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Problems set # 13 **Physics 168**

1. The "high-temperature" superconductor $YBa_2Cu_3O_7$ becomes superconducting when the temperature is decreased to 92 K. Find the superconducting threshold in degree Fahrenheit.

2. The Eiffel Tower is built of wrought iron approximately 300 m tall. Estimate how much its height changes between July (average temperature of 25° C) and January (average temperature of 2° C). Ignore the angles of the iron beams, and treat the tower as a vertical beam.

3. A hot air balloon achieves its buoyant lift by heating the air inside the balloon, which makes it less dense than the air outside. Suppose the volume of the balloon is 1800 m^3 and the required lift is 2700 N (rough estimate of the weight of the equipment and passenger). Calculate the temperature of the air inside the balloon which will produce the required lift. Assume that the outside air temperature is 0° C and that air is an ideal gas under these conditions. What factors limit the maximum altitude attainable by this method for a given load? (Neglect variables like wind. To a first approximation assume the pressures inside and outside the balloon are equal.)

4. A 20 L tank of oxygen is at a pressure of 0.3 $P_{\rm atm}$ and a 30 L tank of nitrogen is at pressure of 0.6 $P_{\rm atm}$. The temperature of each gas is 300 K. The oxygen is then transferred into the 30 L tank containing the nitrogen, where the two mix. What is the pressure of the mixture if its temperature is 300 K?

5. What volume is occupied by 1 mol of an ideal gas at a temperature of 0° C and a pressure of 1 atm?

6. A gas has a volume of 2 L, a temperature of 30° C, and a pressure of 1 atm. When the gas is heated to 60° C and compressed to a volume of 1.5 L. What is its new pressure?

7. The molar mass of hydrogen is 1.008 g/mol. What is the average mass of a hydrogen atom in a glass of H_2O?

8. A helium-filled balloon escapes a child's hand at sea level and 20° C. When it reaches an altitude of 3000 m, where the temperature is 5° C and the pressure is only 0.7 atm, how will its volume compare to that at sea level. (To a first approximation assume the pressures inside and outside the balloon are equal.)

9. Estimate how many molecules of air are in each 2 L breath you inhale that were also in the last breath Galileo took. [Hint: assume the atmosphere is about 10 km high and of constant density.]

10. (*a*) Estimate the speed of an amino acid whose molecular mass is 89 u in a living cell at 37° C. (*b*) What would be the rms speed of a protein of molecular mass 50,000 u at 37° C.

11. The two isotopes of uranium, ^{235}U and ^{238}U (the superscripts refer to their atomic mass), can be separated by a gas-diffusion process by combining them with fluorine to make the gaseous compound UF_6. Calculate the ratio of the rms speeds of these molecules for the two isotopes at constant T.

12. The escape speed at the surface of a planet of radius R is $v_{\rm e} = \sqrt{2\tilde{g}R}$, where $\tilde{g}$ is the acceleration due to gravity at the surface of the planet. If the rms speed of a gas is greater than about 15% to 20% of the escape speed of a planet, virtually all the molecules of that gas will escape the atmosphere of the planet. (*a*) At what temperature is $v_{\rm rms}$ for O_2 equal to 15% of the escape

speed of the Earth? (*b*) At what temperature is $v_{\rm rms}$ for H_2 equal to 15% of the escape speed for Earth? (*c*) Temperatures in the upper atmosphere reach 1000 K. How does this help account for the low abundance of hydrogen in Earth's atmosphere? (*d*) Compute the temperatures for which the rms speeds of $\rm O_2$ and $\rm H_2$ are equal to 15% of the escape speed at the surface of the moon, where $\tilde{g}$ is about one-sixth of its value on Earth and the radius of the moon is $R = 1738$ km. How this account for the absence of an atmosphere on the moon?

13. The local poison control center wants to know more about carbonmonoxide and how it spreads through a room. You are asked (*a*) to calculate the mean free path of a carbon monoxide molecule and (*b*) to estimate the mean time between collisions. The molar mass of carbon monoxide is 28 g/mol. Assume that the CO molecule is traveling in air at 300 K and 1 atm, and that the diameter of both CO molecules and air molecules are 3.75×10^{-10} m.

Enrichment

14. A small hot air balloon has a volume of 15.0 $\rm m^3$ and is open at the bottom.The air inside the balloon is at an average temperature of 46° C, while the air next to the balloon has a temperature of 24° C, and a pressure, on average, of 1 atm. The balloon is tethered to prevented from rising, and the tension in the tether is 10 N. Use 0.029 kg/mol for the molar mass of air. (Neglect the gravitational force on the fabric of the balloon.) What is the pressure on average inside the balloon?

15. The escape speed for gas molecules in the atmosphere of Jupiter is 60 km/s and the surface temperature of Jupiter is typically −150°. Calculate the rms speeds for (*a*) $\rm H_2$, (b) $\rm O_2$, and (c) $\rm CO_2$ at this temperature. (d) Are $\rm H_2$, $\rm O_2$, and $\rm CO_2$ likely to be found in the atmosphere of Jupiter?

16. The escape speed for gas molecules in the atmosphere of Mars is 5.0 km/s and the surface temperature of Mars is typically 0°. Calculate the rms speeds for (*a*) $\rm H_2$, (b) $\rm O_2$, and (c) $\rm CO_2$ at this temperature. (d) Are $\rm H_2$, $\rm O_2$, and $\rm CO_2$ likely to be found in the atmosphere of Mars?

17. Show that the rms speed of molecules in a gas is given by $v_{\rm rms}\sqrt{3P/\rho}$, where P is the pressure in the gas and ρ is the gas density.

18. Show that for a mixture of two gases at the same temperature, the ratio of their rms speeds is equal to the inverse ratio of the square roots of their molecular masses.

19. Show that the pressure P of a gas can be written $P = \frac{1}{3}\rho v_{\rm rms}^2$, where ρ is the density of the gas and $v_{\rm rms}$ is the rms speed of the molecules.

20. A gas absorbs 400 J of heatand at some time does 120 J of work on a piston. What is the change in the internal energy of the system? [Solution on slides.]