Sample Test for Unit VI

Potentially useful equations:

$$p_{\text{abs}} = p_{\text{g}} + p_{\text{atm}} \qquad \Delta p = \rho_f g h \qquad Y = \frac{F/A}{\Delta L/L_0}$$

$F_B = \rho_f V$ or $F_B = mg$ stress, strain: get these from definition of elastic modulus (Y)

Also will include: thermal expansion, ideal gas law, pressure conversions as needed

1. 1. An aluminum wire (Young's modulus = 7.0×10^{10} N/m^2) is 4.0 m long and has a diameter of 2.4 mm (circular cross-section). It is used to support a 68 kg load. What will be the elongation of the wire?

2. The absolute pressure inside an automobile tire is 3.03×10^5 Pa on a day when the atmospheric pressure is 1.02×10^5 Pa. What pressure would be shown on a tire pressure gauge?

3. a) Plasma (p = 1030 kg/m^3) flows from a bag through a tube into a patient's vein. What is the (gauge) pressure of the plasma as it enters the vein if the bag is held 1.4 m above the patient's arm?

   b) How high should the bag be held to provide the same pressure when giving a transfusion to an astronaut on the moon where g = 1.63 m/s^2?

4. a) A force of 4.6 N is applied to the plunger of a hypodermic syringe which has a cross-sectional area of 2.5 cm^2. Determine the force necessary to prevent the fluid from coming out of a needle whose cross-sectional area is 0.0080 cm^2.

   b) Given that a pressure of 760 mm Hg is equivalent to 1.01×10^5 N/m^2, find the minimum force that must be applied to the plunger to inject fluid into a vein in which the blood pressure is 12 mm Hg.

5. A balloon and gondola have a total mass of 150 kg. The volume capacity of the balloon is 500 m^3. Find the maximum payload which can be lifted when the balloon is filled with hydrogen. The density of hydrogen is 0.090 kg/m3 and the density of air is 1.3 kg/m^3.

6. a) Convert 80°F to Celsius and Kelvin.

   b) Convert -40°C to Fahrenheit.

7. An iron pipe is 50 m long at room temperature (20°C). If the pipe is to be used for steam (100°C), how much allowance must be made for expansion, and what will the new length of the pipe be? ($\alpha = 12 \times 10^{-6}\,^\circ\text{C}^{-1}$)

8. a) Helium gas is stored in a 0.014 m^3 tank at a temperature of 24°C and a pressure of 27 atm. The gas is then transferred into a balloon. What is the volume of the balloon if the pressure has dropped to 1.0 atm and the gas temperature falls to -35°C?

   b) What is the volume of the balloon after the gas has warmed to its original temperature of 24°C?

9. Describe what happens when the temperature of a gas is increased while its volume is held constant. Explain this change based on the Kinetic-Molecular Theory.

Short Answers:

1. Young's modulus is the ratio of the stress over the strain: $Y = \frac{F/A}{\Delta L/L_o}$. Here the force, F is the weight of the load (mg), and the area is a circle of radius 1.2×10^{-3} m ($A = \pi r^2$). Since Y is given, rearrange the equation to get ΔL:

$$\Delta L = L_o \frac{F/A}{Y} = 8.4 \times 10^{-3}\,\mathrm{m} \quad \text{(or 8.4 mm)}$$

2. $p_\mathrm{g} = p - p_\mathrm{atm} = 2.01 \times 10^5$ Pa (which is equal to 29 psi)

3. a) The pressure at the bottom of the tube is the gauge pressure from the depth of fluid: $p_\mathrm{g} = \rho g h = 1.4 \times 10^4\,\mathrm{Pa}$

   b) $p_\mathrm{g} = \rho g_\mathrm{moon} h$, so solve for h as $h = p_\mathrm{g}/(\rho g_\mathrm{moon}) = 8.4\,\mathrm{m}$

4. a) The pressure at both ends has to be the same $(p_1 = p_2)$, so that

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \text{so that} \quad F_2 = F_1 \frac{A_2}{A_1}$$

   and then $F_2 = 1.5 \times 10^{-2}$ N.

   b) Again, use $p = F/A$, where $p = 12\,\mathrm{mm\,Hg} = 1.59 \times 10^3\,\mathrm{Pa}$, then $F = 0.40$ N (Also need to convert $A = 2.5 \times 10^{-4}\,\mathrm{m}^2$.)

5. Assume that $m_\mathrm{gb} = 150$ kg is for the gondola and the *empty* balloon (i.e., the mass of the hydrogen gas, m_h, is separate.) The hydrogen-filled balloon displaces higher-density air, so there is an upward buoyant force F_B equal to the weight of the displaced air: $F_B = \rho_\mathrm{air} V g$, where V is the volume of the balloon. The maximum load, m_l, adds just enough weight so that the total weight $F_g = (m_\mathrm{gb} + m_\mathrm{h} + m_l)g$ is balanced by the buoyant force (zero acceleration). So from Newton's second law: $F_B - F_g = 0$, so that

$$\rho_\mathrm{air} V g = (m_\mathrm{gb} + m_\mathrm{h} + m_l)g$$

   Divide by g and isolate m_l:

$$m_l = \rho_\mathrm{air} V - m_\mathrm{gb} - m_\mathrm{h}$$

   where $m_h = \rho_\mathrm{h} V$. Plug in the numbers to get $m_l = 455\,\mathrm{kg}$. (Note that we neglect the buoyant force on the gondola and load because their densities are so much greater than air that the buoyant force is negligible compared to their weight.)

6. a) $T_C = \frac{5}{9}(T_F - 32) = 26.7°\mathrm{C} = 299.8\,\mathrm{K}$

   b) $T_F = \frac{9}{5} T_C + 32 = -40°$F.

7. The pipe's original length is $L_o = 50\,\mathrm{m}$, and the change in temperature is $\Delta T = 100°\mathrm{C} - 20°\mathrm{C} = 80\,\mathrm{C}°$. Thus the change in length is $\Delta L = L_o \alpha\, \Delta T = 0.048\,\mathrm{m}$, so that $L = L_o + \Delta L = 50.05\,\mathrm{m}$.

8. As in the homework, use the ideal gas law: $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$, so that $V_2 = V_1 \left(\frac{p_1}{p_2}\right)\left(\frac{T_2}{T_1}\right)$, where the temperature must be *absolute*, i.e., in Kelvin. For part (a), $V_2 = 0.30\,\mathrm{m}^3$, and for part (b), $V_2 = 0.38\,\mathrm{m}^3$. (Either start from the part a answer or redo part a with the temperature not changing.)

9. At constant volume, an increase in temperature causes an increase in pressure. At the microscopic level, the temperature increase causes the average gas particle speed to increase, i.e., each particle has increased average kinetic energy. This results in particles hitting the container walls more often and with greater average momentum change (greater force). Both effects increase the average pressure (force per area) on the container walls.