1. **Details of Module and its structure**

Module Detail	
Subject Name	**Physics**
Course Name	**Physics 02 (Physics Part 2, Class XI)**
Module Name/Title	**Unit 7, Module 3, Searle's Apparatus** **Chapter 9, Mechanical Properties of Solids**
Module Id	**keph_20903_eContent**
Pre-requisites	**Knowledge about elastic behaviour of materials, Young's modulus longitudinal stress and longitudinal strain**
Objectives	**After going through this lesson, the learners will be able to:** • **Find the force constant of a helical spring by plotting a graph between load and extension** • **Understand the Experimental method to determine Young's modulus of given material in the laboratory** • **Compare the Young's modulus of a material with respect to steel**
Keywords	**Young's modulus, longitudinal stress, longitudinal strain, elastic limit, micrometer screw gauge , spirit level, helical spring, load**

2. **Development Team**

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	Central Institute of Educational Technology, NCERT, New Delhi
Programme Coordinator	Dr. Mohd Mamur Ali	Central Institute of Educational Technology, NCERT, New Delhi
Course Coordinator / PI	Anuradha Mathur	Central Institute of Educational Technology, NCERT, New Delhi
Subject Matter Expert (SME)	Vani Ranga	Salwan Public School, Rajendra Nagar, New Delhi
Review Team	Associate Prof. N.K. Sehgal (Retd.) Prof. V. B. Bhatia (Retd.) Prof. B. K. Sharma (Retd.)	Delhi University Delhi University DESM, NCERT, New Delhi

TABLE OF CONTENTS

1. UNIT SYLLABUS

UNIT 7: PROPERTIES OF BULK MATTER: 24 periods

Chapter–9: Mechanical Properties of Solids:

Elastic behaviour, Stress-strain relationship, Hooke's law, Young's modulus, bulk modulus, shear, modulus of rigidity, Poisson's ratio, elastic energy.

Chapter–10: Mechanical Properties of Fluids:

Pressure due to a fluid column; Pascal's law and its applications (hydraulic lift and hydraulic brakes). Effect of gravity on fluid pressure. Viscosity, Stokes' law, terminal velocity, streamline and turbulent flow, critical velocity, Bernoulli's theorem and its applications. Surface energy and surface tension, angle of contact, excess of pressure across a curved surface, application of surface tension ideas to drops, bubbles and capillary rise

Chapter–11: Thermal Properties of Matter:

Heat, temperature, thermal expansion; thermal expansion of solids, liquids and gases, anomalous expansion of water; specific heat capacity; Cp, Cv - calorimetry; change of state - latent heat capacity. Heat transfer-conduction, convection and radiation, thermal conductivity, qualitative ideas of Blackbody radiation, Wien's displacement Law, Stefan's law, Greenhouse effect.

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 17 MODULES

The above unit is divided into 17 modules for better understanding

Module 1	• Forces between atoms and molecules making up the bulk matter • Reasons to believe that intermolecular and interatomic forces exist • Overview of unit • State of matter • Study of a few selected properties of matter • Study of elastic behaviour of solids • Stationary fluid property: pressure and viscosity • Stationary liquid property: surface tension • Properties of Flowing fluids • Effect of heat on matter
Module 2	• Idea of deformation by external force • Elastic nature of materials • Elastic behaviour • Plastic behaviour • Tensile stress • Longitudinal Stress and longitudinal strain • Relation between stress and strain • Hooke's law • Young's modulus of elasticity 'Y'
Module 3	• Searle's apparatus • Experiment to determine Young's modulus of the material of a wire in the laboratory • What do we learn from the experiment?
Module 4	• Volumetric strain • Volumetric stress • Hydraulic stress • Bulk modulus K • Fish,aquatic life on seabed ,deep sea diver suits and submarines
Module 5	• Shear strain • Shear stress • Modulus of Rigidity G • Poisson's ratio • Elastic energy • To study the effect of load on depression of a suitably clamped meter scale loaded at i)its ends ii)in the middle • Height of sand heaps , height of mountains

Module 6	• Fluids-liquids and gases • Stationary and flowing fluids • Pressure due to a fluid column • Pressure exerted by solid , liquids and gases • Direction of Pressure exerted by solids, liquids and gases
Module 7	• Viscosity- coefficient of viscosity • Stokes' Law • Terminal velocity • Examples • Determine the coefficient of viscosity of a given viscous liquid by measuring terminal velocity of a given spherical body in the laboratory
Module 8	• Streamline and turbulent flow • Critical velocity • Reynolds number • Obtaining the Reynolds number formula using method of dimensions • Need for Reynolds number and factors effecting its value • Equation of continuity for fluid flow • Examples
Module 9	• Bernoulli's theorem • To observe the decrease in pressure with increase in velocity of a fluid • Magnus effect • Applications of Bernoulli's theorem • Examples • Doppler test for blockage in arteries
Module 10	• Liquid surface • Surface energy • Surface tension defined through force and through energy • Angle of contact • Measuring surface tension
Module 11	• Effects of surface tension in daily life • Excess pressure across a curved liquid surface • Application of surface tension to drops, bubbles • Capillarity • Determination of surface tension of water by capillary rise method in the laboratory • To study the effect of detergent on surface tension of water through observations on capillary rise.

Module 12	• Thermal properties of matter • Heat • Temperature • Thermometers
Module 13	• Thermal expansion • To observe and explain the effect of heating on a bi-metallic strip • Practical applications of bimetallic strips • Expansion of solids, liquids and gases • To note the change in the level of liquid in a container on heating and to interpret the results • Anomalous expansion of water
Module 14	• Rise in temperature • Heat capacity of a body • Specific heat capacity of a material • Calorimetry • To determine specific heat capacity of a given solid material by the method of mixtures • Heat capacities of a gas have a large range • Specific heat at constant volume C_V • Specific heat capacity at constant pressure C_P
Module 15	• Change of state • To observe change of state and plot a cooling curve for molten wax. • Melting point, Regelation, Evaporation, boiling point, sublimation • Triple point of water • Latent heat of fusion • Latent heat of vaporisation • Calorimetry and determination of specific latent heat capacity
Module 16	• Heat Transfer • Conduction, convection, radiation • Coefficient of thermal conductivity • Convection
Module 17	• Black body • Black body radiation • Wien's displacement law • Stefan's law • Newton's law of cooling, • To study the temperature, time relation for a hot body by

	plotting its cooling curve • To study the factors affecting the rate of loss of heat of a liquid • Greenhouse effect

MODULE 3

3. WORDS YOU MUST KNOW

- **Rigid body:** is a solid body in which deformation (due to external force) is zero or is so small that it can be neglected. The distance between any two given points in a rigid body remains constant in time regardless of external forces exerted on it. A rigid body is usually considered as a continuous distribution of mass.

- **Interatomic forces:** are the **forces** which mediate interaction between atoms and molecules. These includes **forces** of attraction or repulsion which act between molecules and other types of neighbouring particles, e.g., atoms or ions.

- **Internal structure of Solid:**
  Crystalline solid: is a **solid** material whose constituents (such as atoms, molecules, or ions) are arranged in a highly ordered microscopic structure, forming a regular (geometric) crystal lattice that extends in all directions.
  Lattice: Ionic compounds are made up of ions - positive and negatively charged particles. These positive and negative ions attract each other and group together in quite large structures called lattices. In the lattice, each positive ion is surrounded by several negative ions.

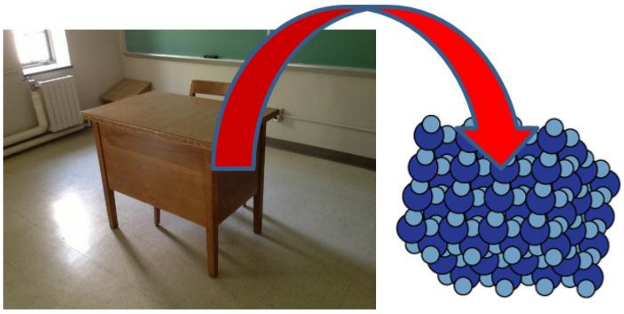
- **Bond length:** In molecular geometry, *bond length* or *bond* distance is the average distance between nuclei of two bonded atoms in a molecule. It is a transferable property of a **bond** between atoms of fixed types, relatively independent of the rest of the molecule.

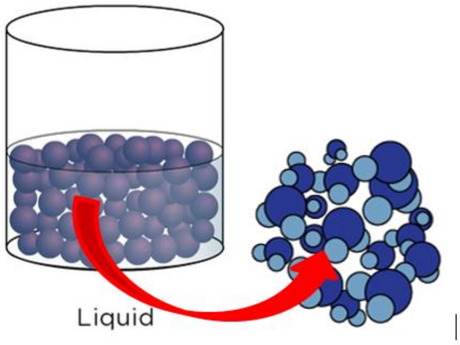
- ***Bond energy:*** bond energy *(E)* is a measure *of* bond strength in a chemical bond.

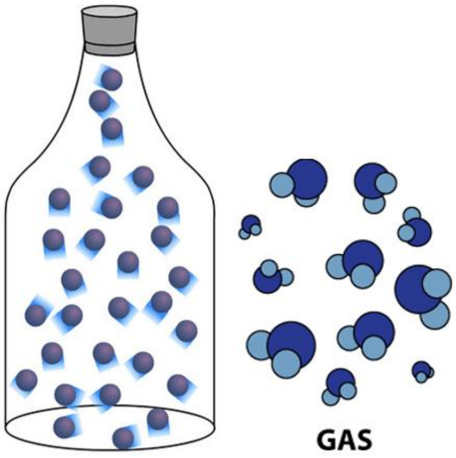
- **Amorphous solid:** or non-crystalline solid is a solid that lacks the long-range order or arrangement of atoms and molecules in the solid, which is characteristic of a crystal. The term is often called glassy

- **Molecular structure of Liquid:** A **liquid** is a nearly incompressible fluid that conforms to the shape of its container but retains a (nearly) constant volume independent of pressure. As such, it is one of the three states of matter (the others being solid, gas), and is the only state with a definite volume but no fixed shape. A liquid is made up of tiny vibrating particles of matter, such as atoms, held together by interatomic/ intermolecular bonds which are weaker as compared to those in solids.
  A liquid is able to flow and take the shape of its container.
  Unlike a gas, a liquid does not disperse to fill every space of the container, and maintains a fairly constant density.
  A distinctive property of the liquid state is surface tension, leading to formation of drops and bubbles.

- **Molecular structure of gases:** **Gas** is one of the fundamental states of matter (the others being solid, liquid).
  A pure gas may be made up of individual atoms like neon, or elemental molecules like oxygen, nitrogen or chlorine. It could also be a compound molecules made from a variety of atoms, like water vapour, carbon dioxide. A gas mixture can contain a variety of pure gases much like the air.
  a gas unlike liquids and solids, has a vast separation of the individual gas particles. This separation usually makes a colourless gas invisible to the human observer.







The pictures show the molecular density in the three states of matter

- **Elasticity:** The property of solids by virtue of which they regain their original shape and size even after the deforming forces are removed is called **elasticity.**

- **Plasticity:** The property of solids by virtue of which they do not regain their original shape and size even after the deforming forces are removed is called **plasticity**.

- **Longitudinal stress:** A body develops longitudinal or tensile stress, in case the shape of the solid has more length and the deforming force changes its length (increase or decrease) like a wire or a rod.

  Its magnitude is $= \frac{\textit{deforming force}}{\textit{area}}$ ***within elastic limit.***

- **Longitudinal strain: Strain** is the measure of deformity along length

  Longitudinal strain = change in length /original length= **Strain** $= \frac{\Delta l}{L}$
- **Hooke's law: Hooke's law** states longitudinal stress is proportional to longitudinal strain within elastic limit

- **Stress strain graph:** The stress strain graph shows the elastic and plastic behaviour of solids. **Salient points on the graph are elastic limit.**

4. INTRODUCTION

We have considered the internal structure of crystalline solids. The role of interatomic forces keeping the solid structure intact and the effect of external deforming forces tending to change the shape and size of bodies. Once the deforming force is removed the body tends to regain its original shape and size, the difficulty for it to regain depends upon the magnitude of external deforming force and how often such forces are applied on the body.

We talked about longitudinal stress and longitudinal strain. This was applicable if the body shape was with more length as compared to other dimensions. Like wires, strips. Cycle tubes may be seen to increase in length but decrease in diameter.

We learnt about Hooke's law and importance of elastic limit. Elastic limit tells us whether a length of wire will regain its original length or become plastic in the sense not follow Hooke's law and just stretch.

From the previous module 'elastic behaviour of materials', we conclude that material which stretches to a lesser extent for a given load is more elastic in contrast to the misnomer, a material which stretches more, is more elastic.

Let us consider a stretched wire. Suppose we have a wire that has a length L and radius r and suppose a load F is applied to the stretched wire to produce an elongation of ΔL.

For this case,

$$\text{stress} = F/A = F/\pi r^2$$

and,

$$\text{strain} = \Delta L/L$$

From **Hooke's law, stress is proportional to strain**, or

$$F/A = Y\ \Delta L/L$$

where Y is the elastic constant of proportionality for a change in length and is called **Young's modulus**.

Solving for Y,
we get,

$$Y = \frac{stress}{strain} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \frac{F \times L}{A \times \Delta L}$$

Or { Y=stress/strain=(F/A)/(ΔL/L) =(F×L) / (A×ΔL)}

Now,
we will engage ourselves with two experiments, which, we can perform in the laboratory in order to understand elasticity and determine Young's modulus of elasticity for a metal.

5. TO STUDY OF THE SPRING CONSTANT OF A HELICAL SPRING FROM ITS LOAD-EXTENSION GRAPH.

Apparatus and material required

Helical spring with a pointer attached at its lower end and a hook/ ring for suspending a hanger; a rigid support/clamp stand; five or six slotted masses (known) for hanger; a cm scale.

What is a helical spring?
A coil spring, also known as a helical spring, is a mechanical device which is typically used to store energy and subsequently release it, to absorb shock, or to maintain a force between contacting surfaces.

Pictures shows some helical springs

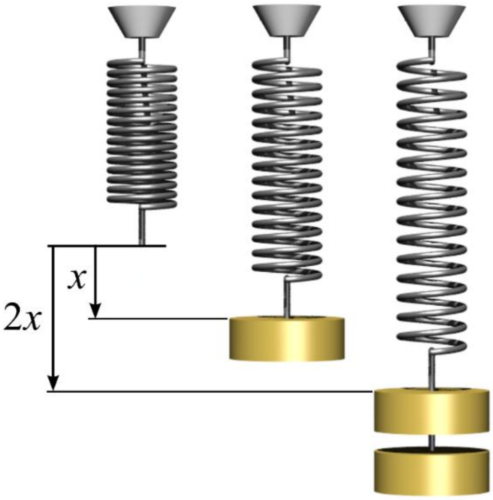
What do hanger and slotted weights look like?

https://images-na.ssl-images-amazon.com/images/I/41B-UdQ0mWL._SX342_.jpg

Principle

When an external force is applied to a body, the shape of the body changes or deformation occurs in the body. Restoring forces (having magnitude equal to the applied force) are developed within the body which tend to oppose this change. On removing the applied force, the body regains its original shape.

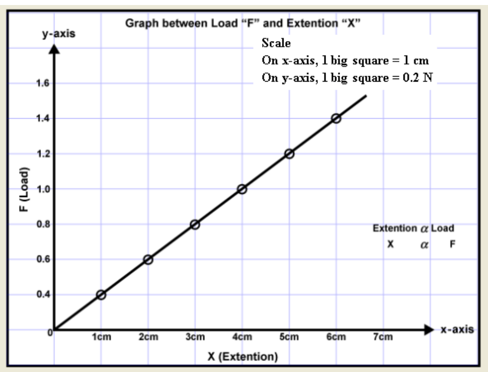
In the case of load – extension graph for a helical spring, the internal restoring force, developed in the spring, is equal to the deforming force (or load) applied; this however, holds only up to a certain limiting value of the deforming force; this limiting value is known as the 'elastic limit' of the given material.



The extension due to the load is x ,2x notice as we load the spring it stretches longitudinally hence longitudinal stress and strain are being considered

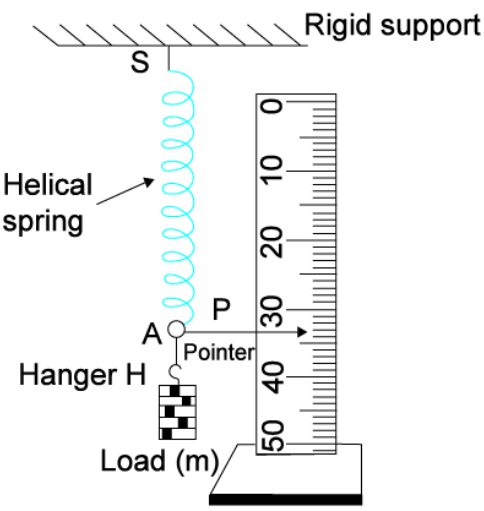
For small changes in length (or shape/ dimensions) of a body (wire), within the elastic limit, the magnitude of the elongation or extension is directly proportional to the applied force (Hooke's law).

Following Hooke's law,



the spring constant (or force constant) of a spring is given by:
Spring constant, k = Restoring force -F/Extension- x

Which physically tells us how much extension will take place per unit load .



Experimental arrangement to study extension of a spring under different loads

Thus, the spring constant is the restoring force per unit extension in the spring.

Its value is determined by the elastic properties of the spring.

A given load is attached to the free end of the spring which is suspended from a rigid point support (a nail fixed to a wall) Or a suitable strong stand

A load (slotted weight) is placed in the hanger and the spring gets extended/elongated due to the applied force.

By measuring the extensions, produced by the forces applied by different loads (slotted mass) in the spring and plotting the load (force) extension graph, the spring constant of the spring can be determined.

Procedure

i) Suspend the helical spring, SA, having a pointer, P, at its lower free end, A, freely from a rigid point support, as shown in Fig.
The spring is suspended vertically as the force on it is applied by slotted weights (being pulled under gravity).
What if the stand cannot be held vertical?
Would the spring still hang vertically?
Why should the stand with scale be vertical? in case it is not how will you record the elongation of the spring?
What additional precaution will you take in order to make accurate and reliable observations?

ii) Set the scale close to the spring vertically. Take care that the pointer moves freely over the scale without touching it and the tip of the pointer is in front of the graduations on the scale. (sometimes a mirror strip is attached to the scale, or scale is marked on a mirror strip this is done to remove error due to parallax)

iii) Find out the least count of the scale. It is usually 1 mm or 0.1 cm.

Least count is necessary to record the elongation of the spring under any load provided by the slotted weights.
We must also ensure that the slotted weights are of equal value to ensure same elongation. In case the slotted weights are not of equal value you can still do the experiment and use the slope of the load extension graph to give the value of k

iv) Record the initial position of the pointer on the scale, with just the hanger but without any slotted mass suspended from the hook.

This keeps the spring vertical

v) Suspend the hanger, H (of known mass, say 20 g) from the lower free end, A, of the helical spring and record the position of the pointer, P on the scale.

vi) Put a slotted mass on the hanger gently. Wait for some time for the load to stop oscillating so as to attain equilibrium (rest) position, or even hold it to stop. Record the position of the pointer on the scale. Record observations in a table with proper units and significant figures.

vii) Put another slotted mass on the hanger and repeat Step (vi).

viii) Keep on putting slotted masses on the hanger and repeat Step(vi). Record the position of the pointer on the scale every time.

ix) Compute the load/force **F (= mg)** applied by the slotted mass m and the corresponding extension (or stretching), x in the helical spring.

Here g is the acceleration due to gravity at the place of the experiment.

x) Plot a graph between the applied force F along x-axis and the corresponding extension x (or stretching) on the y-axis.
Take suitable scale to use most of the graph paper. Write the scale for both x and y axis.

xi) You will find that the force-extension graph is a straight line,
May be some points do not lie on the most favoured line. This does not matter. In experimentation it is possible that one or two reading may be off. You can ignore such readings. Find the 1/slope $\left(\frac{\Delta F}{\Delta x} = \frac{F}{x}\right)$of the straight line.

xii) Find out the spring constant K of helical spring from the slope of the straight line graph.

Observations

Least count of the metre scale= ... mm= ... cm
Mass of the hanger = ... g
Mass of individual slotted weights = …..g

Computing spring constant of the helical spring

S. No.	Mass suspended from the spring, M	Force, F = mg	Position of the pointer	Extension, x	Spring constant, K (= F/x)
	(10^{-3} Kg)	(N)	(cm)	(10^{-2} m)	(N m^{-1})
1	0				
2	20				
3	.				
4	.				
5	.				
6	.				
.	.				
.	.				
.	.				
.	.				

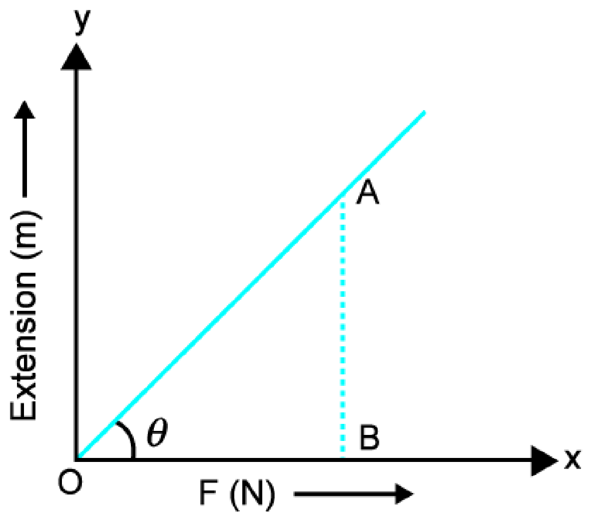
Mean Spring constant K = ...

Plotting load - extension graph for a helical spring

Take force, F along the x-axis and extension, x along the y-axis.
Choose suitable scales to represent F and x. Plot a graph between F and x
What is the shape of the curve of the graph you have drawn? Why is it so?

Calculations

Choose two points, O and A, wide apart on the straight line OA obtained from load extension graph, as shown below. From the point A, draw a perpendicular AB on x-axis. Then, from the graph



Load extension graph
Add video link

THINK ABOUT THIS

- **The spring should be suspended from a rigid support and it should hang freely so that it remains vertical.**

If support is not perfectly rigid, some error may creep in due to the yielding of the support.

- **The slotted weights are not standard weights and are of different values**

- Two springs A (of thicker wire) and B (of thinner wire) of the same material, loaded with the same mass on their hangers, are suspended from a rigid support.

Which spring would have more value of spring constant?

- **Soft massive spring of mass M_S and spring constant K has extension under its own weight**.

  What mass correction factor for the extension in the spring would you suggest when a mass, M is attached at its lower end?

  [**Hint:** Extension X_m of the spring of mass M_s with the mass M attached at its lower end would be $X_m \frac{F}{K} = (M + \frac{M_s}{2})(\frac{g}{K})$]

- If we take springs of the same material but of different diameters of the wires.
  - **Would the spring constant be the same?**
  - **How will the spring constant vary?**

- **Slotted weights should be chosen according to elastic limit of the spring.**

- **After adding or removing the slotted weight on the hanger, wait for some time before noting the position of the pointer on the scale because the spring takes time to attain equilibrium position**.

- **If we take two springs of the same diameter of the wires but of different materials. How the spring constant vary? And why?**

- **If we use a rubber band instead of a spring would the results be the same?**

  What difficulty would you face due to constant stretching and compressing of the rubber band? (Think of elastic hysteresis, elastic fatigue)

- **If we use a cycle tube instead of the spring.**
  The cycle tube would stretch under the influence of the weights (deforming force) but its diameter would become smaller. Why?

Would the value of stress change even if the deforming force increases uniformly?
What about strain?
What about elastic limit?

WHAT INFERENCE DO YOU DRAW FROM THE ACTIVITY?

How load affects various springs
You may also see the simulation
https://phet.colorado.edu/en/simulation/mass-spring-lab

If you load the spring by hanging weights off the end and measure the net stretch, then F is independent and x is dependent.

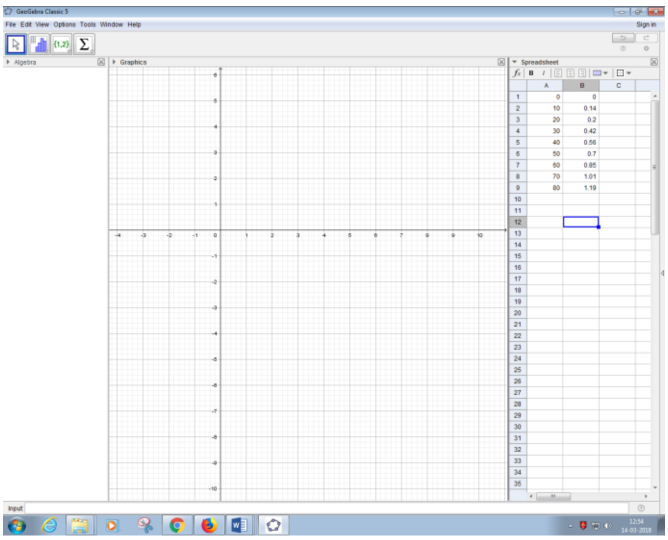
EXAMPLE

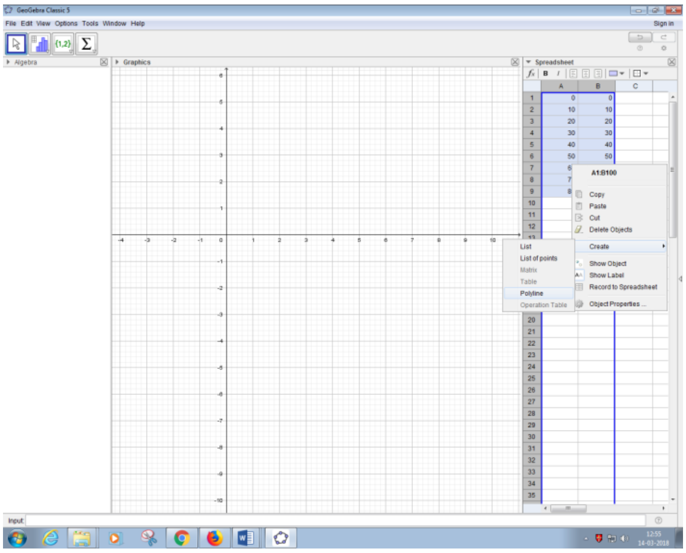
The force extension values are given in the table below

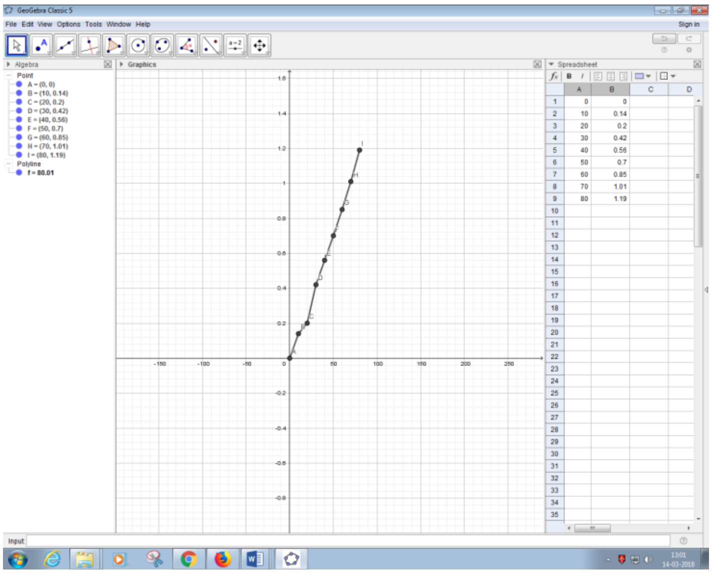
Force (N)	0	10	20	30	40	50	60	70	80
Extension (mm)	0	0.14	0.20	0.42	0.56	0.70	0.85	1.01	1.19

Plot a graph find the spring constant and the energy stored in the system
Use geo gebra app to plot the graph

1. **down load the app it is free**
2. **go to view**
3. **click on spread sheet**
4. **fill the table**
5. **select the table**
6. **right click to draw a polyline**
7. **Adjust x and y axis for better clarity**







On the x axis we have force and y axis we have the extension
The slope of the line = 1/k
K= change in force/corresponding extension

$$k = \frac{(60-20)N}{(0.85-0.20)mm} = \frac{40}{0.65 \times 10^{-3}m} = 61.53 \times 10^{3} Nm^{-1}$$

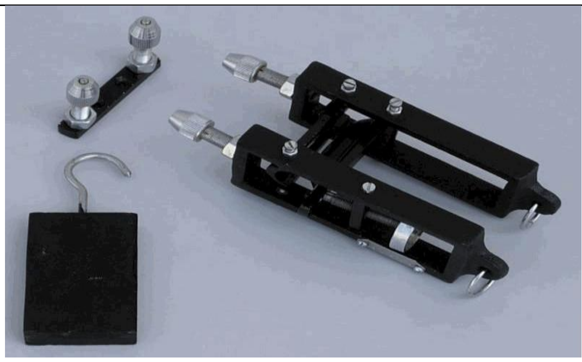
Energy stored in the wire =average force x extension

$$= \frac{1}{2}(80-10)N \times (1.19-0.14mm) = \frac{1}{2} 70 \times 1.05 Nmm = 36.75 \times 10^{-3} Nm$$
$$= 36.75 \times 10^{-3} J$$

6. EXPERIMENT TO DETERMINE YOUNG'S MODULUS OF ELASTICITY

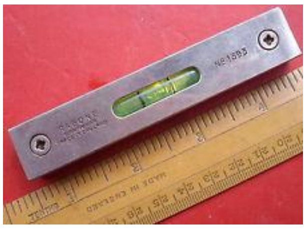
The appartus used to measure Young's modulus is called Searle's Apparatus.

Apparatus:

Searle's Apparatus consisting of two metal frames, 1 kg hanger	
Screw gauge	
Slotted weights	

- A spirit level rests horizontally with its one end hinged in the frame of wire A. The other end of the spirit level rests on a tip of a speedometer screw fitted in the frame attached to wire B.

Spirit level is an instrument designed to indicate whether a surface is horizontal or not. It is used by carpenters, construction workers etc.



The picture shows a spirit level placed against a scale edge

How does a spirit level work?

A spirit level, bubble level or simply a level is an instrument designed to indicate whether a surface is horizontal (level).

The air bubble in the small tube with spirit (hence the name of the apparatus)
The air bubble, being lighter moves towards the level which is higher.
Close up of the bubble between the black lines marked.

Picture shows an air bubble between the two parallel lines
***You can make one with a plastic bottle with a cap. Take a small bottle fill it almost full with water. Cap the bottle. Place it horizontally on a table. The air bubble will be at the centre and on the top away from the table. Now raise any one end of the bottle with respect to the other. Watch the bubble. What can you predict about the surface*?**

A typical experimental arrangement to determine the Young's modulus of a material of wire under tension is shown.

We will understand the apparatus and justify its application to calculate Young's modulus of the material of the wire

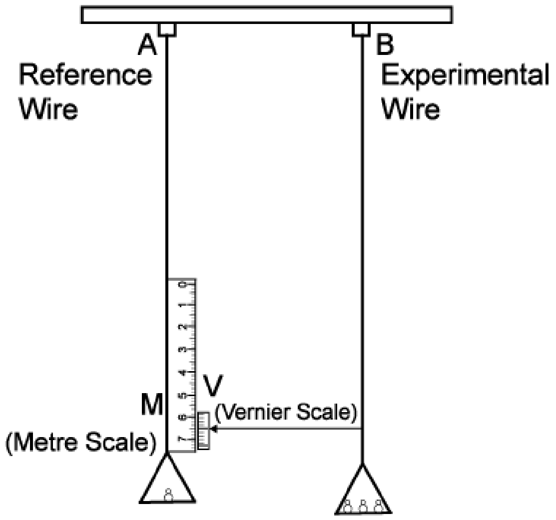


Fig. 9.6: An arrangement for the determination of Young's modulus of the material of a wire

NCERT LAB manual

- It consists of two long straight wires of same length and equal radius suspended side by side from a fixed rigid support.
  The typical length of the wire in the laboratory is 1.60-180 cm.
  The two wires are placed side by side so that we can compare the lengths and determine the elongation produced in one with respect to the other.

Wire lengths are as large as possible so that the elongation in wire B is sizable and hence measurable.

It is therefore necessary that they are of the same length and have the same area of cross section
Do you think the material of the two wires should also be the same?
Why should the support be rigid?
It can be understood that if the support was not rigid the wire cannot be kept stretched and the deforming weight will not elongate it in one direction.
How will you ensure that the wire B is uniform?
Diameter of the experimental wire B at different lengths should be noted to check that it is uniform.
Why should the wire B be homogeneous?

- The wire A (called the reference wire) carries a millimetre main scale M and a pan to place a weight. A standard weight of 1 kg is suspended from the hook of one frame attached to it which keeps the wire stretched.
- The wire B (called the experimental wire) of uniform area of cross-section also carries a pan in which known weights can be placed. Usually 1 kg hanger from the hook of frame attached to B.

The weight in the pan, an attached to wire A is added to keep the wire stretched. This is also called dead weight, the millimetre main scale is attached so as to show the increase in length in the experimental wire (B).

The known weights in the pan attached to wire B cause the external deforming force.

- A Vernier scale V is attached to a pointer at the bottom of the experimental wire B, and the main scale M is fixed to the reference wire A. The weights placed in the pan exert a downward force and stretch the experimental wire causing a tensile (longitudinal) stress. The elongation of the wire (increase in length) is measured by the Vernier arrangement.
Within elastic limit the external deforming force is equal to longitudinal stress developed within the wire opposite to the deforming force.

- The reference wire is used to compensate for any change in length that may occur due to change in room temperature, since any change in length of the reference wire due to temperature change will be accompanied by an equal change in experimental wire.

So the wires should be of the same material

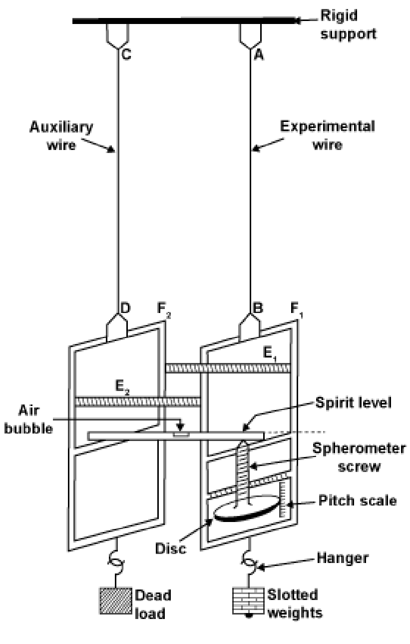
- Both the reference and experimental wires are given an initial small load to keep the wires straight, all kinks removed. The Vernier reading is noted. Now the experimental wire is gradually loaded with more weights to bring it under a tensile stress and the Vernier reading is noted again.
  There should be no kinks, knots in the wires as the stress would not be equal to the deforming force per unit area at all points in the wires.

- In many Searle's apparatuses a sphero-meter is given instead of a Vernier scale. This improves the accuracy as its least count is 0.001 cm instead of 0.01 cm

  A sphero-meter works on the principle of the micrometer screw. It is used to measure either very small thickness of flat materials like glass or the radius of curvature of a spherical surface thus getting its name.

- A spirit level rests horizontally with its one end hinged in the frame B. The other end of the spirit level rests on the tip of the sphero-meter screw fitted in the frame A. The sphero-meter screw can be rotated up and down along a vertical pitch scale marked in millimetre.
  The sphero-meter screw is rotated till the bubble comes in the middle of the spirit level. This reading is recorded with the zero load on experimental wire.

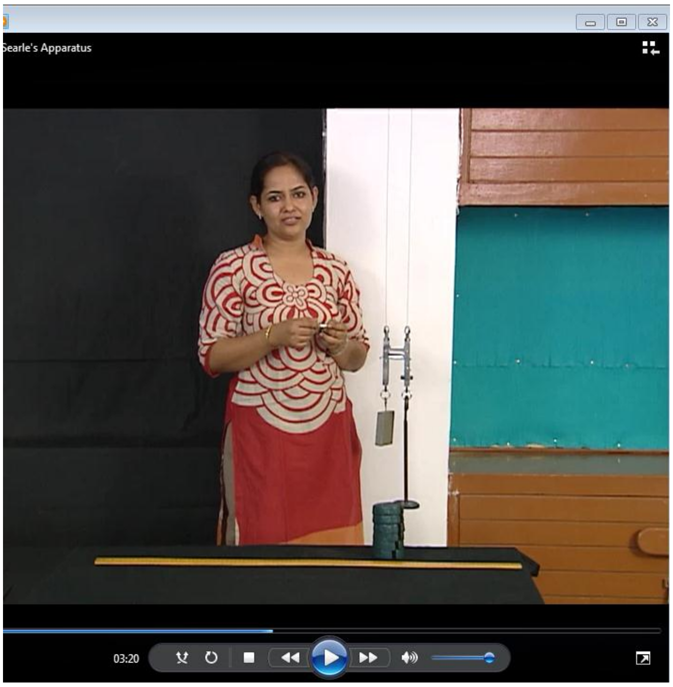
  The two frames are kept together by cross bars forming a frame.



Searle's apparatus

https://c2.staticflickr.com/6/5660/30405496324_f0c512014b_o.png

Follow the video



Here we measure the increase in length, as the micrometer attached to the spirit level needs to be brought upwards to bring the sprit level bubble between the dark lines.
This is because wire B elongates due to additional; load and the side of the frame attached to B lowers. So the air bubble in the spirit level moves towards A
Find the pitch and least count of the sphero-meter screw attached to frame of wires A and B.

Initial spherometer reading is the reference. The elongation in the wire B with respect to length of wire A can be measured.
Load is added gradually and time should be allowed for stretching of wire B.

- The difference between two micrometer readings gives the elongation produced in the wire.
- Calculate

  Let r and L be the initial radius and length of the experimental wire, respectively.
  Then the area of cross-section of the wire would be πr^2.
  Let M be the mass that produced an elongation ΔL in the wire.
  Thus, the applied force is equal to Mg, where g is the acceleration due to gravity.
  From the Young's modulus of the material of the experimental wire is given by

$$Y = \frac{Mg}{\pi r^2}\frac{L}{\Delta L}$$

Procedure:

- Put ½ kg or 500g weight on the hanger and wait for a minute to allow the wire to extend.
- Notice the movement of the bubble of the spirit level.
- Rotate the sphero-meter screw to bring the bubble back to centre. Record this reading for the ½ kg load.
- Multiply the breaking stress of steel wire with the cross-sectional area to find the breaking load of the wire.
  The maximum load on the experimental wire should not exceed one-third of the breaking load
- Repeat the above steps by adding ½ kg load eight times, each added step by step. For example: first reading is recorded with one ½ kg weight, second reading with two ½ kg weights, third reading with three ½ kg weights and so on. Record the reading for each slotted weight added.

- Now remove one slotted and notice the movement of the bubble. Again rotate the screw to bring the bubble in the centre and record the reading of the spherometer.
- Repeat the above step by removing the slotted weights one by one and record the observation for each slotted weight removed.

Observation table:

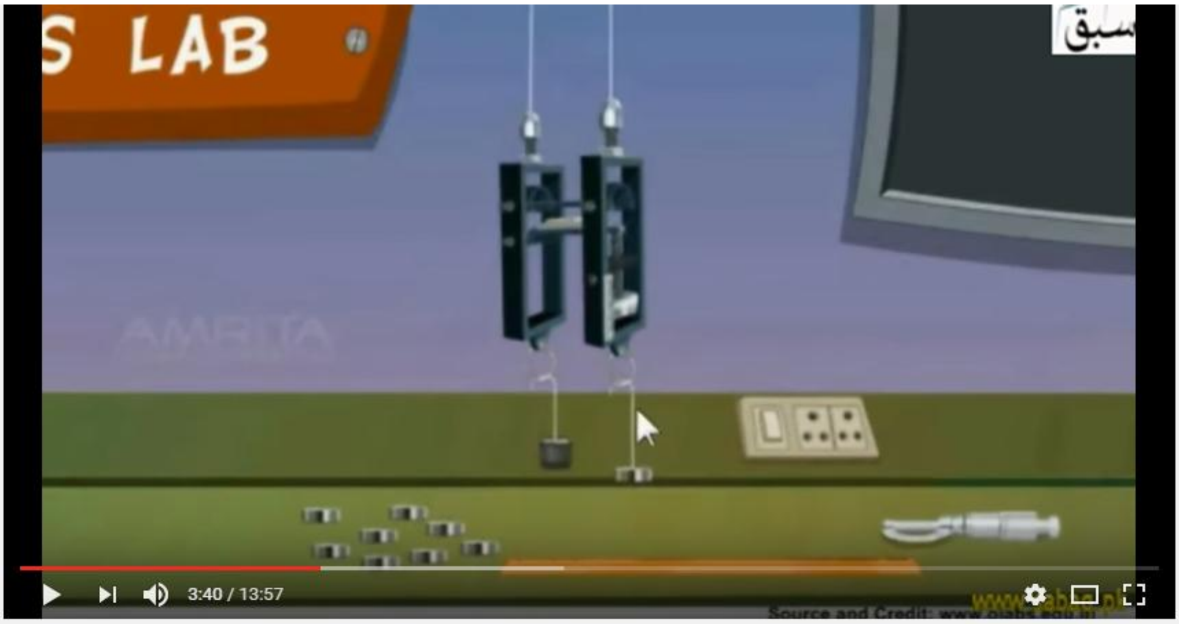
Diameter of the experimental wire

S.No.	Main Scale Reading	Circular Scale Division	Circular Scale Reading	Total reading

Load and extension

S. No.	Load on hanger (kg)	Sphero-meter reading		Mean	Extension for load
		Adding load	Removing load		

- https://www.youtube.com/watch?v=R_fM6Ba96_o
  put ours

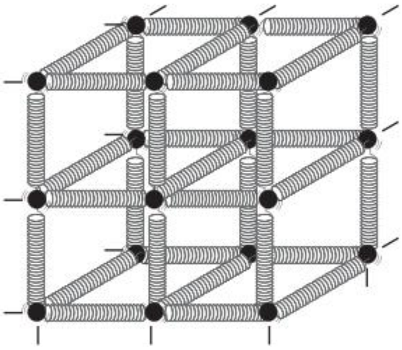


Find the young's modulus of wire by searle apparatus

Calculate the value Young's modulus using the readings obtained

7. WHAT DO WE LEARN FROM THE EXPERIMENTS?

Since the elongation and compression in metals is very small the first experiment with the spring allows us to imagine the spring like behaviour of molecular structure as we had seen in earlier modules.



Spring-ball model for the illustration of elastic behaviour of solids.

If you try to displace any ball from its equilibrium position, the spring system tries to restore the ball back to its original position. Thus elastic behaviour of solids can be explained in terms of microscopic nature of the solid.

Searle's apparatus helped us determine the value of Young's modulus of elasticity of the material of the wire.

The order of magnitude for commonly used are 10^9 N/m^2.

Young's moduli, elastic limit and tensile strengths of some materials.

Substance	Young's modulus 10^9 N/m² σ_y	Elastic limit 10^7 N/m² %	Tensile strength 10^7 N/m² σ_u
Aluminium	70	18	20
Copper	120	20	40
Iron (wrought)	190	17	33
Steel	200	30	50
Bone			
(Tensile)	16		12
(Compressive)	9		12

Which is more elastic, aluminium or steel?
You are required to hang a heavy board from a tall building using wires. Which wire would you choose and why?
Predict the young's modulus for a strong cotton thread
Why is steel more elastic as compared to rubber band?

8. Let us revise the content:

Q. **How is stress measured?**

Answer: Stress is measured by the external deforming force applied per unit area, within elastic limit.

Q**. Give unit of stress.**

Answer: The S.I. unit of stress is newton per meter^2 (N/m^2)

Q. **Define elastic limit.**

Answer: The maximum stress, up to which a body remains elastic, is called elastic limit.

Q. **Define normal stress.**

Answer: Stress is normal when deforming force is applied perpendicular (normal) to the surface of the body e.g. loaded wire, compressed body.

Q. **What deformation is produced by a normal stress**?

Answer: Normal stress produces change in length and volume.

Q. **Define tangential stress.**

Answer: Stress is tangential when deforming force is applied along (tangential) to the surface of the body. E.g. a book pressed by a hand tangentially.

Q. **What deformation is produced by a tangential stress?**

Answer: Tangential stress produces change in shape.

Q. **Define strain.**

Answer: Strain = change in configuration/ original configuration

Q. **Give unit of strain.**

Answer: Strain has no unit because it is a ratio of two similar quantities.

Q. **Define longitudinal strain.**

Answer: The ratio of the change in length to original length of the body, is called longitudinal strain on the body.

Q. **State Hooke's law.**

Answer: Hooke's law states: "within elastic limit, the extension of an elastic body is directly proportional to the tension (stretching force)".

$F = -kx$

Here, k is spring constant. '-ve' sign shows the direction of restoring force towards the mean position.

Q. **State the Hooke's law modified by Thomas Young**.

Answer: The modified Hooke's law states: "within elastic limit, the stress is proportional to the strain".

Strain ∝ stress or stress ∝ strain

Or stress = Modulus of Elasticity × strain

Q. **Define coefficient (or modulus) of elasticity.**

Answer: The constant ratio of stress and strain is called coefficient of modulus of elasticity of the material of the body.

Q. **Give unit of modulus of elasticity**.

Answer: The S.I. unit of modulus of elasticity is newton per meter squared (Nm^{-2})

Q. **Define longitudinal or Young's modulus of elasticity.**

Answer: The ratio of the normal stress to the longitudinal strain produced by it is called Young's modulus of elasticity. It is represented by the symbol 'Y'.

Q. **Define yield point.**

Answer: It is a stage beyond a elastic limit, up to which there is more extension but thinning of wire remains uniform.

9. SUMMARY

In this module we have considered two experiments:

- **Elongation and compression of a spring by loading a freely suspended spring from a rigid support**
- **Plotting Load extension graph to study Hook's law and use the activity to understand the idea of stress, strain and elastic limit.**
- **Determine the Young's modulus of elasticity of a material in the shape of a wire using Searle's apparatus**