

ACDB4011 CHEMISTRY OME FINAL EXAM

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SHOW ALL WORK !!! USE CORRECT UNITS AND SIGNIFICANT DIGITS. YOU MAY SHOW YOUR WORK ON THE BACK OF THE SHEET BUT INDICATE YOUR ANSWER ON THE FRONT.

PERIODIC TABLE AND REFERENCE DATA CAN BE TORN OFF OF THE EXAM

THERE ARE 11 QUESTIONS, 100 POINTS TOTAL TIME 120 min

QUESTION 1:

For each of the following statements determine if it is **TRUE** or **FALSE**. Circle the correct answer. In each case justify your choice.

1. (2p) The elements in the periodic table are arranged in the order of increasing number of electrons.

TRUE ☒ FALSE ☐ they are arranged in order of increasing number of protons (atomic number)

2. (2p) Multiple bonds are usually shorter and stronger than single bonds between the same atoms

TRUE ☒ FALSE ☐ double bonds are shorter and stronger than single, triple are stronger + shorter than single + double

3. (2p) In 1 mole of water there are 6.02×10^{23} atoms of oxygen.

TRUE ☒ FALSE ☐ 1 mole of water would be 6.02×10^{23} molecules of H_2O

4. (2p) Ideal gas equation describes well the behaviour of gases when the pressure and temperature of this gas tend to 0 atm and 0 K, respectively.

TRUE ☒ FALSE ☐ ideal gas equation describes behaviour at STP, 273K and 1 atm pressure.

2nd marker believed that but the answer is actually justified there. E.K. Q8a is answered incorrectly and full credit

77.5

74.5

14.5

6.5

6.5

5. (2p) Activation energy of nitrocellulose and RDX is 86 kJ/mol and 199 kJ/mol, respectively. RDX is less stable than nitrocellulose.

TRUE / ~~FALSE~~

RDX is more stable as it requires more energy to start the reaction

6. (2p) The C_2H_4 molecule has six bonding electron pairs and no lone pairs.

~~TRUE~~ / FALSE

1, double bond (2 e⁻ pair), 4 single bonds.

7. (2p) For a hypothetical reaction $A + B \rightarrow C$ that is a second order in A, doubling the concentration of A will double the rate of the overall reaction.

TRUE / ~~FALSE~~

doubling [A] will increase rate by a factor of 4

8. (2p) For every 10° C increase in temperature, the rate of thermal decomposition of explosive material decreases by factor of two.

~~TRUE~~ / FALSE

9. (2p) Volume of gas produced in the detonation process decreases when the oxygen balance becomes less negative.

~~TRUE~~ / FALSE

more negative Δ = more gas
less negative Δ = less gas

10. (2p) The value of the equilibrium constant, K_{eq} , will increase when more reactants are added to the reaction system at a constant temperature.

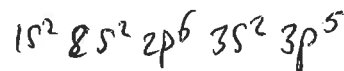
~~TRUE~~ / FALSE

9

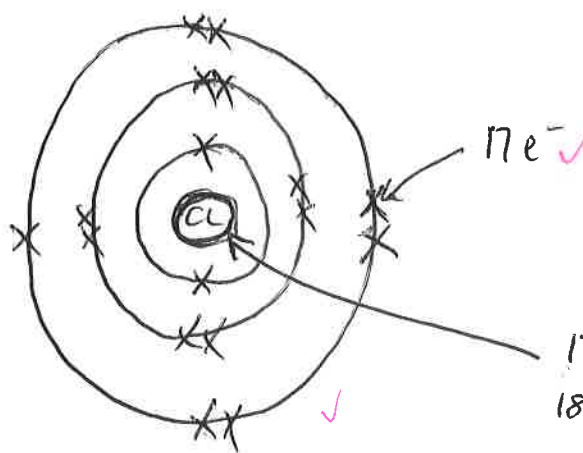
QUESTION 2:

- a) (3p) Draw the Bohr model for a chlorine atom. Specify the number of orbits and indicate the position of all subatomic particles within the atom and their charges.

$$\text{Orbits (n)} = 3 \checkmark$$



2, 8, 18



17 protons (+ charge) ✓
18 neutrons (neutral charge) ✓
20 neutrons for ^{37}Cl ✓
Go: ^{37}Cl ✓

3p

- b) (3p) Give the definition of mass number and explain why for the Cl atom the average atomic mass is 35.453.

relative mass of an atom ~~based~~ based on ^{12}C .
The atomic mass is the average mass x abundance of all isotopes of Chlorine. Since Chlorine occurs as Chlorine-35, and Cl-37, the atomic mass is an average of these based on their abundance.

3p

- c) (2p) How many protons and neutrons are there in chlorine-37?

$$\text{Protons} = 17 \checkmark$$

$$\text{Neutrons} = 37 - 17 = 20 \checkmark$$

2p

- d) (1p) What is the charge on the chlorine atom when it achieves octet?



1p

6

9

8

QUESTION 3:

Many fireworks contain metal compounds that emit visible light. The colour given by calcium compounds at the wavelength of 616 nm is orange-red.

a) (3p) Calculate the energy of one photon of the orange-red light emitted by a calcium atom. 2p

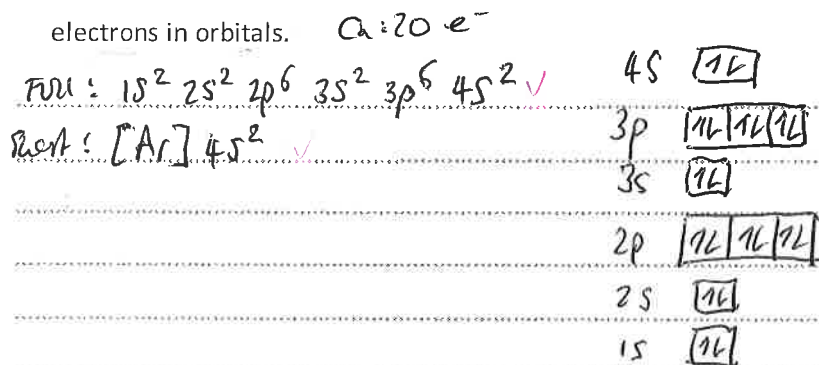
Show your calculations.

$$v = \frac{c}{\lambda} \quad E = h\nu \quad \lambda = \frac{c}{\nu}$$

$$\nu = \frac{3.0 \times 10^8}{616 \times 10^{-9}} = 2.05 \times 10^{15} \text{ Hz} \quad E = 6.63 \times 10^{-34} \times 2.05 \times 10^{15}$$

$$E = 1.36 \times 10^{-18} \text{ J}$$

b) (3p) Write the full and shorthand electron configuration for calcium and show ALL the electrons in orbitals. 3p



c) (3p) The colours seen in fireworks are a result of the emission of visible light. Describe how these colours are produced. 3p

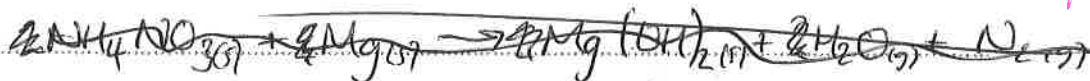
Electrons gain energy and jump from a lower energy level to a higher energy level. As they are unstable at higher energy levels, they fall back down, emitting light of a particular frequency. The energy absorbed is specific to the energy level from which the electron came from.

8

QUESTION 4:

When ammonium nitrate and magnesium metal are mixed in a stoichiometric ratio, they form a pyrotechnic composition that decomposes to form magnesium oxide, water vapour, and nitrogen gas.

a) (2p) Write a balanced equation showing all products for the decomposition of this mixture. 1p



b) (2p) What percentage of magnesium, by mass, is contained in the stoichiometric mixture? 2p

$$\text{Mixture Mr} = 104$$

$$\% \text{ Mg} = \frac{24}{104} \times 100 = 23.08\%$$

c) (3p) Using the standard heats of formation listed below, calculate the heat of reaction for molar quantities of the reactants. Is this process exothermic or endothermic? Explain 3p

Ammonium nitrate (solid) -365 kJ/mol

Magnesium oxide (solid) -601 kJ/mol

Water (gas) - 242 kJ/mol

$$\Delta H_r = 365 + (-601 + -242)$$

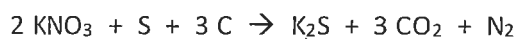
$$\Delta H_r = -478 \text{ kJ}$$

- Process is exothermic. Energy is released during the decomposition reaction.

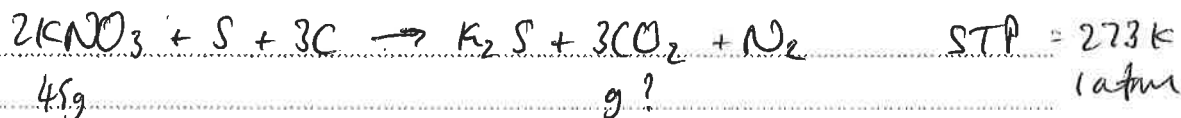
d) (3p) How does the heat of reaction from this reaction compare with 2.8 kJg^{-1} provided by one gram of TNT. Op

QUESTION 5:

A simple chemical equation for the combustion of gunpowder can be written as:



a) (4p) Assuming that the reaction above can be carried out at STP, how many grams of CO_2 are formed from the decomposition of 45 g of KNO_3 ? 4p



$$n(\text{KNO}_3) = \frac{45}{101.097}$$

$$n(\text{CO}_2) = 0.6677 \times 44.01$$

$$= 0.445 \text{ mol} \quad \checkmark$$

$$m(\text{CO}_2) = 29.39\text{g} \quad \checkmark$$

$$n(\text{CO}_2) = \frac{0.445}{2} \times 3 = 0.6677 \text{ mol} \quad \checkmark$$

b) (4p) How many litres of gas products would form from the decomposition of 45 g of potassium nitrate at STP? 4p

~~4 mol of gas products~~ $PV = nRT$

$n(\text{CO}_2) = 0.6677$ $V = \frac{nRT}{P}$

$n(\text{N}_2) = \frac{0.445}{2} \times 1 = 0.2225$ $V = 0.8902 \times 0.0821 \times 273$

total mol of gas = $0.6677 + 0.2225$
 $\approx 0.8902 \text{ mol}$

$V = 19.95 \text{ L}$

c) (4p) 45 g KNO_3 at STP is heated to 100°C and the pressure is reduced to 700 mmHg. What is the new volume of the gases? Use the appropriate gas laws to support your answer. DO NOT USE THE IDEAL GAS EQUATION! 4p

$760 \text{ mmHg} = 1 \text{ atm}$
 $700 \text{ mmHg} = \frac{1}{760} \times 700 = 0.921 \text{ atm}$
 New Volume = $19.95 \left(\frac{1}{0.921} \right) \left(\frac{373}{273} \right)$

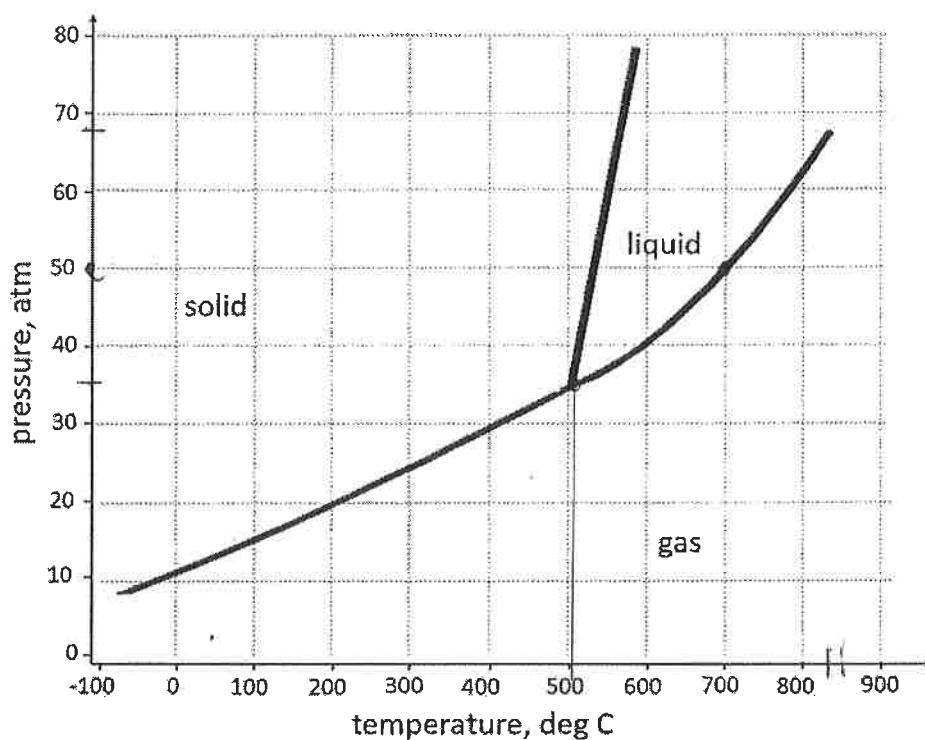
$T = 273 \text{ K}$
 $100^\circ \text{C} = 373 \text{ K}$
 $nV = 29.60 \text{ L}$

B: $P \propto V$ C: $V \propto T$ CL: $T \propto P$

$P \downarrow V \uparrow$ $T \uparrow V \uparrow$

QUESTION 6:

The phase diagram of an unknown compound X, is shown below:



- a) (2p) What is the value of temperature and pressure at a critical point? How is substance X called above the critical point?

825°C, 68 atm. Supercritical Fluid. ✓

2p

- b) (2p) If you stored a bottle containing compound X on the work desk in the lab, what phase would it most likely be in?

Gas.

2p

- c) (2p) If a sample of pure X is to be a mixture of liquid and gas, which point marks the sample's lowest possible temperature and pressure? Name all transitions occurring at this specific temperature and pressure.

500°C, 35 atm. Evaporation, condensing

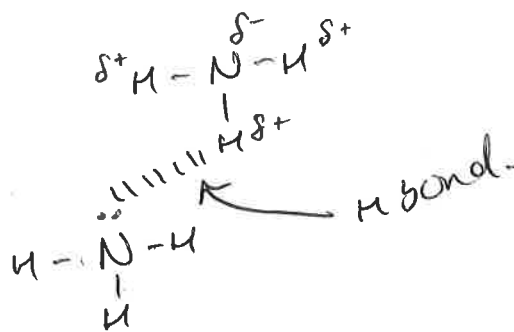
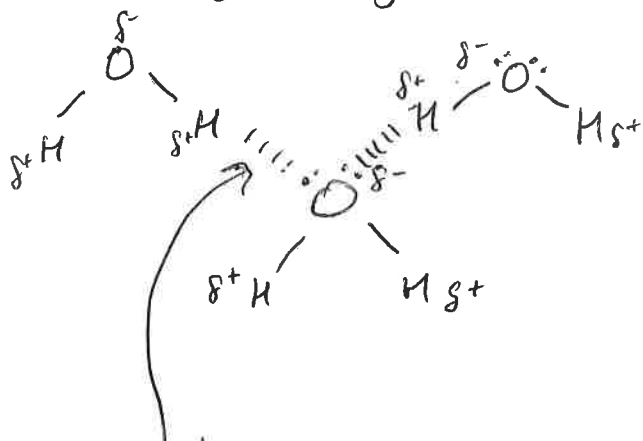
1p

d) (2p) What is the vapour pressure of substance X at 700° C?

QUESTION 7:

(4p) The normal boiling point is 100° C for H₂O and -33.3° C for NH₃, even though the two molecules have almost identical atomic weights. Explain this difference in terms of intermolecular forces. Use an appropriate drawing to support your answer.

Both molecules form hydrogen bonds ~~with other~~ between molecules. ^{the O atom in} H₂O can form ~~up to~~ 2 ^{the N atom in} H bonds in the liquid phase, whereas ^{the N atom in} NH₃ ~~only has~~ can only form 1. This is because the O atom has 2 lone pairs that ~~are attracted to~~ form H bonds with the δ^+ H atoms on another H₂O molecule. N in NH₃ only has 1 lone pair, thus ~~can only form 1 H bond with the~~ δ^+ H on another NH₃.



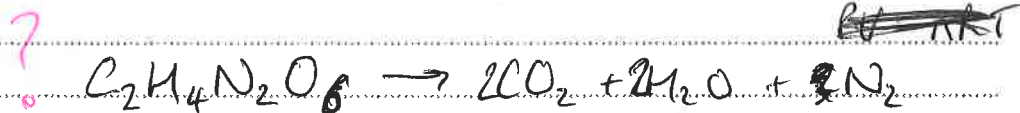
- more energy is required to break 2 H bonds compared to 1, therefore the BP is higher in H₂O.

- The polar charge occurs due to ¹¹ O + N ~~having~~ being more electronegative than the H, thus pulling electrons in the bond, closer to the O + N respectively.

QUESTION 8:

Some high explosives have the general formula $C_a H_b N_c O_d$. The oxidiser (O) and the fuel (C, H) are present in the same molecule. Nitrogen atoms are present, so there is a highly exothermic production of hot N_2 gas.

- a) (4p) For an unknown explosive of general formula $C_a H_b N_c O_d$ and a molar mass of 152 g/mol, determine the coefficients a, b, c, and d, if 152 g of this material decomposes to form 44.8 dm³ of CO_2 , 44.8 dm³ of H_2O , and 22.4 dm³ of N_2 .



4p

- b) (2p) Which of the produced gases will move fastest and explain why?

~~the one that is more gassy because its a smaller molecule compared with CO_2 + H_2O . $M_r(H_2O) = 18 g mol^{-1}$ vs $CO_2 = 44 g mol^{-1}$ and $N_2 = 28 g mol^{-1}$~~
 H_2O will move faster because its a smaller molecule.
 $M_r H_2O = 18 g mol^{-1}$ vs $CO_2 = 44 g mol^{-1}$, ~~H_2O~~ $N_2 = 28 g mol^{-1}$
 Smaller molecules ~~will~~ have more kinetic energy.

- c) (3p) The oxygen balance of an explosive is the mass of oxygen either in excess (the balance is positive) or in deficit (the balance is negative) of that required for complete oxidation of C and H. The oxygen balance is expressed as a percentage of the oxygen weight over the molar mass of the explosive. Calculate the oxygen balance for the explosive with the formula determined in part a).

3p

$$\Omega = \frac{16}{M_r} \left(d - 2a - \frac{b}{2} \right) \times 100$$

$$M_r(C_2H_4N_2O_8) = 152 \text{ g mol}^{-1}$$

$$\Omega = \frac{16}{152} \left(6 - (2 \times 2) - \left(\frac{4}{2} \right) \right) \times 100$$

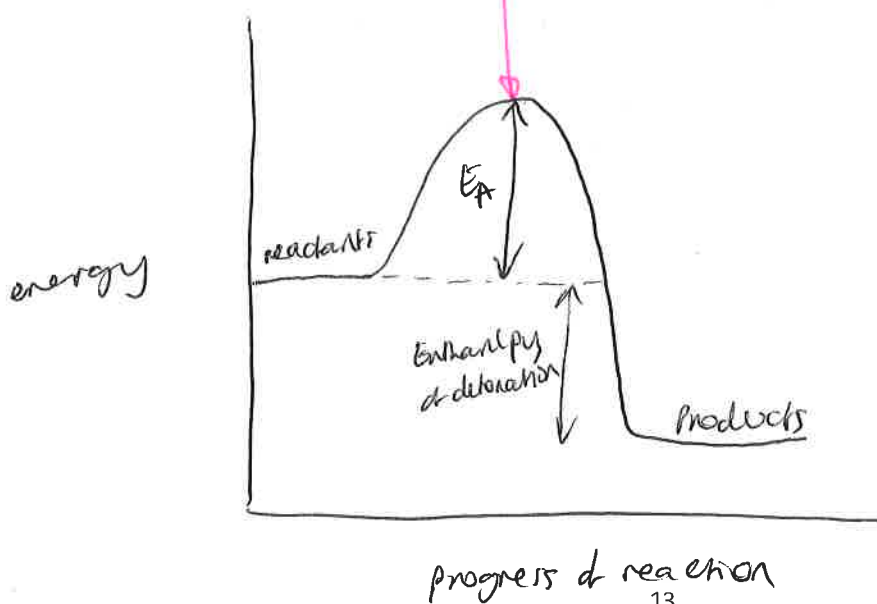
$$\Omega = 0\% \quad \checkmark$$

QUESTION 9:

An explosive, RDX has an enthalpy of detonation of $-1106 \text{ kJ mol}^{-1}$.

- a) (3p) Sketch the reaction profile ("energy" vs. "progress of reaction") showing the reactants, products, activated complex, enthalpy of detonation, and the activation energy.

2.5p



- b) (3p) Using the Arrhenius equation $k = A \exp(-E_a / RT)$ to support your answer, explain the relationship between activation energy, E_a , and the fraction of colliding molecules that result in a reaction.

3p

The greater the activation energy, the less there will be less colliding molecules with sufficient energy to overcome the E_a barrier. Therefore, less collisions resulting in a reaction, and the slower the rate of reaction.

$$k = A e^{\frac{-E_a}{RT}}$$

QUESTION 10:

- (4p) A 500 g sample of TNT ($C_7H_5N_2O_6$) is burned in a bomb calorimeter containing 610 g of water at an initial temperature of $20.0^\circ C$. The heat capacity of the calorimeter is $420 J/^\circ C$. Once the reaction is completed final temperature of the water and calorimeter increased to $23.0^\circ C$. Using these data, calculate the heat of combustion of TNT in kJ/mol . The specific heat of water is $4.184 J/g \cdot ^\circ C$.

0.5p

$$E = 500g \times 420 \times (23 - 20) = 630,000 J$$

$$E(H_2O) = 610 \times 4.184 \times (23 - 20) \quad m(TNT) = 213 g/mol$$

$$E(H_2O) = 7656.72 J$$

$$630,000 - 7656.72$$

$$m E = m C \Delta T \checkmark$$

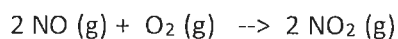
$$E_{system} = -surrounding$$

3.5

3.5

4p QUESTION 11:

Nitrous oxide, NO_2 , is a common propellant for rocket motors and it forms according to the following chemical equation:



- a) (4p) Three experiments were conducted to determine the values of the initial rate of formation of NO_2 as the concentrations of the reactants change. Use the data in the table below to determine the order of the reaction with respect to each reactant and write the rate law for the reaction

experiment	NO, mol/L	O_2 , mol/L	Initial rate, mol/L-s
1	0.012	0.020	0.102
2	0.024	0.020	0.204
3	0.024	0.040	0.204

$$\text{rate} = k[\text{NO}][\text{O}_2]$$

$$\text{total order of reaction} = 2$$

- b) (3p) Calculate the value of the rate constant. What is the unit of k?

2p

$$0.102 \text{ rate} = k(0.012)(0.020) \quad \text{mol/Ls} = k \text{ mol/L} \times \text{mol/L}$$

$$0.102 = k \cdot 2.4 \times 10^{-4} \text{ K}$$

$$k = \frac{0.102 \text{ mol/Ls}}{2.4 \times 10^{-4} \text{ mol}^2/\text{L}^2} = 425 \text{ mol/Ls}$$

$$\frac{\text{mol}}{\text{L} \cdot \text{s}} \cdot \frac{\text{L}^2}{\text{mol}^2} = \frac{\text{L}}{\text{mol} \cdot \text{s}}$$

- c) (2p) Which direction will the equilibrium shift if the overall pressure of the system is increased?

2p

~~The equilibrium will remain the same and remain at equilibrium.~~

equilibrium will shift towards the products as more collisions will occur, resulting in more product. ✓

Diwedd/End

