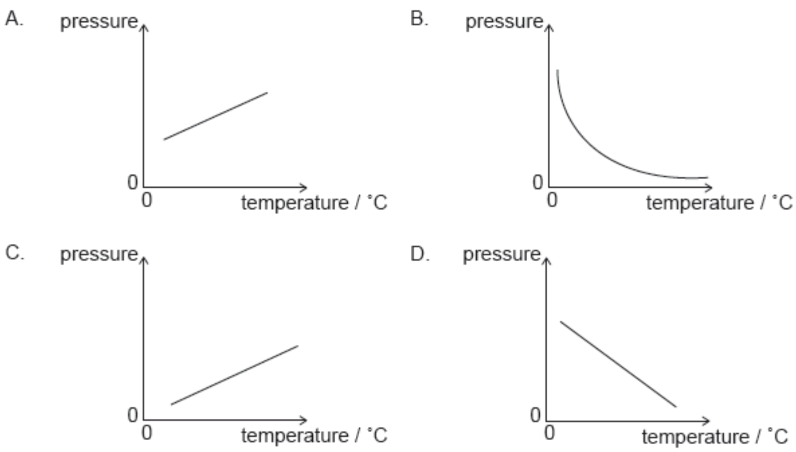
R2019_3 *[64 marks]*

1. A fixed mass of an ideal gas is trapped in a cylinder of constant volume and its temperature is varied. Which graph shows the variation of the pressure of the gas with temperature in degrees Celsius? *[1 mark]*



Markscheme

A

2. What are the units of the ratio $\frac{\text{specific heat capacity of copper}}{\text{specific latent heat of vaporization of copper}}$? *[1 mark]*

A. no units

B. k

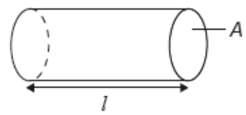
C. k^{-1}

D. k^{-2}

Markscheme

C

3. A sealed cylinder of length *l* and cross-sectional area *A* contains *N* molecules of an ideal gas at kelvin temperature *T*. *[1 mark]*



What is the force acting on the area of the cylinder marked *A* due to the gas?

A. $\frac{NRT}{l}$

B. $\frac{NRT}{lA}$

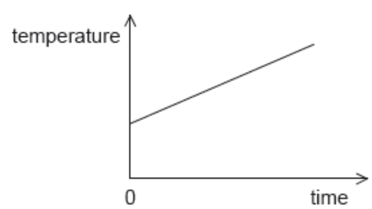
C. $\frac{Nk_BT}{lA}$

D. $\frac{Nk_BT}{l}$

Markscheme

D

4. The graph shows how the temperature of a liquid varies with time when energy is supplied to the liquid at a constant rate *P*. The gradient of the graph is *K* and the liquid has a specific heat capacity *c*. *[1 mark]*



What is the mass of the liquid?

A. $\frac{P}{cK}$

B. $\frac{PK}{c}$

C. $\frac{Pc}{K}$

D. $\frac{cK}{P}$

Markscheme

A

5. A sealed container contains water at 5 °C and ice at 0 °C. This system is thermally isolated from its surroundings. What happens to the total internal energy of the system? *[1 mark]*

A. It remains the same.

B. It decreases.

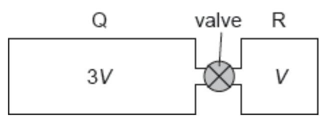
C. It increases until the ice melts and then remains the same.

D. It increases.

Markscheme

A

6. Q and R are two rigid containers of volume 3 *V* and *V* respectively containing molecules of the same ideal gas initially at the same temperature. The gas pressures in Q and R are *p* and 3*p* respectively. The containers are connected through a valve of negligible volume that is initially closed. *[1 mark]*



The valve is opened in such a way that the temperature of the gases does not change. What is the change of pressure in Q?

A. $+p$

B. $\frac{+p}{2}$

C. $\frac{-p}{2}$

D. $-p$

Markscheme

B

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

7a. Calculate the pressure of the gas. *[1 mark]*

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Markscheme

«$\frac{3.0 \times 8.31 \times 290}{0.15}$»

48 «kPa»

[1 mark]

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg^{-1} K^{-1}.

7b. Calculate, in kg, the mass of the gas. *[1 mark]*

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Markscheme

mass = «$\frac{860}{3100 \times 23}$» 0.012 «kg»

*Award **[1]** for a bald correct answer.*

[1 mark]

7c. Calculate the average kinetic energy of the particles of the gas. *[1 mark]*

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Markscheme

$\frac{3}{2}$ $1.38 \times 10^{-23} \times 313 = 6.5 \times 10^{-21}$ «J»

[1 mark]

7d. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. *[3 marks]*

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Markscheme

larger temperature implies larger (average) speed/larger (average) KE of molecules/particles/atoms

increased force/momentum transferred to walls (per collision) / more frequent collisions with walls

increased force leads to increased pressure because P = F/A (as area remains constant)

Ignore any mention of PV = nRT.

[3 marks]

An ideal monatomic gas is kept in a container of volume 2.1×10^{-4} m^3, temperature 310 K and pressure 5.3×10^5 Pa.

8a. State what is meant by an ideal gas. *[1 mark]*

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Markscheme

a gas in which there are no intermolecular forces

OR

a gas that obeys the ideal gas law/all gas laws at all pressures, volumes and temperatures

OR

molecules have zero PE/only KE

Accept atoms/particles.

[1 mark]

8b. Calculate the number of atoms in the gas. *[1 mark]*

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Markscheme

N = «$\frac{pV}{kT} = \frac{5.3 \times 10^{5} \times 2.1 \times 10^{-4}}{1.38 \times 10^{-23} \times 310}$» 2.6×10^{22}

[1 mark]

8c. Calculate, in J, the internal energy of the gas. *[2 marks]*

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Markscheme

«For one atom $U = \frac{3}{2}kT$» $\frac{3}{2} \times 1.38 \times 10^{-23} \times 310$ / 6.4×10^{-21} «J»

U = «$2.6 \times 10^{22} \times \frac{3}{2} \times 1.38 \times 10^{-23} \times 310$» 170 «J»

Allow ECF from (a)(ii)

*Award **[2]** for a bald correct answer*

Allow use of $U = \frac{3}{2}pV$

[2 marks]

The volume of the gas in (a) is increased to 6.8×10^{-4} m^3 at constant temperature.

8d. Calculate, in Pa, the new pressure of the gas. *[1 mark]*

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Markscheme

p_2 = «$5.3 \times 10^5 \times \frac{2.1 \times 10^{-4}}{6.8 \times 10^{-4}}$» 1.6×10^5 «Pa»

[1 mark]

8e. Explain, in terms of molecular motion, this change in pressure. *[2 marks]*

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Markscheme

«volume has increased and» average velocity/KE remains unchanged

«so» molecules collide with the walls less frequently/longer time between collisions with the walls

«hence» rate of change of momentum at wall has decreased

«and so pressure has decreased»

The idea of average must be included

Decrease in number of collisions is not sufficient for MP2. Time must be included.

Accept atoms/particles.

[2 marks]

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg^{-1} K^{-1}.

9a. Determine, in kJ, the total kinetic energy of the particles of the gas. *[3 marks]*

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Markscheme

ALTERNATIVE 1

average kinetic energy = $\frac{3}{2}1.38 \times 10^{-23} \times 313 = 6.5 \times 10^{-21}$ «J»

number of particles = $3.0 \times 6.02 \times 10^{23} = 1.8 \times 10^{24}$

total kinetic energy = $1.8 \times 10^{24} \times 6.5 \times 10^{-21} = 12$ «kJ»

ALTERNATIVE 2

ideal gas so $U = KE$

$KE = \frac{3}{2}8.31 \times 131 \times 3$

total kinetic energy = 12 «kJ»

[3 marks]

9b. Explain, with reference to the kinetic model of an ideal gas, how an increase in temperature of the gas leads to an increase in pressure. *[3 marks]*

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Markscheme

larger temperature implies larger (average) speed/larger (average) KE of molecules/particles/atoms

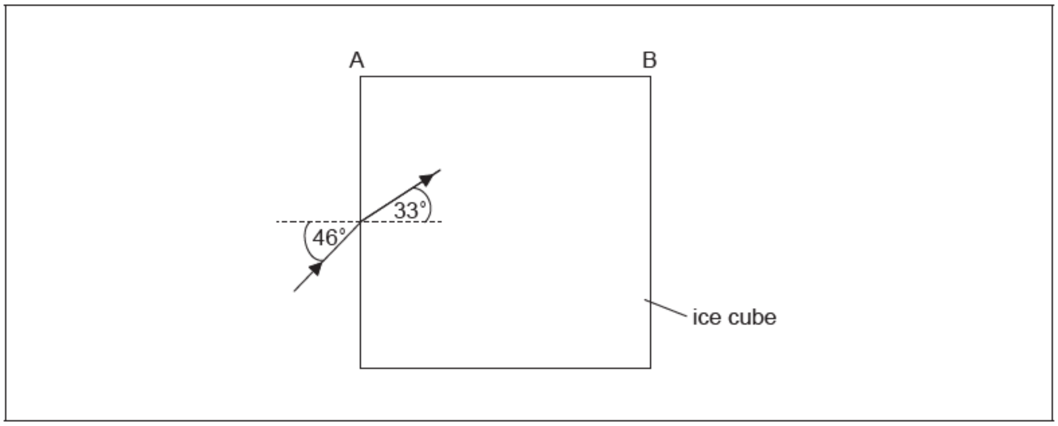
increased force/momentum transferred to walls (per collision) / more frequent collisions with walls

increased force leads to increased pressure because P = F/A (as area remains constant)

Ignore any mention of PV = nRT.

[3 marks]

A large cube is formed from ice. A light ray is incident from a vacuum at an angle of 46˚ to the normal on one surface of the cube. The light ray is parallel to the plane of one of the sides of the cube. The angle of refraction inside the cube is 33˚.



10a. Calculate the speed of light inside the ice cube. *[2 marks]*

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Markscheme

«$v = c\frac{\sin i}{\sin r}$ =» $\frac{3\times10^{8}\times\sin(33)}{\sin(46)}$

2.3×10^{8} «m s^{-1}»

10b. Show that no light emerges from side AB. *[3 marks]*

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Markscheme

light strikes AB at an angle of 57°

critical angle is «$\sin^{-1}\left(\frac{2.3}{3}\right)$ =» 50.1°

49.2° from unrounded value

angle of incidence is greater than critical angle so total internal reflection

OR

light strikes AB at an angle of 57°

calculation showing sin of "refracted angle" = 1.1

statement that since 1.1>1 the angle does not exist and the light does not emerge

[Max 3 marks]

10c. Sketch, on the diagram, the subsequent path of the light ray. *[2 marks]*

Markscheme

total internal reflection shown

ray emerges at opposite face to incidence

Judge angle of incidence=angle of reflection by eye or accept correctly labelled angles

With sensible refraction in correct direction

Each side of the ice cube is 0.75 m in length. The initial temperature of the ice cube is –20 °C.

10d. Determine the energy required to melt all of the ice from –20 °C to water at a temperature of 0 °C. *[4 marks]*

Specific latent heat of fusion of ice = 330 kJ kg^{-1}
Specific heat capacity of ice = 2.1 kJ kg^{-1} k^{-1}
Density of ice = 920 kg m^{-3}

Markscheme

mass = «*volume* x *density*» $(0.75)^3$ x 920 «= 388 kg»

energy required to raise temperature = 388 x 2100 x 20 «= 1.63 x 10^7 J»

energy required to melt = 388 x 330 x 10^3 «= 1.28 x 10^8 J»

1.4 x 10^8 «J» ***OR*** 1.4 x 10^5 «kJ»

Accept any consistent units

Award ***[3 max]*** *for answer which uses density as 1000 kg^{-3} (1.5× 10^8 «J»)*

10e. Outline the difference between the molecular structure of a solid and a liquid. *[1 mark]*

Markscheme

in solid state, nearest neighbour molecules cannot exchange places/have fixed positions/are closer to each other/have regular pattern/have stronger forces of attraction

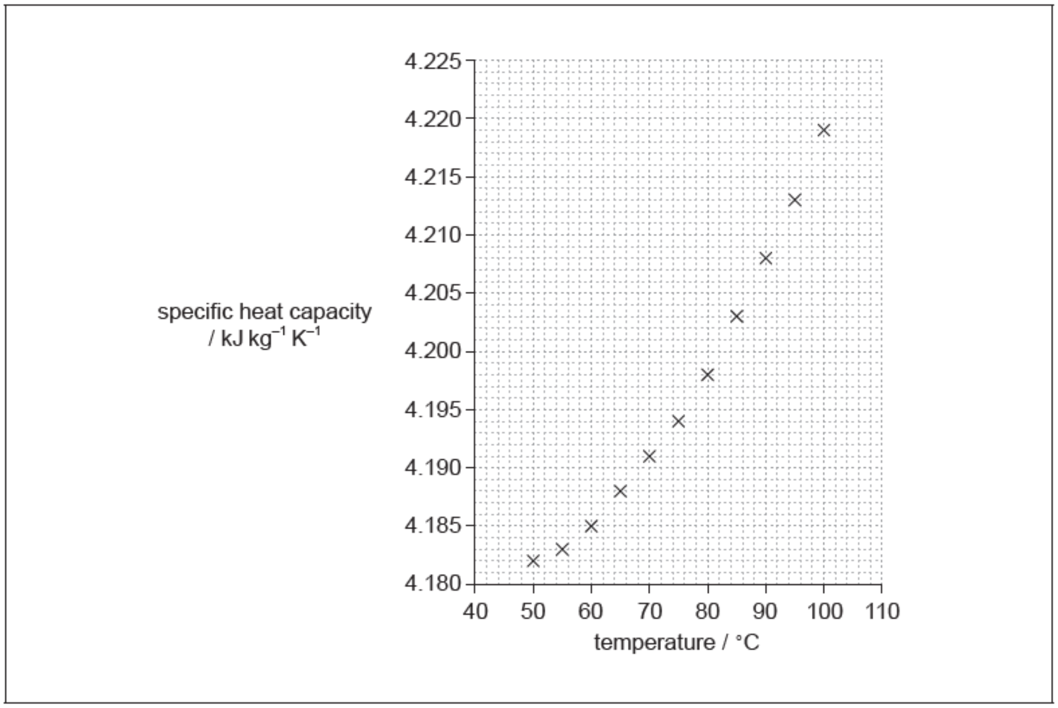
in liquid, bonds between molecules can be broken and re-form

OWTTE

Accept converse argument for liquids

[Max 1 Mark]

In an experiment, data were collected on the variation of specific heat capacity of water with temperature. The graph of the plotted data is shown.



11a. Draw the line of best-fit for the data. *[1 mark]*

Markscheme

single smooth curve passing through all data points

Do not accept straight lines joining the dots

Curve must touch some part of every x

11b. Determine the gradient of the line at a temperature of 80 °C. *[3 marks]*

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Markscheme

tangent drawn at 80 °C

gradient values separated by minimum of 20 °C

9.0×10^{-4} «kJ kg^{-1} K^{-2}»

Do not accept tangent unless "ruler" straight.

Tangent line must be touching the curve drawn for MP1 to be awarded.

Accept values between 7.0×10^{-4} and 10×10^{-4}.

Accept working in J, giving 0.7 to 1.0

11c. State the unit for the quantity represented by the gradient in your answer to (b)(i). *[1 mark]*

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Markscheme

kJ kg^{-1} K^{-2}

Accept J instead of kJ

Accept °C^{-2} instead of K^{-2}

Accept °C^{-1} K^{-1} instead of K^{-2}

Accept C for °C

The uncertainty in the values for specific heat capacity is 5%.

Water of mass (100 ± 2) g is heated from (75.0 ± 0.5) °C to (85.0 ± 0.5) °C.

11d. Calculate the energy required to raise the temperature of the water from 75 °C to 85 °C. *[1 mark]*

Markscheme

«0.1 x 4.198 x 10 =» 4.198 «kJ» ***or*** 4198 «J»

Accept values between 4.19 and 4.21

11e. Using an appropriate error calculation, justify the number of significant figures that should be used for your answer to (c)(i). *[3 marks]*

Markscheme

percentage uncertainty in ΔT = 10%

«2% + 5% + 10%» = 17%

absolute uncertainty «0.17 × 4.198 =» 0.7 «kJ» therefore 2 sig figs

OR

absolute uncertainty to more than 1 sig fig and consistent final answer

Allow fractional uncertainties in MP1 and MP2

Watch for ECF from (c)(i)

Watch for ECF from MP1

Watch for ECF from MP2

Do not accept an answer without justification

12a. Define *internal energy.* *[2 marks]*

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Markscheme

mention of atoms/molecules/particles

sum/total of kinetic energy and «mutual/intermolecular» potential energy

Do not allow "kinetic energy and potential energy" bald.
Do not allow "sum of average ke and pe" unless clearly referring to total ensemble.

12b. 0.46 mole of an ideal monatomic gas is trapped in a cylinder. The gas has a volume of 21 m^3 and a pressure of 1.4 Pa. *[4 marks]*

(i) State how the internal energy of an ideal gas differs from that of a real gas.

(ii) Determine, in kelvin, the temperature of the gas in the cylinder.

(iii) The kinetic theory of ideal gases is one example of a scientific model. Identify **one** reason why scientists find such models useful.

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Markscheme

i

«intermolecular» potential energy/PE of an ideal gas is zero/negligible

ii

THIS IS FOR USE WITH AN ENGLISH SCRIPT ONLY

use of $T = \frac{PV}{nR}$ ***or*** $T = \frac{1.4 \times 21}{0.46 \times 8.31}$

Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.

*Award **[2]** for a bald correct answer in K.*

*Award **[2 max]** if correct 7.7 K seen followed by –265 °C and mark BOD. However, if only –265 °C seen, award **[1 max]**.*

7.7 K

Do not penalise use of "°K"

ii

THIS IS FOR USE WITH A SPANISH SCRIPT ONLY

$T = \frac{PV}{nR}$

$T = \frac{1.4 \times 2.1 \times 10^{-6}}{0.46 \times 8.31}$

T = 7.7 ×10^{-6} K

Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.

Uses correct unit conversion for volume

*Award **[2]** for a bald correct answer in K. Finds solution. Allow an ECF from MP2 if unit not converted, ie candidate uses 21 m3 and obtains 7.7 K*

Do not penalise use of "°K"

iii

models used to predict/hypothesize

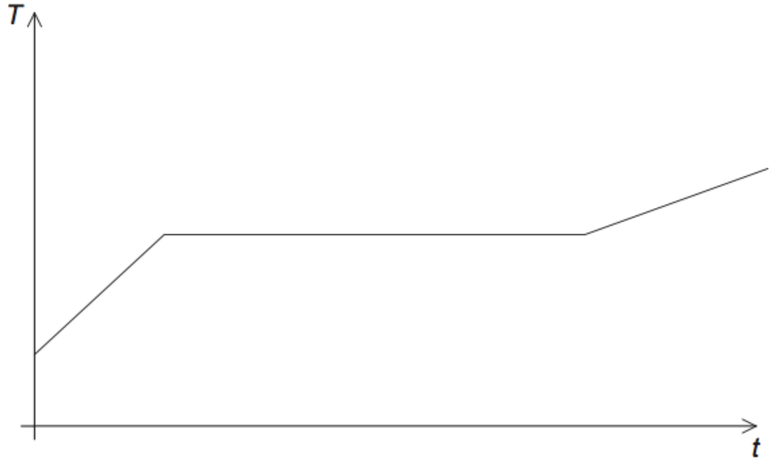
explain

simulate

simplify/approximate

*Allow similar responses which have equivalent meanings. Response needs to identify **one** reason.*

13. A substance is heated at constant power. The graph shows how the temperature *T* of the substance varies with time *t* as the state of the substance changes from liquid to gas. *[1 mark]*



What can be determined from the graph?

A. The specific heat capacity of the gas is smaller than the specific heat capacity of the liquid.

B. The specific heat capacity of the gas is larger than the specific heat capacity of the liquid.

C. The specific latent heat of fusion of the substance is less than its specific latent heat of vaporization.

D. The specific latent heat of fusion of the substance is larger than its specific latent heat of vaporization.

Markscheme

B

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14. Which of the following is **not** an assumption of the kinetic model of ideal gases? *[1 mark]*

A. All particles in the gas have the same mass.

B. All particles in the gas have the same speed.

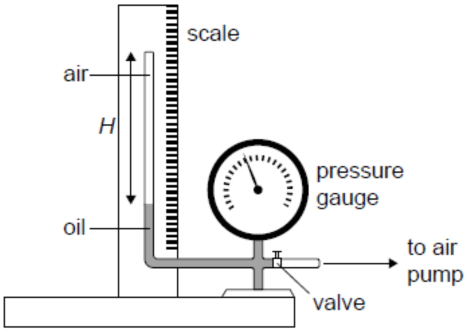
C. The duration of collisions between particles is very short.

D. Collisions with the walls of the container are elastic.

Markscheme

B

The equipment shown in the diagram was used by a student to investigate the variation with volume, of the pressure *p* of air, at constant temperature. The air was trapped in a tube of constant cross-sectional area above a column of oil.



The pump forces oil to move up the tube decreasing the volume of the trapped air.

15a. The student measured the height *H* of the air column and the corresponding air pressure *p*. After each reduction in the volume the student waited for some time before measuring the pressure. Outline why this was necessary. *[1 mark]*

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Markscheme

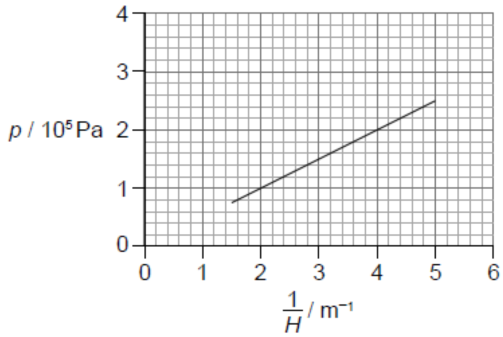
in order to keep the temperature constant

in order to allow the system to reach thermal equilibrium with the surroundings/OWTTE

Accept answers in terms of pressure or volume changes only if clearly related to reaching thermal equilibrium with the surroundings.

[1 mark]

15b. The following graph of p versus $\frac{1}{H}$ was obtained. Error bars were negligibly small. *[3 marks]*



The equation of the line of best fit is $p = a + \frac{b}{H}$.

Determine the value of b including an appropriate unit.

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Markscheme

recognizes b as gradient

calculates b in range 4.7×10^4 to 5.3×10^4

Pa m

*Award **[2 max]** if POT error in b.*
Allow any correct SI unit, eg kg s^{-2}.

[3 marks]

15c. Outline how the results of this experiment are consistent with the ideal gas law at constant temperature. *[2 marks]*

Markscheme

$V \propto H$ thus ideal gas law gives $p \propto \frac{1}{H}$

so graph **should be** «a straight line through origin,» as **observed**

[2 marks]

15d. The cross-sectional area of the tube is 1.3 × 10^{-3} m^2 and the temperature of air is 300 K. Estimate the number of moles of air in the tube. *[2 marks]*

Markscheme

$n = \frac{bA}{RT}$ ***OR*** correct substitution of one point from the graph

$n = \frac{5 \times 10^4 \times 1.3 \times 10^{-3}}{8.31 \times 300} = 0.026 \approx 0.03$

Answer must be to 1 or 2 SF.

Allow ECF from (b).

[2 marks]

15e. The equation in (b) may be used to predict the pressure of the air at extremely large values of $\frac{1}{H}$. Suggest why this will be an unreliable estimate of the pressure. *[2 marks]*

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Markscheme

very large $\frac{1}{H}$ means very small volumes / very high pressures

at very small volumes the ideal gas does not apply
OR
at very small volumes some of the assumptions of the kinetic theory of gases do not hold

[2 marks]