Physics 301

Homework due 13 November 2024

1) Consider a gas of atoms, each having mass m, maintained at Kelvin temperature T inside an enclosure. The atoms emit light which passes (in the x-direction) through a window of the enclosure and can be observed as a spectral line. A stationary atom would emit light at the well defined frequency υ_0. Because of the Doppler Effect, the frequency of the light observed from the atom having an x-component of velocity v_x is not υ_0 but rather $\upsilon = \upsilon_0 \left(1 + \frac{v_x}{c}\right)$, where c is the speed of light. As a result of the Doppler Effect, the light registered by the spectroscope has a distribution of frequencies.

(a) Calculate the mean frequency $\bar{\upsilon}$ of the light observed; (b) Calculate the dispersion, $\overline{(\Delta\upsilon)^2} \equiv \overline{(\upsilon - \bar{\upsilon})^2}$, in the frequency of the light observed; (c) Explain how measurements of the dispersion of a spectral line observed in starlight allow one to determine the temperature of the star.

2) (a) Stowe problem 18-11; (b) Stowe problem 18-12. Additional information needed to complete this problem: The mass of an air molecule is about 5×10^{-26} kg.

3) (a) Stowe problem 19-12; (b) Stowe problem 19-13.

4) Suppose that the molecules of a gas interact with each other through a radial force of magnitude $F = CR^{-s}$, where s is a positive integer.

(a) Use dimensional analysis to show how the total scattering cross section is related to the molecules' relative speed v, their masses m, and the force constant C; (b) How does the coefficient of viscosity of this gas depend on the temperature T?

5) A spacecraft in the shape of a cube of edge length L moves through space with a velocity $\vec{v}$ parallel to one of its edges. The spacecraft has mass M. The surrounding gas consists of molecules of mass m at temperature T; the number n of molecules per unit volume is small, so the mean free path of the molecules is much larger than L. Assume that collisions of the molecules with the spacecraft are elastic. Assume that $|\vec{v}|$ is small compared to the mean speed of the gas molecules. Estimate the mean retarding force exerted on the spacecraft by its collisions with the interplanetary gas. Ignore the distribution of velocities of the gas molecules. If the spacecraft is not subject to external forces other than the collisions with the gas, how long a time will elapse before the velocity of the craft is reduced to half its original value?