Homework 3

Due **September 17 by 11:59pm via Canvas upload**
Please show all work, writing solutions/explanations clearly, or no credit will be given. You are encouraged to work together, but everyone must turn in independent solutions; do not copy from others or from any other sources.

1. A neutral carbon atom has an ionization potential of 11.3 eV. Consider the case of a free electron that has exactly enough kinetic energy to collisionally ionize the atom from its ground state.
   (a) What is the speed of the electron?
   (b) What would its speed be if the electron were instead a proton?
   (c) What is the temperature of a gas in which the average particle kinetic energy is exactly enough to collisionally ionize neutral atoms of carbon?

2. Imagine that we measure absorption lines due to a gas comprising hydrogen and carbon-12, with temperature $T = 100$ K.
   (a) What is the temperature of this gas, in degrees Fahrenheit?
   (b) What is the Doppler broadening (the $\Delta\lambda/\lambda$) of a hydrogen line at $\lambda = 6563$ Å?
   (c) What is the Doppler broadening of a carbon line at $\lambda = 6560$ Å?
   (d) Which element's lines will be broader in physical units (e.g., Å), and why? (Hint: "Why?" here means to provide a physical reason, not "because the equation says so.")
   (e) How does this broadening change when we consider spectral lines of these same elements that have longer wavelengths?

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3. An old joke: A man is pulled over by a police officer after running a red light. “But officer,” he says, “it was all the Doppler shift’s fault—I was moving towards the red light, so it looked green to me!” (Cue laughter.) How fast would the man need to drive for the red light ($\lambda = 700$ nm) to look green ($\lambda = 550$ nm)? Give your answer in miles per hour.

4. Starting from the Maxwell-Boltzmann distribution (either in terms of velocity or energy), show that

   (a) the most probable speed of a particle (i.e., the peak of the distribution) is $v_p = \sqrt{\frac{2kT}{m}}$;

   (b) the average speed is $\langle v \rangle = \sqrt{\frac{8kT}{\pi m}}$;

   (c) and the mean kinetic energy per particle is $\langle E \rangle = \frac{3}{2}kT$.

   (Apropos nothing, here are some solutions to a couple random definite integrals:

$$\int_0^\infty x^{3/2} e^{-x} dx = \frac{3}{4}\sqrt{\pi}$$

$$\int_0^\infty x^3 \exp(-x^2) dx = \frac{1}{2}.)$$