L7b: Am I getting it #1?

Some things you may need for this quiz:
Mass density: Air (at 20°C) = 1.4 kg/m³
Fresh water (at 20°C) = 1000 kg/m³

1. What is the mass of the air in this room? Assume dimensions of 15x20x40 meters. Pick closest answer. (Does the magnitude of your answer make sense?)

(a) 0.15 kg
(b) 0.5 kg
(c) 1.5 kg
(d) 15 kg
(e) 15000 kg

\[ \frac{1.4 \text{ kg}}{\text{m}^3} \times 12000 \text{ m}^3 = 17,000 \]

2. The pressure outside of a window onboard the space station is zero, while the pressure inside is 1 atm = 101.5 kPa (or 101,500 Pa). If the window has an area of 0.5 m², what is the net force on the window? (Pick closest answer)

(a) 50 N
(b) 500 N
(c) 1500 N
(d) 5000 N
(e) 50000 N

\[ F = |(P_{\text{out}} - P_{\text{in}})A| \]

\[ F = 50,700 \text{ N} \]
Physical Sciences 2: Lecture 7b

Demo: Liquids are incompressible
Density of a gas: \( 1.4 \text{ kg/m}^3 \)
Density of a liquid: \( 1000 \text{ kg/m}^3 \)

Demo: water does not compress -- using a flask filled with water as a hammer

Activity 1A: atmospheric pressure

1. The air is completely evacuated from a 55 Gallon drum with a pump. The drum has a height of 90 cm and a diameter of 60 cm. With an atmospheric pressure of 101.5 kPa, what is the force applied by the atmosphere on the top of the evacuated drum?

\[
F = PA
\]

\[
F_{\text{net}} = P_{\text{out}}A - P_{\text{in}}A = (P_{\text{atm}} - P_{\text{in}})A = 29000 \text{N}
\]

\[\frac{101.5 \text{kPa}}{101.5 \text{kPa}} \times 0.3 \text{m}^2 = 30 \text{ kPa} \times 0.3 \text{m}^2 = 9 \text{kPa} \times 0.3 \text{m}^2 = 27 \text{ N} \]

Activity 1B: Pascal's principle

Pascal's principle: If the pressure at one point in a fluid is changed, the pressure is changed by the same amount at any other point in the fluid.

Also useful: The pressure is the same at all points along a horizontal line in a static fluid.

1. In the figure (below left), is the pressure higher at point B or point A. Explain

![Same pressure at A and B](image)

2. A car that weighs 10000N (2250 lbs) is raised with a hydraulic lift, as shown below. The area of the small piston is \( A_1 = 5 \text{ cm}^2 \) while the area of the larger piston supporting the car is \( 200 \text{ cm}^2 \). Which force \( F_2 \) is needed to lift the 2250 lbs car?

\[
\frac{F_1}{A_1} = \frac{F_2}{A_2}
\]

\[
F_1 = \frac{A_1}{A_2} F_2 = 50 \text{ lbs}
\]

\[
2250 \text{ lbs} = \frac{200 \text{ cm}^2}{5 \text{ cm}^2} = 45 \text{ cm}^2
\]

\[
F_1 = PA_1 = 45 \text{ cm}^2 \times 200 \text{ cm}^2
\]

![Hydraulic lift diagram](image)
Activity 2: pressure increases with depth

Pressure in a fluid (e.g. water) increases with depth. You’ve all experienced this while swimming under water. In this activity you will derive the following expression for the fluid pressure as a function of depth: \( P_1 = P_0 + \rho gh \)

1. **Draw a free body diagram of the parcel of water.** The parcel of water is a rectangular cell of water with volume = \( Ah \). The pressure applied to the top surface is \( P_0 \), the pressure applied to the bottom surface is \( P_1 \), and the side pressure is \( P_i \). (Hint: Use \( F = PA \))

2. **Write down Newton’s 2nd law (\( \sum F = ma \)) and solve for the pressure \( P_i \) at the bottom surface of the cube.**

\[
\sum F_y = ma_y \\
F_{bot} - F_{above} - F_g = 0 \\
P_i A - P_0 A - mg = 0 \Rightarrow P_i A - P_0 A - \rho_w A h g = 0
\]

3. At which depth will a scuba diver experience a pressure of 2 atm? Note: 1 atm = 101.5 kPa

\[
\rho \Delta P = \rho g h \\
1000 \text{ kg/m}^3 \times (1 \text{ atm} - 2 \text{ atm}) = \rho g h \\
h = 10 \text{ m}
\]

**Bonus:** Imagine a bubble instead of a parcel of water (a bubble with volume = \( Ah \)). We know bubbles rise quickly to the surface of the water. Using the previous result, can you derive the net force that propels this bubble upward? What is its upward acceleration?

*This is an oversimplification, but fun nonetheless.

\[
\sum F_y = ma_y \Rightarrow F_{bot} - F_{exp} - m\text{air}g = m\text{air}a_y \\
(P_i - P_0) A - \rho_{\text{air}} g h = \rho_{\text{air}} m a_y \\
a_y = \frac{(P_i - P_0)}{\rho_{\text{air}} h} - g
\]
Activity 3A: Archimedes Principle

Archimedes Principle: A fluid exerts an upward buoyant force \( F_B \) on an object immersed in or floating on a fluid. The magnitude of the buoyant force equals the weight of the fluid displaced by the object.

\[
F_B = -\rho_{\text{fluid}} V_{\text{displaced}} g
\]

1. Which of the below spheres (cork, aluminum, or lead) experiences the largest buoyant force? Explain

All have same \( F_B \)

2. If the cork is 1/10th the density of water, then what percentage of the cork remains submerged, once it floats to the surface and rests there.

\[
\sum F_y = m g - F_B = 0
\]

\[
-m g + \rho_w V_{\text{disp}} g = 0
\]

\[
-\rho_{\text{cork}} V_{\text{cork}} g + \rho_w V_{\text{disp}} g = 0
\]

\[
\rho_{\text{cork}} V_{\text{cork}} \cdot g + \rho_w V_{\text{disp}} \cdot g = 0
\]

\[
\rho_{\text{cork}} V_{\text{cork}} = \rho_w V_{\text{disp}}
\]

\[
\rho_{\text{cork}} = \frac{\rho_w}{10}
\]

\[
\frac{\rho_{\text{cork}} V_{\text{cork}}}{\rho_w V_{\text{disp}}} = \frac{1}{10}
\]

Bonus

It is found that a person that weighs 947 N when weighed in air and 44 N when weighed underwater.

(a) What is her average density? (b) ...and body fat?

Siri eqn.: % body fat = \( 495 / \text{(average density)} - 450 \), where average density is measured in g/cm\(^3\).

\[
\sum F_y = m g = 0
\]

\[
F_B + F_N - m g = 0
\]

\[
F_N = 947 N
\]

\[
F_B = m g = 903 N
\]

\[
V_{\text{disp}} = 0.092 m^3 = V_{\text{athlete}}
\]

\[
\rho_{\text{athlete}} = \frac{m}{V} = \frac{97 kg}{0.092 m^3} = 1050 kg/m^3
\]

% fat = \( \frac{495}{1.059 \times 10^3} - 450 = 21% \)
Activity 3B: Archimedes Principle

1. A 10660 kg lead sphere with density of 10660 kg/m³ is carried onboard a large ship. If the sphere drops to the bottom of the water, will the water level of the ‘pool’ rise, drop, or stay the same? Support your answer with the proper equations.

**Bonus:** What is the density of a billiard ball if 80% if its volume stands above the liquid mercury? Note: Radius of billiard ball is 6 cm

\[ \text{mg} = F_g \]

\[ V_{\text{ball}} = \frac{m_{\text{mercury}} V_{\text{disp}}}{5} \]

\[ \rho_{\text{ball}} = \frac{m_{\text{mercury}}}{5} = \frac{13600 \text{ kg/m}^3}{5} \]