Mark schemes

1. (a) (If not in a vacuum) gas atoms will collide with air atoms, changing their direction or speed distribution. ✓

There must be some indication of a change of the oven gas molecules associated with collisions

If temperature change is mentioned this must be related to speed distribution for the mark

1

(b) Finds time taken for one rev AND/OR time for 1/8 rev ✓

(Uses speed = distance/time to get)

= 0.500 / 1.04 × 10^{-3} = 480 m s^{-1} ✓

(so about 500 m s^{-1})

1 rev in 1/120 s or 0.00833 s

Time for 45º or 1/8 rev = 1.04 × 10^{-3} s

Must have 2 or more sf answer but 500 m s^{-1} is acceptable as a final answer provided the calculated time for 45º or 1/8 rev is shown and rounded down to 2 sf

2

(c) Mass of one atom = m = 0.209/NA = 3.47 × 10^{-25} kg ✓$_1$

✓$_1$ *May be seen in the substitution of the equation that follows*

✓$_2$ $\frac{m}{3k}$*(answer (b))*^{2}

Substitutes m and answer (b) in $\frac{1}{2}m(c_{rms})^2 = \frac{3}{2}kTkT$ and rearranges ✓$_2$

T = 1930 K ✓$_3$

✓$_3$ *Accept 2095 K or 2100 K if 500 m s^{-1} used*

A correct answer also gains the second mark

3

(d) (Pressure is due to collisions of atoms with oven walls) With fewer atoms fewer collisions <u>per second</u> ✓$_{1a}$

✓$_{1a}$ *There must be a reference to frequency or rate of collision*

but average momentum change per collision stays the same
or
therefore the total momentum change per second falls (so pressure drops) ✓$_{2a}$

OR

Reference to $pV = \frac{1}{3}Nm(c_{rms})^2$ ✓$_{1b}$

c_{rms} is constant as T is constant hence p ✓ N (so pressure drops) ✓$_{2b}$

✓$_{1b}$ *The equation may be in any equivalent kinetic theory form*

$pV = nRT$ is not acceptable unless a connection is made between T and c_{rms}

2

(e) ($pV = nRT$)

leaked $n = \frac{V((p_1 - p_2)}{RT}$ ✓

= 8.42 × 10^{-3} mol

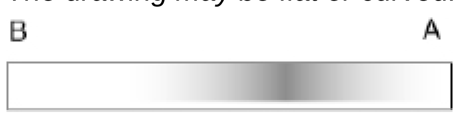
*ecf for T from **(c)***

1

(f) At higher temp atoms will be faster (so drum will not have turned as far) ✓$_{1a}$

Darkest area will be closer to A ✓$_{2a}$

✓$_1$ *Accept drawing but allow any degree of maximum darkness. The drawing may be flat or curved.*



Allow

more atoms will pass through S as it passes the oven, for the first mark

making the dark patch darker, for the second mark. This must be linked to the more atoms

2

[11]

2. A

0.10 kg s^{-1}.

[1]

3. B

u

[1]

4. (a) 28 (°C) ✓

1

(b) The energy transferred reduces the number of nearest atomic neighbours

First alternative must not imply total loss of intermolecular forces or neighbours.

A reference to 'breaking <u>the</u> bonds' implies all the bonds and does not gain the mark.

No mark for saying bonds weaken.

However these errors in discussing the bonds does not prevent a mark coming from another point

OR
allows atoms to move their centre of vibration

Last alternative might be expressed as 'atoms change from fixed positions to them being able to slide around each other'.

Ignore any references to changes in separation.

OR
breaks some of the (atomic) bonds

OR
crystalline to amorphous ✓ (owtte)

An explanation that involves increasing the kinetic energy will lose the mark.

So will any description that implies it becomes a gas.

1

(c) The (total or mean) kinetic energy remains constant. ✓
The (total or mean) potential energy increases. ✓

2

(d) The <u>mean</u> speed/<u>mean</u> kinetic energy increases ✓

Ignore references to larger separation (because it's not always true): collisions (as it is not a gas) or measures of randomness (which are usually too vague).

Condone use of average for mean.

Don't allow velocity instead of speed.

During this time interval the atoms are all in the liquid form so no credit for references that indicate a change of state.

1

(e) Using both $\Delta Q = mc\Delta\theta$ **and** $\Delta Q = P\Delta t$ ✓

$$\left(c = \frac{P\Delta t}{m\Delta\theta} = \frac{35 \times (14.8 - 11.2) \times 60}{0.25 \times (110 - 28)} = 369\right)$$

c = 370 ✓ (allow 365–375)

J kg^{-1} K^{-1} ✓ (or J kg^{-1} C^{-1})

First mark can be given by seeing the substitution which may have some errors for example not using exactly 28. These will be penalised in the second mark.

Correct answer gains first two marks NB 400 J kg^{-1} K^{-1} shows candidate has wrongly made calculations for the solid. No mark for the unit if a solidus is used because of the uncertainty of whether the K is on the top or bottom line. (which is correct J / kg / K or J / kg K ?)
However allow a prefix if kilojoules are used for example.

3

(f) (Using both $\Delta Q = ml$ and $\Delta Q = P\Delta t$)

$$l\left(=\frac{P\Delta t}{m}\right) = \frac{35 \times ((11.2 - 1.8) \times 60)}{0.25} = 79 \text{ kJ kg}^{-1}$$ ✓

hence M = gallium ✓ (condone an ecf consistent with the calculation provided a comment is made if the value falls outside the range of the table)

The calculation yields1.3 kJ kg^{-1} if the 60 seconds is omitted.

Interim stage heat supplied = 19.7 kJ

A valid calculation must be shown to gain this second mark.

2

[10]

5. B

temperature in °C pressure in Pa

[1]

6. A

4.3 m s^{-1}

[1]

7. (a) Total energy supplied (= Pt) = 12 × 890 = 10 680 (J) ✓$_1$

✓$_1$ *Substitution or answer.*

Heat energy to evaporate nitrogen at its boiling point (= ml) = 0.05 × 2.0 × 105 = 10 000 (J) ✓$_2$

✓$_2$ *Substitution or answer.*

(Use of $Q = mc\Delta\theta$)

Attempt to use $c = \left(\frac{Q}{m \times \Delta\theta}\right) = \frac{(10680-10000)}{0.050\times(77-70)}$ ✓3

✓3 Allow any attempt at substitution with (77 – 70) or 7 correct but ΔQ does not have to be correct so can even show an addition.

specific heat capacity of liquid nitrogen =

$c = 1.9 \times 10^3$ ✓4 (allow 1 sig fig due to the small temperature difference)

✓4 Allow 1 sig fig due to the small temperature difference. No ecf – correct answer only.

J kg^{-1} K^{-1} or J kg^{-1} °C^{-1} ✓5 {taken from the answer line but if not present can come from the body of the answer space}

✓5 Correct answer Consistent with 4th mark and only in the form shown ie no double or single solidus/oblique lines.

Only penalise the kelvin unit if it has an obvious loop at the top – allow if simply small.

5

(b) (Use of volume = $\frac{m}{\rho}$)

nitrogen gas = $\frac{0.050}{3.8}$ = 0.013 (m^3) ✓1 {if both given both must be correct}

✓1 Substitution or answer and can be seen without label or explanation.

nitrogen liquid = $\frac{0.050}{810}$ = 0.000062 (m^3)

OR

a reference to the volume being negligible ✓2

✓2 Substitution or answer or words.

Work done in expanding (= X = $p\Delta V$)

= $1.0 \times 10^5 \times 0.013 = 1.3 \times 10^3$ (J) ✓3

✓3 Evidence of ΔV or calculation introduced with 'work done =' is required for the mark.

For an ecf the product must be shown in full with the substitution of the ecf being clear.

which is less than 1.0×10^4 J/the energy to change state = Y (ie X < Y) ✓4

✓4 Allow ecf from part (a) for this mark provided the statement is consistent with the figures.

OR

If the ecf comes from the 3rd mark above then the work done in expanding must be clearly labelled for the comparison or have units of J i.e it cannot be compared with a number that just happens to be on the page.

4

[9]

8. **D** **[1]**

9. **C** **[1]**

10. (a) It is the <u>sum/total</u> of the (kinetic and potential) energies of the <u>particles/atoms/molecules</u> (that move at random in the gas) ✓$_1$

✓$_1$ Cannot be an average or a rms energy. Nor a vague reference to an energy of or in the gas.

For reference to kinetic energy of the gas or molecules ✓$_2$

✓$_2$ This is independent of the first mark provided energy of the gas is given in some form. So here an average kinetic energy would be acceptable.

2

(b) (Using) the gas laws it is the temperature at which the volume/pressure of a gas extrapolates to zero

OR

(Using $pV = nRT$ or $pV = NRT$) it is the temperature when pV or V or p is zero

OR

Plotting data of volume (or pressure) against temperature the plot extrapolates and crosses the temperature axis at absolute zero OWTTE ✓$_1$

✓$_{1\ first}$ Condone 'becomes/is zero' or phrases like 'said to be zero' or 'thought to be zero'.

✓$_{1\ second}$ Just quoting Charles' law or the Pressure law is not enough.

✓$_{1\ third}$ Allow the information in the form of a sketch.

(whereas) using the kinetic energy it is the temperature at which the (random) motion stops or can be extrapolated to stop or the kinetic energy (of the particles) is zero. ✓$_2$

✓$_2$ The zero must be very explicit e.g. not just very very small. Allow reference to zero point energy/residual kinetic energy at 0 K/uncertainty at 0 K

2

(c) Mass of argon atom = $\frac{\text{molar mass}}{N_A}$

$= \frac{4.0 \times 10^{-2}}{N_A} = \frac{4.0 \times 10^{-2}}{6.02 \times 10^{23}}$ = 6.6(4) × 10^{-26} (kg) ✓$_1$

✓$_1$ Substitution of the molar mass or the answer gains the mark. Also the numbers may be seen in the equation of the second mark.

$$c_{rms} = \left(\frac{3kT}{m}\right)^{1/2}$$

$= \left(\frac{3 \times 1.38 \times 10^{-23} \times 310}{6.64 \times 10^{-26}}\right)^{1/2}$ ✓$_2$ {k can be in form of a symbol}

✓$_2$ Give a mark for this rearrangement and substitution even if the mass is incorrect.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

= 440 (m s^{-1}) ✓$_3$

✓$_3$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

Alternative 1

$\frac{m(c_{rms})^2}{2}$ or $(E_k)_{average} = \left(\frac{3kT}{2}\right) = \frac{3RT}{2N_A}$ ✓$_{1Alt1}$

✓$_{1Alt1}$ The Mark is for introducing R/NA in the mean energy equation.

$c_{rms} = \left(\frac{3RT}{mN_A}\right)^{1/2} = \left(\frac{3 \times 8.31 \times 310}{4.0 \times 10^{-2}}\right)^{1/2}$ ✓$_{2Alt1}$ {R can be in form of a symbol}

✓$_{2Alt1}$ The mark is for the use of the molar mass.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

= 440 (m s^{-1}) ✓$_{3Alt1}$

✓$_{3Alt1}$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

{On most occasions answer 5.7 × 10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used}

Alternative 2

$(E_k)_{average} = \frac{3kT}{2} = \frac{3 \times 1.38 \times 10^{-23} \times 310}{2}$ = 6.42 × 10^{-21} (J)

OR

$(E_k)_{total} = (E_k)_{average} \times N_A = 6.42 \times 10^{-21} \times 6.02 \times 10^{23}$

$(E_k)_{total} = 3.86 \times 10^3$ (J) ✓$_{1Alt2}$

✓$_{1Alt2}$ The mark can be given for evaluating either the average or the total kinetic energy.

$$c_{rms} = \left(\frac{2 \times (their\ energy)}{\text{molar mass}}\right)^{1/2} = \left(\frac{2 \times (E_k)_{total}}{\text{molar mass}}\right)^{1/2}$$

✓$_{2Alt2}$ Give a mark for this rearrangement and substitution even if the energy is incorrect.

c_{rms} must be the only unknown in the equation, data and constants to be shown.

$$\left(\frac{2 \times 3.86 \times 10^3}{4.0 \times 10^{-2}}\right)^{1/2}$$ ✓$_{2Alt2}$

= 439 (m s^{-1}) ✓$_{3Alt2}$

✓$_{3Alt2}$ Only allow a correct answer so no ecf from the second mark.

A correct answer gains all three marks

{On most occasions answer 5.7 × 10^{-10} m s^{-1} yields 2 marks as the wrong mass has been used}

Note the slightly different answers for the third mark which depends on the route taken.

2

(d) (In equilibrium at the same temperature) both gases have the same <u>mean or average</u> kinetic energy ✓

Allow 'they are the same' as a bold statement. However if this is not an opening statement following the question then 'mean or average' must be used.

2

(e) Particles/atoms/molecules collide with the piston/walls and change momentum ✓$_1$

✓$_1$ Ignore any reference to particles colliding with each other.

(The piston provides the) force = <u>rate of change</u> of momentum or <u>impulse</u>(*Ft*) = change in momentum ✓$_2$

(The particles give a force on the piston producing a pressure)

A relevant reference to pressure = force divided by/over area or F/A ✓$_3$

✓$_3$ Relevant = reference to Piston or arising from the particles. (ie where or what)

If no mark is scored give a mark for P = F/A alone

3

(f) **change**

the volume could be increased

explanation

which increases the <u>time between collisions</u> OR <u>results in less frequent collisions</u> (with the piston/wall so reducing the rate of change of momentum)

OR

which increases the area of the piston/wall (and so reduces the pressure)

change

the temperature could be reduced

explanation

which reduces the momentum (change at the wall)

OR

(and) increases the time between collisions or reduces the frequency of collisions (reducing the rate of change of momentum)

✓ ✓ ✓

An explanation in terms of the gas laws is not acceptable.

3 marks

for 2 changes and 2 explanations

2 marks

for 2 changes and 1 explanation

1 mark

for 1 change with corresponding explanation

OR

2 changes with no adequate explanation

If a wrong change is given, eg. reduce the mass, then only one mark is available for one change with corresponding explanation.

3

[14]

11. **C**

[1]

12. **A**

[1]

13. (a) Specific latent heat of fusion is the <u>energy</u> (required) to change 1 kg / unit mass of material from the solid state to the liquid state or melt/fuse ✓

Without a change of temperature or at the freezing/melting temperature/point ✓

The direction of energy transfer must be consistent with the direction of the change of state (If energy to change… is given then required or needed is implied)

2nd mark stands alone.

2

(b) (Dividing both sides of the equation $\Delta Q = m\,c\,\Delta\theta$ by Δt gives $\Delta Q/\Delta t = m\,c\,\Delta\theta/\Delta t$ or

$\Delta\theta = (\Delta Q/\Delta t\,) \times \Delta t/m\,c$ where $m = \rho V$)

$\Delta\theta = 2700 \times (60 \times 60) / (4.5 \times 1000 \times 4200)$ ✓

Full substitution correct ✓

Temperature rise = $\Delta\theta$ = 0.51 (K) ✓ (= 0.514 K)

Working <u>must be seen</u> as there is a self-cancelling error with two 1000 factors.

So answer alone gains the 3rd mark only.

First mark can be gained if (60 × 60) is absent even if not re-arranged.

The change of temperature may be written as a difference between 28 °C and an unknown temperature (allow in kelvin written either way round ie with incorrect sign)

*1 sig fig is **not** acceptable.*

Useful numbers:

$4.5 \times 1000 \times 4200 = 1.89 \times 10^{7}$

$2700/(4500\times4200) = 1.4 \times 10^{-4}$

Max 2 if:

Omits (60 × 60) giving 1.43×10^{-4} K

Omits 60 giving 8.57×10^{-3}

3

(c) (When the pump is working at speed) the pump is <u>doing work</u> (on the water) ✓

Work (and heat both) can raise the temperature of a body (as stated in the 1st Law of thermodynamics) (this may be expressed as work is converted to thermal energy) OWTTE

OR

The pump increases the randomness / turbulence of the water/molecules

OR

The <u>mean</u> square speed/*mean* kinetic energy is proportional to the (absolute) temperature ✓
(this may be given in the form on an equation) OWTTE

(Lenient mark – a reference to random motion or more collisions may gain this mark but a simple increase in kinetic energy is not enough).

Do not penalise answers that go nowhere unless they directly contradict a marked answer.

2

[7]

14. **C**

[1]

15. **C**

[1]

16. **B**

[1]

17. (a) The volume / size of the gas molecules is negligible / point mass or point molecule

Or molecules are <u>point</u> masses

Or small <u>compared</u> to the volume / size occupied by of the gas ✓
owtte

No mark for all the same size or spherical.

Without the comparison the word used must suggest extremely small.

Zero volume is wrong.

1

(b) (using $N = PV/kT$)

$N = (1.0 \times 10^5 \times 0.70 \times 10^{-3}/(1.38 \times 10^{-23} \times 300)$ ✓ (first mark is for converting the temperature to kelvin and using it in a valid equation)

$N = 1.7 \times 10^{22}$ molecules ✓ (1.69×10^{22} molecules)

Alternatively (using $n = PV/RT$)

$n = (1.0 \times 10^5 \times 0.70 \times 10^{-3} / 8.31 \times 300) = 0.028$ mol ✓ (first mark is for converting the temperature to kelvin and using it in a valid equation)

N (= $n N_A = 0.028 \times 6.02 \times 10^{23}$) = 1.7×10^{22} molecules ✓ (1.69×10^{22} molecules)

Correct answer scores both marks

Power of 10 issue = AE

Temperature conversion = PE

2

(c) (using $T_B = T_A V_B / V_A$)
$T_B = 300 \times 0.50 / 0.70 = 214$ (K) ✓
Change in temperature (= 214 – 300) = (–) 86 (K)✓
Or
T_B (= PV/Nk) = $1.0 \times 10^5 \times 0.50 \times 10^{-3}/(1.38 \times 10^{-23} \times 1.69 \times 10^{22})$
= 214 (K) ✓
Change in temperature (= 214 – 300) = (–) 86 (K)✓ (± 1 K)
Or
T_B = (PV/nR) = $1.0 \times 10^5 \times 0.50 \times 10^{-3} /(0.028 \times 8.31)$
= 215 (K) ✓
Change in temperature (= 215 – 300) = (–) 85 (K)✓

Correct answer scores both marks

Let the last mark stand alone provided an attempt at calculating T_B is made.

Also allow working in Celsius for this last stand-alone mark.

2

(d) An appropriate calculation might be:

(If the temperature remained constant $P_C = P_B V_B / V_C$)

$P_C = 1.0 \times 10^5 \times 0.50 \times 10^{-3} / 0.30 \times 10^{-3} = 1.7 \times 10^5$ (Pa) ✓

(but the pressure at C is higher than this so) the temperature at C is different / higher / not constant ✓

Or

(If the temperature remained constant $P_C V_C$ would equal $P_B V_B$)

$P_B V_B = 1.0 \times 10^5 \times 0.50 \times 10^{-3} = 50$

$P_C V_C = 2.05 \times 10^5 \times 0.30 \times 10^{-3} = 61$ ✓

($P V$ is not equal) the temperature at C is different / higher / not constant ✓

Or a full calculation can be given using $P V / T$ = constant.

$P_B V_B / T_B = 1.0 \times 10^5 \times 0.5 \times 10^{-3} / 214 = (0.234 \text{ J K}^{-1})$

$T_C = P_C V_C$ / constant $= 2.05 \times 10^5 \times 0.30 \times 10^{-3} / 0.234$

$T_C = 263$ K ✓

the temperature at C is different / higher / not constant ✓

On its own higher temperature scores 0. ***Additionally there must be a reference to a correct calculation to obtain the last mark.***

The question only requires the candidate to spot a change. The two marks are for each side of a comparison.

Complete figures are not always required. For example in the last alternative the common factor 10^5 could be missing.

2nd alternative may come from a ratio.

Depending on the sig figs used in the substitution of data the temperature has a range 256 – 270 K

PV = NkT may be used as another alternative.

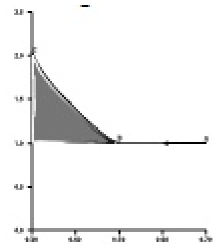
On a few occasions the full paper may be required to view.

2

(e) work done on gas from **A** to **B** (using $W = P\Delta V$ or W = area under the graph = $1.0 \times (0.70 - 0.50) \times 10^{-3}$) = 20 (J) ✓
giving a reference to the work done being the area under the graph ✓

The third mark can be obtained in the following ways:

calculating the area indicated corresponds to the additional work done on the gas from **B** to **C**



(166 mm^2 where 1 mm^2 = 0.05 J) = 8.3 J √
(allow 8.0 – 10.0 J)

Or

The total work done (566 mm^2 where 1 mm^2 = 0.05 J) = 28.3(J) ✓

(allow 28.0 – 30.0 J)

This second mark can be obtained from an attempt at an area calculation that involves the curved section of the graph.

NB 'additional work' must be quoted to give mark for 8 – 10 J.

This 3rd mark is for a correct evaluation and not for details of the process.

3

[10]

18. **B**

[1]

19. **A**

[1]

20. (a) The molecules (continually) move about in random motion✓

Collisions of molecules with each other and with the walls are elastic✓

Time in contact is small compared with time between collisions✓

The molecules move in straight lines between collisions✓

ANY TWO

Allow reference to 'particles interact according to Newtonian mechanics'

2

(b) Ideas of pressure = F / A and F = rate of change of momentum✓

Mean KE / rms speed / mean speed of air molecules increases✓

More collisions with the inside surface of the football each second✓

Allow reference to 'Greater change in momentum for each collision'

3

(c) Radius = 690 mm / 6.28) = 110 mm or T = 290 K ✓ seen

volume of air = 5.55×10^{-3} m^3✓

$n \times 29$(g) = 11.4 (g)✓ n = 0.392 mol

Use of $pV = nRT = \dfrac{0.392 \times 8.31 \times 290}{5.55 \times 10^{-3}\ \text{m}^3}$ ✓

$p = 1.70 \times 10^5$ Pa ✓

Conclusion: Appropriate comparison of their value for p with the requirement of the rule, ie whether their pressure above 1×10^5 Pa falls within the required band✓

Allow ecf for their n V and T✓

6

[11]

21. A

[1]

22. B

[1]