4

THE GASEOUS STATE

Content

4.1 Ideal gas behaviour and deviations from it

4.2 $pV = nRT$ and its use in determining a value for M_r

Learning Outcomes

Candidates should be able to:

(a) state the basic assumptions of the kinetic theory as applied to an ideal gas.

(b) explain qualitatively in terms of intermolecular forces and molecular size:

  (i) the conditions necessary for a gas to approach ideal behaviour

  (ii) the limitations of ideality at very high pressures and very low temperatures

(c) state and use the general gas equation $pV = nRT$ in calculations, including the determination of M_r

9647_2015

❹ The gaseous state

MCQs

04-1-M-01 [RJ]

A 2g sample of hydrogen at temperature T and of volume V exerts a pressure p. Deuterium, ${}^{2}_{1}H$, is an isotope of hydrogen.

Which of the following would also exert a pressure of p at the same temperature T?

A a mixture of 1g of hydrogen and 1g of deuterium of total volume V

B a mixture of 1g of hydrogen and 2g of deuterium of total volume V

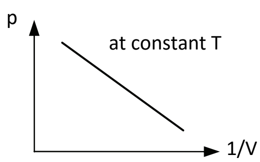
C a mixture of 1g of hydrogen and 2g of deuterium of total volume 2V

D a mixture of 2g of hydrogen and 2g of deuterium of total volume 2V

04-1-M-02 [TM]

Which of the following diagrams correctly describes the behaviour of a fixed mass of an ideal gas?

A



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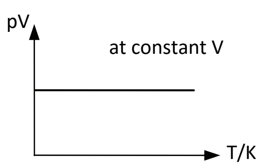

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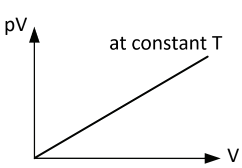

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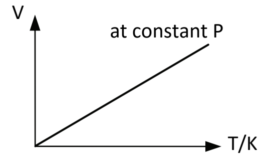


04-1-M-03 [RJ]

Which gas is most likely to deviate most from ideal gas behaviour?

A HCl

B He

C CH_4

D N_2

04-1-M-04 [RJ]

0.080 g of a liquid compound was completely vaporized in a gas syringe at 127°C and a pressure of 1 atmosphere. 81 cm^3 of vapour was produced. What was the relative molecular mass of the liquid?

A 32.4

B 18.5

C 20.4

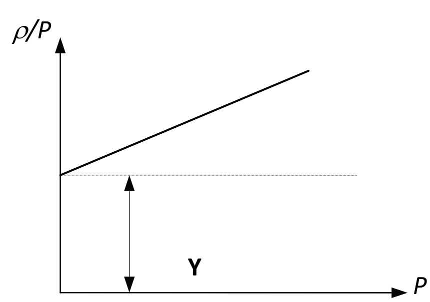
D 64.8

04-1-M-05 [HC]

The ideal gas equation, referring to n moles of gas is $PV = nRT$. A graph of ρ/P versus P is obtained for a gas **X** where

ρ = density of gas in g dm^{-3}

P = pressure of gas in atm and



At $P = 0$ atm and $T = 273$ K, the relative molecular mass of **X** is

A 273R**Y**

B 273**Y**/R

C R**Y**/273

D 273R/**Y**

04-1-M-06 [VJ]

Which gas can be most easily liquefied by cooling and applying pressure?

A Ar

B H_2

C HF

D CH_4

04-1-M-07 [HC]

Which one of the following gas samples contains the greatest number of moles? Assume the gas is ideal.

A 50 dm^3 at 1 atm and 400 K

B 40 dm^3 at 2 atm and 500 K

C 30 dm^3 at 3 atm and 600 K

D 20 dm^3 at 4 atm and 700 K

04-1-M-08 [RJ]

P and **Q** are ideal gases that do not react together. The mass of 1 mole of P is four times that of **Q**.

If all measurements are taken at standard temperature and pressure, which statement(s), according to the kinetic theory of gases, is/are correct?

1 The average kinetic energy of a molecule of **P** is equal to that of a molecule of **Q**.

2 The mass of 1 dm^3 of **P** is four times that of 1 dm^3 of **Q**.

3 On mixing 1 dm^3 of **P** with 1 dm^3 of **Q**, the partial pressure of each gas in the mixture is 50 kPa (0.5 atm).

A 1, 2 and 3 are correct.

B 1 and 2 only are correct.

C 2 and 3 only are correct.

D 1 only is correct.

04-1-M-09 [TM]

A 5.0 dm^3 sample of oxygen at a pressure of 200 kPa and 2.0 dm^3 sample of nitrogen at a pressure of 500 kPa are introduced into a 2.5 dm^3 vessel at constant temperature.

What is the total pressure in the vessel?

A 500 kPa

B 700 kPa

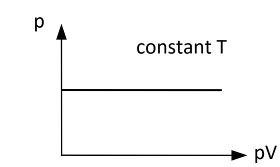
C 725 kPa

D 800 kPa

04-1-M-10 [HC]

Which of the following diagrams correctly describes the behaviour of a fixed mass of an ideal gas?

A



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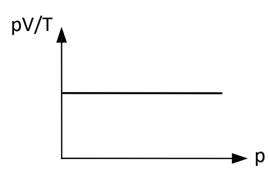

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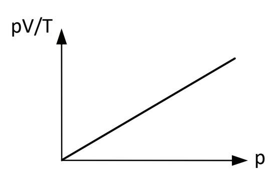

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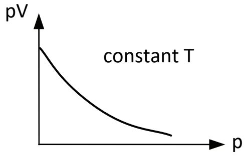


04-1-M-11 [HC]

If the behaviour of a gas is described exactly by the equation $pV = nRT$, which of the following must be true of the gas?

1 It cannot be liquefied.

2 The pressure of a fixed mass of gas is inversely proportional to the volume at constant temperature.

3 There are no intermolecular forces between the particles of the gas.

A 1, 2 and 3 are correct.

B 1 and 2 only are correct.

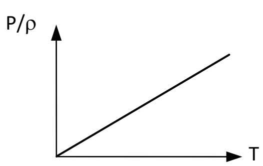
C 2 and 3 only are correct.

D 1 only is correct.

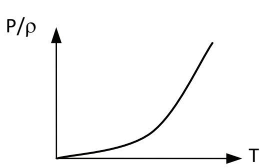
04-1-M-12 [TM]

Which of the following is the most accurate representation of a graph of P/ρ vs T for an ideal gas? (P = pressure; ρ = density; T = temperature in °C)

A



B



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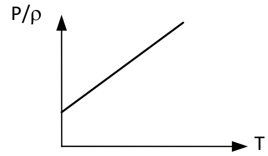
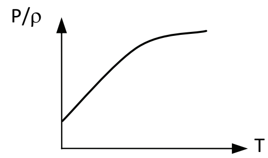
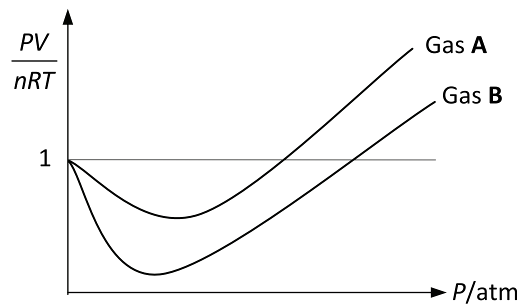


D



04-1-M-13 [RJ]

The following graphs were obtained for gases **A** and **B**:



The two gases are O_2 and NH_3. What deduction(s) can be drawn from the graphs?

1 Gas **B** has stronger intermolecular forces of attraction between its molecules than gas **A**.

2 Molecules of gas **A** are larger than molecules of gas **B**.

3 Gases **A** and **B** are NH_3 and O_2 respectively.

A 1, 2 and 3 are correct.

B 1 and 2 only are correct.

C 2 and 3 only are correct.

D 1 only is correct.

04-1-M-14 [VJ]

At standard temperature and pressure, easily liquefiable gases (e.g. SO_2, Cl_2) show greater deviation from ideal behaviour compared to gases that are difficult to liquefy (e.g. N_2, CO).

Which of the following statements best explains this phenomenon?

A Larger molecular volume of easily liquefiable gases causes greater impacts on vessel walls during collisions. This leads to greater deviation from ideality.

B For real gases, $PV > nRT$ due to repulsion between molecules. This effect is more significant for gases that are difficult to liquefy.

C The spread in kinetic energies is smaller in molecules of easily liquefiable gases, giving rise to greater deviation.

D Negligible intermolecular forces operate among molecules. This assumption is more valid for molecules that are difficult to liquefy.

04-1-M-15 [TM]

A volume of 0.12 m^3 of oxygen measured at 6.0×10^4 Nm^{-2} and 0.15 m^3 of argon at 8.0×10^4 Nm^{-2} are passed into a vessel having a capacity of 0.5 m^3. What is the total pressure of gas in the vessel if the temperature is kept constant?

A 1.84×10^4 Nm^{-2}

B 2.40×10^4 Nm^{-2}

C 3.84×10^4 Nm^{-2}

D 14.0×10^4 Nm^{-2}

04-1-M-16 [HC]

Which of the following is **not** a basic assumption of the kinetic theory of gases?

A The atoms or molecules have negligible size in comparison with the space they occupy.

B The kinetic energy of the atoms or molecules in a gas increases as the temperature is raised.

C Collisions between the individual particles and the retaining vessel are perfectly elastic.

D The particles of a given gas have the same kinetic energy at a given temperature.

04-1-M-17 [TM]

Which of the following is an **incorrect** assumption made in the kinetic theory about an ideal gas?

A The molecules are in a state of continual, random motion.

B The gas particles have constant interactions with one another.

C The gas particles have negligible volume compared to the volume of the container.

D The average kinetic energy of the particles increases as the temperature increases.

04-1-M-18 [VJ]

The Gas Laws can be summarized by the ideal gas equation: $pV = nRT$, where each symbol has its usual meaning.

Which of the following statements are correct?

1 The density of an ideal gas at constant temperature is inversely proportional to the temperature.

2 The volume of a given mass of an ideal gas is doubled if its temperature is raised from 25°C to 50°C at constant pressure.

3 The pressure is doubled when the volume is doubled for a given mass of ideal gas at constant temperature.

A 1, 2 and 3 are correct.

B 1 and 2 only are correct.

C 2 and 3 only are correct.

D 1 only is correct.

04-1-M-19 [VJ]

If 0.50g of methanal (HCHO) was vaporized at 100°C and 100 kPa pressure, the volume, in m^3, of gas formed would be

A 5.17×10^{-4}

B 1.39×10^{-4}

C 0.139

D 0.0155

04-1-M-20

[*Examine in* 2014]

Use of the Data Booklet is relevant to this question.

Iodine is a black, shiny, non-metallic solid and a member of Group VII. It sublimes easily on heating to give a purple vapour.

A sample of iodine vapour of mass 6.35 g has a volume of 1.247 dm^3 when maintained at constant temperature and a pressure of 1.00×10^5 Pa.

If iodine vapour acts as an ideal gas, what is the temperature of the iodine vapour?

A 300 K

B 600 K

C 300,000 K

D 600,000 K

[**Teachers' Comments**]

26% of candidates chose the correct answer. One of the most commonly chosen incorrect answers, chosen by 30% of candidates, is if candidates do not appreciate that iodine vapour consists of I_2, with an M_r of 254. The other most commonly chosen incorrect answers, chosen by 33% of candidates, is if candidates do not convert the volume 1.247 dm^3 into 1.247×10^{-3} m^3. This question requires candidates to insert the data in the question into $pV = nRT$, and then to rearrange the expression to find T.

Questions – 4

04-1-Q-01 [NA]

Fluorine is a highly reactive gas that can undergo different types of reactions.

(a) Fluorine reacts with methane to form compound **X**, a gaseous fluorinated hydrocarbon, which when inhaled can cause disorientation and nausea in a person.

In one such synthesis at 500K and 173.5kPa, 0.263g of compound **X** was formed, which occupied a volume of 90 cm^3.

(i) Calculate the relative molecular mass of compound **X**.

(ii) Suggest an identity for compound **X**.

(iii) Suggest, with reasons, whether methane or compound **X** show greater deviation from ideal gas behaviour.

To confirm the identity of compound **X**, it was analysed using a mass spectrometer.

(iv) Identify the ions at the following m/e values. [*supplementary topic*]

m/e	Ions
69	
51	
50	
31	
12	

(v) Draw and label all the valence orbitals of the carbon atom.

(b) Fluorine when bubbled through an aqueous solution of sodium iodide produced iodine that required 48.0 cm^3 of 0.200 mol dm^{-3} of sodium thiosulfate to completely discharge the iodine colour.

(i) Use relevant data from the Data Booklet to construct balanced equations for the two reactions described above.

(ii) Calculate the volume of fluorine gas required to completely discharge the iodine colour at room temperature and pressure.

04-1-Q-02 [HC]

(a) Draw the shape and show the bond angle of a molecule of ammonia. State the type of bonding present between ammonia molecules.

(b) (i) Ammonia can be produced by heating ammonium chloride with calcium hydroxide. This reaction also produces a white solid. Write a balanced equation for this reaction.

(ii) The ammonia gas was collected in an 800 cm^3 glass bulb at 1.5×10^5 Pa and 25°C. What was the minimum mass of ammonium chloride that was used in the reaction?

04-1-Q-03 [TM]

The nitrates of the elements in Group 2 of the Periodic Table decompose when they are heated.

(a) When magnesium nitrate decomposes, two gases are evolved and a white solid remains.

Write a balanced equation to show the above reaction.

(b) Nitrates of most Group I metals decompose in a different way from those in Group 2. When 1.45 g of sodium nitrate, $NaNO_3$, is strongly heated, it gives 1.17 g of a pale yellow solid and 204 cm^3 of the colourless gas referred to in (a).

[Gas measurement was conducted at 25°C under the atmospheric pressure of 1 atm.]

(i) Calculate the number of moles of sodium nitrate being heated.

(ii) Calculate the number of moles of gas evolved.

(iii) Use your answers in (b)(i) and (ii) to complete and balance the equation for the decomposition of sodium nitrate on heating and hence determine the formula of the pale yellow solid.

(iv) The experiment was repeated under different conditions to check whether the gas evolved obeys the ideal gas law. At 110 °C and a pressure of 5 atm, strong heating of 1.45 g of sodium nitrate produces 25 cm^3 of the colourless gas. Check, by performing calculations, whether the colourless gas obeys the ideal gas law at the stated conditions.

(v) Under what conditions would the colourless gas behave ideally?

04-1-Q-04 [RJ]

Gas cylinders A and B each contain an ideal gas at low pressure and 298K. The volume of container A is twice that of container B, but the number of moles of ideal gas contained in A is only half of that in B.

(a) Calculate the ratio of the gas pressures in the two containers A and B.

(b) If the ideal gas in container A is replaced by an equal number of moles of ammonia, which cannot be considered as an ideal gas under these conditions, suggest and explain how the pressure in container A may change, if at all.

04-1-Q-05 [VJ]

Hydrazine, N_2H_4 was used as rocket fuel for Messerschmidt 163 rocket fighter in World War II and for the American Gemini and Apollo spacecraft.

(a) Draw the Lewis structure for the hydrazine molecule and state its shape, indicating all bond angles.

(b) Hydrazine is also commonly used as a strong reducing agent. It is proposed that an electrochemical cell can be made using the following overall reaction whereby hydrazine is oxidized to nitrogen gas in an acidic medium.

(i) Write a balanced half equation for the reaction occurring at the anode and cathode.

(ii) Given that the E^{θ}_{cell} value for the overall reaction is +2.01V and the standard reduction potential for the anode reaction is +0.54V, calculate the standard reduction potential for the cathode reaction.

(iii) However, when the above reaction between hydrazine and nitrate ions was conducted under standard conditions in a laboratory, the reaction failed to proceed. Suggest a plausible reason for this.

(iv) State and explain the effect on the E^{θ}_{cell} of the reaction on adding aqueous potassium hydroxide to the anode compartment of the electrochemical cell.

(c) Unlike hydrogen, hydrazine shows a marked deviation from the ideal gas behaviour that is predicted by the kinetic theory of gases.

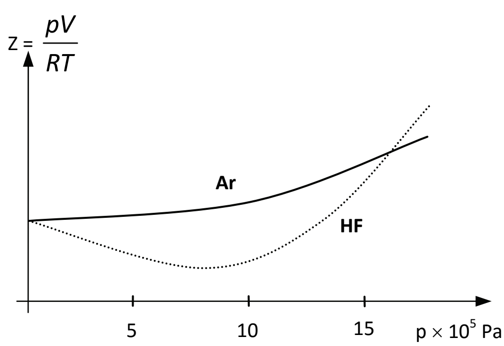
(i) Under what conditions of temperature and pressure would you expect the behaviour of hydrazine to be similar to that of an ideal gas?

(ii) Sketch the graph of pressure against the reciprocal of volume for a given amount of ideal gas at constant temperature.

(iii) How would you expect the volume of a given amount of hydrazine at a pressure of 10×10^5 Pa and 285 K to qualitatively compare with that of an ideal gas under similar conditions? Explain the difference (if any) you have stated.

04-1-Q-06 [HC]

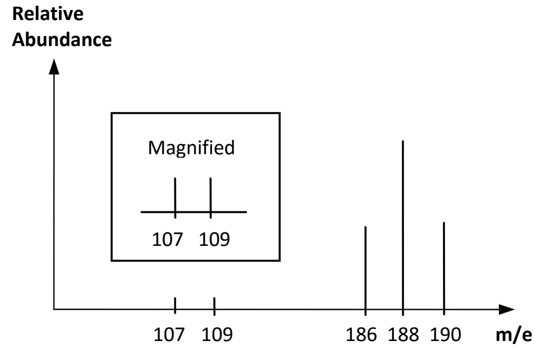
(a) The compressibility factor (Z) plot for 1 mole of each of hydrogen fluoride and argon is shown below.



(i) On the axes above, sketch the shape of the graph of 1 mole of an ideal gas.

(ii) Account for the differing extents of deviation from the ideal gas behaviour for hydrogen fluoride and argon at pressures below 5×10^5 Pa.

(b) Under certain conditions, mass spectrometry can be used to elucidate organic reaction mechanisms. When a reacting mixture of bromine gas and ethene was injected into the mass spectrometer, the following spectrum was obtained. (Relative abundance of ^{79}Br : ^{81}Br is 1:1.) [*supplementary topic*]



(i) In the table below, identify the species responsible for the peaks of m/e values 186, 188 and 190 and account for their relative abundance in the ratio 1 : 2 : 1.

m/e	Species	Relative abundance
186		
188		
190		

(ii) Suggest a structure for the species responsible for the peak at m/e = 107.

(iii) Suggest a reason for the very low abundance of the peaks at m/e = 107 and 109.

04-1-Q-07 [TM]

(a) The properties of ideal gases can be summarized in the ideal gas equation

$PV = nRT$

(i) Calculate the value of PV/RT for one mole of an ideal gas.

(ii) On the same axes sketch and label the curves obtained when PV/RT is plotted against P for

1 an ideal gas

2 carbon dioxide gas at room temperature

(b) The noble gases find many useful applications in gas discharge tubes ("neon lights"), where light is emitted as a result of the ionization of gaseous atoms.

(i) Suggest two reasons why the noble gases become less ideal in their behaviour down the group from helium to xenon.

(ii) Under what conditions of temperature and pressure is the behaviour of real gases most nearly ideal? Explain your answer.

(c) (i) Draw a dot-and-cross diagram to show the arrangement of electrons in a CO_2 molecule.

(ii) Describe and discuss the intramolecular and intermolecular bonding in CO_2.

04-1-Q-08 [VJ]

(a) Attractions between molecules of a gas cause its behaviour to be non-ideal. Under which two physical conditions are these attractions likely to be greatest?

(b) Four samples of known masses of volatile compound **X** were expanded into separate vessels each of volume 15 dm^3 at different pressures. The temperature in all the vessels was 100°C. The relative molecular masses, RMM, of **X** for each sample were determined using the Ideal Gas Equation. The results are as shown:

Sample	Mass of **X**/g	Pressure/ Nm^{-2}	RMM of **X**
A	0.002	6.831	60.5
B	0.015	31.011	
C	0.030	51.685	119
D	0.050	86.128	120

(i) Calculate the relative molecular mass of **X** for sample B.

(ii) The compound **X** used was pure ethanoic acid. Comment on the relative molecular masses of **X** obtained for each sample.

(iii) Draw the structure of the predominant species of **X** at high pressures and state the interaction responsible for the structure.

04-1-Q-09 [NA]

(a) The pressure-volume measurements for 1700 g of NH_3(g) at 25°C are given below.

P/atm	V/dm^3	P × V/ atm dm^3
0.1	244.5	24.45
0.4	61.02	24.41
2.0	12.17	24.34
8.0	2.925	23.40
9.8	2.360	23.13
9.8	0.020	0.20
20.0	0.020	0.40

(i) Why did the pressure-volume values begin to get smaller above 2 atm?

(ii) Why are there two volume readings at 9.8 atm?

(iii) Why does the volume of NH_3 remain constant even though the pressure increases from 9.8 atm to 20.0 atm?

(b) NH_3(g) decomposed at 500 K into the elements according to the following equilibrium

$$2NH_3(g) \rightleftharpoons N_2(g) + 2H_2(g)$$

It was found that at equilibrium, 90% of the NH_3 had decomposed and the pressure in the system was 1 atm.

(i) What are the partial pressures of the 3 components in the equilibrium mixture?

(ii) Calculate the equilibrium constant, K_p, at 500°C, stating the units.

Answer keys:

MCQ

04-1-M-01 D

04-1-M-02 D

04-1-M-03 A

04-1-M-04 A

04-1-M-05 A

04-1-M-06 A

04-1-M-07 B

04-1-M-08 C

04-1-M-09 D

04-1-M-10 B

04-1-M-11 A

04-1-M-12 C

04-1-M-13 D

04-1-M-14 A

04-1-M-15 C

04-1-M-16 D

04-1-M-17 B

04-1-M-18 D

04-1-M-19 A

04-1-M-20 B

Questions

04-1-Q-01

(a)(i) 70.0

(ii) 70

(iii) **X** shows a stronger deviation from ideal gas behavior and strong pd-pd forces of attraction

(iv) CF_3^+, CHF_2^+, CF_2^+, CF^+, C^+

(b)(i) $F_2 + 2I^- \rightarrow 2F^- + I_2$, $2S_2O_3^{2-} + I_2 \rightarrow 2I^- + S_4O_6^{2-}$

(ii) 115 cm^3

04-1-Q-02

(a) Shape: pyramidal; Bond angle: 107^o

(b)(i) $Ca(OH)_2 + 2NH_4Cl \rightarrow CaCl_2 + 2NH_3 + 2H_2O$

(ii) 2.59g

04-1-Q-03

(a) $Mg(NO_3)_2 \rightarrow MgO + 2NO_2 + ½O_2$

(b)(i) 0.01706

(ii) 8.50×10^{-3}

(iii) $NaNO_3(s) \rightarrow NaNO_2\ (s) + ½O_2\ (g)$

(iv) 53.8 cm^3

(v) High temperature and low pressure

04-1-Q-04

(a) ¼

(b) Strong forces of attraction reduce the force of impact of the molecules on the vessel walls

04-1-Q-05

(b)(i) $N_2H_4(l) \rightarrow N_2(g) + 4H^+(aq) + 4e$ (anode); $NO_3^-(aq) + 4H^+(aq) + 3e \rightarrow NO(g) + 2H_2O(l)$ (cathode)

(ii) 1.47 V

(iii) thermodynamically feasible but kinetically not feasible

(iv) $E^\theta_{oxidation}$ decreases; overall E^θ_{cell} increases

(c)(i) High temperature and low pressure

(iii) The volume of N_2H_4 is less than that of an ideal gas

04-1-Q-06

(a)(ii) The deviation is due to significant intermolecular attractions between gas particles

(b)(i) $[CH_2{}^{79}BrCH_2{}^{79}Br]^+$, 1/4; $[CH_2{}^{79}BrCH_2{}^{81}Br]^+$, 1/2; $[CH_2{}^{81}BrCH_2{}^{81}Br]^+$, 1/4

(ii) The peak was due to the formation of the cyclic bromonium intermediate

(iii) The intermediate species are unstable

04-1-Q-07

(a)(i) 1

(b)(i) Down the group, attractive forces between the atoms become stronger due to larger atomic size as a result of more electrons. The gas volume is negligible compared to the space occupied by the gas becomes less valid

(ii) High temperature and low pressure

(c)(ii) Intramolecular – 2 double covalent bonds. Intermolecular – non-polar, id-id forces of attraction

04-1-Q-08

(a) Low temperature and high pressure

(b)(i) 100

(ii) sample D is dimmers; sample A is monomers; samples B and C is a mixture of monomers and dimmers

(iii) hydrogen bonding

04-1-Q-09

(a)(i) higher pressure causes formation of hydrogen bonds; the gas is no longer ideal

(ii) The volume drops sharply as gaseous ammonia changes into liquid

(iii) The particles are closely packed together in a liquid

(b)(i) 0.711 atm

(ii) 30.8 atm^2