CH301H – Principles of Chemistry I: Honors
Fall 2011, Unique 51040

Exam 2
6 October 2011

Name: Key

You may use your textbook and a calculator for arithmetic.

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community."

I certify that the work on this exam is entirely my own.

Signature Date

1. (15 points) True / False. Indicate whether each of the following statements are true, false, or if there is no way to know (NWTK) from the information given.

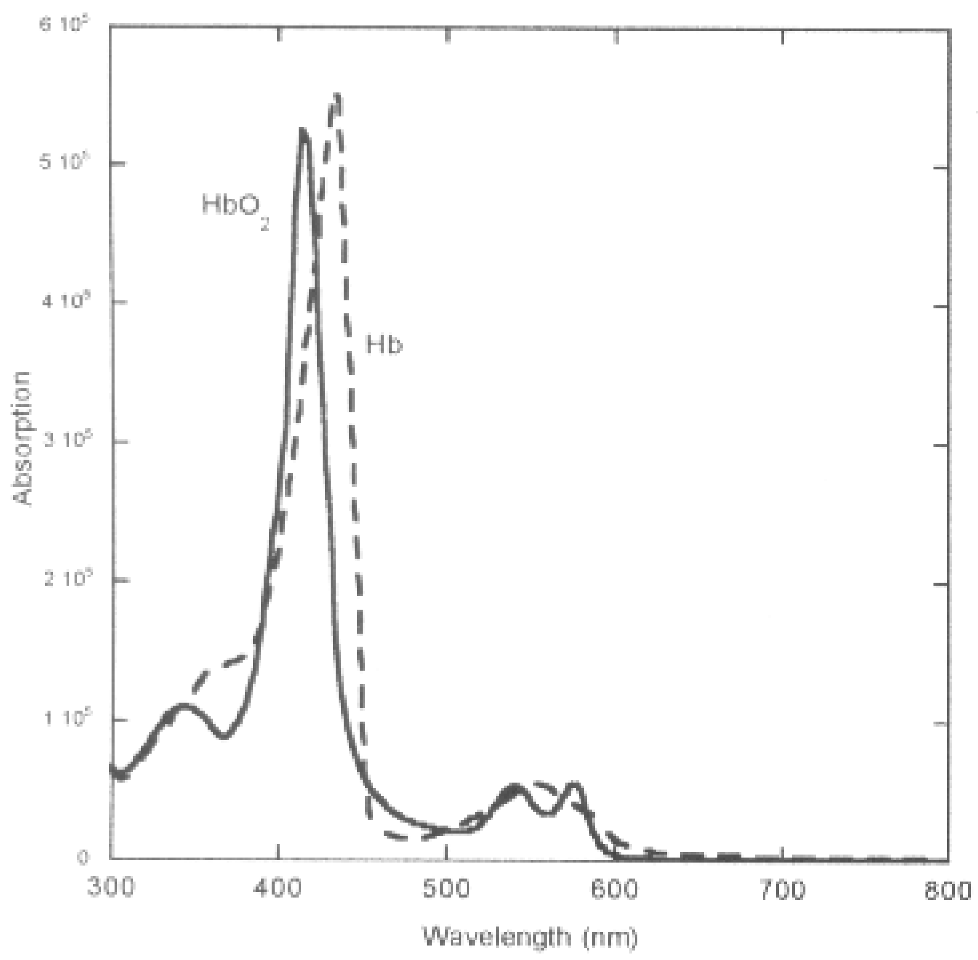
a. True False NWTK In quantum mechanics, it is possible to know the momentum of a particle exactly.

b. True False NWTK Ultraviolet radiation is higher energy than microwave radiation.

c. True False NWTK The wavelength of a neutron traveling at 10^4 m s^{-1} is longer than the wavelength of a neutron traveling at 10^3 m s^{-1}.

$v\uparrow \Rightarrow \lambda\downarrow$ $\qquad \lambda = \frac{h}{p} = \frac{h}{mv}$

d. True False NWTK The absorption spectra of oxygenated hemoglobin (HbO_2, solid line) and deoxygenated hemoglobin (Hb, dashed line) are shown below. The ratio of absorption at 400 nm : absorption at 420 nm is a useful measurement of the quantity of oxygen in the blood.



e. True False NWTK For a particle confined to a box of length L, the $n = 2$ state has 2 nodes.

2. (20 points) Using the Bohr model, determine the energy necessary to remove the last electron from fluorine. How does your answer compare to the known value?

$$E_n = \frac{-Z^2 e^4 m_e}{8 \epsilon_0^2 n^2 h^2}$$

F^{8+}: $Z = +9$

$$\Delta E = \cancel{E(n=\infty)}^{\to 0} - E(n=1) = IE$$

$$\Delta E = 0 - \frac{-(9)^2 e^4 m_e}{8\epsilon_0^2 (1)^2 h^2} = 2.18\times10^{-18}\,J \left(\frac{9^2}{1^2}\right)$$

$$\Delta E = 1.8\times10^{-16}\,\frac{J}{atom}\left(6.242\times10^{18}\,\frac{eV}{J}\right) = 1100\,eV/atom$$

From Table 3.1, $IE_9 = 1103.08\,eV$, so the Bohr model does a pretty good job approximating the IE.

3. (20 points) The kinetic energy of a photoelectron ejected from the surface of a metal is equal to the energy of the incoming photon minus the energy required to liberate the photoelectron from the material.

a) Write an equation that describes the kinetic energy of a photoelectron, based on the statement above.

$KE = h\nu - E_0$

E_0 will be described by $h\nu_0$

$$\boxed{\begin{aligned} KE &= h\nu - h\nu_0 \\ KE &= h(\nu - \nu_0) \end{aligned}}$$

b) Determine the kinetic energy of a photoelectron ejected from the surface of a material that has a threshold energy of 5 eV by UV radiation 300 nm in wavelength.

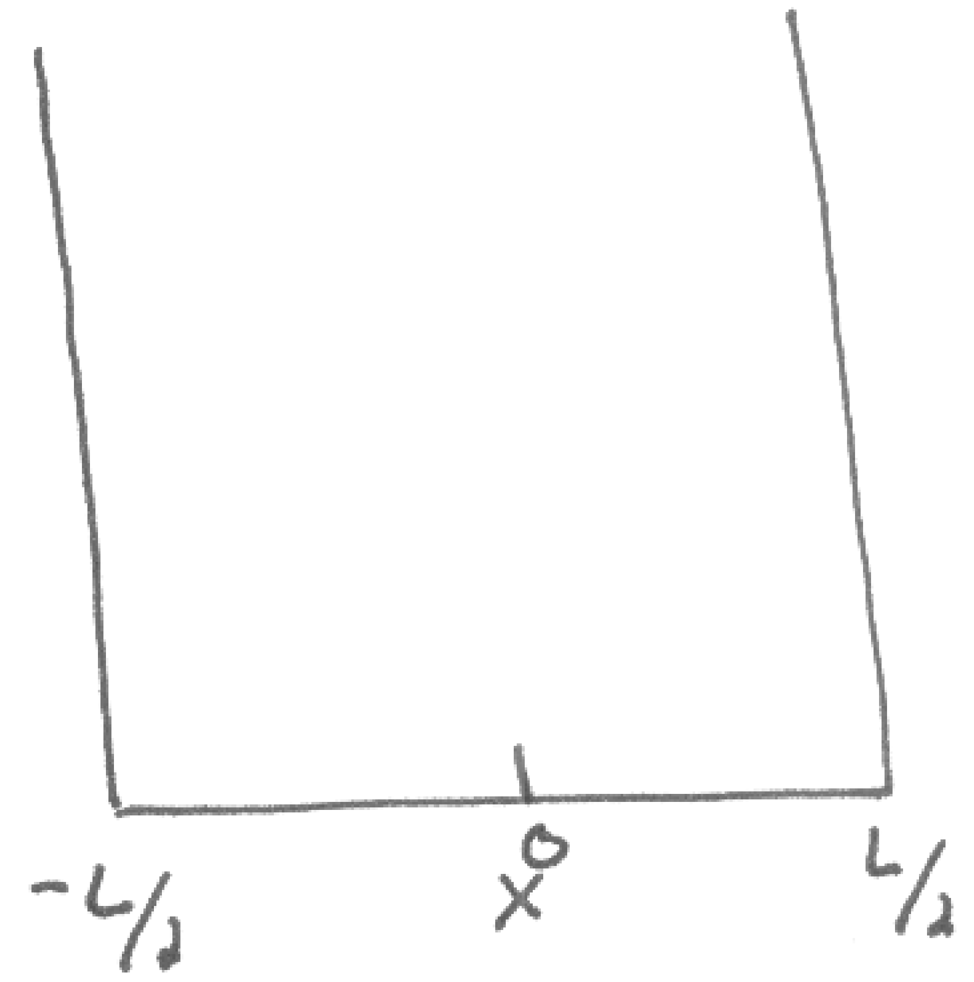
$$E_0 = 5\,eV\left(1.602\times10^{-19}\,\frac{J}{eV}\right) = 8.01\times10^{-19}\,J$$

$$E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34}\,J\,s)(3.0\times10^{8}\,m/s)}{(300\times10^{-9}\,m)} = 6.63\times10^{-19}\,J$$

$E < E_0 \Rightarrow$ the light is not high enough energy to kick off the photoelectron.

4. (20 points) Consider a quantum mechanical particle in a box that is bound between $-L/2$ and $L/2$ (a box of length L that is centered at $x = 0$).

a) Draw the box.



b) What are the boundary conditions that the wavefunction of this particle must satisfy in order to be a solution to this problem?

$$\psi(-L/2) = 0$$

$$\psi(L/2) = 0$$

c) A wavefunction for the lowest energy (ground) state defined by these boundary conditions is:

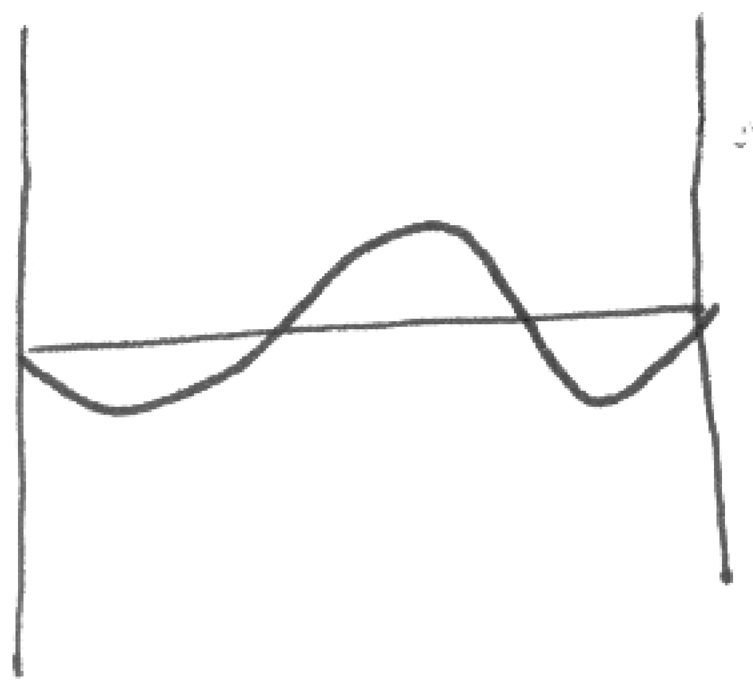
$$\psi_1 = \sqrt{\frac{2}{L}} \cos\left(\frac{\pi x}{L}\right)$$

What is the wavefunction for the first excited state of the system?

$$\psi_2 = \sqrt{\frac{2}{L}} \cos\left(\frac{3\pi x}{L}\right)$$

need to make sure that value in the cos is always a multiple of $\pi/2$

d) Does this first excited state wavefunction have any nodes? If so, how many and at what values of x?



nodes at $\pm \frac{L}{6}$

e) Write down an integral that you would need to solve to find the probability that the particle in the first excited state of the wavefunction is located between $x = -L/4$ and $x = +L/4$ of the box.

$$P = \int_{-L/4}^{L/4} \frac{2}{L} \cos^2\left(\frac{3\pi x}{L}\right) dx$$

f) What is the value of this integral? If you can't determine a number, estimate the value (more than half, roughly 0.25, etc.).

Solve exactly or estimate $\quad 1/3 < P < 1/2$

5. (15 points) Determine the de Broglie wavelength of a helium atom moving at 353 m s^{-1} (the average speed of helium atoms cooled to 20 K).

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

$v = 353 m/s$

$m = m(\text{proton}) + m(\text{neutron}) + m(\text{electron})$

$= 1.7 \times 10^{-27} kg + 1.7 \times 10^{-27} kg + 9.1 \times 10^{-31} kg$

$m = 3.4 \times 10^{-27} kg$

$$\lambda = \frac{(6.626 \times 10^{-34} Js)}{(3.4 \times 10^{-27} kg)(353 m/s)}$$

$$\boxed{\lambda = 5.5 \times 10^{-10} m = 5.5 \text{ Å}}$$

6. (10 points) The position of an electron is known to a precision of 1 Å. What is the minimum uncertainty in its velocity?

$\Delta x = 1\,\text{Å}$

$\Delta x \Delta p \geq \frac{h}{4\pi}$

$\Delta p_{min} = \frac{h}{4\pi\,\Delta x} = \frac{(6.626 \times 10^{-34}\,Js)}{4\pi\,(1 \times 10^{-10}\,m)}$

$\Delta p_{min} = 5.3 \times 10^{-25}\,kg\,m/s$

$\Delta p_{min} = m_e \Delta v_{min}$

$\Delta v_{min} = \frac{\Delta p_{min}}{m_e} = \frac{5.3 \times 10^{-25}\,kg\,m/s}{9.1 \times 10^{-31}\,kg}$

$\boxed{\Delta v_{min} = 5.8 \times 10^{5}\,m/s}$