Fall 2022 **Chemistry 1000 Midterm #2X** ____/70 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, November 17th, 2022. I understand that breaking this agreement would constitute academic misconduct. The minimum penalty would be a mark of 0/70 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 8 pages of questions (four 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
/ 4	/ 4	/ 4	/ 2	/ 3	/ 7	/ 6	/ 6	/ 4	/ 10	/ 2	/ 13	/ 5		/ 70

1. Complete the following table. You may find the partial periodic table (copied from the Data Sheet) helpful. *Misspelled elements will not get full credit.* **[4 marks]**

Atomic Number (*Z*)	Symbol	Name
23	V	vanadium
25	Mn	manganese
29	Cu	copper
32	Ge	germanium

Chem 1000 Standard Periodic Table

1																	18
1.0079 **H** 1	2											13	14	15	16	17	4.0026 **He** 2
6.94 **Li** 3	9.0122 **Be** 4											10.81 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	20.1797 **Ne** 10
22.990 **Na** 11	24.3050 **Mg** 12	3	4	5	6	7	8	9	10	11	12	26.9815 **Al** 13	28.085 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.45 **Cl** 17	39.95 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	21	22	23	24	25	26	27	28	29	30	31	32	33	78.971 **Se** 34	79.904 **Br** 35	83.798 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.95 **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	183.84 **W** 74	186.207 **Re** 75	190.2 **Os** 76	192.23 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	204.38 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(209) **Po** 84	(210) **At** 85	(222) **Rn** 86
(223) **Fr** 87	(226) **Ra** 88	**Ac-Lr**	(267) **Rf** 104	(268) **Db** 105	(271) **Sg** 106	(272) **Bh** 107	(270) **Hs** 108	(276) **Mt** 109	(281) **Ds** 110	(280) **Rg** 111	(285) **Cn** 112	(284) **Nh** 113	(289) **Fl** 114	(288) **Mc** 115	(293) **Lv** 116	(292) **Ts** 117	(294) **Og** 118

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	173.05 **Yb** 70	174.967 **Lu** 71
(227) **Ac** 89	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	(237) **Np** 93	(244) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(257) **Md** 101	(259) **No** 102	(262) **Lr** 103

Radioactive elements: mass number given for longest lived isotope: e.g. (98)

Developed by Prof. R. T. Boeré (updated 2021)

2. Complete the following table. **[4 marks]**

Chemical Formula	Name
KCl	potassium chloride
FeF_3	iron(III) fluoride
Li_2S	lithium sulfide
TiO_2	titanium(IV) oxide

3. In CHEM 1000, you learned about two different diagonal relationships, each of which involves one alkaline earth metal and one other element. **[4 marks]**

(a) Identify the two pairs of elements involved in these diagonal relationships. It must be clear which two elements are paired according to each diagonal relationship. *[2 marks]*

Your answer may use either names or symbols to refer to the elements (but please be consistent!).

Li and Mg Be and Al

(b) Choose one of your answers to part (a) and give an example of a reaction that shows their diagonal relationship. Your reaction equations (one for each element) must be balanced and show all states of matter. *[2 marks]*

There were many possible answers to this question. Some reasonable answers include:

Both Li and Mg react with nitrogen gas:

$$6\ Li_{(s)} + N_{2(g)} \rightarrow 2\ Li_3N_{(s)}$$
$$3\ Mg_{(s)} + N_{2(g)} \rightarrow Mg_3N_{2(s)}$$

The oxides of both Be and Al are both amphoteric and therefore react with aqueous base:

$$BeO_{(s)} + 2\ OH^-_{(aq)} + H_2O_{(l)} \rightarrow [Be(OH)_4]^{2-}_{(aq)}$$
$$Al_2O_{3(s)} + 2\ OH^-_{(aq)} + 3\ H_2O_{(l)} \rightarrow 2\ [Al(OH)_4]^-_{(aq)}$$

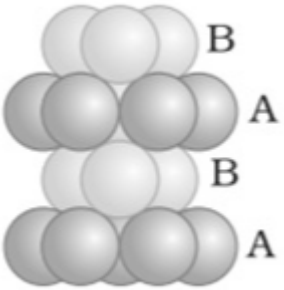
Both Be and Al can form complexes with four hydroxide ions surrounding the metal cation:

$$Be(OH)_{2(s)} + 2\ OH^-_{(aq)} \rightarrow [Be(OH)_4]^{2-}_{(aq)}$$
$$Al(OH)_{3(s)} + OH^-_{(aq)} \rightarrow [Al(OH)_4]^-_{(aq)}$$

4. The atoms in a metal are arranged in lattices. The two images below show the two different types of "closest packing" lattices. Label each image with the name of the corresponding lattice type. **[2 marks]**

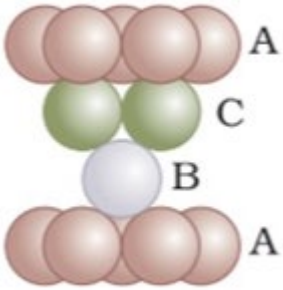
Please write the full name. Abbreviations will receive only partial credit.

(a)



hexagonal closest packing

(b)



cubic closest packing

"face centered cubic" is also acceptable for this diagram

5. Aluminium metal is produced industrially via electrolysis of aluminium oxide. **[3 marks]**

(a) Write the balanced chemical equation for this electrochemical reaction. *[2 marks]*

Include all states of matter.

$$2\ Al_2O_{3(l)} + 3\ C_{(s)} \rightarrow 4\ Al_{(l)} + 3\ CO_{2(g)}$$

(b) Clearly identify whether Al is oxidized or reduced in this reaction. *[1 mark]*

reduced

The oxidation state of Al in Al_2O_3 is +3. The oxidation state of Al in Al is 0. As such, the oxidation state of Al in this reaction decreases or "is reduced".

6. Write balanced chemical equations for each of the following reactions. **[7 marks]**

Include states of matter. If no reaction occurs, write "NO REACTION".

(a) Sodium metal is added to a flask containing liquid bromine ($Br_{2(l)}$).

$2\ Na_{(s)} + Br_{2(l)} \rightarrow 2\ NaBr_{(s)}$

(b) Beryllium metal is added to water at room temperature.

no reaction

(c) Magnesium carbonate $\left(MgCO_{3(s)}\right)$ is added to a solution of aqueous acid $\left(H^{+}_{(aq)}\right)$.

$MgCO_{3(s)} + 2\ H^{+}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

(d) Aluminium oxide is added to concentrated aqueous sodium hydroxide $\left(NaOH_{(aq)}\right)$.

$Al_2O_{3(s)} + 2\ NaOH_{(aq)} + 3\ H_2O_{(l)} \rightarrow 2\ Na[Al(OH)_4]_{(aq)}$

or $Al_2O_{3(s)} + 2\ OH^{-}_{(aq)} + 3\ H_2O_{(l)} \rightarrow 2\ [Al(OH)_4]^{-}_{(aq)}$

7. 9.015 g of an unknown metal (M) reacts with water to produce 16.1 L hydrogen gas at a temperature of 25°C and a pressure of 1 bar (100 kPa). A generalized balanced reaction equation is provided below. Use this equation to help you identify the unknown metal. **[6 marks]**

$$2\ M_{(s)} + 2\ H_2O_{(l)} \rightarrow 2\ MOH_{(aq)} + H_{2(g)}$$

Step 1: Calculate moles of H_2 produced (using ideal gas law)

$PV = nRT$

$$n_{H_2} = \frac{PV}{RT} = \frac{(100\ kPa)(16.1\ L)}{\left(8.314\ 462\ \frac{Pa \cdot m^3}{mol \cdot K}\right)(298.15\ K)} \times \frac{1\ m^3}{1000\ L} \times \frac{1000\ Pa}{1\ kPa} = 0.649\ mol$$

Step 2: Calculate moles of M reacted (using mole ratio)

$$n_M = 0.649\ mol\ H_2 \times \frac{2\ mol\ M}{1\ mol\ H_2} = 1.30\ mol\ M$$

Step 3: Calculate molar mass of M and identify element

$$M_M = \frac{m_M}{n_M} = \frac{9.015\ g}{1.30\ mol} = 6.94\ \frac{g}{mol}$$

The metal is therefore lithium (Li).

8. You learned in class that many metals form oxides when reacted with oxygen gas. Some alkali metals can also form peroxides or superoxides when oxidized. **[6 marks]**

A peroxide ion has the formula O_2^{2-} while a superoxide ion has the formula O_2^-.

(a) Given the formulas provided above for these two diatomic ions, deduce the chemical formulas for: *[2 marks]*

- Sodium peroxide Na_2O_2

O_2^{2-} has a charge of -2 so, to make a neutral ionic compound, you need to add cations with a total charge of +2. Since sodium cations each have a charge of +1, you need two of them. That gives Na_2O_2.

- Potassium superoxide KO_2

O_2^- has a charge of -1 so, to make a neutral ionic compound, you need to add cations with a total charge of +1. Since potassium cations each have a charge of +1, you need one of them. That gives KO_2.

(b) Draw one valid Lewis diagram for each of the two ions. *[4 marks]*

Include non-zero formal charges on the appropriate atoms.

Please do not be disturbed that it is impossible to make all atoms in one of these Lewis diagrams obey the octet rule. Just draw the best Lewis diagram that you can given the number of available electrons.

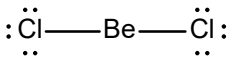
O_2^{2-}



O_2^-



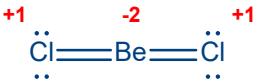
9. The most commonly drawn Lewis diagram for $BeCl_2$ is shown below. **[4 marks]**



(a) What is unusual about this Lewis diagram? *[1 mark]*

Be does not obey the octet rule.

(b) Draw another Lewis diagram for $BeCl_2$ which does not suffer from the same problem as the one drawn above. *[2 marks]*

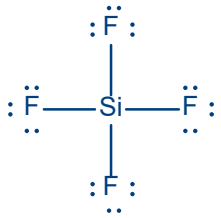
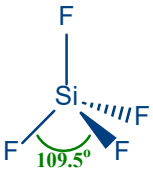
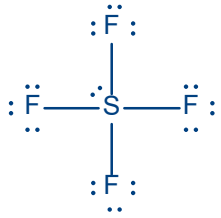
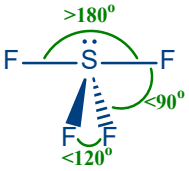


(c) Briefly explain why the answer to part (b) is not necessarily the best Lewis diagram for this compound. *[1 mark]*

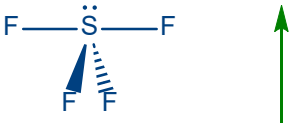
In the answer to (b), all three atoms have formal charges whereas in the answer to (a), all three atoms are neutral. It is particularly bad that the more electronegative chlorine atoms have positive formal charges while the electropositive beryllium atom has a formal charge of -2.

10. Complete the table below. **[10 marks]**

Include any non-zero formal charges on the appropriate atom(s).

Formula	Lewis Diagram	Electron Group Geometry *(in words)* **and** Molecular Geometry *(in words)*	Drawing of molecule showing its 3-dimensional geometry (using wedges-and-dashes notation where appropriate) **and** Labeled Bond Angles
SiF_4		tetrahedral *and* tetrahedral	
SF_4		trigonal bipyramidal *and* seesaw	

11. One of the two molecules in the question above is polar. Redraw the polar molecule in the space below and clearly show the direction of the net dipole. **[2 marks]**



12. Hard water contains the soluble salt $Ca(HCO_3)_2$. In regions with hard water, kettles quickly become lined with deposits of the white solid $CaCO_3$. This is due to the shift of the following chemical equilibrium when water is boiled: **[13 marks]**

$$Ca(HCO_3)_{2(aq)} \rightleftharpoons CaCO_{3(s)} + CO_{2(g)} + H_2O_{(g)}$$

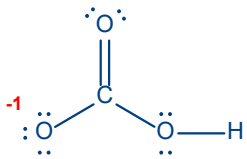
(a) Briefly explain why $Ca(HCO_3)_2$ is more soluble in water than $CaCO_3$. *[2 marks]*

The carbonate ion (CO_3^{2-}) has a larger negative charge than the bicarbonate ion (HCO_3^-), so the ionic bonds between Ca^{2+} and CO_3^{2-} will be stronger than those between Ca^{2+} and HCO_3^-.

As such, the lattice energy for $CaCO_3$ is much larger than for $Ca(HCO_3)_2$. This means that it requires more energy to break apart the ions in the lattice and $CaCO_3$ is therefore much less soluble in water than $Ca(HCO_3)_2$.

(b) Draw **<u>one</u>** valid resonance structure for the HCO_3^- ion. *[2 marks]*

Include any non-zero formal charges on the appropriate atom(s).

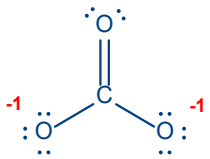


(c) How many valid resonance structures can be drawn for the HCO_3^- ion (including the one above)? *[1 mark]*

2

(d) Draw **<u>one</u>** valid resonance structure for the CO_3^{2-} ion. *[2 marks]*

Include any non-zero formal charges on the appropriate atom(s).



(e) How many valid resonance structures can be drawn for the CO_3^{2-} ion (including the one above)? *[1 mark]*

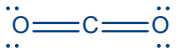
3

(f) If we measure the lengths of all three $C-O$ bonds in the CO_3^{2-} ion, how many different values would we expect to obtain? Justify your answer by calculating the bond order for each $C-O$ bond. *[2 marks]*

All three $C-O$ bonds in CO_3^{2-} have the same length.

They all have a bond order of $\frac{4}{3} = 1\frac{1}{3}$.

(g) Draw a Lewis diagram for CO_2. Is the $C-O$ bond length in CO_2 longer or shorter than it is in CO_3^{2-}? Explain your choice. *[3 marks]*

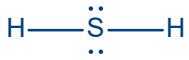


The $C-O$ bonds in CO_2 both have a bond order of 2.

As such, they are shorter than the $C-O$ bonds in CO_3^{2-}.

13. **[5 marks]**

(a) Draw a Lewis diagram for H_2S. *[1 mark]*



(b) Draw a Lewis diagram for SCl_2. *[1 mark]*



(c) Use the data provided in the table below to calculate the approximate standard enthalpy change ($\Delta_r H°$) for the reaction between hydrogen sulfide and chlorine gas: *[3 marks]*

$$H_2S_{(g)} + Cl_{2(g)} \rightarrow SCl_{2(g)} + H_{2(g)}$$

Table of Bond Dissociation Enthalpies

Bond	$\Delta_{BD}H°\left(\frac{kJ}{mol}\right)$
$H-H$	432
$H-S$	347
$Cl-Cl$	243
$S-Cl$	271

$$\Delta H \approx \sum \Delta_{bd}H(bonds\ broken) - \sum \Delta_{bd}H(bonds\ formed)$$
$$\Delta H \approx [2\Delta_{bd}H(H-S) + \Delta_{bd}H(Cl-Cl)] - [2\Delta_{bd}H(S-Cl) + \Delta_{bd}H(H-H)]$$
$$\Delta H \approx \left[2\left(347\,\frac{kJ}{mol}\right) + \left(243\,\frac{kJ}{mol}\right)\right] - \left[2\left(271\,\frac{kJ}{mol}\right) + \left(432\,\frac{kJ}{mol}\right)\right]$$
$$\Delta H \approx -37\,\frac{kJ}{mol}$$