Chemistry 20A
Dr. E.R Scerri
Mid Term
October 2015

Question	Points scored	Points scored
1	9	13
2	10	12
3	13	13
4	10	12
total	42	50

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Last, First

Signature [redacted]

ID # [redacted]

TA name [redacted]

Instructions: **This exam has 4 questions plus a periodic table at end of exam. Verify you have the right number of pages before you begin. Write your name on each page.** Raise your hand if you don't understand a question. **SHOW YOUR WORK!** No credit will be given for an unsubstantiated or illegible answer. Write legibly, use proper units throughout and use significant figures in all answers.

For questions requiring explanations do not exceed the line limit shown by dotted lines. If you do it will not even be read by the grader!

Possibly useful information:

12 inches = 1 foot, 2.54 cm = 1 inch.

$h = 6.63 \times 10^{-34}$ J sec $N_o = 6.022 \times 10^{23}$ mol^{-1} $c = 3.00 \times 10^{8}$ m sec^{-1}

$m_e = 9.11 \times 10^{-31}$ kg 1 a.m.u. = 1.66×10^{-27} kg 1 Å = 10^{-10} m

$g = 9.81$ m/s 1 eV = 1.602×10^{-19} J $\varepsilon_0 = 8.85 \times 10^{-12}$ C^{2}J^{-1}m^{-1}

$e = 1.602 \times 10^{-19}$ C

$V_{electrostatic}(r) \propto Q_1Q_2/r$; K.E. $= 1/2mv^2 = p^2/2m$

$F = -\Delta V/\Delta r$ $\Delta E = E_f - E_i = \varepsilon_{photon} = h\nu$

$\lambda\nu = c$ $h\nu = h\nu_{\circ} + $ K. E.(electron)

$\lambda = \dfrac{h}{mv} = \dfrac{h}{p}$ $m\Delta v\Delta x = \Delta p\Delta x \geq \dfrac{h}{4\pi}$

$E_n = -(2.18 \times 10^{-18}\ J)Z_{eff}^2/n^2$; $r_n = (0.529\ Å)n^2/Z_{eff}$

n-ℓ-1 spherical (radial) nodes; ℓ angular nodes; n-1 total nodes

$r_{nl} = (n^2 a_0 / Z)\{1 + \frac{1}{2}[1 - \dfrac{l(l+1)}{n^2}]\}$ $a_0 = 5.29 \times 10^{-11}$m

$\Psi_{1s} = (Z^3/\pi a_0^3)^{1/2} e^{-Zr/a_0}$ Probability = $\Psi^2 dV$

Potassium: Ionization energy: 418.8 kJ/mol Electron Affinity: 48.384 kJ/mol

Chlorine: Ionization energy: 1251.1 kJ/mol Electron Affinity: 349.0 kJ/mol

ΔE Coulomb = $(Q_1 Q_2) / 4\pi\varepsilon_0 R$

1a. Explain how Planck's formula for the intensity of black body radiation

$$\rho_T(\nu) = (8\pi h\nu^3 / c^3).[1/(e^{h\nu/kT} - 1)]$$

reduces to the classical formula, $\rho_T(\nu) = (8\pi kT\nu^2)/c^3$

at the high temperature limit. You are expected to show the mathematical steps and any assumptions made along the way. (5) 5

② $u \to 0 \Rightarrow e^u \approx u+1$

① $\lim_{T\to\infty} \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{e^{h\nu/kT}-1}$ $\quad \frac{h\nu}{kT} \to 0 \; e^{h\nu/kT} \approx \frac{h\nu}{kT} + 1$

③ $\Rightarrow \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{\frac{h\nu}{kT}} = \frac{8\pi h\nu^3}{c^3} \cdot \frac{kT}{h\nu} = \frac{8\pi kT\nu^2}{c^3}$ ← Classical formula

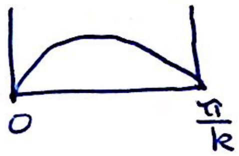
We recover the classical formula by finding $\lim_{T\to\infty} \rho_T(\nu)$

1b. Consider finding the solution to the Schrodinger equation for the particle in a 1-D box. Suppose that the solution has been narrowed down to, $\psi(x) = A\sin kx$ after applying the first boundary condition that the function has to be zero at x = 0. Now apply a second boundary condition for x = L, where L is the length of the box in order to find the value of k. Also briefly explain the significance of your result. (5) 1

@ $x = L$, $\psi(L) = 0$

$\sin x = 0$ where $x = 0, \pi$

$\therefore \psi(x) = A\sin kx$



-3

$\Rightarrow kL = \pi \Rightarrow \boxed{k = \frac{\pi}{L}}$ so $\psi(x) = A\sin\left(\frac{\pi x}{L}\right)$

$k = n\pi/L$

-1

This is important because now both sides of the wave are held onto the x-axis. These boundary conditions allow the wave to be some $\frac{n\lambda}{2}$. With this we can quantize this 1D wave due to harmonic motion and modes. Schrödinger did this in 3D for 3 quantum # numbers.

1c. Explain why the a.m.u. (atomic mass unit) is lower than the mass of the proton or the neutron. (3) 3

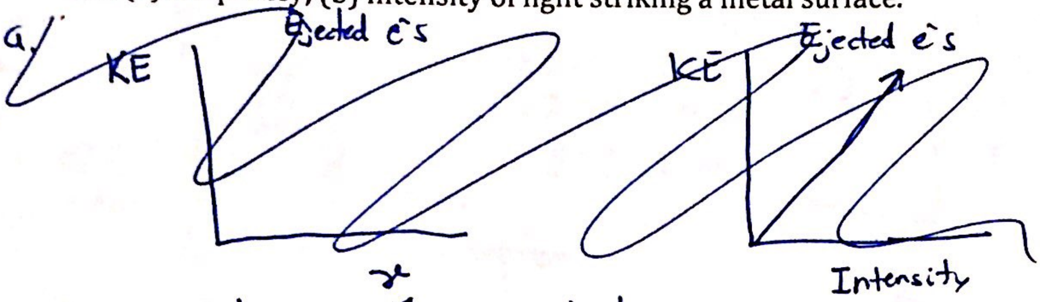
amu is lower because $_{12}C$ sacrifices some of the nucleus' mass for binding energy. So $\frac{1}{12}$ the mass of $_{12}C$ (an amu) is lower in mass.

Total 13

9

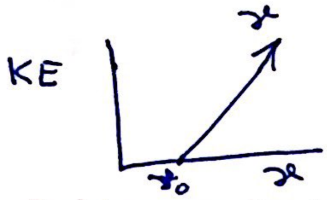
2a. Sketch two graphs to show how the kinetic energy of ejected electrons varies with (a) frequency, (b) intensity of light striking a metal surface. (3)

a/

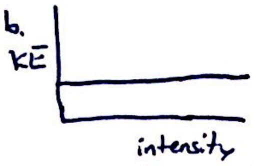


3

a.



b.



(b) assumes ν_0 has been met. If not, KE=0

2b. Explain any puzzling features of these graphs from the point of view of the classical theory that existed before Einstein introduced his approach to the photo-electric effect. (3)

One would expect KE to directly depend on intensity, because intensity is the energy of a wave. It seems logical that higher intensity waves would transfer more energy to the electrons, increasing KE. Having a minimum ν_0 also makes little sense, because it suggests energy isn't continuous like in classical mechanics.

1

2c. Light with a wavelength of 400 nm (nanometers) strikes the surface of cesium metal resulting in the ejection of electrons with a kinetic energy of 1.54 x 10-19 J. Calculate the work function of this metal. (4)

4

$E = \Phi + KE$

$\Phi = E - KE$

$\lambda\nu = c$

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

$400\,\cancel{nm} \times \frac{10^{-9}m}{1\,\cancel{nm}}$

$\Phi = \frac{hc}{\lambda} - 1.54\times10^{-19}J$

$\Phi = \frac{(6.63\times10^{-34}\,J\,sec)(3.00\times10^{8}\,m/sec)}{400\times10^{-9}\,m} - 1.54\times10^{-19}J = \cancel{3.432} = 3.43\times10^{-19}J$

2d. Now calculate the threshold wavelength for cesium. (2)

2

$E = h\nu$

$\cancel{3.43E^{-2}}$

$3.43\times10^{-19}J = (6.63\times10^{-34}J\,sec)\nu$

$\nu_0 = 5.18\times10^{19}\ \cancel{Hz}\ Hz$

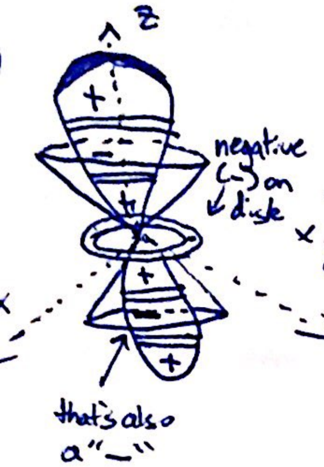
10 Total 12.

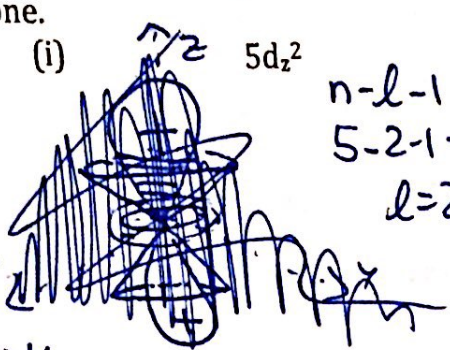
$\lambda\nu_0 = c$

$\lambda = \frac{c}{\nu_0} = \frac{3.00\times10^{8}\,m/s}{5.18\times10^{19}\,Hz} = \cancel{5.795\times10^{-12}m}\ 5.79\times10^{-12}m$

3a. Draw the following orbitals and show all nodes and phases that are present in each one. (6)

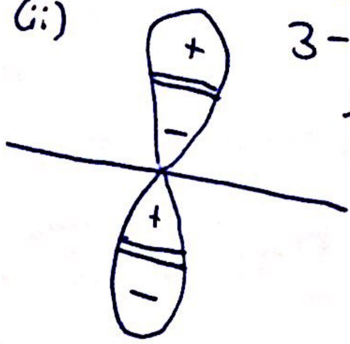
(i) $5d_{z^2}$ (ii) 3p





n-l-1
5-2-1=2 radial
l=2 planar

(ii)



n-l-1
3-1-1=1 radial
l=1 planar

6

3b. Sketch a graph of Ψ against the distance from the nucleus for a 3s orbital. (2)

3s

Probability Amplitude

2

3c. What two features of this graph are not easily interpreted physically although strictly correct? (2)

When $r \rightarrow 0$, Ψ is very large. This seems to suggest a high probability to find the electron near the nucleus, but it is the probability to find it by the volume of a sphere of radius r.

The graph also becomes negative. This doesn't mean negative probability, because amplitude isn't physical.

2

3d. By means of labeled diagrams show how each of these 'problems' can be resolved to provide a more physically meaningful representation of the 3s orbital in the hydrogen atom? (3)

3

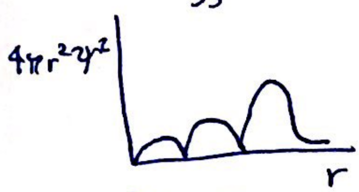
Issue of Amplitude

3s

Probability Density

Issue of Probability

3s



Radial Probability Distribution

tot 13

4a. Calculate the probability of finding an electron at a distance of one Bohr radius from the nucleus in a 1s orbital of a He^{+} ion, inside a volume of $(10.0 \times 10^{-12})^3$ cubic meters. (6)

5

$$\Psi_{1s} = (Z^3/\pi a_o^3)^{1/2} e^{-Zr/a_o}$$

$$\Psi_{1s} = \left(8/[\pi(5.29\times10^{-11} m)^3] \right)^{1/2} e^{-2a_o/a_o}$$

$$(4.14750197 5\times10^{15}) e^{-2} = 3.06\times10^{16} m^{-3}$$

Multiply by Volume => Prob: $(3.06\times10^{16} m^{-3})(10.0\times10^{-12} m)^3 = \boxed{3.06\times10^{-17}}$

4b. Calculate the average distance from nucleus of an electron in a 2p orbital in an ion of Li^{+2}. (6)

5

$$r_{nl} = (n^2 a_o / Z)\left(1 + \tfrac{1}{2}\left[1 - \frac{l(l+1)}{n^2}\right]\right)$$

n=2
l=1

$$= \left(\frac{4a_o}{3}\right)\left(1 + \tfrac{1}{2}\left[1 - \tfrac{2}{4}\right]\right)$$

$$= \frac{4}{3}a_o\left(1 + \tfrac{1}{4}\right) = \frac{4}{3}a_o\left(\tfrac{5}{4}\right) = \frac{20}{12}a_o$$

$$= \frac{20}{12}a_o = \frac{20}{12}(5.29\times10^{-11} m) = \boxed{8.82\times10^{-11} m}$$

Total 12