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

Learning Standards and List of Formulae in Chapter 2

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.

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.

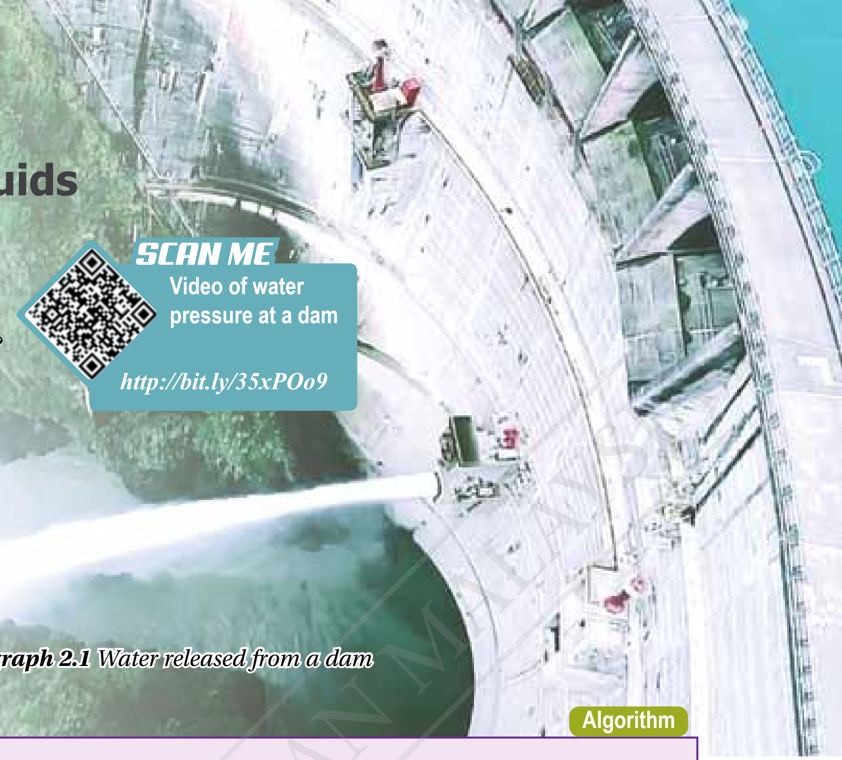
http://bit.ly/2FxZKU6

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.

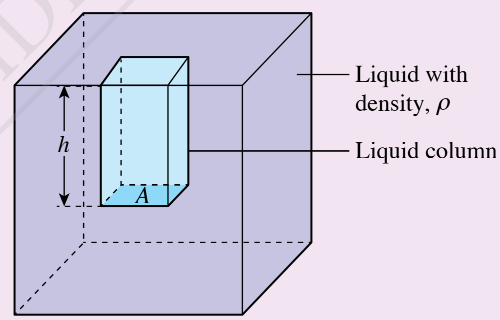


Figure 2.1

Volume of liquid column, V = ☐ [Volume = base area × height]

Mass of liquid column, m = ☐ [Mass = volume × density]

Weight of liquid column, W = ☐ [Weight = mass × gravitational acceleration]

Pressure at the base of liquid column, P = ☐ $\left[\text{Pressure} = \frac{\text{Weight of column}}{\text{Surface area}}\right]$

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.

LS 2.1.1

Liquid pressure is calculated using the following formula.

$$P = h\rho g$$

where P = liquid pressure
h = depth of liquid
ρ = density of liquid
g = gravitational acceleration

The S.I. unit for pressure, P is pascal (Pa)
1 Pa = 1 N m^{-2} or 1 kg m^{-1} 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 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 cm, 12.0 cm, 16.0 cm and 20.0 cm.
5. Record the difference in height of the water columns, D in Table 2.1.

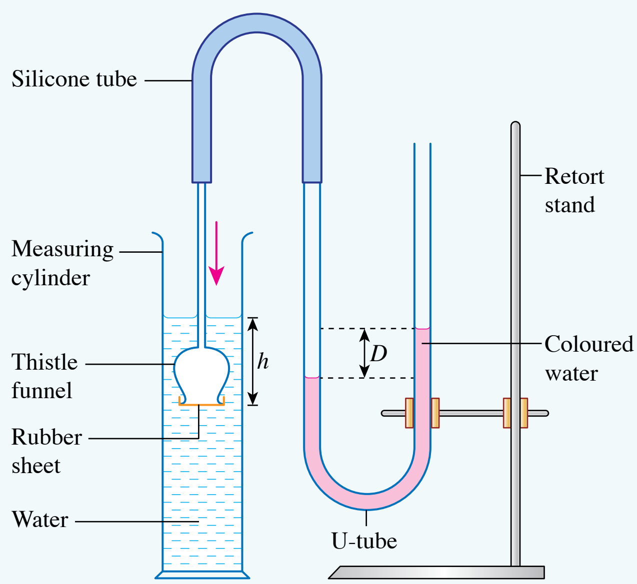


Figure 2.2

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.

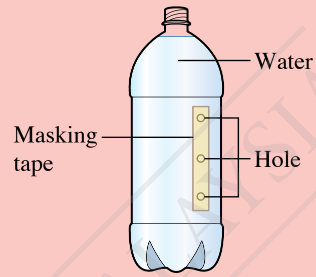
Conclusion:
What conclusion can be drawn from this experiment?

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, ρ
(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.

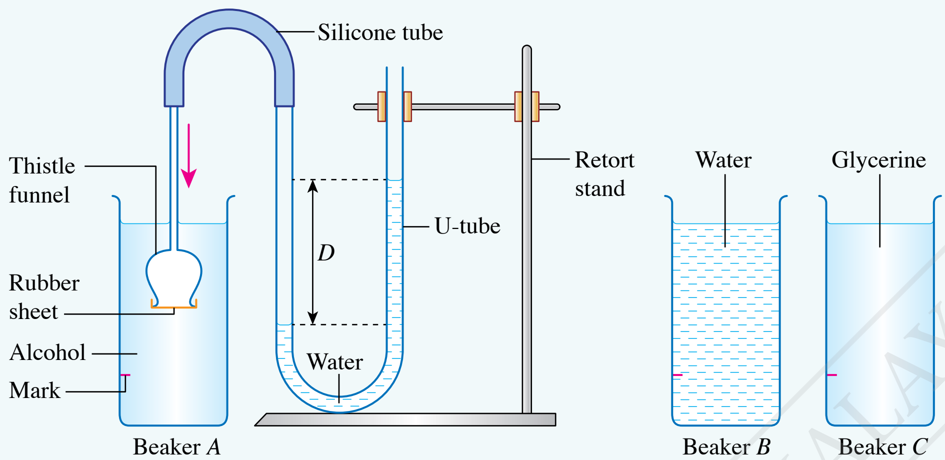


Figure 2.3

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.
4. 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.
5. Repeat steps 3 and 4 for beaker *B* and beaker *C*.
6. 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, ρ / kg m^{-3}	Difference in height of water columns, *D* / 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:

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

Activity 2.2

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.

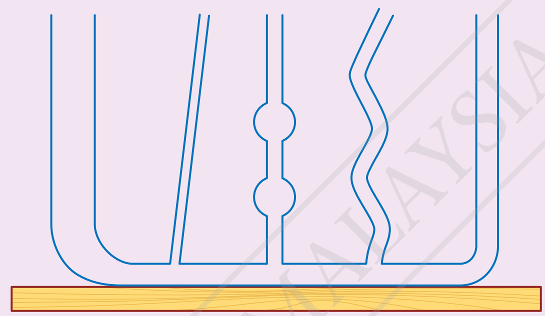


Figure 2.4

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/3023kiV

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

***Figure 2.5** Water spurting out of a bottle*

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.

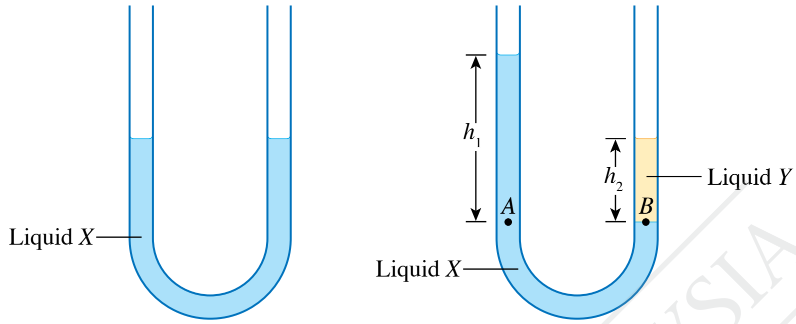


***Figure 2.6** A U-tube filled with liquid X and liquid Y*

Liquid pressure at point *A*, $P_1 = h_1 \rho_1 g$, where ρ_1 = density of liquid *X*
Liquid pressure at point *B*, $P_2 = h_2 \rho_2 g$, where ρ_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*, ρ_1 is known, the density of liquid *Y*, ρ_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 = $h\rho g + P_{atm}$, where P_{atm} = atmospheric pressure

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

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 kg m^{-3} and atmospheric pressure is 100 kPa. [Gravitational acceleration, g = 9.81 m s^{-2}]

(a) What is the pressure experienced by the fish caused by the water around it?

(b) Calculate the actual pressure acting on the fish.

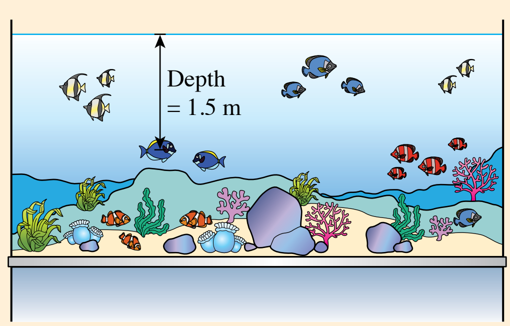


Figure 2.7

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, ρ = 1 050 kg m^{-3}
   Gravitational acceleration, g = 9.81 m s^{-2}
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_{atm} = 100 kPa

Actual pressure $= h\rho g + P_{atm}$
$= 15.5 + 100$
$= 115.5$ kPa

Example 2

Figure 2.8 shows a U-tube filled with water and olive oil. The density of water is 1 000 kg m^{-3}. Calculate the density of olive oil.

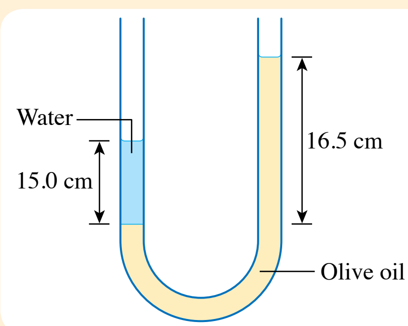


Figure 2.8

Solution

Density of olive oil, ρ_2
Height of water column, h_1 = 15.0 cm
Density of water, ρ_1 = 1 000 kg m^{-3}
Height of olive oil column, h_2 = 16.5 cm

$$h_1\rho_1 g = h_2\rho_2 g$$
$$h_1\rho_1 = h_2\rho_2$$
$$15.0 \times 1\,000 = 16.5 \times \rho_2$$
$$\rho_2 = \frac{15.0 \times 1\,000}{16.5}$$
$$= 909.1 \text{ kg m}^{-3}$$

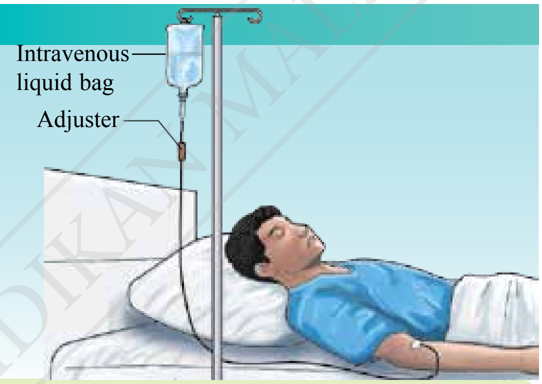
Applications of Pressure in Liquids in Our Lives

Position of water tank in the house

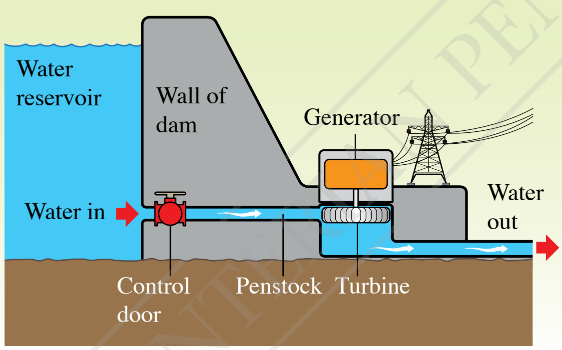
- A water tank is usually placed in the space between the ceiling and the roof.
- The difference in height between the water level in the tank and the water tap produces a high water pressure at the tap.
- Water flows at high speed when the tap is turned on.

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.

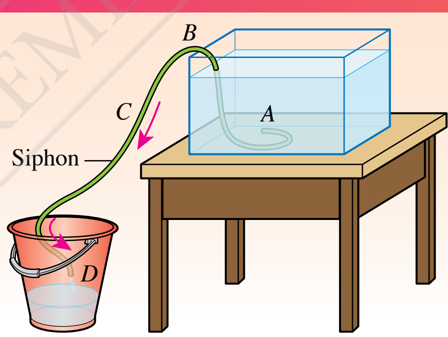


Construction of a dam



- 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 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, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 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, ρ = 1 060 kg m^{-3}, gravitational acceleration, g = 9.81 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:	Situation 2:
A diver in the sea experiences water pressure. This water pressure is caused by the weight of the water column acting on him.	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.

SCAN ME
Video on the effects of atmospheric pressure
http://bit.ly/2FyJcLM

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, $\rho = 8.5 \times 10^{-2}$ kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}.

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).

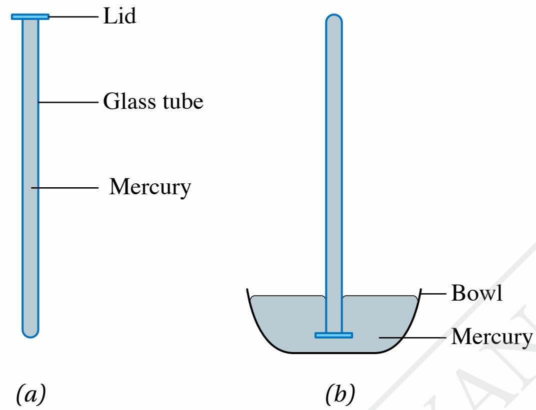


Figure 2.10 *Preparation of a mercury barometer*

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.

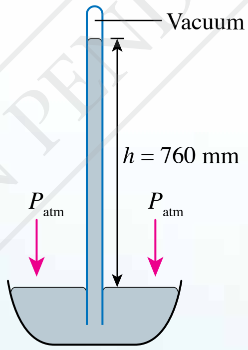


Figure 2.11 *Mercury barometer*

EAC 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 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_{atm} = 760 mm Hg.

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

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

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

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

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.

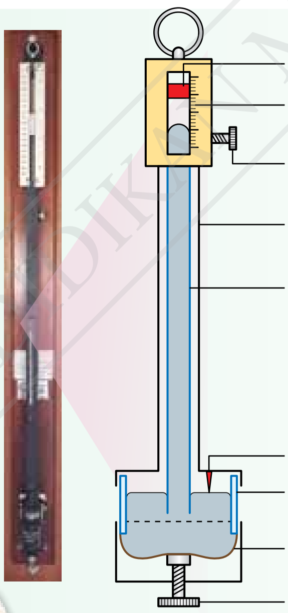


Figure 2.12 *Fortin barometer*

Brain-Teaser

What is the height of a water barometer?

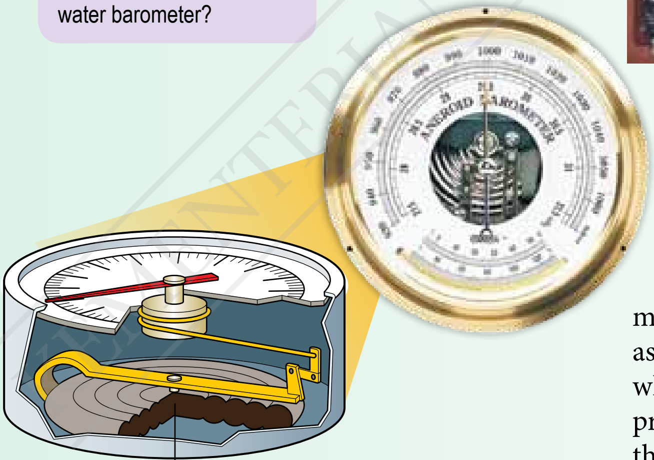


Figure 2.13 *Aneroid barometer*

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.

LS 2.2.2

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 ±0.1 mm Hg	Lower accuracy, up to ±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.

UNIT PRESSURE

pascal (Pa)
- S.I. unit of pressure
- Used in the field of science
- Values of pressure need to be converted to the unit Pa before substitution in physics formulae
- Atmospheric pressure at the peak of Mount Kinabalu is about 60 000 Pa

mm Hg
- Manometric unit of pressure
- Used in the fields of medicine, meteorology, aviation and science
- Blood pressure of 120/80 recorded by a doctor is in mm Hg

m H_2O
- A metric unit
- Used for pressures of water in the sea, water reservoirs and dams
- Water pressure in the Bakun Dam is 150 m H_2O

millibar (mbar)
- A smaller metric unit
- Used in the field of meteorology
- Equivalent to the unit hectopascal (hPa)

  1 millibar = 1 hPa
- Atmospheric pressure is 1 013 mbar

***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, $\rho = 1.36 \times 10^4$ kg m^{-3} and gravitational acceleration, $g = 9.81$ 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

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

3. $P = h\rho g$

4. $P = 0.16 \times 1.36 \times 10^4 \times 9.81$
   $= 2.13 \times 10^4$ Pa

Example 2

The maximum pressure that a wall at the seaside can withstand is 3.6×10^5 Pa. What is this maximum pressure in m H_2O?
[Density of H_2O, $\rho = 1.00 \times 10^3$ kg m^{-3} and gravitational acceleration, $g = 9.81$ m s^{-2}]

Solution

Maximum pressure, $P = 3.6 \times 10^5$ Pa
Density of H_2O, $\rho = 1.00 \times 10^3$ kg m^{-3}
Gravitational acceleration, $g = 9.81$ 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_2O

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 of 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

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

- 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.

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

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

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/VidNitro

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.

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, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]
3. What is the actual pressure at a depth of 125 m in a dam? State your answer in m H_2O and pascal.
   [Atmospheric pressure = 10.3 m H_2O, density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 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*

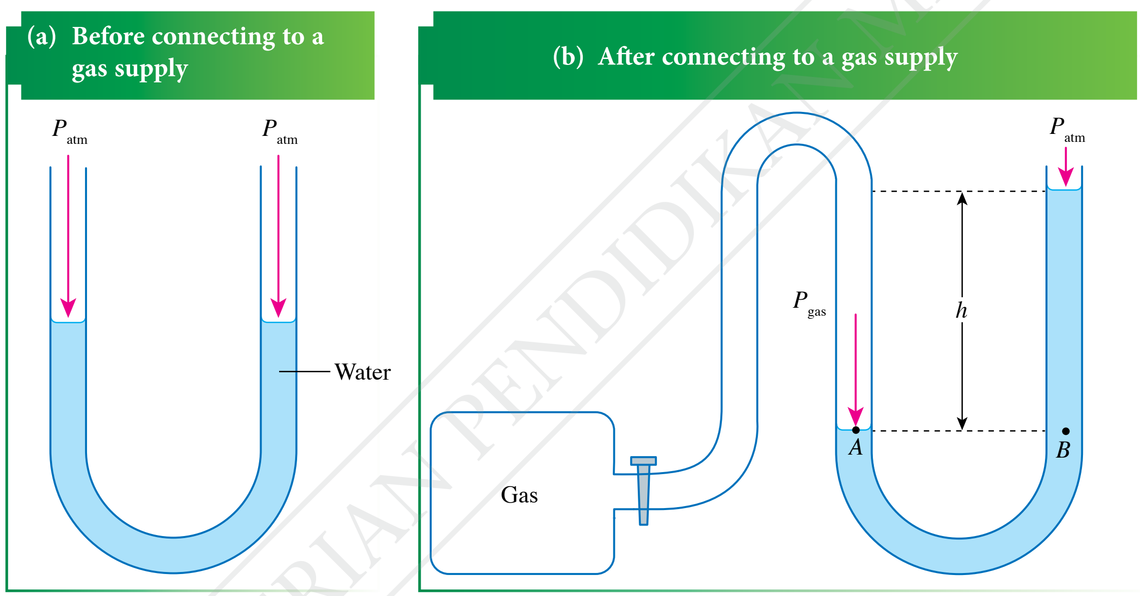


Figure 2.17 *Water manometer before and after connecting to a gas supply*

Pressure at A = gas pressure, P_{gas}

Pressure at B = pressure due to water column h + atmospheric pressure

$= h \text{ cm } H_2O + P_{atm}$

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

Pressure at A = pressure at B

$$P_{gas} = h \text{ cm } H_2O + P_{atm}$$

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.

LS 2.3.1

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.

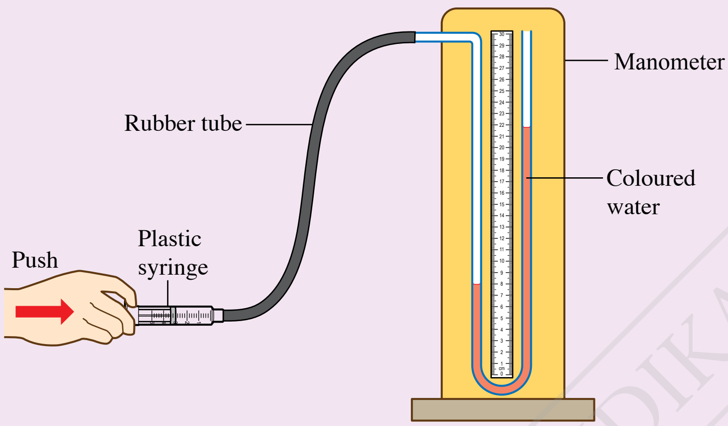


Figure 2.18

SCAN ME
Video of demonstration of a simple manometer
http://bit.ly/DemoMano

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 m H_2O.
   [Use the value P_{atm} = 10 m H_2O]

Results:

Table 2.4

Reading on the syringe, V / ml	Height, h / m	Air pressure, P / m H_2O
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.

Solving Problems in Daily Life Involving Gas Pressure

Example 1

Figure 2.19 shows a mercury manometer connected to a flask with compressed gas.
[Atmospheric pressure, P_{atm} = 76 cm Hg,
density of Hg, ρ = 13 600 kg m^{-3} and
gravitational acceleration, g = 9.81 m s^{-2}]

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

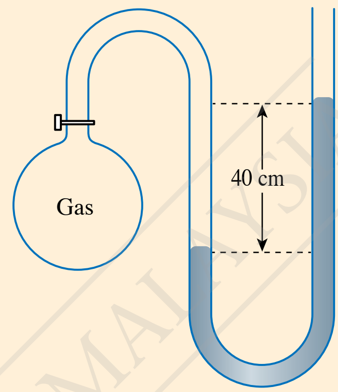


Figure 2.19

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 of compressed gas, P in the unit cm Hg
2. Height of column, h = 40 cm
   Atmospheric pressure,
   P_{atm} = 76 cm Hg
3. $P = h + P_{atm}$
4. $P = 40 + 76$
   $= 116$ cm Hg

(b) Pressure of compressed gas, P in Pa
To convert cm Hg to Pa
Height, h = 116 cm = 1.16 m
Density of Hg, ρ = 13 600 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Gas pressure, $P = h\rho g$
$= 1.16 \times 13\,600 \times 9.81$
$= 1.55 \times 10^5$ Pa

(c) 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.

(a) What is the difference between the air pressure in the pipe and the atmospheric pressure in cm Hg?

(b) If the atmospheric pressure is 75 cm Hg, what is the air pressure in the pipe in Pa?
[Density of Hg, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

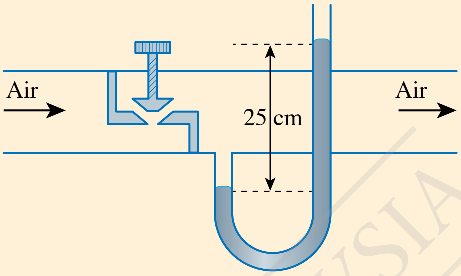


Figure 2.20

Solution

(a) Difference in pressure = height of mercury column
= 25 cm Hg

(b) Density of Hg, ρ = 13 600 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Atmospheric pressure, P_{atm} = 75 cm Hg
Air pressure in the pipe, $P = h + P_{atm}$

Air pressure in the pipe, P = 25 + 75
= 100 cm Hg

To convert cm Hg to Pa:
$P = h\rho g$
$= (100 \times 10^{-2}) \times 13\,600 \times 9.81$
$= 1.33 \times 10^{5}$ Pa

Formative Practice 2.3

1. Figure 2.21 shows a water manometer connected to a flask containing gas.
   (a) Compare the gas pressure in the flask with the atmospheric pressure.
   (b) State the difference between the gas pressure and the atmospheric pressure in m H_2O.
   (c) Calculate the gas pressure in pascal.
   [Density of water, ρ = 1 000 kg m^{-3} gravitational acceleration, g = 9.81 m s^{-2} and atmospheric pressure = 10.3 m H_2O]

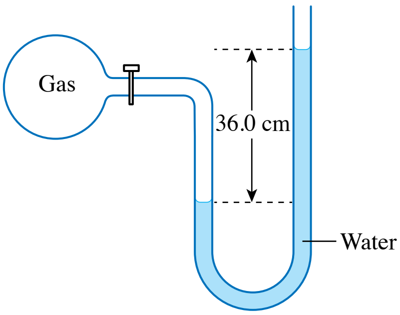


Figure 2.21

2. What are the advantages of using a mercury manometer compared to a water manometer?

3. 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, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

LS 2.3.2

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.

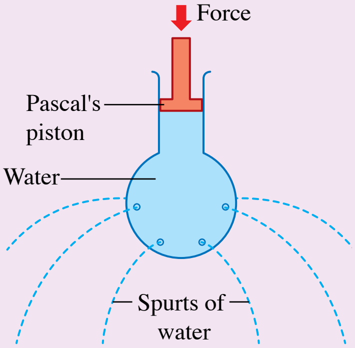


Figure 2.22

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.

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.**

LS 2.4.1

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

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

Force = pressure × surface area

Activity 2.7

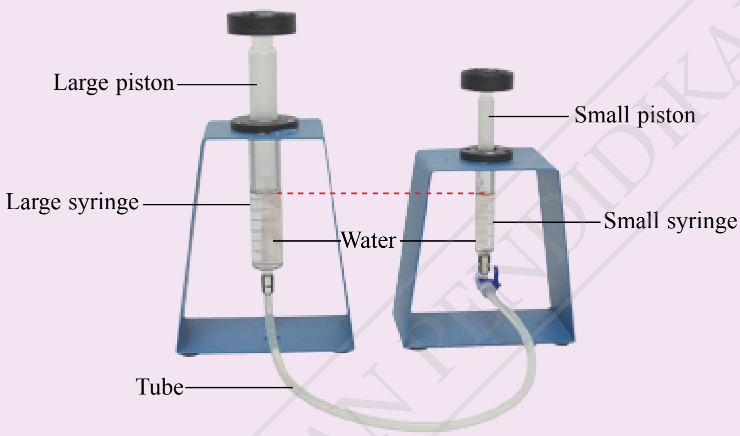
Aim: To study a simple hydraulic system as a force multiplier

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

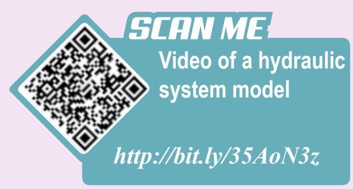
Material: Water

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.

LS 2.4.2

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.

Brain-Teaser

What are the advantages of a hydraulic system?

Brain-Teaser

Why is water not used in a hydraulic system?

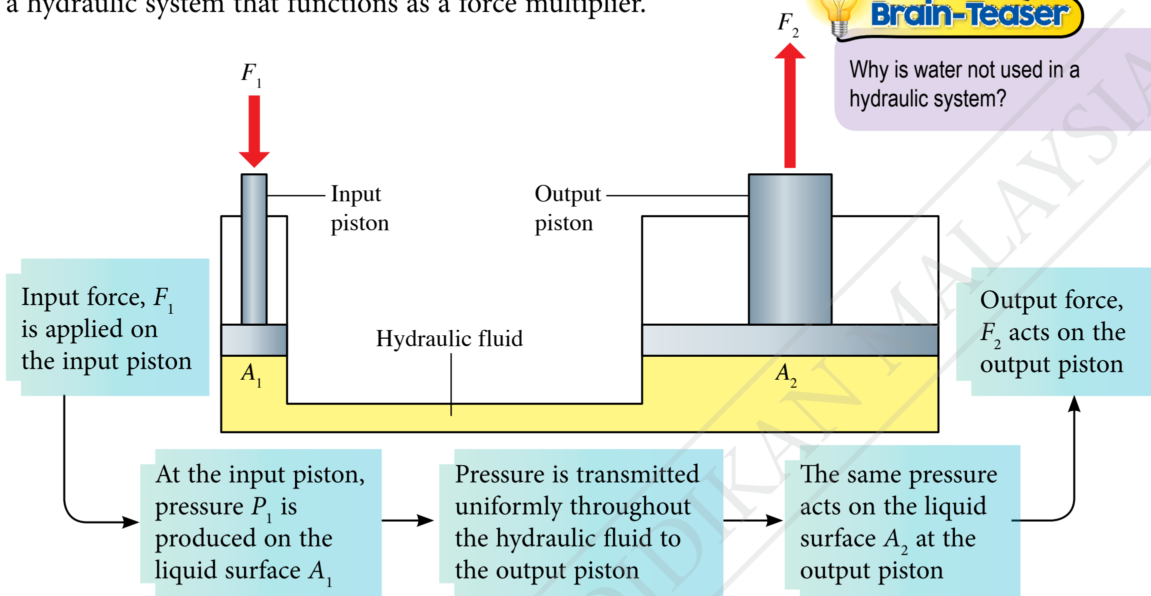


Figure 2.23 *A hydraulic system*

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

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

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

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

Therefore, $P_2 = P_1$

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$ ➔ 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 $\dfrac{A_2}{A_1}$

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/2N8Ntty

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.

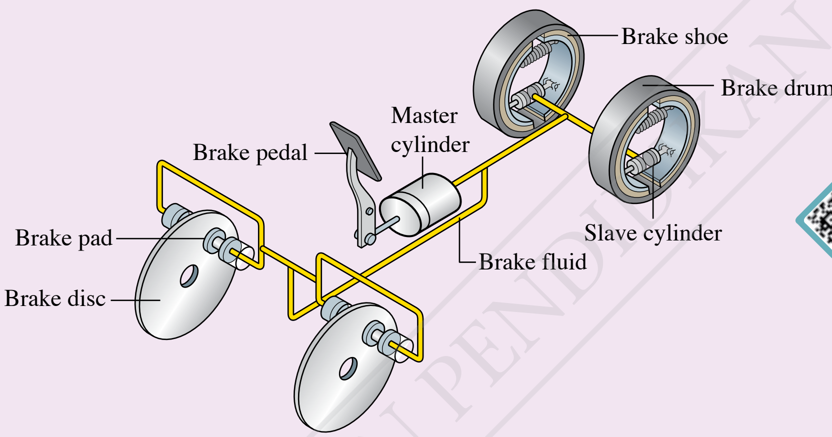


Figure 2.24

SCAN ME
Video of applications of Pascal's principle
http://bit.ly/2N6pk6H

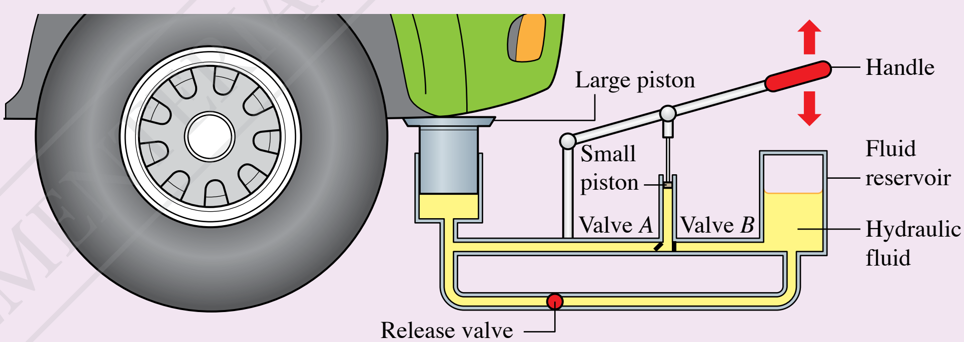


Figure 2.25

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.

Solving Problems in Daily Life Involving Pascal's Principle

Example 1

Figure 2.26 shows a hydraulic system. Calculate:

(a) the multiplying factor

(b) the output force, F_2

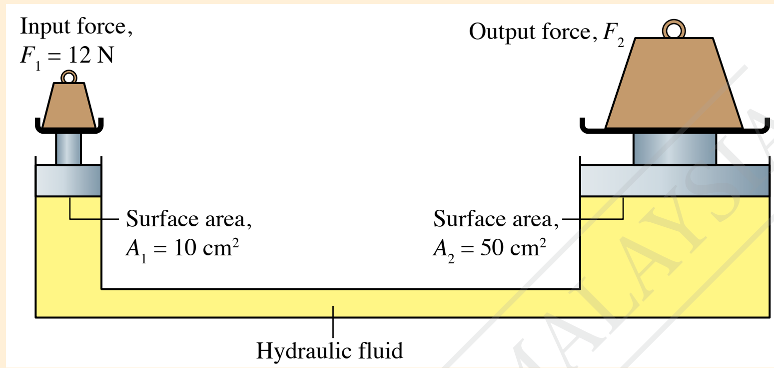


Figure 2.26

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
2. Surface area, A_1 = 10 cm^2
   Surface area, A_2 = 50 cm^2
3. Multiplying factor $= \dfrac{A_2}{A_1}$
4. Multiplying factor $= \dfrac{50}{10}$
   $= 5$

(b) Output force, F_2

Multiplying factor = 5

Input force, F_1 = 12 N

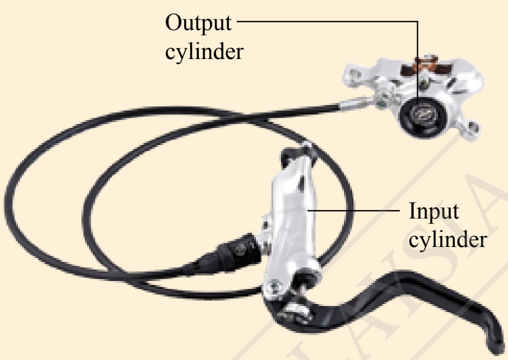
$$\text{Output force, } F_2 = \frac{A_2}{A_1} \times F_1$$
$$= 5 \times 12$$
$$= 60 \text{ N}$$

LET'S ANSWER

http://bit.ly/307ltvD

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 cm². 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, $F_1 = 60$ N

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

Output force (braking force), $F_2 = 840$ N

Cross-sectional area of output cylinder = A_2

Formula for Pascal's principle, $\dfrac{F_2}{A_2} = \dfrac{F_1}{A_1}$

$$\frac{840}{A_2} = \frac{60}{0.80}$$

$$A_2 = \frac{840 \times 0.80}{60}$$

$$= 11.2\ \text{cm}^2$$

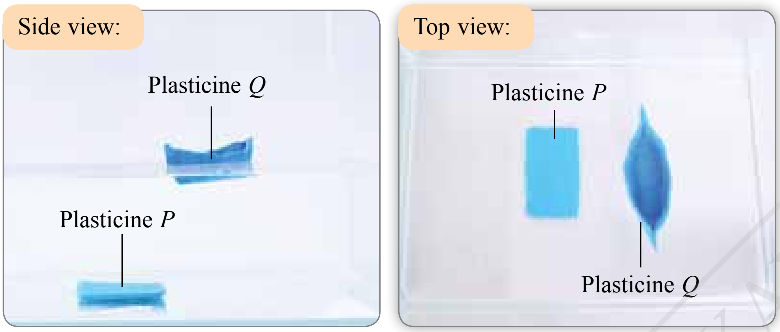
Formative Practice 2.4

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 cm². Calculate the output force produced on a piston with surface area 6.4 cm².
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?

2.5 Archimedes' Principle

Buoyant Force

Photograph 2.7 shows two pieces of plasticine, *P* and *Q* with the same mass. When the two pieces of plasticine are placed in a container with water, plasticine *P* sinks while plasticine *Q* floats on the surface of the water. How does this situation occur?



Photograph 2.7 *Plasticine in a container of water*

My Glorious Malaysia

Tengku Tengah Zaharah Mosque at Teluk Ibai, Terengganu is the first floating mosque in Malaysia. This mosque is built on a floating platform at the estuary of a river and can accommodate up to 2 000 worshippers. The buoyant force produced by the water around the platform supports the weight of the mosque.

Activity 2.9

Aim: To discuss the buoyant force on an object immersed in a liquid

Instructions:

1. Carry out this activity in pairs.
2. Study Figure 2.27 that shows a cylinder submerged in a liquid.
3. Compare the depth of the top surface and the depth of the bottom surface of the cylinder.
4. Compare the liquid pressure on the top surface with the liquid pressure on the bottom surface of the cylinder.
5. Compare the magnitude on the force on the top surface with the magnitude of the force on the bottom surface on the cylinder caused by the liquid pressure.
6. What is the direction of the resultant force acting on the cylinder as a result of the difference in liquid pressure?

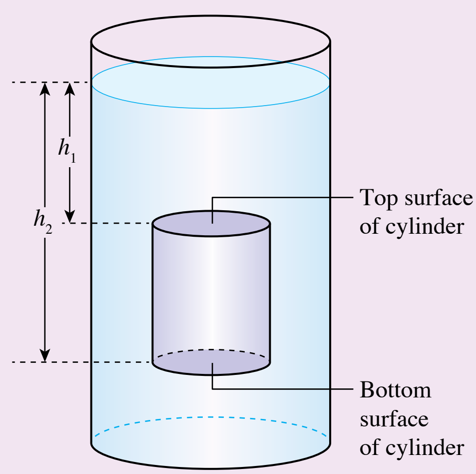


Figure 2.27

Buoyant force is the **force acting upwards on an object immersed in a liquid when there is pressure difference between the lower surface and upper surface of the object.** The formula for buoyant force can be derived as follows:

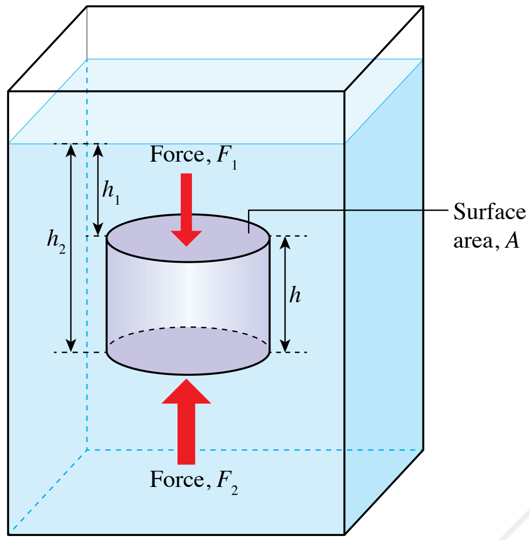


Figure 2.28 *Cylinder fully submerged in a liquid*

Info GALLERY

Fluids consist of liquids and gases. Archimedes' principle is usually applied to liquids because liquids have a higher density than gases. However, Archimedes' principle should be applied to gases in conditions where the magnitude of the buoyant force cannot be neglected compared to the weight of the object. An example of this is the motion of hot air balloons.

Pressure on the top surface, $P_1 = h_1\rho g$

Force acting on the top surface, $F_1 = P_1 A$
$= h_1\rho gA$

Pressure on the bottom surface, $P_2 = h_2\rho g$

Force acting on the bottom surface, $F_2 = P_2 A$
$= h_2\rho gA$

Resultant force, F (upwards) $= F_2 - F_1$
$= h_2\rho gA - h_1\rho gA$
$= \rho A\,(h_2 - h_1)\,g$
$= \rho Ahg$
$= \rho Vg$

This resultant force is the buoyant force, F_B.

BRIGHT Info

Height of cylinder, $h = (h_2 - h_1)$
Volume of cylinder, $V = Ah$
$V = A(h_2 - h_1)$,
The volume of cylinder is the same as the volume of water displaced.

BRIGHT Info

Since $\rho = \frac{m}{V}$, the mass of water displaced is $m = \rho V$.

Weight of water displaced,
$W = mg$
$W = \rho Vg$

Archimedes' principle **states that an object which is partially or fully immersed in a fluid will experience a buoyant force equal to the weight of fluid displaced.**

Buoyant force = Weight of fluid displaced
$F_B = \rho Vg$

SCAN ME
EduwebTV: Archimedes' principle
http://bit.ly/2t4fBXY

LS 2.5.1

Experiment 2.3

Inference: Buoyant force depends on weight of liquid displaced

Hypothesis: The greater the weight of liquid displaced, the greater the buoyant force

Aim: To determine the relationship between the buoyant force and the weight of liquid displaced

Variables:

(a) Manipulated: Weight of water displaced
(b) Responding: Buoyant force
(c) Constant: Density of water

Apparatus: Slotted weights, Eureka can, beaker, spring balance, electronic balance, retort stand and wooden block

Material: Water

Procedure:

1. Set up the apparatus as shown in Figure 2.29.

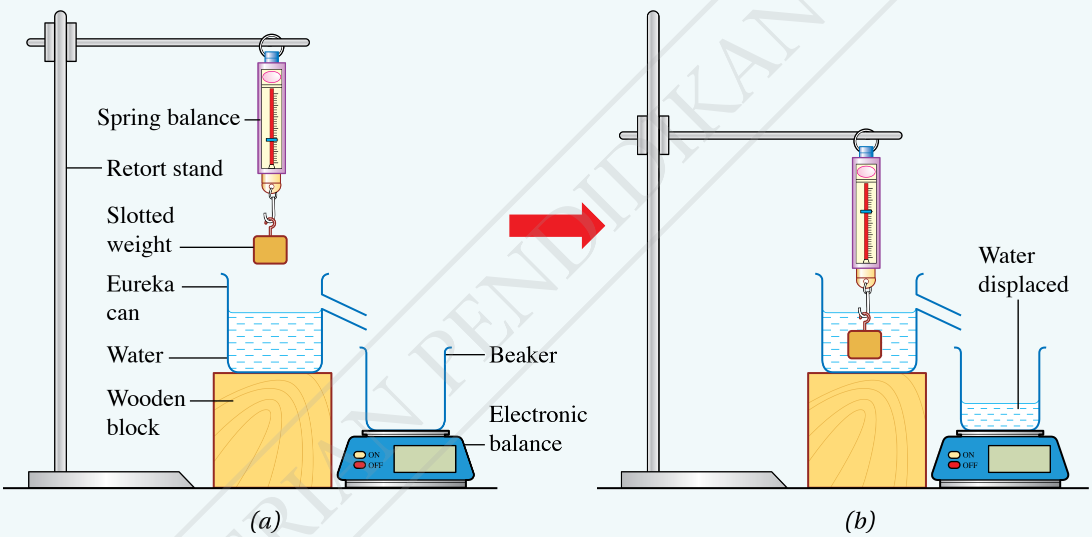


Figure 2.29

2. Hang a 100 g slotted weight on the spring balance. Record the weight of the slotted weight in the air, W_A in Table 2.6.
3. Place the beaker on the electronic balance. Reset the reading of the electronic balance to zero.
4. Immerse the slotted weight fully into the water. Record the weight of the slotted weight in water, W_W.
5. Calculate the buoyant force, $F_B = W_A - W_W$.
6. From the reading of the electronic balance, calculate the weight of water displaced, W_D. [Assume 1 kg = 10 N]
7. Repeat steps 2 to 5 using slotted weights of mass 200 g, 300 g, 400 g and 500 g.
8. Record all your results in Table 2.6.

Results:

Table 2.6

Weight in the air, W_A / N	Weight in water, W_W / N	Weight of water displaced, W_D / N	Buoyant force, F_B / N

Data analysis:

1. Plot the graph of W_D against F_B.
2. Calculate the gradient of the graph.

Conclusion:

What conclusion can be drawn from this experiment?

Prepare a complete report for this experiment.

Discussion:

1. What is the value of the gradient of the graph?
2. State the relationship between the buoyant force and the weight of water displaced based on the results of the experiment.

Figure 2.30 shows the flow and relationship between the concepts involved in Experiment 2.3.

Object in the air	Object submerged in liquid	Object displaces liquid	Object experiences apparent loss in weight	Buoyant force acts on object
Weight of object in air is the actual weight of object	Weight of object in liquid is the apparent weight of object	Volume of liquid displaced = volume of the submerged part of the object	Apparent loss in weight of an object = weight of an object in the air – weight of an object in liquid	Buoyant force = weight of liquid displaced

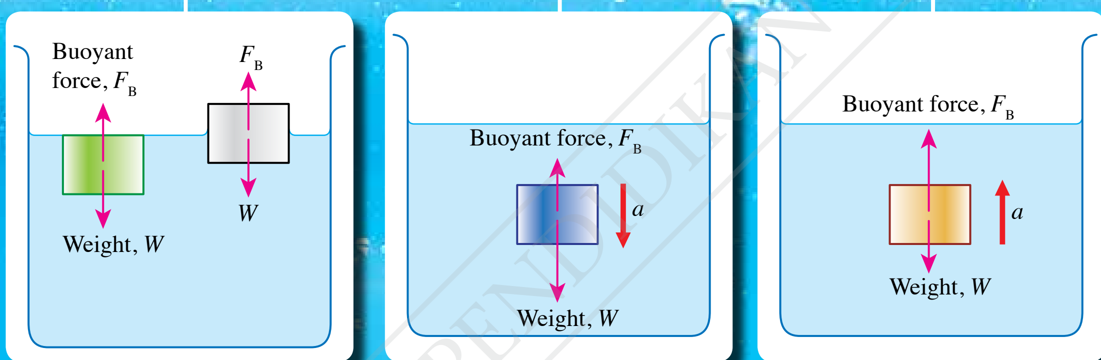
Figure 2.30 *Relationship between concepts that explain buoyant force and the weight of liquid displaced*

Buoyant force = Weight of liquid displaced
= Apparent loss in weight

Relationship between the Equilibrium of Forces and the State of Floatation of an Object in a Fluid

When an object is submerged in a fluid, the object experiences two forces: the weight of the object, W due to gravity and the buoyant force, F_B due to the fluid displaced. The state of floatation of the object is determined by the relative magnitudes of the two forces.
Figure 2.31 summarises the state of floatation of an object in a fluid.

State of floatation of an object in a fluid



$W = F_B$	$W > F_B$	$W < F_B$
Resultant force = 0	Resultant force downwards	Resultant force upwards
Balanced force	Unbalanced force	Unbalanced force
Object is stationary	Object moves downwards with an acceleration, a	Object moves upwards with an acceleration, a

Figure 2.31 *State of floatation of an object in a fluid*

Figure 2.32 shows the forces acting on a ship floating on the surface of the sea.

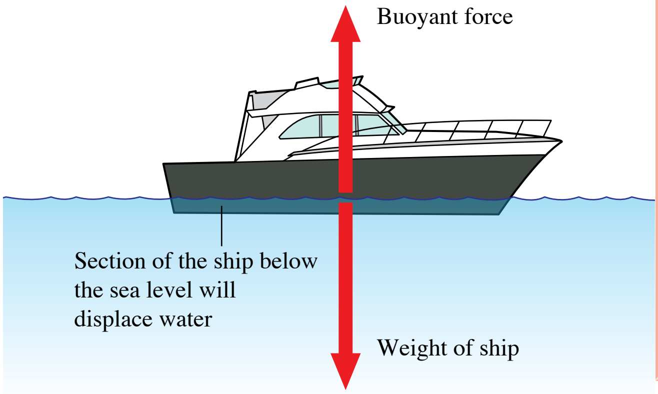


Figure 2.32 *Ship floating on the sea*

Forces acting on the ship are in equilibrium. The resultant force on the ship is zero.
Hence, weight of ship = buoyant force

Based on Archimedes' principle,
Buoyant force = weight of water displaced

Therefore,
Weight of ship = weight of water displaced

Volume of sea water displaced = volume of the section of the ship immersed in sea water

This shows that an object floating on the surface of water needs to displace an amount of water which has the same weight as the weight of the object.

Info GALLERY

A ship can float on the vast sea or a narrow canal if there is enough water to displace until the weight of water displaced is equal to the weight of the ship.

Applications of Archimedes' Principle in Daily Life

A hydrometer is a measuring instrument that applies Archimedes' principle to measure the density of liquids. The hydrometer will float at different levels of depth in liquids with different densities as shown in Figure 2.33. When the hydrometer is stationary in a liquid, the weight of liquid displaced is equal to the weight of the hydrometer. In a less dense liquid, a larger section of the hydrometer is immersed in the liquid to displace a larger volume of liquid, and vice versa. Figure 2.34 shows a milk hydrometer that is commonly used at milk manufacturing factories to test the dilution of milk.

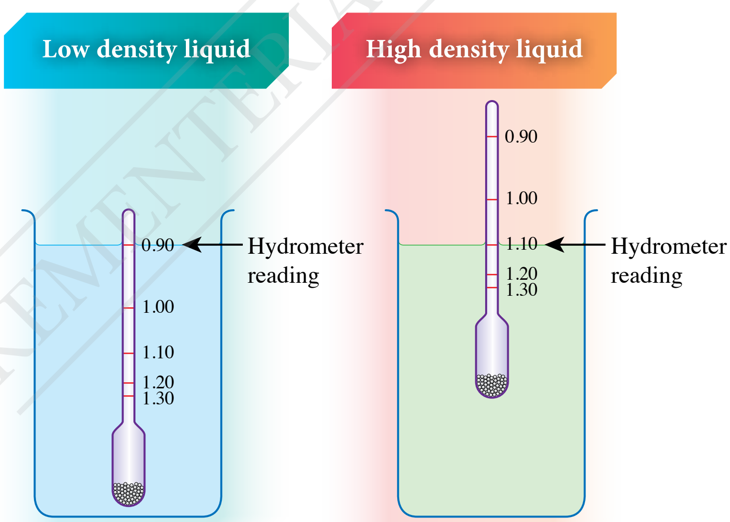
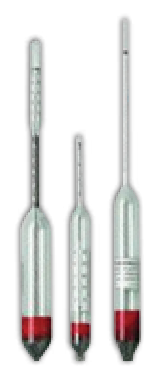


Figure 2.33 *Measuring the density of liquid using a hydrometer*



- Used in milk manufacturing factories
- To test the dilution of milk
- Range: 1.000 – 1.240 g cm^{-3}

Figure 2.34 *Milk hydrometer*

LS 2.5.2 2.5.3

Activity 2.10

Aim: To use a hydrometer to determine the density of various liquids

Apparatus: Hydrometer and three 100 ml measuring cylinders

Materials: Distilled water, olive oil and glycerine

Instructions:

1. Fill three measuring cylinders with distilled water, olive oil and glycerine respectively.
2. Immerse the hydrometer slowly into the distilled water. Record the reading of the hydrometer when it is stationary.
3. Remove the hydrometer. Clean and dry the hydrometer.
4. Repeat steps 2 and 3 for olive oil and glycerine.
5. Record all your readings in Table 2.7.

Info GALLERY

A hydrometer measures specific gravity, that is the density of a liquid relative to the density of water. The hydrometer reading is the density of the liquid if the density of water is 1.00 g cm^{-3}.

Results:

Table 2.7

Type of liquid	Density / g cm^{-3}
Distilled water	
Olive oil	
Glycerine	

Discussion:

1. Why does the scale of the hydrometer not start from zero?
2. Why is the smaller scale reading of the hydrometer at the top end of the tube?
3. State one precaution while carrying out this activity.

How does a submarine submerge and emerge in the sea? Carry out Activity 2.11 to show the working principle of ballast tanks in submarines.

Activity 2.11

STEM ISS

Aim: To construct a Cartesian diver to show the working principle of ballast tanks in a submarine

Apparatus: 1.5 litre plastic bottle and a test tube that can be inserted into the plastic bottle

Materials: Masking tape, water and food colouring

Instructions:

1. Prepare the apparatus as shown in Figure 2.35(a).
2. Fill the test tube with water until it is three quarter full. Invert the test tube and quickly put it inside the plastic bottle. The test tube should float on the surface of the water as shown in Figure 2.35(b).

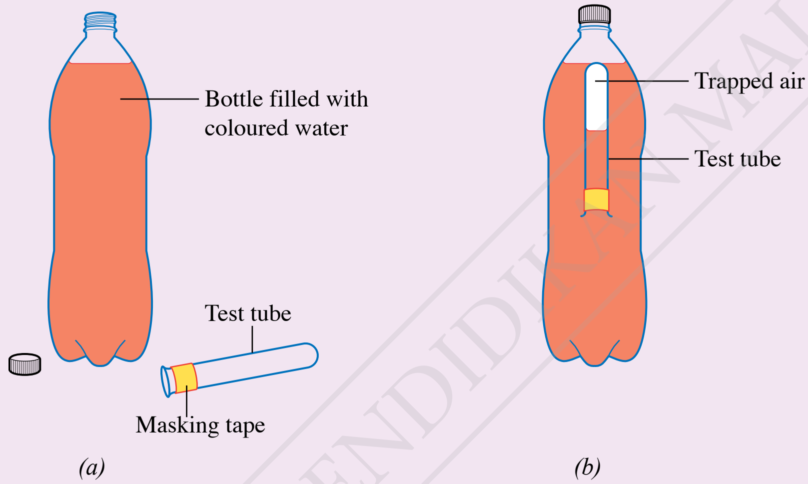


Figure 2.35

3. Observe the level of water in the test tube.
4. Squeeze the lower part of the bottle so that the test tube sinks slowly to the base of the bottle. Observe the level of water in the test tube.
5. Slowly release the pressure on the bottle so that the test tube moves up again to the surface of the water. Observe the change in the level of water in the test tube.

Discussion:

1. (a) Compare the level of water in the test tube when the test tube is floating on the surface and when it sinks to the base of the bottle.
   (b) Compare the volume of water in the test tube when it is floating on the surface and when it sinks to the base of the bottle.
2. How does the volume of air in the test tube change when the test tube moves up from the base of the bottle to the surface of the water?
3. Explain the movement of the test tube by applying Archimedes' principle.

SCAN ME
Video of a Cartesian diver
http://bit.ly/2uwbnbS

Figure 2.36 shows the ballast tanks found in a submarine. The working principle of the ballast tanks in a submarine is similar to the working principle of the Cartesian diver in Activity 2.11.

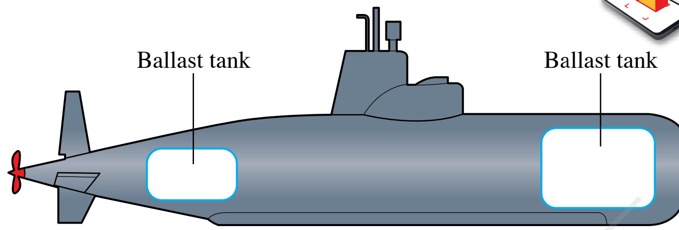
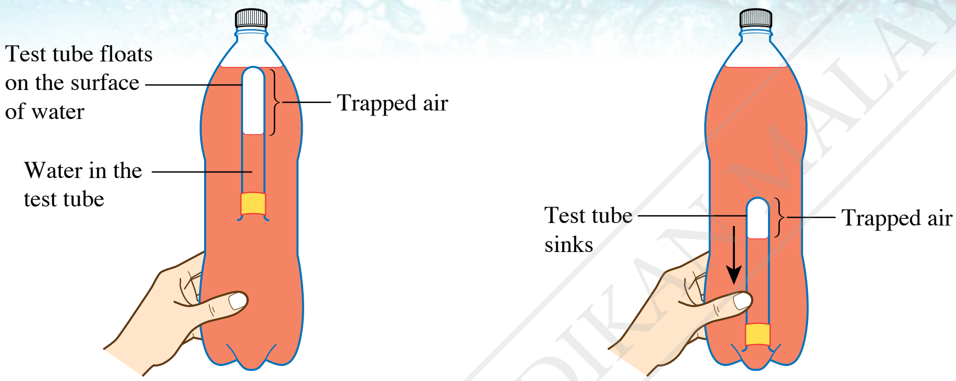


Figure 2.36 *Ballast tanks in a submarine*



(a) Test tube floating on the surface of water

(b) Test tube sinks in the water

Figure 2.37 *Working principle of ballast tanks in a submarine*

Figure 2.37 shows the working principle of ballast tanks using the Cartesian diver. When the test tube is floating on the surface of the water, the total weight of the test tube and the weight of the water in it is equal to the buoyant force. The pressure exerted on the wall of the bottle causes water to be pushed into the test tube. This causes the weight of water in the test tube to increase. Therefore, the total weight of the test tube and the weight of the water in it is greater than the buoyant force. A resultant force acting downwards is produced and causes the test tube to sink to the base of the bottle.

Activity 2.12

ISS / ICS

Aim: To search for information on the applications of Archimedes' principle

Instructions:

1. Carry out a Gallery Walk activity.
2. Scan the QR code to watch the video on the applications of Archimedes' principle for the three examples given.
3. Then, scan the QR code given on page 75 or refer to other reference materials to obtain further information on:

SCAN ME
Video on the applications of Archimedes' principle
http://bit.ly/35AE3gM

(a) Ship and Plimsoll line

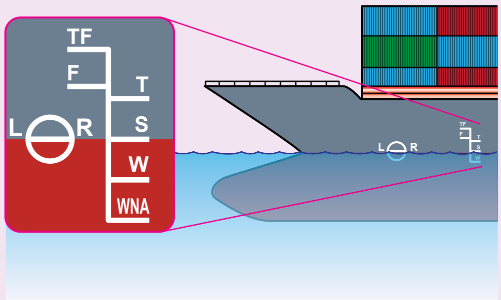


Figure 2.38

SCAN ME
Ship and Plimsoll line
https://bit.ly/2XVxLGv

(b) Submarine

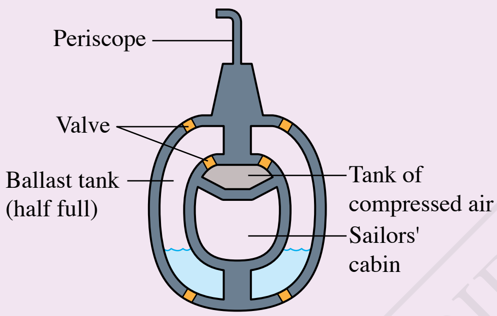


Figure 2.39

SCAN ME
Submarine
http://bit.ly/2DLLcPI

(c) Hot air balloon

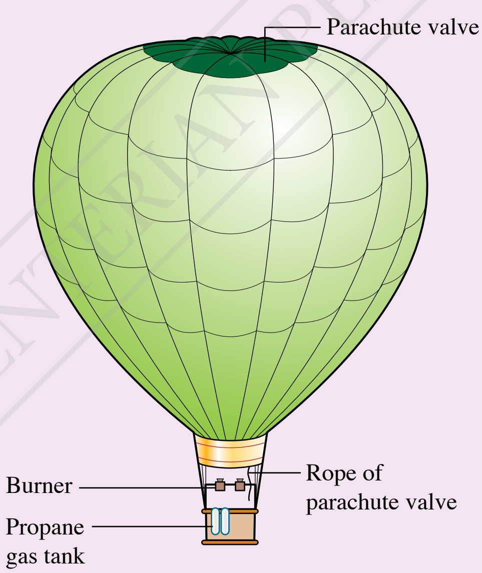


Figure 2.40

BRIGHT Info

Balloon goes up when:
- parachute valve is closed
- burner is ignited
- air is heated up
- weight of balloon $<$ buoyant force

Balloon comes down when:
- parachute valve is opened
- hot air is released
- burner is turned off
- weight of balloon $>$ buoyant force

SCAN ME
Hot air balloon
http://bit.ly/2PeeL1Y

4. Present your findings in the form of a multimedia presentation entitled ‘Applications of Archimedes' Principle in Daily Life’.

Solving Problems Involving Archimedes' Principle and Buoyancy

When an object is in a fluid:

Buoyant force = weight of fluid displaced
$$F_B = \rho V g$$

When an object is floating in a fluid:

Buoyant force = weight of object
= weight of fluid displaced

LET'S ANSWER

http://bit.ly/35JwZyh

Example 1

Figure 2.41 shows a line L on a boat. The volume of the boat below the line L is 2.8 m^3. The mass of the boat is 600 kg. What is the weight of the maximum load that can be carried by the boat?
[Density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

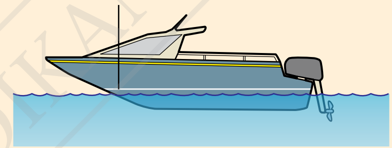


Figure 2.41

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. Let the weight of maximum load that can be carried = B

2. Volume of boat below line L = 2.8 m^3
When the boat floats with a depth of immersion at line L, volume of water displaced, V = 2.8 m^3
Density of water, ρ = 1 000 kg m^{-3}
Gravitational acceleration, g = 9.81 m s^{-2}
Mass of boat, m = 600 kg

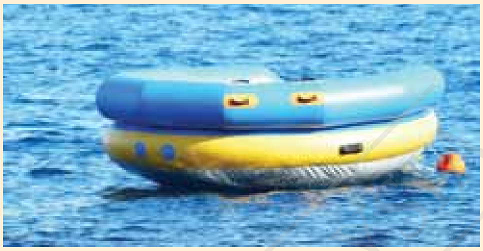
3. Weight of boat, $W = mg$
$W + B$ = buoyant force
= weight of water displaced
$= \rho V g$

4. $W = 600 \times 9.81$
$= 5\ 886$ N
$5\ 886 + B = 1\ 000 \times 2.8 \times 9.81$
$B = 27\ 468 - 5\ 886$
$= 21\ 582$ N

Example 2

Photograph 2.8 shows a raft floating in the sea. The mass of the raft is 54 kg and the density of sea water is 1 080 kg m^{-3}.
[Gravitational acceleration, g = 9.81 m s^{-2}]

(a) What is the weight of the raft?
(b) Compare the weight of the raft with the weight of sea water displaced.
(c) Calculate the volume of water displaced by the raft.



Photograph 2.8 *Raft*

Solution

(a) Weight of raft, W
Mass of raft, m = 54 kg
Gravitational acceleration, g = 9.81 m s^{-2}

$$\begin{aligned} W &= mg \\ &= 54 \times 9.81 \\ &= 529.74 \text{ N} \end{aligned}$$

(b) The raft is in equilibrium
Weight of raft = buoyant force
According to Archimedes' principle,
buoyant force = weight of water displaced
Therefore,
weight of raft = weight of sea water displaced

(c) Volume of water displaced, V
Weight of raft, W = 529.74 N
Density of sea water, ρ = 1 080 kg m^{-3}
Weight of raft = weight of sea water displaced

$$\begin{aligned} W &= \rho V g \\ 529.74 &= 1\ 080 \times V \times 9.81 \\ V &= \frac{529.74}{1\ 080 \times 9.81} \\ &= 0.05 \text{ m}^3 \end{aligned}$$

Formative Practice 2.5

1. State Archimedes' principle.

2. A small boat displaces 3.8×10^{-2} m^3 of sea water. Calculate the buoyant force acting on the boat.
[Density of sea water, ρ = 1 050 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

3. Figure 2.42 shows a block of mass 0.48 kg and volume 5.0×10^{-4} m^3 being held in water. The density of water is 1 000 kg m^{-3}. Determine the movement of the block when it is released.
[Density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

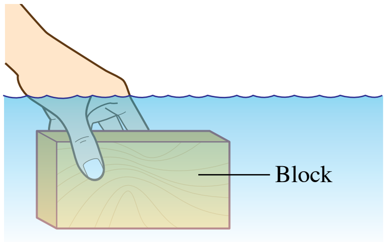


Figure 2.42

2.6 Bernoulli's Principle

Figure 2.43 shows a pupil trying to lift a folded piece of paper by blowing air below the paper. When he blew hard below the paper, the paper was pressed close to the surface of the table. It is due to the difference in velocity of air and pressure.

SCAN ME
Video on the effect of blowing air on a piece of paper
http://bit.ly/2QGxvce

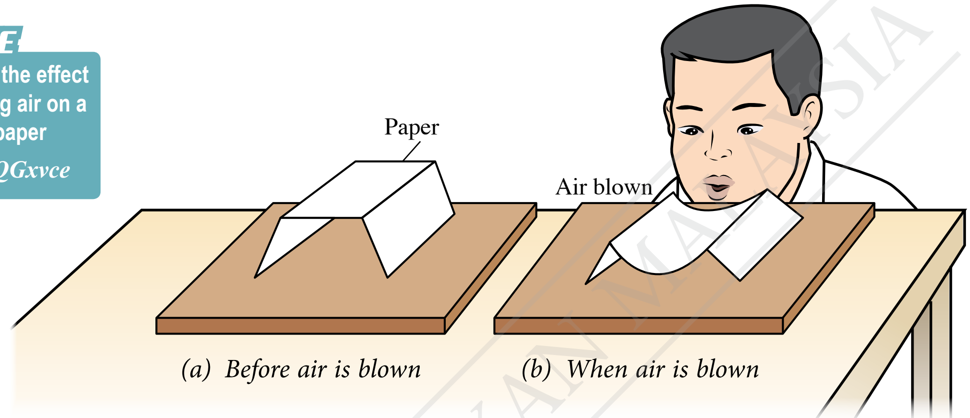


Figure 2.43 *Effect of blowing air below a folded piece of paper*

Activity 2.13

Aim: To generate the idea that high velocity of fluids creates a region of low pressure

Apparatus: Retort stand and Venturi tube

Materials: A4 paper, two balloons, thread, water and drinking straw

Instructions:

A Paper

1. Hold a piece of A4 paper with both hands and blow across the top surface of the paper as shown in Photograph 2.9.
2. Observe the movement of the paper.

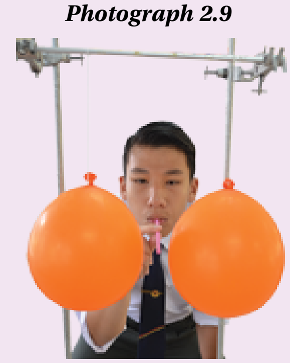
Photograph 2.9

Discussion:

1. Compare the velocity of air above and below the paper.
2. Describe the movement of the paper when air is blown above it.

B Balloons

1. Hang two inflated balloons near each other as shown in Photograph 2.10.
2. Use a drinking straw to blow air into the space between the two balloons.
3. Observe the movement of the balloons.



Photograph 2.10

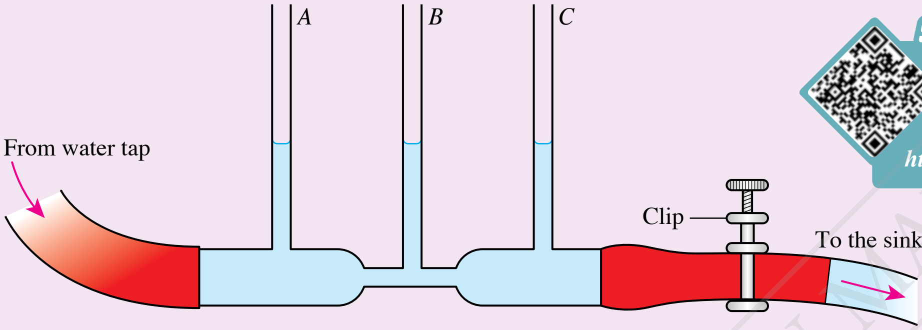
LS 2.6.1

Discussion:

1. Compare the velocity of air in between the two balloons with the velocity of air around them.
2. Describe the movement of the two balloons.

C Venturi tube

1. Set up the Venturi tube as shown in Figure 2.44.



SCAN ME
Video of venturi tube
http://bit.ly/2FApLlL

Figure 2.44

2. Turn on the water tap and let water flow into the Venturi tube until the water levels in the vertical tubes *A*, *B* and *C* are half the heights of the tubes.
3. Open the clip to allow the water to flow out into the sink. Adjust the water tap and the clip to control the water flow until the water levels in the vertical tubes are stable. Observe the heights of the water columns in the tubes.

Discussion:

1. What is the relationship between the height of the water column in the three tubes with the water pressure?
2. Compare the heights of the water columns in tubes *A*, *B* and *C*.

The observations in Activity 2.13 are caused by the effect of fluid velocity on the pressure in the fluid. The flow of air at high velocity produces a region of low pressure compared to the pressure of the surroundings. The pressure difference produces a force that acts from the region of higher pressure towards the region of lower pressure. The effect of the action of this force can be seen in the movement of the paper and balloons as shown in Figure 2.45 and Figure 2.46.

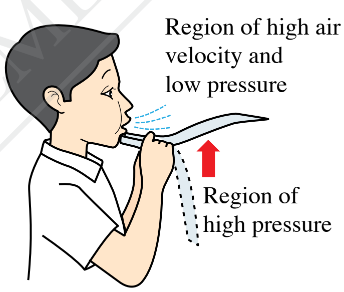


Figure 2.45 *Paper pushed upwards*

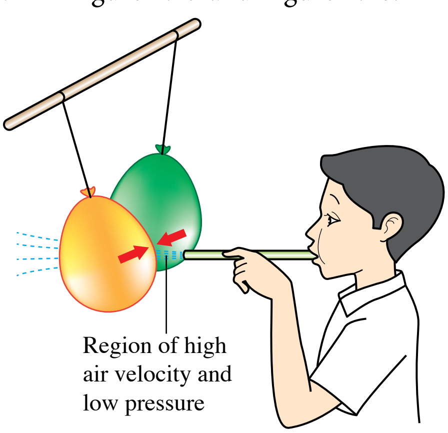


Figure 2.46 *Balloons move closer to each other*

LS 2.6.1

In a Venturi tube, the heights of the water columns in tubes *A*, *B* and *C* show the pressure at *X*, *Y* and *Z* respectively as shown in Figure 2.47.

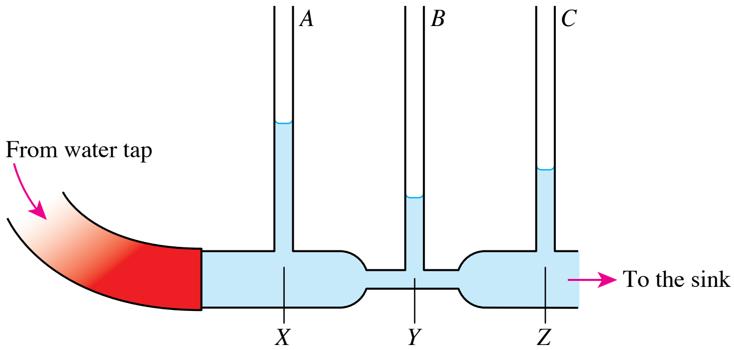


Figure 2.47 *Venturi tube*

The pressure at *X* is higher than the pressure at *Z* because water flows from *X* to *Z*. Therefore, the height of the water column in tube *A* is higher than the height of the water column in tube *C*.

The velocity of water depends on the cross-sectional area of the tube. The smaller the cross-sectional area, the higher the velocity of the water. From *X* to *Y*, the velocity of the water increases and the water pressure decreases. From *Y* to *Z*, the velocity of the water decreases and the water pressure increases.

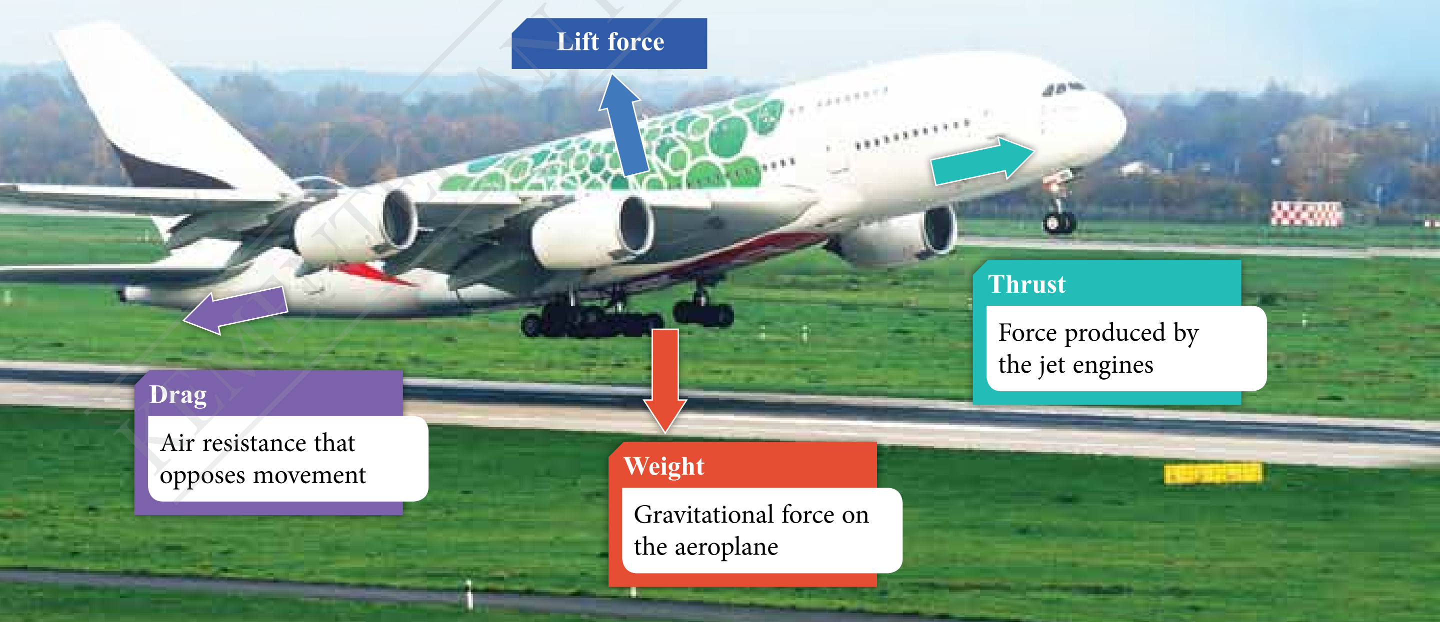
Bernoulli's principle states that when the velocity of a fluid increases, the pressure in the fluid decreases and vice versa.

SCAN ME
EduwebTV: Bernoulli's Principle
http://bit.ly/35IDnG6

Info GALLERY
When a fluid flows continuously in a pipe, the smaller the diameter of the pipe, the higher the velocity of fluid.

Lift Force

Photograph 2.24 shows an aeroplane taking off at the airport. How is the lift force produced to lift the aeroplane up into the air?



Photograph 2.11 Aeroplane taking off at the airport

Activity 2.14

Aim: To observe the effect of lift force

Apparatus: Filter funnel, silicone tube, aerofoil kit and retort stand

Material: Ping pong ball

Instructions:

A Filter funnel with a ping pong ball

1. Set up the apparatus as shown in Figure 2.48. Place the ping pong ball in the inverted filter funnel.
2. Hold the filter funnel and blow hard through the silicone tube connected to the filter funnel. Observe the movement of the ping pong ball.

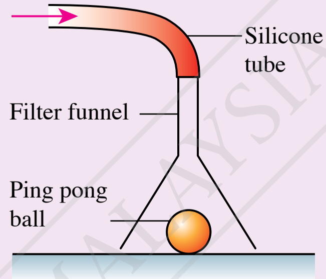


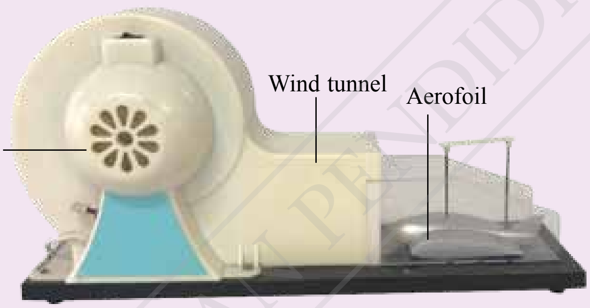
Figure 2.48

Discussion:

1. Identify the region where air flows with high velocity.
2. What happens to the ping pong ball? Explain your answer.

B Aerofoil kit

1. Set up the aerofoil kit as shown in Photograph 2.12.



Photograph 2.12

2. Switch on the blower so that a stream of air blows past the aerofoil. Observe the motion of the aerofoil.
3. Switch off the blower. Observe the motion of the aerofoil.

Discussion:

1. What happens to the aerofoil when air is blown?
2. What is the direction of the resultant force on the aerofoil?
3. Compare the pressure in the air that flows over the top surface and the bottom surface of the aerofoil.
4. Identify the regions of air flow with high velocity and low velocity around the aerofoil.

Let's Try

Paper aeroplane

http://bit.ly/306FSks

SCAN ME

Video of aerofoil kit

http://bit.ly/2FAA35c

Effect of Lift Force on a Ping Pong Ball

Lift force is produced from the difference in pressure caused by the flow of air at different velocities. Air flowing at a high velocity above the ping pong ball as shown in Figure 2.49 produces a region of low pressure. The difference between the high pressure below the ball and the low pressure above the ball produces a resultant force upwards. This resultant force is the lift force that lifts up the ping pong ball.

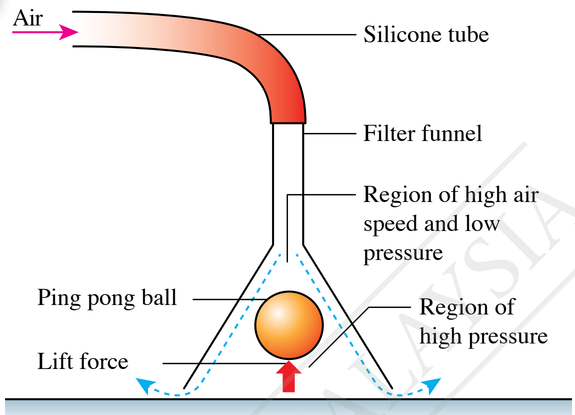


***Figure 2.49** Effect of lift force on the ping pong ball*

Production of Lift Force by the Aerofoil

The aerofoil shape of the wing of an aeroplane causes air to flow at different speeds past the top section and the bottom section. According to Bernoulli's principle, the higher air velocity at the top section produces a region of low pressure while the lower air velocity at the bottom section produces a region of high pressure. This difference in pressure produces a lift force acting upwards on the aeroplane as shown in Figure 2.50.

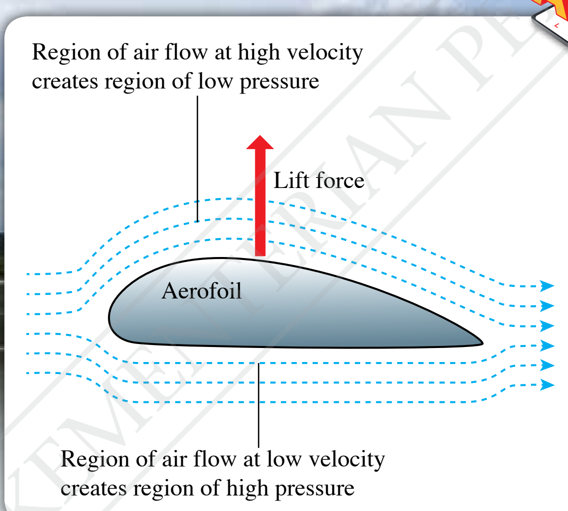


***Figure 2.50** Production of lift force by the aerofoil*

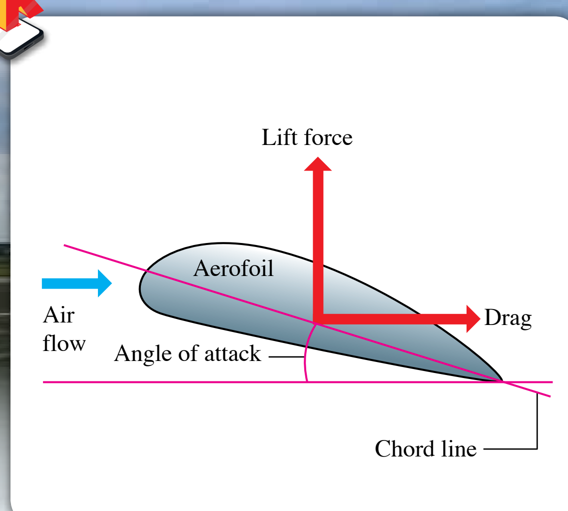


***Figure 2.51** Angle of attack on aerofoil*

The total lift force acting on the aeroplane is also affected by the angle of attack as shown in Figure 2.51. When the aerofoil is at a certain angle of attack, the aerofoil exerts a force on the air flow. According to Newton's Third Law of Motion, a reaction force will act on the wing of the aeroplane and contribute to the lift force that acts on the aeroplane.

LS 2.6.2

Applications of Bernoulli's Principle in Daily Life

Bernoulli's principle is applied widely in various fields from small devices in homes to large commercial aircraft.

Activity 2.15

ISS / ICS

Aim: To search for information on applications of Bernoulli's principle in daily life

Instructions:

1. Carry out this activity in groups.
2. Study Figure 2.52 that shows four applications of Bernoulli's principle in daily life.

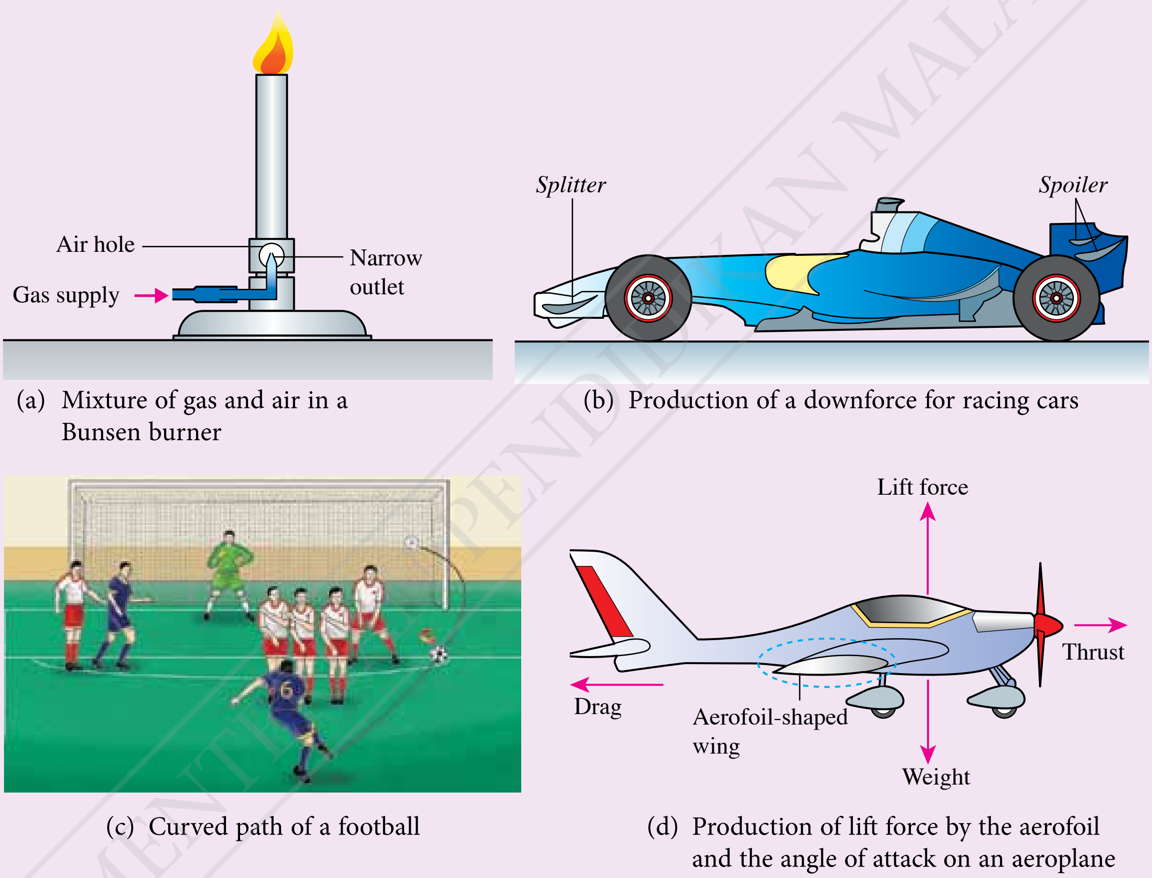


***Figure 2.52** Applications of Bernoulli's principle in daily life*

3. For each application, search for further information.
4. Prepare a multimedia report of your findings.

SCAN ME
Application of Bernoulli's principle
http://bit.ly/35ez4TI

Activity 2.16

STEM | ISS | ICS

Aim: To design a paper aeroplane based on the applications of Bernoulli's principle and Newton's Third Law of Motion

Instructions:

1. Carry out this activity in groups.
2. Gather information on paper aeroplanes from reading materials or websites covering the following:
   (a) materials required
   (b) design of a paper aeroplane that can fly far for a long time
   (c) the way to launch the paper aeroplane
   (d) direction of wind during launch
3. Use the K-W-L Data Strategy Form.
4. Sketch a diagram showing the design of the paper aeroplane.
5. Build the paper aeroplane according to the suggested design.
6. Launch the paper aeroplane and observe its flight.
7. Identify the aspects of design and the method of launching that requires improvement.
8. Discuss steps for improvement that can be carried out.
9. Build a new paper aeroplane and test its flight.
10. Present the design and the paper aeroplane.

SCAN ME
K-W-L Data Strategy Form
http://bit.ly/301Sucu

SCAN ME
Guideline to design a paper aeroplane
https://go.nasa.gov/366nLNb

Note
Take into consideration Bernoulli's Principle and Newton's Third Law of Motion.

Formative Practice 2.6

1. State Bernoulli's principle.
2. Explain three ways of using a piece of A4 paper to demonstrate Bernoulli's principle.
3. Figure 2.53 shows the cross section of the wing of an aeroplane when the aeroplane is accelerating along the runway and when it begins to take off from the runway.

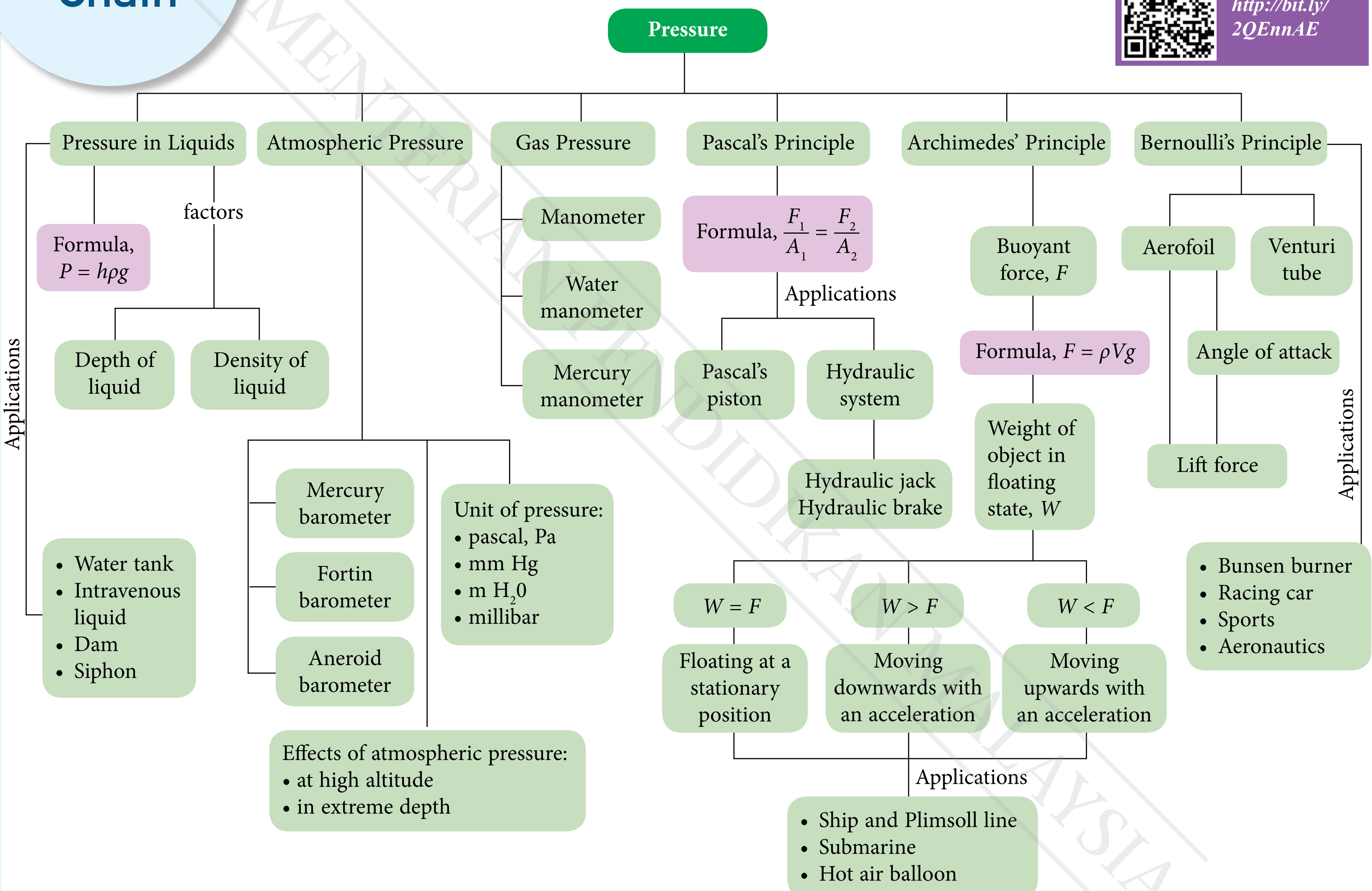
(a) *Accelerating along the runway* (b) *Taking off from the runway*

Figure 2.53

With the aid of labelled diagrams, explain how the lift force is produced when the aeroplane takes off.

Concept Chain

Interactive Games
http://bit.ly/2QEnnAE



Self-Reflection

SCAN ME
Download and print Self-Reflection
http://bit.ly/35BhLeJ

1. New things I have learnt in the chapter on 'Pressure' are ________.
2. The most interesting thing I have learnt in this chapter is ________.
3. The things I still do not fully understand are ________.
4. My performance in this chapter.

   Poor | 1 | 2 | 3 | 4 | 5 | Very good

5. I need to ________ to improve my performance in this chapter.

QUIZ PORTAL
http://bit.ly/37UiPw0

Summative Practice

1. (a) Derive the formula for pressure at depth h in a liquid with density ρ.
   (b) Calculate the pressure at depth of 24 m in a lake that contains water with a density of 1 120 kg m^{-3}.
   [Gravitational acceleration, $g = 9.81$ m s^{-2}]

2. Figure 1 shows the apparatus for comparing the densities of two types of liquid after some air is sucked out of the apparatus.
   (a) Explain why the pressure at point A is equal to the pressure at point B.
   (b) Calculate the density of liquid X.
   [Density of water, ρ = 1 000 kg m^{-3}]

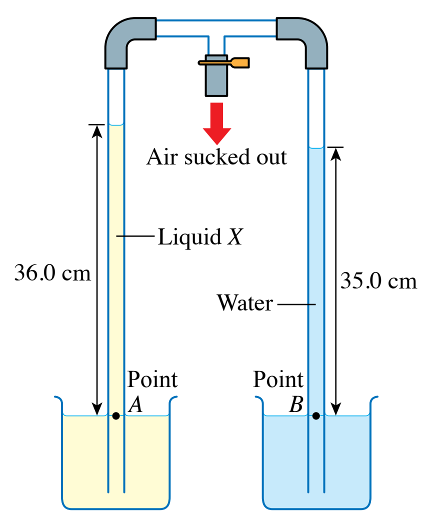


Figure 1

3. Compare and contrast the existence of pressure in the liquids and the atmospheric pressure.

4. Figure 2 shows a U-tube containing mercury.

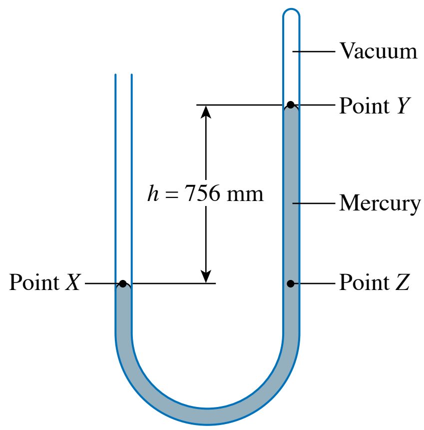


Figure 2

(a) What is the pressure acting on point X and point Y on the surface of mercury?

(b) By comparing the pressure at point X and point Z, explain why the height of the mercury column, h is a measure of atmospheric pressure.

(c) Determine the atmospheric pressure in Pa.
[Density of mercury, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

5. A mercury manometer is connected to a cylinder containing gas. The gas pressure in the cylinder and the atmospheric pressure are 180 kPa and 103 kPa respectively.
Sketch a diagram of the manometer connected to the gas cylinder. Determine the height of the mercury column in your sketch.
[Density of mercury, ρ = 13 600 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

6. In a hydraulic brake system, the driver of the vehicle applies a force of 80 N on the brake pedal. This force is multiplied by the mechanical lever system to be a 400 N input force on the hydraulic liquid in the master cylinder. The diameter of the master cylinder and the diameter of the slave cylinder are 0.8 cm and 2.5 cm respectively.

(a) Calculate the pressure on the hydraulic liquid in the master cylinder.

(b) State the principle that enables pressure to be transmitted from the master cylinder to the slave cylinder.

(c) What is the braking force produced at the slave cylinder to stop the rotation of the wheel?

7. A wooden block with volume 3.24×10^{-3} m^3 is released in a tank of water. By doing the relevant calculations, sketch the state of buoyancy of the wooden block in the tank.
[Density of wood, ρ = 920 kg m^{-3}, density of water, ρ = 1 000 kg m^{-3} and gravitational acceleration, g = 9.81 m s^{-2}]

8. Figure 3 shows two designs of a hydraulic jack, *X* and *Y* which were suggested by a technician.

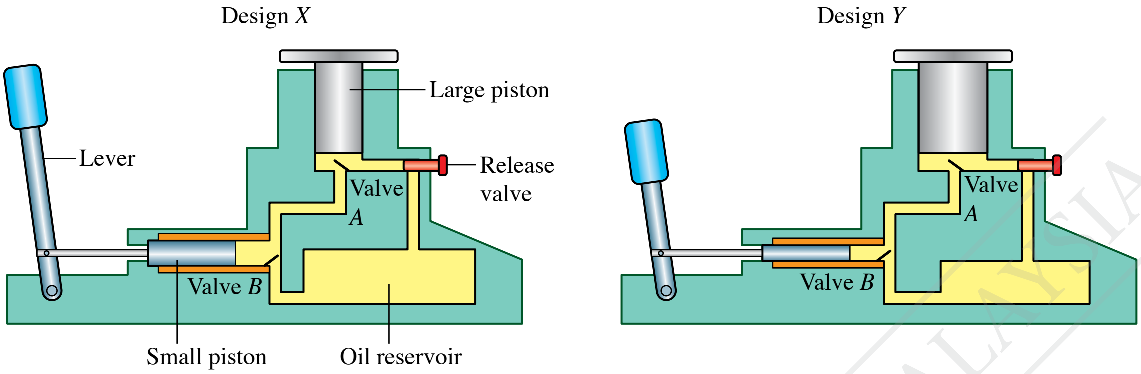


Figure 3

(a) By referring to design *X*, describe the operation of the hydraulic jack.

(b) Study design *X* and design *Y*. Compare the advantages and disadvantages of design *X* and design *Y*.

(c) Based on your answer in 8(b), suggest a design of hydraulic jack that can produce a larger output force and lift a load to a greater height.

9. A hot air balloon is in a stationary position in the air.

(a) State Archimedes' principle.

(b) Explain the relationship between the weight of the balloon and the weight of air displaced.

(c) When the flame of the burner is extinguished and the parachute valve is opened, the balloon begins to descend. Explain how this action enables the balloon to descend to the ground.

10. Figure 4 and Figure 5 show the same metal blocks of mass 0.050 kg hanging from a spring balance, immersed in water and cooking oil respectively.

(a) Compare the pressure at point *A* and point *B* in Figure 4. Explain your answer.

(b) Explain how the difference in pressure in 10(a) exerts a buoyant force on the metal block.

(c) Calculate the density of cooking oil if the density of water is 1 000 kg m^{-3}.
[Gravitational acceleration, $g = 9.81$ m s^{-2}]

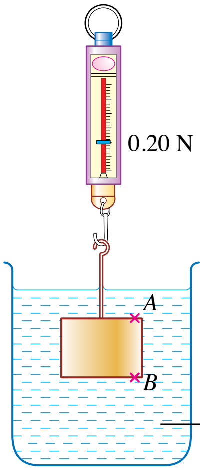


Figure 4

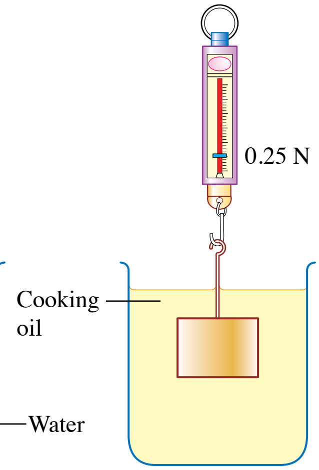


Figure 5

11. Photograph 1 shows a racing car that is stabilised by downforce while being driven at high speed.

Photograph 1

Explain the production of the downforce due to the air flowing past the:
(a) inverted aerofoil-shaped spoiler
(b) top and bottom sections of the car

21st Century Challenge

12. Figure 6 shows part of the hydraulic brake system of a car. A driver finds that the brake has to be pressed harder and further in to stop the car.

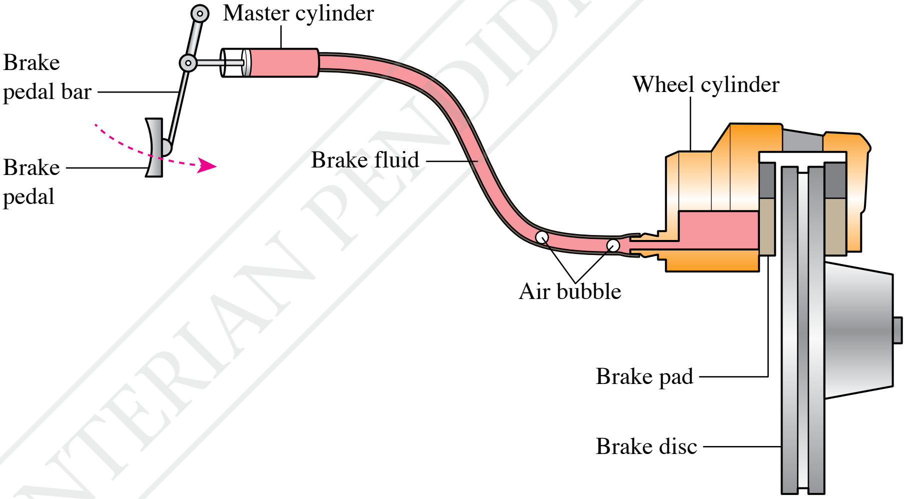


Figure 6

(a) Identify the weaknesses in the hydraulic brake system of the car.
(b) By using suitable physics concepts, suggest modifications to the brake system so that the car can be stopped more effectively. Your answer should include the following aspects:
(i) characteristics of the brake fluid
(ii) cross-sectional area of the master cylinder
(iii) cross-sectional area of the wheel cylinder
(iv) length of the brake pedal bar
(v) other suitable designs