NAME:_____ Student Number:_____

Spring 2013 **Chemistry 1000 Midterm #1A** ____/ 52 marks

INSTRUCTIONS:
1) Please read over the test carefully before beginning. You should have six pages of questions and a formula/periodic table sheet.
2) If your work is not legible, it will be given a mark of zero.
3) Marks will be deducted for incorrect information added to an otherwise correct answer.
4) Marks will be deducted for improper use of significant figures and for missing or incorrect units.
5) Show your work for all calculations. Answers without supporting calculations will not be given full credit.
6) You may use a calculator.
7) You have 90 minutes to complete this test.

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam until after 8:00pm Mountain Time on Wednesday, February 13th, 2013. I understand that breaking this agreement would constitute academic misconduct, a serious offense with serious consequences. The minimum punishment would be a mark of 0/52 on this exam and removal of the "overwrite midterm mark with final exam mark" option for my grade in this course; the maximum punishment would include expulsion from this university.

Signature: _____ Date: _____
Course: CHEM 1000 (General Chemistry I)
Semester: Spring 2013
The University of Lethbridge

Spelling matters!

Fluorine = F Fluorene = $C_{13}H_{10}$

Flourine =



Question Breakdown

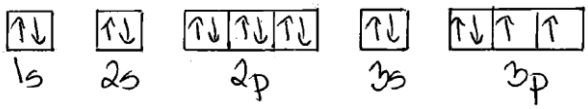
Q1	/ 5
Q2	/5
Q3	/5
Q4	/ 4
Q5	/ 2
Q6	/ 7
Q7	/ 4
Q8	/ 8
Q9	/ 5
Q10	/ 3
Q11	/ 4

Total	/ 52

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1. **[5 marks]**

(a) Draw the orbital occupancy diagram (aka "orbital box diagram") for sulfur (S). *Clearly label each subshell.* *[2 marks]*



(b) Write the electron configuration for sulfur. *Do not use the noble gas abbreviation.* *[1 mark]*

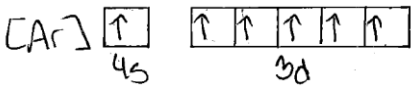
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$

(c) What is the charge of the most common ion of sulfur? Why? *[2 marks]*

-2 When two electrons are added to sulfur, the resulting electron configuration is $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$, the same as the nearest noble gas (argon)

2. *Due to a computer glitch, there wound up being two different versions of Version A. The only difference was this question. Both answers are given here.* **[5 marks]**

(a) Draw the <u>valence</u> orbital occupancy diagram (aka "orbital box diagram") for chromium (Cr). *Clearly label each subshell.* *[2 marks]*



(b) Write the electron configuration for chromium. *Use the noble gas abbreviation.* *[1 mark]*

$[Ar]\ 4s^1\ 3d^5$

(c) Briefly explain what is unusual about the electron configuration of chromium. *[1 mark]*

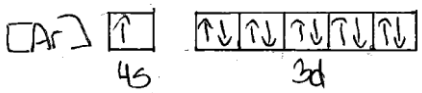
The electrons in chromium do not obey the aufbau order. The 4s subshell was not completely filled even though there are electrons in the 3d subshell.

(d) Write the electron configuration for the Cr^{2+} ion. *Use the noble gas abbreviation.* *[1 mark]*

$[Ar]\ 3d^4$

<u>or</u>

(a) Draw the <u>valence</u> orbital occupancy diagram (aka "orbital box diagram") for copper (Cu). *Clearly label each subshell.* *[2 marks]*



(b) Write the electron configuration for copper. *Use the noble gas abbreviation.* *[1 mark]*

$[Ar]\ 4s^1\ 3d^{10}$

(c) Briefly explain what is unusual about the electron configuration of copper. *[1 mark]*

The electrons in copper do not obey the aufbau order. The 4s subshell was not completely filled even though there are electrons in the 3d subshell.

(d) Write the electron configuration for the Cu^+ ion. *Use the noble gas abbreviation.* *[1 mark]*

$[Ar]\ 3d^{10}$

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3. The emission spectrum for hydrogen atoms contains four wavelengths of visible light:

410 nm, 434 nm, 486 nm, 656 nm

These lines are red, violet (purple), blue and cyan (blue-green). **[5 marks]**

(a) Match each colour to the appropriate wavelength: *[1 mark]*

red = _656_ nm violet = _410_ nm

Wavelength is inversely proportional to energy per photon. Within the visible region of the electromagnetic spectrum, red light has the longest wavelength while violet light has the shortest wavelength.

(b) Why was it an important observation that hydrogen atoms can only emit a limited number of wavelengths of light? How did this observation change our understanding of the structure of the atom? *[4 marks]*

- Before these observations, the Rutherford model was used to describe the atom. In this model, electrons existed in a cloud around the nucleus and could have any energy. If this was the case, electrons in any atom should be able to absorb (and later emit) light with any energy. Since energy is inversely proportional to wavelength ($E = \frac{hc}{\lambda}$), this can be restated as "electrons in any atom should be able to absorb (and later emit) light with any wavelength".
- The inconsistency between experimental evidence and the Rutherford model of the atom meant that this model could not be correct. It was replaced by the Bohr model of the atom, which introduced the concept of orbitals for electrons.
- In the Bohr model of the atom, the energy of electrons was quantized (i.e. there was a fixed set of allowed values). Each orbital had a specific allowed energy (though more than one orbital could have the same energy – e.g. the three different 2p orbitals have the same energy).
- Thus, an atom could only absorb (and later emit) light whose energy was equal to the difference in energy between two different orbitals. In this way, the Bohr model of the atom was consistent with the new experimental evidence.

Hydrogen can absorb (and later emit) more than just four wavelengths of light. It can also absorb (and later emit) various wavelengths in the infrared and ultraviolet regions of the spectrum. The key observation was that it didn't absorb <u>every</u> wavelength.

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4. A laser delivers light with a wavelength of 4.8 nm, and each pulse delivers 6.42×10^{-11} J of energy. If a single pulse from this laser is used to demonstrate the photoelectric effect, what is the maximum number of electrons that could be ejected from atoms in the metal? **[4 marks]**

Every photon can eject one electron from the metal. So, the maximum number of electrons that could be ejected from the metal is equal to the number of photons in the pulse of light.

To calculate the number of photons in the pulse of light, first calculate the energy of each photon in the pulse. Then compare the energy of a single photon to the energy in the whole pulse.

$$\lambda = 4.8nm \times \frac{1m}{10^9 nm} = 4.8 \times 10^{-9} m$$

$$c = \lambda\upsilon$$

$$\upsilon = \frac{c}{\lambda} = \frac{2.997925 \times 10^8 \frac{m}{s}}{4.8 \times 10^{-9} m} \times \frac{1Hz}{1\frac{1}{s}} = 6.2 \times 10^{16} Hz$$

$$E_{photon} = h\upsilon = \left(6.626070 \times 10^{-34} \frac{J}{Hz}\right)\left(6.2 \times 10^{16} Hz\right) = 4.1 \times 10^{-17} J$$

$$N_{photons} = \frac{E_{pulse}}{E_{photon}} = \frac{6.42 \times 10^{-11} J}{4.1 \times 10^{-17} \frac{J}{photon}} = 1.6 \times 10^6 \ photons$$

$$N_{electrons} = N_{photons} = 1.6 \times 10^6 \ electrons$$

2 sig. fig.

5. Use the equation $\Delta x \cdot \Delta p > \frac{h}{4\pi}$ to demonstrate why Heisenberg's uncertainty principle has the greatest effect on particles with small masses. **[2 marks]**

$p = mv$ therefore $\Delta p = \Delta(mv)$

Since the uncertainty in mass is usually negligible, $\Delta p = m\Delta v$.

Substituting this into $\Delta x \cdot \Delta p > \frac{h}{4\pi}$ gives $\Delta x \cdot (m\Delta v) > \frac{h}{4\pi}$ or $m \cdot \Delta x \cdot \Delta v > \frac{h}{4\pi}$

If mass (m) is small, either uncertainty in position (Δx), uncertainty in velocity (Δv) or both must be large in order for the three terms multiplied together to be larger than the constant ($h/4\pi$).

Many students tried to argue this backward, claiming that a large m meant that Δx and/or Δv would have to be small – but if all three terms are large then m·Δx·Δv will easily be larger than $h/4\pi$. When working with inequalities, you have to be very careful of the direction in which you argue.

It was also common for students to imply that only Δx was affected by changing the mass. For full marks, both Δx and Δv had to be addressed.

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6. **[7 marks]**

(a) How many different orbitals in a single atom can have $n = 3$? *[1 mark]*

9 *maximum # orbitals in shell = $n^2 = 3^2 = 9$*

(b) How many different electrons in a single atom can have $n = 3$? *[1 mark]*

18 *maximum of 2 electrons per orbital = 2×9=18*

(c) List all the orbitals in a single atom with $n = 3$ and clearly indicate the value of ℓ for each orbital. *You do not need to draw pictures of the orbitals.* *[5 marks]*

$\ell = 0$ $3s$

$\ell = 1$ $3p_x$ $3p_y$ $3p_z$

$\ell = 2$ $3d_{xy}$ $3d_{xz}$ $3d_{yz}$ $3d_{z^2}$ $3d_{x^2-y^2}$

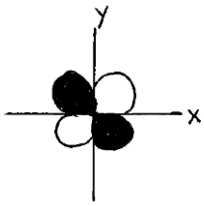
It was very clear from the answers to this question that many students were confused by what was meant by "listing" orbitals. When asked to name or list orbitals, give their labels (aka names) as I did above.

Since the confusion was fairly universal, credit was given to a variety of formats of answers (the most common alternative approach was to list sets of m_ℓ values); however, for full credit, the list needed to have nine orbitals with sufficient correct information to identify each (whether that was a complete set of quantum numbers or complete labels).

Simply listing 3s, 3p and 3d did not earn full credit as that is listing three subshells not nine orbitals.

7. **[4 marks]**

(a) Draw a $6d_{xy}$ orbital. *Include labeled axes and clearly show the phases. Do NOT draw the radial nodes.* *[1 mark]*



(b) Give one set of quantum numbers that could correspond to an electron in a $6d_{xy}$ orbital. *[2 marks]*

n = 6, $\ell = 2$, $m_\ell = +2$, $m_s = +½$

Other acceptable values for m_ℓ are +1, 0, -1 or -2. The other acceptable value for m_s is –½ . Listing ranges is not acceptable. Every electron has one value for each number.

(c) How many radial nodes are there in a $6d_{xy}$ orbital? *[1 mark]*

3

Total number of nodes = n - 1 = 6 – 1 = 5. Number of planar nodes = ℓ = 2.
Since all nodes are either planar or radial, there are 3 radial nodes.

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8. Complete the table below. Only complete the last column for isotopes which you have identified as radioactive. **[8 marks]**

Isotope	**N**	**Z**	**Radioactive?** *(circle yes or no)*	**Predict mode(s) of decay: name the type of decay and write a balanced chemical equation** *(for radioactive isotopes only)*
^{23}Na	12	11	no	
^{30}Na	19	11	yes	beta emission: $^{30}_{11}Na \rightarrow ^{30}_{12}Mg + ^{0}_{-1}\beta$
^{55}Zn	25	30	yes	positron emission: $^{55}_{30}Zn \rightarrow ^{55}_{29}Cu + ^{0}_{+1}\beta$ or electron capture: $^{55}_{30}Zn + ^{0}_{-1}e \rightarrow ^{55}_{29}Cu$

- *Some students suggested alpha decay for ^{55}Zn, but alpha decay only lowers N/Z if N>Z. Theoretically, alpha decay cannot occur in isotopes with Z < 28 (maximum on binding energy curve), and it has never been observed in isotopes with Z < 52.*
- *Some students tried to use multiple decays to get a stable isotope as a product; however, each of these reactions is a separate decay with a separate equation. Also, it may take several decays of different types to reach a stable isotope (see examples of decay series in lecture notes).*

9. **[5 marks]**

(a) Explain why half-life is an important consideration when choosing an isotope for radioactive dating of a sample. Your answer should clearly address the consequences of choosing an isotope with an inappropriate half-life. *[4 marks]*

- Half-life refers the length of time that it takes for a reaction to proceed halfway. As such, it is a measure of how quickly a radioactive isotope decays.
- If an isotope is chosen whose half-life is too short, the isotope will have decayed too quickly, and there will no longer be a measurable amount of that isotope left in the sample.
- If an isotope is chosen whose half-life is too long, the isotope will not have decayed quickly enough, and there will not be a measurable difference between the initial amount of isotope and current amount of isotope.

(b) Suggest a range of reasonable half-lives for isotopes that would be useful in radioactive dating of a sample suspected to be 25,000 years old. *[1 mark]*

2,500 years to 250,000 years

I was just looking for a reasonable estimate (educated guess). For full marks, the range of half-lives needed to include the estimated age of the sample and not be overly huge.

If the half-life of the radioactive isotope were equal to the age of the item, the amount of that isotope would have decreased by half, giving a substantial and measurable change AND half of that isotope would remain, an amount which should be readily detectable.

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The utility of each isotope varies depending on a variety of factors; however, a reasonable prediction would be that most radioactive isotopes can be used to date items with estimated ages between 1/10th of their half-life and ten times their half-life.

Some isotopes offer even wider ranges than this. e.g. ^{14}C is useful from 1/30th to ten times its half-life; ^{234}U is useful from 1/50th to eight times its half-life

10. If a sample of radioactive material has a half-life of 16 hours, how long will it take for 80.% of the sample to decay? **[3 marks]**

If 80.% of the sample decays then 20.% is left. Therefore, N = 0.20 N_o (or N_2 = 0.20 N_1).

First, calculate the decay constant (k) from the half-life ($t_{½}$).

Then use $\ln\left(\frac{N_2}{N_1}\right) = -k(t_2 - t_1)$ to solve for the time (or $t_2 - t_1$) it takes for that decay.

$$\ln(2) = k \cdot t_{1/2}$$
$$k = \frac{\ln(2)}{t_{1/2}} = \frac{\ln(2)}{16h} = 0.043\,\tfrac{1}{h} = 0.043h^{-1}$$

$$\ln\left(\frac{N_2}{N_1}\right) = -k(t_2 - t_1)$$
$$t_2 - t_1 = \frac{\ln\left(\frac{N_2}{N_1}\right)}{-k} = \frac{\ln\left(\frac{0.20N_1}{N_1}\right)}{-0.043\,\frac{1}{h}} = \frac{\ln(0.20)}{-0.043\,\frac{1}{h}} = 37h$$

11. The first step in the actinium decay chain is the decay of ^{239}Pu to ^{235}U. Calculate the energy change for this reaction. *Report your answer in J/mol.* **[4 marks]**

First, write a balanced chemical equation to ensure that all reactants and products are accounted for.

$$^{239}_{94}Pu \rightarrow ^{235}_{92}U + ^{4}_{2}\alpha$$

Then find the mass difference for this nuclear reaction. All reactants and products except beta particles (electrons) must be included.

Finally, use the mass difference to find the energy change for the reaction. Expect the energy change to be negative since the reaction occurs.

$$\Delta m = m_{products} - m_{reactants} = \left(235.043930\,\tfrac{g}{mol} + 4.001506179\,\tfrac{g}{mol}\right) - \left(239.052163\,\tfrac{g}{mol}\right) = -0.006727\,\tfrac{g}{mol}$$

addition/subtraction so 6 decimal places

$$\Delta E = \Delta mc^2 = \left(-0.006727\,\tfrac{g}{mol}\right)\left(\frac{1kg}{1000g}\right)\left(2.997925\times10^{8}\,\tfrac{m}{s}\right)^2\left(\frac{1J}{1\,\frac{kg\cdot m^2}{s^2}}\right) = -6.046\times10^{11}\,\tfrac{J}{mol}$$ 4 sig. fig.

Exact masses of the isotopes are available on the data sheet.

It is incorrect to add up masses of protons, neutrons and electrons since you have no data available for the binding energies of each isotope.

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Some Useful Constants and Formulae

Fundamental Constants and Conversion Factors

Atomic mass unit (u)	$1.660\,539 \times 10^{-27}$ kg	Planck's constant	$6.626\,070 \times 10^{-34}$ J·Hz^{-1}
Avogadro's number	$6.022\,141 \times 10^{23}$ mol^{-1}	Proton mass	1.007 277 u
Bohr radius (a_0)	$5.291\,772 \times 10^{-11}$ m	Neutron mass	1.008 665 u
Electron charge (e)	$1.602\,177 \times 10^{-19}$ C	Rydberg Constant (R_H)	$2.179\,872 \times 10^{-18}$ J
Electron mass	$5.485\,799 \times 10^{-4}$ u	Speed of light in vacuum	$2.997\,925 \times 10^{8}$ m·s^{-1}

Formulae

$$c = \lambda\upsilon \qquad E = h\upsilon \qquad p = mv \qquad \lambda = \frac{h}{p} \qquad \Delta x \cdot \Delta p > \frac{h}{4\pi}$$

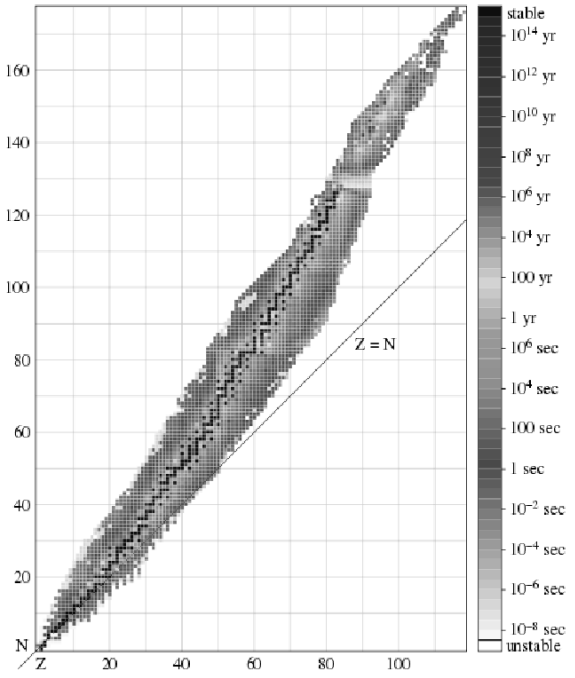
$$r_n = a_0 \frac{n^2}{Z} \qquad E_n = -R_H \frac{Z^2}{n^2} \qquad E_k = \frac{1}{2}mv^2$$

$$\Delta E = \Delta m c^2 \qquad A = -\frac{\Delta N}{\Delta t} \qquad A = kN \qquad \ln\left(\frac{N_2}{N_1}\right) = -k(t_2 - t_1) \qquad \ln(2) = k \cdot t_{1/2}$$

Some Useful Masses

$^{239}_{94}Pu$	239.052 163 u
$^{235}_{92}U$	235.043 930 u
$^{4}_{2}\alpha$	4.001 506 179 u
$^{1}_{1}p$	1.007 276 467 u
$^{1}_{0}n$	1.008 664 916 u

Band of Stability Graph



The graph at the right shows the band of stability. Stable isotopes are in black. Isotopes that exist but are not stable are shown in varying shades of gray with the shades of gray corresponding to different half-lives.

The original version of the graph used a rainbow colour scale.
http://commons.wikimedia.org/wiki/File:Isotopes_and_half-life_eo.svg

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CHEM 1000 Periodic Table

1																	18
1.0079 **H** 1	**2**											**13**	**14**	**15**	**16**	**17**	4.0026 **He** 2
6.941 **Li** 3	9.0122 **Be** 4											10.811 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	20.1797 **Ne** 10
22.9898 **Na** 11	24.3050 **Mg** 12	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	26.9815 **Al** 13	28.0855 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.4527 **Cl** 17	39.948 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	44.9559 **Sc** 21	47.88 **Ti** 22	50.9415 **V** 23	51.9961 **Cr** 24	54.9380 **Mn** 25	55.847 **Fe** 26	58.9332 **Co** 27	58.693 **Ni** 28	63.546 **Cu** 29	65.39 **Zn** 30	69.723 **Ga** 31	72.61 **Ge** 32	74.9216 **As** 33	78.96 **Se** 34	79.904 **Br** 35	83.80 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.94 **Mo** 42	(98) **Tc** 43	101.07 **Ru** 44	102.906 **Rh** 45	106.42 **Pd** 46	107.868 **Ag** 47	112.411 **Cd** 48	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	131.29 **Xe** 54
132.905 **Cs** 55	137.327 **Ba** 56	**La-Lu**	178.49 **Hf** 72	180.948 **Ta** 73	183.85 **W** 74	186.207 **Re** 75	190.2 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	204.383 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(210) **Po** 84	(210) **At** 85	(222) **Rn** 86
(223) **Fr** 87	226.025 **Ra** 88	**Ac-Lr**	(261) **Rf** 104	(262) **Db** 105	(263) **Sg** 106	(262) **Bh** 107	(265) **Hs** 108	(266) **Mt** 109	(281) **Dt** 110	(283) **Rg** 111							

138.906 **La** 57	140.115 **Ce** 58	140.908 **Pr** 59	144.24 **Nd** 60	(145) **Pm** 61	150.36 **Sm** 62	151.965 **Eu** 63	157.25 **Gd** 64	158.925 **Tb** 65	162.50 **Dy** 66	164.930 **Ho** 67	167.26 **Er** 68	168.934 **Tm** 69	173.04 **Yb** 70	174.967 **Lu** 71
227.028 **Ac** 89	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	237.048 **Np** 93	(240) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(258) **Md** 101	(259) **No** 102	(260) **Lr** 103

Developed by Prof. R. T. Boeré