classification scheme can be used in conjunction with eqn. IIIE-13b to determine which flow regime is present under given conditions. When the gas falls within the perfect gas region, eqn. III-13b is adapted to this specific case by substituting $n_v = p/kT$. This gives

$$\lambda_c = \frac{kT}{\sqrt{2}\,\sigma^+ p} \qquad \text{(IIIE-15)}$$

Exercise 12. Determine the mean free path and mean free time for nitrogen gas at STP.

Example 6. If vacuum insulation is to be at all effective, the pressure level must be below that within the continuum region. It is desirable that it be low enough to establish a free molecular transport regime. For a thermos bottle using nitrogen gas and a 1 cm separation gap, determine the threshold (i.e., continuum limit) pressure level and desired (i.e., free molecule limit) pressure level for operation at room temperature (300 K), liquid nitrogen temperature (77 K), and liquid helium temperature (4.2 K).

The required pressure levels are established by the Knudsen number limits, 10^{-2} and 10. The corresponding pressures are established from eqns. IIIE-14 and 15.

$$p = \frac{kT}{Kn\sqrt{2}\,L\,\sigma^+}$$

From Table IIIE-2, $\sigma^+_{N_2} = 44.2\ (\mathring{A})^2$. Thus at 300 K, the threshold pressure is

$$p_1 = \frac{1.380 \cdot 10^{-23}\ \text{J/(part K)} \cdot 10^{-5}\text{bar m}^3\text{/J} \cdot 300\ \text{K}}{10^{-2}\sqrt{2} \cdot 1\ \text{cm} \cdot 44.2(\mathring{A})^2 \cdot 10^{-20}\ \text{m}^2(\mathring{A})^2 \cdot 10^2\text{m/cm}} = 6.63 \cdot 10^{-4}\text{bar}$$

A similar calculation shows that the free particle limit pressure is $p_2 = 6.63 \cdot 10^{-7}$bar. At 77 K, $p_1 = 1.70 \cdot 10^{-4}$bar, $p_2 = 1.70 \cdot 10^{-7}$bar; and at 4.2 K, $p_1 = 9.28 \cdot 10^{-6}$bar, $p_2 = 9.28 \cdot 10^{-9}$bar.

The preceding exercises demonstrate that a combination of low pressure and/or small physical dimensions are required to establish the free particle regime in a molecular gas. These conditions are present within most high vacuum systems and on the exterior of extra-atmospheric vehicles. However, an overwhelming majority of molecular gas applications are within the continuum flow regime.

II. FREE PARTICLE RADIATION TRANSPORT

The rapidly moving photons are an important means of heat transport through gases. Photon-photon collisions are normally overshadowed by photon-molecule scattering. Hence, it is this process that prescribes photon mean free paths. Examining the form of eqn. IIIE-13a, we would expect shorter photon mean free paths in higher density gaseous media. This is indeed the case. However, the greatest variation in photon mean free paths is associated with variations in the collision cross section. Photon-molecule collisions are electromagnetic in character. Thus dipole molecule gases (e.g., H_2O, CO) and molecules that can be easily distorted into dipoles (e.g., CO_2) have far bigger cross sections for photon collisions than monatomic or homonuclear diatomic molecule gases. Since the principal constituents in air are homonuclear diatomic, air is relatively transparent to