CHAPTER 07

Hydrostatics: The Physics of Fluids

7.1 FLUIDS AT REST?

Fluids play a central role in our daily lives. But what are they? We breathe them, we drink them and they flow through our veins. The sea is a fluid; and the atmosphere; and the core of the Earth. In a car, there are fluids in the tyres, the petrol tank, the radiator, the combustion chambers of the engine, the exhaust pipe, the lubrication system and the hydraulic brakes. Medicine, too, relies on an understanding of fluids in action: the pumping of kidney dialysis machines and the anaesthetist using a heart–lung machine, to name just two. The safe movement of fluids is of vital importance to society. Ruptured oil pipelines and blood vessels are reminders of what can happen if the physics of them is neglected. An understanding of the physics of fluids is essential to society.

You probably already know that fluids include liquids and gases — substances that flow. But they are more than just that. In this chapter we will be considering the science of fluids at rest — **hydrostatics**.

Have you ever wondered about these questions concerning fluids:

- Sugar flows out of a packet when I tip it up. Is sugar a fluid?
- Fresh eggs sink in water but stale eggs float. What is happening?
- In England, sandshoes are called 'plimsolls'. Why is this and who was Plimsoll?
- Why is quicksand so deadly? Why can't you get out?
- Could you walk across a tub of mercury? How far down would you sink?
- Why do some scuba divers die when they come up to the surface too fast?
- Car brake fluid strips the paint off cars if it is spilt. Why don't they use water or oil?
- If a doctor said your blood pressure was '120 over 80' would you care?
- Unwanted pets are sometimes killed by 'decompression'. It sounds cruel — is it?

NOVEL CHALLENGE

Long ago people predicted high and low tides based on observed regularities, but they didn't have a theory of tides. Was this science?

What is a fluid?

A **fluid** is a substance that can flow. Gases and liquids can flow — solids can't. Fluids take on the shape of any container in which they are put. Some materials such as pitch take a long time to flow, but eventually they do, so we call them fluids. Glass in medieval windows is now thicker at the bottom than at the top because it has slumped a bit. Glass too is a fluid, although a very **viscous** (thick) one. 'Viscous' comes from the Latin *viscum* meaning 'bird-lime'. This was a sticky gum applied to branches to trap bird pests in orchards. Of liquids, the least viscous is liquid helium (–270°C), which is so mobile that it creeps up and over the sides of its container.

But maybe everything will flow eventually so maybe everything is a fluid! What's the point of distinguishing between fluids and solids? The point is: no, not everything is a fluid. Ice isn't, steel isn't, bricks aren't. A fluid is a system of particles loosely held together by their own attractive forces or by the restraining forces exerted by the walls of the container. A fluid

Photo 7.1
Pitch drop experiment. Professor John Mainstone of the Department of Physics at the University of Queensland, with the current pitch drop about two years after the previous drop.

will flow even if the forces are very weak. A solid will not flow at all unless the applied forces are in excess of some threshold value. Pitch and glass are fluids of high viscosity. Even if the force is small they will flow, although very slowly. (See photo of pitch drop experiment on previous page.) However, in practical and useful terms, we can think of fluids as being substances that can be pumped along pipes.

PRESSURE 7.2

When a fluid is placed into a container it exerts a force on any surface exposed to it. The magnitude of this force divided by the area over which the force acts is called **pressure**.

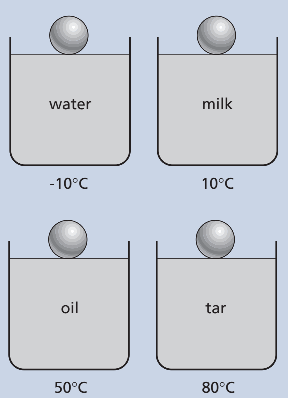
$$\text{Pressure} = \frac{\text{force}}{\text{area}} \qquad P = \frac{F}{A}$$

NOVEL CHALLENGE

In setting the world record for a bed of nails, a 60 kg man lay down on 259 nail points in a 30 × 45 cm board. The contact area for each nail with his skin was 10 mm^2. Then a 268 kg weight was placed on top of him. Calculate the pressure of the nails on his skin.

NOVEL CHALLENGE

Which of the following ball bearings will fall most slowly?



NOVEL CHALLENGE

You can exert a force of 250 N with your incisor teeth and 1220 N with your molars. *Which do you estimate to produce the higher pressure?* Note: *your front incisors are about 8 mm × 0.2 mm and your molars are about 8 mm × 8 mm.*

If the force is in newtons (N) and the area in square metres (m^2), the pressure is in **pascals** (Pa). One pascal equals one newton per square metre. Although pressure is defined in terms of a vector quantity, it is not a vector quantity itself. The unit *pascal* was named after the French scientist and mathematician **Blaise Pascal** (1623–62). Pascal suffered from a condition known as a soft fontanelle, in which the cartilage between the bones of the skull never properly hardened. This gave rise to migraine headaches so severe that it halted his scientific thinking. Nevertheless he made huge contributions to science and philosophy during his 39 years on Earth. Although to physicists he is best remembered for his work on pressure, in general he is remembered for his remarkable insights in religious thinking, fragments of which are recorded in his book *Pensées*. A computer language has since been named in his honour.

NEI Activity 7.1 HIGH PRESSURE

The *Guinness Book of Records* lists the highest atmospheric pressure ever recorded on Earth as 108.38 kPa in Siberia in 1968. Where was the lowest recorded; what was it and when?

Table 7.1 SOME PRESSURES

	PRESSURE (Pa)
Centre of the Sun	2×10^{16}
Centre of the Earth	4×10^{11}
Highest sustained laboratory pressure	2×10^{10}
Deepest ocean trench	1×10^{10}
Spike heels on dance floor	1×10^{6}
Car tyre	3×10^{5}
Atmosphere at sea level	1×10^{3}
Blood pressure	2×10^{4}
Loudest tolerable sound	30
Faintest detectable sound	3×10^{-5}
Best laboratory vacuum	1×10^{-12}

Example

A person has a mass of 65 kg. The contact area between his shoes and the floor is 315 cm^2. Calculate the pressure he exerts on the floor.

Solution

Force (weight) = mg = 650 N; area = 315 cm^2 = $\frac{315}{100 \times 100}$ m^2 = 0.0315 m^2.

$$P = \frac{F}{A} = \frac{650}{0.0315} = 20\ 600\ \text{Pa}$$

You can have a high pressure without a large force. A chisel (Figure 7.1) has a sharp tip and when a small force is applied it will easily penetrate wood (and your shoe if you drop it). A small force of 1 newton applied to the handle will be transferred to the point and produce a very large pressure. If the point has an area of 10^{-6} m^2, the pressure will be:

$$P = \frac{F}{A} = \frac{1}{10^{-6}} = 10^6\ \text{Pa (1 megapascal)}$$

Because many surfaces cannot stand this pressure, the chisel will penetrate them. Hardwood or pine are good examples.

This concept helps us to understand the action of knives, needles and nails. They work because of the small contact area. On the other hand, army tanks and bulldozers work on the reverse principle — the bigger the surface area of their caterpillar treads, the less likely they are to sink into muddy ground. Four-wheel drive owners will know that this technique can be applied when driving in loose sand on a beach. Tyres can be deflated to half normal pressure to increase the surface area and hence lessen the amount they sink into the sand (Figure 7.2).

NOVEL CHALLENGE

The pressure in an aeroplane's tyre was measured with a pressure gauge at sea level. The plane flew off and landed on a high mountain airstrip. If the temperature was the same as at sea level, how would the pressure gauge reading compare with that at sea level?

Figure 7.1

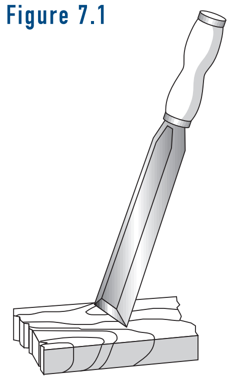
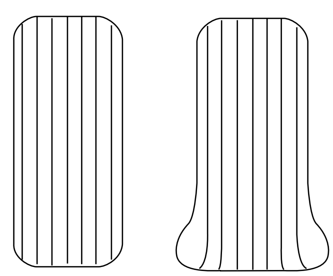


Figure 7.2
In soft sand it often helps to deflate the tyres to about half the normal pressure.



NEI Activity 7.2 ROADS AND TYRES

Roads gradually break up from the constant pressure of passing car and truck tyres. But big trucks are not always the worst offenders as their load is often spread over eighteen or more tyres.

Part A

- Use a ruler to measure the contact area of a bicycle tyre with a flat surface while a person is sitting on the bike. Measure or estimate the total mass of the bike plus rider and calculate the pressure exerted by the tyres on the surface. Assume that half the weight is supported by each tyre.
- Repeat for a car. The mass of the car will be in the owner's handbook. Most cars are between 1000 kg and 2000 kg.

Part B

Rank the following in order of the pressure exerted by the tyres on the road. Include the two results from above.

- A BMX bicycle; mass 20 kg plus rider 45 kg; contact area 10 cm × 5 cm per tyre.
- A Porsche 911 Carerra, mass 1370 kg, on four tyres, each with a contact area of 15 cm × 20 cm.
- A Landcruiser, mass 2960 kg, on four tyres, each with a contact area of 17 cm × 22 cm.
- A fully laden semi-trailer of mass 42 t; 22 tyres, each with a contact area of 20 cm × 20 cm.

Questions

1 A girl with a weight of 500 N stands in snow on a pair of skis. Each ski has a contact area of 1.5 m × 0.13 m. Calculate the pressure on the snow.

2 Calculate the pressure at the bottom of a round swimming pool of diameter 6.0 m filled to a depth of 1.2 m.

NOVEL CHALLENGE

Four car tyres are inflated to the same pressure. One wheel is jacked up.
How does this change the pressure in the jacked-up tyre and in the other three?