UNIT 9

PRESSURE

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Structure

9.0 Introduction

9.1 Objectives

9.2 Pressure

9.3 SI Units of Pressure

9.4 Pressure in a Liquid

9.5 Pressure exerted by Gases

9.6 Atmospheric Pressure

9.7 Let Us Sum Up

9.8 Unit-End Exercises

9.9 Answers to Check Your Progress

9.10 Answers to Unit-End Exercises

9.0 INTRODUCTION

When we cut a mango with a knife, we use the sharp edge instead of the blunt edge. We also notice that nails are pointed and that it is more suitable to wear shoes with flat soles on soft ground. Certain animals which live in sandy or muddy regions have "large" feet so that they do not sink too deeply into the sand or mud. In all the examples mentioned above, we are making use of the concept "pressure".

"Pressure" is not only associated with solids but also with liquids and gases. A diver experiences an increasing pressure as he or she dives further down under sea water. Atmospheric pressure which is air pressure affects our lives on a daily basis as it helps to determine the weather.

This unit will give you an overview of the "pressure" exerted by solids, liquids, gases and their applications.

9.1 OBJECTIVES

After going through this unit, you should be able to:

- define pressure
- state the SI unit for pressure
- discuss the pressure exerted by solids, liquids and gases
- calculate the pressure exerted by a solid
- calculate the pressure inside a liquid
- demonstrate an understanding of atmospheric pressure
- identify various applications of pressure in our daily life

9.2 PRESSURE

It is easier to cut an orange with a sharp knife than with a blunt knife. This is because, while cutting, the sharp knife has a very small area of contact with the orange. When using the blunt edge of a knife, the force we apply to cut the orange is acting over a larger area. So, when we apply a force, the effect of the force depends on both the force and the area of contact. Therefore, we introduce a new term called pressure.

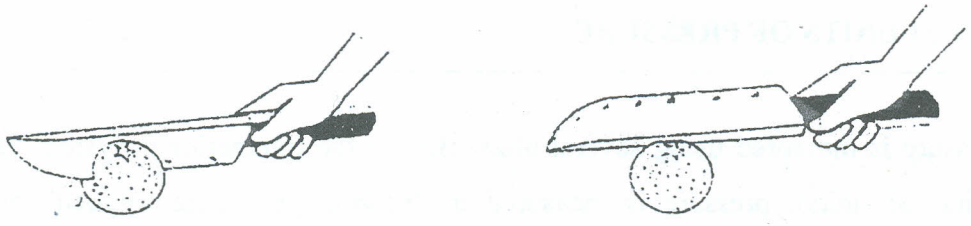


Figure 1: Cutting an orange

Definition of Pressure

Pressure is defined as ***the force acting at right angles per unit area.***

$$\text{Pressure} = \frac{\text{FORCE AT RIGHT ANGLE}}{\text{AREA ON WHICH FORCE ACTS}}$$

The force exerted by a solid object on a surface is its weight, W.

$$W = \text{mass x acceleration due to gravity} = mg$$

where g=acceleration due to gravity =10 ms^{-2}.

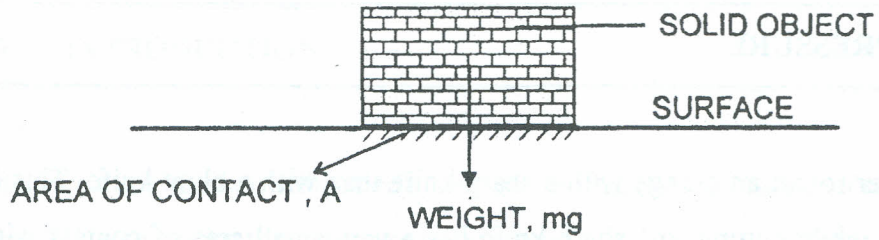


Figure 2: Pressure exerted by solid object

$$P = \frac{FORCE}{AREA} = \frac{WEIGHT}{AREA} = \frac{mg}{A}$$

9.3 SI UNITS OF PRESSURE

Pressure is measured using several units. But, in the International System of Units (SI units), pressure is measured in "newton per metre squared" or N/m^2.This unit is named the *pascal* (Pa) in honour of Blaise Pascal who made early discoveries about pressure.

$$1\ N/m^2 = 1\ Pa$$

Worked Example 1

Calculate the pressure under a woman's feet if her mass is 50 kg and the area of her shoes in contact with the ground is

(i) 2.00 cm^2 (high heel)

(ii) 200 cm^2 (flat sole)

(Take acceleration due to gravity, $g = 10\ ms^{-2}$)

Solution:

(i) Given: Mass, m = 50 kg

Weight of girl = F = m g = 50 × 10 N = 500 N

Area, A = 2.00 cm^2 = 2.00 × 10^{-4} m^2

$$\text{Pressure, } P = \frac{F}{A} = \frac{500}{2.00 \times 10^{-4}} = 2.5 \times 10^6 \text{ Pa}$$

(ii) Area, A = 200 cm^2 = 200 × 10^{-4} m^2

Weight of girl, F = 500 N

$$\text{Pressure, } P = \frac{F}{A} = \frac{500}{200 \times 10^{-4}} = 2.5 \times 10^4 \text{ Pa}$$

The pressure exerted by the stiletto heels in (i) is much greater than that exerted by the flat soles in (ii).

When a person wears stiletto heels, the weight of the person is concentrated over a very small area. This makes it difficult to walk across soft surfaces such as grass. Stiletto heels can also damage vinyl floors.

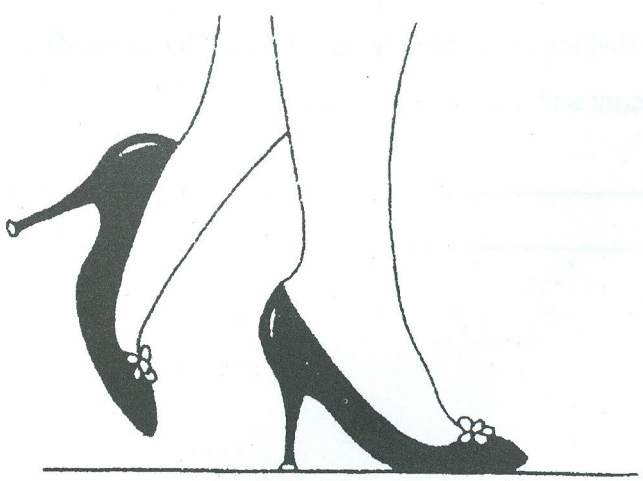
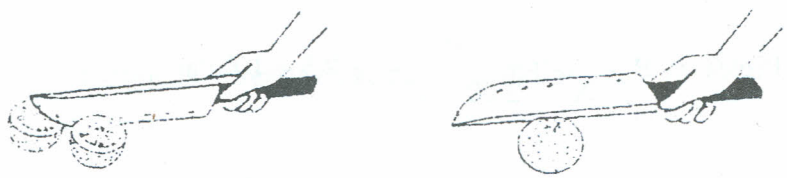


Figure 3: Stiletto heels

Activity 1

Pressure depends on the area of contact

Materials: A knife, two oranges.



Sharp edge (small area) Blunt edge (large area)

Figure 4: Cutting an orange

Steps:

- Hold the knife so that its sharp surface is in contact with the orange.
- Cut one of the oranges with the sharp edge.
- Cut the other orange using the back of the knife.
- Note the effect on the orange in both cases.
- Compare the two results.

What can you deduce about the pressure exerted by the knife in relation to the area of contact?

Check Your Progress

1. State the SI unit of pressure.

_____

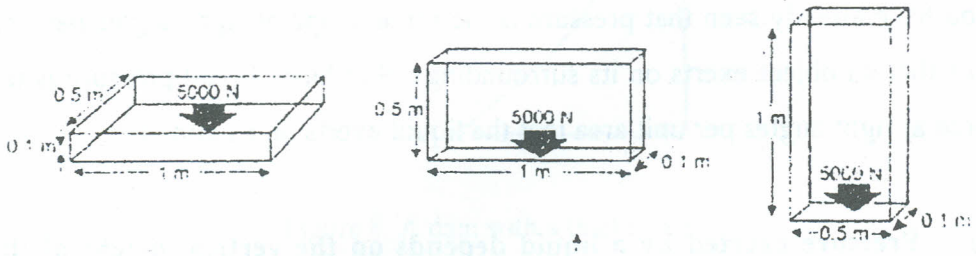
2. A lady wearing high heels would sink further into soft ground than when she wears a pair of shoes with flat soles. Explain.

_____

_____

_____

3. Figure 5 shows the same metal block resting on a surface in three different positions. The weight of the block is 5000 N. Calculate the pressure exerted by the block for each position.



(i) (ii) (iii)

Figure 5: A metal block in three different positions.

9.4 PRESSURE IN A LIQUID

If we make a hole on the bottom or side of a container full of water, the water flows out. In Figure 6, the water in the container is exerting a pressure against the bottom and sides of the container. We say that a liquid exerts pressure in all directions.

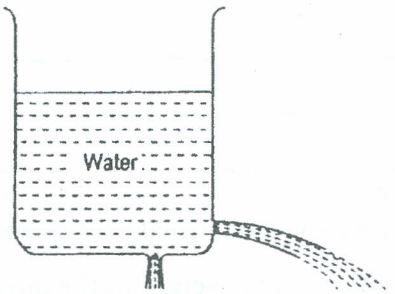
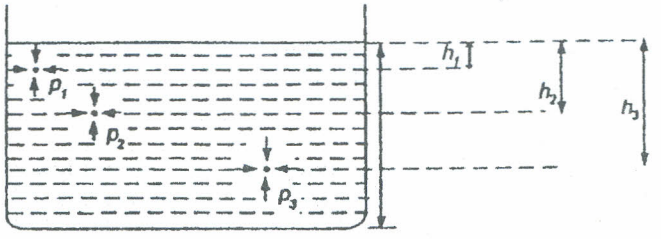


Figure 6: A liquid exerts a pressure in all directions

You have already seen that pressure is the force acting at right angles per unit area that an object exerts on its surroundings. Similarly, liquid pressure is the force at right angles per unit area that the liquid exerts on its container.

(i) Pressure exerted by a liquid depends on the vertical height of the liquid column.

Figure 7 shows a liquid in a container. When an object is placed in that liquid, the deeper the object is, the more pressure it experiences. This is because of the height of the liquid above the object or the depth of the object in the liquid.



$P_3 > P_2 > P_1$ since $h_3 > h_2 > h_1$

Figure 7: Pressure increases with depth

Therefore, in a liquid, the pressure will vary, being greatest on the bottom of the vessel and minimum at the surface. There are several examples that show that pressure in a liquid depends on the vertical height of the liquid column.

Example 1

A swimmer diving down in the sea experiences an increase in pressure with depth. As depth increases, the swimmer experiences an increase in pressure.

Example 2

Figure 8 shows a dam. The base of the dam is made thicker because the pressure of the water increases with depth.

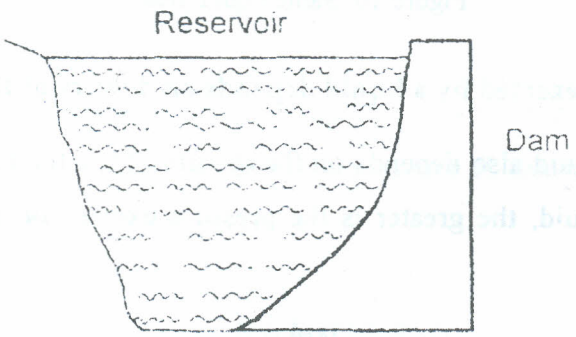


Figure 8: A dam with a thicker base

Example 3

Figure 9 shows two vessels. In both vessels, the pressure exerted by the liquid at the bottom is the same. This is because, no matter how wide the vessels, the pressure at the bottom depends only on the ***vertical height of the liquid*** above the bottom surface.

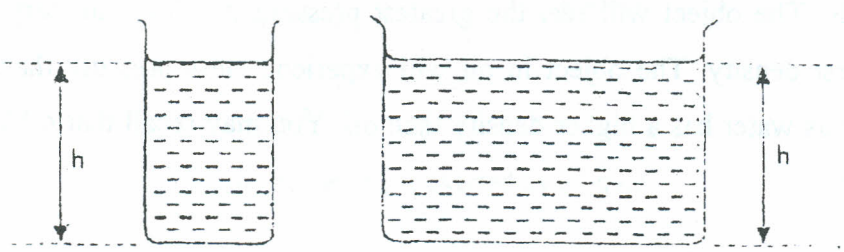


Figure 9: Pressure in a liquid

Example 4

The interconnected vessels in Figure 10 show that pressure depends only on the vertical height h and not on the shape of the vessels.

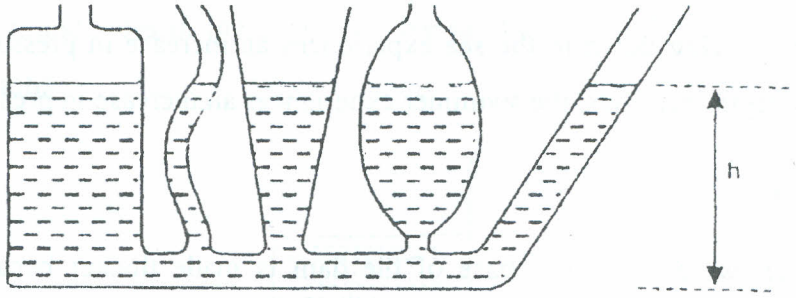


Figure 10: Same liquid pressure

(ii) Pressure exerted by a liquid depends on density of the liquid

Pressure in a liquid also depends on the *density* of the liquid. The greater the density of a liquid, the greater is the pressure exerted on the object in that liquid.

Table 1: Density of Liquids	
Liquid	**Density, kg/m^3**
Water	1000
Oil	800
Mercury	13 600

Table 1 gives the values for the densities of water, oil and mercury. In Figures 11(a), 11(b) and 11(c), an object is immersed at same vertical height h in the liquids. The object will feel the greatest pressure in (c) as mercury has the greatest density. The object in oil will experience less pressure than that in water as water has a higher density than oil. You may recall that oil floats on water.

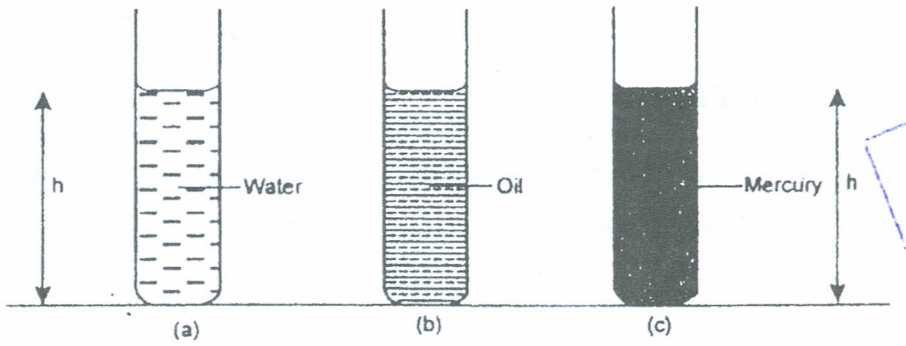


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Figure 11: Pressure depends on density

We can sum up to say that the pressure exerted by a liquid depends on:

(i) the vertical height of the liquid above the object (or the depth of the object in the liquid).

(ii) the density of the liquid.

The above statement about liquid pressure can be expressed mathematically using a formula. The formula that gives the pressure P exerted by a liquid on an object placed in that liquid is given by:

$$P = h\rho g$$

where

h = the height of the liquid above the object.

ρ (rho) = $\dfrac{\text{mass}}{\text{volume}}$ = **density** of liquid.

g = acceleration due to gravity = $10\ ms^{-2}$

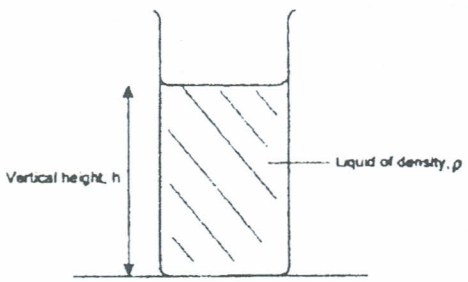

Figure 12: Pressure exerted by a liquid

In Figure 12, when h is in metres, ρ in kg/m^3 and $g = 10ms^{-2}$, then P is in Nm^{-2} (or pascal, pa).

Check Your Progress

4. Write down the formula used to calculate the pressure of a liquid at a particular depth. Explain each term in the formula.

5. Calculate the pressure 100 m below the surface of water. Density of water is 1000 kg/m^3. Assume $g = 10\ ms^{-2}$.

Activity 2

Pressure depends on depth

Materials: One plastic bottle, water, cork screws.

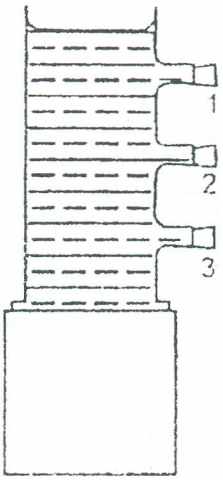

Figure 13: Pressure depends on depth

Steps:

- Punch three small holes at different heights on the sides of the plastic bottle and close them with cork screws.
- Fill the bottle with water.
- Observe how the water spurts out from the three holes when the cork screws are removed.
- Draw a diagram in the space provided below to describe how the water comes out of the holes.

Diagram:

Check Your Progress

6. In Figure 14, the height of the liquid's surface above the bottom of the four vessels is the same.

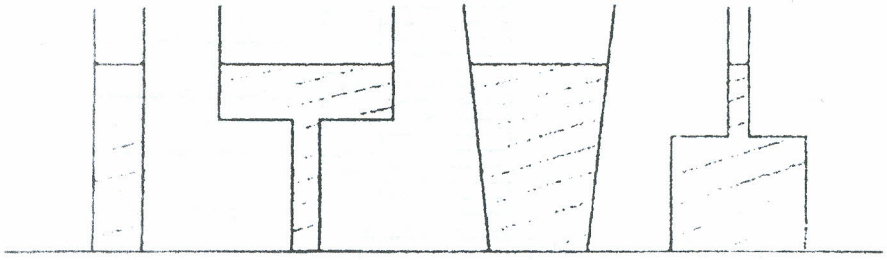

Figure 14: Same liquid in different vessels

(i) In which vessel is the pressure of the fluid at the base of the vessel the greatest?

(ii) Explain.

9.5 PRESSURE EXERTED BY GASES

Most of you have blown a balloon or used a pump to inflate a bicycle tyre. In both cases, you have used an important property of a gas which is its pressure.

As shown in Figure 15, a gas is composed of a large number of molecules which are constantly moving in all directions. The gas molecules are colliding with each other and with the walls of the container. As the gas molecules collide with the walls of its container, a force is produced. This force causes a pressure on the walls of the container.

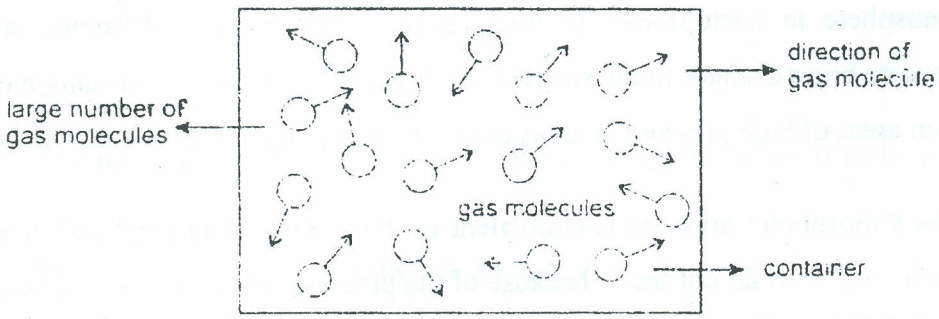

Figure 15: Pressure exerted by gas

9.6 ATMOSPHERIC PRESSURE

The atmosphere is defined as the air surrounding the Earth. The air is composed mainly of gases such as nitrogen and oxygen with small amounts of carbon dioxide and water vapour. The air surrounding us exerts a pressure on us all the time and in all directions and this air pressure is called atmospheric pressure.

Atmospheric pressure is caused by the weight of air molecules. At sea level, the atmospheric pressure is about 10^5 Pa.

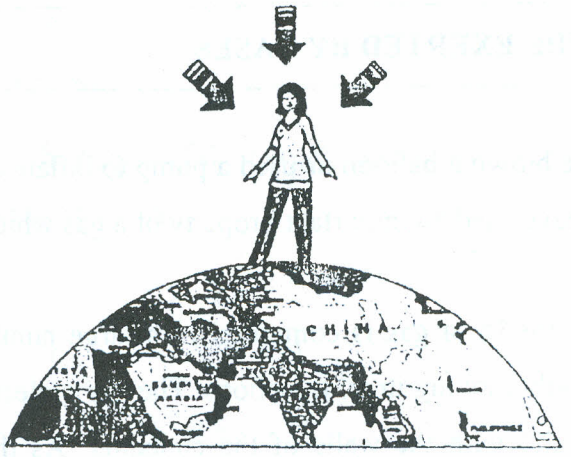

Figure 16: Atmospheric (air) pressure is all around us

Every night we hear the MBC TV presenter give the value of the pressure of the atmosphere in hectopascals (1 hectopascal = 100 pascals). Changes in air pressure bring changes in the weather and make winds blow. Air usually moves from areas of high pressure to areas of low pressure, and this produces winds.

This atmospheric pressure is equivalent to the weight of an elephant on your shoulders. You do not feel it because of the presence of air inside your body. The air pressure inside your bodies balances the atmospheric pressure outside. If you have ever been to the top of a high mountain, you may have noticed that your ears pop. Your ears pop in order to balance the pressure between the outside and inside of your ear.

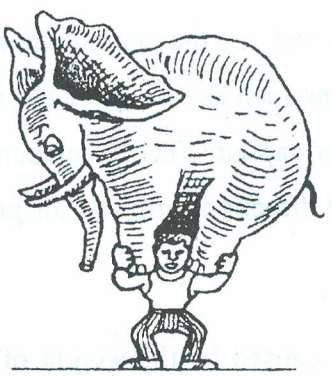

Figure 17: Atmospheric pressure is a large pressure

9.7 LET US SUM UP

In this Unit, you have learnt the following:

1. Pressure is defined as ***the force acting at right angles per unit area***.

$$\textbf{Pressure} = \frac{FORCE}{AREA}$$

2. In the International System of Units (SI units), pressure is measured in "newton per metre squared" or N/m^2.
3. At a depth h in a liquid, the pressure is the weight per unit area at that point. The formula that gives the pressure P exerted by a liquid on an object placed in a liquid is given by:

$$P = h\rho g$$

4. Pressure in a liquid depends on depth
5. The pressure in different liquids, at the same depth, varies directly with the density.
6. When gas molecules collide with the walls of a container, a force perpendicular to the walls is produced. This force causes a pressure on the walls of the container.
7. Atmospheric pressure is caused by the weight of air molecules. At sea level, the atmospheric pressure is about 10^5 Pa.

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9.8 UNIT - END EXERCISES

1. A block weighing 1000N rests on an area of $4\,m^2$. Calculate the pressure exerted by the block on the surface which supports it.
2. Why is the cutting edge of a knife made very thin?
3. Figure 18 shows a dam.
   (i) Where is the pressure greatest?
   (ii) Why is the dam of this shape?

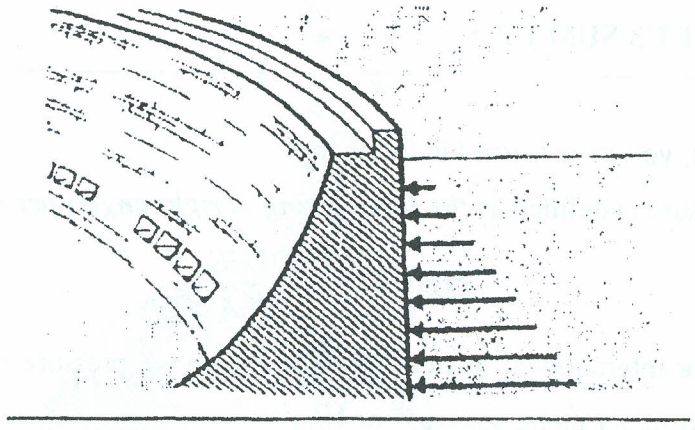


Figure 18: A dam

4. Calculate the pressure at the bottom of a column of air 2 km high. The density of air is 1.2 kg/m^3. Assume $g = 10ms^{-2}$.

5. What is the pressure experienced at a point on the bottom of a swimming pool, 9 metres deep? (The density of water is 1.00 x 10^3 kg/m^3).

6. A tall cylinder, like the one shown in Figure 19, is often used to demonstrate that the pressure in a column of water changes with depth.

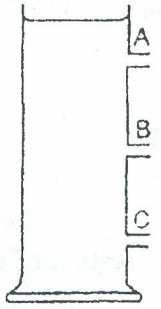


Figure 19: Pressure changes with depth

(a) Draw three lines in the diagram to show the possible paths of the water as it flows out of the three holes A, B and C.

(b) At which of the three holes is the pressure greatest?

7. In Figure 20, water is placed into containers of different shapes which are connected together. The water level is shown in two of the containers. Draw the water level in the other sections of the apparatus.

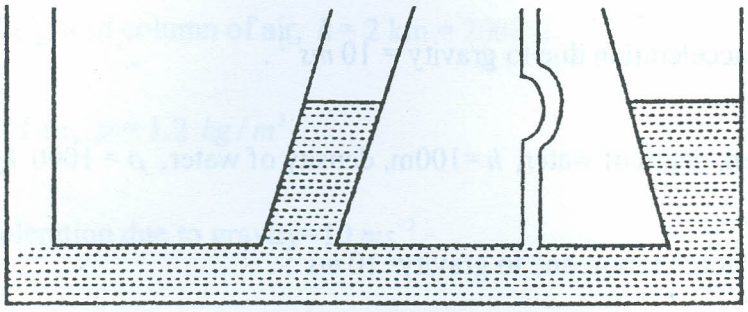


Figure 20: Water in containers of different shapes

9.9 ANSWERS TO CHECK YOUR PROGRESS

1. N/m^2 or Pa (pascal)
2. The weight of the lady is the force acting due to gravity. For high heels the area of contact with the ground is smaller than for flat soles. Therefore, the pressure exerted by high heels is greater than with flat soles. So, the lady sinks further into soft ground.
3. Given, weight of block = F = 5000 N

   (i) Area of contact with surface for block (i) = $1 \times 0.5 = 0.5\ m^2$

   Pressure exerted by block (i), $P = \frac{F}{A} = \frac{5000}{0.5} = 10\,000$ Pa

   (ii) Area of contact with surface for block (ii) = $1 \times 0.1 = 0.1\ m^2$

   Pressure exerted by block (ii), $P = \frac{F}{A} = \frac{5000}{0.1} = 50\,000$ Pa

   (iii) Area of contact with surface for block (iii) = $0.5 \times 0.1 = 0.05\ m^2$

   Pressure exerted by block (iii), $P = \frac{F}{A} = \frac{5000}{0.05} = 100\,000$ Pa

(iv) $P = h\rho g$ where h = the height of the liquid above the object.

4. $\rho = \frac{\text{mass}}{\text{volume}}$ = density of liquid ;

g = acceleration due to gravity = 10 ms^{-2}.

5. Given, depth of water, h =100m, density of water, ρ = 1000 kg/m^3

g = acceleration due to gravity=10 ms^{-2}.

Pressure below the surface of water= P= $h\rho g$ 1000 x 10 x 10=100 000 P

6. (a) For all the four vessels, the pressure is the same at the base of the vessel.

(b) This is because pressure at the base of the vessel depends on the height of the liquid column above the base. The height is the same for all the vessels and therefore, the pressure exerted by the liquid is the same.

9.8 ANSWERS TO UNIT - END EXERCISES

1. Given, weight of block, W = 1000 N and area, A = 4 m^2

$$P = \frac{\text{FORCE}}{\text{AREA}} = \frac{\text{WEIGHT}}{\text{AREA}} = \frac{1000}{4} = 250 \text{ N/m}^2$$

2. Since, $P = \frac{\text{FORCE}}{\text{AREA}}$, then when area of contact is small the pressure is large. The cutting edge of a knife is made small, so that the area of contact with the object it is cutting is small. Therefore, applying a force will cause a large pressure.

3. (i) The pressure is greatest at the base of the dam.

(ii) Since pressure increases with depth, the force per unit area at the base of a dam is greater than at the top. This is why dams are built much thicker at the base.

4. Given, height of column of air, $h = 2$ km $= 2000$m

density of air, $\rho = 1.2\ kg/m^3$

g = acceleration due to gravity$=10\ ms^{-2}$

Pressure due to the column of air = P = $h\rho g = 2000 \times 1.2 \times 10 = 24\ 000$ Pa

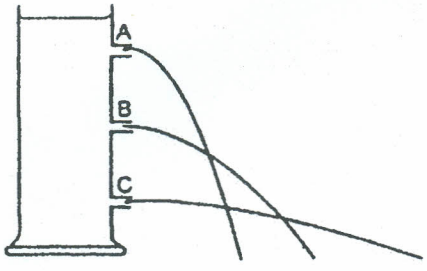
5. Given, depth of pool, $h = 9$ m

density of air, $\rho = 1000\ kg/m^3$

g = acceleration due to gravity $=10\ ms^{-2}$

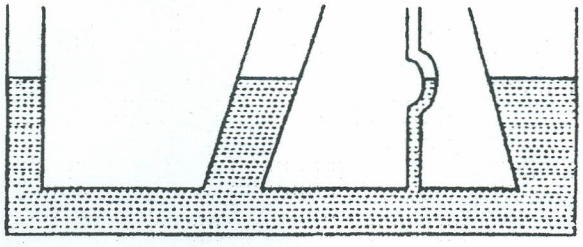
Pressure at the bottom of pool = P = $h\rho g = 9 \times 1000 \times 10 = 90\ 000$ Pa

6. (a)



(b) The pressure is greatest at hole C.

7.



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