Fall 2022 **Chemistry 1000 Final Exam** ____/130 marks

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam until after 4:30pm Mountain Time on Friday, December 16th, 2022. I understand that breaking this agreement would constitute academic misconduct. The minimum penalty would be a mark of 0/130 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 13 pages of questions (seven 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. If you require extra space for any answer, use either the back of the cover page or the back of the last page. Leave a note by the original question so that the person marking that question knows where to find your answer.
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 3 hours to complete this test.

Question Breakdown

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Total
/ 5	/ 2	/16	/ 8	/ 6	/ 6	/11	/ 6	/ 4	/ 2	/ 3	/ 4	/15	/10	/12	/ 5	/ 3	/ 6	/ 5	/ 1	/130

1. Complete the following table by providing both the name and symbol for the neutral element being described. **[5 marks]**

Description	Element	
	Symbol	**Name**
The noble gas that does **not** have 8 valence electrons.	He	helium
A chalcogen that is a solid at room temperature and standard atmospheric pressure.	S Se Te Po	sulfur *or* sulphur selenium tellurium polonium
An element whose most common allotrope is diatomic (i.e. has a molecular formula with the format X_2).	H N O F Cl Br I	hydrogen nitrogen oxygen fluorine chlorine bromine iodine
The element with an allotrope in which each molecule contains 60 atoms.	C	carbon
The element with a diagonal relationship with aluminium.	Be	beryllium

2. Give two examples of ways in which metals differ from non-metals. **[2 marks]**

Answers may include:

- Metals conduct heat
- Metals conduct electricity
- Metals are ductile
- Metals are malleable
- Metals are shiny
- Metals produce oxides that are basic/react with acid
- Metals have low ionization energies
- Metals tend to form cations rather than anions
- Metals form lattices rather than discrete molecules

3. Fill in each blank with the word or phrase that best completes the sentence. **[16 marks]**

(a) When comparing ultraviolet light, visible light and infrared light, the highest energy photons will be for ultraviolet light.

(b) According to Heisenberg's Uncertainty Principle, the more precisely we know a particle's momentum, the less accurately we can know its position *or* location.

(c) A $3p$ orbital has quantum numbers including $n = 3$ and $l = 1$.

(d) The maximum number of **orbitals** in a single atom that can have $n = 4$ is 16.

The maximum number of **electrons** in a single atom that can have $n = 4$ is 32.

(e) A Lewis acid is defined as an electron pair acceptor.

One example of a good Lewis acid is _____. *Too many valid answers to list. Common answers might include any transition metal cation, CO_2, SO_3, BF_3, $AlCl_3$, etc.*

(f) A Lewis base is defined as an electron pair donor.

One example of a good Lewis base is _____. *Too many valid answers to list. Common answers might include NH_3, Cl^-, Br^-, I^-,etc.*

(g) If a flask contains two different noble gases, the noble gas with the smaller mass will have faster moving particles. *(We are looking for a relative property not an element name.)*

(h) When SO_3 is dissolved in water, an acid is produced. Its chemical formula is H_2SO_4 and its name is sulfuric acid.

(i) Sodium metal and sodium hydroxide are both produced via electrolysis *or* electrochemical reaction of sodium chloride. The key difference between the industrial production of sodium metal and the industrial production of sodium hydroxide is the presence of water as an additional reactant in the chlor-alkali cell.

(j) If 100g of a nuclide with a half-life of 10 days is allowed to decay for 20 days, 25 g of the original nuclide will remain.

4. Antimony has two naturally occurring isotopes and an average atomic mass of 121.760 u. 57.36% of naturally occurring antimony atoms are $^{121}_{51}Sb$ which has an isotopic mass of 120.904 u. **[8 marks]**

(a) How many protons, neutrons and electrons does a neutral atom of $^{121}_{51}Sb$ contain? *[3 marks]*

51 protons 70 neutrons 51 electrons

(b) What is the percent abundance of the other naturally occurring isotope of antimony? *[1 mark]*

$100\% - 57.36\% = 42.64\%$ 2 decimal places

(c) What is the isotopic mass of the other naturally occurring isotope of antimony? *[3 marks]*

$$121.760\ u = \left(\frac{57.36\%}{100\%}\right)(120.904\ u) + \left(\frac{42.64\%}{100\%}\right)(x)$$

$$121.760\ u = (0.5736)(120.904\ u) + (0.4264)(x)$$

$$x = \frac{121.760\ u - (0.5736)(120.904\ u)}{0.4264}$$

$x = 122.9\ u$ 4 sig. fig.

(d) What is the complete symbol (including both atomic number and mass number) for the other naturally occurring isotope of antimony? *[1 mark]*

$^{123}_{51}Sb$

5. Complete each of the following nuclear reaction equations **and** classify each reaction by writing the reaction type in the space to the right of the equation. **[6 marks]**

(a) $^{236}_{92}U \longrightarrow \boxed{^{103}_{42}Mo} + {}^{131}_{50}Sn + 2{}^{1}_{0}n$ fission *or* nuclear fission

(b) $^{37}_{18}Ar + {}^{0}_{-1}e \longrightarrow \boxed{^{37}_{17}Cl}$ electron capture

(c) $^{11}_{6}C \longrightarrow {}^{11}_{5}B + \boxed{^{0}_{1}\beta}$ positron emission

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

Include states of matter.

(a) Potassium metal is added to a flask containing liquid water.

$2\,K_{(s)} + 2\,H_2O_{(l)} \rightarrow 2\,KOH_{(aq)} + H_{2(g)}$

or $2\,K_{(s)} + 2\,H_2O_{(l)} \rightarrow 2\,K^+_{(aq)} + 2\,OH^-_{(aq)} + H_{2(g)}$

(b) Lithium metal is reacted with nitrogen gas.

$6\,Li_{(s)} + N_{2(g)} \rightarrow 2\,Li_3N_{(s)}$

(c) Aluminium metal is added to concentrated aqueous sodium hydroxide $(NaOH_{(aq)})$.

$2\,Al_{(s)} + 2\,NaOH_{(aq)} + 6\,H_2O_{(l)} \rightarrow 2\,Na[Al(OH)_4]_{(aq)} + 3\,H_{2(g)}$

or $2\,Al_{(s)} + 2\,OH^-_{(aq)} + 6\,H_2O_{(l)} \rightarrow 2\,[Al(OH)_4]^-_{(aq)} + 3\,H_{2(g)}$

7. Hard water often contains Ca^{2+} cations. **[11 marks]**

(a) What is the other cation most commonly responsible for making water hard? *[1 mark]*

Mg^{2+}

(b) In class, you discussed one method for softening water using an ion exchange column. Briefly explain how this method softens water. Does anything replace the Ca^{2+} removed? If so, what? *[3 marks]*

*Your answer does **not** need to address column regeneration.*

The ion exchange column contains beads with negative charges. Sodium cations (Na^{+}) maintain charge balanced. When water is passed through the column, the calcium cations are more strongly attracted to the column because they have a greater positive charge than the sodium cations. This removes calcium cations from the hard water, replacing them with sodium cations.

(c) Another method for softening water involves addition of a strong base such as $NaOH$. This precipitates out the calcium as $CaCO_3$ according to the net ionic equation shown below:

$$Ca^{2+}_{(aq)} + 2\ HCO^{-}_{3(aq)} + 2\ OH^{-}_{(aq)} \rightarrow CaCO_{3(s)} + 2\ H_2O_{(l)} + CO^{2-}_{3(aq)}$$

i. $CaCO_3$ is a chemical formula. What is this compound's name? *[1 mark]*

calcium carbonate

ii. $NaOH$ is a chemical formula. What is this compound's name? *[1 mark]*

sodium hydroxide

iii. What mass of $NaOH$ would be required to remove all Ca^{2+} cations from $2.50\ L$ of hard water containing $1.25 \times 10^{-3}\ M\ Ca^{2+}$? Assume that the reaction goes to completion. *[5 marks]*

Step 1: Calculate moles of Ca^{2+}

$n_{Ca^{2+}} = 2.50\ L \times \left(1.25 \times 10^{-3}\ \frac{mol}{L}\right) = 0.003125\ mol$ *(3 sig. fig.)*

Step 2: Calculate moles of $NaOH$ required (using mole ratio)

$n_{NaOH} = 0.003125\ mol\ Ca^{2+} \times \frac{2\ mol\ NaOH}{1\ mol\ Ca^{2+}} = 0.00625\ mol\ NaOH$

Step 3: Calculate mass of $NaOH$ required

$M_{NaOH} = 39.9971\ \frac{g}{mol}$

$m_{NaOH} = 0.00625\ mol \times 39.9971\ \frac{g}{mol} = 0.250\ g$ 3 sig. fig.

8. Consider the Group 13 element indium (In). **[6 marks]**

(a) Write the electron configuration for a neutral atom of indium in the ground state. *[2 marks]*

Use the noble gas abbreviation.

$[Kr]5s^2 4d^{10} 5p^1$

(b) Predict the **<u>two</u>** most common ions that indium will form, and write the electron configuration for each of those two ions (clearly indicating which electron configuration corresponds to which ion). *[4 marks]*

Use the noble gas abbreviation.

In^+ $[Kr]5s^2 4d^{10}$

In^{3+} $[Kr]4d^{10}$

9. Consider an oxygen atom (O) and an oxide anion (O^{2-}). **[4 marks]**

(a) Write the electron configuration for each of these species. *[2 marks]*

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

O $1s^2 2s^2 2p^4$

O^{2-} $1s^2 2s^2 2p^6$

(b) Which of these two species has a larger radius? Briefly explain your choice. *[2 marks]*

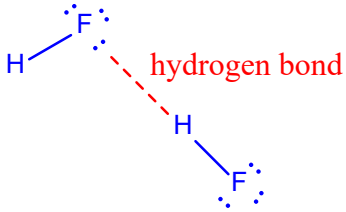
O^{2-} has a larger radius. The two species have the same number of protons, but O^{2-} has two more valence electrons. As such, there is more electron-electron repulsion in O^{2-} and that increases the volume of space occupied by the electrons. The increased number of electrons also means that every valence electron experiences less attraction to the positive charge of the nucleus due to increased shielding of that positive charge by the increased number of other valence electrons.

10. Rank the following four elements from smallest to largest first ionization energy: **[2 marks]**

$$C, K, Ne, Si$$

smallest first ionization energy ___ K ___ ___ Si ___ ___ C ___ ___ Ne ___ largest first ionization energy

11. Draw a diagram showing hydrogen bonding in a sample of liquid HF. For full marks, the hydrogen bond must be clearly labeled, and molecules must be drawn as complete Lewis diagrams. **[3 marks]**



Hydrogen bonding is an intermolecular force. It is therefore impossible to show hydrogen bonding without drawing at least two molecules.

12. Calcium carbide (CaC_2) is an interesting ionic compound used to produce the fuel acetylene. **[4 marks]**

(a) Industrially, calcium carbide is produced by reacting calcium oxide with carbon $(C_{(s)})$. The other product of this reaction is carbon monoxide. Write a balance chemical equation for this reaction. *[2 marks]*

Include all states of matter.

$$CaO_{(s)} + 3\,C_{(s)} \rightarrow CaC_{2(s)} + CO_{(g)}$$

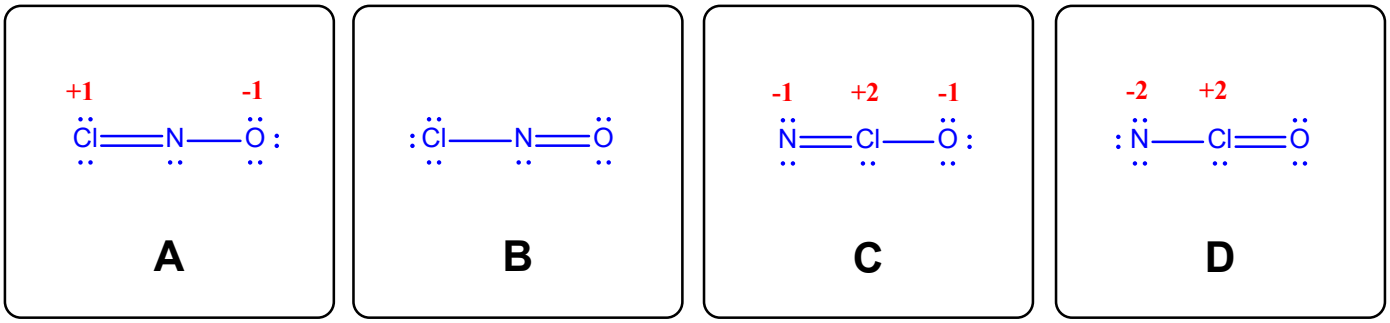
(b) Draw a valid Lewis diagram for the carbide ion (C_2^{2-}). *[2 marks]*

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



13. Nitrosyl chloride is a powerful oxidizing agent with the molecular formula $NOCl$. The central atom is **not** oxygen. In this question, you will consider potential Lewis diagrams for nitrosyl chloride. **[15 marks]**

(a) Four potential skeletons for Lewis diagrams of nitrosyl chloride have been drawn below. They have been labeled **A**, **B**, **C** and **D** for easy reference. Complete each Lewis diagram by adding the appropriate number of lone pairs and any non-zero formal charges. *[7 marks]*



(b) What is the correct term to describe the relationship between Lewis diagram **A** and Lewis diagram **B**? (In other words, complete the phrase "**A** and **B** are _____.") *[1 mark]*

resonance structures

(c) What is the correct term to describe the relationship between Lewis diagram **A** and Lewis diagram **C**? (In other words, complete the phrase "**A** and **C** are _____.") *[1 mark]*

isomers

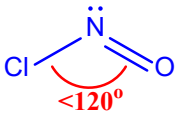
(d) Which of the four Lewis diagrams is the best Lewis diagram for nitrosyl chloride? Briefly explain your choice. *[2 marks]*

B

It's the Lewis diagram in which all three atoms have formal charges of zero.

(e) Assuming that your answer to part (d) is correct, use VSEPR to predict the electron group geometry and molecular geometry of nitrosyl chloride. Draw a diagram showing this geometry and label the bond angle.

(If you didn't have an answer to part (d), choose any one of your Lewis diagrams and answer for it. In this case, you must clearly indicate the diagram for which you are answering. If you go back and add an answer to part (d) later, you are required to update part (e).) *[4 marks]*



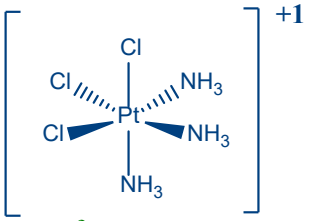
trigonal planar electron group geometry

bent molecular geometry

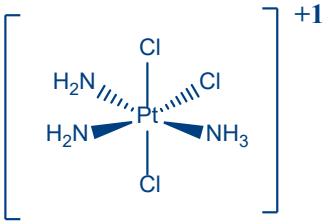
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14. Consider the complex ion $[PtCl_3(NH_3)_3]^+$. **[10 marks]**

(a) It is possible to draw two different isomers for this chemical formula, a *fac* isomer and a *mer* isomer. Draw a 3-dimensional diagram for each of these two isomers (using wedges and dashes as appropriate) and clearly identify which diagram corresponds to each isomer. *[3 marks]*



fac



mer

(b) What is the oxidation state of platinum in $[PtCl_3(NH_3)_3]^+$? *[1 mark]*

+2 *or* II

(c) What is the coordination number of platinum in $[PtCl_3(NH_3)_3]^+$? *[1 mark]*

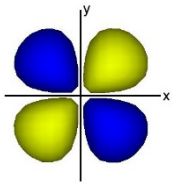
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(d) In the crystal field of the $[PtCl_3(NH_3)_3]^+$ complex ion, the $5d$ orbitals are split into two groups, each at a slightly different energy level. Identify the three $5d$ orbitals in the lower energy level. *[3 marks]*

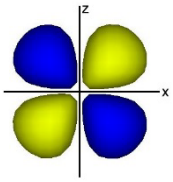
$5d_{xy}$ $5d_{xz}$ $5d_{yz}$

(e) Draw **one** of the three $5d$ orbitals in the lower energy level. Your drawing must include labeled axes and must show relative phases. You must clearly label exactly which $5d$ orbital you chose to draw. *[2 marks]*

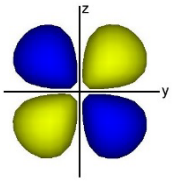
$5d_{xy}$



$5d_{xz}$



$5d_{yz}$



Radial nodes were not requested therefore not required.

15. The red colour of ruby is due to the presence of a small number of Cr^{3+} ions in octahedral coordination sites in the mineral corundum (Al_2O_3). **[12 marks]**

(a) Give another name for Al_2O_3 using the naming rules taught in CHEM 1000. *[1 mark]*

aluminium oxide *or* aluminum oxide

(b) Write the electron configuration for a neutral atom of Cr. *[2 marks]*

Use the noble gas abbreviation.

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

(c) Write the electron configuration for Cr^{3+}. *[1 mark]*

Use the noble gas abbreviation.

$[Ar]3d^3$

(d) Consider the following three sets of quantum numbers. Which one could describe one of the valence electrons in the Cr^{3+} ion in ruby? For each of the **three** sets of quantum numbers, clearly explain why it either could or could not describe a valence electron in Cr^{3+}. *[3 marks]*

- $n = 2,\ l = 1,\ m_l = 0,\ m_s = -\frac{1}{2}$ NO – describes a $2p$ orbital so not valence
- $n = 3,\ l = 2,\ m_l = 2,\ m_s = +\frac{1}{2}$ YES – describes a $3d$ orbital so valence
- $n = 3,\ l = 3,\ m_l = 0,\ m_s = -\frac{1}{2}$ NO – illegal combination (l must be less than n)

(e) Given that we observe a red colour for the ruby, what colour(s) of light must Cr^{3+} absorb? *[1 mark]*

green

(f) If the splitting energy of Cr^{3+} in ruby is found to be $3.794 \times 10^{-19}\ J$, calculate the wavelength of light absorbed by the ruby. Report your answer in nm. *[4 marks]*

Step 1: Calculate frequency of light (can be skipped if use $E = \frac{hc}{\lambda}$ to combine steps 1 and 2)

$E = h\nu$ therefore $\nu = \frac{E}{h} = \frac{3.794\times10^{-19}\ J}{6.626\ 070\times10^{-34}\ \frac{J}{Hz}} = 5.726 \times 10^{14}\ Hz$

Step 2: Calculate wavelength of light in meters

$c = \lambda\nu$ therefore $\lambda = \frac{c}{\nu} = \frac{2.997\ 925\times10^{8}\ \frac{m}{s}}{5.726\times10^{14}\ Hz} = 5.236 \times 10^{-7}\ m$

Step 3: Convert wavelength into nanometers

$\lambda = 5.236 \times 10^{-7}\ m\ \times \frac{10^9\ nm}{1\ m} = 523.6\ nm$ 4 sig. fig.

16. When light with a wavelength of 470.0 nm falls on the surface of potassium metal, electrons are emitted with a kinetic energy of $1.87 \times 10^{-21} J$. Calculate the threshold energy (or work function) for potassium metal. **[5 marks]**

Step 1: Convert wavelength into meters

$$\lambda = 470.0\ nm \times \frac{1\ m}{10^9\ nm} = 4.700 \times 10^{-7}\ m$$

Step 2: Calculate frequency of light (can be skipped if use $E = \frac{hc}{\lambda}$ to combine steps 2 and 3)

$$c = \lambda\nu \quad \text{therefore} \quad \nu = \frac{c}{\lambda} = \frac{2.997\,925 \times 10^8\ \frac{m}{s}}{4.700 \times 10^{-7}\ m} = 6.379 \times 10^{14}\ Hz$$

Step 3: Calculate energy of one photon of light

$$E_{photon} = h\nu = \left(6.626\,070 \times 10^{-34}\ \frac{J}{Hz}\right)(6.379 \times 10^{14}\ Hz) = 4.226 \times 10^{-19}\ J$$

Step 4: Calculate threshold energy

$$E_{photon} = E_{threshold} + E_{kinetic(electron)}$$

$$E_{threshold} = E_{photon} - E_{kinetic(electron)}$$

$$E_{threshold} = (4.226 \times 10^{-19}\ J) - (1.87 \times 10^{-21}\ J) = 4.208 \times 10^{-19}\ J$$ 4 sig. fig.

$1.87 \times 10^{-21}\ J = 0.0187 \times 10^{-19}\ J$ *and* $4.226 - 0.0187 = 4.208$ *since we are using addition/subtraction sig. fig. rules for this part of the question. Therefore 4 sig. fig. is correct.*

17. Calculate the wavelength associated with a lithium atom having a mass of 7.02 u traveling at $6.0 \times 10^7\ \frac{m}{s}$. Report your answer in m. **[3 marks]**

Step 1: Convert mass into kg

$$m = 7.02\ u \times \frac{1.660\,539 \times 10^{-27}\ kg}{1\ u} = 1.17 \times 10^{-26}\ kg$$

Step 2: Calculate wavelength using deBroglie equation

$$\lambda = \frac{h}{\rho} \quad \text{and} \quad \rho = mv \quad \text{therefore} \quad \lambda = \frac{h}{mv}$$

$$\lambda = \frac{6.626\,070 \times 10^{-34}\ \frac{J}{Hz}}{(1.17 \times 10^{-26}\ kg)\left(6.0 \times 10^7 \frac{m}{s}\right)} \times \frac{1\ \frac{kg \cdot m^2}{s^2}}{1\ J} = 9.5 \times 10^{-16}\ m$$ 2 sig. fig.

18. Calculate the energy change for the following nuclear reaction. **[6 marks]**

You may answer (a) and (b) in whichever order is more convenient for you.

$$^{10}_{5}B + ^{4}_{2}\alpha \rightarrow ^{13}_{6}C + ^{1}_{1}H$$

Nuclide	Isotopic Mass (u)
$^{1}_{1}H$	1.007 83
$^{4}_{2}\alpha$	4.002 60
$^{10}_{5}B$	10.012 94
$^{13}_{6}C$	13.003 35

(a) Report your answer in Joules per mole of $^{10}_{5}B$ reacted.

(b) Report your answer in Joules per atom of $^{10}_{5}B$ reacted.

Step 1: Convert mass defect (1 u = 1 g/mol)

$$\Delta m = m_{products} - m_{reactants}$$
$$\Delta m = (m_{C-13} + m_{H-1}) - (m_{B-10} + m_{\alpha})$$
$$\Delta m = (13.003\ 35\ u + 1.007\ 83\ u) - (10.012\ 94\ u + 4.002\ 60\ u)$$
$$\Delta m = -0.004\ 36\ u = -0.004\ 36\ \frac{g}{mol}$$

5 decimal places therefore 3 sig. fig.

Step 2: Convert mass defect into kg/mol

$$\Delta m = -0.004\ 36\ \frac{g}{mol} \times \frac{1\ kg}{1000\ g} = -4.36 \times 10^{-6}\ \frac{kg}{mol}$$

Step 3: Calculate energy change in J/mol (1 J = 1 kg·m²/s²)

$$\Delta E = \Delta mc^2 = \left(-4.36 \times 10^{-6}\ \frac{kg}{mol}\right)\left(2.997\ 925 \times 10^{8}\ \frac{m}{s}\right)^2$$
$$\Delta E = -3.92 \times 10^{11}\ \frac{kg \cdot m^2}{s^2 \cdot mol} = -3.92 \times 10^{11}\ \frac{J}{mol}$$

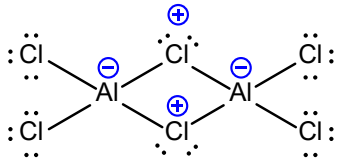
Step 4: Convert energy change from J/mol into J per atom of boron

$$\Delta E = -3.92 \times 10^{11}\ \frac{J}{mol} \times \frac{1\ mol}{6.022\ 141 \times 10^{23}\ atoms} = -6.51 \times 10^{-13}\ \frac{J}{atom}$$

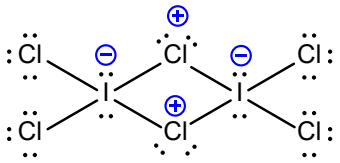
3 sig. fig.

It is also acceptable to convert the mass defect from u into kg by multiplying by $1.660\ 539 \times 10^{-27}\ \frac{kg}{u}$. *That gives* $\Delta m = -7.24 \times 10^{-30}\ kg$. $\Delta E = \Delta mc^2$ *then gives* $-6.51 \times 10^{-13}\ J$ *which can be multiplied by Avogadro's number to get* $-3.92 \times 10^{11}\ \frac{J}{mol}$.

19. Both aluminium and iodine form chloride compounds containing bridging chlorine atoms, as shown in the diagrams below: **[5 marks]**



Al_2Cl_6



I_2Cl_6

(a) Complete each diagram by adding any non-zero formal charges to the appropriate atoms. *[2 marks]*

(b) One of these two compounds is planar. Identify which is the planar compound, and briefly explain why. Your explanation must address both why your choice is planar **and** why the other compound is not. *[3 marks]*

I_2Cl_6

The Al atoms in Al_2Cl_6 have tetrahedral geometry, so Al_2Cl_6 is definitely not planar.

The I atoms in I_2Cl_6 have square planar geometry, so I_2Cl_6 can be (and is) planar.

20. What was the most useful and/or interesting thing you learned in CHEM 1000? **[1 mark]**

…AND THAT'S ALL FOR CHEM 1000.
HAPPY HOLIDAYS!