Pressure

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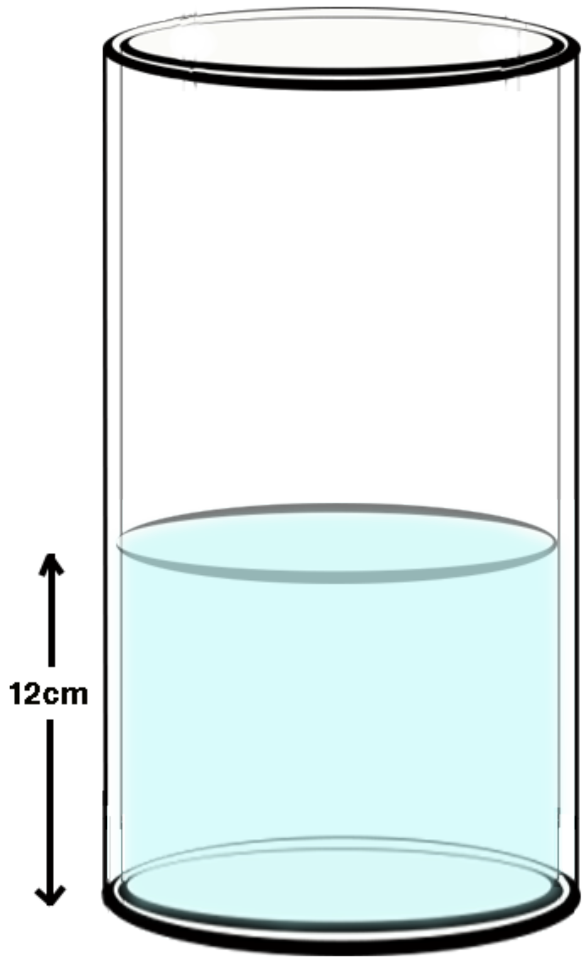
When you go down to the bottom of a swimming pool the weight of water above you compresses your body. You might not notice that if the pool is only a metre deep, but you will feel it if you can get down to five metres. We say that *pressure* rises as we go deeper into water. To understand what pressure is, and how to calculate it, we draw a diagram that corresponds to the glass cylinder featured in the article on buoyancy (link below).



A weight of 12 cm of water pushes down on the base, of area A.

The weight of water is the density ρ times the volume V. So that we may calculate this force anywhere, for any liquid, in any cylinder, we write an equation with symbols.

The force is the weight of water.

$$F = mg \quad \text{… the mass of water times g.}$$

The mass of water is the density ρ times the volume V.

$$F = \rho g V$$

$$= \rho g h A \quad \text{… where } h \text{ is the depth.}$$

We can calculate the force if we know the density of the liquid ρ, the value of g where we are, the depth of the liquid in a cylinder h, and the area of the base A.

To get the answer in newtons the density must be in kilograms per cubic metre (1000 for water), g must be in newtons per kilogram (10 on earth), the depth h was 0.12 metres in our example and the area of the base (that we calculated using πr^2) is 0.017 square metres.

$$1000 \times 10 \times 0.12 \times 0.017 = 20.4 \text{ newtons}$$

To two significant figures the answer is 20 N, the balance reading for the weight of water in the cylinder (see *Buoyancy*).

Pressure is defined as Force over Area. Dividing both sides of the equation above by A gives the pressure as …

$$P = \rho g h$$

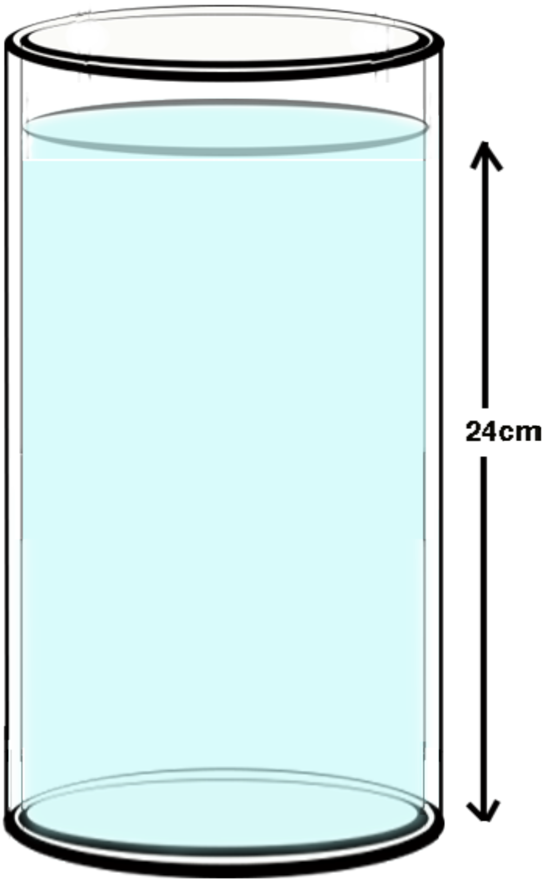
Pressure in *water* on *earth* depends only on the depth h.

The pressure at the bottom of the water in our example is …

$$P = 1000 \text{ x } 10 \text{ x } 0.12 = 12000 \text{ N/m}^2$$

The unit of pressure, newtons per square metre, is called the Pascal.

Suppose the depth of water in the cylinder is doubled.



The pressure at the bottom of the water is given by ρgh as before.

$$P = 1000 \text{ x } 10 \text{ x } 0.24 = 24000 \text{ Pascals}$$

Pressure at the bottom is doubled when the depth is doubled.
Supposing water in a high board diving pool is 10 metres deep.

The pressure at the bottom due to the water above is ρgh.

$$P = \rho gh = 1000 \text{ x}10 \text{ x } 10$$

$$= 100\,000 \text{ Pascals.}$$

That pressure is *one atmosphere*, the pressure due to the weight of the air above the surface of the earth.

When this was first studied and explained by Italians 300 years ago it caused arguments. Scientists of the day did not believe air had weight. With a plastic coke bottle, a pump, and an accurate gram balance the mass of air per litre can be found, (link below) but in 1700 that was not easy to do.

Suppose air has a mass of 1 gram per litre. That figure is a bit low, but it's close enough for now. Putting that into kilograms per cubic meter by multiplying by1000 and dividing by 1000 makes the density of air as about *one kilogram per cubic meter*. That's true, but I don't expect you to believe that without reading the linked article.

Suppose air was at ground-level density all the way up and then suddenly ended, like water in a lake, not the real atmosphere that gets thinner and thinner with altitude.

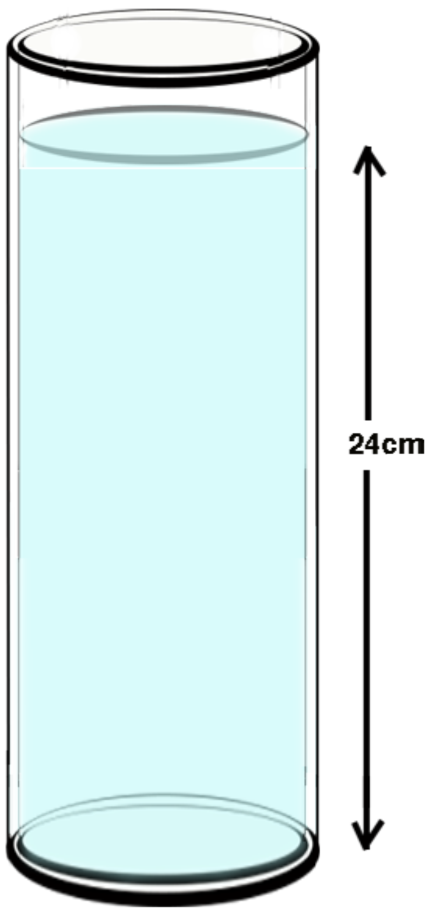
How deep is this imaginary uniform atmosphere?

$$P = \rho gh$$

So … $h = P/\rho g = 100\,000/(1\text{x}10) = 10\,000$ meters (10 km)

Now: the radius of the earth is 6400 km. What is the mass of the atmosphere? Physics can be quite clever sometimes.

If the area of the base of the cylinder is halved the force on the bottom is halved, but the pressure at the bottom remains the same.



The pressure at the bottom = $\rho g h$

= 1000 x10 x 0.24 = 24 000 P

The pressure two metres down in a lake, in a swimming pool, and in the fish tank at right is the same.

The pressure two metres down in sea water is a little higher because dissolved salt increases the density of sea water.

Breathing under water

If you take along hose down the bottom of a swimming pool and try to breath through it you will find that you can't draw air into your lungs. If you are scuba diving you have a regulator and you are breathing air at the combined pressure of the air and the water above you.

A serious condition called the "bends" can affect divers who surface too quickly. Too long at depth under water causes nitrogen to dissolve in the blood and body tissues. Surfacing too quickly allows nitrogen bubbles to expand in the bloodstream and tissues, causing pain and damage. In an extreme case death may follow. A diver with the bends can be put in a compression chamber for hours to allow the dissolved gas to escape very slowly.

Sperm whales and other marine mammals can dive to great depths and resurface without damage. How exactly they are able to do this has puzzled scientists for many years.

https://commons.wikimedia.org/wiki/File:Mother_and_baby_sperm_whale.jpg#file

If you are interested you could search the web for the latest findings.