13 ELASTIC AND MOLECULAR PROPERTIES OF MATTER

Thank God I escaped the effect of the energy possesed by that elastic catapult.

ELASTIC PROPERTIES OF SOLIDS
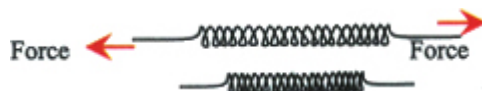
OBJECTIVES

At the end of this section, students should be able to:

➡ explain the elastic properties of solids;

➡ state Hooke's law of elasticity and solve simple problems on Hooke's law;

➡ sketch force-extension graph and explain proportional and elastic limits, yielding and breaking points;

➡ explain Young's modulus;

➡ calculate the energy stored in an elastic wire and springs.

One of the effects of a force is its ability to deform or distort matter. Forces that change the shape or size of a body are:

- stretching forces or tension in an elastic body

- compressing forces or forces that bring about squeezing of a body

The change in length produced by stretching a body is called **extension;** when the body is squeezed, the change in length is called **contraction.**

Extension = New length – Original length.

$$e = l - l_0$$

Some materials regain their original shape and size when the force changing their shape or size is removed. These materials are said to be **elastic**.

Elastic materials have the ability to regain their original size

after being deformed by a force.

Examples of elastic materials are rubber bands, springs and metallic wires. Materials, which do not regain their original size after the force causing deformation had been removed, are said to be **plastic**.

Elasticity

Elasticity is the property of a material, which makes it regain its original size after the force causing the distortion has been removed.

Molecular explanation of elasticity

The molecules of a solid exert forces on each other. This force, called **intermolecular force,** is responsible for the elastic properties of a solids. ***Stretching a solid move the molecules far from their rest positions, the molecules resist this changes in their position by attracting each other.*** The attracting force brings the molecules to their normal average position when the force pushing them apart is removed.
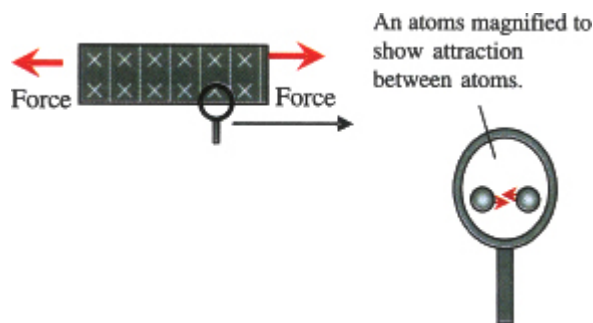

Figure 13.1a Atoms pushed apart attract each other to return to their normal average separation

Squeezing a material pushes the molecules closer than their average separation. The molecules resist the squeezing force by repelling each other. The repulsive forces return the molecules to their normal average separation when the squeezing force is removed.
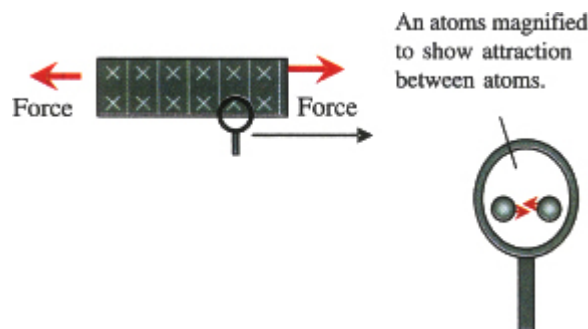

Figure 13.1b Atoms compressed repel each other to return to their normal average separation.

Loading a spring

The length of a spiral spring increases if a weight is hanged at the lower free end. Increasing the weight in steps increases the extension. Robert Hooke discovered the relation between extension and the force producing it.

Hooke's law

Hooke's law states that if a material is not stretched beyond its elastic limit, extension produced is directly proportional to the applied force (load).
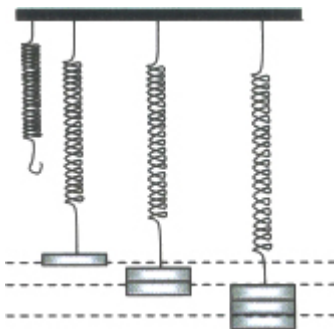

Figure 13.2 extension is proportional to weight

Force α extension

F α e   F = ke

k is the force or elastic constant of the material. **Force constant of a material is the force which produces a unit extension.**

$$k = \frac{F}{e}$$

The unit of force constant is Newton per metre (Nm^{-1}).

$$\text{Force constant} = \frac{\text{Force}}{\text{extenstion}}$$

How to find the force constant of a spring

Apparatus: Retort stand, spring, mass, pointer or needle, metre rule and plasticine.

Procedure

(a) Set up the apparatus as shown in Figure 13.3, measure and record the position of the pointer R_o.

(b) Hang the masses at the lower end of the spring; read the new position of the pointer R. Find the extension by evaluating e = R – Ro.

(c) Increase the masses in steps. Measure and record in each case, the position of the pointer R and find the extension produced.

(d) Remove or unload the masses in steps. Read and record the compression (e) in each case.

(e) Find the average of the loading and unloading and record your observations.

(f) Tabulate your readings as shown in a table below.

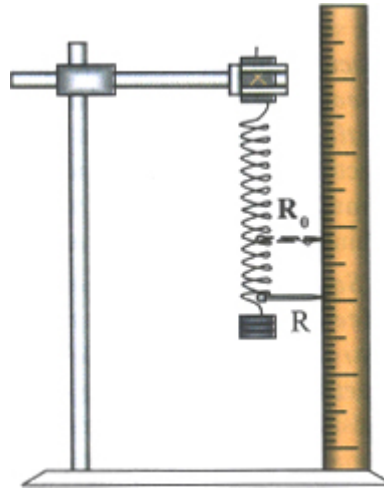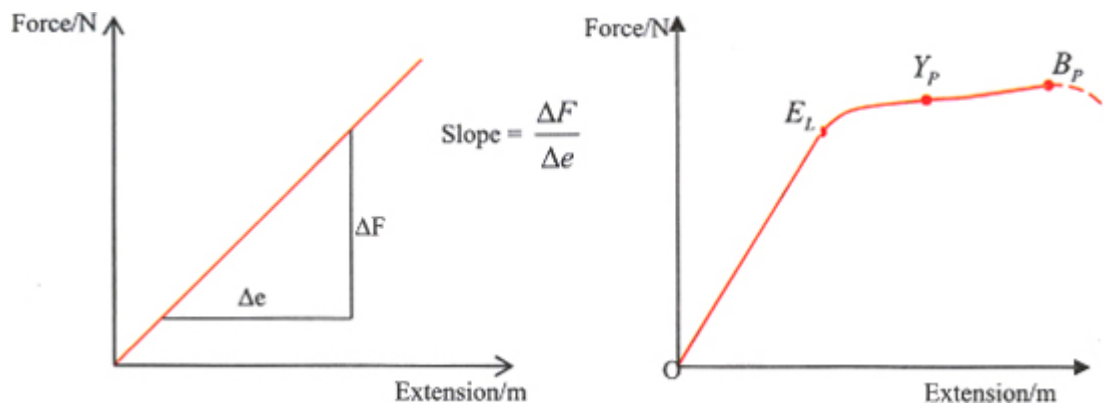| Weight/N	Extension/cm		
	Loading	Unloading	Average

Figure 13.3 Loading a spiral spring

(g) Plot a graph of weight (force) against extension.

The force-extension graph for the experiment discussed above is a straight line through the origin. **The slope of the graph is the force constant of the spring** used in the experiment.

Force – extension graph

Continuous loading of a material will make it snap or cut. The force – extension graph is shown below.

Elastic region and elastic limit

E_L is the elastic limit. The material obeys Hooke's law perfectly up to the elastic limit.

The region OE_L is the elastic region where an extension of a material is directly proportional to the applied force. The material always regains

its original size if the applied force is removed.

Elastic limit is the maximum weight (force) the material can withstand without losing its elasticity.

Alternatively, it is the maximum extension the material can produce and still regain its elastic properties if the force applied is removed.

Yield point is the point after the elastic limit beyond which the material loses its elasticity and becomes plastic. A material becomes plastic when the bonds between the layers of molecules are broken and the internal structures of the material changed. A plastic material does not regain its original size if the applied force is removed.

Breaking point (B$_p$)

The plastic behaviour of the material continues until the breaking point. At the breaking point, the bonds between the molecules are completely broken and the material breaks or snaps if the weight is increased beyond this point. **Breaking point is the maximum weight (force) the wire or spring can withstand without breaking.** If a force greater than the breaking point is applied to the wire, it will break.

Tensile stress, tensile strain and Young's modulus

Application of a force can change the size of a body. The extension produced by a material under tension depends on the size of the force or tension exerted on it, the cross-sectional area and the length of the material.

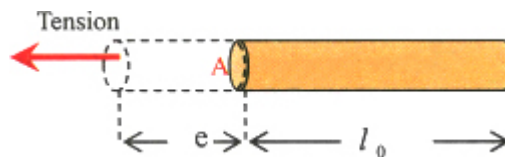l_0 = original length of the material

e = change in length or extension.

Figure 13.4 Body under tension

Tensile stress is the force acting normally on a unit cross sectional area of a material.

$$Tensile\ stress = \frac{Force}{Area\ of\ cross-section} = \frac{F}{A}$$

The unit of stress is Newton per squared metre (Nm^{-2}). Stress on a material is high when applied force is high and cross-sectional area of the material small.

Tensile strain is the extension produced per unit length of a material.

$$\text{Tensile strain} = \frac{change\ in\ length}{original\ length} = \frac{e}{l_0}$$

Strain has no unit because it is the ratio of two lengths. Tensile strain is constant in the elastic region. Beyond the elastic limit, strain increases very fast until the material snaps.

Young's modulus

Stress and strain act together on a material. An application of a force produces both stress and strain at the same time. The strain on a material is proportional to the stress if the elastic limit is not exceeded. Within the elastic region, the ratio of stress to strain is a constant.

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

The constant is called **Young's modulus**.

Young's modulus is the ratio of tensile stress to tensile strain.

$$\therefore \text{Young's modulus} = \frac{\text{Tensile stress}}{\text{Tensile strain}} = \frac{F/A}{e/l_0}$$

$$E = \frac{F}{A} \times \frac{l_0}{e} \quad \text{or} \quad F = \frac{EAe}{l_0}$$

F = force or tension exerted on the material.

e = change in length or extension, A = cross sectional area of the material and l_0 = original length of the material.

The unit of Young's modulus is Newton per squared metre (Nm^{-2}).

Elastic energy

Energy is used to stretch or compress a material. This energy is stored in the material as elastic potential energy and is equal to the work done in stretching or compressing the material. **Elastic potential energy is the energy stored in a stretched or compressed material**.

Work done in stretching a material

The work done in stretching a material is a measure of the energy

stored in it.

Work done = Average force × Extension

Average force $= \frac{1}{2}F$ and $F = k \times e$

$$W = \frac{1}{2}F \times e = \frac{1}{2}k \times e^2$$

The energy stored in a stretched spring or the work done in stretching the spring is the area under the force-extension graph. This is equal to the area of the triangle OPN for a changing force or the area of rectangle PQRS for a constant force.
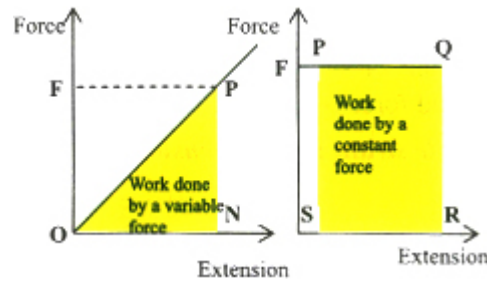

Figure 13.5 Work done is the area under force – extension graph

Worked examples

1   A spiral spring natural length 1.5m is extended 0.005m by a force of 0.8N. What will be its length when the applied force is 3.2N?

Original length $l_0 = 1.5m$

Extension= 0.005m

$$\text{Force constant} = \frac{\text{Force}}{\text{extension}} = \frac{0.8N}{0.005m}$$

Force constant = 160Nm^{-1}

Force = Force constant × extension

3.2N = 160Nm^{-1}× extension

$$\therefore \text{extension} = \frac{3.2N}{160Nm^{-1}} = 0.02m$$

New length = original length + extension

New length = 1.5m + 0.02m = 1.52m

Method 2

$$k = \frac{F}{e} \text{ and } e = l - l_0$$

$$k = \frac{0.8}{0.005} = \frac{3.2}{l-1.5}$$

$$160(l-1.5) = 3.2 \Rightarrow l-1.5 = 0.02$$

$$l = 1.5 + 0.02 = 1.52m$$

2   The force constant of a spring is 5.6gcm^{-1}. If 120g mass is hanged at

the lower end calculate: (a) the extension produced (b) the work done in stretching the wire.

(a)

$$\therefore \text{extension} = \frac{\text{Force}}{\text{Forceconstant}} = \frac{120g}{5.6gcm^{-1}}$$

Extension = 21.4cm.

(b) $Work\ done = \frac{1}{2}F \times e$

Weight = mass × gravity

$$W = \frac{120 \times 10}{1000} = 1.2N \text{ and extension } = 0.214m$$

$$Work\ done = \frac{1}{2} \times 1.2 \times 0.214 = 0.1284J$$

3   The length of a spiral spring is 25cm when a weight of 25N is hanged at the lower end. When the weight is increased to 40N, the length of the spring is 28cm. Calculate:
(a) the original length of the spring.
(b) the force constant of the spring.

(a) $\text{Force constant} = \frac{\text{Force}}{\text{extension}}$

$$k = \frac{25}{0.25 - l_0} = \frac{40}{0.28 - l_0}$$

$$25(0.28 - l_0) = 40(0.25 - l_0)$$

$$\therefore l_0 = 0.2m = 20cm$$

(b) $k = \frac{25}{0.25 - 0.20} = 500Nm^{-1}$

Method 2

Increase in force 40N – 25N = 15N

Increase in extension = 28cm – 25cm = 3cm

15N produces an extension of 3cm

(a) $\therefore$5N = 1cm $\Rightarrow$ 25N = 5cm

   Original length = 25cm – 5cm = 20cm

(b) F = k × e

   15N = k × 0.03m

   k = 500Nm⁻¹

3   A metal wire of length 2.5m and diameter 2.0 mm is stretched by a force of 400N. If the force constant of the wire is 5000Nm⁻¹ and $\Pi = \frac{22}{7.}$ calculate;
(a)   the extension of the wire.

(b) the tensile stress and tensile strain on the wire.

(c) the young modulus of the wire.

(a) $\therefore$ extension $= \dfrac{\text{Force}}{\text{Forceconstant}}$

$$\text{extension} = \dfrac{400}{5000} = 0.08\text{m}$$

(b) Tensile stress $= \dfrac{\text{Force}}{\text{Area}} = \dfrac{F}{\pi r^2} = \dfrac{400}{\frac{22}{7} \times 0.001^2}$

Tensile tress $= 1.273 \times 10^8 \text{Nm}^{-1}$

Tensile strain $= \dfrac{\text{Extension}}{\text{Original length}} = \dfrac{0.08}{2.5}$

Tensile strain $= 0.032$

(c) Young's modulus $= \dfrac{\text{Tensile stress}}{\text{Tensile strain}}$

Young's modulus $= \dfrac{1.273 \times 10^8 \, \text{Nm}^{-2}}{0.032}$

Young's modulus $= 3.978 \times 10^9 \text{Nm}^{-2}$.

Summary

- **Extension** is the change in length produced by stretching a body.
- **Elastic materials** have the ability to regain their original size after being deformed by a force.
- **Elasticity** is the property of a material which makes it to regain its original size after the force causing the distortion has been removed.
- **Hooke's law** states that if the elastic limit of a material is not exceeded, extension produced is directly proportional to the applied force or load.
- **Force constant** of a material is the force which produces a unit extension. It is the slope of force – extension graph.
- **Elastic limit** is the maximum weight (force) the material can withstand without losing its elasticity. It is also the maximum extension the material can produced and still regain its elasticity if the applied is removed.
- **Yield point** is the point after the elastic limit beyond which

the material loses its elasticity and becomes plastic.

- **Tensile stress** is the force acting normally on a unit cross sectional area of a material.
- **Tensile strain** is the extension produced per unit length of a material.
- **Young modulus** is the ratio of tensile stress to tensile strain.
- **Elastic potential energy** is the energy stored in a stretched or compressed material.
- **Energy stored** in a stretched spring or the work done in stretching the spring is the area under the force – extension graph.

Practice questions 13a

1. (a) Define elasticity, extension and elastic constant. Write the equation which links *extension* and *elastic constant.*
   (b) A force of 50N extends a material by 0.05m. Calculate:
     (i) the force constant of the material.
     (ii) the work done to stretch the material.

2. (a) State Hooke's law of elasticity.
   (b) Describe an experiment to verify Hooke's law and state **two** precautions taken to ensure accurate results.
   (c) The length of a spring is 16 cm when a load of 5 N is attached to it. When the load attached to the spring is 20 N the length is 19 cm. Calculate the:
     (i) force constant of the spring.
     (ii) original length of the of the spring.
     (iii) work done in stretching the spring.

3 (a) Define the following:
     (i) elasticity;
     (ii) elastic limit;
     (iii) elastic constant.
   (b) States Hooke's law of elasticity.
   (c) A wire gradually stretched until it snaps. Stretch a load – extension graph for the wire on the graph indicate the elastic limit, breaking point and yielding point.
   (d) A spring of natural length 30.0cm is stretched to 35.0cm by a load of 15N. Calculate:
     (i) the extension produced;
     (ii) the elastic constant of the spring;
     (iii) work done in stretching the spring.

4. A metal wire of length 1.2m and cross sectional area 2.0 Ã—

$10^{-7}m^2$ is stretched by a force of 50.0N. Assuming the force constant of the metal is $6000Nm^{-1}$ calculate:

 (i) the tensile stress and tensile strain;
 (ii) the Young modulus of the metal;
 (iii) the work done in stretching the wire;

5. (a) Define tensile stress and strain. How are they related?
 (b) A force of 40N is used to extend 4m length of a wire by 0.00024m. If the Young modulus of the wire is $2.0 \times 10^{11}Nm^{-2}$, calculate:

 (i) the tensile strain on the wire;
 (ii) the tensile stress on the wire;
 (iii) the diameter of the wire.

MOLECULAR PROPERTIES OF LIQUIDS

OBJECTIVES

At the end of this topic, students should be able to:

➡ explain cohesion, adhesion and why some liquids wet solid surfaces but others donâ€™t;

➡ define surface tension in liquids;

➡ state some effects of surface tension;

➡ state the factors affecting surface tension and two uses of surface tension.

Cohesion and adhesion

The molecules of a liquid attract each other. **Cohesion** and **adhesion** are two types of forces acting between liquid molecules or between solid and liquid molecules.

Cohesion is the attractive force between molecules of the same substance.

The attractive force between molecules of glass, water and mercury are cohesive forces. *The cohesive force of a liquid is strongest at the surface.*

Adhesion is the attractive force between molecules of different substances.

Examples of adhesion are:

• paint molecules stick to the wall by adhesion;

• tissue paper, wigs of kerosene and towel soak liquid by strong adhesion;

• water wets or sticks to the glass wall by adhesion;

• gum and paper, glue and wood are held together by force of adhesion.

Cohesion and adhesion explains why water wets glass but mercury does not. When water is in contact with glass surface, the adhesion of water molecules to glass molecules is stronger than the cohesion of water-to-water molecules, therefore, water wets or sticks to the glass surface.

If mercury is in contact with glass surface, the cohesion of mercury-to-mercury molecules is stronger than adhesion of mercury molecules to glass molecules; therefore, mercury does not wet or stick to the glass surface. Mercury withdraws from the glass surface to form spherical droplets. The shape of the droplets is slightly affected by gravity. Bigger droplets are flattened because of their large weights.
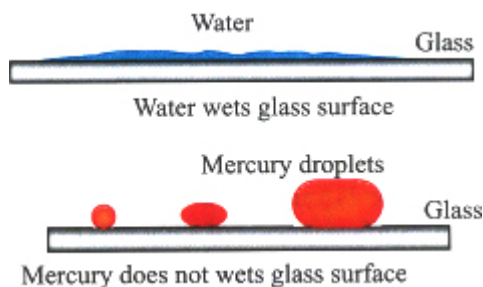

Figure 13.6 adhesion and cohesion

Surface tension

The liquid surface is in a state of tension. This is because the cohesion of the liquid molecules at the surface tends to pull them closer. *The tension on the surface molecules make the liquid surface to contract and behave like an elastic skin enclosing the molecules.*

Surface tension is the force per unit length acting at right angles ot one side of a line drawn in the surface.

Coefficient of surface tension (γ)

The coefficient of surface tension of liquid is the force acting normally per unit length on a body on the liquid surface.

$$\gamma = \frac{F}{l} \text{ or } F = \gamma l$$

F = surface tension, l = length of body on water
γ = coefficient of surface tension
The unit of coefficient of surface tension is Newton per metre (Nm^{-1})

Worked example

A needle of length 10cm floats on water. If the force acting per unit length of the needle is 0.7Nm^{-1}, calculate the surface tension supporting the weight of the needle.

Solution

Length of floating needle $(l) = 10cm = 0.1m$.

Coefficient of surface tension $(\gamma) = 0.07Nm^1$.

Surface tension$(F) = \gamma l = 0.07 \times 0.1$

$\therefore F = 0.007N$

Molecular explanation of surface tension

The molecules at the surface of a liquid are slightly far from each other than the molecules inside the liquid. Cohesive forces of the surface molecules tend to pull them together making the liquid surface to contract.

The contraction of the liquid surface creates tension on it causing it to behave like an elastic skin. Surface tension of a liquid is explained as follows: inside the liquid, each molecule is attracted in all direction with the same molecular forces. The resultant force on these molecules is zero. At the surface, vapour molecules outside the liquid are few when compared with the liquid molecules inside. The resultant attraction for the liquid molecules at the surface is downward. This resultant downward force on the surface molecules makes the surface of a liquid to be under tension.
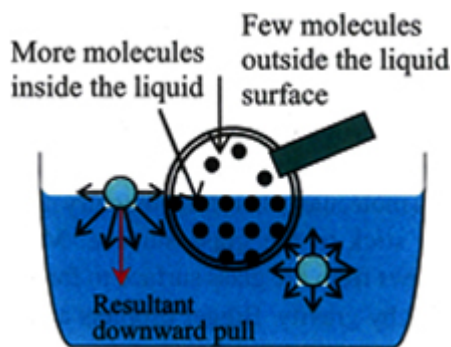

Figure 13.6a Molecular explanation of surface tension

Effects of surface tension

There are evidences to support the concept of surface tension.

1. Surface tension can make a steel needle float on water

Rub grease or candle wax on a steel needle and place it on a filter. Carefully put the filter on water surface. The paper slowly absorbs water and sinks to the bottom leaving the needle floating on water.

The needle floats because surface tension supports its weight. The water surface is depressed slightly where the needle rest on the water. Pond stakers depend on surface tension to walk across water surface.
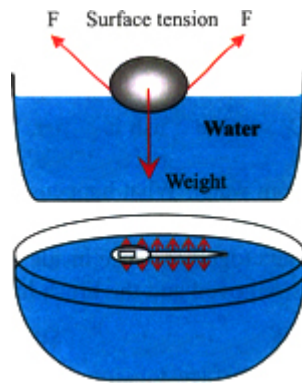
Figure 13.7 surface tension supports the weight of a floating needle

2. Water droplets from taps are spherical

Raindrops and water dripping from taps are spherical in shape. This is because surface tension pulls the molecules into a spherical shape to give them minimum surface area and least energy. Spheres have the lowest energy and surface area for the same volume when compared with other shapes. Small droplets are spherical while bigger droplets are distorted by gravity.
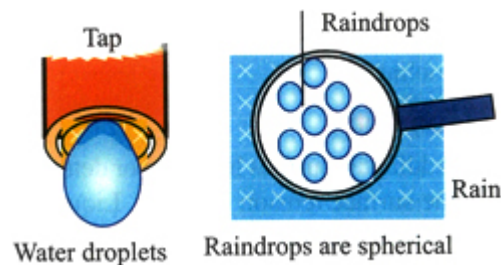

Figure 13.8 Raindrops and water droplets are spherical

3. Water poured into a cup will rise slightly above the rim of the cup without overflowing

If water is poured into a cup, it rises slightly above the rim and forms a wall preventing the water from spilling over. Surface tension holds the molecules of water in, so that it does not pour out. If some drops of soap solution or kerosene are added to the water, surface tension is reduced causing the water to overflow.
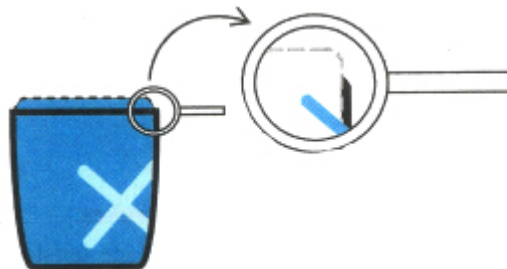

Figure 13.9 Water rises slightly above the rim due to surface tension

4. Soap film tends to reduce its surface area because of surface tension pulling equally in every direction

Make a wire loop and attach on it a fine loop of string. Dip the wire

loop in a soap solution to form a soap film as shown in Figure 13.10. When the soap film between the strings is pierced, surface tension pulls the loop of string in every direction to form a circle. This experiment confirms that a surface under tension contracts.
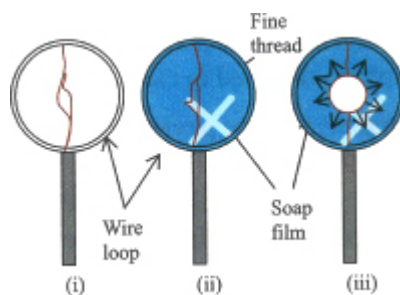

Figure 13.10 surface tension

5. A paintbrush dipped in water spreads in water but clings together outside water

Dip a paintbrush in water. What do you observe about the hairs of the brush? Now remove the brush from water. What happens to the brush hairs?

Outside the water, surface tension pulls the brush hairs together. Once inside water, surface tension is removed and the brush hairs spread out.

Figure 14.11 paint brush dipped in water

Factors that affect surface tension

The surface tension of a liquid depends on a number of factors as mentioned below.

• **Temperature**

Heating a liquid decreases its surface tension because the surface expands on heating. On the other hand, cooling a liquid increases the surface tension since the surface contracts on cooling.

• **Impurities**

Adding impurities like soap or detergent solutions, alcohol, kerosene, oil and camphor reduces the surface tension of water. Liquids with higher density, if added to water, will increase its surface tension.

• Nature of the liquid

Volatile liquids like alcohols, have low surface tension while liquids with high viscosity like syrup and engine oil have high surface tension. If a liquid with low surface tension is added to water, it reduces the surface tension of water.

Recall the three factors with the code **TIN**.

Applications of surface tension

1. *Reduction of surface tension is used to kill mosquito and to control sea waves.*

    When oil is poured on a pool of water containing mosquito's larvae, the surface tension is reduced. The mosquito's larva sinks and dies. Oil is also poured on high sea to lower surface tension and break up sea waves and tides.

2. *Reduction of surface tension is used to remove dirt from clothing fibres.*

    Detergent and soap solutions reduces surface tension of water to enable water penetrate dirt particles attached to clothing fibres and remove them with ease.

3. *Surface tension prevents water from passing through the fabrics of canvas, raincoat and umbrella.*

    Water proof materials are added to the fabric of raincoats, umbrellas and canvas to increase surface tension effects. These materials can hold up water and prevent it from dripping through the holes of the fabric. When the inside of these materials are rubbed with hand, surface tension is broken; water begins to leak freely through their fabrics.

4. *Toy boats work on surface tension effect*

    Toy boats with camphor attached at the rear can move across water surface. The camphor dissolves in water reducing the surface tension where the camphor toucheds the water. The greater surface tension in front moves the boat forward. The movement of the toy boat stops when the surface tension in the water is uniform.

Summary

- Cohesion is the attractive force between molecules of the same substance.
- Adhesion is the attractive force between molecules of different substances.
- Surface tension is the force which acts along the liquid surface, making it to contract and behave like an elastic skin.
- The coefficient of surface tension of liquid is the force acting normally per unit length on a body on the liquid surface.

- The evidences which support the idea of surface tension are:
  - a needle can be made to float on water;
  - water droplets are spherical;
  - water poured into a cup will rise slightly above the rim of the cup without overflowing;
  - soap film tends to reduce its surface area as a result surface tension pulling equally in every direction;
  - a paintbrush dipped in water spreads in water but clings together outside water.
- Surface tension of a liquid depends on nature of the liquid, impurities and temperature.
- Reduction of surface tension is used to kill mosquito and to control sea waves.
- Reduction of surface tension is used to remove dirt from clothing fibres.
- Surface tension prevents water from passing through the fabrics of raincoat and umbrella.

Capillary action

OBJECTIVES

At the end of this section, students should be able to:
- explain the capillary action of liquids;
- define angle of contact;
- state the effects of capillary action and uses.

Liquid can rise or fall in a capillary tube.

The rising up or fall of liquid in a capillary tube is called capillary action.

Capillary action is caused by surface tension effect.

Water is one of the liquids which rise up in a capillary tube above the level of water in the bowl. Liquids like water which rise up in a capillary tube, always form a **concave meniscus** with air (that is, they curve upwards towards the solid surface). The smaller the capillary bore, the higher the liquid rises in the capillary tube.

Water rises up the capillary tube because the adhesion of water to glass is more than the cohesion of water molecules.
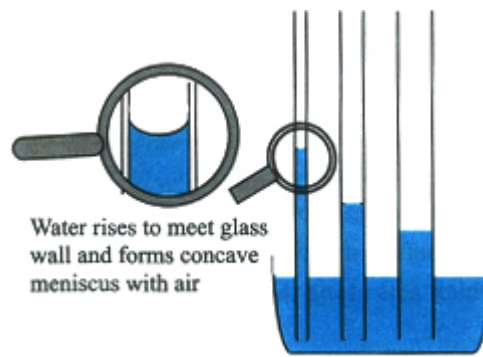
Figure 13.12 Capillary action of water in narrow capillary tubes

Water lifts up to the level where the cohesive force is equal to the force of adhesion; that is, water stops rising in the tube when its **weight** is balanced by the **surface tension**.
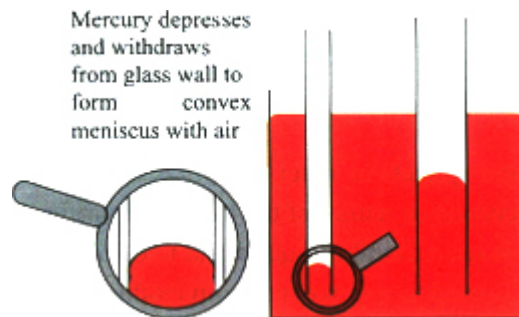

Figure 13.13 Capillary action of mercury in narrow capillary tubes

If the same capillary tubes are dipped into a bowl of mercury, the level of mercury falls or is depressed in the capillary tubes. Mercury is depressed in the tube because the surface tension or cohesion is greater than the adhesion. The depression stops where the surface tension or cohesion is equal to the adhesion. The smaller the bore of the capillary tube, the more the mercury is depressed in it.

Angle of contact

The angle of contact is angle measured inside the liquid between the tangent drawn on the meniscus of the liquid and the solid surface at the point of contact

Figure 13.14 angle of contact

Characteristics of liquid with angle of contact less than 90°(θ < 90°)

The angle of contact is acute (less than 90°) for liquids which rise up

in a capillary tube. A liquid with angle of contact less than 90°:

- wets the solid surface;
- forms concave meniscus with air;
- rises up in a capillary tube;
- has its adhesive force greater than the cohesive force.

Characteristics of liquid with angle of contact greater than 90° (θ > 90°)

The angle of contact is obtuse (between 90° and 180°) for liquids which fall or is depressed in a capillary tube. Such a liquid:

- does not wet the solid surface;
- forms a convex meniscus with air;
- falls or depresses in the capillary tube;
- has its cohesive force greater than the adhesive force.

Effects of capillary action

(i) The soaking of liquids by blotting papers, tissue papers, and towels are due to capillary action.

(ii) Rising up of liquids in porous substances like soil, rise of water up the stem of plants and rise of kerosene up the wicks of lamps and stoves, are due to capillary action.

Summary

- Capillary action is the rising up or falling of liquid level in a capillary tube.
- Water rises up the capillary tube because the adhesion of water to glass is more than the cohesion of water molecules.
- Mercury is depressed in a capillary tube because surface tension or cohesion of its molecules is greater than the adhesion of mercury to solid surface.
- Angle of contact is angle measured inside the liquid between the tangent drawn on the meniscus of the liquid and the solid surface at the point of contact.
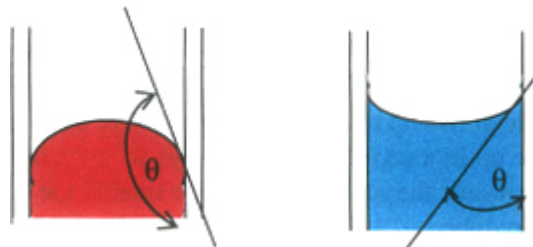
Practice questions 13b

1. What is surface tension? Use molecular forces to explain the surface tension effect.
2. State three:
   (i) examples to illustrate surface tension effect.
   (ii) ways to reduce the surface tension of a liquid.

(iii) uses of surface tension.
3.   What do you understand by capillary action?
4.   Use surface tension effect to explain why water level rises in a capillary tube while mercury level is depressed.
5.   (a) Explain the terms: adhesion, cohesion and surface tension.
   (b) Explain why water sticks to the glass surface but mercury does not.
6.   (a) Define the terms capillary action, cohesion and angle of contact;
   (b) State the characteristics of liquids with angle of contact less than 90°.
7.   (a) A tent canvas holds water without leaking. When it is touched with a hand, water begins to drip from the tent. Explain this.

Viscosity and terminal velocity

OBJECTIVES

At the end of this section, students should be able to:

➡ explain viscosity and classify liquids according to their viscous properties;

➡ explain terminal velocity;

➡ give at least two examples of viscosity.

Viscosity

Some liquids flow more easily through pipes and bottles than others; water pours out easily from bottles than syrup and honey. Liquids like honey, syrup and engine oil, which flow slowly through pipes are called **viscous liquids.** The resistance to motion is high in a viscous liquids; they oppose the motion of objects falling through them.

The resistance of a liquid to flow, measures its viscosity. Liquids flow through a pipe in layers. Different layers slide at different velocities. The layer in contact with the pipe sticks to it and does not move. The next layer slides over the stationary layer at low velocity. The velocity of the layers increases towards the centre of the pipe. **Liquids flow with ease towards the centre of the pipe where velocity between layers is high and liquid friction low.** Where the velocity between layers is low, liquid friction is high and the flow of liquid is slow. Liquid friction is called **viscosity**.

Viscosity is the friction that exists between two layers of a liquid sliding over each other.

Terminal velocity

The velocity of a body falling through a viscous liquid depends on the viscosity of the liquid. If a solid object is allowed to fall through a viscous liquid, the velocity increases as the object falls through the

liquid. The velocity however, does not increase indefinitely as the viscosity of the liquid opposes the motion of the object. The velocity of the body soon reaches a constant called **terminal velocity**.

Terminal velocity is maximum velocity attained by a body falling through a viscous liquid.

Three forces acts on any object falling through a viscous liquid. They are:

- **the weight of the falling object (W).** The weight of the object pulls it downward and makes it accelerate downwards.
- **the upthrust of the displaced liquid (U).** The upthrust opposes the motion of the object and therefore acts upwards.
- **the viscous force or drag (V).** The viscous force or drag is the liquid friction resisting the motion of the object falling through the liquid.

As a body falls through a viscous liquid, the viscous force and the upthrust of the liquid resist its motion. The resultant force accelerating the body downwards is given by

$$W - (V + U) = ma$$

The viscous force increases as the speed of the body increases. When the speed becomes constant, the viscous force reaches its greatest value; the resultant force on the body at this point is zero. The body falls through the liquid with a constant or terminal velocity.

$$\therefore W - (V + U) = 0 \ or \ W = V + U$$

A body falling through a viscous liquid like glycerol and engine oil, reaches its terminal velocity faster than a body falling through water.
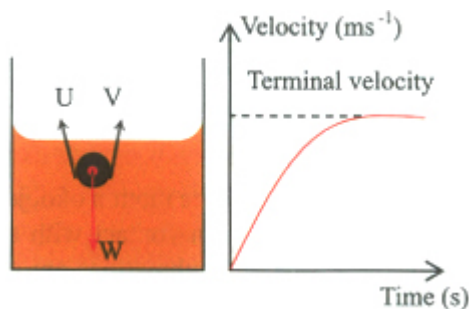

Fig 13.15 A body falling through a liquid

Determination of terminal velocity

Apparatus

Long measuring cylinder, engine oil or glycerol, a small metal ball, rubber bands and stop clock or watch.
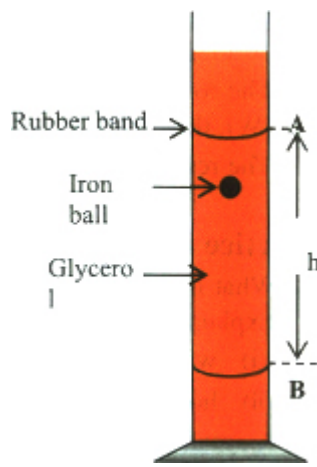
Figure 13.15 Determination of terminal velocity

Procedure

a.   A steel ball of diameter much less than the diameter of the measuring cylinder, is allowed to fall in a long transparent tube filled with glycerol or any other viscous liquid.

b.   The ball attains terminal velocity before the point A. Two rubber bands are placed at two points A and B such that AB = **h** cm.

c.   A stop clock is used to time the fall of the iron ball between A and B. The experiment is repeated for different values of **h**

d.   The iron ball is falling with a constant velocity if the times measured are in proportion to the distances (h).

The terminal velocity is given by:

$$v = \frac{h}{t}$$

V = terminal velocity, t = time.
h = distance between A and B

Application of viscosity and terminal velocity

1. Reduction of friction by viscous liquid
Highly viscous liquid like engine oil is used to reduce solid friction between two surfaces in contact.

2. Parachutes with large surface area reach terminal velocity faster.
The parachute reaches terminal velocity fast because of the viscous drag of air. The viscous drag of air or air resistance opposes the downward motion until a terminal velocity is reached. For the same reason, raindrops fall with a constant velocity close to the earthâ€™s surface.

3. Knowledge of viscous drag is used in the construction of airplane and modern cars.
Viscous drag opposes the motion of objects in a fluid. Resistance to

motion is high if large surface area of the object is in contact with the fluid. This makes the object to come to rest faster. Aeroplanes, cars and submarines are streamlined to reduce their area in contact with fluid. A simple pendulum for the same reason should have small surface area and thin string to swing for a longer time.

Summary

- Liquids like honey, syrup and engine oil which flows slowly through pipes are called viscous liquids. Viscosity is the friction that exists between two layers of a liquid sliding over each other.
- Terminal velocity is maximum velocity attained by a body falling through a viscous liquid.
- The forces acting on a body falling through a viscous liquid are the weight of the object (W), the upthrust of the displaced liquid (U) and the viscous force or drag (V).
- The resultant force accelerating the body downward is given by W – (U+V) = ma

Practice questions 13c

1. What is viscosity? State two effects of viscosity.
2. Explain why:
   (i) water pours easily from a bottle than honey;
   (ii) honey pours easily when it is warmed.
3. A small iron balls dropped in a long transparent tube, containing glycerol, reaches its <u>terminal velocity</u> after some time.
   (i) Explain the statement above.
   (ii) With a sketch identify the forces acting on the iron ball as it falls through the glycerol.
4. (a) Describe the different stages of the motion of an iron ball falling through a viscous liquid inside a tall cylinder from the time it was dropped till the time it touched the base of the cylinder.
   (b) Sketch the velocity – time graph for the motion and state what each of the graph represents.
5. (a) What are the differences between friction and viscosity?
   (b) Explain why a body falling through a viscous liquid attains a terminal velocity.

Past questions

1. Young's modulus of elasticity is the ratio of stress to strain,

provided the load does not exceed the
A. breaking point.
B. elastic limit.
C. plastic limit.
D. stress limit.
E. yield point.

2.　Use the following data to determine the length of a wire when a force of 30N is applied; assuming Hooke's law is obeyed.

Force applied (N)	0	5	1030	
Length of wire (mm)	500.0	500.5	501.0	L

A. 3.0mm
B. 3.5mm
C. 503.0mm
D. 503.5mm
E. 506.0mm

3　An elastic string of length **l** is elastically stretched through a length **e** by a force **F**. the area of cross-section of the sting is **A**, and its Young modulus is **E**. Which of the following expressions is correct?
A.
B.
C.
D.
E.

4.　The ratio of tensile stress to tensile strain is known as
A. modulus of rigidity.
B. modulus of elasticity.
C. shear modulus.
D. bulk modulus.
E. Young's modulus.

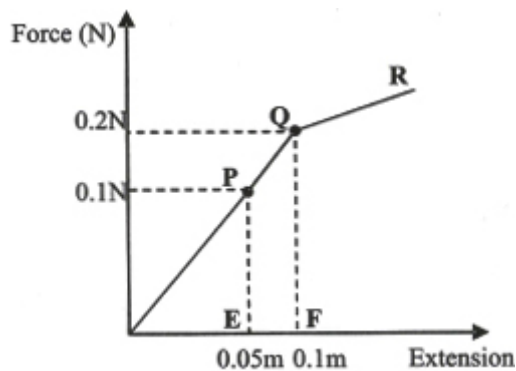5　On top of a spiral spring of force constant $500Nm^{-1}$ is placed a mass of $5 × 10^{-3}$ kg. If the spring is compressed downwards by a length of 0.02m and released, calculate the height to which the mass is projected.
A. lm
B. 8m
C. 4m
D. 2m

6.

The diagram above shows the force – extension curve of a piece of wire. The energy stored when the wire is stretch from **E** to **F** is

A. 1.5×10^{-2}J

B. 7.5×10^{-2}J

C. 7.5×10^{-3}J

D. 2.5×10^{-3}J

<div align="right">**JAMB**</div>

7   In an experiment to determine Young's modulus for a wire, several loads are attached to the wire and the corresponding extensions measured. The tensile stress in each case depends on the

A.   Load and the extension.

B.   Load and the radius of the wire.

C.   Radius of the wire the extension.

D.   Extension and the original length of the wire.

8.   The spiral spring of a spring balance is 25.0cm long when 5N hangs on it and 30.0cm when the weight is 10N. What is the length of the spring if the weight is 3N assuming Hooke's law is obeyed?

A.   15.0cm

B.   17.0cm

C.   20.0cm

D.   23.0cm

<div align="right">**JAMB**</div>

9.   If beaker is filled with water, it is observed that the surface of water is not horizontal at the glass-water interface. This behaviour is due to

A.   friction

B.   viscosity

C.   surface tension

D.   evaporation

<div align="right">**JAMB**</div>

10   Water does not drip through an open umbrella of silk unless the inside of the umbrella is touched. Which of the following phenomena

is responsible for this?
A. Surface tension.
B. Hydrostatic upthrust
C. Viscosity.
D. Diffusion
E. Osmosis.

11. Which of the following explains the concave meniscus of water in a clean glass tube? The
   A. adhesion between water and glass molecules is greater than the cohesion between water molecules.
   B. cohesion between water molecules is greater than the adhesion between glass and water molecules.
   C. molecules of water near the glass move faster than the molecules at the centre of the tube.
   D. molecules of water at the water-air boundary are often attracted to the centre of the tube.
   E. weight of the liquid pulls the central part of the surface down.

12. When a paint brush is removed from clean water, the bristles of the brush are pulled together because of
   A. the viscosity of the surrounding air.
   B. the low density of water.
   C. surface tension forces.
   D. the weight of the brush bristles.
   E. the mass of the brush bristles.

13. Which of the following substances is most viscous at room temperature?
   A. Water
   B. Alcohol
   C. Petrol
   D. Palm oil
   E. Kerosene

14. Which of the following statements about viscosity are correct? When a ball falls through a viscous liquid
   I   viscosity opposes the gravitational force on the ball
   II viscosity opposes the upthrust on the body
   III viscosity is in the same direction as the upthrust on the ball
   IV the ball falls faster in a more viscous liquid
      A. I and III only

B. I and II only
C. II and IV only
D. III and IV only
E. I, II and IV only

15. Viscosity of a liquid does not depend on the
    A. Nature of liquid.
    B. Relative velocity between the liquid layers.
    C. Area of the surface in contact
    D. Temperature of the liquid.
    E. Normal reaction between the liquid layers.

16. (a) What is surface tension? Explain the phenomena in terms of intermolecular forces.
    (b) Describe a simple experiment to demonstrate the surface tension of a liquid.
    (c) State three examples to illustrate the effect of surface tension.
    (d) Why does water wet a clean glass surface whereas mercury does not?
    (e) State two methods by which surface tension of a liquid may be reduced.

17. (a) Explain the following terms:
       (i) *viscosity* (ii) *terminal velocity*.
    (b) (i) Describe an experiment to determine the terminal velocity of a steel ball falling through a jar of glycerol.
       (ii) State **two** precautions that should be taken to ensure ccurate results.
    (c) State **two**:
       (i) effects of viscosity;
       (ii) applications of viscosity.

18. (a). State Hooke's law of elasticity.
    (b) A spring of force constant $1500Nm^{-1}$ is acted by a constant force of 45N. Calculate the potential energy stored in the spring.

19. (a) State **two** characteristics of a liquid that:
       (i) wets its container,
       (ii) does not wet its container.
    (b) State **two** methods by which surface tension of a liquid can be reduced.

20. (a) Explain the *elastic constant of a substance.*
    (b) The graph of force applied to an elastic substance against extension produced is a straight line through the origin. State the physical significance of the area under the graph.

WASSCE

21. Define (i) Elasticity (ii) Young's modulus
    (ii) Force constant.
    (b) A force of 40N applied at the end of a wire of length 4m and diameter 2.00mm produces an extension of 0.24mm.
    Calculate the;
    (i) stress on the wire
    (ii) strain on the wire, $\{\pi = 3.14\}$.

WASSCE

22. (a) Explain the rise of water in a glass capillary tube using the kinetic theory.
    (b) What is diffusion? State two factors which affect the rate of diffusion.
    (c) A wire is gradually stretched until it snaps. Sketch a load – extension graph for the wire and indicate on the graph
    (i) elastic limit;
    (ii) yield point;
    (iii) maximum load;
    (iv) breaking point.

23. (a) (i)Explain diffusion (ii) State one factor that affects the rate of diffusion.
    (b) State three practical applications of capillarity.
    (c) (i) State Hooke's law of elasticity.
    (ii) A spring of force constant $300Nm^{-1}$ is compressed such that its length shortens by 3cm. Calculate the energy stored in the spring.
    (d) (i) Mention the physical phenomenon that can be to explain why a razor blade can float on water.
    (ii) State **two** methods by which such a razor blade can be made to sink in water.

WASSCE

24. (a) (i) State Hooke's law.
    (ii) The table below represents the loads that hung on a spring balance with the pointer pointing to various marks.

Load (N)	5	10	F
Marks (cm)	8	12	30

Calculate the value of F that will send the pointer to the 30cm marks.

(b) (i) Define surface tension.

 (ii) State two effects of surface tension in everyday life.

(c) (i) What is meant by adhesion and cohesion.

 (ii) Give one illustrative example for each of adhesion and cohesion.

25. (a) Define Young's modulus.

(b) State the physical quantities one has to measure in order to determine the Young modulus of a wire.

(c) A spiral spring, loaded with a piece of metal, extends by 10.5cm in air. When the metal is fully submerged in water, the spring extends by 6.8cm. Calculate the relative density of the metal. {Assuming Hooke's law is obeyed}.

26. (a) Define the term surface tension.

(b) Calculate the force required to lift a needle 4cm long off the surface of water if the surface tension of water is $7.3 \times 10^{-2} Nm^{-1}$.

(c) Define (i) elasticity; (ii) Young's modulus; (iii) force constant.

A force of 40N is applied at the end of a wire 4m long and produces an extension of 0.24mm. If the diameter of the wire is 2.00mm, calculate the stress and strain on the wire.

(d) (i) Define the angle of contact. (ii) Draw sketches to show angles of contact for a capillary tube dipped vertically in **water** and **mercury**.

27. (a) (i) State Hooke's law of elasticity. (ii) Describe an experiment to verify Hooke's law.

 (iii) State two precautions you would take if you were to perform this experiment in the laboratory.

(b) A spiral spring of natural length 20.00cm has a scale hanging freely in its lower end. When an object of mass 40g is placed in the pan, its length becomes 21.80cm.

When another object of mass 60g is placed in the pan, the length becomes 22.05cm.

Calculate the mass of the scale pan {$g = 10ms^{-1}$}.