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Discussion 2L

Fall 2016

Chemistry 20A
Midterm Two

You have one hour to complete these four problems. You may use your calculator. Not all of the problems are equally complex, but all have the same number of points. Please spend your time accordingly.

Good luck!

$E = h\nu$

$E = \frac{n^2 h^2}{8mL^2}$

$E = \frac{Z^2}{n^2}(\mathrm{Ryd})$

$r = \frac{n^2}{Z}(a_0)$

Question	Score
1	5
2	7
3	3
4	10
Total	25 /100

$mvr = n\frac{h}{2\pi}$

$n = 3$ triple bond
$n = 1$ single bond
$n = 2$ double bond

1. (20 points) **Carbon carbon bonds**
The motion of an electron in a carbon carbon single bond or multiple bond can be thought of as being equivalent to the motion of those electrons in a one-dimensional box of length given by the bond length. The bond length of a single carbon carbon bond is 154pm, a double bond is 134pm, while a triple bond has a length of 120pm.

$E = \frac{n^2h^2}{8mL^2}$

$1.54\ \text{Å} = .154 \times 10^{-10}\ m$

$1.20\ \text{Å}$

$n = 1$

(a) (5 points) C_2H_6 ethane (with a single bond) can be made from ethene C_2H_4 (with a double bond) using a nickel catalyst and hydrogen gas. Write a balanced chemical reaction for this process.

$h\nu = \frac{n^2h^2}{8mL^2}$

(b) (10 points) During this reaction, you are asked to probe the conversion process using spectroscopy to see the elimination of carbon carbon double bonds and the creation of carbon carbon single bonds. What is the wavelength of the longest wavelength emission line from the double bond and what is the longest wavelength of emission from the single bond? You may assume the electron is returning to its ground state.

$\nu = \frac{n^2h}{8mL^2}$

going to $n = 1$

$n = 1$

(c) (5 points) It turns out that triple bonded ethylene C_2H_2 may have been included as an impurity in your sample of ethene. What wavelength emission line should you look for to see if you indeed had ethylene in your sample?

m = mass electron

(a) $C_2H_4 + H_2 \xrightarrow{\text{catalyst (Nickel)}} C_2H_6 + 5$

$\frac{hc}{\lambda} = \Delta E = \frac{h^2}{8m_eL^2}(n_f^2 - n_i^2)$

(b) double bond

$c = \lambda\nu$
$\nu = \frac{c}{\lambda}$

$E_n = \frac{n^2h^2}{8mL^2}$

$\cancel{h\nu = \frac{n^2h^2}{8mL^2}}$

$\frac{c}{\lambda} = \frac{n^2h}{8mL^2}$

$\frac{\lambda}{c} = \frac{8mL^2}{n^2h}$

$L = .134 \times 10^{-10}\ m$

$\lambda = \frac{c8mL^2}{n^2h}$

$\lambda = \frac{8mcL^2}{h} = \cancel{44.2\ m}$

single bond

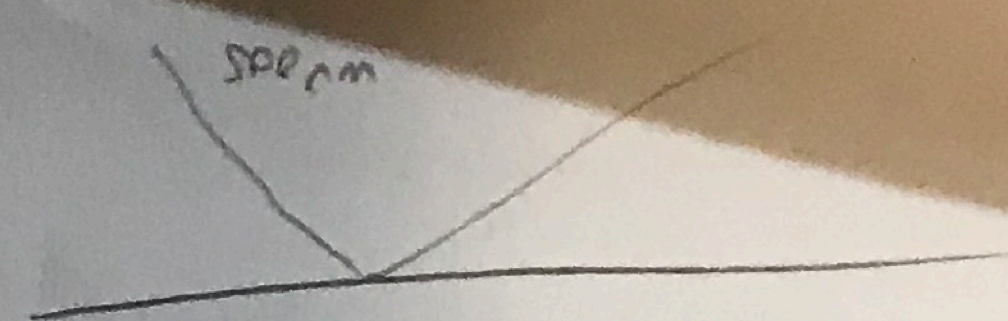
$\lambda = \frac{c8mL^2}{n^2h}$ $L = .154 \times 10^{-10}\ m$

$\lambda = \frac{8mcL^2}{h} = \cancel{59.8\ m}$

(c) $\lambda = \frac{c8mL^2}{n^2h}$ $L = .120 \times 10^{-10}\ m$

$= \cancel{39.59\ m}$

7



2. (25 points) **Radiation pressure and the photoelectric effect**
Consider a beam of light at wavelength 500nm striking a mirror perpendicularly and being totally reflected.

500×10^{-9} m

(a) (10 points) How many photons per second must strike the mirror to produce a force of 10^{-3}N? 2

(b) (10 points) What is the minimum amount of power (energy per second) necessary to produce this beam of light at the necessary intensity? You may assume all of the light in the beam hits the mirror. 0

(c) (5 points) Now the mirror is replaced by a piece of metal with a work function $\Phi_0 = 2.00$eV. The same color (500nm) light hits the metal. They are all absorbed and a stream of electrons leaves the metal heading directly back at the incoming light beam. What is the maximum kinetic energy of the ejected electrons? The wavelength of the light is then increased until no more electrons are ejected. What is this new wavelength? 5

$1 eV = 1.602 \times 10^{-19}$ J

$F = ma$ $\quad kg\ m/s^2$

$F = N$

(a) $E_{max} = h\nu - \Phi$ $\qquad p = \frac{h}{\lambda}$ $\qquad \lambda = \frac{h}{p}$

$\frac{10^{-3} N}{time} = \Phi$ work $\qquad \lambda = \frac{h}{mv}$ $\qquad$ (work)(time) = Force

$\frac{c}{\lambda_0}$ $\qquad \frac{F}{t} =$ work

$\frac{10^{-3} N}{time} = h\nu_0$ $\qquad \frac{10^{-3} N}{time} = h\left(\frac{c}{500 \times 10^{-9} m}\right)$

(b)

0

$\Phi_0 = 2eV \left| \frac{1.602 \times 10^{-19} J}{1 eV} \right. = 3.20 \times 10^{-19}$ J $\qquad 0 = h\nu - \Phi$

$\frac{c}{\lambda}$ $\qquad v = 0$ $\qquad c = \nu\lambda$

(c) $E_{max} = h\nu - \Phi$ $\qquad \Phi = h\nu$

$\frac{1}{2}mv^2 = h\nu - \Phi$ $\qquad \Phi = h\left(\frac{c}{\lambda}\right)$

$\frac{1}{2}mv^2 = h\left(\frac{c}{500 \times 10^{-9}}\right) - 3.20 \times 10^{-19}$ J $\qquad \frac{\Phi}{h} = \frac{c}{\lambda}$ $\qquad \frac{\lambda}{c} = \frac{h}{\Phi}$ $\qquad \lambda = \frac{ch}{\Phi}$

$E_{max} = 3.9756 \times 10^{-19} - 3.20 \times 10^{-19}$ $\qquad \boxed{\lambda = 6.212 \times 10^{-7} m}$ $\qquad \lambda = \frac{ch}{3.20 \times 10^{-19}}$

$\boxed{E_{max} = 7.72 \times 10^{-20} J}$

3. (25 points) **Detecting an electron in conducting polymer**
A certain polymer (chain of atoms) of length L has m delocalized electrons. These may be treated as noninteracting particles in a one-dimensional box of length L. We will assume that only two electrons may be in each quantum state of the box. A special probe can be used to allow an electron at the highest energy level of the system to escape. The probability of that escape is proportional to the absolute square of the electron's wavefunction at the position of the probe x: Probability $\propto |\psi(x)|^2$. From a series of experiments you have the following information:

- Experiment one: In the ground state of the molecule, one finds that there is a maximum probability of an electron escaping and reaching the probe when the probe is at locations: $x_n = (2n-1)L/8$ where $n = 1, 2, 3, 4$. There are no other maxima. Remember this is the highest energy electron in the system. highest $n=4$
- Experiment two: The two longest wavelengths of light that the molecule can absorb are: $\lambda_1 = 323.7$nm and $\lambda_2 = 416.2$nm. $n=1$ $\frac{L}{8}$
- Experiment three: It is found that the molecule can absorb a UV photon at wavelength $\lambda_3 = 194.2$nm. While the molecule is in this excited state, the probe is scanned across the molecule. The results are the same as that found in experiment one. That is to say that the locations of maximum escape probability are again given by the set x_n. $n=2$ $\frac{3L}{8}$

$n=3$ $\frac{5L}{8}$

a) (15 points) Find the length of the molecule based on the information given above.

b) (10 points) Make a energy level diagram for this molecule, label each state by its quantum number(s), and show which states are occupied by electrons (either singly or doubly). Finally, label which transitions were being observed in experiments that found absorption at wavelengths $\lambda_{1,2,3}$. How many electrons are there? $n=4$ $\frac{7L}{8}$

a) $E_n = \frac{h^2 n^2}{8mL^2}$ $\quad h\nu \overset{?}{=} \frac{h^2 n^2}{8mL^2}$ +3 $\quad \frac{h\left(\frac{c}{\lambda}\right)\cdot 8m}{h^2 n^2} = \frac{1}{L^2}$

$4^2 - 1^2 = 15$ $\quad L^2 = \frac{h^2 n^2}{8mh\frac{c}{\lambda}} = \sqrt{L^2} = \sqrt{\frac{hn^2}{8m\frac{c}{\lambda}}}$

$L = \sqrt{\frac{hn^2}{8m\frac{c}{\lambda}}}$

$\lambda_1 = 323.7 \times 10^{-9}$ m

$L = \sqrt{\frac{hn^2}{8m\frac{c}{\lambda}}}$

7

$\lambda_2 = 416.2 \times 10^{-9}$ m $\quad L_1 = 1.21 \times 10^{-9}$ m

$L = \sqrt{\frac{h(4^2-1^2)}{8m\frac{c}{\lambda}}} = L = \sqrt{\frac{h(15)}{8m\frac{c}{\lambda}}}$ $\quad L_2 = 1.376 \times 10^{-9}$

4.(25 points) **Atomic Transitions and the Bohr model**
In this problem we consider quantum transitions in atoms in two different contexts.

assume ↓

(a) (15 points) Suppose an atom in an excited state can return to the ground state in two steps. It first falls to an intermediate state, emitting radiation of wavelength λ_1, and then to the ground state, emitting radiation of wavelength λ_2. The same atom can also return to the ground state in one step, with the emission of radiation of wavelength λ. How are λ_1, λ_2, and λ related? How are the frequencies of the three radiations related?

highest excited → 3
intermediate state → 2 λ_1
ground state → 1 λ_2

$n=1$ λ_2
$n=2$ λ_1
$n=3$ λ

(b) (10 points) Consider a series of single electron ions with various nuclear charges Z. How does the orbital velocity of the electron in its ground state depend on Z? For what atomic species would you expect to see electron speeds to be comparable to the speed of light (say 1/3 of the speed of light)?

(a) $E = \frac{Z^2}{n^2}$ (rydberg)

$h\nu = \frac{Z^2}{n^2}$ (rydberg)

$h\left(\frac{c}{\lambda}\right) = \frac{Z^2}{n^2}$ (rydberg)

$Z^2 (\text{rydberg}) \left(\frac{1}{n_i^2} - \frac{1}{n_f^2}\right)$

$h\left(\frac{c}{\lambda}\right) = \text{rydberg} \cdot 2^2 \left(\frac{1}{2^2} - \frac{1}{3^2}\right)$

$\frac{hc}{\lambda} = \text{rydberg}\ 2^2 \left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$ −3 +4

$\lambda = \frac{hc\,(n_f^2 - n_i^2)}{2^2 (\text{rydberg})}$

$\lambda_1 = \frac{hc\left(\frac{1}{2^2} - \frac{1}{3^2}\right)}{2^2(\text{rydberg})} = \frac{1}{4} - \frac{1}{9} = \frac{5}{36}$ (constant)

constant

λ_1 will be smallest

λ_2 will be middle

λ will be largest

$\lambda_2 = \frac{hc\left(\frac{1}{1^2} + \frac{1}{2^2}\right)}{2^2(\text{rydberg})} = 1 - \frac{1}{4} = \frac{3}{4}$ (constant)

$\lambda = \frac{hc\left(\frac{1}{1^2} - \frac{1}{3^2}\right)}{2^2(\text{rydberg})} = 1 - \frac{1}{9} = \frac{8}{9}$ (constant)

So $c = \nu\lambda$

$\frac{c}{\lambda} = \nu$

the frequencies: ν_1 will be largest

ν_2 will be middle

ν_3 will be smallest

due to inverse relation between ν and λ

For calculations

$F_{coulomb} = ma$

$c = 3\times10^8$ m/s

(b) $\frac{2e^2}{4\pi\epsilon_0 r^2} = m\left(\frac{v^2}{r}\right)$

$\sqrt{\frac{2e^2}{4\pi\epsilon_0 rm}} = v$ +3

relationship on how it depends

$\frac{2e^2}{4\pi\epsilon_0 rm} = \frac{1}{3}(c)^2$

$\frac{2}{mr} = \frac{c^2 4\pi\epsilon_0}{3}$

$\frac{2}{mr} = .0111$

ratio = .0111

10/25

Midterm 1