7 Pressure

Videos & questions on the CD ROM

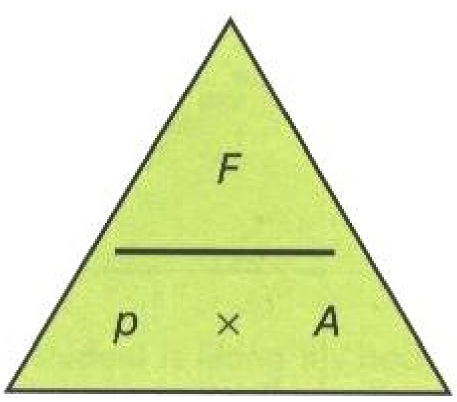
The snowmobile in the picture can travel over soft snow because its weight is spread by the skis over a large area of snow. If the rider got off and stood on the snow, he would probably sink into it up to his knees, even though he is much lighter than the snowmobile.

If a pair of shoes has small heels, the wearer can easily damage a wooden floor by sinking into it. And a drawing pin is pushed into a notice board by the pressure of your thumb.

In every case the question is not just what force is used, but also what area it is spread over. Where there is a large force over a small area, we have a high pressure, and a small force over a large area gives us a low pressure.

Pressure is measured in newtons per square metre (N/m^2), but note that it is often given the special name of pascal (Pa).

In order to measure how 'spread out' a force is, use this formula:



$$p = \frac{F}{A}$$

p = pressure in pascals, Pa (or newtons per square metre, N/m^2)

F = force in newtons, N

A = area in m^2

Note: 1 Pa = 1 N/m^2

WORKED EXAMPLE

What pressure on the snow does the snowmobile make if it has a weight of 800 N and the runners have an area of 0.2 m^2?

Write down the formula:	$p = \frac{F}{A}$
Confirm that F is in N and A is in m^2	
Substitute the values for F and A:	$p = \frac{800}{0.2}$
Work out the answer and write down the units:	p = 4000 Pa
	= 4 kPa

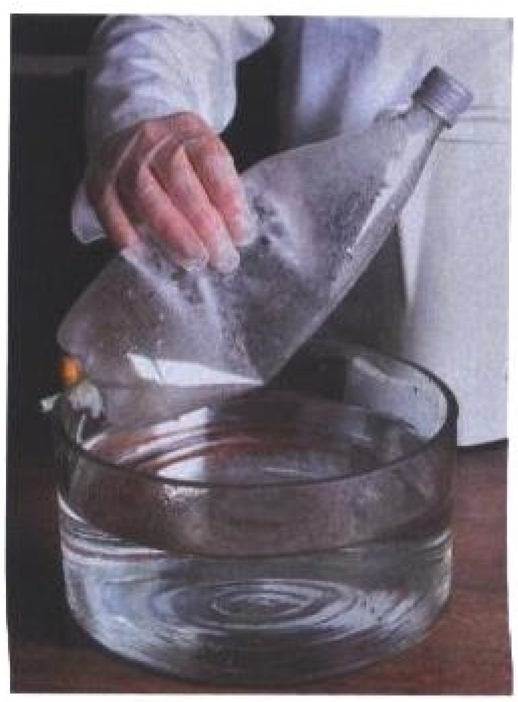
Note that 4 kPa is a very low pressure. If you stand on the ground in basketball shoes, the pressure on the ground will be around 20 kPa. The wheel of a car generates a pressure on the ground of around 200 kPa. Pressures can be quite high, and so the kPa is often used.

ATMOSPHERIC PRESSURE

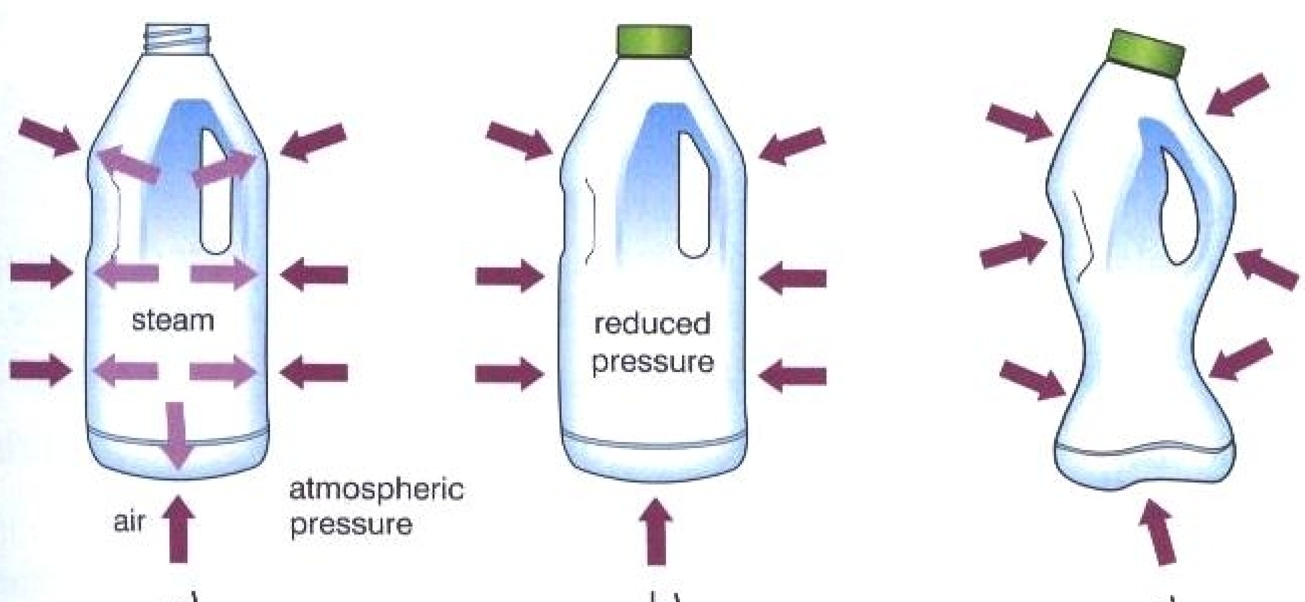
Because we have spent all of our lives living in the atmosphere of the Earth, we seldom think that we have 20 km or so of air pressing on us. We do not feel the pressure because it does not just push down, it pushes us inwards from all sides. Our lungs do not collapse, because the same air pressure flows into our lungs and presses outwards. It would be a very different story if our lungs did not contain any air and there was a vacuum inside them.

We can show this by seeing how a plastic bottle collapses if the air is removed from it.

The plastic bottle is filled with steam from a kettle so that the air in it is replaced by the steam. The lid is screwed onto the bottle, and the bottle is cooled by immersing it in cold water. When the steam turns back into water, the bottle collapses due to the pressure of the air outside.



Warning: steam from a kettle is extremely dangerous, and much more so than boiling water. You must never put your hands near the steam coming out of a boiling kettle, and you must not perform this experiment without suitable safety equipment and training.

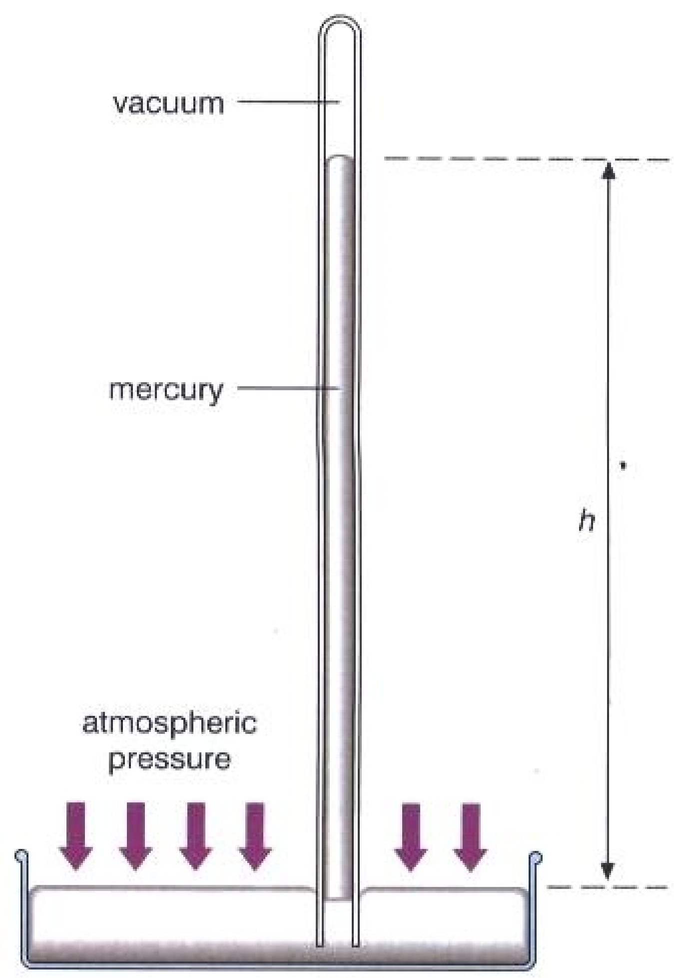


a) Bottle with same pressure inside and out. The pressure inside is from steam at atmospheric pressure.
b) Bottle with internal pressure removed. You can do this with a strong metal bottle, but not with a plastic one.
c) Plastic bottle collapsed.

Atmospheric pressure is approximately 100 kPa. This value is a pure coincidence. In fact it is around 101.3 kPa, though it increases and decreases by 5 per cent or so depending on the weather. But in the same way that we often take g to be 10 m/s^2 on the Earth when it is more accurately 9.8 m/s^2, we often choose to take atmospheric pressure to be 100 kPa.

Pressure is also measured in bar and millibar. Normal atmospheric pressure is approximately 1 bar. The pressure on a scuba diver's cylinder of air can easily be 200 bar. You will see millibar used in some weather forecasts. Atmospheric pressure is approximately 1000 mbar.

THE MERCURY BAROMETER



The mercury barometer is made of a glass tube, sealed at the top. It contains mercury, and the base of the tube dips into a beaker, and below the surface of the mercury in the beaker.

Atmospheric pressure pushes down on the mercury in the beaker, which in turn pushes mercury up the tube.

If the space above the mercury in the tube is a vacuum, then nothing is pushing down on the top of the mercury in the tube, and atmospheric pressure will push the mercury up until the pressure of the column of mercury balances the atmospheric pressure. The height h from the top of the mercury in the beaker, to the top of the mercury in the tube can be used to calculate atmospheric pressure.

This height h is approximately 760 mm of mercury, and in some countries atmospheric pressure is still quoted in mm of mercury.

Note that mercury has a convex (curved-upwards) shape when in contact with glass. You should measure to the top of the mercury in the tube, and to the flat surface of the mercury in the beaker.

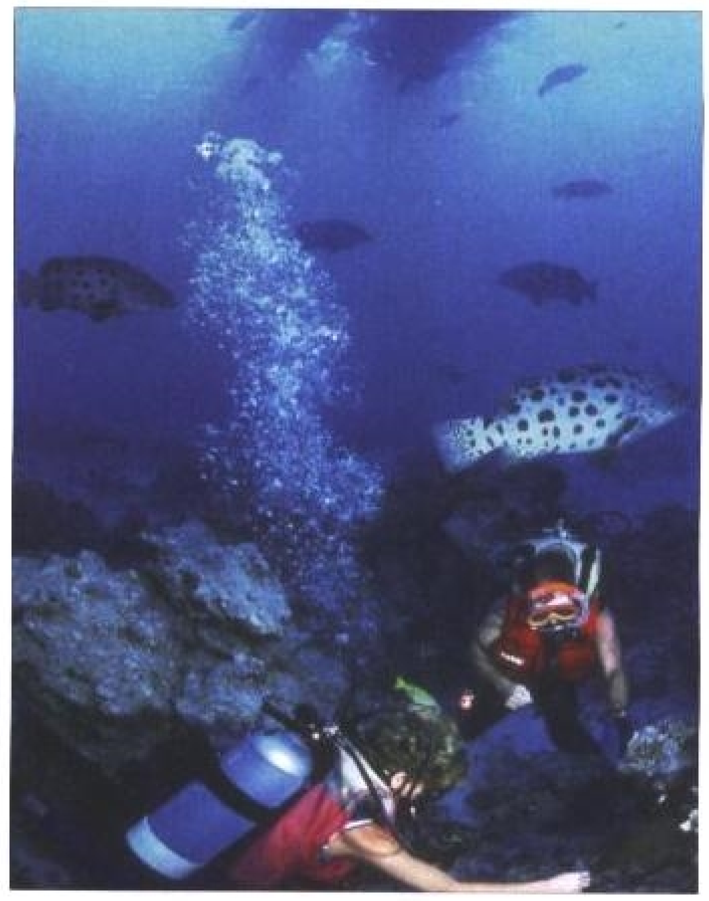
Mercury barometers are no longer made because mercury is a highly poisonous metal with a poisonous vapour.

PRESSURE AND DEPTH

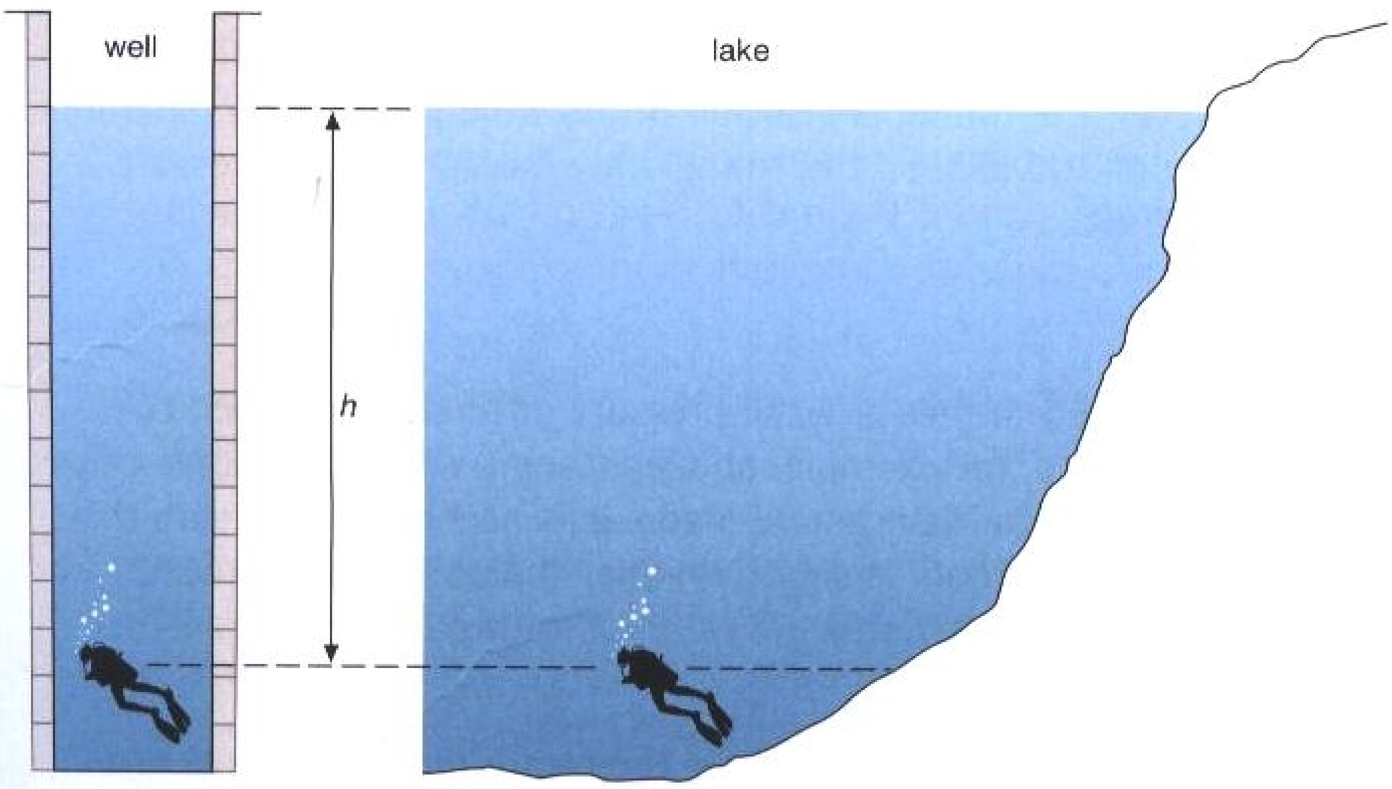
If you dive below the water, the height of the water above you also puts pressure on you. At a depth of 10 m of water, the pressure has increased by 100 kPa, and for each further 10 m of depth the pressure increases by another 100 kPa. The rapid increase in pressure explains why scuba divers cannot go down more than 20 m without great difficulty.

The hull of a submarine is made very strong so that the submariners can breathe air at the normal pressure.

The increase in pressure below the surface of a liquid depends on (a) the depth below the surface and (b) the density of the liquid. So the pressure will be much higher at a certain depth below the surface of mercury than it is below the surface of water. It does not depend on anything else, and note in particular that the pressure does not depend on the width of the water. If a diver goes to inspect a well, the pressure 10 m below the surface is the same as the pressure 10 m below the surface of a large lake. This explains why an engineer who is designing a dam needs to make it the same thickness whether the lake that has to be held back is 100 km long or only 100 m long.



These scuba divers breathe compressed air at high pressure to prevent their lungs collapsing due to the high pressure from the water above them. This is a safe sport, but only because novices are trained to a very high standard.



The pressure on the diver is the same in the well and in the lake. In both cases it depends only on the density of the liquid and his depth, *h*.

The pressure below the surface of a fluid, and in fact between any two points in the fluid can be calculated by the following equation:

pressure difference = height × density × strength of the gravitational field

$$p = h \times d \times g$$

p = pressure difference in pascals (Pa)

d = density in kilograms per cubic metre (kg/m^3)

g = acceleration of free fall (m/s^2)

Note that the density d must be in kg/m^3. If it is quoted in g/cm^3, you must convert it.

Scientists often use the Greek letter ρ for density, and write the above equation as

$p = h\rho g$

Note that there is one major cause of confusion. Consider the pressure on a scuba diver. Before he jumps in, the pressure on him is already 100 kPa (or 1 bar). When he has dived down 10 m, the pressure on him increases by 100 kPa, so the total pressure on him is now 200 kPa (2 bar). The pressure is coming 100 kPa from the air above him, and 100 kPa from the water above him. At 20 m, the total pressure on him is 300 kPa, and so on.

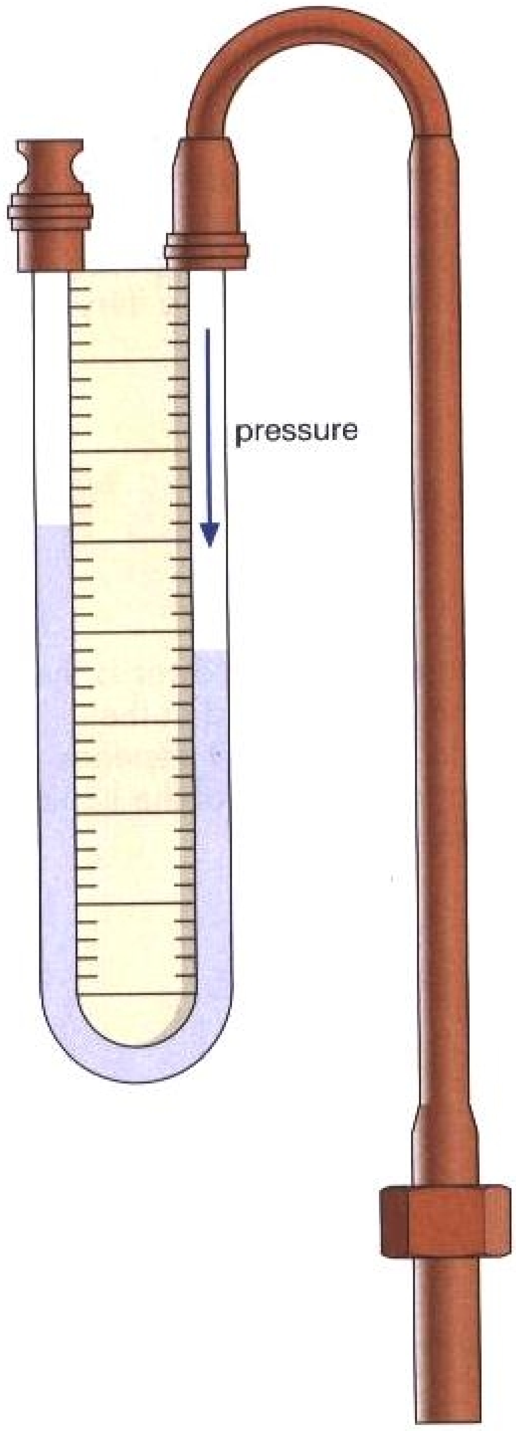
WORKED EXAMPLE

An aquarium in a 'sea life' centre has a tunnel through a tank of water at a depth of 5 m below the surface. The manufacturer guarantees the tunnel to a pressure difference of 200 kPa. Is the tunnel safe?

Write down the equation:	$p = h \times d \times g$
Substitute the values into the equation:	$p = 5 \times 1000 \times 10$
Work out the answer and write down the unit:	$p = 50\,000$ Pa
	= 50 kPa.

The tunnel is safe.

Note that the total pressure on the outside of the tunnel is 50 kPa from the water, plus 100 kPa from the air pushing on top of the water, giving 150 kPa. However, the tunnel is also full of air, which is pushing outwards with a pressure of 100 kPa. So the tunnel only has to stand a pressure difference of 50 kPa.



This manometer is used to measure the pressure in the supply of heating gas to a building. The U tube is filled with water and the height difference is measured. The pressure should be about 3000 Pa above atmospheric pressure, which is a height difference of 0.3 m. The gas won't burn properly if the pressure is wrong.

THE MANOMETER

Manometers are used to measure the pressure difference between two regions. They are used, for example, on cleanrooms where computer chips and other semiconductor devices are made. It is necessary to ensure that the pressure inside the room is slightly higher than outside in order to prevent dust finding its way into the cleanroom through small gaps in the wall.

A manometer is mounted on the wall of the cleanroom. It consists of a tube of plastic or glass, bent into the U shape shown, and filled with a liquid that is often oil. If there is a pressure difference between the ends of the manometer, the liquid moves until the pressure difference is balanced by the *difference* in height of the ends of the liquid. The greater the pressure, the greater the difference in height. You will note immediately that the liquid will be blown out if the pressure difference is too great.

Oil is often used rather than water because water evaporates and also because oil, being less dense, makes the manometer more sensitive: for the same pressure difference, the oil will move further.

The pressure difference between the two regions is given by the following equation:

$\Delta p = hdg$

This is basically the same equation as $p = h \times d \times g$.

WORKED EXAMPLE

The manometer on an industrial machine shows that the oil is being pushed towards the machine and the height difference, h is 20 cm. What is the pressure inside the machine if the pressure outside is 100 kPa? The oil has a density of 800 kg/m^3.

Write down the equation:	$\Delta p = hdg$
Substitute the values into the equation:	$\Delta p = 0.2 \times 800 \times 10$
Be sure to convert the height, h into m:	20 cm = 0.2 m
Work out the answer and write down the unit:	$\Delta p = 1600$ Pa
	= 1.6 kPa

The pressure inside the machine must be lower than atmospheric pressure.
Therefore the pressure inside the machine = (100 − 1.6) kPa

= 98.4 kPa

A manometer.

REVIEW QUESTIONS

Q1 Calculate the pressure generated by an ordinary shoe heel (person of mass 40 kg, heel 5 cm x 5 cm), an elephant (of mass 500 kg, foot of 20 cm diameter) and a high-heeled shoe (person of mass 40 kg, heel of area 0.5 cm^2). Which ones will damage a wooden floor that starts to yield at a pressure of 4000 kPa?

Note that to convert from cm^2 to m^2 you need to divide by 10 000.

Q2 The pressure gauge on a submarine in a river was reading 100 kPa when it was at the surface. If a sailor notices that the gauge is now reading 250 kPa, how deep is he? How would the answer change if he were diving in seawater that is slightly denser than fresh water?