UNIT 5

PRESSURE AND DEFORMATION IN SOLIDS

Why it is difficult to cook food at high altitudes?

Student Learning Outcomes (SLOs)

The students will

- [SLO: P-09-B-55] Illustrate that forces may produce a change in size and shape of an object.
- [SLO: P-09-B-56] Define and calculate the spring constant.
- [SLO: P-09-B-57] Sketch, plot and interpret load-extension graphs for an elastic solid and describe the associated experimental procedures.
- [SLO: P-09-B-58] Define and use the term 'limit of proportionality' for a load-extension graph.
- [SLO: P-09-B-59] Illustrate the applications of Hooke's law.
- [SLO: P-09-B-77] Define and calculate pressure.
- [SLO: P-09-B-78] Describe how pressure varies with force and area in the context of everyday examples.
- [SLO: P-09-B-79] Analyse in situations how pressure at a surface produces a force in a direction at right angles to the surface.
- [SLO: P-09-B-80] Justify that the atmosphere exerts a pressure.
- [SLO: P-09-B-81] Describe that atmospheric pressure decreases with the increase in height above the Earth's surface.
- [SLO: P-09-B-82] Explain that changes in atmospheric pressure in a region may indicate a change in the weather.
- [SLO: P-09-B-83] Analyse the workings and applications of a liquid barometer.
- [SLO: P-09-B-84] Just why and analyse quantitatively how pressure varies with depth in a liquid.
- [SLO: P-09-B-85] Analyse the workings and applications of a manometer.
- [SLO: P-09-B-86] Define and apply Pascal's law.

UNIT 5 PRESSURE AND DEFORMATION IN SOLIDS

Matter is made up of atoms and molecules. Applying external forces like weight, pressure, heat, etc., causes the deformation of the matter, which in turn changes the matter's shape, dimension, and orientation.

Solid matter is made up of atoms and molecules which packed closely. The intermolecular space between the atoms is significantly less than in liquid and gas. Because of this property of solids, they retain their original shapes easily, and the atoms or molecules return to equilibrium after removal force.

In the case of liquid and gaseous matter, the atoms and molecules are loosely packed, and the deformation of this matter takes less force as compared to solids, Liquids and gaseous matter do not retain their equilibrium state unless an external force is applied again. Some examples include a stretched rubber band as shown in figure 5.1, a bent metal rod and a shattered glass as shown in figure 5.2.

FIGURE 5.1 RUBBER BAND

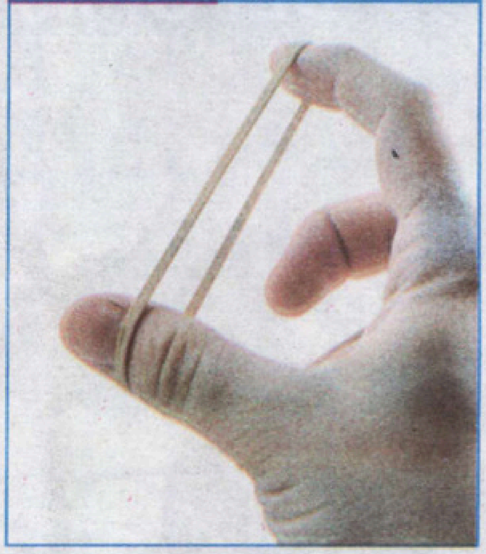
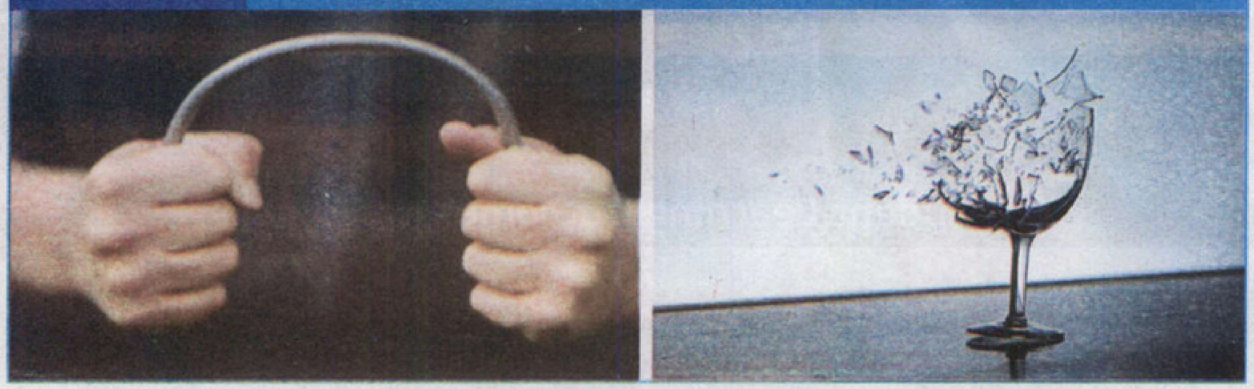


FIGURE 5.2 BENT METAL ROD AND SHATTERED GLASS



5.1 ELASTICITY

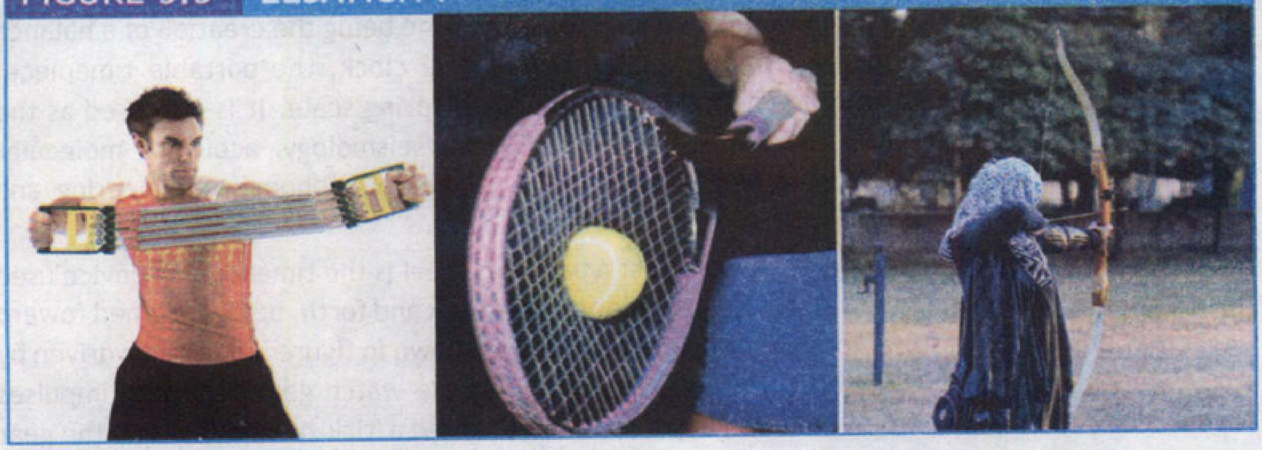
'The ability of a deformed body to return to its original shape and size when the deforming forces are removed is called elasticity'.

When a stretched spring is released, it comes back to its original form. When a tennis racket hits a tennis ball, the shape of the ball is distorted or deformed, but it regains its original shape when it bounces off the tennis ball. Similarly, when an archer shoots an arrow, she bends the bow which comes back to its original form after the arrow is released as shown in figure 5.3.

Not all materials return to their original shapes when a deforming force acting on it is removed. Materials that do not return to their original shapes after being distorted are said to be inelastic. Examples of inelastic materials are plasticine, clay and dough.

Most materials are elastic up to a certain limit known as the elastic limit. Beyond the elastic limit a material will not return to its original dimensions when the deforming force is removed.

FIGURE 5.3 ELSATICITY



5.1.1 HOOKE'S LAW

When a spring is stretched or compressed (with in elastic limit), the extension or compression is directly proportional to the applied force (Figure 5.4). This relationship is known as Hooke's law which states that **within elastic limits the extension (or compression) x is directly proportional to the restoring force F_{res}, i.e.**

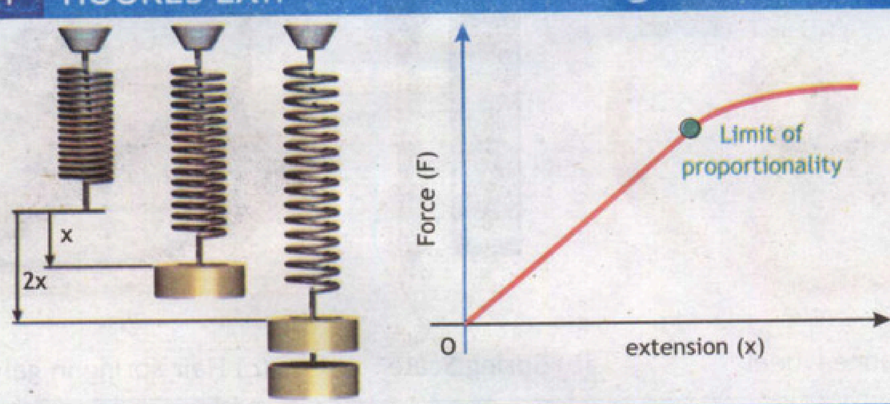
$$F_{res} \propto -x \quad \text{or} \quad F_{res} = -kx$$

$$\text{therefore } k = \frac{-F_{res}}{x} \qquad (5.1)$$

where 'k' is the ratio of restoring force to the extension and is known as the force constant or spring constant having units N m^{-1}. The negative sign shows that force is directed against displacement. This relationship is also true for a wire under tension. Provided that the limit of proportionality is not exceeded, a graph of stretching force against extension is a straight line through the origin, as shown in figure 5.4.

The gradient of the line F/x is the spring constant 'k'. Hooke's Law is obeyed up to the limit of proportionality. Beyond this point, stretching force and extension are no longer directly proportional and the graph begins to curve.

FIGURE 5.4 HOOKES LAW



5.1.2 APPLICATIONS OF HOOKE'S LAW

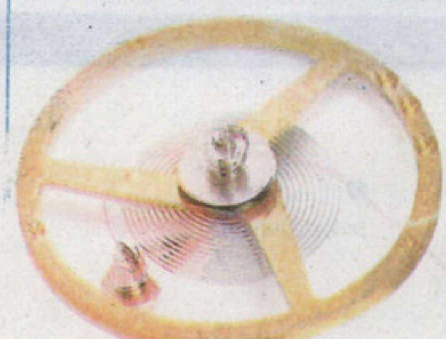
Hooke's law has many important practical applications, with one being the creation of a balance wheel, which made possible the creation of the mechanical clock, the portable timepiece. Hooke's law is also used as a fundamental principle behind spring scale. It is also used as the foundation for diving boards and car suspension systems, seismology, acoustics molecular mechanics and even in medical science.The spring is a marvel of human engineering and creativity, still in use in many modern day instruments.

A. Balance wheel of the mechanical watches: A balance wheel is the timekeeping device used in mechanical watches. It is a weighted wheel that rotates back and forth, being returned toward its center position by a spiral torsion spring or hairspring as shown in figure 5.5 (a). It is driven by the escapement, which transforms the rotating motion of the watch gear train into impulses delivered to the balance wheel. Each swing of the wheel (called a 'tick' or 'beat') allows the gear train to advance a set amount, moving the hands of watch forward. The combination of the mass of the balance wheel and the elasticity of the spring keep the time between each oscillation or 'tick' very constant.

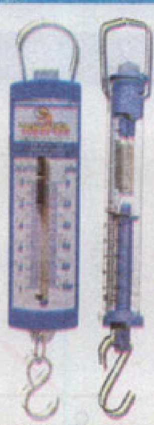
B. Spring Scale: A spring scale (spring balance) is a type of mechanical force measuring instrument that make use of spring. This device is mainly used to weigh items or objects by connecting them to a hook at it bottom as shown in figure 5.5 (b). Since by Hooke's law the force or weight that extends a spring is directly related to the distance that the spring is extended from its initial position. The spring scale converts this extension to measuring weight using an analog or digital gauge attached to the device.

C. Galvanometer: Galvanometer is a device used for detecting current or voltage. It make use of the hair spring which not only electrical connection to coil and restoring the pointer back, but also make the deflection proportional to the force according to Hooke's law as shown in figure 5.5 (c). And since the force is proportional to the current, it permits us to draw an analogue scale under the pointer and measure the current.

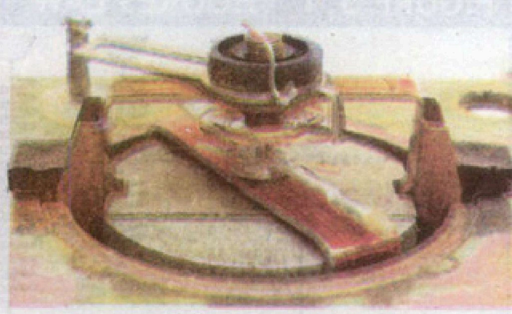
FIGURE 5.5 APPLICATIONS OF HOOKE'S LAW



(a) Balance wheel

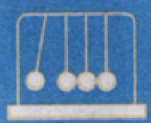


(b) Spring Scale



(c) Hair spring in galvanometer

MINI-LAB

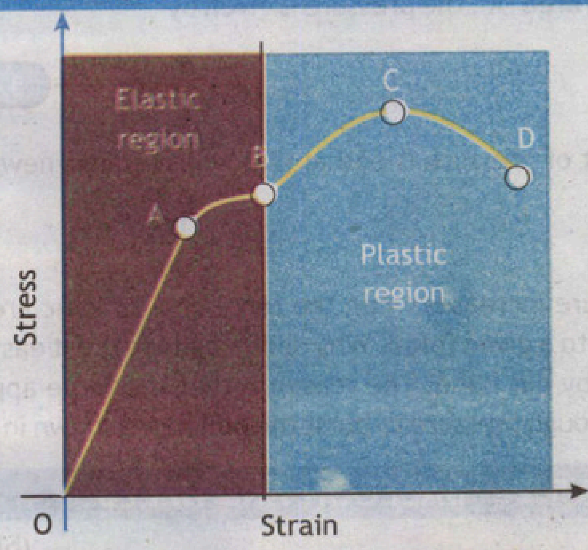


What would happen to the reading if two or more spring balances are hung one below the other in series?

Stress and strain curves: Stress and strain curves are measured by stress tester, one such machine Rockwell hardness tester is shown in the figure 5.6 (a). The applied stress is increased and the change in length is noted. The values are then printed on graph. A typical graph for metal is shown in the figure 5.6 (b). Here, Point, A, is the limit of proportionality, the limit up to which Hooke' law is obeyed called **proportional limit.** Point, B, is the elastic limit, the limit up to which material shows elastic behavior also called **yield strength**, point C is the maximum stress a material can bear before fracture (breaking) called **ultimate stress** and point D, is the breaking point, where material breaks.

FIGURE 5.6 STRESS STRAIN ANALYSIS

(a) Hardness testing machine



(b) typical stress - strain curve

EXAMPLE 5.1: SPRING CONSTANT OF A SPRING CHAIR

Kamil sits on a spring chair as shown in the figure. If Kamil's weight is 50 kg and compresses the spring by about 10 cm, when he sits on the chair, find the spring constant of this chair's spring.

GIVEN

Mass of Kamil 'm' = 50 kg

Extension in spring 'x' = 10 cm = 0.1 m

REQUIRED

Spring constant 'k' = ?

SOLUTION:

The force stretching the spring is equal to weight of the body, given by:

$$W = F = mg = 50\ kg \times 9.8\ m/s^2 = 490\ N$$

From Hook's law: $F = kx$ or $k = \frac{F}{x}$ Putting values: $k = \frac{490\,N}{0.1m}$

Therefore, $\boxed{k = 4{,}900\,N/m}$ Answer

So, the given chair spring has a spring constant of 4,900 N/m.

5.2 PRESSURE

Pressure is defined as force per unit area. Pressure is represented by letter 'P', if force 'F' is applied on area 'A', the pressure is given by

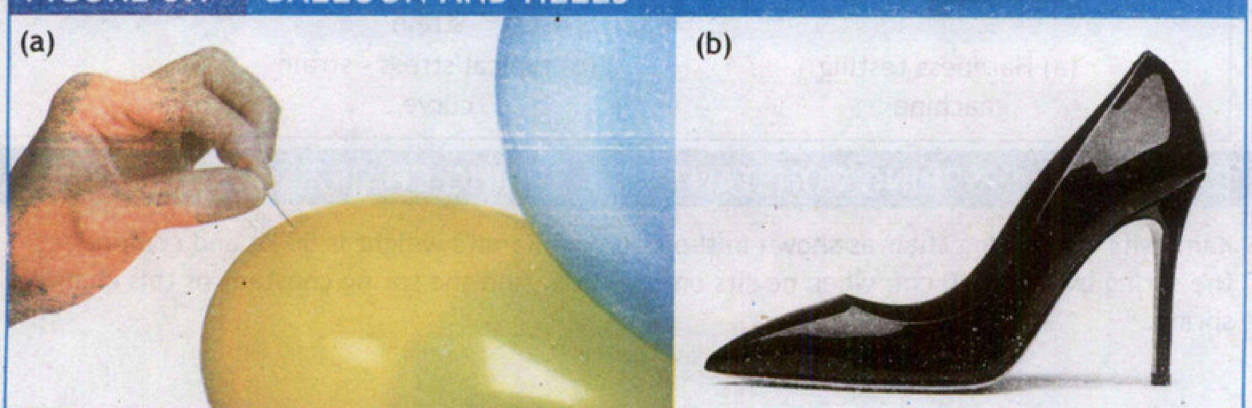
$$P = \frac{F}{A} \qquad (5.2)$$

The SI unit of pressure is pascal (Pa) which equals newton per square meter (N/m^2).

$$1\,Pa = \frac{1\,N}{1\,m^2}$$

The pressure increases when the force on a specific area is increased or when a smaller area is subjected to a given force. Why does a balloon burst easily when pricked with a pin, but not when squeezed by our hand? The reason is that the force applied to the small area of the needle tip creates enough pressure to burst the balloon as shown in figure 5.7 (a).

FIGURE 5.7 BALLOON AND HEELS



(a) (b)

Getting stepped on by a high-heeled shoe hurts more than getting stepped on by a flat one. This is because the weight of the body is concentrated on a smaller area with a pencil heel shoe, as illustrated in figure 5.7 (b).

Have you ever wondered why a blunt knife cannot cut meat easily? When you apply the same force on sharp and blunt knife, the sharp knife offers little surface area thereby increasing pressure, which help to cut meat easily as shown in figure 5.8.

FIGURE 5.8 SHARP AND BLUNT KNIFE

EXAMPLE 5.2: WEIGHT AS PRESSURE ON GROUND

Abdurrahman was standing at the stage of a hall for a speech. What pressure does he apply on the stage if his two feet cover an area of 400 cm^2? (b). If for a while he stands on one foot, what will be the pressure under that foot? (Take his mass 50 kg).

GIVEN

Mass of Abdullah 'm' = 50 kg

Area of two feet 'A_1' = 400 cm^2 = 400 × $10^4 m^2$ = 0.04 m^2

Area of one foot 'A_2' = $A_1/2$ = 0.04 $m^2/2$ = 0.02 m^2

REQUIRED

(a) Pressure with both feet 'P_1' =?

(b) Pressure with one foot 'P_2' =?

SOLUTION:

Weight of Abdurrahman will be given by: W = mg = 40 kg × 9.8 m/s^2 = 490 N

$$P = \frac{F}{A} = \frac{W}{A} \quad \text{—— } 1$$

(a) For both feet the equation 1 can be written as: $P_1 = \frac{W}{A_1}$

Putting values $P_1 = \frac{490\,N}{0.04\,m^2}$

Therefore $\boxed{P_1 = 12{,}250\,N/m^2 = 12{,}250\,Pa = 12.25\,kPa}$ —— Answer

(b) For one foot the above equation can be written as $P_2 = \frac{W}{A_2}$

$$\text{Putting values } P_2 = \frac{490\,N}{0.02\,m^2}$$

Therefore $\boxed{aPk5.42 = aP005,42 =^2 m/ N005,42 =_2}$ Answer

Thus, for the same force (or weight), if area is halved pressure becomes double.

5.3 ATMOSPHERIC PRESSURE

Pressure is particularly useful for dealing with liquids and gases, as it exerts pressure in every direction. That's why during swimming we feel pressure on all parts of our body. Similarly we live at the bottom of the earth's atmosphere, which pushes inward on our bodies just like the water in a swimming pool.

'The pressure that atmospheric particles exert on the surface of earth and all over the surface of objects on the earth is called atmospheric pressure'. The pressure of the air at a given place varies slightly according to the weather and height from sea level. At sea level, the pressure of the atmosphere on average is 1.013×10^5 Nm^2 (or 1.013×10^5 Pa). This value lets us define a commonly used unit of pressure, the atmosphere (abbreviated atm), such that

$$\mathbf{1\ atm = 1.013 \times 10^5\ Pa}$$

Another unit of pressure sometimes used (in meteorology and on weather maps) is the bar, which is defined as

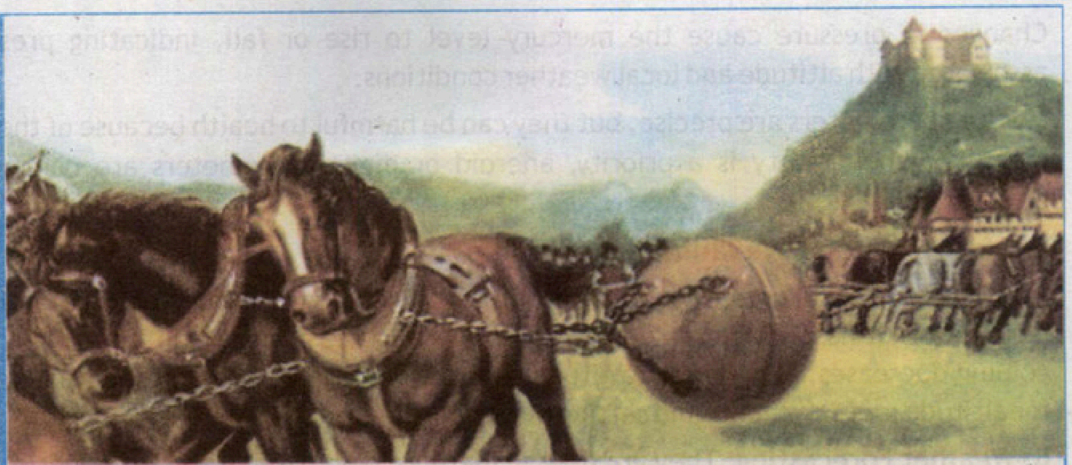
$$\mathbf{1\ bar = 1.000 \times 10^5\ Pa.}$$

How a suction cup gets its sticking force? It is because of the atmospheric pressure. When we push the cup against a smooth wall, we actually force the air out of the cup, allowing atmospheric pressure to hold it to the wall. Another example of atmospheric pressure can be seen when we pump the air out of sealed can, atmospheric pressure produces an inward force that is unopposed, this results in the collapse of the can (figure 5.9).

FIGURE 5.9 SUCTION CUP AND AIR EVACUATED FROM SEALED CAN

(a) (b)

POINT TO PONDER



In 17th century Otto Von Guricke (German physicist) fitted two hollow bronze hemispheres together and removed the air from the resulting sphere with a pump. Two eight horse teams were unable to pull the halves apart, even though the hemispheres fell apart when the air was readmitted.

5.3.1 MEASUREMENT OF ATMOSPHERIC PRESSURE

A liquid barometer is a device that measures atmospheric pressure using the principles of hydrostatics and the behavior of liquids. The most common type of liquid barometer is the mercury barometer.

The liquid barometer works on the principle of hydrostatic equilibrium, which states that the pressure at any point in a fluid at rest is the same at all depths.

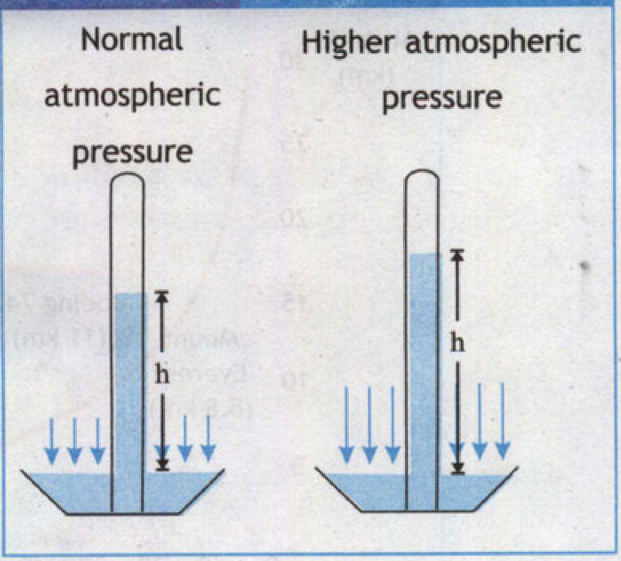
In a mercury barometer, a tube filled with mercury is inverted into a container of mercury. The mercury in the tube seeks a level where the weight of the mercury column is balanced by atmospheric pressure on the surface of the mercury in the container. The height of the mercury column in the tube represents the atmospheric pressure as shown in the figure 5.10. At sea level, the atmosphere will push down mercury in the tub and make it rise up in a tube to a height of approximately 760 millimeters (mmHg) or 29.92 inches.

$$1\ \text{atm} = 760\ \text{mmHg} = 101.325\ \text{kPa}$$

The torr is another unit of pressure, equivalent to 1 mmHg.

$$1\ \text{atm} = 760\ \text{torr}$$

FIGURE 5.10 BAROMETER



Changes in pressure cause the mercury level to rise or fall, indicating pressure variations associated with altitude and local weather conditions.

Mercury barometers are precise, but they can be harmful to health because of the toxic nature of mercury. When safety is a priority, aneroid or digital barometers are commonly chosen as alternatives.

Liquid barometers have various applications:

A. Altitude Measurement: Liquid barometers (including mercury barometers), can estimate altitude. As atmospheric pressure decreases with increasing altitude, the height of the mercury column decreases, allowing for altitude calculations. They are essential instruments in aviation for altitude measurements and setting aircraft altimeters.

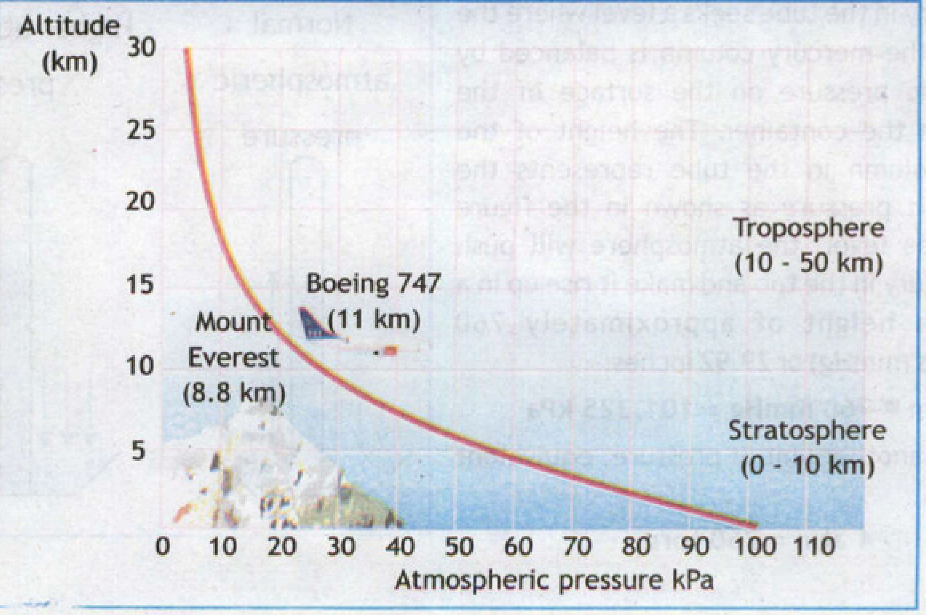
B. Weather Forecasting: They are used in meteorology to measure atmospheric pressure, which is associated with weather changes. A falling barometer may indicate an approaching storm, while a rising barometer suggests improvement in weather conditions.

C. Industrial Applications: Liquid barometers are used in industrial settings where precise pressure measurements are needed for specific processes or equipment.

5.3.2 ATMOSPHERIC PRESSURE AND HEIGHT FROM SURFACE OF EARTH

The atmospheric pressure decreases as we go up from the surface of earth. On mountains the atmospheric pressure is lower than at sea level, decreasing gradually to zero. The climbers at high altitudes encounter lower atmospheric pressure due to the thinner air. The thinner air causes breathing difficulties due to the lower level of oxygen. The graph in figure 5.11 shows that at Mount Everest (height of 8.8 km above sea level) the atmospheric pressure is only 33 kPa, and where Boing 747 flies the atmospheric pressure is around 23 kPa.

FIGURE 5.11 ATMOSPHERIC PRESSURE AND HEIGHT

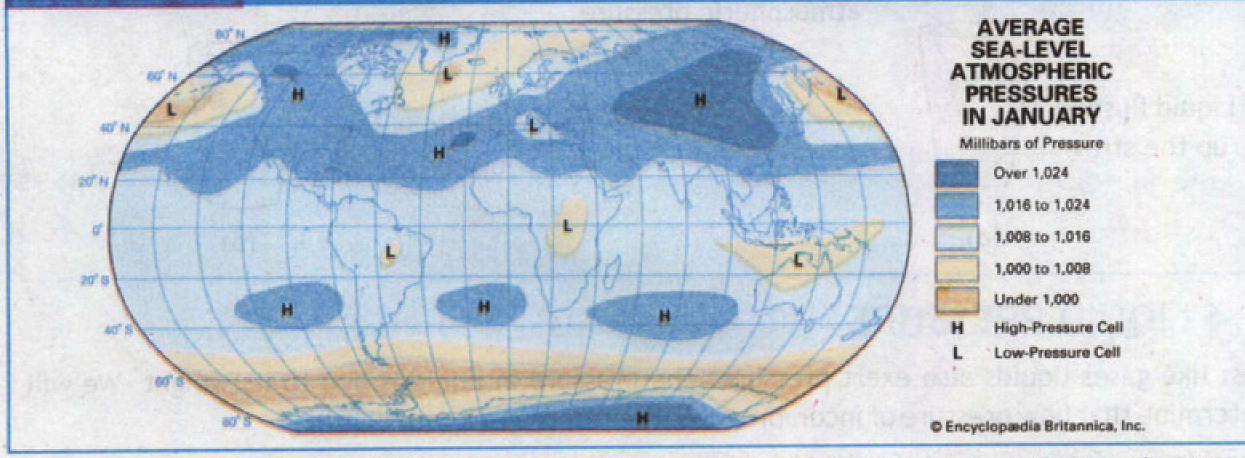


5.3.3 ATMOSPHERIC PRESSURE AND WEATHER

Barometers that are kept in the same place at the same height above sea level show some variation in atmospheric pressure from day to day. These pressure variations are shown on weather maps (fig. 5.12). The lines in the map joining all those places with the same atmospheric pressure are called isobars. The unit for pressure used in weather maps is the millibar (mbar).

$$1\ mbar = 100\ Pa$$

FIGURE 5.12 PRESSURE MAP



Usually the range of atmospheric pressure varies from the very high pressure of 1040 mbar to as low as 950 mbar. Winds move from high pressure regions to low pressure regions. The strength of the wind is determined by the pressure difference. From the weather map, when the isobars are packed closely together, it indicates a high pressure difference.

5.3.4 APPLICATIONS OF ATMOSPHERIC PRESSURE

(A) DRINKING BY STRAW: The drinking through straw is possible by lowering the pressure in the mouth below atmospheric pressure as shown in figure 5.13 (a). The action of sucking increases the volume of lungs, thereby reducing the air pressure in the lungs and the mouth. The atmospheric pressure acting on the surface of the liquid will then be greater than the pressure in the mouth, thus forcing the liquid to rise up the straw into the mouth.

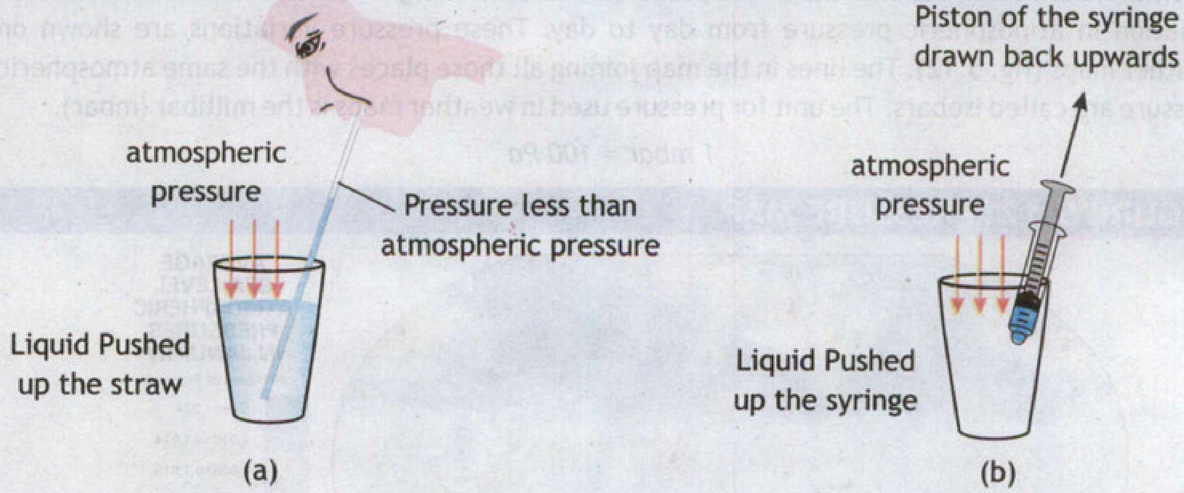
(B) DRAWING LIQUID BY SYRINGE: We can draw liquid up the syringe, as shown in Figure 5.13 (b), the piston of the syringe is drawn back upwards. This decreases the pressure within the cylinder. Atmospheric pressure acting on the surface of the liquid drives the liquid into the cylinder through the nozzle of the syringe.

POINT TO PONDER

Why it is difficult to cook food at high altitudes?

As altitude increases and atmospheric pressure decreases, the boiling point of water decreases. To compensate for the lower boiling point of water, the cooking time must be increased. Turning up the heat will not help cook food.

FIGURE 5.13 APPLICATIONS OF ATMOSPHERIC PRESSURE



5.4 LIQUID PRESSURE

Just like gases liquids also exert pressure. The pressure in liquid is due to its weight. We will determine that how pressure of incompressible liquid increases with depth.

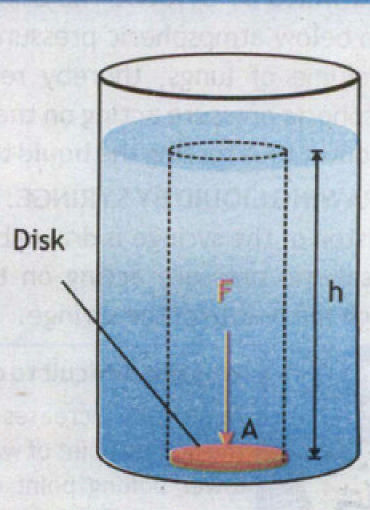
Consider a column of liquid of height 'h' , base area 'A' at the bottom of a tank in liquid and density 'ρ' as shown in figure 5.14. The force acting on a base area is the weight of the cylindrical column of liquid of mass 'm' is,

$$F = W = mg \quad \text{——} (1)$$

The mass 'm' of the cylindrical liquid, in terms of density 'ρ' is given by,

$$\rho = \frac{m}{V} \quad \text{or} \quad m = \rho V \quad \text{——} (2)$$

FIGURE 5.14 LIQUID PRESSURE



Since the fluid forms a cylindrical volume V shown by dotted lines in the figure which has height h and area of cross section A. Therefore

$$V = Ah \quad \text{——} (3)$$

putting equation 3 in equation 2, we get

$$m = \rho Ah \quad \text{——} (4)$$

putting equation 4 in equation 1, we get

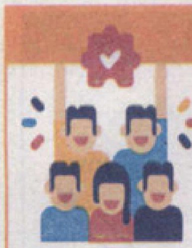
$$F = \rho Ahg \quad \text{——} (5)$$

Since pressure is defined as $$P = \frac{F}{A} \quad \text{——} (6)$$

putting equation 5 in equation 6, we get $$P = \frac{\rho Ahg}{A}$$

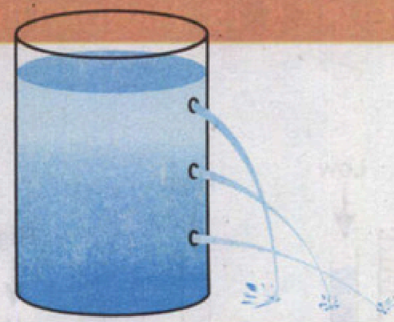
therefore $P = \rho h g$ (5.3)

from equation 7.3 we deduce that the pressure in a liquid depends on the depth and density of the liquid.



ACTIVITY

Drill holes at different heights on a can as shown in the figure and fill it with water. Water will spurt out fastest and furthest from the lowest hole and slowest and nearest from the highest hole. This means that the pressure in a liquid increases with depth because the further down you go, the greater the weight of liquid above it.



EXAMPLE 7.3: LIMITS ON SUBMARINE DEPTH

A submarine was moving in the Pacific Ocean (the largest and deepest ocean) at a depth of 8.5 km. How much pressure is exerted upon the submarine if density of water is 1000 kg/m^3?

GIVEN

Depth = height h = 8.5 km = 8500 m

Density of water ρ = 1000 kg/m^3

Acceleration due to gravity g = 9.8m/s^2

REQUIRED

Pressure P = ?

SOLUTION:

The pressure exerted on a body inside a liquid, can be given by: $P = \rho gh$

Putting values $P = (1000\,kg/m^3) \times (9.8\,m/s^2) \times (8.500\,m)$

Therefore $\boxed{P = 8.55 \times 10^7\ N/m^2 = 8.55 \times 10^7\ Pa}$ Answer

The water will exert a pressure of 8.33×10^7 Pa or 83.3 MPa on the submarine.

5.5 MANOMETER

A manometer can be defined as a device that is used to measure the pressure in a fluid using fluid dynamics. The fluid can be a gas or a liquid.

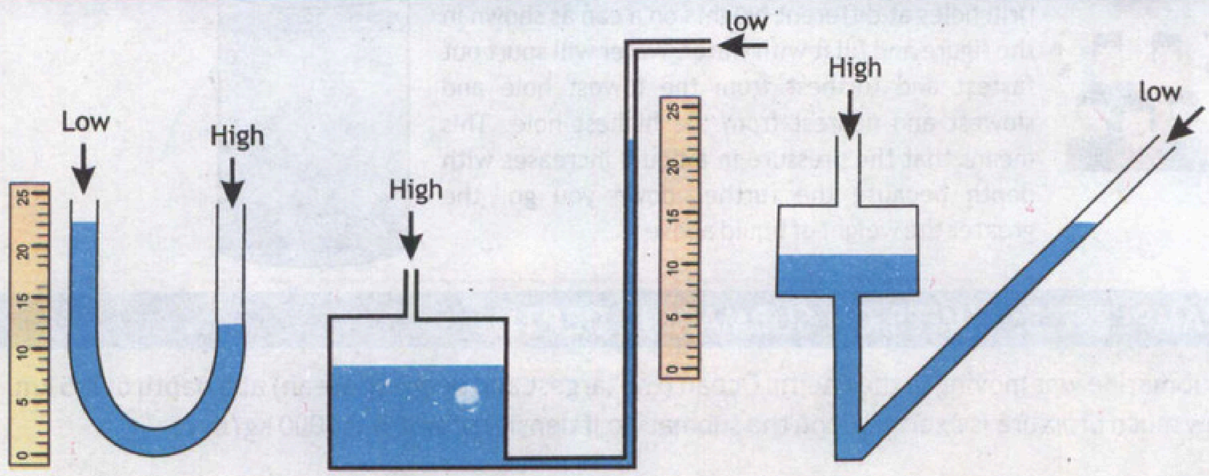
In other words, we can define it as a gauge that is used to measure pressure present in the fluids. Also, it is used in laboratory experiments to demonstrate the pressure of air on a liquid column or vice versa

The formula of a manometer is as follows:

$$P = \rho g h \quad (5.4)$$

Where *'P'* is the pressure of the fluid, *'ρ'* is the density of the fluid, *'g'* is the gravitational acceleration exerted by the earth, and *'h'* is the height till which the fluid rises in a manometer.

FIGURE 5.15 MANOMTRE TYPES



(a) U-tube Manometer (b) Well Reservoir Manometer (c) Inclined Manometer

The working principle of a manometer is that one end is connected to a seal-tight gas to measure the source of pressure. Whereas, its other end is left open to the atmospheric pressure of the earth. If the pressure present in it is greater than 1 atm then the fluid present in the column will be forced down by that pressure. However, it will cause an increase in equal amounts in the present column.

5.5.1 APPLICATION OF MANOMETER

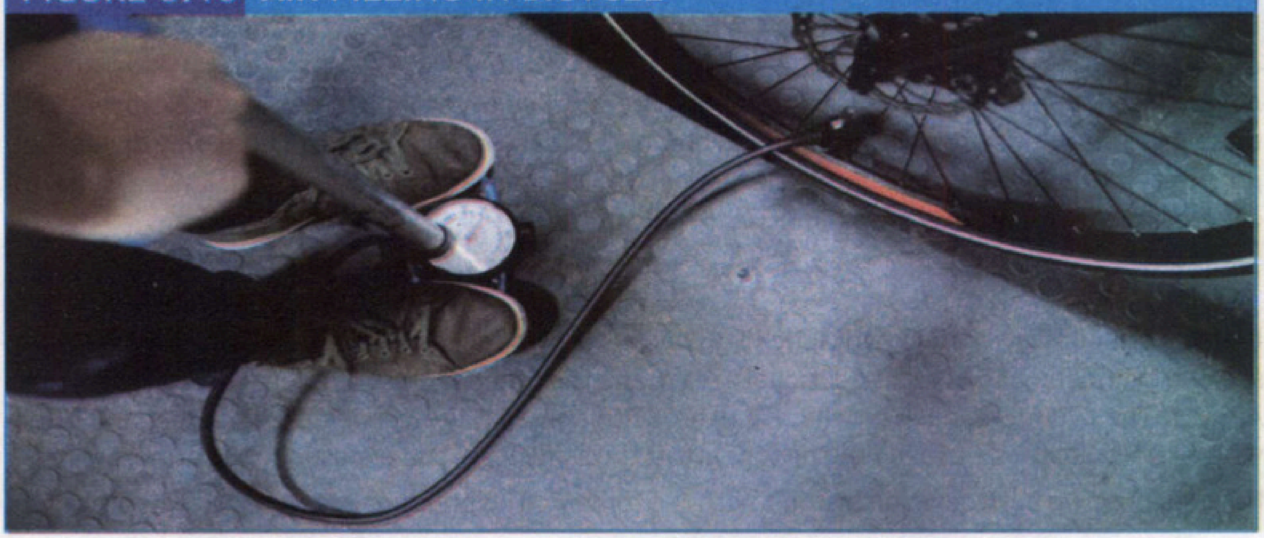
- It is used to measure the pressure of the fluids using mechanical properties of fluids.
- It is also used to measure vacuum.
- It is also used to measure the flow of the fluid.
- It is used to measure the filter pressure drop of the fluids.
- It is also used for meter calibrations.
- It is used to measure leak testing.
- It is also used to measure the liquid level present in a tank.

TABLE 5.2: DIFFERENCE BETWEEN MANOMETER AND BAROMETER	
Manometer	**Barometer**
It is a device that is used to measure the pressure of the fluid but that of a liquid concerning the earth's atmospheric pressure.	It is a device that is used to measure fluid pressure but that of air as it can differ with distance when it's below or above sea level
It comes in different forms	It comes only in one basic design for all its types
These are filled with mercury or any heavy liquid material but in some cases, they can be filled with a lighter liquid material	**In all its cases, these are only filled with** mercury or any heavy liquid material

5.6 PASCAL'S PRINCIPLE

When we pump a bicycle tire, we apply a force on the pump that in turn exerts a force on the air inside the tyre. The air responds by pushing not only against the pump but also against the walls of the tyre. As a result, the pressure increases by an equal amount throughout the tyre as shown in figure 5.16.

FIGURE 5.16 AIR FILLING IN BICYCLE



In general, if the pressure in a fluid is increased at any point in a container (such as at the valve of the tyre), the pressure increases at all points inside the container by exactly the same amount. Blaise Pascal (1623-1662) noted this fact, what is now called Pascal's principle (or Pascal's law):

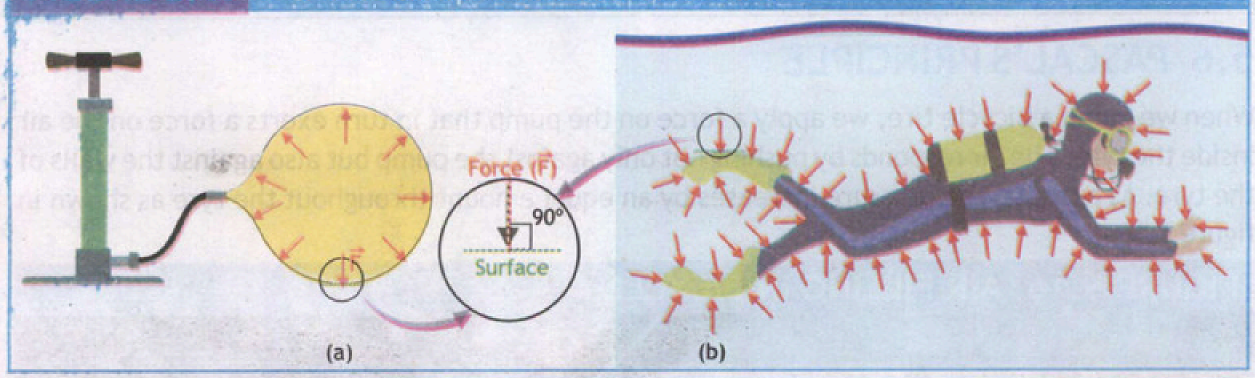
An external pressure applied to an enclosed fluid is transmitted unchanged to every point within the fluid.

The relationship between pressure and force on a surface is described by Pascal's Principle, which explain how pressure at a surface produces a force in a direction perpendicular (at right angles) to the surface.

Since pressure is transmitted equally in all directions, the force generated ($F = P \times A$) is also distributed equally in all directions. The force acts perpendicular to the surface because the pressure is acting uniformly in all directions. If there were a component of force parallel to the surface, the object would exert force on the fluid parallel to it as a consequence of Newton's third law. This would result in an uneven distribution of forces, contradicting the principles of Pascal's Principle.

When you blow up a balloon, the pressure inside the balloon goes up. This pressure spreads out evenly in all directions. The force from the pressure pushes outward and goes straight across the surface of the balloon, making it get bigger as shown in figure 5.17 (a).

FIGURE 5.17 FORCE ACTS PERPENDICULARLY



As you dive deeper underwater, the pressure increases due to the weight of the water above. The force exerted by this pressure is perpendicular to the surface of your body. This is why divers feel pressure on their ears, and it also explains why deep-sea divers need specialized suits to counteract the pressure as shown in figure 5.17 (b).

5.7.1 HYDRAULIC LIFT

Pascal's principle at work in hydraulic lift, which is shown schematically in Figure 5.18. Here we see two cylinders, one of cross-sectional area A_1 and the other of cross-sectional area A_2 (such that $A_2 > A_1$). The cylinders, each of which is fitted with a piston, are connected by a tube and filled with a Hydraulic fluid. Initially the pistons are at the same level and exposed to the atmosphere.

Now, suppose we push down on piston 1 with the force F_1. The pressure P_1 exerted by this piston is:

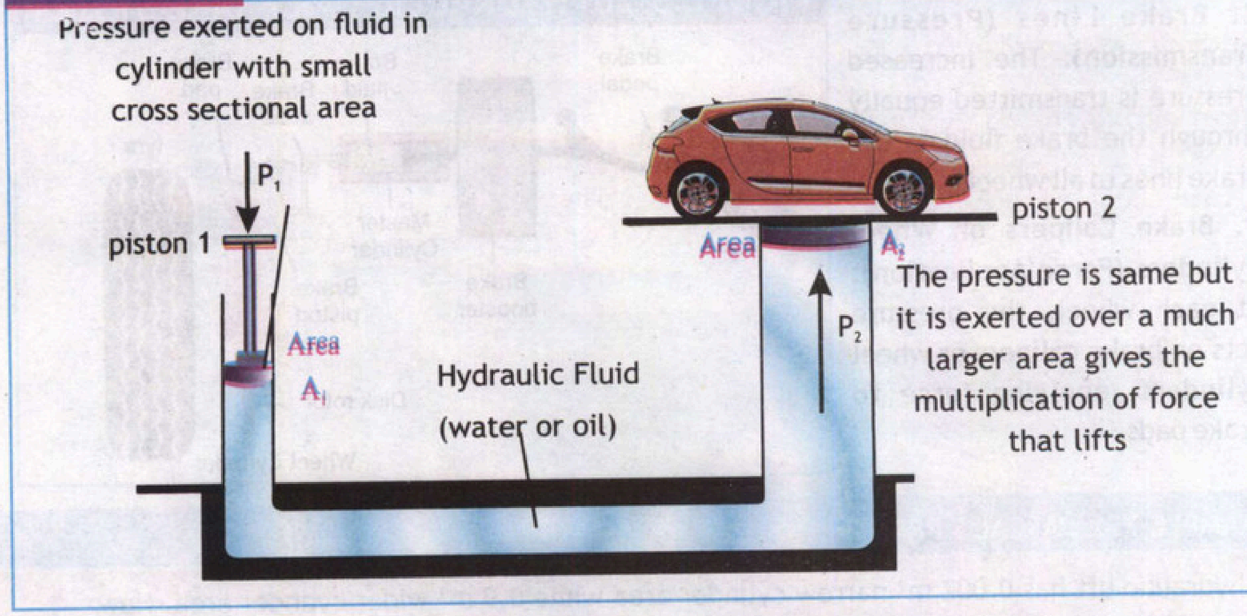
$$P_1 = \frac{F_1}{A_1} \qquad (1)$$

Similarly, the pressure on the piston lifting vehicle is P_2, which can be written as

$$P_2 = \frac{F_2}{A_2} \quad \text{——} (2)$$

By pascal's principle $P_2 = P_1$ —— (3)

FIGURE 5.18 HYDRAULIC ELEVATOR OR LIFT



putting values from equation 1 and equation 2 in equation 3 and rearranging for F_2 , we get

$$F_2 = \frac{A_2}{A_1} F_1 \quad \text{——} (5.5)$$

Equation 5.5 shows that depending on the ratio A_2/A_1 the force F_2 can be as large as possible. To be specific, let's assume that A_1 is 100 times greater than A_2. Then, by pushing down on piston 1 with a force F_1 we push upward on piston 2 with a force of F_2 = 100 F_1. Our force has been magnified 100 times! Hence a relatively small effort can be used to overcome a much larger load.

FIGURE 5.19 HYDRAULIC CAR LIFT

5.7.2 HYDRAULIC CAR BRAKE SYSTEM

The operation of hydraulic car brake system as shown in figure 5.20 is based on Pascal's principle, in the brake system:

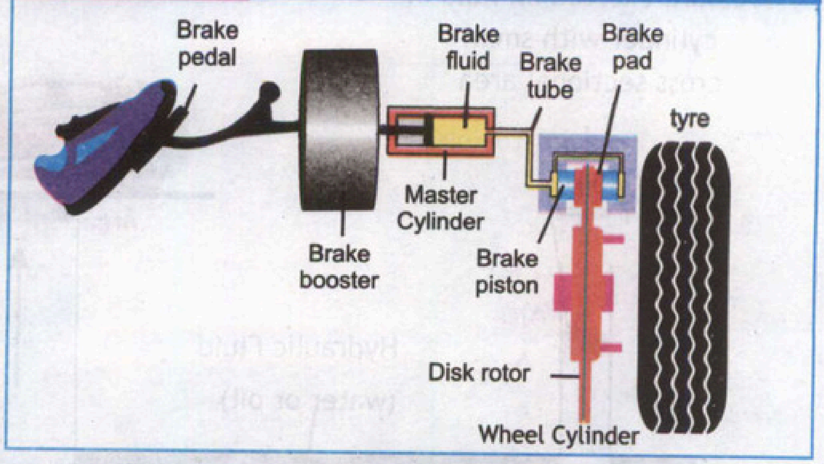
A. Brake Pedal (Force Input): When we press the brake pedal, it exerts force on the master cylinder's piston.

B. Master Cylinder (Pressure Increase): The force on the piston increases the pressure in the brake fluid.

C. Brake Lines (Pressure Transmission): The increased pressure is transmitted equally through the brake fluid in the brake lines to all wheels.

D. Brake Calipers or Wheel Cylinders (Force Application): At each wheel, the pressure acts on brake calipers or wheel cylinders, applying force to brake pads.

FIGURE 5.20 HYDRAULIC CAR BRAKE SYSTEM



EXAMPLE 7.4: PASCAL'S PRINCIPLE

A hydraulic lift has 0.002 m² narrow cylinder area while 0.9 m² wider cylinder area. How much force must be applied at the narrow cylinder if a car weighing 1800 kg is to be lifted?

GIVEN

Area of narrow cylinder 'A_1' = 0.002 m^2

Area of wider cylinder 'A_2' = 0.9 m^2

Mass of car 'm' = 1800 kg

REQUIRED

Force at narrow cylinder F_1 = ?

SOLUTION: First we will find weight of the car as this will be the force applied on car:

$$w = mg = F_2 = 1800\ \text{kg} \times 9.8\ \text{m/s}^2 = 17{,}640\ \text{N}$$

From Pascal's principle $F_1 = \frac{A_1}{A_2}F_2$ Putting values $F_1 = \frac{0.002\,m^2}{0.9\,m^2} \times 17{,}640\,N$

Therefore $\boxed{F_1 = 39.2\,N}$ Answer

That is why we use hydraulic lifts to lift heavy weights with much smaller force than their weight.

SUMMARY

Elasticity is the property of a body, which enables the body to regain its original dimension when the deforming force acting on it is removed.

Hooke's law states that within elastic limits the extension (or compression) is directly proportional to the force applied.

Pressure is force applied per unit area.

Atmospheric Pressure or barometric pressure is the force exerted by the air (its weight) on unit area.

Barometer is a device used to measure atmospheric pressure.

Monometer is one of the most accurate devices for measuring pressure, including atmospheric pressure in the lower ranges.

Pascal's Principle states that if the pressure at one point of a confined fluid is increased by an amount, the pressure increases by the same amount at all other parts throughout the fluid.

EXERCISE

MULTIPLE CHOICE QUESTIONS

QI. Choose the best possible option.

1. The most elastic material of the following is:

   A. Rubber B. Wood C. Glass D. Steel

2. Hooke's law hold good up to:

   A. proportional limit B. yield limit

   C. elastic limit D. plastic limit

3. A mass of 2 kg is hung by spring, which displaces it through 5 cm. The spring constant is:

   A. 400 N/m B. 40 N/m C. 4 N/m D. 4000 N/m

4. Materials which does not regain its original shape after removal of the load producing deformation are termed as:

   A. Elastic materials B. Plastic materials

   C. Rigid materials D. Hooke's materials

5. SI unit of pressure is:

   A. bar B. newton C. psi D. pascal

6. Which will exert greater pressure?

   A. 3 g needle of tip area $1 mm^2$ B. 4000 kg elephant of total feet area $0.5 m^2$

   C. A girl of mass 40 kg wearing high heel shoes of cross-sectional area $0.5 cm^2$

   D. A loaded ship of mass 2.2×10^7 kg having area $600 m^2$

7. Pressure of 1000 mbars is equivalent to:
   A. 0.1 kPa B. 1 kPa C. 10 kPa D. 100 kPa
8. Pressure of 1 mm Hg is equal to:
   A. 1.316×10^{-3} atm B. 1 atm C. 133.29 atm D. 1.316×10^{5} atm
9. Atmospheric pressure is commonly measured using a:
   A. hygrometer B. barometer C. manometer D. thermometer
10. Pressure of liquid in a container increase with:
   A. base B. volume C. depth D. mass
11. The atmospheric pressure will be smaller at:
   A. Islamabad B. Peshawar C. Lahore D. Murree
12. A girl of mass 50 kg wears heels with an area of 2 cm^2 in contact with the ground. The pressure she exerts on ground is:
   A. 4×10^{-5} Pa B 4×10^{4} Pa C. 4×10^{-4} Pa D. 4×10^{5} Pa
13. Divers wear special suits in order to protect them from:
   A. low pressure B. high pressure
   C. low temperature D. high temperature
14. In a stationary fluid, the local pressure of the fluid vary:
   A. with depth only B. horizontally only
   C. both with depth and along horizontal direction
   D. neither with depth nor along horizontal direction
15. The pressure exerted by a man on the surface of earth will be smaller when he:
   A. stands on both feet B. sits on the ground
   C. stands on one leg D. sleeps on the ground

SHORT RESPONSE QUESTIONS

QII. Give a short response to the following questions

1. While walking on a trampoline. Do you feel more pressure when you stand still or jump up and down? Why does pressure change with movement?
2. How does the shape of a thumb pin help it penetrate surfaces easily?
3. If you blow up a balloon and then tie it closed, why does it stay inflated even though you stop blowing? How does pressure play a role here?
4. Why an inner airtight layer of a space suit is designed to maintain a constant pressure around the astronaut?
5. If a liquid has density twice the density of mercury, what will be height of liquid column in barometer?
6. Why we wouldn't be able to sip water with a straw on the moon?

7. How are we able to break a metal wire by bending it repeatedly?
8. A spring, having spring constant k when loaded with mass 'm', is cut into two equal parts. One of the pars is loaded with the same mass m again. What will be its spring constant now?
9. Why do static fluids always exert a force perpendicular to the surface?
10. How can a small car lifter lifts load heavier than itself?

LONG RESPONSE QUESTIONS

QIII. Give a an extended response to the following questions

1. Define elasticity and elastic limit. Show that a force may produce change in size and shape of solids.
2. What is Hook's law? Illustrate its applications. Also, define and calculate spring constant.
3. Draw and explain force-extension graph for elastic solids.
4. Define and explain pressure. What is effect of area on pressure acting on surface?
5. Explain the term atmospheric pressure along with its units. How atmospheric pressure is measured with liquid barometer? Explain its construction and applications.
6. Explain with examples how atmospheric pressure varies with altitude. What kind of weather change is indicated by variation in the atmospheric pressure? What are different applications of atmospheric pressure?
7. Show that liquid in a container exerts pressure equal to $P = \rho g h$. What is effect of depth on pressure of liquid?
8. State Pascal's law? Describe working principle of hydraulic lift using Pascal's law? What do you mean by force multiplier?

NUMERICAL RESPONSE QUESTIONS

QIV. Solve the following numerical questions.

1. Consider a spring with a spring constant of 8000 N/m. If a force of 500 N is applied to the spring, what will be the displacement of the spring?

   (Ans. 6.25 cm)

2. In a force multiplier, small piston has diameter of 15 cm and large piston has diameter of 30 cm. If 250 N force is applied on the small piston then how much force will produce on large piston?

   (Ans. 1000 N)

3. A hydraulic car lift lifts a car of mass 1000 kg when we apply force of 50 N on small piston. Radius of its small piston is 20 cm. Find the radius of its large piston.

   (Ans. 78.4 cm)

4. Water column in a beaker is 70 cm. Find the pressure of water in beaker. Take density of water as 1000 kg/m^3.

   (Ans. 6.86 kPa)

5. How much force should be applied on an area of 20 cm^2 to get a pressure of 4500 Pa?

   (Ans. 9 N)