Name	Date started	Target end date

GCE A LEVEL — KINETIC THEORY QUESTION PACK

Legacy PH4 · New spec Unit 3 Topic 3 · A2 unit, 25% of A-level

REVISE
.wales

PHYSICS — UNIT 3 · KINETIC THEORY

3.3 Kinetic theory — ideal gas equation, rms speed and the molecular model

Macroscopic and microscopic forms of the ideal gas equation, the kinetic-theory derivation $p = \frac{1}{3}\rho\overline{c^2}$, mean translational KE = &frac32;kT, and the Boltzmann constant.

NEW 2015 SPEC · UNIT 3 TOPIC 3

Estimated time for entire question pack: ~2h 7m

Derived from the legacy PH4 paper's pace of 120 marks in 1h 45m.

*You are advised to **not** attempt to complete all of this in one sitting.*

ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every question from the legacy WJEC PH4 papers (2008 modular spec) that maps onto new-spec Unit 3 Topic 3 (3.3).

Questions are ordered chronologically within each section.

INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

The number of marks is given in brackets at the end of each question or part-question. A calculator is required. The Data Booklet is allowed.

For Examiner's use only

Q	Source	Max	Mark
1	PH4 Jan 10 Q3	7	
2	PH4 Jun 16 Q3	4	
3	PH4 Jan 12 Q1	8	
4	PH4 Jan 13 Q2	7	
5	PH4 Jun 11 Q3	12	
6	PH4 Jan 14 Q2	8	
7	PH4 Jun 10 Q2	13	
8	PH4 Jun 14 Q2	8	
9	PH4 Jun 12 Q5	11	
10	PH4 Jun 15 Q1	13	
	Total	**91**	

Kinetic Theory — what the new spec asks

WJEC GCE A Level Physics (from 2015) · Unit 3: Oscillations & Nuclei · Topic 3.3.

Ideal gas equation (A)

- Macroscopic: $pV = nRT$ (n = moles, $R = 8.31\ \mathrm{J\ mol^{-1}\ K^{-1}}$).
- Microscopic: $pV = NkT$ (N = molecules, k = Boltzmann constant).
- Convert: $N = nN_A$; $k = R/N_A$.

Kinetic theory model (B)

- Large number of molecules in random motion.
- Molecular volume negligible; collisions elastic; no intermolecular forces between collisions.
- Pressure arises from molecular collisions with the container walls.

Microscopic pressure (B)

- Derive $pV = ⅓ Nm<c^2>$.
- Equivalent form: $p = ⅓ \rho <c^2>$.
- Root-mean-square speed: $c_{rms} = \sqrt{(<c^2>)} = \sqrt{(3RT/M)} = \sqrt{(3kT/m)}$.

Mean translational KE (C)

- Per molecule: $½ m<c^2>$ = &frac32; kT.
- Temperature is a direct measure of mean translational KE.
- Internal energy of a monatomic ideal gas: U = &frac32; nRT.

Kinetic Theory in one page

Quick-reference notes — revisit before each section.

Macro gas law

n = moles, $R = 8.31\ \text{J mol}^{-1}\ \text{K}^{-1}$.

T must be in kelvin.

Micro gas law

N = total number of molecules.

k = Boltzmann constant = $1.38 \times 10^{-23}\ \text{J K}^{-1}$.

$N = nN_A$.

Moles

$N_A = 6.02 \times 10^{23}\ \text{mol}^{-1}$.

Molar mass M (kg mol^{-1}) ⇒ mass m of one molecule = M/N_A.

Model assumptions

Large N, random motion.

Molecule volume negligible; collisions elastic.

No intermolecular forces between collisions.

Pressure

$pV = ⅓ Nm\langle c^2 \rangle$.

Equivalent: $p = ⅓ \rho\langle c^2 \rangle$.

rms speed

$c_{rms} = \sqrt{(\langle c^2 \rangle)}$.

$= \sqrt{(3kT/m)} = \sqrt{(3RT/M)}$.

Use single-molecule mass m for the kT version.

Mean KE

½ $m\langle c^2 \rangle$ = &frac32;kT.

$T \propto$ mean translational KE.

Internal energy

U = &frac32; nRT = &frac32; NkT.

Depends only on T (not on V).

Pitfalls

T must be in K, not °C.

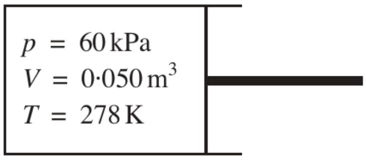
Use m (per molecule) with kT; M (per mole) with RT.

Real gases deviate at high p / low T.

Section index

Use this index to jump straight to the section you need.

3. A gas is contained in a cylinder as shown.



(a) Show that the amount of gas in the cylinder is approximately 1·3 moles. [2]

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(b) (i) The mass of the gas is 0·171kg. Calculate the root-mean-square speed of the gas particles in the cylinder. [3]

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(ii) Calculate the molar mass of the gas in the cylinder. [2]

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Answer part (a) only. Stop after rms speed of the molecules — parts (b)(i) and (b)(ii) (work done, heat supplied at constant pressure) belong to the Thermal Physics question pack.

3. Helium gas is contained in a closed cylinder with a leak-proof moveable piston at one end. Initially the volume is $1.2 \times 10^{-3}\,m^3$, the pressure is 3.0×10^5 Pa and the temperature is 275 K. (Relative molecular mass of helium = 4.0.)

(a) (i) Calculate the mass of the gas in the cylinder. [2]

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(ii) Calculate the rms speed of the molecules. [2]

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(b) The volume of the gas is increased to $1.8 \times 10^{-3}\,m^3$ at constant pressure. Calculate:

(i) the work done by the gas; [2]

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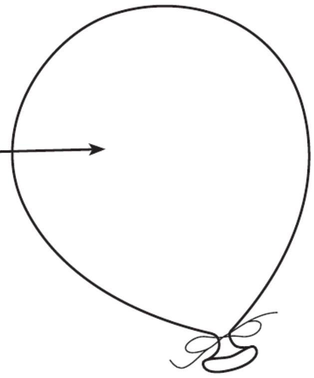
1. A toy balloon contains gas for which data are given.

pressure = 1.10×10^5 Pa

density = $1.25\,\text{kg}\,\text{m}^{-3}$

total mass of air (M) = 3.75 g

number of particles = 8.06×10^{22}



(a) Calculate the rms speed of the molecules inside the balloon. [2]

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(b) Show that the molar mass of the gas inside the balloon is approximately 28. [2]

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(c) (i) Calculate the momentum of a gas molecule of mass 4.65×10^{-26} kg travelling at a speed of $460\,\text{m}\,\text{s}^{-1}$. [2]

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(ii) Calculate the wavelength of a photon of light that has the same momentum as this gas molecule. [2]

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SECTION B

Kinetic theory, rms speed & mean KE

Questions 4 – 8 · 48 marks

2. *(a)* The following equation relates to ideal gases.

$$N \times \frac{1}{2}m\overline{c^2} = \frac{3}{2}nRT$$

In terms of **energy**, explain the meaning of:

$\frac{1}{2}m\overline{c^2}$ [1]

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$\frac{3}{2}nRT$ [1]

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(b) (i) By applying the above equation to one mole of helium gas (or otherwise), calculate the rms speed of helium molecules at 20 °C (the mass of a helium molecule is 6.64×10^{-27} kg). [3]

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(ii) Use your answer to *(b)*(i) to calculate the pressure of helium gas at 20 °C and density 0.19 kg m^{-3}. [2]

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Answer part (a) only. Stop after the relative molecular mass of argon — part (b) (heating at constant pressure, work, heat) belongs to the Thermal Physics question pack.

3. A cylinder fitted with a leak-proof piston contains 2.4×10^{-3} kg of argon gas at a pressure of 100 kPa. The volume of the gas is 1.5×10^{-3} m^3.

(a) (i) (I) Calculate the rms speed of the molecules. [3]

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(II) At any instant some of the molecules will have speeds much greater than the rms speed of all the molecules. How could they have acquired such speeds? [1]

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(III) Three of the molecules have speeds 935 ms^{-1}, 743 ms^{-1}, and 312 ms^{-1}. Calculate the rms speed of these three molecules. [3]

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(ii) There are 0.0600 moles of argon gas in the cylinder.

(I) Show that the temperature of the gas is approximately 300 K. [2]

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(II) Calculate the number of molecules of argon in the cylinder. [1]

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(III) Calculate the relative molecular mass of argon. [2]

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2. *(a)* Using the equations:

$$p = \frac{1}{3}\rho\overline{c^2}$$

$$pV = nRT$$

show that the mean kinetic energy of an individual (monatomic) gas particle of mass m is given by: [3]

$$\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$$

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(b) (i) Calculate the temperature at which argon atoms have a rms speed of 630 m s^{-1}. (Relative molecular mass of argon = 38.) [3]

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(ii) Calculate the rms speed of argon atoms when this temperature is doubled. [2]

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2. The air in a room of dimensions 6.0 m × 5.0 m and height 3.0 m is at atmospheric pressure, 1.01×10^5 Pa, and a temperature of 293 K.

(a) Write two assumptions of the kinetic theory of gases.

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[2]

(b) Calculate the number of air molecules in the room.

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[2]

(c) At some instant three of the molecules in the room have respectively speeds of 350 m s^{-1}, 420 m s^{-1} and 550 m s^{-1}. Calculate the root-mean-square (r.m.s.) speed of these three molecules at this instant.

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[2]

(d) Show that the r.m.s. speed of all the molecules in the room is approximately 500 m s^{-1}. (Mean relative molecular mass of air = 29)

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[4]

(e) Scent is sprayed in one corner of the room.

(i) Use the r.m.s. speed in part *(d)* to estimate a time of travel of a molecule from the spray to the far corner of the room.

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[1]

(ii) Is this a reasonable estimate of the delay between the spraying of the scent and its detection at the far corner of the room? Explain your answer.

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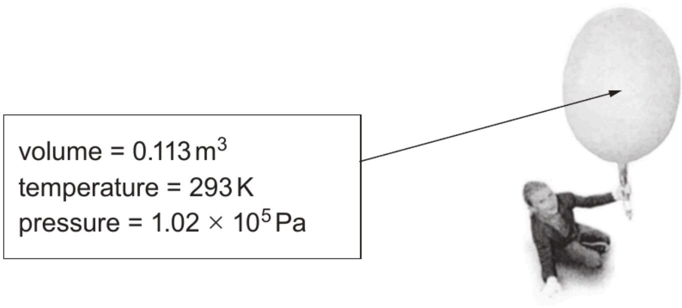
[2]

2. *(a)* A helium weather balloon is to be released.



(i) Show that the density of the helium in the balloon is approximately $0.17\,kg\,m^{-3}$. (The molar mass of helium is $4.00 \times 10^{-3}\,kg\,mol^{-1}$.) [3]

(ii) Calculate the rms speed of helium molecules in the balloon. [2]

(b) The balloon is released and rises to a height where the pressure inside it decreases to 4.5×10^4 Pa and its volume increases to $0.212\,m^3$. Calculate the new rms speed of the helium molecules in the balloon (assume no helium molecules have escaped). [3]

SECTION C

Derivations & internal energy

Questions 9 – 10 · 24 marks

5. A canister of volume 0.025 m^3 contains helium gas at a pressure of 3.04×10^5 Pa and a temperature of 280 K. (Relative molecular mass of helium = 4.0)

(a) Calculate:

(i) the number of moles of the gas in the canister; [1]

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(ii) the number of helium molecules in the canister; [1]

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(iii) the density of the gas; [2]

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(iv) the rms speed of the helium molecules. [2]

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(b) The product of the pressure and volume of an ideal gas may be expressed as

$$pV = nRT.$$

The product may also be written in terms of the mean square speed of the molecules as

$$pV = \frac{1}{3}Nm\overline{c^2}.$$

(i) Derive in clear steps a formula that shows how the internal energy of the ideal gas depends on the temperature of the gas. [4]

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(ii) Calculate the internal energy of the helium gas in the canister. [1]

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Examiner only

Answer **all** *questions.*

1. *(a)* Oxygen gas is held in a sealed container.

(i) Explain in clear steps, using the kinetic theory and Newton's laws of motion, how the oxygen exerts pressure on the walls of the container. [4]

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(ii) If the gas behaves as an ideal gas then:

$$pV = \frac{1}{3}Nm\overline{c^2}$$

State the meaning of each of the terms: [3]

(I) N ....

(II) m ....

(III) $\overline{c^2}$ ....

Examiner only

(b) A container of volume $0.7\,m^3$ holds oxygen gas at a pressure of 4.0×10^5 Pa and a temperature of 288 K. (Relative molecular mass of oxygen gas = 32.)

Calculate:

(i) the number of moles of oxygen gas in the container; [2]

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(ii) the rms speed of the molecules. [3]

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(c) In practice oxygen is not an ideal gas. Give one reason for this. [1]

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END OF QUESTION PACK

10 questions · 91 marks · ~2h 7m

Source: WJEC PH4 (2008 modular spec)

Curated for WJEC Physics 2015 spec A2 Unit 3 — Topic 3 (3.3)