Fall 2022 **Chemistry 1000 Midterm #1X** ____/66 marks

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 Thursday, October 13th, 2022. I understand that breaking this agreement would constitute academic misconduct. The minimum penalty would be a mark of 0/66 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 8 pages of questions (three pages double-sided).
2) You have also been given a data sheet. It does not have a QR code, so nothing written on it will be graded.
3) **DO NOT WRITE ON ANY QR CODE!!!** Work on pages without a QR code will not be graded.
4) You may use a calculator but only for calculation. No other electronic devices are allowed.
5) If your work is not legible, it will be given a mark of zero.
6) Show your work. Answers without supporting reasoning or calculations will not get full credit
7) Marks will be deducted for incorrect information added to an otherwise correct answer.
8) Marks will be deducted for improper use of significant figures and for missing or incorrect units. Show units in every step of all calculations. Significant figures will only be checked in final answers. If a question has subparts (a, b, c, etc.), the answer to each subpart is considered a "final answer".
9) You have 90 minutes to complete this test.

Question Breakdown

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13		Total
/ 5	/ 10	/ 8	/ 4	/ 2	/ 9	/ 3	/ 3	/ 5	/ 4	/ 6	/ 2	/ 5		/ 66

1. Complete the following table. **[5 marks]**

Please m*ake sure that your symbol is formatted in the same way as the example given.*

Symbol	Atomic Number	Mass Number	Number of Protons	Number of Neutrons	Number of Electrons
$^{190}_{76}Os^{2+}$	76	190	76	114	74
$^{82}_{34}Se^{2-}$	34	82	34	48	36

2. Consider a neutral atom of phosphorus (P) in the ground state. **[10 Marks]**

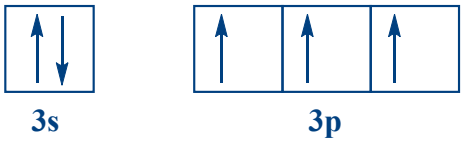
(a) Write the electron configuration for P using line notation. *[2 marks]*

Do <u>not</u> use the noble gas abbreviation.

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

(b) Draw the orbital occupancy diagram for the <u>valence</u> electrons of P. *[3 marks]*

Label each subshell. Do <u>not</u> include core electrons.



(c) Is P paramagnetic or diamagnetic? Briefly explain your choice. *[2 marks]*

paramagnetic

It has at least one unpaired electron giving it a net electron spin.

(d) Consider each set of quantum numbers listed below. Circle "yes" or "no" to indicate whether each set could correspond to an electron in a ground-state neutral atom of phosphorus. *[3 marks]*

- $n = 1,\ l = 0\ , m_l = 0,\ m_s = +\frac{1}{2}$ — YES / NO
- $n = 2,\ l = 2\ , m_l = 1,\ m_s = +\frac{1}{2}$ — YES / NO
- $n = 3,\ l = 1\ , m_l = 2,\ m_s = -\frac{1}{2}$ — YES / NO

3. Consider a neutral atom of cobalt (Co) in the ground state. **[8 marks]**

(a) Write the electron configuration for Co. *Use the noble gas abbreviation.* *[2 marks]*

$[Ar]4s^2 3d^7$

(b) How many valence electrons does Co have? *[1 mark]*

9

(c) Write the electron configuration for Co^{3+}. *Use the noble gas abbreviation.* *[1 mark]*

$[Ar]3d^6$

(d) List <u>one</u> set of quantum numbers that could correspond to one of the <u>valence</u> electrons in Co^{3+}.

[2 marks]

$n = 3$, $l = 2$, $m_l = 0$, $m_s = +\frac{1}{2}$

This is a sample answer. While n must be 3 and l must be 2 , m_l may be any <u>one</u> of +2, +1, 0, -1 or -2 and m_s may be either + ½ or – ½.

(e) List <u>one</u> set of quantum numbers that could correspond to a <u>different</u> valence electron in the same Co^{3+} ion.

$n = 3$, $l = 2$, $m_l = +1$, $m_s = +\frac{1}{2}$ *[2 marks]*

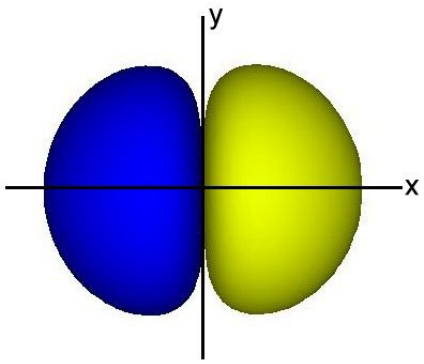
This is a sample answer. The "allowed" values are the same as those for part (d); however, since this is a different valence electron, the set of four quantum numbers may not be identical. As such, at least one of m_l and m_s must be different from the value given in part (d).

4. Sketch each of the following atomic orbitals. Do not attempt to draw radial nodes. **[4 marks]**

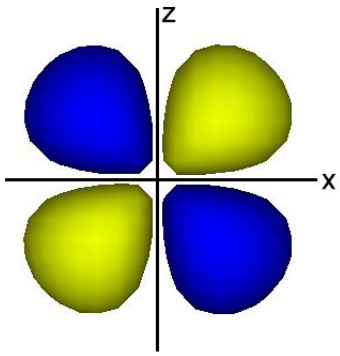
Each diagram should include:

- a drawing of the orbital on clearly labeled axes so that its orientation is clear, and
- relative phases shown using appropriate shading or colours.

(a) $4p_x$



(b) $4d_{xz}$



5. For each of the orbitals listed in the previous question, identify the number of planar nodes and the number of radial nodes. **[2 marks]**

(a) $4p_x$ has __1__ planar nodes and __2__ radial nodes.

(b) $4d_{xz}$ has __2__ planar nodes and __1__ radial nodes.

6. Of the first 20 elements on the periodic table, He, Ne and Ar have the highest first ionization energies but Li, Na and K have the highest second ionization energies. **[9 marks]**

(a) Use both words and sample balanced chemical equations to define the terms "first ionization energy" and "second ionization energy". It must be clear which words/equations you are using to explain each term. *[4 marks]*

First Ionization Energy

The energy required to remove one electron from a neutral atom in the gas phase:

$A_{(g)} \rightarrow A^{+}_{(g)} + e^{-}$

Second Ionization Energy

The energy required to remove one electron from a cation with a +1 charge in the gas phase:

$A^{+}_{(g)} \rightarrow A^{2+}_{(g)} + e^{-}$

(b) Write the electron configurations for Li, Na and K. *Use the noble gas abbreviation.* *[3 marks]*

Li $[He]2s^1$

Na $[Ne]3s^1$

K $[Ar]4s^1$

(c) Explain why Li, Na and K have the highest second ionization energies of the first 20 elements. *[2 marks]*

A complete answer will address how the second ionization energy differs from the first ionization energy in these atoms.

The first electron to be removed from Li, Na or K will be its only valence electron. This only requires a small amount of energy because the valence electron is significantly shielded from the positive charge of the nucleus by all of the core electrons.

Since the only valence electron is removed when converting Li, Na or K to Li^{+}, Na^{+} or K^{+}, a second ionization (giving Li^{2+}, Na^{2+} or K^{2+}) would require removal of a core electron. Core electrons are not as strongly shielded from the positive charge of the nucleus and therefore require much more energy to remove.

7. In CHEM 1000, seven classes of nuclear reactions were discussed. For each of the following reactions, identify which of those seven classes it belongs to. **[3 marks]**

(a) $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$ alpha decay *or* alpha emission

(b) $^{9}_{4}Be + {}^{2}_{1}H \rightarrow {}^{10}_{5}B + {}^{1}_{0}\mathrm{n}$ fusion

(c) $^{235}_{92}U + {}^{1}_{0}\mathrm{n} \rightarrow {}^{152}_{60}Nd + {}^{81}_{32}\mathrm{Ge} + 3\,{}^{1}_{0}\mathrm{n}$ fission

8. Complete and balanced each of the following nuclear reaction equations by filling in all boxes (or, if the box is too small to write in, writing the relevant number/symbol immediately next to the box). **[3 marks]**

(a) $^{59}_{27}Co + \boxed{{}^{1}_{0}n} \rightarrow {}^{60}_{27}Co$

(b) $^{246}_{96}Cm + \boxed{{}^{13}_{6}C} \rightarrow {}^{254}_{102}No + 5\,{}^{1}_{0}\mathrm{n}$

(c) $^{214}_{83}\mathrm{Bi} \rightarrow {}^{214}_{84}Po + {}^{0}_{-1}\beta$

9. For each of the following nuclides: **[5 marks]**

- Indicate whether it is expected to be stable or unstable. Explain your choice.
- If it is expected to be unstable, predict the most likely mode(s) of decay for the nuclide. Explain your choice. *(If two modes of decay are equally likely, please name both.)*

(a) ${}^{123}_{56}Ba$ $Z = 56$ $N = 67$ $\frac{N}{Z} = \frac{67}{56} = 1.2$

This isotope is expected to be unstable because it lies below the Band of Stability.

The most likely mode of decay is either electron capture or positron emission because either of those modes of decay would convert a proton into a neutron, bringing the nuclide closer to the Band of Stability:

${}^{1}_{1}p + {}^{0}_{-1}e \rightarrow {}^{1}_{0}n$ or ${}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{1}\beta^{+}$

(b) ${}^{20}_{10}Ne$ $Z = 10$ $N = 10$ $\frac{N}{Z} = \frac{10}{10} = 1$

This isotope is expected to be stable because it lies on the Band of Stability.

10. Strontium-90 $({}^{90}_{38}Sr)$ is a radioactive by-product of nuclear reactions. It has a half-life of 29 years. If a sample of strontium-90 has an initial activity of $1.2 \times 10^{12}\ Bq$, how much time will it take for the sample's activity to decrease to $2.9 \times 10^{11}\ Bq$? **[4 marks]**

Report your answer in years.

Step 1: Calculate decay constant (k)

$ln(2) = k \cdot t_{1/2}$ therefore $k = \frac{ln(2)}{t_{1/2}} = \frac{ln(2)}{29\ y} = 0.024\ y^{-1}$

Step 2: Calculate time required for described decay $(\Delta t = t_2 - t_1)$

$ln\left(\frac{A_2}{A_1}\right) = -k\Delta t$ therefore $\Delta t = -\frac{ln\left(\frac{A_2}{A_1}\right)}{k} = -\frac{ln\left(\frac{2.9\times10^{11}\ Bq}{1.2\times10^{12}\ Bq}\right)}{0.024\ y^{-1}} = -\frac{ln(0.24)}{0.024\ y^{-1}} = -\frac{-1.42}{0.024\ y^{-1}} = 59\ y$

This is the easiest approach to this question; however, you can also rearrange $A_2 = A_1\left(\frac{1}{2}\right)^{\Delta t/t_{1/2}}$ to isolate Δt. That gives the same answer.

11. A particular metal has a threshold energy* of 222.2 kJ/mol. What is the maximum wavelength of light that will allow an electron to be removed from this metal in a photoelectric effect experiment?

Report your answer in nm. **[6 marks]**

*The terms "work function" and "threshold energy" have the same meaning.

The maximum wavelength of light that can eject an electron from a metal in a photoelectric effect experiment is the wavelength corresponding to light where each photon carries the threshold energy for that metal.

Step 1: Convert the threshold energy from kJ/mol into J/photon

$$E_{photon} = 222.2\,\frac{kJ}{mol} \times \frac{1000\,J}{1\,kJ} \times \frac{1\,mol}{6.022\,141 \times 10^{23}} = 3.690.\times 10^{-19} J$$

Step 2: Calculate the frequency of a photon carrying that energy

$$E_{photon} = h\nu \text{ therefore } \nu = \frac{E_{photon}}{h} = \frac{3.690 \times 10^{-19} J}{6.626\,070 \times 10^{-34} \frac{J}{Hz}} = 5.568 \times 10^{14}\ Hz$$

Step 3: Calculate the wavelength of a photon carrying that energy

$$c = \lambda\nu \text{ therefore } \lambda = \frac{c}{\nu} = \frac{2.997\,925 \times 10^{8}\,\frac{m}{s}}{5.568 \times 10^{14}\ Hz} = 5.384 \times 10^{-7}\ m$$

Step 4: Convert wavelength into nm

$$\lambda = 5.384 \times 10^{-7}\ m \times \frac{10^{9}\ nm}{1\ m} = 538.4\ nm$$

Steps 2 and 3 can be combined using $E_{photon} = \frac{hc}{\lambda}$

12. Consider a successful photoelectric effect experiment (one in which electrons are ejected from the metal). Briefly explain how each of the following modifications would change the outcome of the experiment.

Treat each modification separately. They are <u>NOT</u> sequential and should not be combined. **[2 marks]**

(a) The intensity of the light shone on the metal is doubled.

The current doubles. (Twice as many electrons are ejected.)

(b) The frequency of the light shone on the metal is doubled.

The kinetic energy of the ejected electrons increases.

The kinetic energy does <u>not</u> double. It actually increases by more than that because not all of the energy of the photons in the first experiment turned into kinetic energy; some of it was used to excite the electron out of the atom (the threshold energy or "work function"). When the frequency of the light is doubled, the energy of each photon is doubled – but ALL of that extra energy gets turned into kinetic energy; none of it has to be "spent" exciting the electron out of the atom. This is because each photon can still only eject one electron.

13. A ground-state hydrogen atom absorbs a photon of UV light which excites its electron into the $n = 4$ orbital. Calculate the change in energy of the atom. **[5 marks]**

Report your answer in J.

Step 1: Calculate the energy of the ground-state hydrogen atom

It's ground-state therefore $n = 1$

It's hydrogen therefore $Z = 1$

$$E_{n=1} = -R_H \frac{Z^2}{n^2} = -(2.179\,872 \times 10^{-18}\,J)\frac{(1)^2}{(1)^2} = -2.179\,872 \times 10^{-18}\,J$$

Step 2: Calculate the energy of the hydrogen atom with the electron in $n = 4$

It's hydrogen therefore $Z = 1$

$$E_{n=4} = -R_H \frac{Z^2}{n^2} = -(2.179\,872 \times 10^{-18}\,J)\frac{(1)^2}{(4)^2} = -1.362\,420 \times 10^{-19}\,J$$

Step 3: Calculate the energy change for the hydrogen atom

$$\Delta E = E_{n=4} - E_{n=1} = (-1.362\,420 \times 10^{-19}\,J) - (-2.179\,872 \times 10^{-18}\,J) = 2.043\,630 \times 10^{-18}\,J$$