Chem 332: Problem Set #1

Due in class: Wed., Jan. 16th;
Show all work and attach all plots (appropriately annotated)

(1) Sirius, one of the hottest known stars, has approximately a blackbody spectrum with λ_{max} = 260 nm. Use the Wien displacement law, $\lambda_{\max} T = 2.8978 \text{ x } 10^{-3} \ \text{ m} \cdot \text{K}$, to estimate the surface temperature of Sirius.

(2) At the end of his derivation of the blackbody frequency distribution function, Planck intended to take the limit $h \rightarrow 0$. Show that this limit gives the wrong result, i.e., that Planck's distribution function degrades to the Rayleigh-Jeans distribution function.

$$E_{Planck}(\nu) = \frac{8\pi\nu^2}{c^3}\left[\frac{h\nu}{e^{h\nu/kT} - 1}\right]$$

$$E_{RJ}(\nu) = \frac{8\pi\nu^2}{c^3} kT$$

(hint: consider the series expansion of the exponential function)

(3) The following data were observed in an experiment on the photoelectric effect using potassium:

Kinetic Energy (10^{-19} J)	4.49	3.09	1.89	1.34	0.700	0.311
Wavelength (nm)	250	300	350	400	450	500

Graphically evaluate these data to obtain values for the work function of potassium and Planck's constant.

(4) The observed lines in the emission spectrum of the hydrogen atom are given by

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_1^2} - \frac{1}{n_2^2} \right), \quad \text{where } n_2 > n_1$$

In the notation favored by spectroscopists, $\tilde{\nu} = \frac{1}{\lambda} = \frac{E}{hc}$ and R_H = 109,677, where both are in cm^{-1} ("wavenumber") units. The Lyman, Balmer, and Paschen series refer to n_1 = 1, 2, and 3, respectively.

(a) The first few lines of the visible (Balmer) series in the spectrum of atomic hydrogen lie at λ/nm = 656.46, 486.27, 434.17, and 410.29. Find a value for R_H, the Rydberg constant for hydrogen (please use a graphical method to obtain the best value).

(b) The ionization energy is the minimum energy required to remove the electron. Determine it from your result and express its value in electronvolts (1 eV = 1.602×10^{-19} J).

(5) Calculate the de Broglie wavelength (in m) of

(a) a mass of 1.0 g travelling at 1.0 cm/s,

(b) the same at 95% of the speed of light (ignore relativistic effects),

(c) a hydrogen atom at room temperature (300 K). (Hint: use what you know about the kinetic theory of gases)

(6) Assume that water absorbs light of wavelength 4.20×10^{-6} m with 100% efficiency. How many photons are required to heat 5.75 g of water by 1.00 K at this wavelength? The heat capacity of water is 75.3 J mol^{-1} K^{-1}.