Pressure in a Fluid

Researchers use submarines and robots to explore the bottom of the ocean. The deepest point in the Earth's oceans is the Challenger Deep at the southern end of the Mariana Trench in the Pacific Ocean, almost 11 km beneath the water's surface. Equipment used this deep underwater needs to be able to withstand extremely high pressures.

The Newcastle-based company Tyne Subsea has nine hyperbaric test chambers. These are used to pressure-test products which will be used underwater.

Image courtesy Tyne Subsea / British Engines

Hyperbaric testing facility developed by British Engines/Tyne Subsea and Newcastle University

Their biggest test chamber can simulate water depths to 4500 metres, producing a pressure of up to 45 000 kPa. Testing scientific equipment in this manner is the only way to make sure it will work reliably when it is operating in the depths of the ocean.

Know

1. What is a fluid?
2. Name the unit used to measure pressure.
3. Describe and explain what happens to atmospheric pressure as altitude increases.
4. Describe and explain what happens to the pressure in a liquid as the depth increases.

Apply

5. Atmospheric pressure at ground level is about 101 kPa. Calculate the force exerted by the air on a car roof which has an area of 2.25 m^2.
6. A gardener collects rainwater in a plastic tank which is 75 cm wide, 75 cm long, and 150 cm tall. Calculate the pressure on the base of the tank when it is full of water. Take the density of rainwater to be 1000 kg/m^3.
7. A research submarine can withstand a maximum pressure of 40 180 kPa. Deduce the maximum depth to which the submarine can safely dive. Take the density of seawater as 1025 kg/m^3.

Extend

8. The research submarine in question 7 has a small circular window with a diameter of 5 cm. The pressure inside the submarine is 101 kPa. What is the resultant force acting on the submarine window?

Mark Scheme: Pressure in a Fluid

1. Liquids and gases are fluids: materials which flow and take the shape of their container.
2. Pascals, Pa.
3. Words to the effect of: Air molecules colliding with a surface create atmospheric pressure. The number of air molecules (and so the weight of air) above a surface decreases as the heigh of the surface above the ground increases. So as height increases thee is always less air above a surface than there is at a lower height. So atmospheric pressure decreases with an increase in height.
4. Words to the effect of: Pressure increases because the eight of (the column of) liquid above a surface in the liquid increases with depth.
5. Rearrange: $P = \dfrac{F}{A}$

$$\begin{aligned} F &= P \times A \\ &= 101\,000 \times 2.25 \\ &= 227.25 \text{ kN} \\ &= 227 \text{ kN} \;\; \text{(to 3 sf.)} \end{aligned}$$

6. Use of $P = \rho g h$ to give:

$$\begin{aligned} P &= 1000 \times 9.8 \times 1.5 \\ &= 14\,700 \text{ Pa} \\ &= 15 \text{ kPa} \;\; \text{(to 2 sf.)} \end{aligned}$$

Alternatively, calculation to find:

$$\begin{aligned} \text{Volume of tank } &= 0.75 \times 0.75 \times 1.5 \text{ m}^3 \\ &= 0.843\,75 \text{ m}^3 \end{aligned}$$

Then rearrange $\rho = \frac{m}{V}$ to find :

$$\begin{aligned} \text{mass of water } &= 1000 \times 0.843\,75 \\ &= 843.75 \text{ kg} \\ \text{weight of water } &= 843.75 \times 9.8 \\ &= 8268.75 \\ &= 8300 \text{ N} \;\; \text{(to 2 sf.)} \end{aligned}$$

Finally:

$$\begin{aligned} \text{Pressure on base } &= 15\,000 \text{ Pa} \\ &= 15 \text{ kPa} \;\; \text{(to 2 sf.)} \end{aligned}$$

7. Rearrangement of $P = \rho g h$: $h = \frac{P}{\rho g} = \frac{40\,180\,000}{(1025 \times 9.8)} = 4000 \text{ m} = 4 \text{ km}$
8. Calculation to find:

$$\begin{aligned} \text{area of window } &= 7.85 \times 10^{-3} \text{ m}^3 \\ \text{Resultant pressure } &= (40\,180 - 101) \text{ kPa} \\ &= 40\,079 \text{ kPa} \\ \text{Force = pressure} \times \text{area } &= 40\,079 \times 10^3 \times 7.85 \times 10^{-3} \\ &= 315\,000 \text{ N} \\ &= 315 \text{ kN} \end{aligned}$$