

# CHAPTER

# 2

# Pressure

What are liquid pressure, atmospheric pressure and gas pressure?

What is the effect of the changes in pressure in the sea and atmospheric pressure on human beings?

How is Pascal's principle applied in daily life?

How is Archimedes' principle used in the buoyancy of ships?

How is Bernoulli's principle used in the field of aviation?

You will learn:

- 2.1** Pressure in Liquids
- 2.2** Atmospheric Pressure
- 2.3** Gas Pressure
- 2.4** Pascal's Principle
- 2.5** Archimedes' Principle
- 2.6** Bernoulli's Principle



## Information Portal

A high spirit of inquiry has driven human beings to explore deep into the ocean. A deep sea vehicle is a sea vehicle that can carry people to explore the bottom of the ocean.

Limiting Factor is the name of one such deep sea vehicle. It can carry two explorers and can dive to a depth of 11 000 metres below sea level. At this level of depth, the pressure on the deep sea vehicle is more than one thousand times the pressure at sea level. The body of this vehicle has a structure that can withstand this extreme pressure. The pressure in the cabin is always controlled so that the cabin can accommodate the explorers.



<http://bit.ly/2FyV2Wc>

## Importance of the Chapter

The motion of a deep sea vehicle involves the concept of buoyant force. Atmospheric pressure as well as water pressure at extreme depth is taken into consideration in the design and construction of deep sea vehicles. Understanding of the effect of water pressure at extreme depths enables the preparation for expeditions to the bottom of the sea, the construction of the equipment used, as well as precautions to be taken when working in high pressure environment.



<https://bit.ly/2FsZKU6>

## Futuristic Lens

Remotely controlled deep sea vehicles have the potential to be used in the maintenance of undersea cables and the mining of minerals at the seabed. The engineering technology used in the development of deep sea vehicles has the potential to inspire the construction of cities under the sea in the future.

## 2.1 Pressure in Liquids

Photograph 2.1 shows water being released from a dam. The outlet of the dam is near the base of the dam. Why does the water shoot out at high speed? Why is the outlet constructed near the base of the dam? What are the factors that affect water pressure?



SCAN ME

Video of water pressure at a dam

<http://bit.ly/35xPOo9>



LET'S RECALL



Pressure

<http://bit.ly/2Nbf9xT>

Photograph 2.1 Water released from a dam



### Activity 2.1

Algorithm

**Aim:** To derive the formula  $P = h\rho g$  from the formulae  $P = \frac{F}{A}$  and  $\rho = \frac{m}{V}$

**Instructions:**

1. Carry out this activity in pairs.
2. Consider a liquid column with height,  $h$  and base area,  $A$  in a container filled with the liquid as shown in Figure 2.1.
3. Fill in the blanks to derive the formula for liquid pressure.

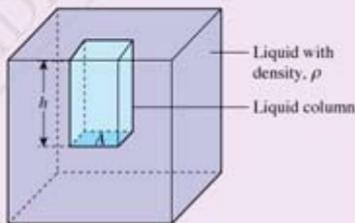


Figure 2.1

Volume of liquid column,  $V =$

[Volume = base area  $\times$  height]

Mass of liquid column,  $m =$

[Mass = volume  $\times$  density]

Weight of liquid column,  $W =$

[Weight = mass  $\times$  gravitational acceleration]

Pressure at the base of liquid column,  $P =$

[Pressure =  $\frac{\text{Weight of column}}{\text{Surface area}}$ ]

$P =$

Note

The pressure at the base of a liquid column is caused by the weight of the liquid column.

**Discussion:**

State three factors that affect liquid pressure.

Liquid pressure is calculated using the following formula.

$$P = h\rho g$$

where  $P$  = liquid pressure  
 $h$  = depth of liquid  
 $\rho$  = density of liquid  
 $g$  = gravitational acceleration

The S.I. unit for pressure,  $P$  is pascal (Pa)  
 $1 \text{ Pa} = 1 \text{ N m}^{-2}$  or  $1 \text{ kg m}^{-1} \text{ s}^{-2}$

### Info GALLERY

Liquid pressure does not depend on its mass, volume, and surface area.

## Factors Affecting Liquid Pressure

### Experiment 2.1

**Inference:** Pressure in a liquid depends on the depth of the liquid

**Hypothesis:** The greater the depth of the liquid, the higher the pressure in the liquid

**Aim:** To study the relationship between the depth of the liquid and the pressure in the liquid

**Variables:**

- (a) Manipulated: Depth of the liquid,  $h$
- (b) Responding: Pressure in the liquid, represented by the difference in height of the water columns,  $D$  between the two water levels in the U-tube
- (c) Constant: Density of the liquid

**Apparatus:** 500 ml measuring cylinder, silicone tube, thistle funnel with its mouth closed by a thin sheet of rubber, U-tube, two half-metre rule and retort stand

**Materials:** Water and food colouring

**Procedure:**

1. Set up the apparatus as shown in Figure 2.2. Initially, the thistle funnel is outside the measuring cylinder and the levels of water in both arms of the U-tube is the same.
2. Immerse the thistle funnel into the measuring cylinder until the depth,  $h = 4.0 \text{ cm}$ .
3. Determine the difference in height of water columns,  $D$  between the two water levels in the U-tube.
4. Repeat steps 2 and 3 for depths,  $h = 8.0 \text{ cm}$ ,  $12.0 \text{ cm}$ ,  $16.0 \text{ cm}$  and  $20.0 \text{ cm}$ .
5. Record the difference in height of the water columns,  $D$  in Table 2.1.

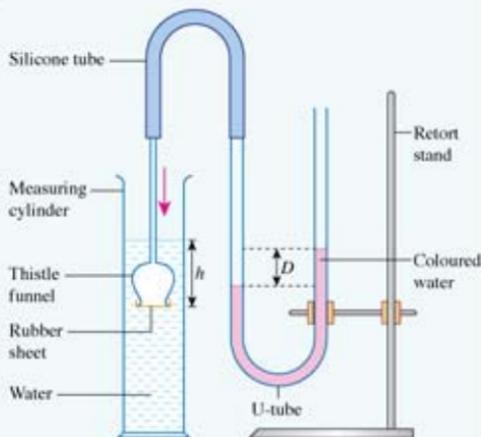


Figure 2.2

**Results:**

Table 2.1

Depth of water, $h$ / cm	Difference in height of water columns, $D$ / cm
4.0	
8.0	
12.0	
16.0	
20.0	

**Data analysis:**

Plot the graph of  $D$  against  $h$ .

**Conclusion:**

What conclusion can be drawn from this experiment?

**Prepare a complete report for this experiment.**

**Discussion:**

1. What is the relationship between water pressure and depth of the water?
2. State one precaution for this experiment.

**Let's Try**

The effect of depth on water pressure can be studied by using a plastic bottle.



After the bottle has been filled with water, the masking tape is removed. The spurt distance of water from the three holes will show the relationship between water pressure and depth.

**Experiment 2.2**

**Inference:** The pressure in a liquid depends on the density of the liquid

**Hypothesis:** The higher the density of the liquid, the higher the pressure in the liquid

**Aim:** To study the relationship between density of the liquid and the pressure in the liquid

**Variables:**

- (a) Manipulated: Density of the liquid,  $\rho$
- (b) Responding: Pressure in the liquid, represented by the difference in height of the water columns,  $D$  between the two water levels in the U-tube.
- (c) Constant: Depth of the liquid

**Apparatus:** Half-metre rule, three 600 ml beakers, U-tube, silicone tube, thistle funnel with its mouth covered by a thin sheet of rubber, and retort stand

**Materials:** Masking tape, water, alcohol and glycerine

**Procedure:**

1. Mark all the beakers 2 cm from the base with masking tape.
2. Set up the apparatus as shown in Figure 2.3.

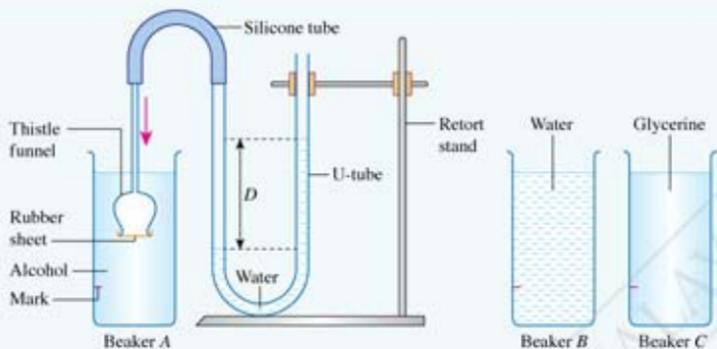


Figure 2.3

- Bring the mouth of the thistle funnel near to the surface of the alcohol in beaker A. Slowly immerse the thistle funnel vertically into the alcohol until the mouth of the thistle funnel is at the same level as the mark.
- Determine the difference in height of the water columns,  $D$  between the two water levels in the U-tube. Then, remove the thistle funnel and dry it.
- Repeat steps 3 and 4 for beaker B and beaker C.
- Record the difference in height of the water columns,  $D$  in Table 2.2.

**Results:**

Table 2.2

Beaker	Type of liquid	Density of liquid, $\rho / \text{kg m}^{-3}$	Difference in height of water columns, $D / \text{cm}$
A	Alcohol	790	
B	Water	1 000	
C	Glycerine	1 300	

**Data analysis:**

Relate the difference in height of the water columns in the U-tube to the density of the liquid.

**Conclusion:**

What conclusion can be drawn from this experiment?

**Prepare a complete report for this experiment.**

**Discussion:**

- Why is the method in Let's Try in page 42 not suitable to study the relationship between density and pressure in a liquid?
- Why is mercury not suitable as the liquid in the U-tube?

**Aim:** To show that cross-sectional area and the shape of a column do not affect pressure in liquids

**Apparatus:** Liquid level apparatus (any shape)

**Materials:** Water and food colouring

**Instructions:**

1. Place an empty liquid level apparatus on the horizontal surface of a table as shown in Figure 2.4.
2. Pour coloured water into the apparatus until almost full.
3. Observe the height of the water level in each column.

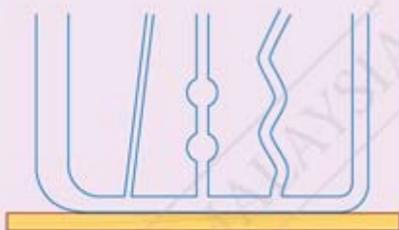


Figure 2.4

**Discussion:**

1. Compare the height of the water level in each column.
2. Discuss whether the pressure in a liquid is affected by the cross-sectional area and the shape of the columns.

Based on the observation in Activity 2.2, the height of water levels in the different columns are the same. This means that cross-sectional area and the shapes of the column do not affect pressure in liquids.

Figure 2.5, shows water spurting out of all three holes at the same level of the plastic bottle has the same horizontal spurt distance.



**SCAN ME**

Video of water spurting out of a bottle

<http://bit.ly/3023k1V>



Figure 2.5 Water spurting out of a bottle

This observation shows that pressure at a point in a liquid acts in all directions. Points at the same level have the same pressure.

**BRIGHT Info**

Points at the same level in a static liquid have the same pressure.

Figure 2.6 shows a U-tube filled with liquid X. Then it is added with liquid Y which does not mix with liquid X. This apparatus can be used to compare the densities of two immiscible liquids.

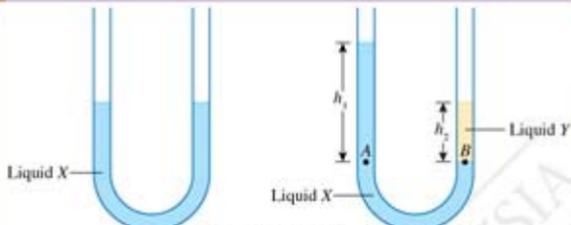


Figure 2.6 A U-tube filled with liquid X and liquid Y

Liquid pressure at point A,  $P_1 = h_1 \rho_1 g$ , where  $\rho_1$  = density of liquid X

Liquid pressure at point B,  $P_2 = h_2 \rho_2 g$ , where  $\rho_2$  = density of liquid Y

Since points A and B are at the same level and both liquids are static,

pressure at point A = pressure at point B

$$P_1 = P_2$$

$$h_1 \rho_1 g = h_2 \rho_2 g$$

$$\text{Therefore, } h_1 \rho_1 = h_2 \rho_2$$

The values of  $h_1$  and  $h_2$  can be measured with a metre rule. If the density of liquid X,  $\rho_1$  is known, the density of liquid Y,  $\rho_2$  can be calculated and vice versa.

### Solving Problems Involving Pressure in Liquids

The formula  $P = h\rho g$  is used to calculate the pressure at a depth in a liquid. The surface of the liquid also experiences pressure. Therefore, the actual pressure experienced by an object in a liquid is calculated with the following formula.

Actual pressure =  $h\rho g + P_{\text{atm}}$ , where  $P_{\text{atm}}$  = atmospheric pressure

### Example 1

Figure 2.7 shows a fish is at a depth of 1.5 m in an aquarium. The density of water in the aquarium is  $1\,050 \text{ kg m}^{-3}$  and atmospheric pressure is 100 kPa. [Gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$ ]

- What is the pressure experienced by the fish caused by the water around it?
- Calculate the actual pressure acting on the fish.

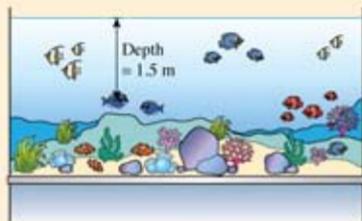


Figure 2.7

### BRIGHT Info

At sea level, atmospheric pressure has a value of about 100 000 Pa, or 100 kPa.

### LET'S ANSWER



<http://bit.ly/2QFcNcV>

## Solution

- (a) **Step 1:** Identify the problem
- Step 2:** Identify the information given
- Step 3:** Identify the formula that can be used
- Step 4:** Solve the problem numerically

1 Pressure on the fish,  $P$

2 Depth of the fish,  $h = 1.5$  m  
Density of aquarium water,  $\rho = 1\,050$  kg m<sup>-3</sup>  
Gravitational acceleration,  $g = 9.81$  m s<sup>-2</sup>

3  $P = h\rho g$

4  $P = h\rho g$   
 $= 1.5 \times 1\,050 \times 9.81$   
 $= 15\,450.8$  Pa  
 $= 15.5$  kPa

(b) Atmospheric pressure,  $P_{\text{atm}} = 100$  kPa

$$\begin{aligned}\text{Actual pressure} &= h\rho g + P_{\text{atm}} \\ &= 15.5 + 100 \\ &= 115.5 \text{ kPa}\end{aligned}$$

## Example 2

Figure 2.8 shows a U-tube filled with water and olive oil. The density of water is  $1\,000$  kg m<sup>-3</sup>. Calculate the density of olive oil.

## Solution

Density of olive oil,  $\rho_2$   
Height of water column,  $h_1 = 15.0$  cm  
Density of water,  $\rho_1 = 1\,000$  kg m<sup>-3</sup>  
Height of olive oil column,  $h_2 = 16.5$  cm

$$h_1 \rho_1 g = h_2 \rho_2 g$$

$$h_1 \rho_1 = h_2 \rho_2$$

$$\begin{aligned}15.0 \times 1\,000 &= 16.5 \times \rho_2 \\ \rho_2 &= \frac{15.0 \times 1\,000}{16.5} \\ &= 909.1 \text{ kg m}^{-3}\end{aligned}$$

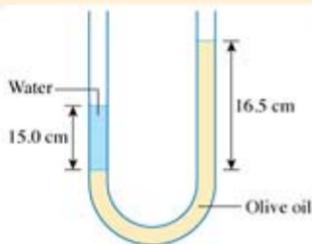


Figure 2.8

## Applications of Pressure in Liquids in Our Lives

### Position of water tank in the house

- A water tank is usually placed in the space between the ceiling and the roof.
- The difference in height between the water level in the tank and the water tap produces a high water pressure at the tap.
- Water flows at high speed when the tap is turned on.

Tank at the top of the house



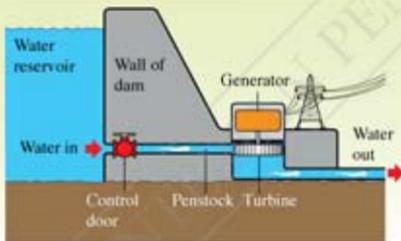
### Position of intravenous liquid

- A bag of intravenous liquid is placed at a position higher than the body of a patient.
- The pressure due to the difference in height of the liquid columns will push the intravenous liquid into the body of the patient.
- The rate of flow of intravenous liquid into the patient's body depends on the height of the bag and can be controlled by the adjuster.

Intravenous liquid bag  
Adjuster

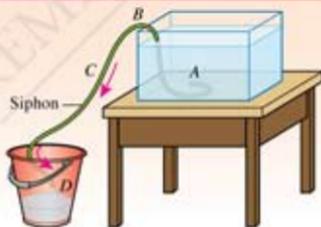


### Construction of a dam



- The wall of a dam is built thicker at the base of the dam because water pressure increases with depth.
- The thicker section of the dam is able to withstand the high water pressure.
- The penstock is at the lower section so that the high water pressure will produce a fast flow of water to drive the turbines.

### Use of the siphon



- A siphon is used to transfer water from a higher region to a lower region.
- One end of the tube that is filled with water is placed in the tank of water at a higher position while the other end is placed at a lower position.
- The flow of water from end D produces a region of lower pressure at point B. Atmospheric pressure pushes water into the tube at A.

Figure 2.9 Applications of pressure in liquids in daily life

A simple siphon consists of a flexible tube. Liquid can be transferred out continuously from a reservoir for a period of time without the use of electrical power. What are the factors that affect the rate of transfer of liquid using a siphon?



## Activity 2.3

STEM ISS ICS

**Aim:** To conduct a study to determine the highest rate of transfer of liquid using a siphon

### Instructions:

1. Carry out this activity in small groups.
2. Gather information on the siphon through reading materials or websites for the following aspects:
  - (a) characteristics of a siphon
  - (b) factors that affect the rate of transfer of liquid
  - (c) the method in determining the rate of transfer of liquid by a siphon
3. Discuss the information required and complete the K-W-L Data Strategy Form.
4. Plan and carry out an experiment to study how the factors identified in 2(b) affect the rate of transfer of liquid.
5. Suggest a design for the siphon and the method of using the siphon that will transfer water at the highest rate of transfer.
6. Construct the siphon following the suggested design and test out the siphon.
7. Suggest improvements that can be made.
8. Present the design of your siphon.



SCAN ME

K-W-L Data  
Strategy Form

<http://bit.ly/301Sucu>

### BRIGHT Info

The rate of transfer of liquid can be defined as the volume of liquid transferred in one second.

Rate of transfer of liquid =  $\frac{V}{t}$  in units  $\text{ml s}^{-1}$ .

V is the volume of liquid transferred in time, t.

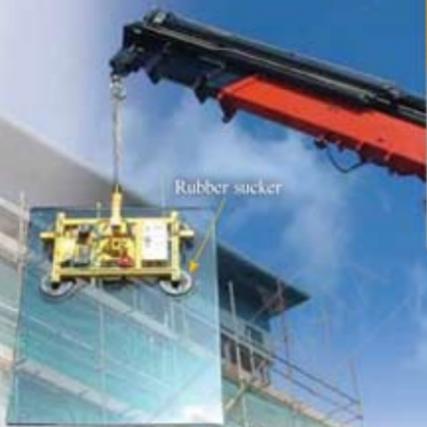
## Formative Practice 2.1

1. State three factors that affect the pressure in a liquid.
2. What is the water pressure at a depth of 24 m in a lake? 🍌  
[Density of water,  $\rho = 1\,000\text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$ ]
3. A diver dives to a depth of 35 m in the sea. What is the actual pressure acting on his body? 🍌  
[Density of sea water,  $\rho = 1\,060\text{ kg m}^{-3}$ , gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$  and atmospheric pressure = 100 kPa]

## 2.2 Atmospheric Pressure

Photograph 2.2 shows a glass sheet lifted using large rubber suckers. How is atmospheric pressure applied in the use of the rubber suckers?

**Atmospheric pressure** is the **pressure due to the weight of the layer of air acting on the surface of the earth**. The earth is surrounded by a thick layer of air consisting of various types of gases. This layer of air has weight and exerts a pressure on the surface of the earth as well as all objects on it. Therefore, all objects on the surface of the earth experience atmospheric pressure.



**Photograph 2.2** Glass sheet lifted using large rubber suckers



### Activity 2.4

**Aim:** To discuss atmospheric pressure from the aspect of the weight of the air acting on objects at the surface of the earth

#### Instructions:

1. Carry out this activity in pairs.
2. Study situations 1 and 2.

#### Situation 1:

A diver in the sea experiences water pressure. This water pressure is caused by the weight of the water column acting on him.

#### Situation 2:

Human beings living on land are surrounded by air.

3. Based on situation 1, explain the existence of atmospheric pressure on human beings in situation 2 from the aspect of the weight of the air acting on him.

#### Discussion:

1. Discuss the similarities and differences between atmospheric pressure and water pressure.
2. Estimate the atmospheric pressure at the surface of the earth. It is given that the thickness of the atmosphere,  $h = 120$  km, the average density of air,  $\rho = 8.5 \times 10^{-2} \text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$ .



**SCAN ME**

Video on the effects of atmospheric pressure

<http://bit.ly/2FyJcLM>

## The Value of Atmospheric Pressure

The value of atmospheric pressure can be measured by using a mercury barometer. A mercury barometer consists of a 1 metre long glass tube containing mercury. Initially, the glass tube filled with mercury and is covered with a lid as shown in Figure 2.10(a). The glass tube is then inverted and the covered end is immersed into a bowl of mercury as shown in Figure 2.10(b).

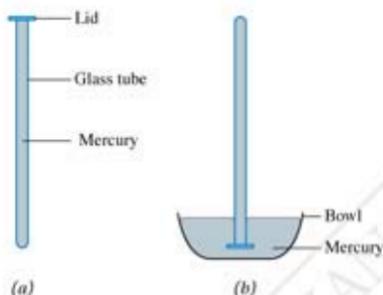


Figure 2.10 Preparation of a mercury barometer

When the lid is removed, the mercury column in the glass tube will fall until a certain height and remain at that height as shown in Figure 2.11.

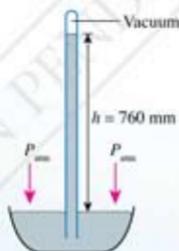


Figure 2.11 Mercury barometer

The atmospheric pressure acting on the surface of the mercury in the bowl supports the mercury column. The height of the mercury column depends on the magnitude of the atmospheric pressure. The value of the atmospheric pressure is stated in terms of the height of the mercury column. If the height of the mercury column,  $h = 760$  mm, then the atmospheric pressure,  $P_{\text{atm}} = 760$  mm Hg.

### EAL History

Evangelista Torricelli conducted an experiment with a mercury barometer in the year 1643. He concluded that the mercury column in the glass tube is supported by atmospheric pressure.

The formula  $P = h\rho g$  is used to obtain the value of atmospheric pressure in pascal (Pa).

$P_{\text{atm}} = 760 \text{ mm Hg}$ , where  $h = 760 \text{ mm} = 0.76 \text{ m}$

Density of mercury,  $\rho = 1.36 \times 10^4 \text{ kg m}^{-3}$

$$\begin{aligned} \text{Atmospheric pressure, } P_{\text{atm}} &= h\rho g \\ &= 0.76 \times 1.36 \times 10^4 \times 9.81 \\ &= 101\,396.16 \text{ Pa} \\ &= 101\,396 \text{ Pa} \end{aligned}$$

The value of atmospheric pressure can change with weather. In addition, the thin air at high altitudes causes the atmospheric pressure to be lower.

### Fortin Barometer and Aneroid Barometer

The Fortin barometer as shown in Figure 2.12 is a mercury barometer that measures atmospheric pressure to a high degree of accuracy. The Fortin barometer has a height of almost one metre. This instrument is usually used to measure atmospheric pressure at meteorological centres.

#### Brain-Teaser

What is the height of a water barometer?



Figure 2.12 Fortin barometer



Figure 2.13 Aneroid barometer

The Aneroid barometer functions mechanically. The partial-vacuum metal box as shown in Figure 2.13 can change its size when there are changes in the atmospheric pressure. This small change in the volume of the box is amplified by a mechanical system to move the pointer of the barometer. Aneroid barometers are suitable to be used in homes, ships and aeroplanes to obtain a quick reading of the atmospheric pressure.

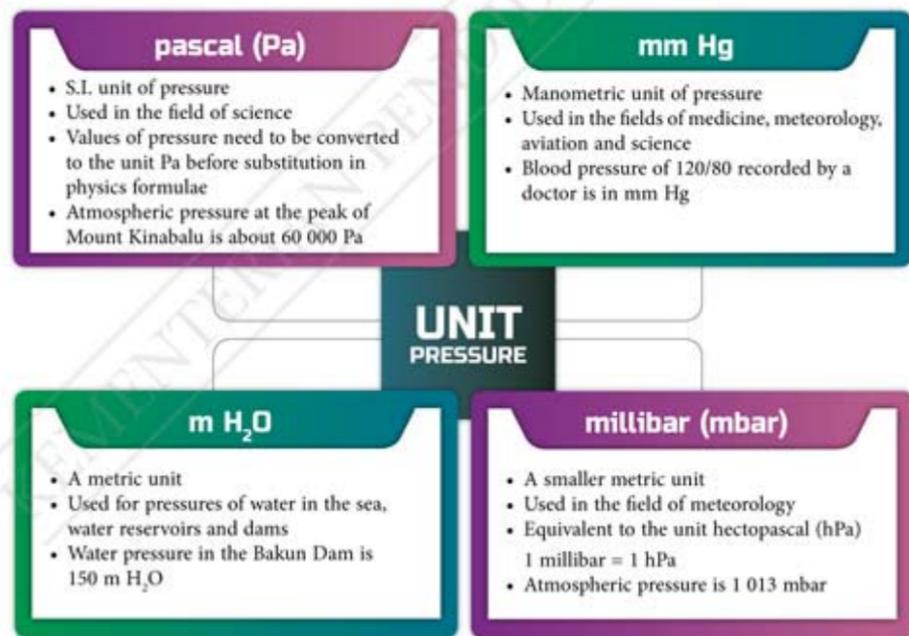
Table 2.3 shows the differences between the Fortin barometer and Aneroid barometer.

**Table 2.3** Differences between Fortin barometer and Aneroid barometer

Fortin barometer	Aneroid barometer
The value of the atmospheric pressure is determined by the changes in the height of the mercury column	The value of the atmospheric pressure is determined by the changes in the volume of the partial-vacuum metal box
Larger size and not portable	Smaller size and portable
Takes a longer time to give a reading for atmospheric pressure	Gives a direct reading for atmospheric pressure
Higher accuracy, up to $\pm 0.1$ mm Hg	Lower accuracy, up to $\pm 1$ mm Hg

### Solving Problems in Daily Life Involving Various Units of Pressure

The S.I. unit of pressure is pascal (Pa). However, a few other units of pressure are still commonly used in various fields. Study Figure 2.14 that shows the use of various units of pressure.



**Figure 2.14** Examples of units of pressure used in daily life

**Example 1**

The blood pressure reading of a patient is 160/100. What is the pressure 160 mm Hg in Pa?

[Density of Hg,  $\rho = 1.36 \times 10^4 \text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$ ]

**LET'S ANSWER**

<http://bit.ly/37T3Y4Z>

**Solution****Step 1:**

Identify the problem

**Step 2:**

Identify the information given

**Step 3:**

Identify the formula that can be used

**Step 4:**

Solve the problem numerically

1 Pressure 160 mm Hg in Pa

3  $P = h\rho g$

2 Height of liquid column,  $h = 160 \text{ mm}$   
 $= 0.16 \text{ m}$   
 Gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$   
 Density of Hg,  $\rho = 1.36 \times 10^4 \text{ kg m}^{-3}$

4  $P = 0.16 \times 1.36 \times 10^4 \times 9.81$   
 $= 2.13 \times 10^4 \text{ Pa}$

**Example 2**

The maximum pressure that a wall at the seaside can withstand is  $3.6 \times 10^5 \text{ Pa}$ . What is this maximum pressure in m H<sub>2</sub>O?

[Density of H<sub>2</sub>O,  $\rho = 1.00 \times 10^3 \text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$ ]

**Solution**

Maximum pressure,  $P = 3.6 \times 10^5 \text{ Pa}$

Density of H<sub>2</sub>O,  $\rho = 1.00 \times 10^3 \text{ kg m}^{-3}$

Gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$

$$P = h\rho g$$

$$h = \frac{P}{\rho g}$$

$$= \frac{3.6 \times 10^5}{1.00 \times 10^3 \times 9.81}$$

$$= 36.7 \text{ m}$$

Maximum pressure = 36.7 m H<sub>2</sub>O

## Effects of Atmospheric Pressure at High Altitude and Effects of Pressure at Extreme Depth under the Surface of the Sea

Figure 2.15 shows the effects of atmospheric pressure at high altitude. Figure 2.16 shows the effects of pressure at extreme depth under the surface of the sea.

### Atmospheric Pressure at High Altitude

At higher altitude:

- Thin air causes the atmospheric pressure to become lower
  - The percentage of oxygen in the air reduces
- Effects on human beings at high altitude:
- Increase in the rate of breathing
  - Lower absorption of oxygen in the lungs
  - Increase in the metabolic rate
  - Loss of appetite
  - Dehydration
  - Inability to think clearly

### Info GALLERY

- At the summit of Mount Kinabalu, the atmospheric pressure is about 60 percent of the atmospheric pressure at sea level.
- At the level of commercial aircraft flight, atmospheric pressure is only a quarter of the atmospheric pressure at sea level.

Adaptations and actions to be taken

#### Mountain climbers

- Prepare and train before climbing
- Prepare equipment such as smartwatch that can measure altitude, blood pressure and body temperature
- Climb at a slow rate to allow the body to adjust to the changes in pressure
- Drink water even when not thirsty to prevent dehydration

#### Aircraft

- Increase the pressure in the aircraft cabin to match the sea level pressure
- Recycle the air in the cabin so that it is fresh and contains adequate oxygen level
- Remind the passengers to drink enough water to prevent dehydration during long distance flights

Figure 2.15 Effects of atmospheric pressure at high altitude

### Info GALLERY

Outer space is the space outside the earth's atmosphere. The pressure in outer space is almost zero. The spacecraft that carries astronauts needs:

- Pressurisation of the spacecraft cabin to match the atmospheric pressure on the earth so that astronauts do not need to wear a pressure suit while in the spacecraft cabin
- Installation of an oxygen generator to supply oxygen to astronauts
- A supply of pressure suits to be worn by astronauts when exiting the spacecraft in order to balance the pressure in the body

## Pressure at an Extreme Depth under the Surface of the Sea

At an extreme depth under the surface of the sea:

- Water pressure increases with its depth
- An increase in depth of 10 m causes an increase in water pressure by 1 atmosphere
- Water pressure and atmospheric pressure are experienced

Effects on human beings at extreme depth under the surface of the sea

- Body tissues absorb excess nitrogen gas
- Nitrogen gas dissolves into the blood
- Inability to think clearly
- Formation of nitrogen bubbles in the tissues or blood vessels if pressure is reduced too rapidly

Adaptations and actions to be taken

**Divers**

- Do physical exercises to enable the body to adapt to a high pressure environment before diving
- Wear a diving suit to slow down heat loss from the body
- Slowly ascend to sea level so that nitrogen bubbles do not form in the tissues and blood vessels

**Submarines**

- Submarine is made of steel or titanium with a circular cross section to withstand the high pressure of surroundings
- Pressure in the cabin of the submarine is controlled to almost the same level as sea level for the comfort of the crew
- Oxygen tanks or electrolytic oxygen generators are provided so that the oxygen supply is adequate

### Info GALLERY

- A diver who dives to a depth of 30 m in search of pearl oysters will experience a pressure 4 times the normal atmospheric pressure.
- Submarines moving to a depth of 240 m experience a very high pressure, which is 25 times the pressure at sea level.



**SCAN ME**

Video of formation of nitrogen bubbles in the tissues or blood vessels

<https://bit.ly/1idNitro>

### Career Booth

Professional divers can serve in the navy, work as commercial divers or serve as recreational trainers at sea. In addition to theoretical knowledge and skills, professional divers need to undergo a series of intensive training in order for the diver's body to adapt to extreme pressure.

Figure 2.16 Effects of extreme depth under the surface of the sea

## Formative Practice 2.2

1. Explain the existence of atmospheric pressure.
2. The height of the mercury column in a barometer is 756 mm Hg on a cloudy day. Calculate the atmospheric pressure at that time in pascal. 🌧️  
[Density of mercury,  $\rho = 13\,600\text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$ ]
3. What is the actual pressure at a depth of 125 m in a dam? State your answer in m H<sub>2</sub>O and pascal. 🌧️  
[Atmospheric pressure = 10.3 m H<sub>2</sub>O, density of water,  $\rho = 1\,000\text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$ ]

## 2.3 Gas Pressure

### Manometer

Photograph 2.3 shows a manometer which consists of a glass U-tube containing coloured water. This apparatus is used to measure gas pressure. Figure 2.17 shows a manometer before and after it is connected to a gas supply.



Photograph 2.3 Manometer

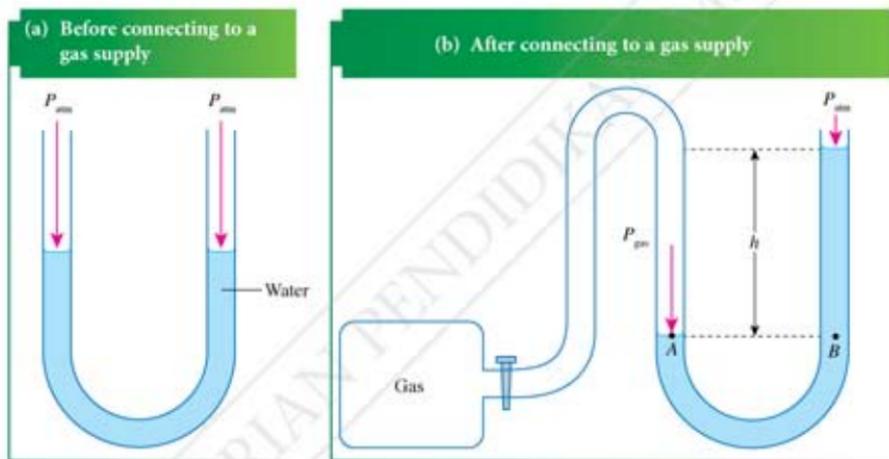


Figure 2.17 Water manometer before and after connecting to a gas supply

Pressure at A = gas pressure,  $P_{\text{gas}}$

Pressure at B = pressure due to water column  $h$  + atmospheric pressure  
 $= h \text{ cm H}_2\text{O} + P_{\text{atm}}$

Point A and point B are at the same level, therefore

Pressure at A = pressure at B

$$P_{\text{gas}} = h \text{ cm H}_2\text{O} + P_{\text{atm}}$$

The height,  $h$  of the water column represents the difference between the gas pressure and atmospheric pressure. Let us carry out Activity 2.5 to understand more about gas pressure in a container by using a water manometer.

## Activity 2.5

**Aim:** To determine the pressure of a gas using a water manometer

**Apparatus:** Manometer, rubber tube, half-metre rule, 10 ml plastic syringe

**Materials:** Water and red colouring

### Instructions:

1. Set up the apparatus as shown in Figure 2.18. Make sure that the volume of air in the syringe is 10 ml and the water levels in both arms of the U-tube are the same.

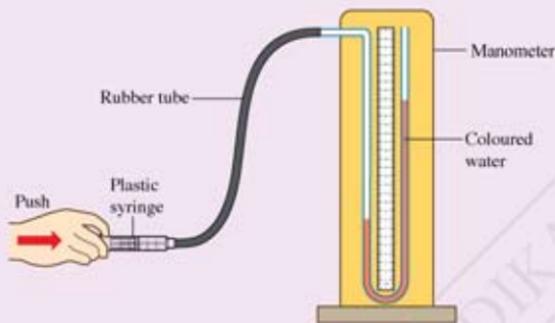


Figure 2.18



2. Push the piston slightly into the syringe until a reading of 8 ml is shown on the syringe so that the water levels in both arms of the glass tube are no longer at the same level.
3. Determine the height,  $h$  between the water levels in both arms of the U-tube.
4. Repeat steps 2 and 3 with readings of 6 ml and 4 ml on the syringe.
5. Record your results in Table 2.4.
6. Calculate the air pressure in the syringe in  $\text{m H}_2\text{O}$ .  
[Use the value  $P_{\text{atm}} = 10 \text{ m H}_2\text{O}$ ]

### Results:

Table 2.4

Reading on the syringe, $V$ / ml	Height, $h$ / m	Air pressure, $P$ / $\text{m H}_2\text{O}$
8		
6		
4		

### Discussion:

1. How can the value of air pressure from this activity be stated in Pa?
2. Suggest a suitable liquid to be used in the manometer for measuring higher gas pressures.

**Example 1**

Figure 2.19 shows a mercury manometer connected to a flask with compressed gas.

[Atmospheric pressure,  $P_{\text{atm}} = 76 \text{ cm Hg}$ , density of Hg,  $\rho = 13\,600 \text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$ ]

- What is the pressure of the compressed gas in cm Hg?
- Calculate the gas pressure in Pa.
- Will your answers in (a) and (b) change if the glass tube of the manometer has a larger diameter?

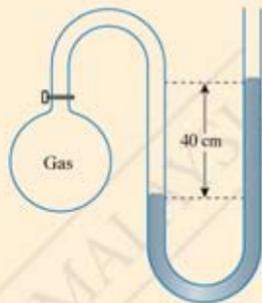


Figure 2.19

**Solution**

- |     |  |  |   |   |
|-----|--|--|---|---|
| (a) | <b>Step 1:</b><br>Identify the problem | <b>Step 2:</b><br>Identify the information given | <b>Step 3:</b><br>Identify the formula that can be used | <b>Step 4:</b><br>Solve the problem numerically |
|-----|--|--|---|---|

1 Pressure of compressed gas,  $P$  in the unit cm Hg

3  $P = h + P_{\text{atm}}$

2 Height of column,  $h = 40 \text{ cm}$   
Atmospheric pressure,  
 $P_{\text{atm}} = 76 \text{ cm Hg}$

4  $P = 40 + 76$   
 $= 116 \text{ cm Hg}$

- Pressure of compressed gas,  $P$  in Pa  
To convert cm Hg to Pa  
Height,  $h = 116 \text{ cm} = 1.16 \text{ m}$   
Density of Hg,  $\rho = 13\,600 \text{ kg m}^{-3}$   
Gravitational acceleration,  $g = 9.81 \text{ m s}^{-2}$   
Gas pressure,  $P = h\rho g$   
 $= 1.16 \times 13\,600 \times 9.81$   
 $= 1.55 \times 10^5 \text{ Pa}$
- The answers obtained in (a) and (b) will not change because pressure in liquids does not depend on the surface area.

**Info GALLERY**

Nowadays, mercury manometers are seldom used because mercury is a very toxic liquid. Digital manometers that use pressure transducer are more common because they are portable and give a more accurate reading.

**LET'S ANSWER**

<http://bit.ly/39QwLJ7>

**Example 2**

Figure 2.20 shows a mercury manometer used to measure the pressure in an air flow pipe.

- What is the difference between the air pressure in the pipe and the atmospheric pressure in cm Hg?
- If the atmospheric pressure is 75 cm Hg, what is the air pressure in the pipe in Pa?  
[Density of Hg,  $\rho = 13\,600\text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$ ]

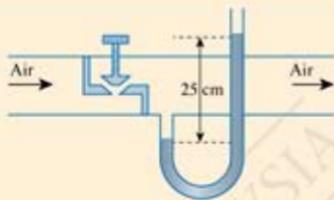


Figure 2.20

**Solution**

- Difference in pressure = height of mercury column  
= 25 cm Hg
- Density of Hg,  $\rho = 13\,600\text{ kg m}^{-3}$   
Gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$   
Atmospheric pressure,  $P_{\text{atm}} = 75\text{ cm Hg}$   
Air pressure in the pipe,  $P = h + P_{\text{atm}}$

$$\begin{aligned} \text{Air pressure in the pipe, } P &= 25 + 75 \\ &= 100\text{ cm Hg} \end{aligned}$$

To convert cm Hg to Pa:

$$\begin{aligned} P &= h\rho g \\ &= (100 \times 10^{-2}) \times 13\,600 \times 9.81 \\ &= 1.33 \times 10^5\text{ Pa} \end{aligned}$$

**Formative Practice 2.3**

- Figure 2.21 shows a water manometer connected to a flask containing gas.

- Compare the gas pressure in the flask with the atmospheric pressure.
- State the difference between the gas pressure and the atmospheric pressure in  $\text{m H}_2\text{O}$ .
- Calculate the gas pressure in pascal. 🍌  
[Density of water,  $\rho = 1\,000\text{ kg m}^{-3}$   
gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$  and atmospheric pressure = 10.3 m  $\text{H}_2\text{O}$ ]

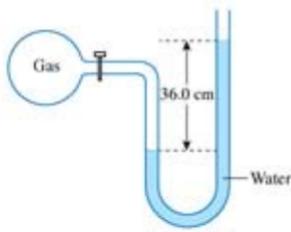


Figure 2.21

- What are the advantages of using a mercury manometer compared to a water manometer?
- A mercury manometer is connected to a steel cylinder containing compressed gas. The pressure of the compressed gas and the atmospheric pressure are 180 kPa and 101 kPa respectively. Calculate the difference in height between the two mercury columns in the manometer. 🍌  
[Density of Hg,  $\rho = 13\,600\text{ kg m}^{-3}$  and gravitational acceleration,  $g = 9.81\text{ m s}^{-2}$ ]

## 2.4 Pascal's Principle

Photograph 2.4 shows a coconut milk extractor that functions by applying the principle of transmission of pressure in a closed fluid. How can a large force be produced to press the grated coconut?

### Let's Try

Video of Pascal's piston



<http://bit.ly/2QX2v6I>



Photograph 2.4 Coconut milk extractor

### Activity 2.6

**Aim:** To generate ideas about the transmission of pressure in liquids

**Apparatus:** Pascal's piston and plastic basin

**Material:** Water

**Instructions:**

1. Fill the plastic basin with tap water until almost full.
2. Immerse the Pascal's piston into the water and pull the piston so that water enters it.
3. Hold the Pascal's piston above the basin and push the piston inwards as shown in Figure 2.22.
4. Observe the flow of water out of the Pascal's piston.

**Discussion:**

What is your observation on the flow of water out of the holes when the Pascal's piston is pushed inwards? Explain your answer.

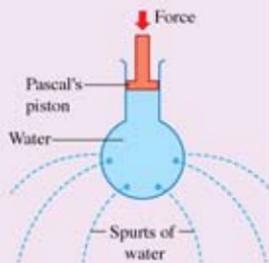


Figure 2.22

When the piston is pushed, a force is exerted on the surface of the water and pressure is produced. This pressure is transmitted uniformly throughout the water in all directions. This causes the water to spurt out from every hole. **Pascal's principle states that the pressure applied on an enclosed fluid is transmitted uniformly in all directions in the fluid.**

## Hydraulic System as a Force Multiplier

According to Pascal's principle, pressure applied on the surface of a liquid is transmitted uniformly throughout the liquid. If this pressure is transmitted to a larger surface area, what is the effect on the force produced on that surface?

### BRIGHT Info

$$\text{Pressure} = \frac{\text{Force}}{\text{Surface area}}$$

$$\text{Force} = \text{pressure} \times \text{surface area}$$

### Activity 2.1

**Aim:** To study a simple hydraulic system as a force multiplier

**Apparatus:** Model of a simple hydraulic system, 3 pieces of 100 g slotted weights, 5 pieces of 50 g slotted weights, 5 pieces of 20 g slotted weights and 5 pieces of 10 g slotted weights

**Material:** Water

**Instructions:**

1. Set up a simple hydraulic system model as shown in Photograph 2.5.
2. Ensure that water levels in both syringes are the same.



Photograph 2.5

3. Place a 50 g slotted weight on the small piston.
4. Add slotted weights (10 g, 20 g, 50 g or 100 g) on the large piston until the water levels in both syringes are the same again.
5. Record the total mass of the slotted weights on the large piston.
6. Repeat steps 3 to 5 with 80 g and 100 g slotted weights on the small piston.

**Results:**

Table 2.5

Mass on the small piston / g	Total mass on the large piston / g
50	
80	
100	

**Discussion:**

1. Compare the pressure on the surface of the water in small syringe and large syringe.
2. Compare the force acting on the small piston with the force acting on the large piston.



SCAN ME

Video of a hydraulic system model

<http://bit.ly/35AoN3z>

A hydraulic system is a system that uses a liquid to transmit pressure. The hydraulic system in Activity 2.7 shows that a force acting on the small piston can produce a larger force on the large piston. This shows that a hydraulic system not only transmits pressure, but also multiplies force. Figure 2.23 shows a hydraulic system that functions as a force multiplier.



What are the advantages of a hydraulic system?



Why is water not used in a hydraulic system?

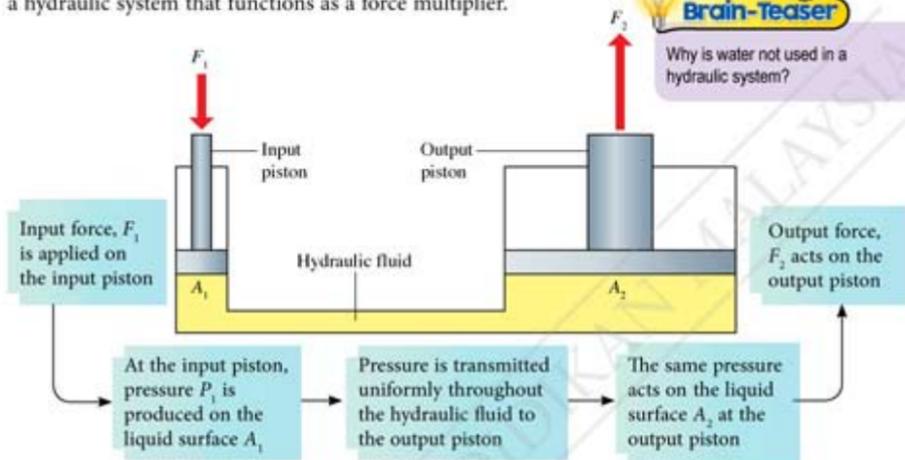


Figure 2.23 A hydraulic system

Based on Figure 2.23, the formula for force multiplier can be derived from Pascal's principle as follows:

$$\text{Pressure on the liquid surface below the input piston, } P_1 = \frac{F_1}{A_1}$$

$$\text{Pressure on the output piston, } P_2 = \frac{F_2}{A_2}$$

Pressure on the output piston is the pressure transmitted from the input piston.

$$\text{Therefore, } P_2 = P_1$$

$$\frac{F_2}{A_2} = \frac{F_1}{A_1} \rightarrow \text{Formula for Pascal's principle}$$



SCAN ME

Simulation of a simple hydraulic system

<http://bit.ly/2QFvKMB>

A hydraulic system is a force multiplier system. When the value of the surface area  $A_2$  is greater than the surface area  $A_1$ , the force on the output piston,  $F_2$  is greater than the force on the input piston,  $F_1$ . This is determined by:

$$F_2 = \frac{A_2}{A_1} \times F_1$$

The value of the multiplying factor is  $\frac{A_2}{A_1}$

## Applications of Pascal's Principle

Pascal's principle is applied in hydraulic systems. A small input force is multiplied to become a larger output force to perform a specific task. How is this principle applied in the hydraulic brake and the hydraulic jack?


**SCAN ME**

Characteristics of hydraulic fluid

<http://bit.ly/2N8Nty>


### Activity 2.8

ISS / ICS

**Aim:** To discuss the applications of Pascal's principle

**Instructions:**

1. Carry out a Round Table activity.
2. Study Figure 2.24 and Figure 2.25 which show the hydraulic brake system of a car and a hydraulic jack respectively.
3. Scan the QR code to watch the video that shows the operations of the hydraulic brake and the hydraulic jack.

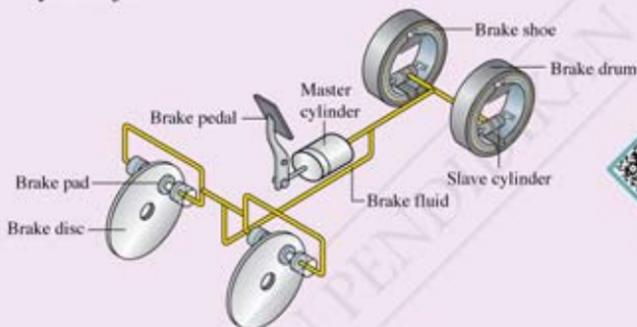


Figure 2.24


**SCAN ME**

Video of applications of Pascal's principle

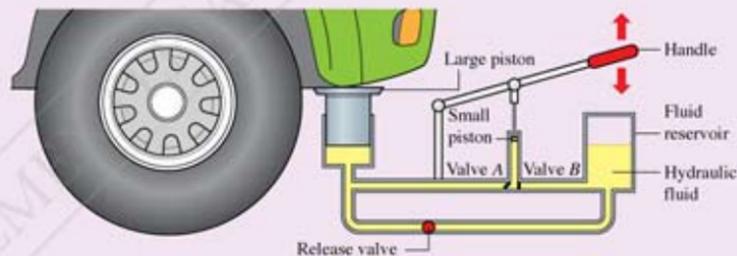
<http://bit.ly/2N6pk6H>


Figure 2.25

4. Surf websites to gather information about the application of Pascal's principle in the hydraulic brake and the hydraulic jack.
5. Each group has to record the information obtained on a piece of paper.
6. Present the outcome of your discussion in the form of a multimedia presentation.

**Example 1**

Figure 2.26 shows a hydraulic system. Calculate:

- (a) the multiplying factor  
 (b) the output force,  $F_2$

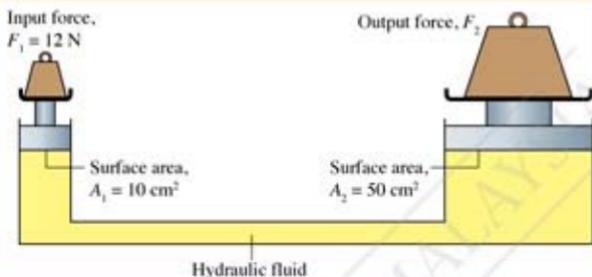


Figure 2.26

**Solution**

- (a) **Step 1:** Identify the problem  
**Step 2:** Identify the information given  
**Step 3:** Identify the formula that can be used  
**Step 4:** Solve the problem numerically

1 Multiplying factor of the hydraulic system

3 Multiplying factor =  $\frac{A_2}{A_1}$

2 Surface area,  $A_1 = 10 \text{ cm}^2$   
 Surface area,  $A_2 = 50 \text{ cm}^2$

4 Multiplying factor =  $\frac{50}{10}$   
 $= 5$

- (b) Output force,  $F_2$

Multiplying factor = 5

Input force,  $F_1 = 12 \text{ N}$

Output force,  $F_2 = \frac{A_2}{A_1} \times F_1$

$$= 5 \times 12$$

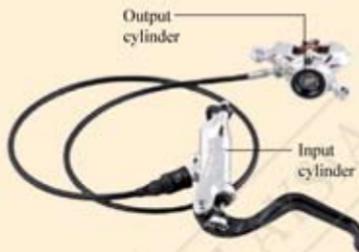
$$= 60 \text{ N}$$

**LET'S ANSWER**

<http://bit.ly/307trvD>

**Example 2**

A technician intends to design a hydraulic brake system for his bicycle as shown in Photograph 2.6. The input force that a cyclist is able to exert is 60 N at the input cylinder which has a cross-sectional area of  $0.80 \text{ cm}^2$ . What is the cross-sectional area of the output cylinder that will produce a braking force of 840 N?



Photograph 2.6

**Solution**

Input force,  $F_1 = 60 \text{ N}$

Cross-sectional area of input cylinder,  $A_1 = 0.80 \text{ cm}^2$

Output force (braking force),  $F_2 = 840 \text{ N}$

Cross-sectional area of output cylinder =  $A_2$

Formula for Pascal's principle,

$$\begin{aligned} \frac{F_2}{A_2} &= \frac{F_1}{A_1} \\ \frac{840}{A_2} &= \frac{60}{0.80} \\ A_2 &= \frac{840 \times 0.80}{60} \\ &= 11.2 \text{ cm}^2 \end{aligned}$$

**Formative Practice 2.4**

1. State Pascal's principle.
2. Describe how a hydraulic machine can achieve force multiplication by applying Pascal's principle.
3. In a hydraulic system, an input force of 4.0 N acts on a piston with surface area  $0.50 \text{ cm}^2$ . Calculate the output force produced on a piston with surface area  $6.4 \text{ cm}^2$ .
4. A pupil has a small syringe with a piston of diameter 1.5 cm. The pupil intends to construct a hydraulic system that can multiply force from 6 N to 72 N. What is the diameter of a large syringe that is required for this hydraulic system? 🍷