Fall 2025 **Chemistry 1000 Midterm #1X** ____/66 marks

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam with (or in the presence of) any CHEM 1000 student who has yet to write it. 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 6 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**				**Total**
/ 8	/ 3	/ 3	/ 4	/ 6	/ 2	/ 4	/ 6	/ 10	/ 6	/ 14				/ 66

1. Fill in each blank with the word, phrase or symbol that best completes the sentence. **[8 marks]**

(a) The charge for the most common monoatomic ion formed from oxygen is **-2**. The electron configuration for that ion is **$1s^2 2s^2 2p^6$**. *Do not use the noble gas abbreviation.*

(b) An atomic orbital with $n = 5$ and $l = 3$ would be referred to as the **$5f$** orbital. It would have **3** planar node(s) and **1** radial node(s).

(c) Wave-particle duality is an important concept in quantum theory.
The photoelectric effect experiment demonstrated that light can act as **particles** *or* **photons**.
The fact that electrons can be diffracted demonstrated that they can act as **waves**.

(d) According to Heisenberg's Uncertainty Principle, increasing the precision with which an electron's momentum is known must decrease the precision with which its **location** *or* **position** can be known.

2. Complete the following table with the number of protons, neutrons and electrons in each species.
[3 marks]

Ion	# protons	# neutrons	# electrons
$^{96}_{42}Mo$	42	54	42
$^{96}_{42}Mo^{2+}$	42	54	40

3. ^{6}He is an unstable nuclide. **[3 marks]**

(a) Calculate the N/Z ratio for ^{6}He. *[1 mark]*

$\frac{N}{Z} = \frac{4}{2} = 2$

(b) Predict the most likely mode of decay for ^{6}He. *[1 mark]*

If there is more than one equally likely mode, choose one.

beta emission

(c) Write a balanced nuclear equation for the decay of ^{6}He. *[1 mark]*

$^{6}_{2}He \rightarrow {}^{6}_{3}Li + {}^{0}_{-1}\beta$

4. Carbon has three naturally occurring isotopes with the following isotopic masses: **[4 marks]**

- carbon-12 has an isotopic mass of 12.000 000 u
- carbon-13 has an isotopic mass of 13.003 355 u
- carbon-14 has an isotopic mass of 14.003 242 u

The natural abundance of carbon-13 varies according to location. At the bottom of the northern Pacific Ocean, the abundance is at its lowest (no pun intended), at 0.9629%. The average atomic mass of carbon in the area is 12.00966 u.

Is carbon-14 measurably contributing to this average atomic mass?

Step 1: Calculate the percent abundance of $^{12}_{6}C$ if there were no carbon-14

$\%_{C-12} = 100\% - \%_{C-13} = 100\% - 0.9629\% = 99.0371\%$

Subtracting a number with 4 decimal places from an exact number, so answer has 4 decimal places (6 sig. fig.).

Step 2: Calculate the average atomic mass of carbon if there were no carbon-14

$$M_C = \frac{\%_{C-12}}{100\%} M_{C-12} + \frac{\%_{C-13}}{100\%} M_{C-13}$$

$$M_C = \left(\frac{99.0371\%}{100\%}\right)(12.000\,000\,u) + \left(\frac{0.9629\%}{100\%}\right)(13.003\,355\,u)$$

$$M_C = 11.8845\,u + 0.1252\,u$$

$$M_C = 12.0097\,u$$

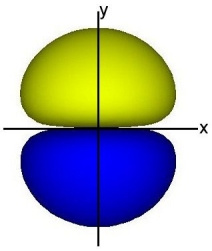
Adding two numbers with 4 decimal places, so answer has 4 decimal places (6 sig. fig).

Therefore, since the "if there were no carbon-14" mass matches the observed average atomic mass, carbon-14 is not measurably contributing to the observed average atomic mass.

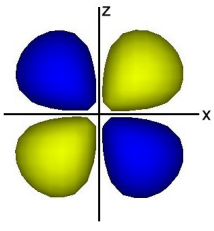
5. Sketch each of the following atomic orbitals. It is **not** necessary to draw radial nodes. **[6 marks]**
Each diagram should include:

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

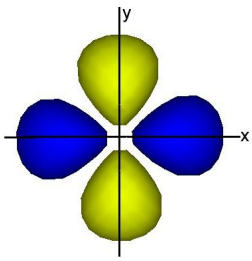
(a) $2p_y$



(b) $3d_{xz}$



(c) $3d_{x^2-y^2}$



6. For each of the following reactions, indicate whether the energy change can be calculated using Bohr's equation by writing either "YES" or "NO" next to the equation. **[2 marks]**

(a) $Rb^{36+} \rightarrow Rb^{37+} + e^-$ yes

(b) $Al^{2+} \rightarrow Al^{3+} + e^-$ no

7. Neither of the following sets of quantum numbers can correspond to any electron. For each set, briefly explain which number is wrong and how it can be changed to give an allowed set of quantum numbers. *If there is more than one way to "fix" the set of quantum numbers, choose one.* **[4 marks]**

(a) $n = 3, l = 1, m_l = 0, m_s = -1$

The only allowed values for m_s of an electron are $+\frac{1}{2}$ and $-\frac{1}{2}$ so change the set to $n = 3, l = 1, m_l = 0, m_s = +\frac{1}{2}$ *or*
$n = 3, l = 1, m_l = 0, m_s = -\frac{1}{2}$

(b) $n = 4, l = 1, m_l = 2, m_s = +\frac{1}{2}$

The only allowed values for m_l are integers from $+l$ to $-l$. As such, the absolute value of m_l cannot be greater than the value of l. Change the set to one of the following:
$n = 4, l = 3, m_l = 2, m_s = +\frac{1}{2}$ *or*
$n = 4, l = 2, m_l = 2, m_s = +\frac{1}{2}$ *or*
$n = 4, l = 1, m_l = 1, m_s = +\frac{1}{2}$ *or*
$n = 4, l = 1, m_l = 0, m_s = +\frac{1}{2}$ *or*
$n = 4, l = 1, m_l = -1, m_s = +\frac{1}{2}$

8. Neither of the following electron configurations can correspond to any ground state atom. For each electron configuration, explain what is wrong, give the correct electron configuration for a ground state atom with the same number of electrons and identify the corresponding neutral element. **[6 marks]**

Incorrect electron configuration	**Why is it incorrect?**	**Correct electron configuration**	**Element symbol**
$1s^2 2p^1$	The aufbau order was not followed ($2s$ was skipped) so this is an excited state.	$1s^2 2s^1$	Li
$1s^2 2s^2 2p^6 3s^3$	An atom cannot have more than 2 electrons in the $3s$ subshell.	$1s^2 2s^2 2p^6 3s^2 3p^1$	Al

9. Consider a neutral atom of cobalt (Co) in the ground-state. **[10 marks]**

(a) Explain the difference between the terms "diamagnetic" and "paramagnetic". *[2 marks]*

All the electrons in a diamagnetic substance are spin-paired; a paramagnetic substance contains at least one electron that is not spin-paired.

or A paramagnetic substance is attracted to a magnetic field; a diamagnetic substance is not. (A diamagnetic substance is weakly repelled by a magnetic field.)

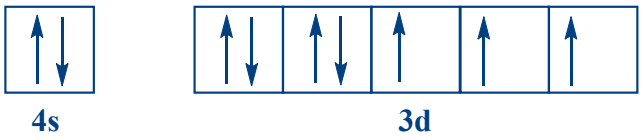
(b) Write the electron configuration for Co. Do NOT use the noble gas abbreviation. *[1 mark]*

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^7$

(c) Write the electron configuration for Co using the noble gas abbreviation. *[1 mark]*

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

(d) Draw an orbital occupancy diagram ("orbital box diagram") showing the **valence** electrons of Co. Label all subshells. Based on your diagram, is Co diamagnetic or paramagnetic? *[4 marks]*



(e) Write the electron configuration for Co^{3+} using the noble gas abbreviation. *[2 marks]*

$[Ar]3d^6$

10. My favorite transition metal has a threshold energy (also called "work function") of 716.0 kJ/mol. Calculate the wavelength of the photon that represents the minimum energy needed for a "positive" photoelectric effect. *Report your answer in nm.* **[6 marks]**

Step 1: Convert the threshold energy from kJ/mol into J/photon (which may just be expressed as J)

$$E = 716.0\ \frac{kJ}{mol} \times \frac{1000\ J}{1\ kJ} = 7.160\ \times\ 10^5\ \frac{J}{mol}$$

$$E = 7.160\ \times\ 10^5\ \frac{J}{mol} \times \frac{1\ mol}{6.022\ 141 \times 10^{23}\ photons} = 1.189\ \times\ 10^{-18}\ \frac{J}{photon}$$

Step 2: Calculate the threshold frequency

$$E = h \cdot \nu$$

$$\nu = \frac{E}{h} = \frac{1.189 \times 10^{-18}\ J}{6.626\ 070 \times 10^{-34}\ \frac{J}{Hz}} = 1.794 \times\ 10^{15}\ Hz$$

Step 3: Calculate the threshold wavelength in meters

$$c = \lambda \cdot \nu$$

$$\lambda = \frac{c}{\nu} = \frac{2.997\ 925 \times 10^8\ \frac{m}{s}}{1.794 \times 10^{15}\ Hz} \times \frac{1\ Hz}{1\ s^{-1}} = 1.671 \times 10^{-7}\ m$$

Step 4: Convert the threshold wavelength into nanometers

$$\lambda = 1.671 \times 10^{-7}\ m \times \frac{10^9\ nm}{1\ m} = 167.1\ nm$$

11. Bismuth only has one naturally occurring isotope, bismuth-209 $\left({}^{209}Bi\right)$. It was once believed that this was the heaviest stable isotope. However, in 2003, it was reported that ${}^{209}Bi$ undergoes alpha decay, with a half-life of 1.9×10^{19} years. This was discovered by measuring decay from 136.9 g of BGO $(Bi_4Ge_3O_{12})$.

[14 marks]

(a) How many atoms of bismuth-209 were present in the 136.9 g sample of BGO? *[4 marks]*

Step 1: Calculate molar mass of BGO

$$M_{BGO} = 4M_{Bi} + 3M_{Ge} + 12M_O$$

$$M_{BGO} = 4\left(208.980\ \frac{g}{mol}\right) + 3\left(72.60\ \frac{g}{mol}\right) + 12\left(15.9994\ \frac{g}{mol}\right) = 1245.71\ \frac{g}{mol}$$

Step 2: Calculate moles of BGO

$$n_{BGO} = 136.9\ g\ BGO\ \times \frac{1\ mol}{1245.71\ g} = 0.1099\ mol\ BGO$$

Step 3: Calculate number of molecules of BGO

$$N_{BGO} = 0.1099\ mol\ BGO \times \frac{6.022\ 141 \times 10^{23}\ molecules}{1\ mol} = 6.618 \times 10^{22}\ molecules\ BGO$$

Step 4: Calculate number of atoms of bismuth-209

$$N_{Bi} = 6.618 \times 10^{22}\ molecules\ BGO \times \frac{4\ atoms\ Bi}{1\ molecule\ BGO} = 2.647 \times 10^{23}\ atoms\ Bi$$

(b) Calculate the decay constant for ${}^{209}Bi$. *[2 marks]*

Report your answer in $years^{-1}$.

$$ln(2) = k \cdot t_{1/2}$$

$$k = \frac{ln(2)}{t_{1/2}} = \frac{ln(2)}{1.9 \times 10^{19}\ \text{years}} = 3.6\ \times 10^{-20}\ \text{years}^{-1}$$

(c) How long would it take for the bismuth in the 136.9 g sample of BGO to emit exactly 10^{22} alpha particles? *[3 marks]*

Report your answer in years.

Step 1: Organize information

$k = 3.6\ \times 10^{-20}\ \text{years}^{-1}$ *(from part (b) of this question)*

$N_1 = 2.647 \times 10^{23}\ atoms\ Bi$ *(from part (a) of this question)*

$N_2 = 2.647 \times 10^{23}\ atoms\ Bi - 10^{22}\ atoms\ Bi$ *(each atom that decays emits one alpha particle)*

$N_2 = 2.547 \times 10^{23}\ atoms\ Bi$

Step 2: Calculate Δt

$$ln\left(\frac{N_2}{N_1}\right) = -k\Delta t$$

$$\Delta t = -\frac{ln\left(\frac{N_2}{N_1}\right)}{k}$$

$$\Delta t = -\frac{ln\left(\frac{2.547 \times 10^{23}\ atoms\ Bi}{2.647 \times 10^{23}\ atoms\ Bi}\right)}{3.6 \times 10^{-20}\ \text{years}^{-1}} = 1.1 \times 10^{18}\ years$$

(d) Calculate the energy released by alpha decay of bismuth-209. *[5 marks]*

Report your answer in J/mol.

$^{209}_{84}Po$	208.982 431 u
$^{209}_{83}Bi$	208.980 399 u
$^{209}_{82}Pb$	208.981 090 u
$^{205}_{81}Tl$	204.974 428 u
$^{4}_{2}He$	4.002 603 254 u

$$^{209}_{83}Bi \rightarrow {}^{205}_{81}Tl + {}^{4}_{2}\alpha$$

Step 1: Calculate mass defect (recognizing that $1u = 1\frac{g}{mol}$)

$\Delta m = M_{Tl-205} + M_{He-4} - M_{Bi-209}$

$\Delta m = \left(204.974\,428\,\frac{g}{mol}\right) + \left(4.002\,603\,254\,\frac{g}{mol}\right) - \left(208.980\,399\,\frac{g}{mol}\right)$

$\Delta m = -0.003\,368\frac{g}{mol}$ 6 decimal places therefore 4 sig. fig.

Step 2: Convert mass defect into $\frac{kg}{mol}$

$\Delta m = -0.003\,368\frac{g}{mol} \times \frac{1\,kg}{1000\,g} = -3.368 \times 10^{-6}\frac{kg}{mol}$

Step 3: Calculate energy change for the reaction

$\Delta E = \Delta m c^2$

$\Delta E = \left(-3.368 \times 10^{-6}\frac{kg}{mol}\right)\left(2.997\,925 \times 10^{8}\,\frac{m}{s}\right)^2 \times \frac{1\,J}{1\,\frac{kg \cdot m^2}{s^2}} = -3.027 \times 10^{11}\frac{J}{mol}$

Therefore $3.027 \times 10^{11}\frac{J}{mol}$ energy is released.