

ACDA4011 CHEMISTRY OME (HNC) FINAL EXAM

91.5

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NAME

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DATE

30/11/28

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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 10 QUESTIONS, 100 POINTS TOTAL (PLUS ANY EXTRA CREDIT EARNED IN THE CLASS). TIME 120 min

12p

QUESTION 1:

For each of the following statements determine if it is **TRUE** or **FALSE**.

T F

12

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

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

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

✓ ☐ ☒ (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.

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

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

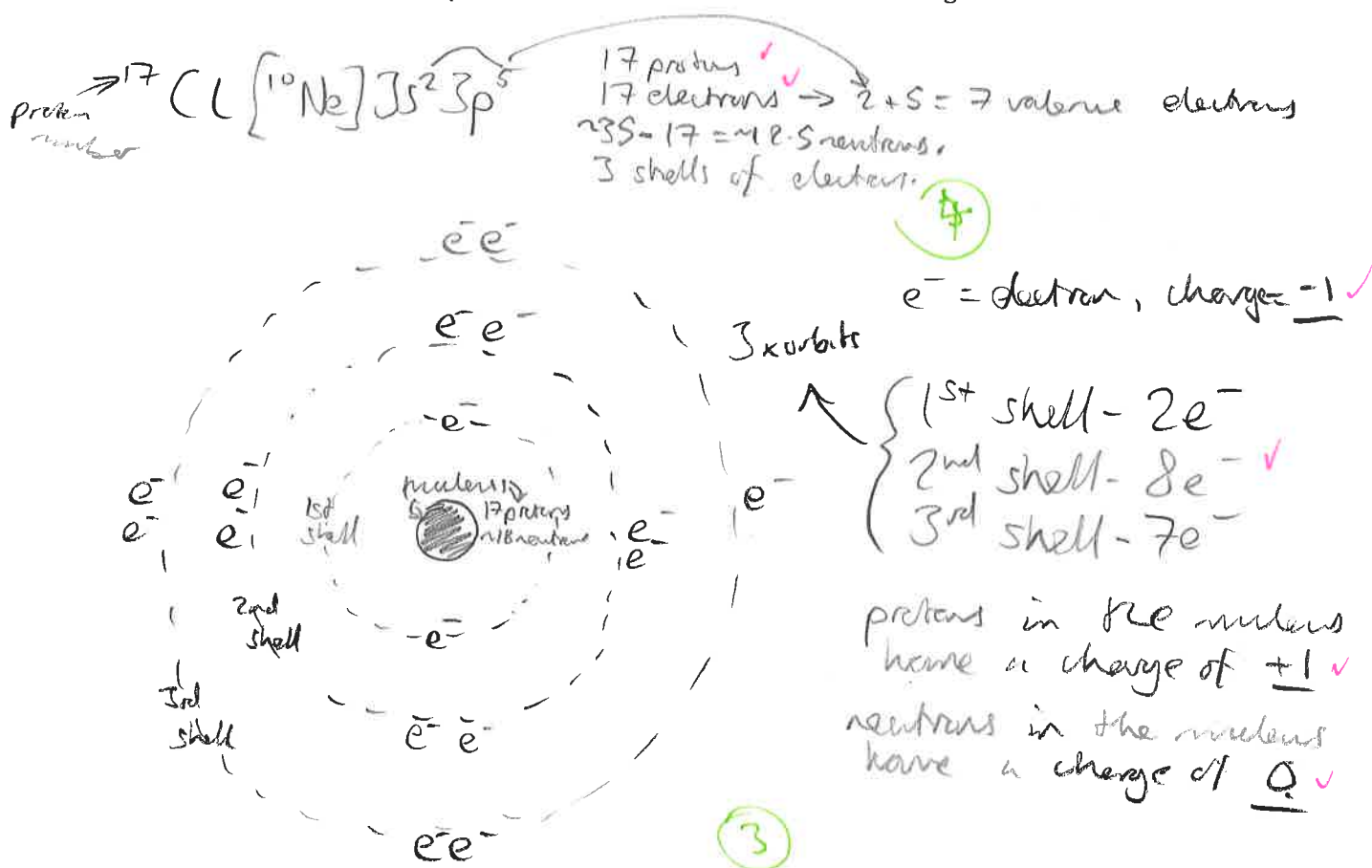
✓ ☐ ☒ (2p) For a hypothetical reaction $A + B \rightarrow C$ that is a second order in A, doubling the concentration of A will double the rate of the overall reaction.

✓ ☒ ☐ (2p) All combustion reactions are exothermic.

- ____ (2p) Volume of gas produced in the detonation process decreases when the oxygen balance becomes less negative.
- ____ (2p) The formula of potassium perchlorate is KClO_3 .

QUESTION 2:

- a) (4p) 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.



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

The mass number is the average mass of an element when taking account of number of isotopes AND the abundance of each isotope. Each isotope has the same proton number but varying numbers of neutrons. Chlorine has a mass of 35.453 because it has at least two isotopes with a varying number of neutrons.

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

$^{37}_{17}\text{Cl}$ has 17 protons
and $37 - 17 = 20$ neutrons.

d) (2p) What will be the charge on chlorine atom when the outer shell is a complete octet?

-1 it will be an anion with a negative charge.

QUESTION 3:

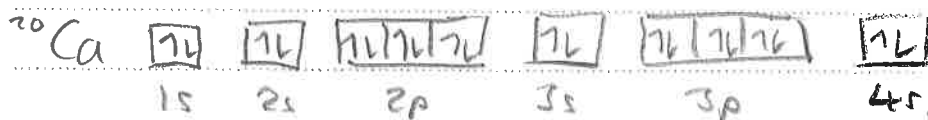
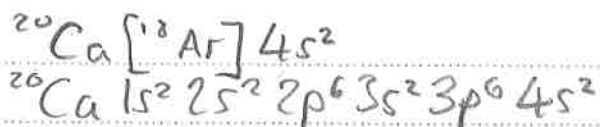
Many fireworks contain metal compounds that emit visible light. The colour given by calcium species at the wavelength of 616 nm is orange-red.

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

Speed of light, $c = \text{wavelength } (\lambda, \text{m}) \times \text{frequency } (\nu, \text{s}^{-1})$
 so $\nu = 3.0 \times 10^8 \text{ m s}^{-1} / 6.16 \times 10^{-7} \text{ m}$
 $\nu = 4.870 \times 10^{14} \text{ s}^{-1}$

Energy, $E = \text{planck's constant, } h, \times \text{frequency } (\nu, \text{s}^{-1})$
 $E = 6.6 \times 10^{-34} \text{ s s} \times 4.870 \times 10^{14} \text{ s}^{-1}$
 $E = 3.214 \times 10^{-19} \text{ J}$

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. Explain how these colours are produced.

Valence electrons in the atoms involved in the firework absorb energy from the chemical reaction of the firework. These valence electrons are excited into higher energy orbits within their atoms. As they relax back to their ground state orbitals, they emit photons of energy in the visible region of the electromagnetic spectrum. The colours correspond to the difference in energy of the ground and excited orbitals of the atoms.

QUESTION 4:

- 4p (4p) Consider only the three elements: S, Se, Cl.

- 3 a) Which one is most metallic?

Se ✓

- b) Which one has the greatest electronegativity?

Cl ✓

- 4 c) Which one has the highest ionisation energy?

Cl ✓

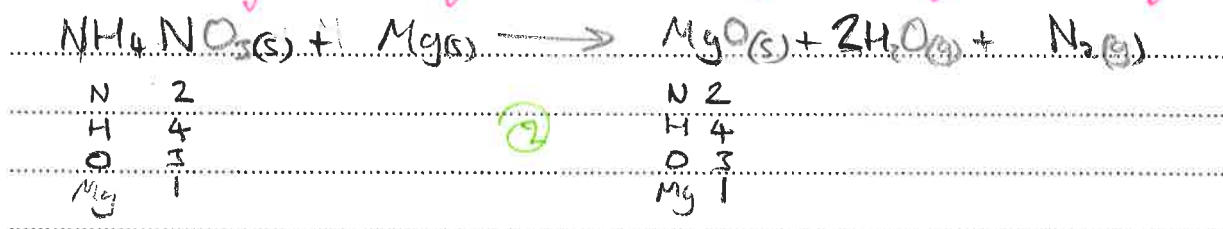
- d) Which one has the smallest atomic radius?

Cl ✓

QUESTION 5:

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.



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

2p

$$M_r \text{ of } \text{NH}_4\text{NO}_3 = 14 + (1 \times 4) + 14 + (16 \times 3) = 80 \text{ g mol}^{-1}$$

$$A_r \text{ of } \text{Mg} = 24 \text{ g mol}^{-1}$$

$$\% \text{ mass of Mg} = \left(\frac{24}{80 + 24} \right) \times 100$$

$$= \frac{24}{104} \times 100$$

$$= 23.08\% \text{ to 2dp}$$

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

Ammonium nitrate (solid) -365 kJ/mol

Magnesium oxide (solid) -601 kJ/mol

Water (gas) - 242 kJ/mol

3p

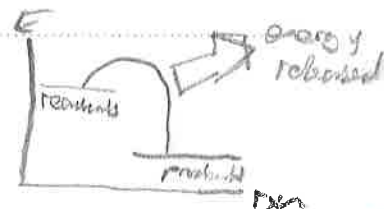
$$\Delta H_{\text{rxn}}^\circ = \sum \Delta H_{\text{products}}^\circ - \sum \Delta H_{\text{reactants}}^\circ$$

$$\Delta H_{\text{rxn}}^\circ = (-601 + (2 \times -242)) - (-365)$$

$$= -1025 - (-365)$$

$$= -720 \text{ kJ mol}^{-1}$$

This process is exothermic because the standard enthalpy of reaction ($\Delta H_{\text{rxn}}^\circ$) calculated above is negative meaning energy is released



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

So 1g of NH_4NO_3 , $M_r = 80 \text{ g mol}^{-1}$ + 24

$$\text{moles} = \frac{\text{mass}}{M_r}$$

$$\text{moles} = \frac{1}{80} = 0.0125 \text{ moles}$$

$$\text{Heat of reaction} = -720 \times 0.0125 = 9 \text{ kJg}^{-1}$$

Therefore because 9 kJg^{-1} is greater than 2.8 kJg^{-1} , the reaction produced more energy per gram than 1 gram of TNT.

(2)

QUESTION 6:

Some high explosives have the general formula $\text{C}_a \text{H}_b \text{N}_c \text{O}_d$. 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 $\text{C}_a \text{H}_b \text{N}_c \text{O}_d$ 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 dm^3 of CO_2 , 44.8 dm^3 of H_2O , and 22.4 dm^3 of N_2 .

$$PV = nRT \Rightarrow V = n \times 22.4 \text{ L mol}^{-1} \Rightarrow n = \frac{V(\text{L})}{22.4 \text{ L mol}^{-1}}$$

$$\text{moles of } \text{CO}_2 = \frac{44.8 \text{ dm}^3}{22.4 \text{ L mol}^{-1}} = 2 \text{ mol}$$

$$\text{moles of } \text{H}_2\text{O} = \frac{44.8}{22.4} = 2 \text{ mol}$$

$$\text{moles of } \text{N}_2 = \frac{22.4}{22.4} = 1 \text{ mol}$$



$$2(44) + 2(18) + 1(28) = 152$$

Therefore $a = 2$, $b = 4$, $c = 2$, $d = 6$

So Formula is $\text{C}_2\text{H}_4\text{N}_2\text{O}_6$. ✓

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

2p

According to Graham's Law of effusion:

$$\frac{V_A}{V_B} = \sqrt{\frac{M_B}{M_A}}$$

(2)

Therefore the smaller the molecular weight of an atom the faster its rate of effusion as a gas will be.

In this case water ($M_w = 18 \text{ g mol}^{-1}$) has the smallest molecular weight and so will move the fastest. ✓

3p

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 this oxygen weight over the molar mass of the explosive. Calculate the oxygen balance for explosive with the formula determined in part a).

$$OB = \frac{16}{M_r} \left(\#O - (2 \times \#C) - \left(\frac{\#H}{2} \right) \right) \times 100.$$

$$OB_{C_2H_4N_2O_6} = \frac{16}{152} \left(6 - (2 \times 2) - \left(\frac{4}{2} \right) \right) \times 100$$

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

$$= \frac{16}{152} (0) \times 100$$

$$= 0\%$$

(3)

Therefore this explosive does not have an excess or deficit of oxygen. The molecule has sufficient oxygen within it to fully oxidize itself. ✓



QUESTION 7:

A simple chemical equation for the combustion of gun powder 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 ?

$$M_r \text{ of } \text{KNO}_3 = 39 + 14 + (16 \times 3) = 101 \text{ g mol}^{-1}$$

$$\text{moles of } \text{KNO}_3 = \frac{45}{101} = 0.446 \text{ mol}$$

$$\text{moles of } \text{CO}_2 = (0.446 / 2) \times 3 = 0.668 \text{ mol}$$

$$M_r \text{ of } \text{CO}_2 = 12 + (16 \times 2) = 44 \text{ g mol}^{-1}$$

$$\text{mass of } \text{CO}_2 = 0.668 \times 44 = 29.406 \text{ g}$$

(4)

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



$$\text{K } a = 2b$$

$$\text{N } a = 2c$$

$$\text{O } 3a = b + 2d$$

$$\text{if } a = 1$$

$$b = \frac{1}{2}$$

$$c = \frac{1}{2}$$

$$d = 3 - \frac{1}{2} = \frac{5}{2}$$

$$\frac{4}{4}$$

$$\frac{2}{4}$$

$$\frac{2}{4} \times 4$$

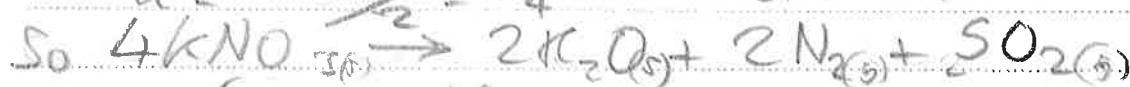
$$\frac{5}{4}$$

$$4 = a$$

$$2 = b$$

$$2 = c$$

$$5 = d$$



$$\text{moles of } \text{KNO}_3 = \frac{45}{101} = 0.446 \text{ mol}$$

$$\text{moles of } \text{N}_2 = (0.446 / 4) \times 2 = 0.222 \text{ moles}$$

$$\text{moles of } \text{O}_2 = (0.446 / 4) \times 5 = 0.558 \text{ moles}$$

$$V \text{ of } \text{N}_2 = 0.222 \times 22.4 \text{ L mol}^{-1} = 4.97 \text{ L}$$

$$V \text{ of } \text{O}_2 = 0.558 \times 22.4 \text{ L mol}^{-1} = 12.50 \text{ L}$$

$$\text{Total gas products} = 4.97 \text{ L} + 12.5 \text{ L} = 17.47 \text{ L}$$

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$$STP = 273K + 1 \text{ atm}$$

$$\rightarrow 39 + 14 + (16 \times 3) = 101 \text{ g mol}^{-1}$$

c) (4p) 45 g KNO_3 at STP is heated to 100 degC 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.

$$PV = nRT \quad n = 45 / 101 = 0.446 \text{ mol}$$

$$101,325 V = 0.446 (8.314) (273)$$

$$V = 9.98 \times 10^{-3} \text{ m}^3 = 9.98 \text{ L}$$

$$P_2 = \left(\frac{700}{760} \right) \times 101,325 = 93325.66 \text{ Pa}$$

$$n = 0.446$$

$$R = 8.314$$

$$T = 273 + 100 = 373K$$

new conditions:

$$93325.66 V = 0.446 (8.314) (373)$$

$$V = 0.014 \text{ m}^3 = 14 \text{ L}$$

So V has increased.

using combined gas Law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \quad (4)$$

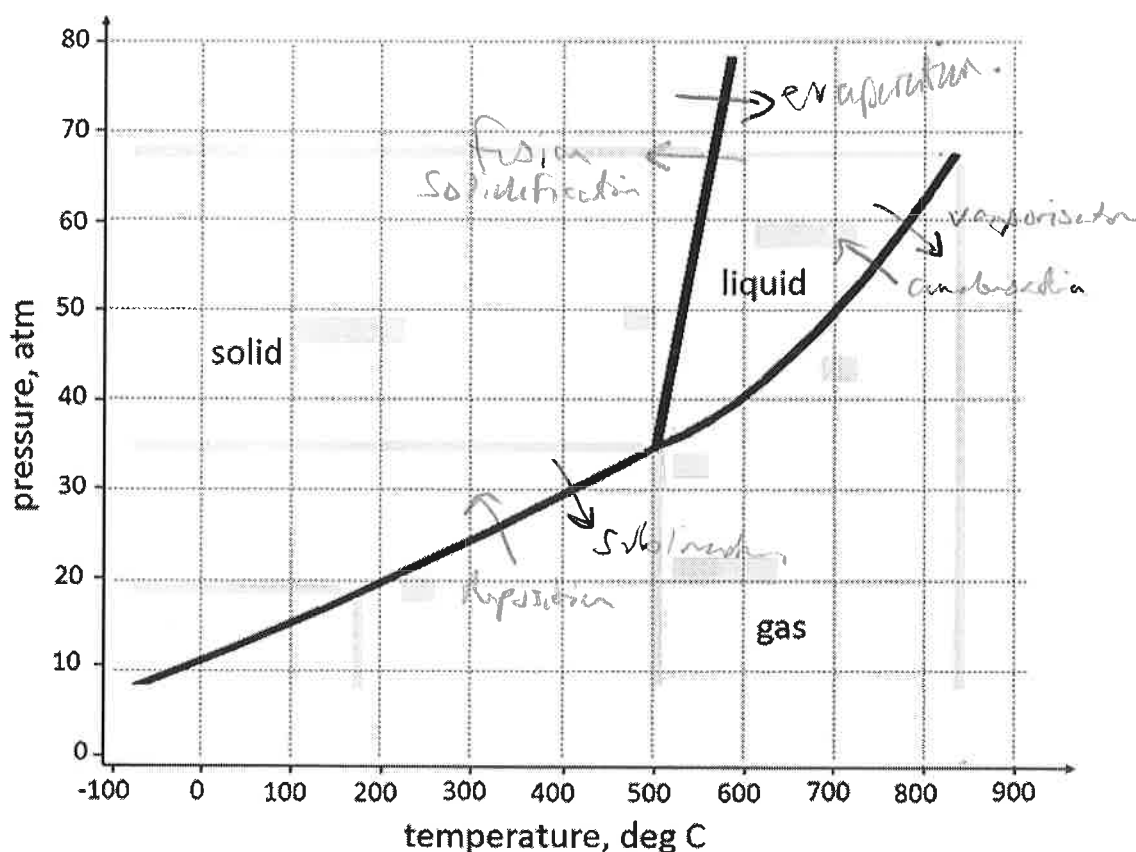
$$\frac{101,325 \times 9.98}{273} = \frac{93325.66 \times V_2}{373}$$

$$V_2 = 14.8 \text{ L}$$

So agrees with this law.

QUESTION 8:

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? What is the term used to describe the state of substance X above this point?

critical point = $\sim 840^{\circ}\text{C}$ & 68 atm ✓

It is now a ~~superfluid~~ ✗

①

- 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

$P = 1\text{ atm}$
 $T = \sim 20^{\circ}\text{C}$

②

- 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.

Near the triple point. $\sim 50^\circ\text{C}$ and 34 atm. (2)
All transitions occurring are vaporization and condensation.
If we hit the triple point then all transitions occur including melting, sublimation, sublimation, evaporation and deposition occur simultaneously, too.

- 2p d) (2p) Can compound X be boiled at 200 deg C? Why?

No, because at 200°C X can only exist as a solid or gas. (2)

- 2p e) (2p) What is the vapour pressure of substance X at 700 deg C?

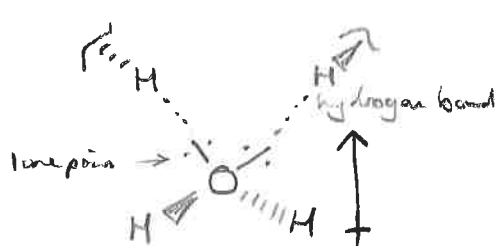
$\sim 50\text{ atm}$. (2)

- 2p f) Does the melting point of X increase, decrease or stay the same as the pressure is increased?

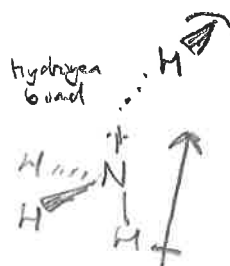
increases. (2)

QUESTION 9:

- a) (4p) The normal boiling point is 100°C for H_2O and -33.3°C for NH_3 , even though the two molecules have almost identical atomic weights. Explain this difference in terms of intermolecular forces, using words or pictures, or both.



(4)



Both molecules are polar molecules capable of forming hydrogen bonds with other molecules.

As water has the ability to make two hydrogen bonds per molecule and ammonia only one, there are greater intermolecular forces in water and more energy is required to break them and change phase.

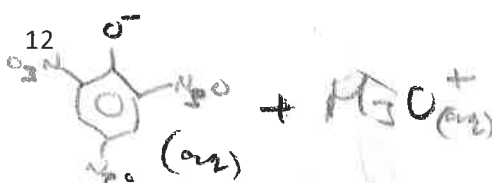
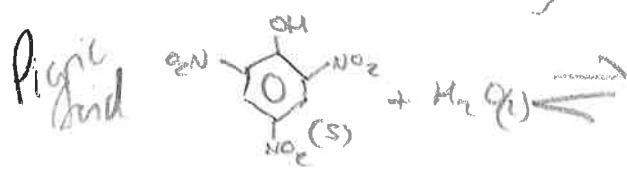
- b) (3p) Give **ONE** specific example of how might water react to give undesirable performance from OME devices? Explain why. To answer this question, refer to your assignment.

3p

(3)

Water promotes corrosion by acting as an electrolyte. Corrosion results in the dissolution of an anode. This means that metals are oxidised from their metallic forms into their oxide forms and lose metallic material properties. This may result in leaking or exposure of OME products in cases in metallic shells, which may lead to inadvertent discharge or damage of OME chemicals to the environment.

Another example is the use of picric acid in explosives. Acids dissolve in water and acidic environments promote corrosion further. Inadvertent discharge of picric acid shells was a problem around the end of the 18th century.

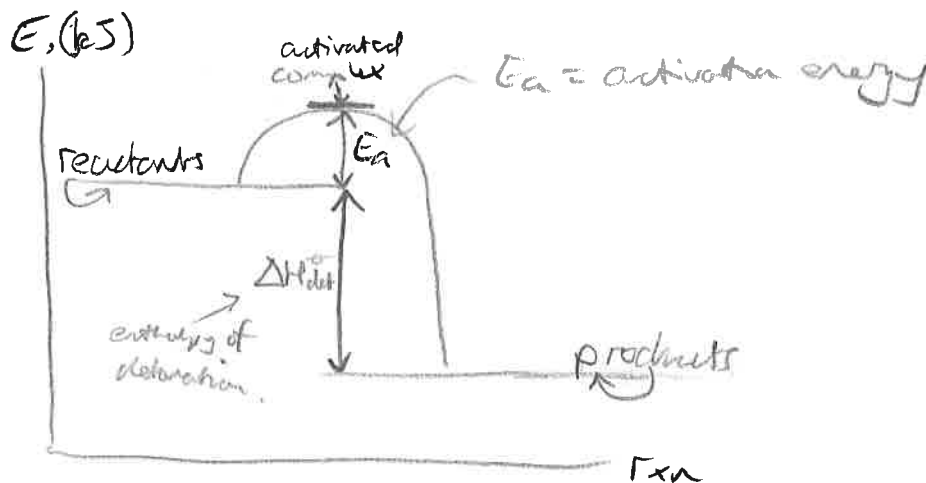


Picric acid would result in more sensitive larger crystals, too.

QUESTION 10:

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



- b) (3p) (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.

1

$k = \text{rate of reaction (Ms}^{-1}\text{)}$
 $A = \text{Frequency of reaction per collision (s}^{-1}\text{) } \rightarrow \text{steric + probability factor}$
 $E_a = \text{activation energy (kJ/mol}^{-1}\text{)}$
 $R = \text{gas constant}$
 $T = \text{Temperature (Kelvin)}$
 $\therefore \text{ if } E_a \text{ increases c.f. } k = A e^{-1/24} = A 0.959 \text{ @ STP}$
 $\text{ to } k = A e^{-2/24} = A 0.920$
 $\text{Then the rate, } k \text{ decreases.}$
 $\text{If } A \text{ increases, } k \text{ increases.}$

EXTRA CREDIT (if earned in class): 4.5 points

4.5

