Chapter 7

FORCE AND PRESSURE

STUDENTS' LEARNING OUTCOMES

After studying this chapter, students will be able to:

- ☑ Define the term pressure.
- ☑ Identify the units of pressure.
- ☑ Explain hydraulics and hydraulic systems by giving examples.
- ☑ Explain how gases behave under pressure.
- ☑ Describe the causes of gas pressure in a container.
- ☑ Explain the working of aerosols.
- ☑ Identify the application of gas pressure.
- ☑ Describe the term atmospheric pressure.

We often use the word 'pressure' such as gas pressure, water pressure, blood pressure, atmospheric pressure, etc., in our daily life. In this chapter, we will learn about pressure, its relation with force and area and its applications.

7.1 Pressure, Force and Area

When water flows out of a tap with greater speed, we say that water is flowing with high pressure. If we put our hand palm under the tap water stream we feel a force (push) on our hand (Figure 7.1). This force acting normally on the surface of our hand palm is termed as **pressure**. Thus pressure can be defined as the force acting normally on unit area of a surface of an object. Mathematically, pressure can be defined as:

Figure 7.1

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Pressure is denoted by P, force is denoted by F and area is denoted by A, then the above

relation can be expressed as:

$$P = \frac{F}{A}$$

From this relation it can be seen that when same force is applied on different areas, the smaller area will experience high pressure while the larger area will experience low pressure. Similarly, when different forces act on the same area, the larger force will exert high pressure while the smaller force will exert low pressure. Let us observe these effects in the following activities.

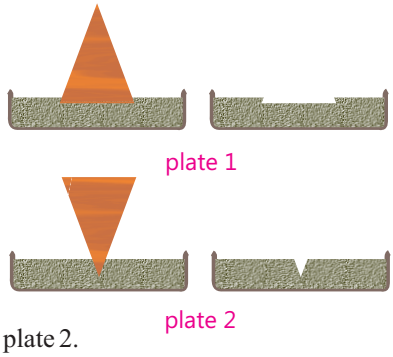
Activity 7.1 - Pressure exerted by the same force on different areas

Material required:

Wedge, two identical plates, wet sand.

Procedure:

- Fill the plates with wet sand and make the sand surface plane.
- Place the wedge with its broader edge downward on the sand in plate 1.
- Pick the wedge up and note depth of the mark/pit made on the sand surface.
- Now invert the wedge and place its narrow edge on the sand in plate 2.
- Pick the wedge up and note the depth of the mark/pit made on the sand surface.



What do you think about the pressure developed by the same force (weight of the wedge) on different areas of sand?

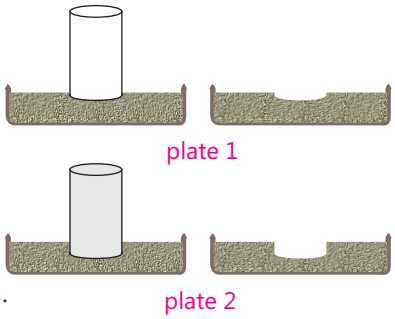
Activity 7.2 - Pressure exerted on the same area by different forces

Material required:

A glass jar, two identical plates, wet sand.

Procedure:

- Fill the plates with wet sand and make the sand surface plane.
- Place the empty jar on the wet sand in plate 1.
- Pick the jar up and note the depth of the mark/pit made on the sand surface.
- Now fill the jar with sand and place it on the wet sand in plate 2.
- Pick the jar up and note the depth of the mark/pit made on the sand surface.



What do you think about the pressure developed by different forces (weight of empty jar and weight of jar filled with sand) on the same area?

For your information.

- A woman wearing high heel exerts more pressure on the carpeted floor as compared to the man having same weight wearing broad heel shoes.

7.1.1 Units of Pressure (N m^{-2}) or pascal (Pa)

Pressure is a physical quantity whose units can be expressed in terms of units of force and area. The unit of force is newton (N) and unit of area is square metre (m^2). As pressure is equal to force per unit area, hence, the unit for its measurement is newton per square metre (N m^{-2}). It is the SI unit of pressure. It is also known as Pascal. Pascal is denoted by Pa.

For your information.

- When a force of one newton (equal to the weight of a 100 g mass) acts perpendicularly on an area of one square metre, the pressure on this area will be one newton per square metre (1N m^{-2}) or one pascal (1 Pa).
- 1Pa (one pascal) is a very small pressure. It is approximately equal to the pressure exerted by a ten rupee note lying flat on a table. For this reason, pressure is usually measured in kilopascals (kPa), a bigger unit of pressure.
- 1 kPa = 1000 Pa (pascal)

Activity 7.3

Ali's weight is 500 N. He is standing on the ground with an area 0.025 m^2 under his feet. We can find pressure exerted by Ali on the floor as:

$$\text{Pressure} = \frac{\text{Force (weight)}}{\text{Area}}$$

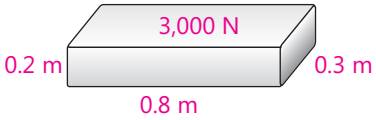
$$= \frac{500\ \text{N}}{0.025\ \text{m}^2} = 20{,}000\ \text{N m}^{-2}$$

What will be pressure exerted by Ali in kilo pascal?

Mini Exercise

A metallic box placed on the floor (as shown in figure) weighs 3000 N.

- What is the pressure exerted by the block lying in this position?
- What will be the pressure exerted by the box if it stands vertically on the smaller face?



7.2 Water Pressure

We observe that the speed of water from a tank coming out of tap on ground floor is greater than the speed of water coming out of a tap on upper storey of our house. Actually, water contained in the tank exerts pressure on its walls. The speed of the water coming out of the tap depends upon the water pressure in the tank. Moreover, the water pressure of the tap depends upon the height of the water tank above the ground floor. That is why, the water tanks are placed on the roof of the top floor. This pressure is transmitted through the pipes to the tap. We will study different characteristics of water pressure or liquid pressure with the help of the following activities:

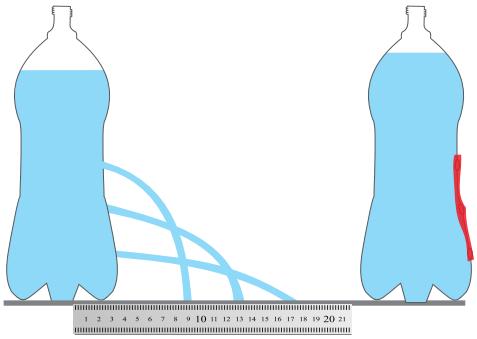
Activity 7.4

Material required:

1.5 litre plastic bottle, iron nail, insulation tape, metre rod, etc.

Procedure:

- Punch three holes at different heights on the side of plastic bottle using a nail as shown in the figure.
- Close these holes by pasting insulation tape.
- Fill the bottle with water up to brim and place it on the floor.
- Remove the tape and observe the ejection of water out of the three holes.
- Note the distances of the streams of water coming out of various holes from the bottle.



- Note the angle which each stream of water makes with the surface of the vessel as it emerges out of the hole.

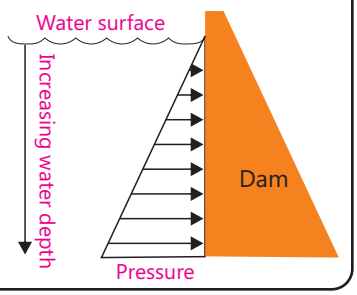
Does water flow out of all the holes with the same speed and pressure?

In what direction does water come out of the holes?

We can infer from this activity that the greater the depth of the water in the vessel, the greater is the pressure of water. Such a liquid pressure which increases with the depth of the liquid in a container is called **hydrostatic pressure**.

Do you know?

Why the supporting wall of a dam is built very broad at the bottom?



We also see that water comes out of the holes in a direction perpendicular to the surface of the bottle. This shows that hydrostatic pressure always acts perpendicular to the surface.

Interesting information.

- Water pressure increases by 10,000 Pa for every one metre down in a lake or in an ocean. That is why the divers feel an increase of pressure on their eardrums even a few metres below the surface of water.
- The deeper you go underwater, the greater the pressure of the water pushing down on you.

7.3 Liquid Pressure in Closed Containers

The liquids or fluids filled in closed containers exert pressure equally in all directions (Figure 7.2). This can be seen by the following activity.

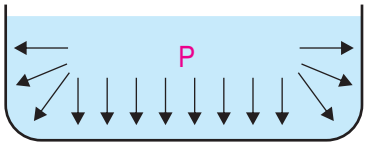


Figure 7.2

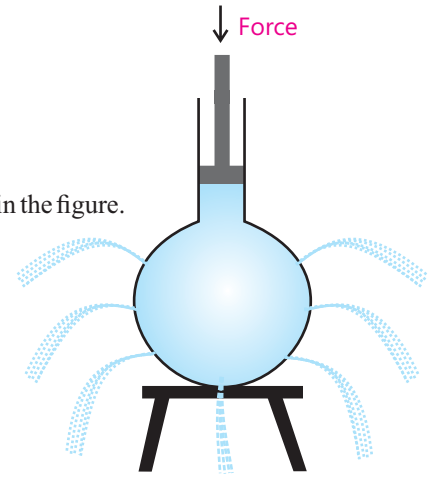
Activity 7.5

Material required:

Plastic bottle fitted with a piston at its mouth, water tub, etc.

Procedure:

- Take a plastic bottle fitted with a piston at its mouth.
- Make a few holes in the bottle at different places as shown in the figure.
- Dip the round part of the bottle in the water contained in a tub or vessel and pull the piston or plunger out to fill the bottle with water.
- Take the bottle out of the tub and push the piston or plunger in the bottle.
- Observe the water flowing out of the holes in the bottle.



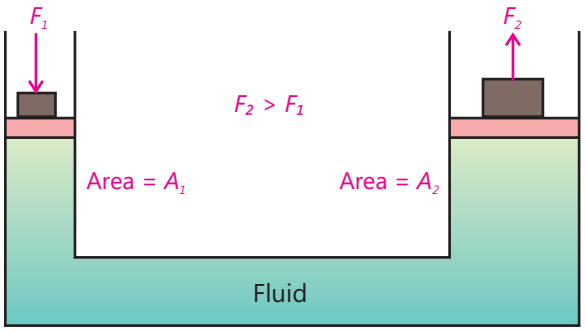
Does water flow out of all the holes with the same pressure?

We observe from this activity that pressure is exerted on fluid enclosed in a vessel is transmitted equally in all directions. This fact was first time discovered by Pascal and is called **Pascal's law**. Pascal's law is only applied to the fluid, filled in closed vessels.

The branch of science which deals with the transmission of fluid pressure through pipes as a source of mechanical force is called **hydraulics.** Such systems are often used to produce a large force with the help of a small force.

For your information.

A force applied on the fluid at smaller piston increases many times when it is transmitted to the fluid at the bigger piston. This is due to the large cross-sectional area of the bigger piston. All the Hydraulic systems work on this principle.



7.4 Applications of Pascal's Law - Hydraulic system

(i) Jack system

Figure 7.3 shows a hydraulic system called hydraulic jack. In this system a small, force F_1 is applied on a small piston which produces pressure P on the oil. Pressure P is transmitted through the pipe to a very large cylinder fitted with a piston. Since area of this piston is very large. So, a very large force is produced by pressure P at this bigger piston which may be used to lift something very heavy such as a car.

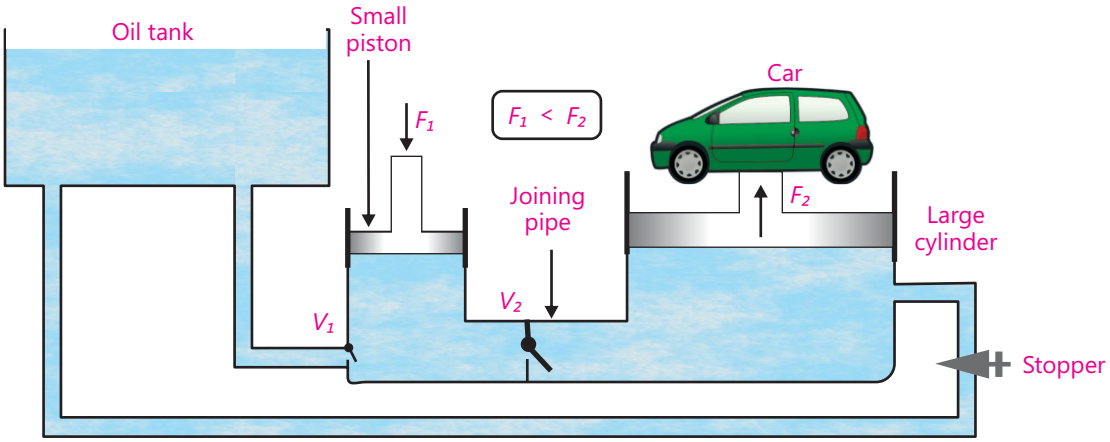


Figure 7.3

Valves V_1 and V_2 prevent the back-flow of oil to the small cylinder so that heavy load remains raised up. When the oil stopper is opened, the oil in the large cylinder flows back to the oil tank and the load is brought down.

(ii) Brake system

Brake system in the cars is another common example of a **hydraulic system** (Figure 7.4). This consists of a pipe and two cylinders. It is filled with special fluid called brake oil. At one end of the pipe there is a cylinder fitted with a small piston called master cylinder. The small piston is connected with brake pedal. At the other end of the pipe there is a second cylinder fitted with a large piston called slave cylinder. When small piston is pushed into master cylinder by applying a small force on brake pedal, the pressure thus produced is transmitted without loss to the slave cylinder. The large piston in the slave cylinder is pushed out with a large force. It then pushes the brake pad out to make it rub against the moving wheel disc. In this way a large frictional force is produced which stops the running wheel.

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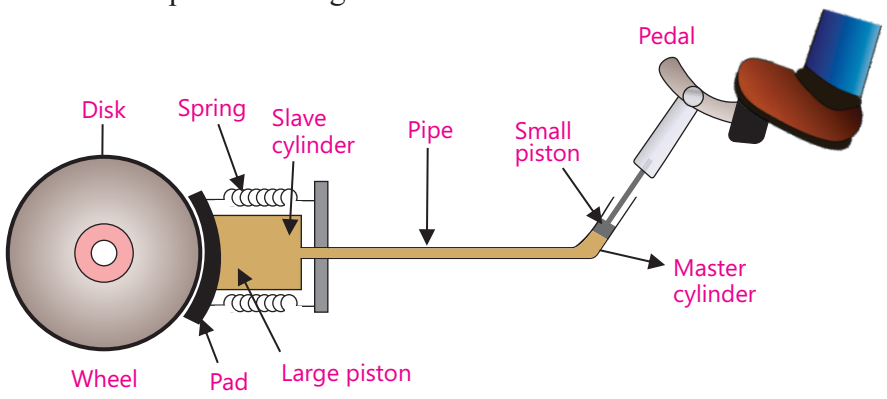


Figure 7.4: Hydraulic brake system

7.5 Gas Pressure in a Container

Molecules of a gas in a container are in a continuous state of random motion in all directions. During their motion, they collide with each other and with the walls of the container. Gas molecules colliding with the walls of the container exert force on the walls of the container and thus produce pressure (Figure 7.5).

If the volume of the container is decreased for the same quantity of gas the distances between the particles also decreases and there are more collisions of the particles with the walls of the container. As a result the gas pressure increases.

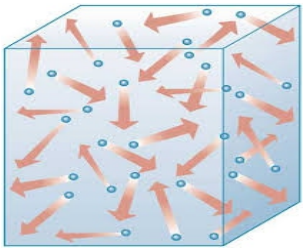


Figure 7.5: Gas pressure in a container

The gas pressure can also be increased by adding more gas in the container. Addition of more gas molecules means more collisions with the walls of the container and hence more pressure.

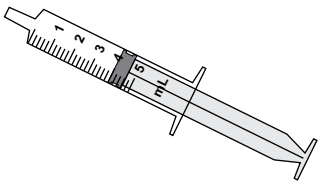
7.5.1 Pneumatics

Compressed air has the ability to do some mechanical work. The branch of science which deals with the study and applications of pressurized gas to produce mechanical motion is called **pneumatics**.

Activity 7.6

Material required:

Plastic syringe



Procedure:

- Take a new plastic syringe and carefully remove its needle.
- Pull out the plunger to fill the air in the syringe.
- Block the opening of the syringe with your finger and press the plunger in.
- You will notice that air inside the syringe is compressed and the plunger is moved back to some extent on releasing.

What do you infer from this activity?

Applications of compressed air

Compressed air is widely used in various daily life activities and in industries. Some common applications of compressed air are mentioned below:

1. Automobile tyres are inflated with compressed air for smooth running of vehicles (Figure 7.6).

2. Spray guns use compressed air for spraying paint (Figure 7.7).

Figure 7.6: Air filling in automobile tyre

Figure 7.7: Spray gun

3. Air powered motors (Figure 7.8) use compressed air to work. Such motors are used at the places where electric motors are not suitable for safety reasons.

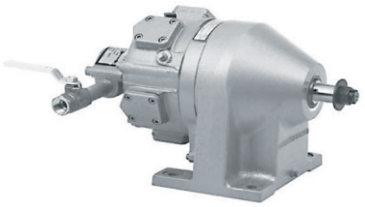


Figure 7.8: Air-powered motor

4. Compressed air is used to operate air-powered (pneumatic) tools like hammers, drills, etc. (Figure 7.9)

5. The compressed air is also used in air brake system in heavy vehicles. When a brake pedal is pressed, the compressed air is released from the storage tank. This air pushes the brake pad against the moving wheel to stop its motion (Figure 7.10).

Figure 7.9: Pneumatic hammer

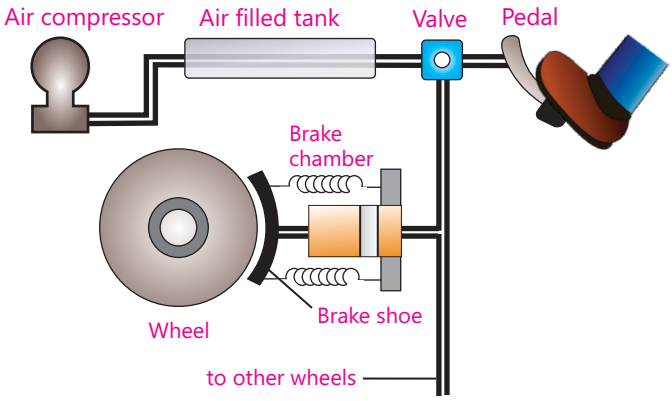


Figure 7.10: Air brake

6. Most of the dentistry tools use compressed air for their working (Figure 7.11). It is safer for the patient.

Figure 7.11: Most of the dentistry tools use compressed air

7.6 Aerosols

The products using 'sol' systems are called aerosols. “Sol” is a mixture of suspended solid or liquid particles in a gas or air. Different types of aerosols are used for various purposes (Figure 7.12). They are used as air fresheners, insect repellents, hair sprays, cleaning agents, spray paints, medicinal sprays (like inhalers.) etc.

Figure 7.12: Aerosol

How do aerosols work?

An aerosol contains a mixture of two fluids. One that boils below room temperature called the propellant and the other one is the product. The product is the substance which is actually used as air freshner, hair spray or insect repellent, etc. The propellant is the means of pushing the product out of the can. Both fluids are stored in a sealed metal can (Figure 7.13). At room temperature, a part of the propellant fluid vaporizes and increases pressure over the product liquid. A long plastic tube runs from the bottom of the can up to a valve system at the top of the can. When valve is opened by pressing the button, a passage from inside of the can to the outside opens. The high-pressure propellant vapour or gas pushes the liquid product up in the plastic tube and then out through the nozzle. The narrow nozzle breaks the flowing liquid into tiny drops which come out as a fine spray.

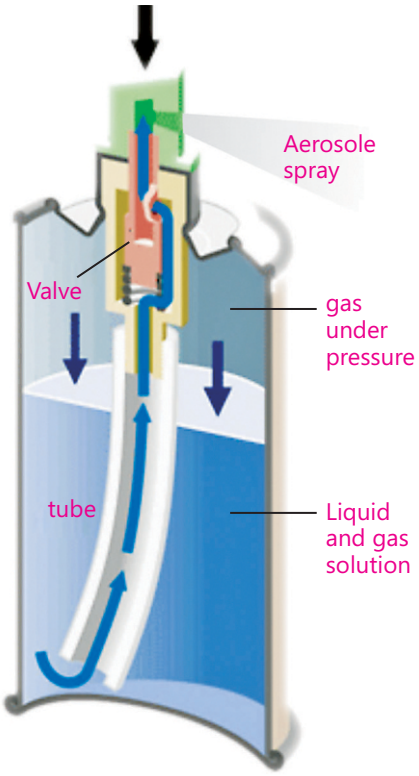


Figure 7.13: Aerosol

7.7 Atmospheric Pressure

Our Earth has a blanket of air around it. The Earth's gravity pulls the air column down. Hence, the air has weight. The weight of the air column (force) per unit area on the Earth is pressure which is termed as atmospheric pressure.

$$\text{Atmospheric pressure} = \frac{\text{Weight of the air}}{\text{Area}}$$

The instrument used to measure the atmospheric pressure is called **barometer**. The unit for measuring atmospheric pressure is the standard atmosphere. The standard atmosphere is abbreviated as **atm**. One atmosphere (1 atm.) is equal to 101,300 Pa or 101.3 kPa at sea level.

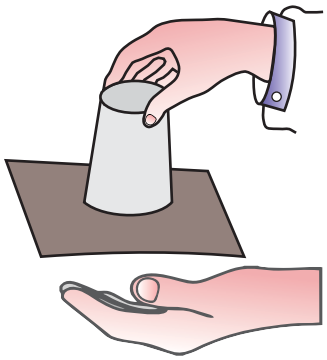
? Do you know?

The atmospheric pressure around us at ground level is about 100,000 Pa (100 kPa).

Activity 7.7

Material required:

Glass, thick paper, water



Procedure:

- Take a glass and fill it with water up to brim.
- Put the paper on the glass.
- Hold and simply press the paper on the glass by keeping hand over the paper.
- Keep on hand over the paper, hold the glass from its lower part by your other hand and invert it.
- Remove the hand from the paper.

Does water fall down?

If not what prevents it from falling?

Atmospheric pressure varies with altitude

The Earth's surface where we live is the bottom of the sea of air. There is more weight of the air and hence more atmospheric pressure at the Earth's surface. As we go up in the air, atmospheric pressure decreases. This is because weight of air decreases as we go up in the air. Thus the people who climb up the hills experience less air pressure than those living at sea level. At sea level the atmospheric pressure is 101300 Pa (101.3 kPa) whereas, at a height of about 5km it falls to about 55000 Pa (55 kPa).

Altitude above the sea level can be determined on the basis of the measurement of atmospheric pressure. The lower the atmospheric pressure the greater is the altitude. When a barometer is calibrated to indicate altitude, the instrument is called **pressure altimeter** (Figure 7.14). Pressure altimeter is used in air crafts. Wrist-mounted altimeter is used by sky divers, hikers and mountain climbers.

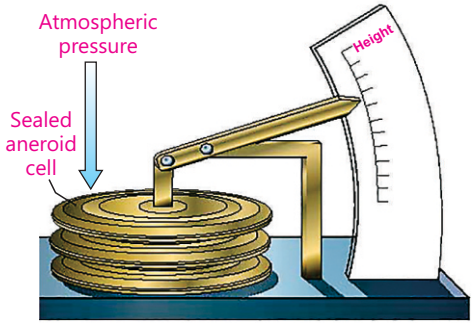


Figure 7.14: Pressure altimeter

Do you know?

- Atmospheric pressure is used for weather forecast.
- The weather is fine when the atmospheric pressure is high as 105000 Pa. when it falls to low, about 92000 Pa, there is a probability of a storm.

KEY POINTS

- The force per unit area acting normally on the surface of an object is called pressure.
- The SI unit of pressure ($N\ m^{-2}$) is called pascal which is denoted by Pa.
- Water contained in a vessel exerts pressure on the walls of the vessel.
- The water pressure in a vessel increases with the increase in depth.
- Pascal's law states that fluids enclosed in a vessel exert pressure which is transmitted equally in all directions.
- The branch of science which deals with the transmission of pressurized liquids through pipes as a source of mechanical force is called hydraulics.
- The particles of a gas in a container all the time collide with each other and with the walls of the container. The force of these collisions produces pressure on the walls of container.
- The branch of science which deals with the study and applications of pressurized gas to produce mechanical motion is called pneumatics.
- The products using 'sol' systems are called aerosols. "Sol" is a mixture of suspended solid or liquid particles in a gas or air.
- Different types of aerosols are used as air freshners, insect repellents, hair sprays, cleaning agents, spray paints, medicinal sprays (like inhalers.) etc.
- The weight of the air column per unit area on a surface is called atmospheric pressure.
- Atmospheric pressure decreases with the height above the ground.

QUESTIONS

7.1 Encircle the correct option.

(i) The SI unit of pressure is:

a. watt b. joule

c. pascal d. newton

(ii) When same amount of force is applied on different areas, it exerts:

a. low pressure on small area. b. no pressure on small area.

c. high pressure on small area. d. high pressure on large area.

(iii) A pressure of $10Nm^{-2}$ is equal to:

a. 10Pa b. 100Pa

c. 1000Pa d. 10,000Pa

(iv) A force of 1800N is acting on the surface area of $0.06m^2$. The pressure exerted by the force will be:

a. 3 kPa
b. 30 kPa
c. 300 kPa
d. 3000 kPa

(v) Hydrostatic pressure of the liquids depends on:

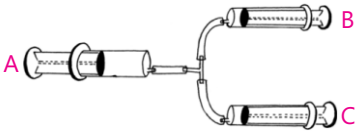
a. shape of the vessel
b. size of the vessel
c. volume of the vessel
d. depth of the liquid

(vi) People on hills experience atmospheric pressure:

a. more than that at the sea level
b. less than that at the sea level
c. same as that at the sea level
d. four times more than that at the sea level

(vii) When the plunger A shown in the figure is pushed:

a. plunge B will move out more than C
b. plunger C will move out more than B
c. both B and C will move out equally
d. neither B nor C will move out



(viii) A gas in a container develops pressure due to:

a. collision of molecules with each other
b. collision of molecules with walls of the container
c. weight of the gas
d. composition of the gas

(ix) As we go up in the air:

a. atmospheric pressure increases
b. atmospheric pressure decreases
c. atmospheric pressure does not change
d. atmospheric pressure becomes zero at the height of 1km

(x) What instrument is used to measure height?

a. Hydrometer
b. Hygrometer
c. Altimeter
d. Sphygmomanometer

7.2 Define the following.

(i) Force

(ii) Area

(iii) Pressure

(iv) Hydraulics

(v) Pneumatics

7.3 Give brief answers.

(i) Give the commonly used units of force.

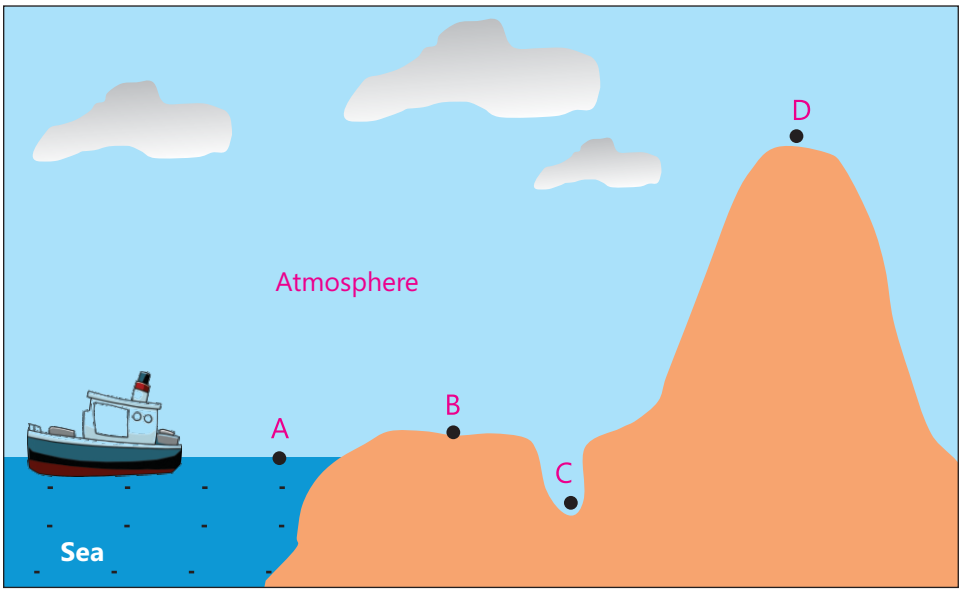
(ii) Give the commonly used units of area.

(iii) Give the commonly used units of pressure.

(iv) State Pascal's law.

(v) Differentiate between hydrostatic pressure and atmospheric pressure.

(vi) In the figure shown below indicate the location where atmospheric pressure is expected to be lowest.



7.4 Explain the following.

(a) Water pressure (b) Atmospheric pressure (c) Aerosols

7.5 Describe an application of Pascal's law.

7.6 Describe the use of a pneumatic system in daily life.