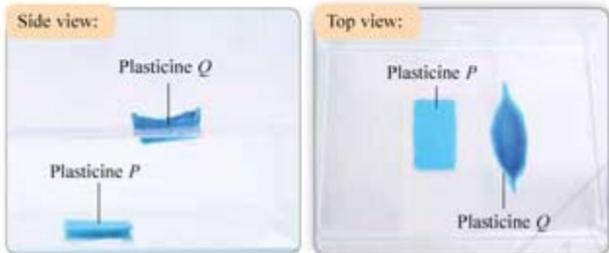# 2.5 Archimedes' Principle

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?

Side view:
Plasticine *Q*
Plasticine *P*

Top view:
Plasticine *P*
Plasticine *Q*

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?
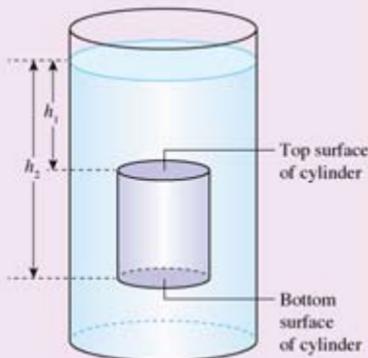
h_1
h_2

Top surface of cylinder

Bottom surface of cylinder

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:
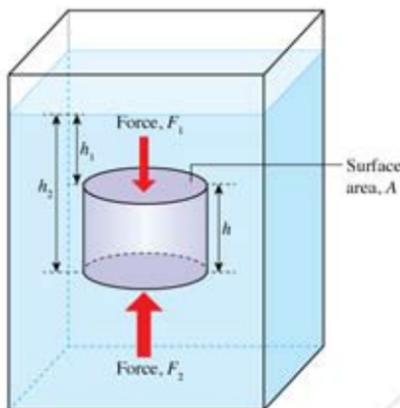

Figure 2.28 *Cylinder fully submerged in a liquid*

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, $F_1 = P_1 A$
$$= h_1 \rho g A$$

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

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

Resultant force, F (upwards) $= F_2 - F_1$
$$= h_2 \rho g A - h_1 \rho g A$$
$$= \rho A (h_2 - h_1) g$$
$$= \rho A h g$$
$$= \rho V g$$

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,
$W = mg$
$W = \rho V g$

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.

SCAN ME

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

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

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.

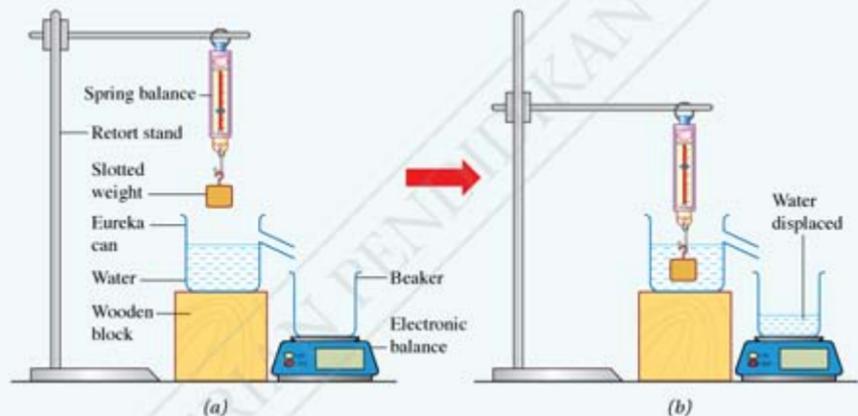*(a)*   *(b)*

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.
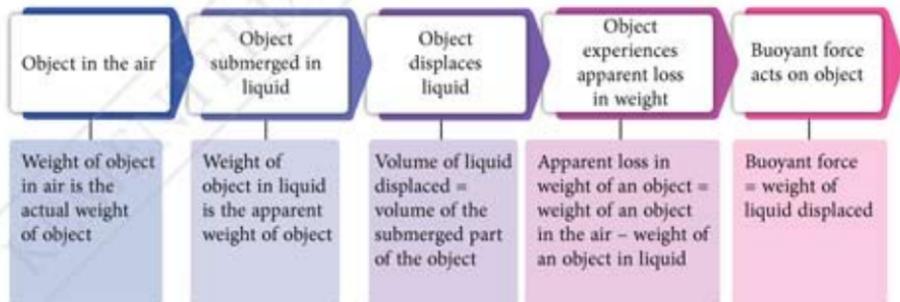
Object in the air	Object submerged in liquid	Object displaces liquid	Object experiences apparent loss in weight	Buoyant force acts on object
Weight of object in air is the actual weight of object	Weight of object in liquid is the apparent weight of object	Volume of liquid displaced = volume of the submerged 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.
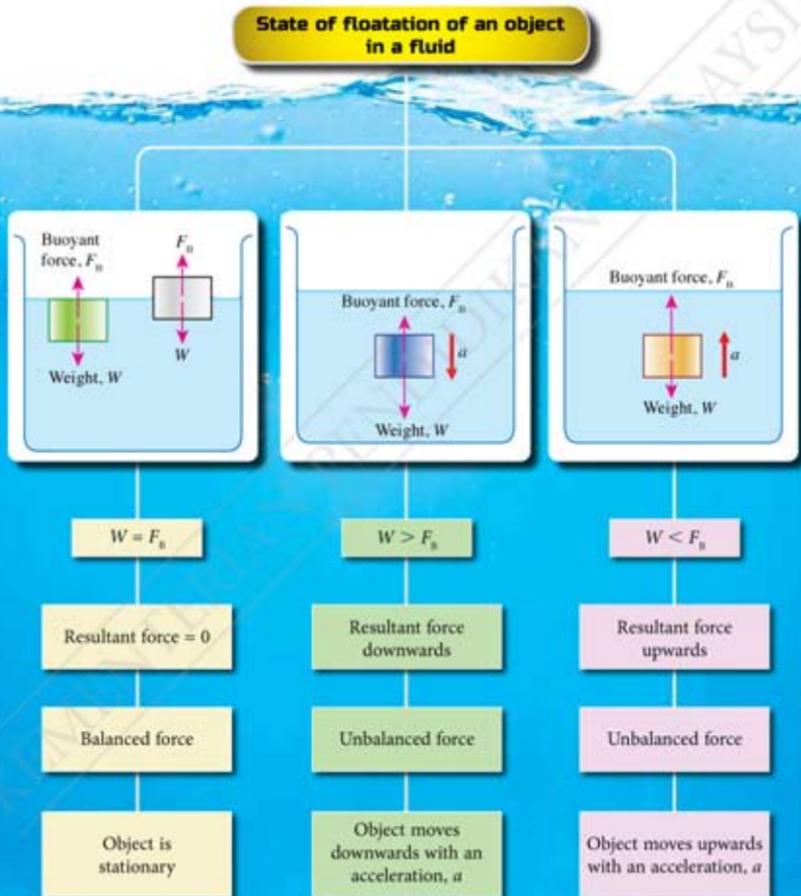Figure 2.31 summarises the state of floatation of an object in a fluid.

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.
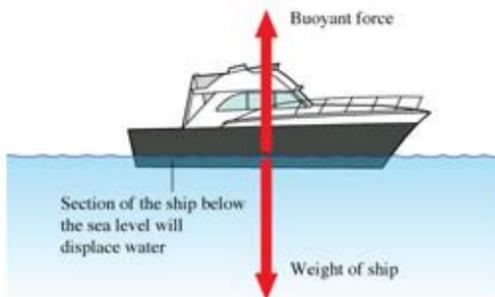

Buoyant force

Section of the ship below the sea level will displace water

Weight of ship

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 = volume of the section
water displaced   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.
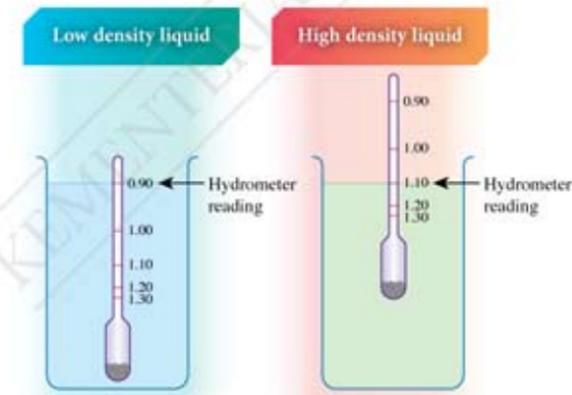

Low density liquid

High density liquid

0.90
1.00
0.90 ← Hydrometer reading
1.00
1.10
1.20
1.30

0.90
1.00
1.10 ← Hydrometer reading
1.20
1.30

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*

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

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).
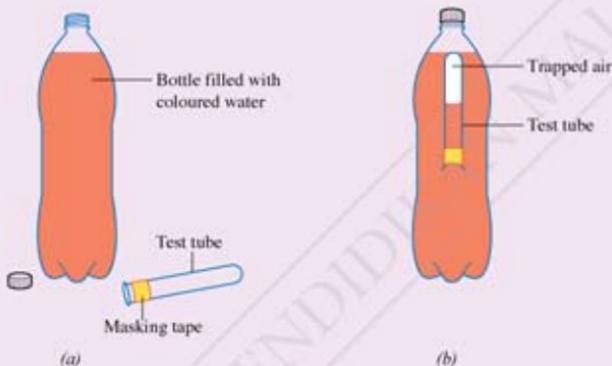

(a) Bottle filled with coloured water — Test tube — Masking tape

(b) Trapped air — Test tube

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.
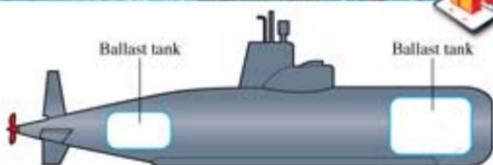

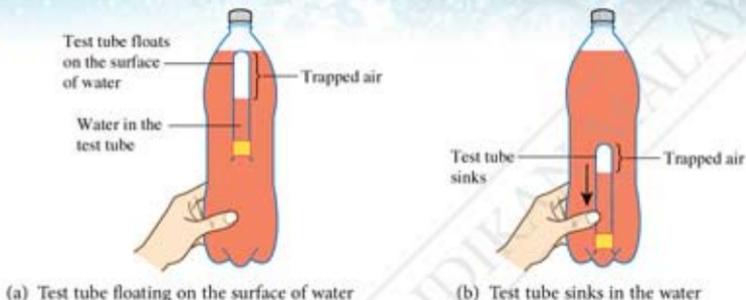*Figure 2.36 Ballast tanks in a submarine*

(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
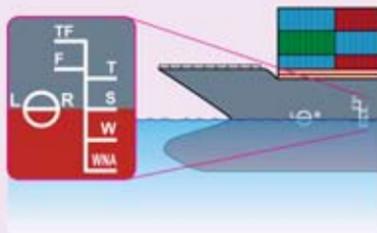
(a) Ship and Plimsoll line

Figure 2.38

(b) Submarine

Figure 2.39

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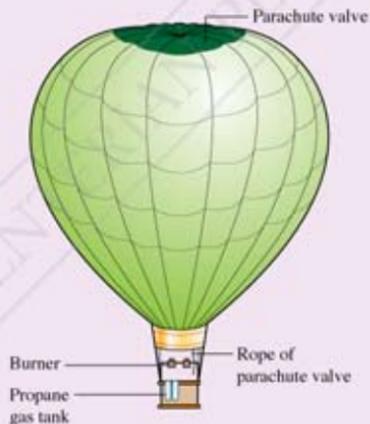
4. Present your findings in the form of a multimedia presentation entitled 'Applications of Archimedes' Principle in Daily Life'.

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**

Example 1

Figure 2.41 shows a line L on a boat. The volume of the boat below the line L is 2.8 m³. 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, $\rho = 1\,000$ kg m⁻³ and gravitational acceleration, $g = 9.81$ m s⁻²]
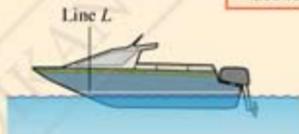

Line L

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 m³
When the boat floats with a depth of immersion at line L, volume of water displaced, $V = 2.8$ m³
Density of water, $\rho = 1\,000$ 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
$$W = 600 \times 9.81$$
$$= 5\,886 \text{ N}$$
$$5\,886 + B = 1\,000 \times 2.8 \times 9.81$$
$$B = 27\,468 - 5\,886$$
$$= 21\,582 \text{ N}$$

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}
   $$W = mg$$
   $$= 54 \times 9.81$$
   $$= 529.74 \text{ N}$$

(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, $\rho = 1\ 080$ kg m^{-3}
   Weight of raft = weight of sea water displaced
   $$W = \rho V g$$
   $$529.74 = 1\ 080 \times V \times 9.81$$
   $$V = \frac{529.74}{1\ 080 \times 9.81}$$
   $$= 0.05 \text{ m}^3$$

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, $\rho = 1\ 050$ 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, $\rho = 1\ 000$ kg m^{-3} and gravitational acceleration, $g = 9.81$ m s^{-2}]
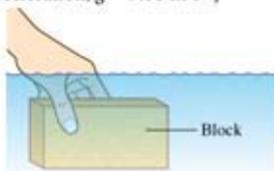
Block

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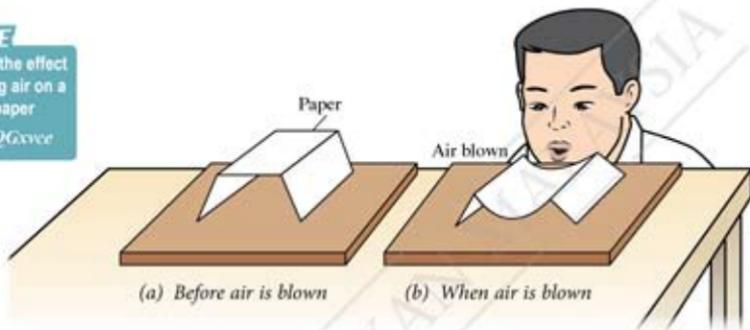Video on the effect of blowing air on a piece of paper
http://bit.ly/2QGxvce

Paper

Air blown

(a) Before air is blown

(b) When air is blown

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.

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.

Photograph 2.9

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.
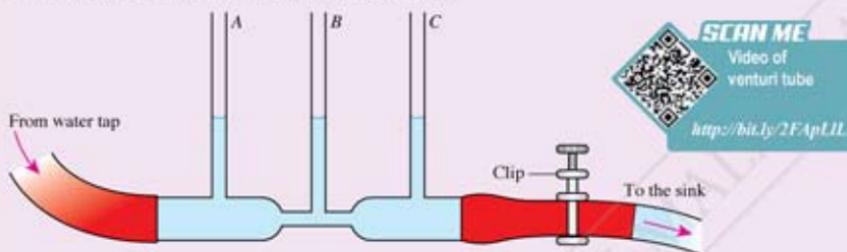
Photograph 2.10

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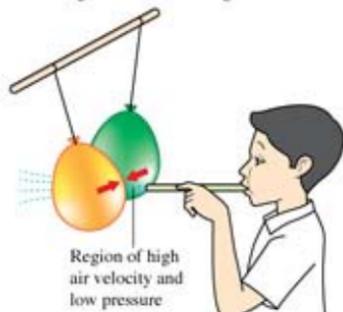
1. Set up the Venturi tube as shown in Figure 2.44.

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

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.
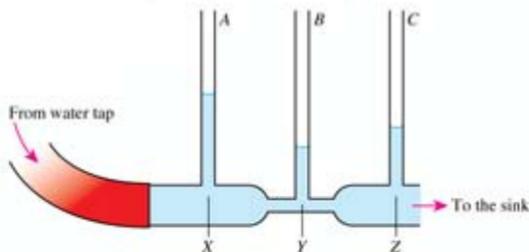

From water tap

To the sink

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.

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?

Lift force

Thrust
Force produced by the jet engines

Drag
Air resistance that opposes movement

Weight
Gravitational force on the aeroplane

Photograph 2.11 Aeroplane taking off at the airport

LS 2.6.1 2.6.2

🌟 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:

Ⓐ **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.
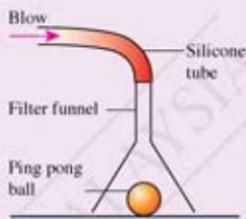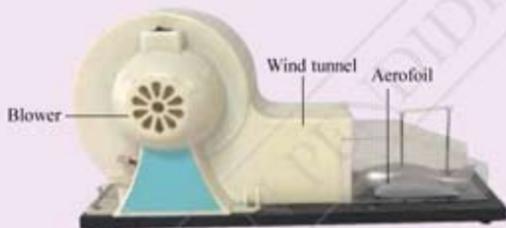

Figure 2.48

Discussion:

1. Identify the region where air flows with high velocity.

2. What happens to the ping pong ball? Explain your answer.

Ⓑ **Aerofoil kit**

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

Photograph 2.12

Let's Try

Paper aeroplane

http://bit.ly/306FSks

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.

SCAN ME
Video of aerofoil kit

https://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.
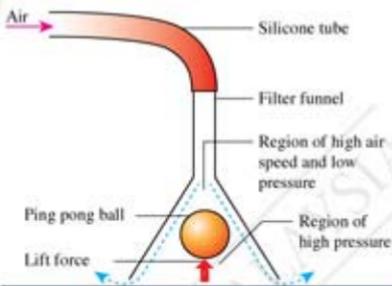

Figure 2.49 *Effect of lift force on the ping pong ball*

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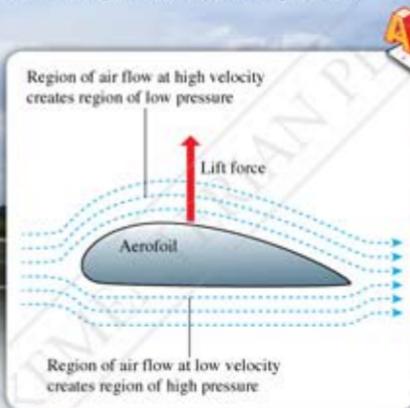
Figure 2.50 *Production of lift force by the aerofoil*

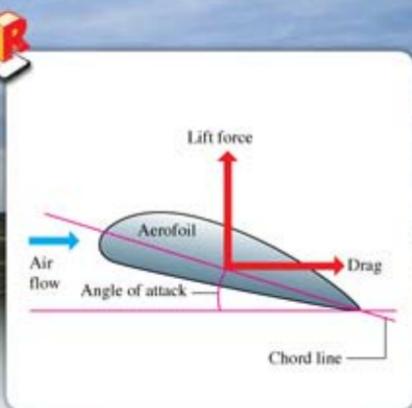Figure 2.51 *Angle of attack on aerofoil*

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.

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.

Air hole
Gas supply
Narrow outlet

(a) Mixture of gas and air in a Bunsen burner

Splitter
Spoiler

(b) Production of a downforce for racing cars

(c) Curved path of a football

Lift force
Thrust
Drag
Aerofoil-shaped wing
Weight

(d) Production of lift force by the aerofoil and the angle of attack on an aeroplane
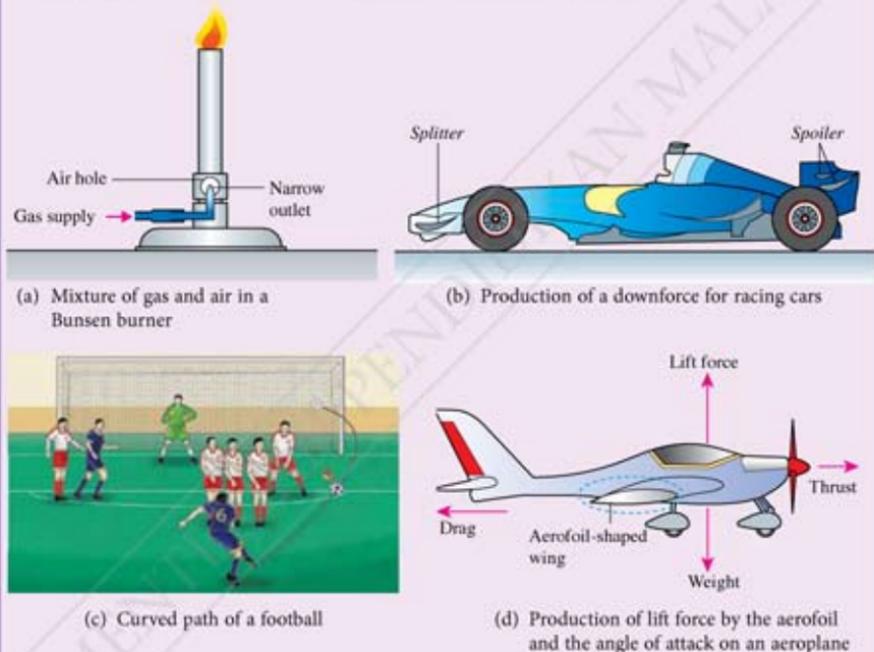
Figure 2.52 *Applications of Bernoulli's principle in daily life*

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/35ez4T1

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.
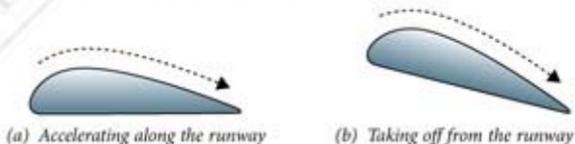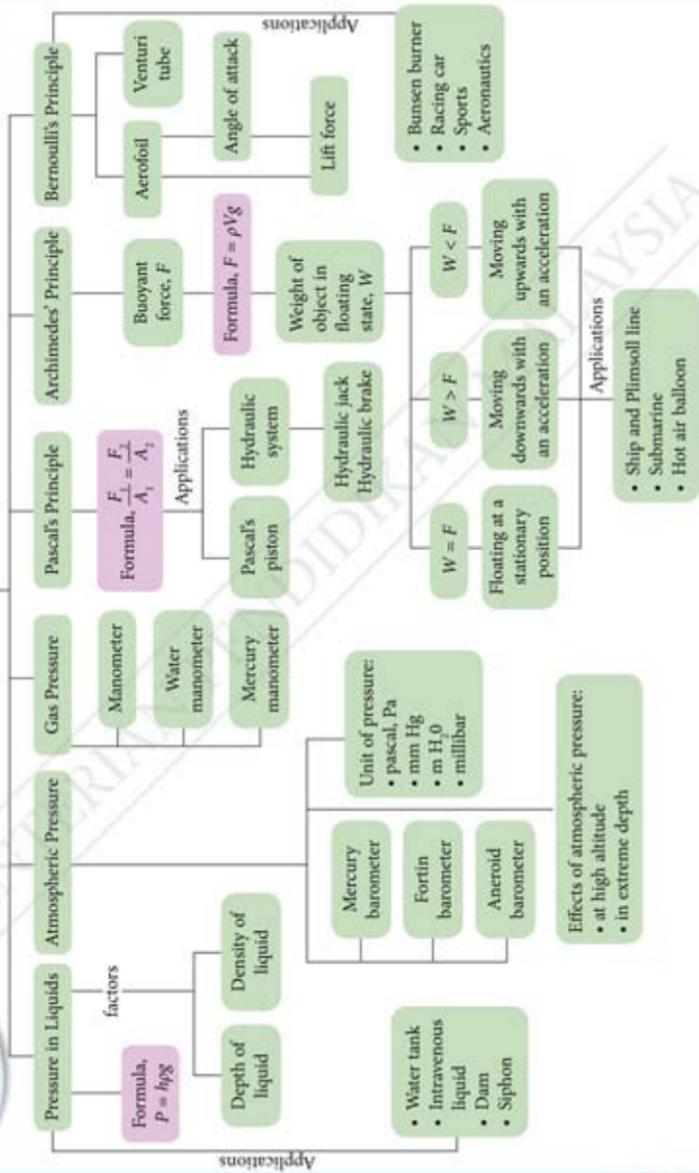

(a) *Accelerating along the runway*   (b) *Taking off from the runway*

Figure 2.53

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

LS 2.6.3

Concept Chain

Pressure

Bernoulli's Principle
- Venturi tube
- Aerofoil → Angle of attack
- Lift force

Applications
- Bunsen burner
- Racing car
- Sports
- Aeronautics

Archimedes' Principle
- Buoyant force, F
- Formula, $F = \rho V g$
- Weight of object in floating state, W
  - $W < F$: Moving upwards with an acceleration
  - $W > F$: Moving downwards with an acceleration
  - $W = F$: Floating at a stationary position

Applications
- Ship and Plimsoll line
- Submarine
- Hot air balloon

Pascal's Principle
- Formula, $\dfrac{F_1}{A_1} = \dfrac{F_2}{A_2}$

Applications
- Hydraulic system
- Pascal's piston
- Hydraulic jack
- Hydraulic brake

Gas Pressure
- Manometer
- Water manometer
- Mercury manometer

Atmospheric Pressure
- Mercury barometer
- Fortin barometer
- Aneroid barometer
- Unit of pressure:
  - pascal, Pa
  - mm Hg
  - m H_2O
  - millibar
- Effects of atmospheric pressure:
  - at high altitude
  - in extreme depth

Pressure in Liquids
- factors
  - Density of liquid
  - Depth of liquid
- Formula, $P = h\rho g$

Applications
- Water tank
- Intravenous liquid
- Dam
- Siphon

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.

Summative Practice

http://bit.ly/37UiPw0

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, $\rho = 1\ 000$ kg m^{-3}]

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

Air sucked out

Liquid X

36.0 cm

Water

35.0 cm
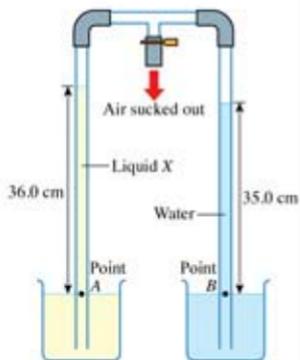
Point A

Point B

Figure 1

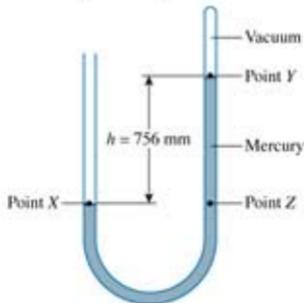4. Figure 2 shows a U-tube containing mercury.

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, $\rho = 13\,600$ 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, $\rho = 13\,600$ 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, $\rho = 920$ kg m^{-3}, density of water, $\rho = 1\,000$ 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.

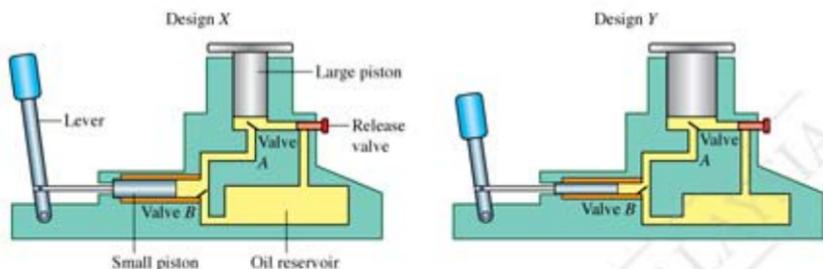Figure 3

(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}.
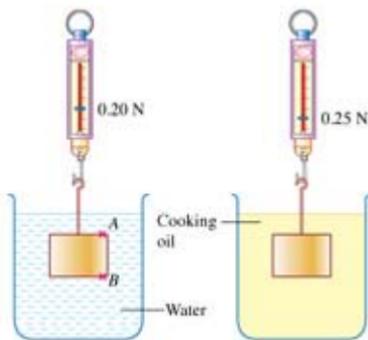[Gravitational acceleration, $g = 9.81$ m s^{-2}]

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.
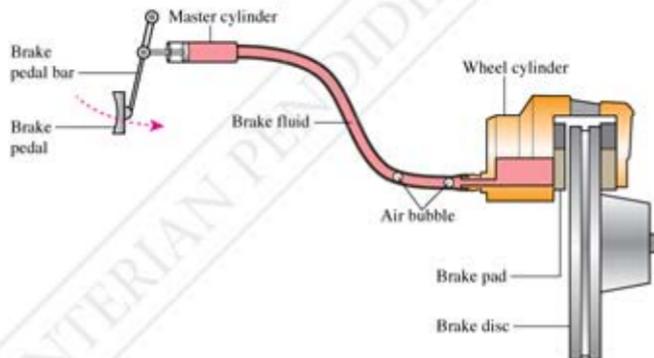

Figure 6

(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