FORCE AND PRESSURE

Do solids obey Pascal's principle?

Explain the problems that will arise in an aeroplane if its hydraulic system is damaged.

Let's study

• Pressure in fluids

Have you ever heard a loud hissing sound made by a heavy vehicle such as a tour bus or oil tanker when the vehicle stops? What is the system that operates in the heavy vehicle and produces this loud hissing sound?

Light motor vehicles such as cars normally use hydraulic brakes. Heavy motor vehicles such as buses and lorries use air brakes that produce a larger frictional force to stop the motion of the vehicle. Nevertheless, both hydraulic brakes and air brakes use a system which applies Pascal's principle.

Keywords

- Pressure in fluids
- Pascal's principle
- Enclosed system
- Hydraulic system
- Hydraulic jack system
- Hydraulic brake system
- Disc brake
- Drum brake
- Dental chair
- Venturi tube
- Venturi effect
- Bernoulli's principle
- Lift
- Aerofoil shape
- Crane

Concept of Pressure in Fluids in an Enclosed System

Have you ever seen the device in Photograph 8.1? What is this device? This device operates based on the effect of pressure in hydraulic fluid in an enclosed system. An **enclosed system** is a physical system where matter cannot enter or leave the system. Name the fluid in this device.

Based on Figure 8.1(a), water from the bottommost hole shoots out the furthest compared to water from the upper holes due to the pressure in the water.

If force is applied to the water surface by compressing the closed plastic bottle, water from each hole will shoot further at an equal additional distance as shown in Figure 8.1(b).
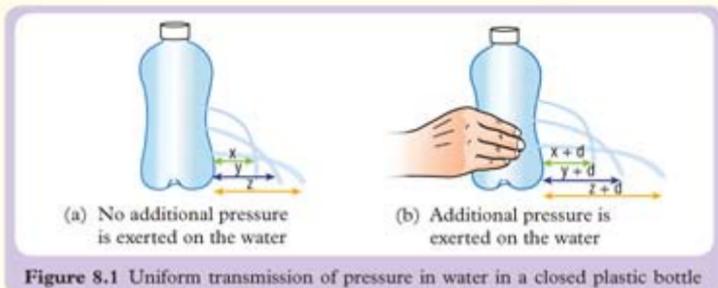
Photograph 8.1

(a) No additional pressure is exerted on the water

(b) Additional pressure is exerted on the water

Figure 8.1 Uniform transmission of pressure in water in a closed plastic bottle

Pascal's principle states that the transmission of pressure exerted on a fluid (liquid or gas) in an enclosed system is uniform throughout the fluid and in all directions.

Activity 8.1

To explain Pascal's principle using Pascal's equipment

Apparatus

Round-bottom flask with fine pores and piston, and large beaker

1. Carry out this activity in groups.
2. Prepare the apparatus set-up (Figure 8.2).
3. Pull the piston up until water fills the flask.
4. Remove the flask from the beaker and push the piston into the flask.
5. Observe and sketch the direction of water shooting out from the fine pores of the flask.

Figure 8.2

Questions

1. How does water shoot out from the fine pores of the flask in all directions? Explain your answer.
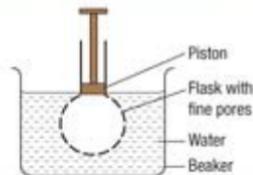2. Sketch the pattern of water shooting out from the fine pores of the flask in Figure 8.3.
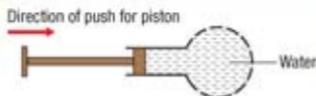

Figure 8.3

Pascal's principle is commonly applied in daily life such as in the operation of the **hydraulic system**.

Operating Principle of Hydraulic System

The basic principle in a hydraulic system is the transmission of pressure in all directions based on Pascal's principle.

The hydraulic system is used to do heavy work such as producing a large output force to lift heavy loads.

Study and understand the following example which shows the operation of the hydraulic system. The hydraulic system is made up of two cylindrical pistons of different surface areas. The fluid commonly used is **water** or **oil** (Figure 8.4). Water or oil is used because they do not have a fixed shape and cannot be compressed.
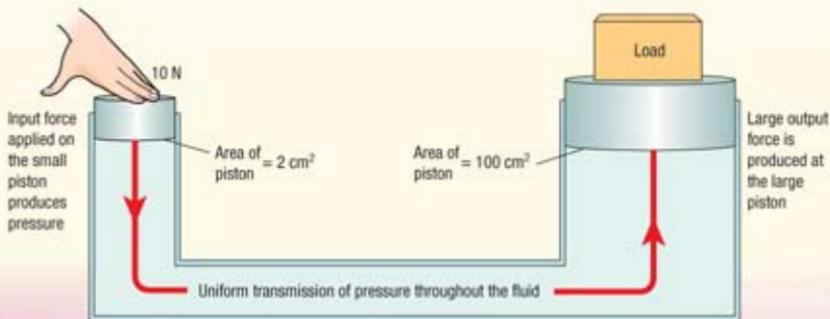

Figure 8.4 Operation of hydraulic system

8.1.1

According to Pascal's principle, the pressure exerted by the small piston is the same as the pressure produced at the large piston.

$$\text{Pressure at small piston} = \text{Pressure at large piston}$$
$$\frac{\text{Input force}}{\text{Area of small piston}} = \frac{\text{Output force}}{\text{Area of large piston}}$$
$$\frac{10\ N}{2\ cm^2} = \frac{\text{Output force}}{100\ cm^2}$$
$$\text{Output force} = \frac{10\ N \times 100\ cm^2}{2\ cm^2}$$
$$= 500\ N$$

Application of Pascal's Principle in Daily Life

The hydraulic system is used to carry out heavy work using a small force. Three examples where Pascal's principle is applied in daily life are the hydraulic jack, hydraulic brake and dental chair.

Hydraulic Jack System

Hydraulic jack is usually used to lift heavy loads such as cars in workshops. Try operating a hydraulic jack. Figure 8.5 shows the structure of a hydraulic jack system.

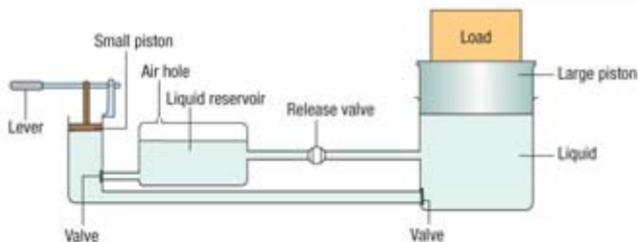**Photograph 8.2** Hydraulic jack

Figure 8.5 Hydraulic jack system

In the hydraulic jack system, the lever is moved downwards and upwards repeatedly to push the loaded large piston upwards with the release valve closed. When the release valve is opened, the loaded large piston will drop back to its original position as shown in Figures 8.6, 8.7 and 8.8.

▶ **Video**

Operation of hydraulic jack
http://buku-teks.com/sc5225a

8.1.1 8.1.2

Operation of hydraulic jack system:

(a) Increasing the height of a loaded large piston

The lever is moved downwards with the release valve closed, valve A closes and valve B opens
(The lever is moved downwards and upwards a few times to lift the load to a desired height)

Pivot
Air hole
Load

❶ Lever is moved downwards

Liquid reservoir

Release valve is closed

❹ Large piston rises

❷ Small piston exerts pressure on the liquid

❸ Liquid transmits its pressure to the loaded large piston and pushes it upwards

Valve A closes

Valve B opens

Figure 8.6 Large piston is raised

Scan AR
Page

(b) Maintaining the height or position of the large piston

The lever is moved upwards with the release valve closed, valve A opens and valve B closes

❷ Liquid from reservoir flows below the small piston through the open valve A

Air hole

Load

❹ Position of large piston is maintained

❶ Lever is moved upwards

Liquid reservoir

Release valve is closed

❸ A constant liquid pressure is exerted on the large piston to maintain its position
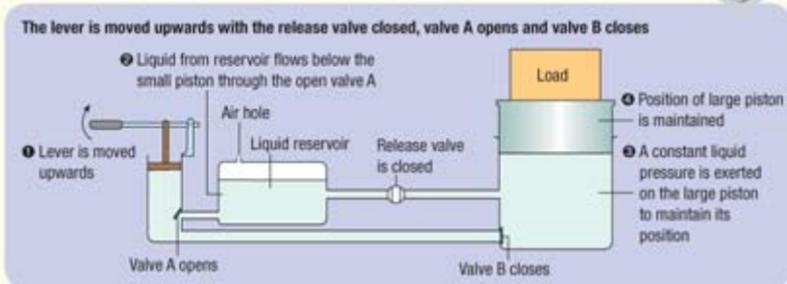
Valve A opens

Valve B closes

Figure 8.7 Position of large piston is maintained

(c) Lowering the large piston back to its original position

The release valve is opened, valve A opens and valve B closes

Large piston goes down to its original position

Air hole
Liquid reservoir

❸ The liquid flows back into the liquid reservoir through the release valve

❷ Loaded large piston exerts pressure on the liquid beneath it

❶ Release valve is opened
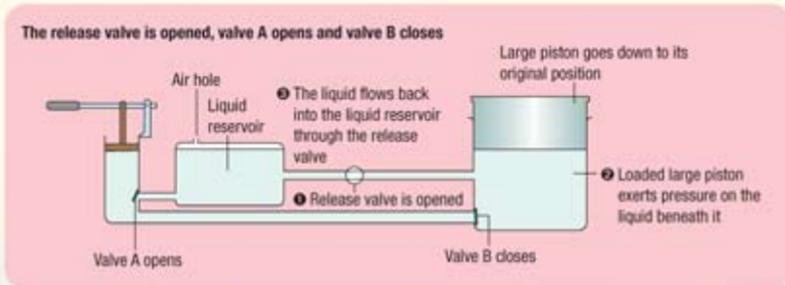
Valve A opens

Valve B closes

Figure 8.8 Large piston returns to its original position

8.1.2

225
KPM

The Hydraulic Brake System

The hydraulic brake system is commonly used to slow down or stop wheeled vehicles such as moving cars. The operation of a hydraulic brake system is shown in Figure 8.9.
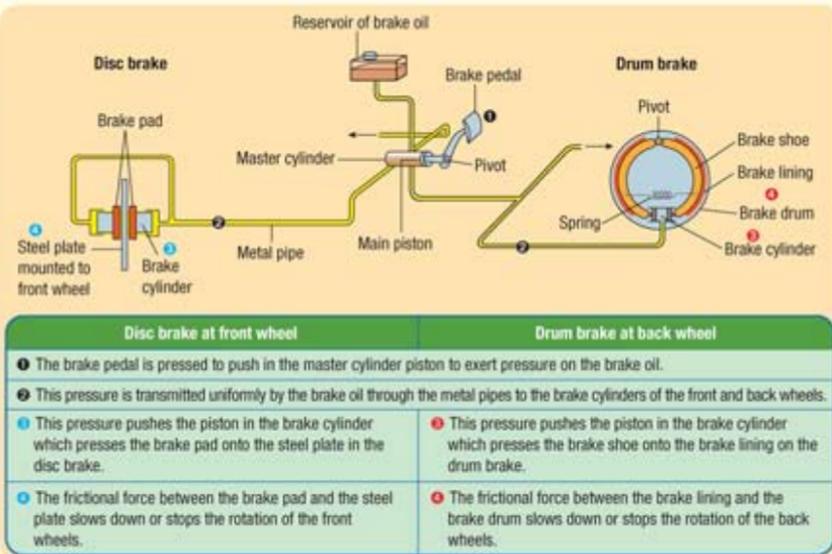
Disc brake at front wheel	Drum brake at back wheel
❶ The brake pedal is pressed to push in the master cylinder piston to exert pressure on the brake oil.	
❷ This pressure is transmitted uniformly by the brake oil through the metal pipes to the brake cylinders of the front and back wheels.	
❸ This pressure pushes the piston in the brake cylinder which presses the brake pad onto the steel plate in the disc brake.	❸ This pressure pushes the piston in the brake cylinder which presses the brake shoe onto the brake lining on the drum brake.
❹ The frictional force between the brake pad and the steel plate slows down or stops the rotation of the front wheels.	❹ The frictional force between the brake lining and the brake drum slows down or stops the rotation of the back wheels.

**Figure 8.9** The hydraulic brake system and its operation

Dental Chair

The operation of the dental chair is related to the hydraulic system. Observe the dental chair in Photograph 8.3. Then, study and understand the application of Pascal's principle in the dental chair as shown in the following video or other sources of information.

▶ **Video**

Is hydraulic system used in a dental chair?
http://buku-teks.com/sc5226b

Application of Pascal's principle in a dental chair
http://buku-teks.com/sc5226c
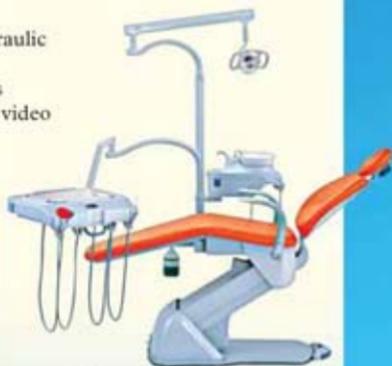
Photograph 8.3
Dental chair

8.1.2

Relationship between Fluid Velocity and Pressure

Study and understand the relationship between fluid velocity and pressure (Figures 8.10 and 8.11).

Figure 8.10 shows that the fluid pressure at P_1, P_2 and P_3 is the same because the fluid is not flowing.
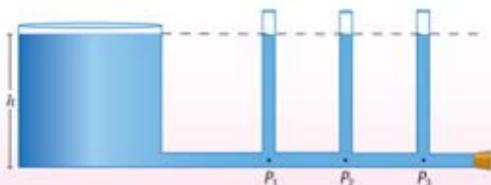

Figure 8.10 Fluid pressure is the same in a fluid that is not flowing

A **Venturi tube** is a non-uniform tube with a narrower centre (Figure 8.11). In Figure 8.11, when the fluid starts to flow, the velocity of the fluid at P_2 is higher than the velocity of the fluid at P_1 and P_3. The narrower the part of the Venturi tube, the lower the pressure in the fluid. This is known as the **Venturi effect**.
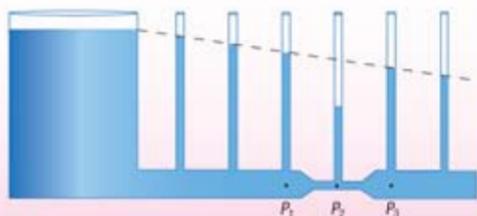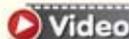

Figure 8.11 The Venturi effect and Bernoulli's principle

When the fluid flows through the narrow part, its velocity increases and the pressure in that region decreases. This is known as **Bernoulli's principle**.

▶ **Video**

Venturi effect and Bernoulli's principle
http://buku-teks.com/sc5227

To explain Bernoulli's principle by using a Venturi tube

Materials
Tap water

Apparatus
Venturi tube, rubber tube and clip

Instructions
1. Carry out this activity in groups.
2. Prepare the apparatus set-up as shown in Figure 8.12.
3. Close the clip. Turn on the tap and allow tubes X, Y and Z to be filled with water.
4. Observe and compare the height of the water level in tubes X, Y and Z.
5. Sketch your observations in figure (a).
6. Open the clip and the tap so that water flows into the sink continuously through the glass tube.
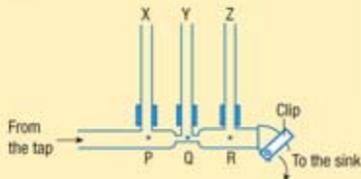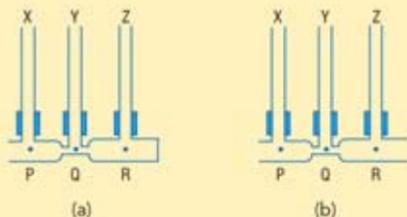7. Repeat step 4. Sketch your observations in figure (b).

Figure 8.12
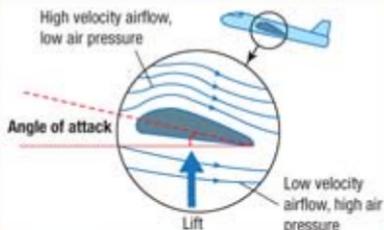
Observations

(a)   (b)

Questions
1. State the relationship between fluid velocity and pressure based on your observations of figures (a) and (b).
2. Name the effect of the change in pressure of the fluid which flows through the narrower part of the Venturi tube.
3. What is the principle shown in the observation in figure (b)?

Application of Bernoulli's Principle in Daily Life

Bernoulli's principle states that a fluid moving at a higher velocity produces a lower pressure in that region.
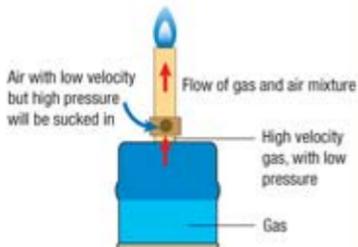
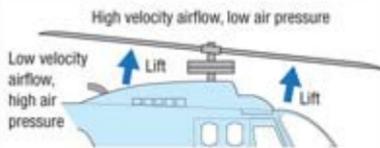8.1.3 8.1.4

Aerofoil-shaped wings of an aeroplane

High velocity airflow, low air pressure

Angle of attack

Lift

Low velocity airflow, high air pressure

The resulting lift on the wing of an aeroplane comes from:
• aerofoil shape
• angle of attack

Bunsen burner

Air with low velocity but high pressure will be sucked in

Flow of gas and air mixture

High velocity gas, with low pressure

Gas

Helicopter

High velocity airflow, low air pressure

Low velocity airflow, high air pressure

Lift

Lift

Drone

High velocity airflow, low air pressure

Low velocity airflow, high air pressure

Lift

Lift
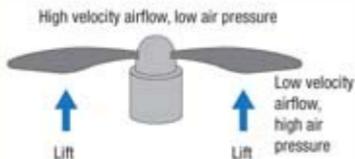
Safety lines near railway tracks at a railway station

High velocity airflow, low air pressure

Force

Low velocity airflow, high air pressure

Safety lines near railway tracks

In the space between a moving train and a person standing near the safety lines, the velocity of the airflow is high and the air pressure is low.

As such, there is a strong possibility for a person who stands beyond the safety lines to be pushed by force towards the moving train. Thus, avoid standing beyond the safety lines.

Figure 8.13 Bernoulli's principle in daily life

8.1.4

To study the application of Bernoulli's principle in daily life

Instructions

1. Carry out this activity in groups.
2. Gather information from the Internet, print media and other electronic media on the application of Bernoulli's principle in various sports such as sailing and windsurfing.
3. Discuss the information gathered.
4. Present the outcome of your group discussion in the form of a report.

Activity · 8.4

21ˢᵗ Century Skills
• TPS, ICS, STEM
• Project-based activity

To design a tool using the principle of pressure in fluids

Instructions

1. Carry out this activity in groups.
2. Design a tool such as a crane to lift heavy loads by using the hydraulic system.
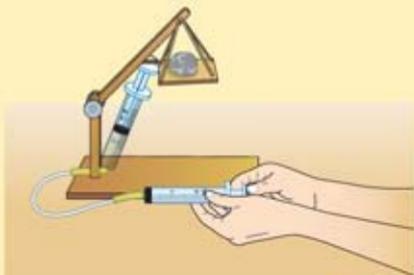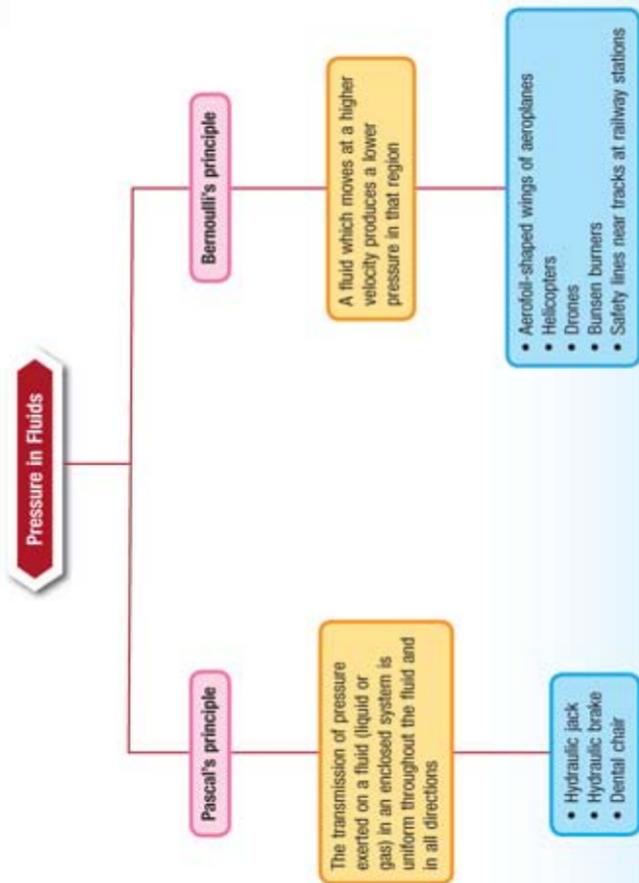3. Present the design of your tool. Discuss how the hydraulic system functions in the design of your tool.

Figure 8.14 An example of a tool design

Formative Practice 8.1

1. State Pascal's principle.
2. State the basic principle of the hydraulic system.
3. Give **three** examples of the application of Pascal's principle in daily life.
4. State Bernoulli's principle.

Summary

Pressure in Fluids

Bernoulli's principle

A fluid which moves at a higher velocity produces a lower pressure in that region

- Aerofoil-shaped wings of aeroplanes
- Helicopters
- Drones
- Bunsen burners
- Safety lines near tracks at railway stations

Pascal's principle

The transmission of pressure exerted on a fluid (liquid or gas) in an enclosed system is uniform throughout the fluid and in all directions

- Hydraulic jack
- Hydraulic brake
- Dental chair

After studying this chapter, you are able to:

8.1 Pressure in Fluids

☐ Explain the concept of pressure in fluids in an enclosed system.
☐ Communicate about the application of Pascal's principle in daily life.
☐ Explain the relationship between fluid velocity and pressure.
☐ Communicate about the application of Bernoulli's principle in daily life.
☐ Design a tool using the principle of pressure in fluids.

Summative Practice 8

Quiz
http://buku-teks.com/sc5232a

Answer the following questions:

1. Figure 1 shows two vehicles moving with the same velocity and producing two different pressures, P_0 and P_1.
   (a) Which pressure is lower?
   (b) Explain your answer in question 1(a).
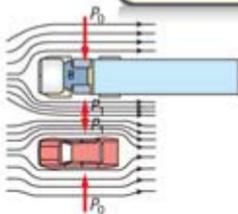   (c) Why is the situation of the two vehicles shown in Figure 1 dangerous? 🧠

Figure 1

Enrichment Practice

2. A dental chair as shown in Figure 2 is an application of Pascal's principle which plays an important role in helping dentists during the dental treatment of their patients. Dental chairs must be easily adjustable for the comfort of both patients and dentists.
   • Build a creative model of a dental chair by applying Pascal's principle.
   • Describe the creative features of your model.
   • Discuss in your group on how the model can be modified into an automated massage chair. 🧠
   • Present your ideas to your class.

Source of reference:
Video on building a model of a dental chair
http://buku-teks.com/sc5232b

Figure 2