin and its cross-section does not remain uniform. Now even if the weight hung on the wire is reduced, the wire keeps becoming then and it breaks while reaching the point D. The region between B and D is called plastic region. The point D on the graph is the **ultimate tensile strength** of the matter.

Beyond this point, addition strain is produced even by a reduced applied force and fracture occurs at point E. For some metals like gold, silver, copper etc. this area is quite high. Wires can be made from these materials. These materials are called **ductile**. This tensile property is found to be negligible in some materials and they start break as soon as the limit of elasticity is crossed. They are called **brittle**. The stress-strain dependence of each material is different. For example, rubber can be pulled to several times its original length and still returns to its original shape. Fig. (a) shows the stress-strain curve of material similar to rubber is shown. Note that although elastic region is very large, the material does not obey Hooke's law over most of the region. An interesting fact among these is that there is no well defined plastic region. Substances like tissue of aorta, rubber etc. which can be stretched to cause large strains are called **elastomers**.

8.5 Coefficients of Elasticity

In the stress-strain curve, Hooke's law is followed in the region OA and in this elastic limit, the strain produced in the material is directly proportional to the stress acting on the material, due to which stress-strain curve is obtained in the form of a straight line up to this region. The slope of this straight line *i.e.* the ratio of stress and strain is called **coefficient of elasticity**. The elasticity coefficients corresponding to longitudinal, volume and shear strains are called Young's Modulus, Bulk Modulus and Modulus of Rigidity respectively and we will study them further.

8.5.1 Young's Modulus of Elasticity

In the following figure, a wire AB is seen hanging from a rigid support. When force F is applied at its lower end by hanging a weight Mg, there is some increase in its length l. As shown in the figure, restoring force F is produced in the wire which opposes the increase in length. When the weight Mg is removed, the wires returns to its original length. This type of elasticity is called longitudinal elasticity. Within elastic limit the ratio of longitudinal stress and longitudinal strain is called Young's Modulus of elasticity of the material of the wire.

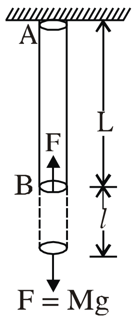


Fig. : Longitudinal elasticity

Young's modulus of elasticity

$$Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{F/A}{l/L}$$

$$Y = \frac{FL}{Al} \text{ Newton/metre}^2 \qquad ...(1)$$

Here, F = Mg and $A = \pi r^2$ (If the radius r of the wire is cylindrical), L is the original length of wire and l is the change in length.

$$\text{Hence,} \quad Y = \frac{MgL}{\pi r^2 l} \text{ Newton/m}^2 \qquad ...(2)$$

If $\pi r^2 = 1$ and $l = L$ then Y = Mg

i.e. Young's Modulus of elasticity is equal to that force which when applied the length of the wire of unit area of cross-section will be doubled. (when Hooke's law is applicable).

In practice, appropriate definition is not possible because with a 1% increase in the length of wire the elasticity limit is usually crossed.

S.I. Unit of Young's Modulus of elasticity 'Y' is $\frac{\text{Newton}}{\text{m}^2}$ and its dimensions are $[ML^{-1}T^{-2}]$.

The value of Young's Modulus of elasticity can only be obtained for solids because liquids and gases do not their own lengths. Thus, it is a characteristics of solid matter only. With increase in temperature the value of coefficient of elasticity decreases.

Comparison of Young's Modulus of Elasticity for different substances :

Steel is more elastic than rubber

Elasticity is that property of the material of a substance due to which the body resists the change of shape or form caused by an external deforming force. It is clear that the more external force has to be applied to bring about a definite change in the shape or form of a body, the more elastic that body will be. If we take steel and rubber wires of equal length and thickness, then to increases their length by the same amount, more weight will have to be hung on the steel wire.

Suppose two wires of steel and rubber are of equal length L and same radius r. Suppose, by hanging Mg weight on them, there is an increase in the length of the steel wire l_S and an increase in the length of the rubber string l_R. If the Young's modulus of elasticity of steel and rubber are Y_S and Y_R respectively then

$$Y_S = \frac{MgL}{\pi r^2 l_S}$$

$$\text{and} \quad Y_R = \frac{MgL}{\pi r^2 l_R}$$

$$\text{Thus} \quad \frac{Y_R}{Y_S} = \frac{MgL/\pi r^2 l_R}{MgL/\pi r^2 l_S} = \frac{l_S}{l_R}$$