

ACDB4011 CHEMISTRY OME FINAL EXAM

54.5

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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

16

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 ordered by Moseley
it is increasing number of
protons - the atomic number = # protons
but this is also # electrons ✓

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

☒ TRUE ☐ FALSE multiple bonds results in more
electrons in the bond + therefore a greater pull
towards the nucleus ✓

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

☒ TRUE ☐ FALSE 1 mole of any substance / element
has 6.02×10^{23} atoms - Avogadro's constant ✓

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 is not at
0 atm / 0 K - these are variables in the
equation ✓

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~~ ✓ nitrocellulose is unstable and requires less energy to break its bonds ✓

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

TRUE ~~FALSE~~ ✓ C forms a double bond leaving no lone pairs, H forms 2 bonds with each carbon ✓

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

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

TRUE ~~FALSE~~ ✓ Increase in temp will increase the rate of decomposition ✓

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

TRUE ~~FALSE~~ ✓ amount of gas produced increases when oxygen balance is negative ✓

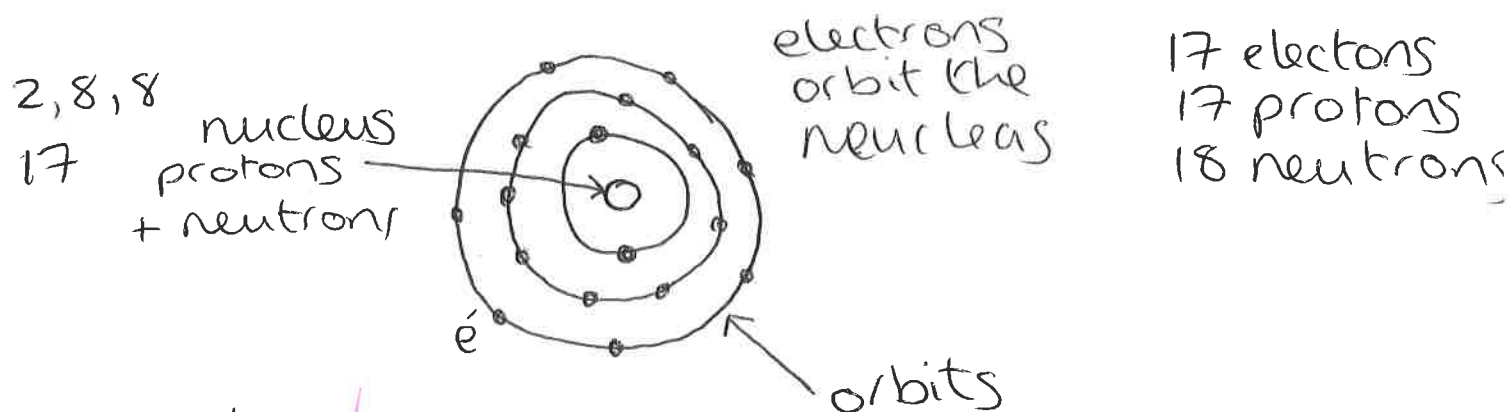
10. (2p) The value of the equilibrium constant, K_{eq} , will increase when more reactants are added to the reaction system at a constant temperature.

TRUE ~~FALSE~~ ✓ K_{eq} is ~~under~~ not affected by the amount of reactants in the system (or the addition of a catalyst) ✓
if T is constant = $k = \text{constant}$

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.



protons + neutrons in the nucleus ✓
protons are ~~positive~~ positive ✓
electrons are negative ✓
neutrons are neutral ✓

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

amu = 35.453 ✓ as Cl atom is a mixture of isotopes ✓ and this is the average value based on the abundance of each isotope. ✓
mass number is the weight of 1 mole of Cl. ✓

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

Cl 37

Protons 17 ✓

Neutrons 20 ✓

Electrons 17

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

7 → 8 + 1 e' = neg charge = negative
= +1

9

9

$$\Delta E = h \times \nu / f$$

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.

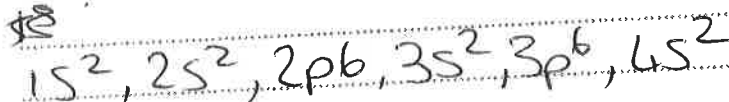
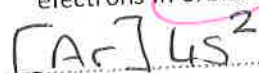
$$c = \lambda \times f$$

$$3.0 \times 10^8 = 616 \times f$$

$$f = 3.0 \times 10^8 / 616000 = 487.013$$

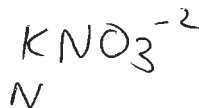
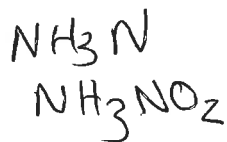
$$\Delta E = h \times f = 6.6 \times 10^{-34} \times 487.013 = 3.214 \text{ J}$$

- b) (3p) Write the full and shorthand electron configuration for calcium and show ALL the electrons in orbitals. Ca 20 2p



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

When excited an electron moves to a higher energy state, but this is unstable + it moves back to a lower energy level. When this move back down occurs it emits energy in the form of light. ✓

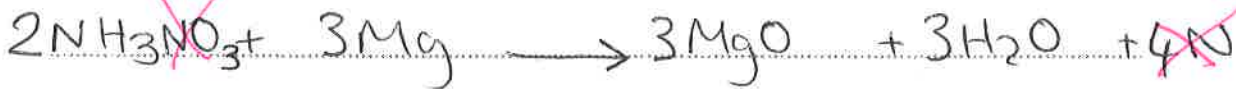


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QUESTION 4:

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.



4N 6H 6O

3O 3O

6H

4N

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

$$\text{Mg} = 24.312 \text{ g/mol}$$

$$24.312 \times 3 = 72.936 \text{ g of Mg}$$

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

$\Delta_{\text{rxn}} H$

$$3 \times \text{ammonium nitrate} = 3 \times -365 = -1095$$

$$3 \times \text{magnesium oxide} = 3 \times -601 = -1803$$

$$3 \times \text{water} = 3 \times -242 = -726$$

$$-1095 + -1803 + -726$$

$$= -3624 \text{ kJ}$$

endothermic - negative heat of formation

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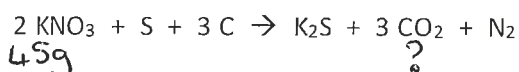
kJ/mol ~~45g~~ kJ/g

d) (3p) How does the heat of reaction from this reaction compare with 2.8 kJ g^{-1} provided by one gram of TNT. 0p

This would be an ~~ex~~ exothermic reaction and more heat would be produced / given out. The other reaction would give off cold / absorb heat.

64 QUESTION 5:

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



2 : 3 ratio

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 ? 1p

STP
1atmos
273K ✓
0°C ✓
22.4L ✓

$$N = n \times \text{mass} \text{ avo} \quad \text{MM}(\text{CO}_2) = 12 + (16 \times 2) = 44 \checkmark$$
$$\text{mass} = n \times \text{MM}$$

$$45 = ? \times 44$$

$$n = 45 / 44 = 1.0227 \text{ molecules/mol}$$

$$1.0227 \times 2 (2 \text{ mols}) = 2.045 \text{ molecules in rxn of KNO}_3$$

$$1.0227 \times 3 (\text{moles of CO}_2) = 3.0681 \text{ CO}_2$$

~~n~~ n

$$\text{mass} = 3.0681 \times 44 = 135 \text{g CO}_2$$

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

$$\text{STP} = \text{molar gas volume} = 22.4 \text{ L}$$
$$3 \times 22.4 = 67.2 \text{ L}$$

- 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 Op

NOT USE THE IDEAL GAS EQUATION!

$$\text{Temp} = 373 \text{ K}$$

$$700 \text{ mmHg} = 0.921 \text{ atmos}$$

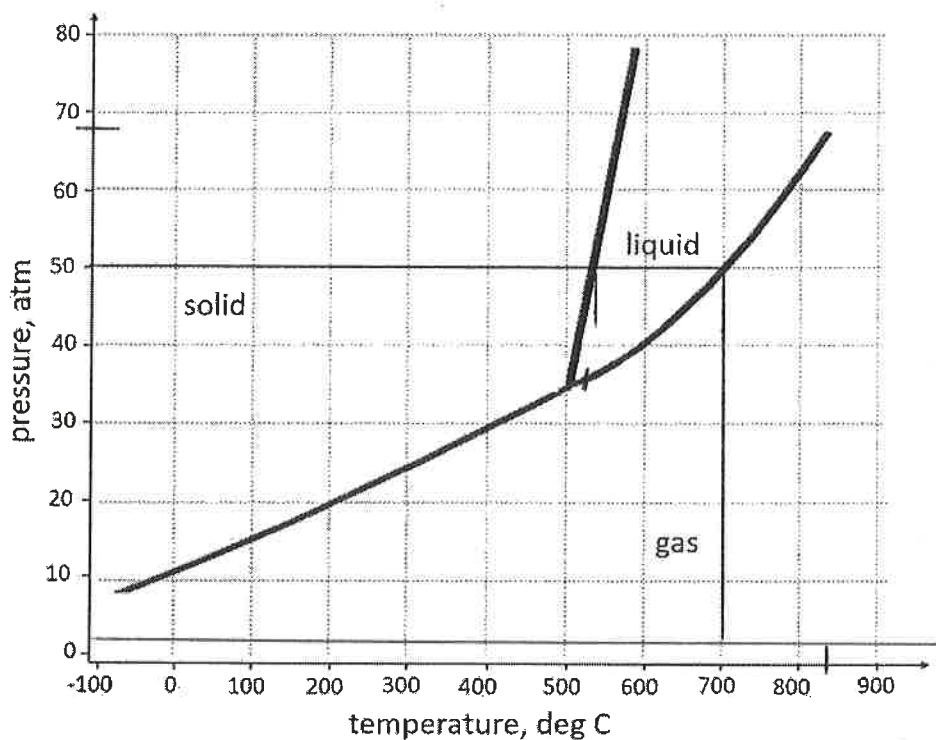
Boyle's $P \downarrow V \uparrow$ ✓
GayLussac $P \uparrow T \uparrow$ ✓

$$V_1 = 67.2 \text{ L} \times \left(\frac{373}{273} \right) \times \left(\frac{0.921}{1} \right) = V_2$$

$$67.2 \times 1.366 \times 0.921 = V_2$$
$$V_2 = 84.54 \text{ L}$$

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?

$T = 840^{\circ}\text{C}$ $P = 68 \text{ atm}$ 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 - 1 atm is in the gas phase 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.

Condensation and boiling ✓
The last point for only liquid and gas is immediately after the triple point - at the TP all 3 states could coexist
approx 520°C on the graph

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

50 atmos

2p

QUESTION 7:

NOF - H = hydrogen

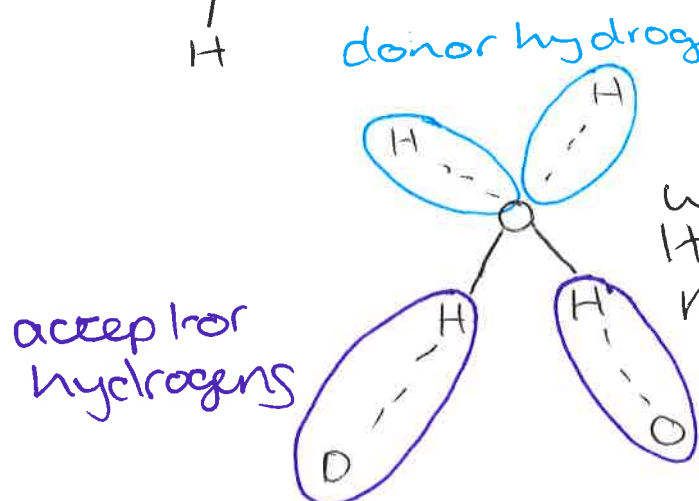
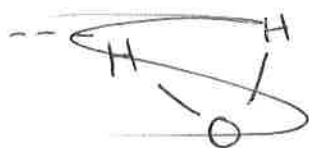
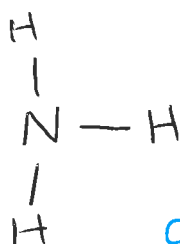
LDF

1p

(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.

everywhere

Both molecules experience hydrogen bonds ✓
~~NH₃ has more hydrogens than H₂O so the overall energy required to break~~



Oxygen is more electronegative and therefore bigger dipole dipoles will occur which makes H₂O experience H bonds + dipole dipole more than NH₃ = higher boiling point

With Oxygen being a bigger element with more electrons in the outer shell the ~~proton~~ atomic radii decreases allowing stronger forces from the nucleus. It is a bigger molecule = more polarizability = squishier = more/stronger forces of attraction
~~oversize size~~

11

In H₂O passing molecules experience temporary forces of attraction as they pass each other. Both compounds also experience London dispersion forces

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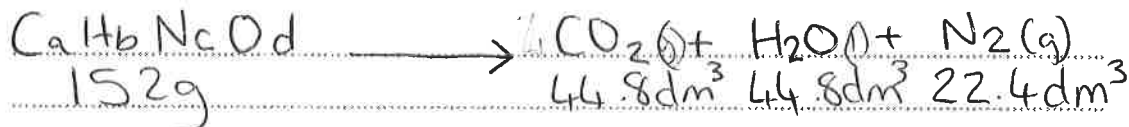
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22.4^L 1atmos 273 K

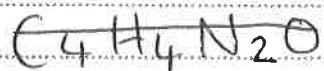
QUESTION 8:

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 .



CO_2 and H_2O 2:1 N_2



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

They will all move at the same speed as they are all at the same pressure.

~~N_2 will travel fastest as it has a higher temperature~~

- 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).

A B C D
C₄H₁₂N₂O₄

$$\Omega = \frac{16}{\text{IMW}} \times \left[d - (2a) - \frac{b}{2} \right]$$

IMW
C = 48
H = 12
N = 28
O = 64

$$\Omega = \frac{16}{152} \times [64 - (2 \times 48) - \frac{12}{2}]$$

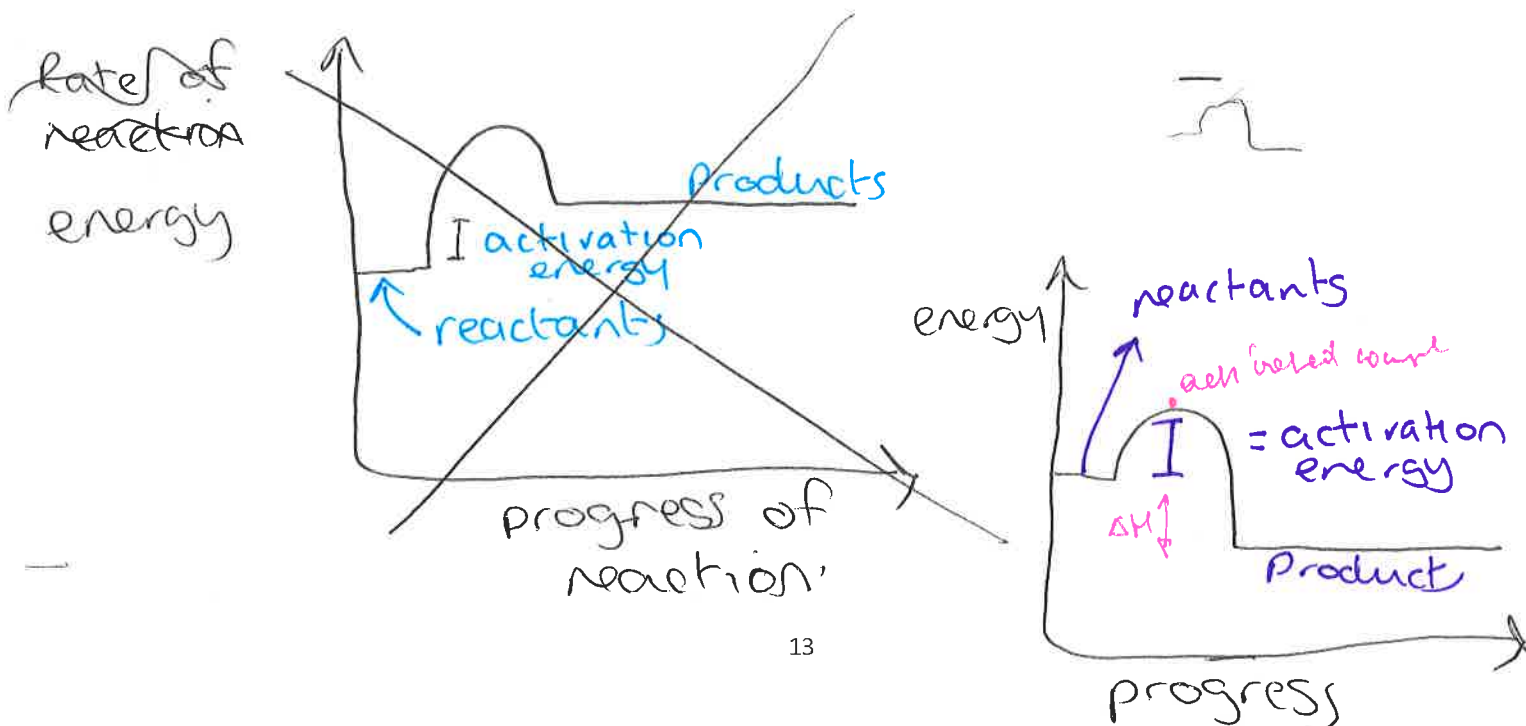
$$\Omega = 0.105 \times [64 - 96 - 10]$$

$$\Omega = -4.41 \%$$

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.



- ↑
- 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

Activation energy is lower if the fraction of colliding molecules resulting in a reaction is higher

$k = \text{rate of reaction}$

$A = \text{constant of material / gas collisions}$

$E_a = \text{activation energy}$

$R = \text{gas constant}$

$T = \text{temp K}$

$A \uparrow \quad E_a \downarrow$

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°C . The heat capacity of the calorimeter is $420 \text{ J/}^\circ\text{C}$. Once the reaction is completed final temperature of the water and calorimeter increased to 23.0°C . Using these data, calculate the heat of combustion of TNT in kJ/mol . The specific heat of water is $4.184 \text{ J/g}^\circ\text{C}$.

0p

Start

610g H_2O

20.0°C

heat capacity $420 \text{ J/}^\circ\text{C}$

Final

23.0°C

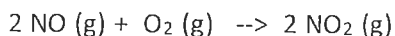
specific heat = $4.184 \text{ J/g}^\circ\text{C}$

3

3

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

$1 \rightarrow 2$ NO doubled, O_2 same rate doubles
 $2 \rightarrow 3$ NO same, O_2 doubled rate same
 $1-3$ NO doubled, O_2 doubled rate double

2nd order

- ① $k = [\text{A}]^2 [\text{B}]$
 ② $k = [\text{A}] [\text{B}]^2$
 ③ $k = [\text{A}]^2 [\text{B}]$

$k =$ When NO doubles rate doubles
 O_2 has no effect on the initial rate.

$$\frac{0.024}{0.040}$$

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

Op

$$k = \frac{[\text{Products}]}{[\text{reactants}]} = \frac{0.024}{0.020} = 1.2$$

no units it is a ratio

$$k = 0.024 / 0.040 = 0.6$$

From reaction 3 where A + B double
and so does rate

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

2p

To the right / products to counter
the shift on the left / reactants

Shift
→

Reactants ⇌ products

Diwedd/End