Ideal Gas & Kinetic Theory Practice Items

1. Which of the following volumes is closest to that occupied by one mole of an ideal gas at standard state temperature and standard pressure?

A. 1 liter
B. 18.9 liters
C. 22.4 liters
D. 24.4 liters

2. A constant volume gas thermometer will be most accurate

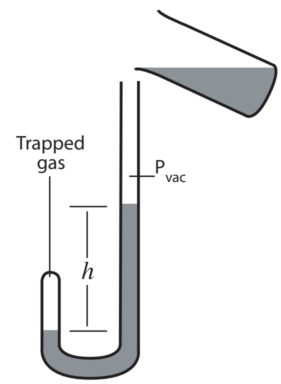
A. at low pressures
B. at low temperatures
C. when conditions for the gas are near the condensation stage
D. if the gas is high density

3. In the interstellar regions of the Milky Way, a temperature of 2.7 K arises from radiation and particle kinetic energy. Matter exists in the form of approximately one million neutral hydrogen atoms per cubic meter. Which is the best estimate of the pressure in interstellar space?

A. 3.5×10^{-19} Pa
B. 3.6×10^{-17} Pa
C. 2.2×10^{-7} Pa
D. 2.7×10^{-6} Pa

4. The U-tube pictured below contains a volume, V_g, of ideal gas trapped by a column of mercury under a vacuum. As mercury is added to the U-tube with the system maintained at constant temperature,

A. the product $V_g h$ maintains a constant value as h increases.
B. the product $V_g h$ decreases.
B. the product $V_g h$ increases.
C. heat flow occurs into the gas.



5. Which of these gases has the lowest molar heat capacity?

A. Ar
B. H_2
C. NH_3
D. C_3H_8

6. What is the approximate ratio of the specific heat (cal/g, constant volume) of neon gas (MW 20.2 g) to the specific heat of krypton gas (MW 83.8 g)?

A. 1:4
B. 1:1
C. 4:1
D. not enough information to determine

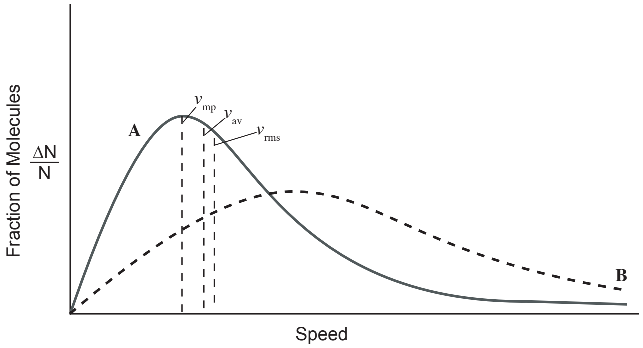
7. Almost all atoms in a sample of helium gas become completely ionized when the thermal energy reaches approximately 3.5×10^3 kJ/mol. At what approximate temperature does helium gas completely ionize?

A. 3,500 K
B. 5,250 K
C. 10,500 K
D. 28,000 K

Passage (Questions 8-12)

Gas molecules move rapidly in all directions in a random fashion. For a given temperature, the Maxwell-Boltzmann distribution describes the variation of speeds among the molecules. The distribution is often represented graphically as a plot of the fraction of molecules vs. speeds. The fraction of molecules with very high speeds or very low speeds is small. The peak of the graph corresponds to the most probable speed. A somewhat higher speed than the most probable speed is the root mean square speed, RMS, which corresponds to the speed of a particle with average kinetic energy. The average speed itself is $0.913 \times$ RMS.

The graph below illustrates the Maxwell-Boltzmann distributions for two gases of equal molecular size present at equimolar concentrations in two separate stoppered flasks. The distribution for gas A is shown with the solid line. The distribution for gas B is shown with the dotted line.



8. In comparison to gas A, Gas B

A. is at a higher temperature.
B. is at a lower temperature.
C. has larger molecules.
D. has smaller molecules.

9. In a sample of gas more molecules have this particular speed than any other.

A. v_{mp}
B. v_{av}
C. v_{rms}
C. impossible to determine

10. Assuming the temperature of gas A were 300K, what is the approximate temperature of gas B?

A. 150 K
B. 425 K
C. 600 K
D. 1200K

11. A graph illustrating the Maxwell-Boltzmann distributions of which of the following two gases at equimolar concentrations in thermal equilibrium would most closely resemble the graph in the passage?

A. O_2 and N_2
B. Ar and Ne
C. CH_4 and He
D. NH_3 and H_2

12. In kinetic theory the mean free path of a particle is the average distance the particle travels between collisions with other moving particles. For gas particles it may be shown that the mean free path, in meters, is

$$l = \frac{k_b T}{\sqrt{2}\pi d^2 P}$$

where k_b is the Boltzmann constant in J/K, T is the temperature in K, P is pressure in Pascals, and d is the diameter of the gas particles in meters.

Which of the following would cause an increase in the mean free path of the particles of a gas?

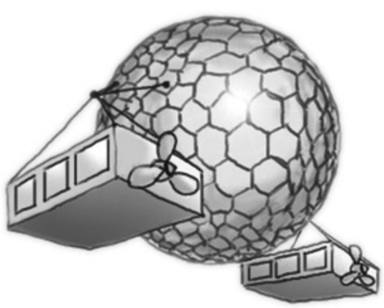
A. increasing the temperature of the gas at constant volume

B. increasing the pressure of the gas at constant volume

C. increasing the volume of the gas at constant temperature

D. ionizing the gas with an electron beam

Passage (Questions 13-16)



A large vacuum dirigible, such as depicted in the artist's rendering above, would produce enormous lift. A spherical vacuum dirigible constructed of a geodesic sphere 200m in diameter with 1.2×10^6 kg devoted to its aluminum frame and carbon fiber skin with 0.5atm internal pressure would be capable of floating in the Earth's atmosphere carrying approximately 1.5×10^6 kg in equipment, cargo and passengers in addition to the mass of its structure and cladding.

Current techniques employed in the design and construction of geodesic domes could produce an extremely stable geodesic sphere as described, prior to evacuation. However, the true challenge would be to construct an airship that could withstand the compressive forces after the vacuum has been introduced. The difficulty of the engineering challenges involved can be appreciated in the determination of the material constraints for a vacuum dirigible comprised of a homogeneous spherical shell enclosing a total vacuum. The total force on a spherical shell of radius R by an external pressure P is $\pi R^2 P$. The force on each hemisphere in equilibrium along the equator will produce the compressive stress given below:

$$\sigma = \frac{\pi R^2 P}{2\pi R h} = \frac{RP}{2h}$$

where h is the shell thickness.

Neutral buoyancy occurs when the shell has the same mass as the displaced air, which occurs when $h/R = \rho_a/(3\rho_s)$, where ρ_a is the air density and ρ_s is the shell density. Combining with the stress equation gives

$$\sigma = \frac{3\rho_s P}{2\rho_a}$$

For terrestrial conditions such a degree of stress is of the same order of magnitude as the compressive strength of aluminum alloys, arguing for the feasibility of the spherical shell design.

Unfortunately this disregards buckling. Using the formula for the critical buckling pressure of a sphere

$$P_{cr} = \frac{2Eh^2}{\sqrt{3(1-\mu^2)}} \frac{1}{R^2}$$

where E is the modulus of elasticity and μ is the Poisson ratio of the shell material, ie. the relationship of transverse bulging to axial compression. (Most potential shell materials possess a Poisson ratio of approximately 0.3). Substituting the condition for neutral buoyancy, $h/R = \rho_a/(3\rho_s)$, gives a necessary condition for a feasible vacuum balloon shell:

$$\frac{E}{\rho_s^{\,2}} = \frac{9P_{cr}\sqrt{3(1-\mu^2)}}{2\rho_a}$$

The requirement is about 4.5 $\times 10^5$ kg^{-1}m^{5}s^{-2}. This cannot even be achieved using diamond ($E/\rho_s^{\,2} \approx 1.0 \times 10^5$ kg^{-1}m^{5}s^{-2}).

In summary, a vacuum dirigible comprised of a homogeneous spherical shell does not appear to be possible given currently available materials. However, dropping the assumption that the shell is a homogeneous material may allow lighter and stiffer structures such as with a honeycomb structure or geodesic construction. A number of engineering groups have claimed success in creating viable designs in recent years although there have been no public demonstrations of a working prototype.

13. A vacuum dirigible could lose buoyancy through the influx of gas molecules through pinhole defects in its carbon fiber skin. Assuming the airship material and air density remained unchanged as temperature increased, the increase in the rate of gas influx in moving from a 0°C environment to a 30°C environment would be approximately

A. 3%
B. 10%
C. 17%
D. 81%

14. A hypothetical vacuum airship achieves neutral buoyancy with an interior pressure of 0.5 atm. What approximate interior temperature within 27°C surroundings would a hot-air balloon of the same volume and mass need to establish to generate the same lift?

A. 54°C
B. 129°C
C. 254°C
D. 327°C

15. According to the passage, construction of a viable vacuum airship comprised of a homogeneous spherical shell might be constructed if a material with the following properties compared to diamond could be developed:

A. 1/2 the rigidity and 1/4 the density
B. the same rigidity and 1/2 the density
C. twice the rigidity with the same density
D. twice the rigidity and twice the density

16. A vacuum dirigible constructed of a homogeneous spherical shell is to be developed for flight within a dense low pressure extra-terrestrial atmosphere. From the information presented in the passage it can be deduced that increasing the design radius

A. would require an increase in the thickness of the shell material directly proportional to the increased radius.
B. would lead to more favorable material constraints as radius increased.
C. would enable the dirigible to operate in higher temperatures.
D. would make it more possible for the dirigible to be constructed from a material having a low Poisson ratio.