

Physics 1114: Unit 6 Homework: Answers

Problem set 1

- A rod 4.2 m long and 0.50 cm^2 in cross-sectional area is stretched 0.20 cm under a tension of 12,000 N.
 - The stress is the Force ($1.2 \times 10^4 \text{ N}$) per Area ($0.5 \text{ cm}^2 = 5.0 \times 10^{-5} \text{ m}^2$), so Stress = $2.4 \times 10^8 \text{ N/m}^2$.
 - The strain is $\Delta L/L_0 = (2.0 \times 10^{-3} \text{ m})/(4.2 \text{ m}) = 4.8 \times 10^{-4}$ (unitless ratio)
 - Young's Modulus = stress/strain = $5 \times 10^{11} \text{ N/m}^2$
- A typical value for systolic blood pressure is 120 mm Hg. Converted to other units, this is (a) $1.6 \times 10^4 \text{ N/m}^2$, (b) 0.16 atm, (c) 2.32 lb/in².
- The arm of a record player exerts a force of 0.0098 N (the weight of 1 gram) on a record. If the diameter of the stylus is 0.0013 cm find the pressure on the record groove in N/m^2 and in atmospheres. (Assume a circular cross-section.)

Pressure = Force/Area, so $p = (9.8 \times 10^{-3} \text{ N})/(1.327 \times 10^{-10} \text{ m}^2) = 7.38 \times 10^7 \text{ N/m}^2 = 730 \text{ atm}$
- The downward force (in N) of the atmosphere acting on the top of a table that measures 3.2 m by 1.2 m is calculated from $p = F/A$ or $F = pA = (1.013 \times 10^5 \text{ N/m}^2)(3.84 \text{ m}^2) = 3.9 \times 10^5 \text{ N}$.
 - The total (pressure) force acting upward on the underside of the table is the same magnitude as the downward force. (Actually it is very slightly larger, providing a very small buoyant force on the table. This is because the underside is at a deeper level in the atmosphere, so the pressure is slightly larger.)
- On a day when the atmospheric pressure is 14.8 psi a tire is inflated to 32.1 psi (psi = lb/in²).
 - The absolute pressure is the gauge pressure plus atmospheric pressure:
 $p = p_{\text{gauge}} + p_{\text{atm}} = (14.8 + 32.1) \text{ psi} = 46.9 \text{ psi}$
 - On the following day, when the atmospheric pressure has fallen to 14.6 psi, the pressure gauge read $p_{\text{gauge}} = p - p_{\text{atm}}$, where p is the absolute pressure. If the air in the tire has the same volume and temperature as before, then the absolute pressure inside does not change. The gauge pressure, then, is $p_{\text{gauge}} = (46.9 - 14.6) \text{ psi} = 32.3 \text{ psi}$. (Note that the net outward force on the walls of the tire does increase because the outside pressure is lower but the inside pressure stays the same).
- The contraction of the left ventricle (chamber) of the heart pumps blood into the body. Assuming that the inner surface of the left ventricle has an area of 85 cm^2 ($A = 8.5 \times 10^{-3} \text{ m}^2$) and the maximum pressure in the blood is 120 mm Hg ($p = 1.6 \times 10^4 \text{ N/m}^2$), the total force exerted by the ventricle at the point of maximum pressure is $F = pA = 136 \text{ N}$.

7. The difference in blood pressure between the top of the head and bottom of the feet of a 1.60 m tall person standing vertically can be calculated using the pressure change in a depth of fluid $\Delta p = \rho gh$. Here, the 'depth' is the person's height and ρ is the density of blood ($\rho = 1030 \text{ kg/m}^3$). Thus, $\Delta p = (1030 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(1.60 \text{ m}) = 1.6 \times 10^4 \text{ N/m}^2$. Note that from Problem 2 you found that $1.6 \times 10^4 \text{ N/m}^2 = 120 \text{ mm Hg}$.
8. For water to come out of a faucet, there has to be enough pressure at the incoming pipe to lift the weight of the water column plus pushing against air pressure. In other words, the (absolute) pressure has to be greater than $p_{\text{atm}} + \rho gh = 1.013 \times 10^5 \text{ N/m}^2 + (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)(40 \text{ m}) = 4.93 \times 10^5 \text{ N/m}^2$.

Problem set 2

1. The gauge pressure of the liquid column weight comes from $p_g = \rho gh$. We want $p_g = 60 \text{ mm Hg} = 8.0 \times 10^3 \text{ N/m}^2$, so

$$8.0 \times 10^3 \text{ N/m}^2 = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)h$$

so that $h = 0.81 \text{ m}$.

The blood pressure in the vein ($18 \text{ mm Hg} = 2.4 \times 10^3 \text{ N/m}^2$) is *gauge* pressure (p_g), so the IV bottle has to be raised so that the fluid gauge pressure (ρgh) matches blood pressure: $p_g = \rho gh$, so

$$2.4 \times 10^3 \text{ N/m}^2 = (1000 \text{ kg/m}^3)(9.8 \text{ m/s}^2)h$$

so that $h = 0.245 \text{ m}$.

2. The force from the lift is $F = pA$, where p is the gauge pressure (maximum of 16 atm). (If the interior pressure were given as the absolute pressure, then atmospheric pressure would have to be subtracted out first.) The maximum force, then, is $F_{\text{max}} = p_{\text{max}}(\pi r^2)$ for a circular cross-section. $F_{\text{max}} = (1.62 \times 10^6 \text{ N/m}^2)(2.27 \times 10^{-2} \text{ m}^2) = 3.68 \times 10^4 \text{ N}$. Setting $F_{\text{max}} = mg$ (the weight), we get $m = 3.75 \times 10^3 \text{ kg}$.
3. A 3.0 N force is applied to the plunger of a hypodermic needle. The diameter of the plunger is 1.0 cm and that of the needle 0.20 mm.

(a) To find the force (F_2) at the needle end, we can use the fact that the pressure is the same at both ends: $p_1 = p_2$. Then $F_1/A_1 = F_2/A_2$, where $A = \pi(d/2)^2$.

$$F_2 = \frac{A_2}{A_1} F_1 = \frac{\pi(d_2/2)^2}{\pi(d_1/2)^2} F_1 = \frac{d_2^2}{d_1^2} F_1$$

$$F_2 = \frac{(0.2 \text{ mm})^2}{(10 \text{ mm})^2} (3.0 \text{ N}) = 1.2 \times 10^{-3} \text{ N}$$

(Since the length units cancel out, we don't have to put the diameters into meters, but they do have to be the same units.)

(b) To push fluid into a vein where the (gauge) pressure is 18 mm Hg ($2.4 \times 10^3 \text{ N/m}^2$), we find the plunger force as $F_1 = pA = (2.4 \times 10^3 \text{ N/m}^2)(\pi(5.0 \times 10^{-3})^2 \text{ m}^2) = 0.19 \text{ N}$

4. The force required to raise a 1000 kg block of concrete to the surface of a freshwater lake is less than mg because of the buoyant force (F_B) from being submerged in water. $F_B = \rho_f V$, where ρ_f is the fluid density (1000 kg/m^3) and V is the displaced volume (the volume of the concrete block: $V_b = m_b/\rho_b = (1000 \text{ kg})/(2.3 \times 10^3 \text{ kg/m}^3) = 0.435 \text{ m}^3$). The lifting force, F_{lift} is the weight of the block minus the buoyant force:

$$F_{\text{lift}} = mg - \rho_f V_b = 5.5 \times 10^3 \text{ N}$$

As the block comes out of the water, the buoyant force decreases (less water displaced), becoming zero when the block is completely out of the water. So the force to lift the block becomes equal to its weight ($m_b g = 9800 \text{ N}$).

5. A freight ship has a horizontal cross-sectional area of 3100 m^2 at the water line. When loaded, the ship drops 6.1 m. The amount of drop times the cross-sectional area of the ship gives the increase in the volume of the ship that is below the water line, i.e., the volume of extra seawater that is displaced. The weight of the displaced seawater equals the weight of the load (floating). So the mass of the load is the mass of the displaced water: $m = \rho_f V = \rho_f A h = (1025 \text{ kg/m}^3)(3100 \text{ m}^2)(6.1 \text{ m}) = 1.94 \times 10^7 \text{ kg}$.
6. To find the maximum load, consider what the maximum buoyant force would be. Since the raft floats when there is no load ($F_B = m_{\text{raft}} g$), as weight is added the raft will be pushed farther down into the water. The most it can be pushed is to when it is just submerged and the volume of displaced water equals the volume of the raft. At that point the buoyant force is $F_B = \rho_f V_{\text{raft}} g$ ($\rho_f = 1025 \text{ kg/m}^3$) which balances the weight of the raft and its load: $F_g = m_{\text{raft}} g + m_{\text{load}} g$.

$$F_B = \text{weight of raft and load}$$

$$\rho_f V_{\text{raft}} g = m_{\text{raft}} g + m_{\text{load}} g$$

The weight of the load, then, is

$$m_{\text{load}} g = \rho_f V_{\text{raft}} g - m_{\text{raft}} g$$

The raft has a volume of 7.49 m^3 . The weight of the raft is $mg = \rho_{\text{wood}} V g = (130 \text{ kg/m}^3)(7.49 \text{ m}^3)(9.8 \text{ m/s}^2) = 9.54 \times 10^3 \text{ N}$. Plug these values in above and get the weight of the load as $6.57 \times 10^4 \text{ N}$, or a mass of 6700 kg .

7. A uniform cube of wood is 0.25 m on each edge. It is floating in pure water with its upper surface 0.07 m above the surface of the water. To determine the density of the wood, we must find the mass of the block. (We know that the volume is $V = l^3 = 1.56 \times 10^{-2} \text{ m}^3$, and $\rho = m/V$.) Since the block is floating, $F_B = F_g$:

$$\rho_f V g = m_{\text{block}} g$$

$$m_{\text{block}} = \rho_f V$$

The mass of the block equals the mass of the displaced water. The volume of water is the volume of the submerged part of the block: $V = (0.25 \text{ m})(0.25 \text{ m})(0.25 - 0.07 \text{ m}) = 1.125 \times 10^{-2} \text{ m}^3$. Since $\rho_f = 1000 \text{ kg/m}^3$, then $m_{\text{block}} = 11.25 \text{ kg}$ and $\rho_{\text{block}} = 720 \text{ kg/m}^3$. (Less than water, obviously!)

Problem set 3

1. a) The surface temperature of the sun: $5160 \text{ K} = 4887^\circ\text{C} = 8828^\circ\text{F}$.
b) The “night-time” surface temperature of the moon: $-173^\circ\text{C} = -279.4^\circ\text{F} = 100.15 \text{ K}$.
c) Normal body temperature: $98.6^\circ\text{F} = 37^\circ\text{C} = 310.15 \text{ K}$.
2. An aluminum wire 1.4 km long is strung between two towers for the transmission of electricity.
a) How much does its length change when the temperature goes from -10°C to 40°C ? ($\alpha = 22.2 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$).

$$\Delta L = \alpha L_0 \Delta T = 1.55 \text{ m}$$

- b) If the wire is 1.4 km long when the temperature is -10°C , how long will it be when the temperature reaches 20°C ?

$$\Delta L = \alpha L_0 \Delta T = 0.93 \text{ m}$$

So that $L = 1400.9 \text{ m}$.

3. An automobile tire is filled to a gauge pressure of $2 \times 10^5 \text{ N/m}^2$ at 10°C . After driving 100 km, the temperature within the tire rises to 40°C . What is the pressure within the tire now? Atmospheric pressure is $1.01 \times 10^5 \text{ N/m}^2$.

The original absolute pressure in the tire is $p_1 = p_g + p_{atm} = (2 \times 10^5 + 1.01 \times 10^5) \text{ N/m}^2 = 3.01 \times 10^5 \text{ N/m}^2$. The starting temperature is $T_1 = 283.15 \text{ K}$, and the final temperature is $T_2 = 313.15 \text{ K}$. We assume that the volume of the tire is constant, i.e., $V_1 = V_2$. Using the ideal gas law:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

Divide out the volume ($V_1 = V_2$), and solve for p_2 :

$$p_2 = p_1 \frac{T_2}{T_1} = 3.33 \times 10^5 \text{ N/m}^2$$

So the new gauge pressure is $p_g = p - p_{atm} = 2.3 \times 10^5 \text{ N/m}^2$

4. STP means Standard Temperature and Pressure ($0^\circ\text{C} = 273 \text{ K}$ and 1 atm). If 5.00 m^3 of gas initially at STP is placed under a pressure of 4.0 atm and the temperature of the gas rises to 25°C (298 K), then to find the final volume we again use the ideal gas law:

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

And solve for V_2 :

$$V_2 = V_1 \left(\frac{T_2}{T_1} \right) \left(\frac{p_1}{p_2} \right) = 1.36 \text{ m}^3$$

Note that because of the ratio you don't have to convert pressure to N/m^2 , but the temperature must be in Kelvin (absolute temperature).

5. If 50.0 L of oxygen at 10°C (283 K) and an absolute pressure of 1.88 atm are compressed to 36.6 L and at the same time the temperature is raised to 80°C (353 K), the new pressure is

$$p_2 = p_1 \left(\frac{T_2}{T_1} \right) \left(\frac{V_1}{V_2} \right) = 3.2 \text{ atm}$$

Note that because of the ratio you don't have to convert volume to m³.

6. A sample of gas occupies $2.0 \times 10^{-3} \text{ m}^3$ at an absolute pressure of 1.0 atm and a temperature of 0°C (273 K).
- a) Its volume at the same pressure and a temperature of 200°C (473 K): $V_2 = 3.5 \times 10^{-3} \text{ m}^3$
- b) Its pressure at a volume of $5.0 \times 10^{-4} \text{ m}^3$ and a temperature of 200°C: $p_2 = 6.9 \text{ atm}$
7. Describe what happens when the temperature of a gas is decreased while the pressure remains constant. Explain this change based on the Kinetic-Molecular Theory:

The volume decreases to maintain constant pressure, so density increases. So the pressure stays the same because although the average impulse is smaller from each molecule colliding with the walls, more molecules per time hit the walls because of the higher density.