Workshop Tutorials for Introductory Physics

Solutions to PI1: **Pressure**

A. Review of Basic Ideas:

Under pressure

If the pressure of the air inside a car tyre is equal to atmospheric pressure, the tyre is flat. The pressure has to be **greater** than atmospheric to keep the tyre firm, and the significant quantity is the pressure difference between the inside and outside. When we say that the pressure in a car tyre is 220 kPa, we mean that it is greater than atmospheric pressure (101 kPa) by this amount This is called a **gauge** pressure. The total pressure, called the absolute pressure, is 321 kPa. A pressure of 321 kPa acting on a surface of 1.0 m^2 will produce a force of **321kN**.

The compressed air, inside a car tyre, exerts an outward **force** on the inner surface of the car tyre. The direction of the outward force is always **perpendicular** to the inner surface of the car tyre. Thus at the top of the tyre the force is upwards and at the bottom it is downwards. This keeps all the surfaces of the car tyre firm.

The pressure difference, ΔP, between two points in a fluid is $\Delta P = \rho g \Delta h$ where g is the acceleration due to gravity, ρ is the density of the fluid and Δh is the height difference between the two points. In human beings, there is a difference in pressure between the blood at the feet and the heart. In the reclining position, the head, heart and feet are at the same elevation and the pressures are the same. For a standing adult whose heart is 1.30 m above his feet the pressure difference is:

$\Delta P = \rho_{\text{blood}}\, g\, \Delta h$

$= 1060 \text{ kg.m}^{-3} \times \mathbf{9.8 \text{ m.s}^{-2}} \times 1.30 \text{ m}$

$= 1.35 \times 10^4 \text{ Pa} = \mathbf{13.5 \text{ kPa}}$

So the blood has to be "pumped uphill" from the feet to the heart. This is achieved by one way valves and the squeezing of veins during walking. Note that this is a first approximation, the actual processes are much more complicated.

B. Activity Questions:

1. Suction cups and Magdeburg plates

The suction cup must have the air squeezed out of it and make a complete seal with the surface to stick to it. If the seal isn't complete, air can enter the cup, removing the pressure difference and allowing the cup to fall off.

The Magdeburg plates are hard to pull apart when there is a vacuum between them, but easy to pull apart when there is air. A fluid exerts a force perpendicular to a surface it comes in contact with: $F=PA$. If there is a difference in pressure across a surface this results in a net force which is directed from the region of greater to lower pressure. In the case of the Magdeburg plates, when air is removed from the region between the plates the pressure between the plates is less than the atmospheric pressure outside the plates. This difference in pressure results in a net force inwards, holding the plates together.

2. Hydrostatic paradox

The containers have different masses (because they contain different amounts of water), so they must have different weights.

Another argument goes as follows: the pressure is the same at the bottom of each container (because they are filled to the same height). But they all have the same base area, so the force experienced by the base of each container is the same. Therefore, they should all give the same reading on the scale. This second argument is wrong because we have only considered the force of the water on the base of the containers. When calculating the force of the water on the container, we must include the forces on the sides, which may have a component in the vertical direction.

3. Squirting

The water will come out perpendicular to the container wall, as this is the direction of the net force.
In each of these activities the liquid is held in by the low pressure in the tube or bottle. When this pressure is increased to atmospheric pressure, by opening the lid or removing the finger, the water will come out.

4. Hollow tube and disc

The disc stays attached when there is a pressure difference exerting a force which holds it in place. When the pressure difference decreases such that the force falls below *mg* of the disc, the disc falls.

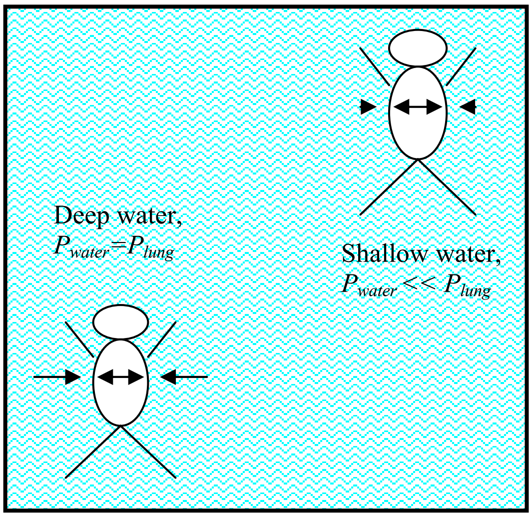
C. Qualitative Questions:

1. Absolute and gauge pressures.

a. Blood pressure is a measure of pressure above atmospheric, it is a relative or *gauge* pressure.

b. Atmospheric pressure is the only absolute pressure given here, both blood pressure and tyre pressure are gauge pressures, i.e. pressure above atmospheric.

c. You are told not to hold your breath when surfacing because as you get higher, the external pressure from the water decreases. The air in your lungs exerts a pressure outwards on your lungs, while the water outside you exerts an inward pressure. As you rise and the water pressure decreases, the air in your lungs is able to expand. If there is too much air in them pushing outwards, and not enough pressure outside them, they could rupture!



d. You are issued with lead belts and inflatable packets to adjust your buoyancy; lead to make you more dense, allowing you to sink, inflatable packets to make you less dense, allowing you to float.

2. Reservoir walls and water depth.

a. Pressure increases as depth as $P=\rho gh$. Pressure = (force/area) so the wall needs to withstand greater force at the bottom, hence it is built to be thicker at the bottom.

b. Changing the surface area does not change the pressure because it does not change the depth, hence there is no need to further reinforce the wall.

D. Quantitative Question:

Giraffe's blood pressure.

a. The heart needs to pump blood up by 2.5m, again using $P=\rho gh$,
$P=\rho gh$ = 1060 kg.m^{-3} × 9.8 m.s^{-2} × 2.5 m = 26 kPa. This is the minimum pressure the heart must supply to get blood to the brain, in practice it would need to be a bit higher to get it to circulate once there.

b. When the giraffe drinks he will have **double** this pressure at his head if the heart is still supplying this pressure.

c. If he didn't bend down and thus lower his heart with respect to his head, he'd get a terrible headache (at least) from the high pressure at his head, and possibly burst capillaries. Fortunately the giraffe compensates for the pressure changes by having very tight skin on his legs and strong blood vessels. The heart also adjusts its pressure to suit the giraffe's posture.