Fall 2025 **Chemistry 1000 Final Exam** ____/150 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 0/150 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 14 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 the back of the cover 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		Total
/17	/ 4	/ 6	/ 6	/ 3	/11	/15	/11	/14	/10	/ 8	/ 9	/10	/ 9	/ 10	/ 6	/ 1		/ 150

1. Fill in each blank with the word, phrase or symbol that best completes the sentence. If options are provided in brackets after a blank; choose one of them to fill the blank. **[17 marks]**

(a) A neutral atom of ^{72}Ge has 32 protons, 40 neutrons and 32 electrons.

(b) Hydrogen has three isotopes: protium, deuterium and tritium.

(c) In CHEM 1000, we discussed two allotropes of oxygen. They are molecular oxygen (O_2) and ozone (O_3).

(d) Electronegativity is a periodic trend which combines two other periodic trends. Those two periodic trends are first ionization energy and electron affinity.

(e) The formula for the gas made in both a Down's Cell and the Chlor-Alkali industrial process is Cl_2.

(f) CaO would be expected to have a larger *(larger/smaller)* lattice energy than CaS.

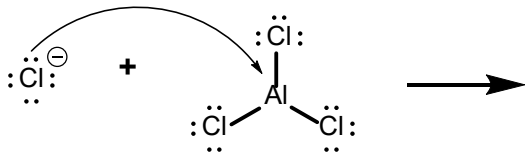
(g) The chemical formula for aluminium oxide is Al_2O_3. When aluminium oxide is reacted with aqueous hydroxide, a soluble anion is formed which has the chemical formula $[Al(OH)_4]^-$. *For full marks, the chemical formula for the anion must include its charge.*

(h) A molecule which has 'see saw' molecular geometry must have trigonal bipyramidal electron group geometry.

(i) In B_2H_6, there is an unusual bonding pattern in which a pair of electrons is shared by 3 atoms.

(j) A flask at room temperature contains the five lightest noble gases. The name of the noble gas whose particles have the highest root-mean-square speed is helium.

(k) In the reaction below, the Lewis acid is $AlCl_3$ and the chemical formula for the product is $[AlCl_4]^-$.



2. Complete the following table, giving the name and symbol for an element meeting each description. *Misspelled elements will not get full credit.* **[4 marks]**

Description	Symbol	Name
The element with the highest electronegativity	F	fluorine
The halogen that is a liquid at room temperature	Br	bromine
The element that is produced using the Claus process	S	sulfur *or* sulphur
The alkali metal that reacts with nitrogen gas	Li	lithium

3. Complete the following table. Names should follow the IUPAC conventions taught in class. **[6 marks]**

Misspelled names will not get full credit.

Chemical Formula	Name
H_2SO_3	sulfurous acid *or* sulphurous acid
$Mn(NO_3)_2$	manganese(II) nitrate
$(NH_4)_2CO_3$	ammonium carbonate
Cu_3N	copper(I) nitride
VF_5	vanadium(V) fluoride
$NaClO_2$	sodium chlorite

4. Write the ground-state electron configuration for each of the following species. **[6 marks]**

Use the noble gas abbreviation; however, listing only a noble gas is not acceptable; all valence electrons must be explicitly listed.

(a) Ne $[He]2s^2 2p^6$

(b) In $[Kr]5s^2 4d^{10} 5p^1$

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

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

5. For each pair, circle the atom/ion with the larger radius. **[3 marks]**

(a) S vs. Se *Se is immediately below S on the periodic table, so they are in the same group but Se has one additional shell of electrons.*

(b) P vs. P^{3-} P^{3-} has the same number of protons as P *but three more electrons. The extra electrons increase both shielding and electron-electron repulsion so the valence electrons in P^{3-} are not held as tightly to the nucleus as in P.*

(c) Cs^+ vs. Ba^{2+} Cs^+ has the same number of electrons as Ba^{2+} *but one less proton. As such, the positive charge of the nucleus is smaller so the valence electrons in Cs^+ are not held as tightly to the nucleus as in Ba^{2+} .*

6. Consider a neutral atom of nickel (Ni) in the ground-state. **[11 marks]**

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

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^8$

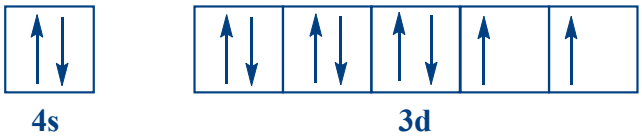
(b) Write the electron configuration for Ni using the noble gas abbreviation. *[1 mark]*

$[Ar]4s^2 3d^8$

(c) How many core electrons and how many valence electrons does Ni have? *[2 marks]*

___18___ core electrons ___10___ valence electrons

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



Ni is paramagnetic

(e) Choose any one electron in your orbital occupancy diagram in part (d). Circle it. *[2 marks]*

For the electron you circled, write a complete set of quantum numbers.

If a $4s$ electron is circled, the answer should be:

- $n = 4, l = 0, m_l = 0$ *and either* $m_s = +\frac{1}{2}$ *or* $m_s = -\frac{1}{2}$

If a $3d$ electron is circled, the answer should be:

- $n = 3, l = 2,$ *either* $m_l = +2$ *or* $m_l = +1$ *or* $m_l = 0$ *or* $m_l = -1$ *or* $m_l = -2$ *and either* $m_s = +\frac{1}{2}$ *or* $m_s = -\frac{1}{2}$

(f) Write the electron configuration for Ni^{2+} using the noble gas abbreviation. *[1 mark]*

$[Ar]3d^8$

7. Consider the following coordination complex of nickel: $[Ni(NH_3)_3(CN)(en)]Cl$. **[15 marks]**

"en" stands for ethylenediamine which has the chemical formula $NH_2CH_2CH_2NH_2$

(a) What is the charge of the complex ion $[Ni(NH_3)_3(CN)(en)]^{???}$? *[1 mark]*

+1

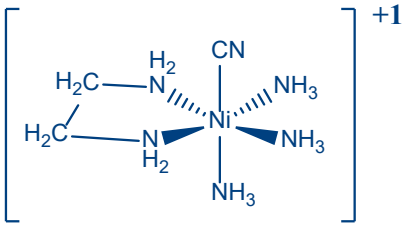
(b) What is the oxidation state of nickel in this complex? *[1 mark]*

+2 *or* II

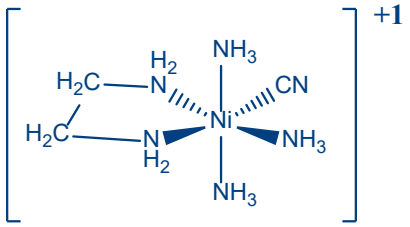
(c) What is the coordination number of nickel in this complex? *[1 mark]*

6

(d) There are two possible stereoisomers for this complex ion. Draw both and label each as *cis*, *trans*, *fac* or *mer*. *[3 marks]*

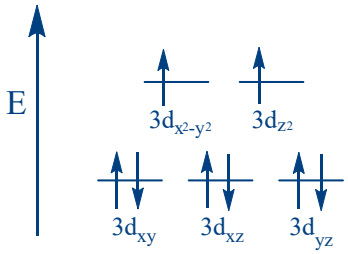


fac



mer

(e) According to crystal field theory, the $3d$ orbitals of the nickel ion are divided into two groups, each of which has a different energy level. Draw the crystal field splitting diagram for the nickel ion in this complex. Include electrons and label each orbital. *[3 marks]*

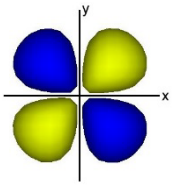


(f) Draw a picture of each $3d$ orbital in the lower energy group. *[6 marks]*

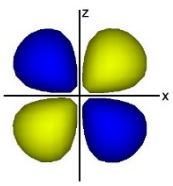
For full marks, your diagrams must show axes, phases and nodes, and each orbital must be labeled.

All nodes are along the axes.

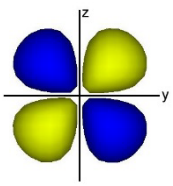
$3d_{xy}$



$3d_{xz}$



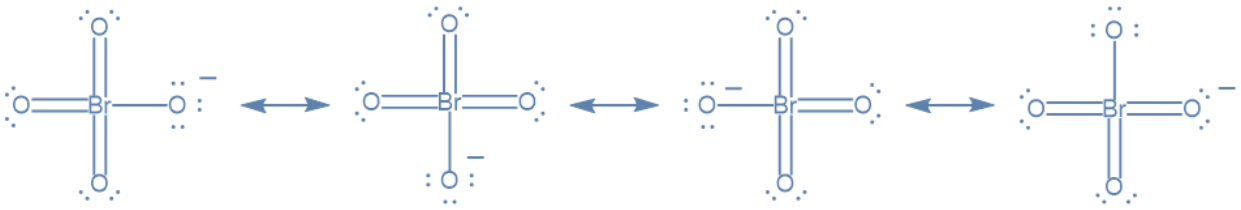
$3d_{yz}$



8. The following questions are related to the perbromate ion (BrO_4^-) **[11 marks]**

(a) Draw all possible resonance structures of perbromate that have minimized formal charges. *[5 marks]*

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



(b) What is the bond order for a Br–O bond in perbromate? *[1 mark]*

$\frac{(2+2+2+1)}{4} = \frac{7}{4}\left(or\ 1\frac{3}{4}\right)$

(c) Provide the chemical formulas for the other oxoanions that Br can form. *[3 marks]*

Your answers must include the charge of each ion.

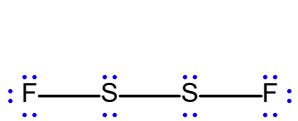
BrO_3^-, BrO_2^- and BrO^-

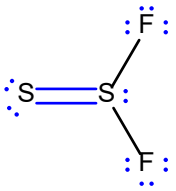
(d) Unlike bromine, fluorine can only form one oxoanion. Of the four oxoanions discussed in parts (a) to (c) of this question, which one is still a viable ion when Br is replaced with F? Why are the others impossible? *[2 marks]*

FO^-

Adding another oxygen atom would force two covalent bonds and a positive formal charge onto fluorine, which is impossible.

9. Two different structures can be imagined for a molecule with the chemical formula S_2F_2. The connectivity for each is shown below. **[14 marks]**





(a) Convert each of the drawings above into a Lewis diagram for S_2F_2 with <u>minimized formal charges</u>. *Include any non-zero formal charges on the appropriate atom(s).* *[2 marks]*

see drawings above

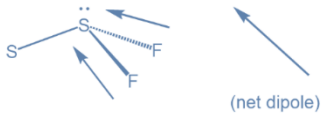
(b) Complete the following table. *[6 marks]*

Connectivity	**S-S bond order**	**Electron group geometry for central S (in words)**	**Molecular geometry for central S (in words)**
F-S-S-F *(diagram on left)*	1	tetrahedral	bent
S-SF_2 *(diagram on right)*	2	tetrahedral	trigonal pyramidal

(c) For each of the two Lewis diagrams, draw a VSEPR diagram that clearly shows the molecular geometry. *Lone pairs are only required to be shown on the VSEPR diagrams if they are on a central atom.* *[2 marks]* *Use wedge-and-dash notation if required to show three dimensional geometry.*



(no net dipole in this orientation)



(net dipole)

(d) On each VSEPR diagram in (c), draw dipole vectors for each polar bond and, next to each molecule, draw its net dipole (if there is one; if not, write “no net dipole”). *[4 marks]*

see drawings above

10. Write balanced chemical equations for each of the following reactions. **[10 marks]**

For reactions performed in aqueous solution, net ionic equations are acceptable (but not required). Include states of matter. Remember that atoms and charges must BOTH be balanced...

(a) Cesium (Cs) metal reacts with water.

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

(b) Sulfur trioxide gas reacts with water.

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$$

(c) Fluorine gas reacts with water to give hydrofluoric acid and oxygen.

$$2\,F_{2(g)} + 2\,H_2O_{(l)} \rightarrow 4\,HF_{(aq)} + O_{2(g)}$$

(d) Magnesium metal reacts with aqueous hydrobromic acid.

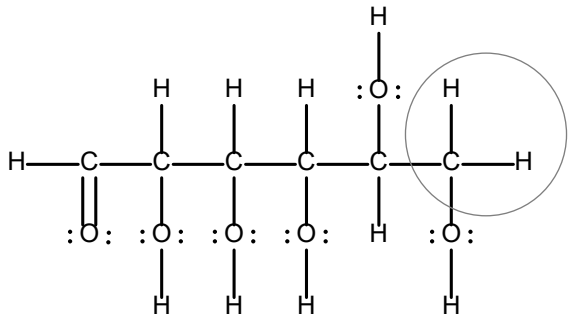
$$Mg_{(s)} + 2\,HBr_{(aq)} \rightarrow MgBr_{2(aq)} + H_{2(g)}$$

or $$Mg_{(s)} + 2\,H^+_{(aq)} \rightarrow Mg^{2+}_{(aq)} + H_{2(g)}$$

(e) White phosphorus reacts with chlorine gas to give solid phosphorus pentachloride.

$$P_{4(s)} + 10\,Cl_{2(g)} \rightarrow 4\,PCl_{5(s)}$$

11. A Lewis diagram for glucose $\left(C_6H_{12}O_{6(s)}\right)$ is shown below. **[8 marks]**



(a) What is the molecular geometry of the carbon atom that has a double bond to oxygen? *[1 mark]*

trigonal planar

(b) A circle has been drawn around three atoms. What is the approximate $H-C-H$ bond angle involving these atoms? *[1 mark]*

$109.5°$

(c) Glucose undergoes a combustion reaction as follows: *[6 marks]*

$$C_6H_{12}O_{6(s)} + 6\,O_{2(g)} \rightarrow 6\,CO_{2(g)} + 6\,H_2O_{(g)}$$

At 25 °C and 1.0 bar, what volume of $CO_{2(g)}$ will be produced if 25 g of glucose are fully combusted? *Report your answer in L.*

Step 1: Calculate the number of moles of glucose used

$$M_{glucose} = 12\left(1.0079\,\frac{g}{mol}\right) + 6\left(12.011\,\frac{g}{mol}\right) + 6\left(15.9994\,\frac{g}{mol}\right) = 180.157\,\frac{g}{mol}$$

$$n_{glucose} = 25\ g \times \frac{1 mol C_6H_{12}O_6}{180.157 g} = 0.14\ mol$$

Step 2: Use mole ratio to calculate the number of moles of $CO_{2(g)}$ produced

$$n_{CO_2} = 0.14\ mol\ glucose \times \frac{6\ mol\ CO_2}{1\ mol\ glucose} = 0.83\ mol$$

Step 3: Calculate the volume of $CO_{2(g)}$ produced in L

$$PV = nRT$$

$$V_{CO_2} = \frac{nRT}{P} = \frac{(0.83\ mol)\left(8.314462\frac{Pa \cdot m^3}{mol \cdot K}\right)(298\ K)}{1.0\ bar} \times \frac{1000\ L}{1\ m^3} \times \frac{1\ bar}{100\,000\ Pa} = 21\ L$$

12. Lead poisoning can result from the ingestion of lead-containing compounds from sources including lead paint and contaminated drinking water. **[9 marks]**

(a) Write the ground-state electron configuration for a neutral atom of lead (Pb). *[2 marks]*

Use the noble gas abbreviation.

$[Xe]6s^2 4f^{14} 5d^{10} 6p^2$

(b) Lead can form two stable ions. What are their charges? Clearly explain your choices. *[3 marks]*

+2 and +4

The electron configuration for Pb^{4+} is $[Xe]4f^{14}5d^{10}$ which is a pseudonoble gas configuration.

The electron configuration for Pb^{2+} is $[Xe]6s^2 4f^{14}5d^{10}$. As such, all subshells are either completely full or completely empty (the inert pair effect).

(c) Lead has the following isotopic composition. Calculate the average atomic mass for lead. *[3 marks]*

Isotope	Mass (u)	Abundance
$^{204}_{82}Pb$	203.973	1.4 %
$^{206}_{82}Pb$	205.974	24.1 %
$^{207}_{82}Pb$	206.976	22.1 %
$^{208}_{82}Pb$	207.977	52.4 %

$$M_{av} = \frac{1.4\%}{100\%} M_{Pb-204} + \frac{24.1\%}{100\%} M_{Pb-206} + \frac{22.1\%}{100\%} M_{Pb-207} + \frac{52.4\%}{100\%} M_{Pb-208}$$
$$= \frac{1.4\%}{100\%}(203.973u) + \frac{24.1\%}{100\%}(205.974u) + \frac{22.1\%}{100\%}(206.976u) + \frac{52.4\%}{100\%}(207.977u)$$
$$= 2.9u + 49.6u + 45.7u + 109u$$
$$M_{av} = 207u$$

(d) This average atomic mass can be used for calculations involving neutral lead atoms or for calculations involving lead ions. Why? *[1 mark]*

The only difference between the composition of a neutral atom and an ion of the same element is the number of electrons. Compared to the mass of an atom, the mass of an electron is negligible. So, the masses of a neutral atom and an ion of the same element are similar enough to be the same to the first three decimal places.

13. Beryllium-8 is highly unstable towards decay into alpha particles. **[10 marks]**

Nuclide	Isotopic Mass
$^{4}_{2}He$	4.002 603 254 u
$^{8}_{4}Be$	8.005 305 10 u
$^{12}_{6}C$	12.000 000 00 u

(a) Based on the general properties of nuclides discussed in CHEM 1000, should we expect ^{8}Be to be an unstable nuclide? Briefly explain. *[2 marks]*

No, it is expected to be stable. It is a small nuclide with $\frac{N}{Z} = 1$. Also, it has both an even number of protons and an even number of neutrons.

(b) Write a balanced nuclear equation for this decay. *[1 mark]*

$^{8}_{4}Be \rightarrow 2\ ^{4}_{2}\alpha$

(c) Calculate the energy released by this decay. *[4 marks]*
Report your answer in Joules.

Step 1: Calculate mass defect (in kg)

$\Delta m = 2(4.002\ 603\ 254\ u) - 8.005\ 305\ 10\ u$

$\Delta m = -0.000\ 098\ 59\ u \times \frac{1.660539 \times 10^{-27}\ kg}{1\ u}$

$\Delta m = -1.637 \times 10^{-31}\ kg$

Step 2: Calculate energy released using mass-energy equivalence

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

$\Delta E = -1.637 \times 10^{-31}\ kg \times \left(\frac{2.997925\ m}{s}\right)^2 = \boxed{-1.471 \times 10^{-14}\ J}$

Therefore, the amount of energy released is $1.471 \times 10^{-14}\ J$.

(d) Carbon-12 has the same N/Z ratio as beryllium-8, but it is stable. Based on the mass defect of the hypothetical decay of ^{12}C into alpha particles, explain why ^{12}C is stable. *[3 marks]*

$$^{12}_{6}C \rightarrow 3\ ^{4}_{2}\alpha$$

$\Delta m = 3(4.002\ 603\ 254\ u) - 12.000\ 000\ 000\ u = \boxed{+0.007\ 809\ 762\ u}$

The mass defect is positive, so energy is not released.

14. The Potassium-Argon (K-Ar) method is used to estimate the ages of rocks. It is based on the observation that $^{40}_{19}K$ decays to $^{40}_{18}Ar$. The half-life of $^{40}_{19}K$ is $1.248 \times 10^9\ years$. **[9 marks]**

(a) The decay of $^{40}_{19}K$ to $^{40}_{18}Ar$ might occur via either of two possible one-step decay processes. Name those two processes and write a balanced nuclear equation for each. *[4 marks]*

It must be clear which name corresponds to which equation.

Electron capture: $^{40}_{19}K + {}^{0}_{-1}e \rightarrow {}^{40}_{18}Ar$

Positron emission: $^{40}_{19}K \rightarrow {}^{40}_{18}Ar + {}^{0}_{1}\beta$

(b) Hypothetically, if a piece of Martian rock was found to contain $2.021 \times 10^{-10}\ mol\ ^{40}_{19}K$ at the time of measurement, how many atoms of $^{40}_{19}K$ would have been present in that piece of rock 5.00 billion years $(5.00 \times 10^9\ years)$ ago? Assume no other events occur to affect the decay process. *[5 marks]*

Method 1:

$$N_2 = N_1\left(\frac{1}{2}\right)^n$$

$$n = \frac{\Delta t}{t_{1/2}} = \frac{5.00\times10^9\ y}{1.248\times10^9\ y} = 4.01$$

$$N_1 = \frac{N_2}{\left(\frac{1}{2}\right)^n} = \frac{2.021\times10^{-10}\ mol}{\left(\frac{1}{2}\right)^{4.01}} = 3.247 \times 10^{-9}\ mol$$

$$N_1 = 3.247 \times 10^{-9}\ mol \times \frac{6.022\times10^{23}\ atoms}{1\ mol} = 1.956 \times 10^{15}\ atoms$$

Method 2:

Step 1: Calculate the rate constant (k)

$$k = \frac{ln(2)}{t_{1/2}} = \frac{0.6931}{1.248\times10^9\ y} = 5.554 \times 10^{-10} y^{-1}$$

Step 2: Calculate N_1 in moles

$$ln\frac{N_2}{N_1} = -k\Delta t$$

$$ln\frac{N_2}{N_1} = -5.554 \times 10^{-10} y^{-1}\ (5.00 \times 10^9\ y) = -2.78$$

$$\frac{N_2}{N_1} = e^{-2.78} = 0.062$$

$$N_1 = \frac{N_2}{0.062} = 3.2 \times 10^{-9}\ mol$$

Step 3: Convert N_1 into atoms

$$N_1 = 3.2 \times 10^{-9}\ mol \times \frac{6.022\times10^{23}\ atoms}{1\ mol} = 2.0 \times 10^{15}\ atoms$$

15. **[10 marks]**

(a) Write a balanced chemical equation for the fourth ionization of beryllium. *[1 mark]*

$Be^{3+} \rightarrow Be^{4+} + e^{-}$

(b) Which is larger, the first ionization energy of beryllium or the fourth ionization energy of beryllium? Briefly, justify your answer. *[2 marks]*

The fourth ionization energy is larger.

Removing an electron from Be^{3+} requires more energy than removing an electron from Be because the electron in Be^{3+} feels the whole +4 charge from the nucleus whereas the valence electrons in Be are shielded by each other as well as the two core electrons.

(c) Which is easier to calculate, the first ionization energy of beryllium or the fourth ionization energy of beryllium? Briefly, justify your answer. *[2 marks]*

The fourth ionization energy of beryllium is easier to calculate

because Be^{3+} only has one electron

so there is only one force of attraction to calculate **or** so we don't have to factor in electron-electron repulsion (or shielding)

(d) Calculate the ionization energy that was your answer to part (c). *[5 marks]*
Report your answer in kJ/mol.

$$I_4 = 0J - E_{n=1} = 0J - \left(-R_H \times \frac{Z^2}{n^2}\right) = 0J - \left(-R_H \times \frac{4^2}{1^2}\right)$$

$$I_4 = 16R_H = 16 \times (2.179\,872 \times 10^{-18} J)$$

$$I_4 = 3.487\,795\,2 \times 10^{-17} J \text{ per atom}$$

$$I_4 = 3.487\,795\,2 \times 10^{-17} \frac{J}{atom} \times \frac{1kJ}{1000J} \times \frac{6.022141 \times 10^{23} atoms}{1mol}$$

$$I_4 = 2.100\,399 \times 10^{4} \frac{kJ}{mol}$$

16. The van der Waals equation of state includes two constants (a and b), the value for each of which is specific to the species being studied. **[6 marks]**

$$\left(P + a\frac{n^2}{V^2}\right)(V - bn) = nRT$$

(a) Would you expect NH_3 or CH_4 to have a larger value for a? Why? What does a correct for? *[3 marks]*

NH_3

a corrects for the intermolecular forces between gas particles in a nonideal gas

NH_3 is polar. CH_4 is nonpolar. Also, NH_3 can hydrogen bond. As such, the intermolecular forces between molecules of NH_3 are stronger than those between molecules of CH_4.

(b) Would you expect NH_3 or CH_4 to have a larger value for b? Why? What does b correct for? *[3 marks]*

CH_4

b corrects for the volume occupied by gas particles

A molecule of CH_4 is larger than a molecule of NH_3 and therefore occupies more volume.

17. 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!