Past-paper walk-through

The mole ▪ 15.1

eXercise

Questions in this set

- 9702/43 N24 Q3 ▪ 8 marks
- 9702/42 M25 Q3 ▪ 12 marks
- 9702/42 M23 Q8 ▪ 11 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 3

9702/43 N24 ▪ Q3 ▪ 8 marks

(a)(i) State what is meant by the Avogadro constant. **[1]**

(a)(ii) State the relationship between the Avogadro constant N_A, the molar gas constant R and the Boltzmann constant k. **[1]**

Question 3

	sample X	sample Y
pressure		
amount of substance		
mean-square speed of molecules		
internal energy		

Question 3

9702/43 N24 ▪ Q3 ▪ 8 marks

(b)(i) Complete Table 3.1 by giving expressions, in terms of some or all of N, m, T, V and the constants in (a)(ii), for the quantities indicated.

Table 3.1

	sample X	sample Y
pressure		
amount of substance		
mean-square speed of molecules		
internal energy		

Question 3

[4]

(b)(ii) The temperature of sample X is now varied.
On Fig. 3.1, sketch the variation with thermodynamic temperature of the root-mean-square (r.m.s.) speed of the molecules of the gas. **[2]**

Solution 3

(a)(i)

Mark scheme

- number of particles per unit amount of substance

(a)(ii)

Mark scheme

- $N_A = R/k$

Solution 3

(b)(i)

Mark scheme

- X pressure and Y pressure both $= NkT/V$
- X amount $= N/N_A$ and Y amount $= 2N/N_A$
- X mean-square speed $= 3kT/m$ and Y mean-square speed $= 3kT/2m$
- X internal energy $= 3NkT/2$ and Y internal energy $= 3NkT$

Solution 3

(b)(ii) Worked steps

Know. The mean kinetic energy of a molecule is set by the temperature alone: $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$.

Equation. Rearranging, $\langle c^2\rangle = \dfrac{3kT}{m}$, so the root-mean-square speed is

$$c_{\mathrm{r.m.s.}} = \sqrt{\frac{3kT}{m}}.$$

Solution 3

Substitute. Everything except T is constant for one gas, so $c_{\text{r.m.s.}} \propto \sqrt{T}$.

Answer. The line starts at the **origin** — at $T = 0$ the molecules would have no kinetic energy — and rises with a **decreasing gradient**, because the square root grows ever more slowly. Quadrupling T only doubles the speed.

Solution 3

Check. The curve must never come back to either axis: a higher temperature can never give a lower speed, and the speed is never zero at a non-zero temperature.

Mark scheme

- line passing through the origin and not returning to either axis
- curve with positive decreasing gradient

Question 3

9702/42 M25 ▪ Q3 ▪ 12 marks

3 **(a)** Two metal cuboids P and Q are in thermal contact with each other.

(i) P and Q are in thermal equilibrium.

State what is meant by the term thermal equilibrium.

Question 3

(ii) Data for P and Q are given in Table 3.1.

Table 3.1

	P	Q
specific heat capacity / $J\,kg^{-1}\,K^{-1}$	390	910
mass / kg	0.54	0.37

P and Q are initially both at the same temperature.

P is supplied with 24 kJ of thermal energy. After some time, P and Q are once again both at the same temperature as each other.

P and Q are perfectly insulated from the surroundings.

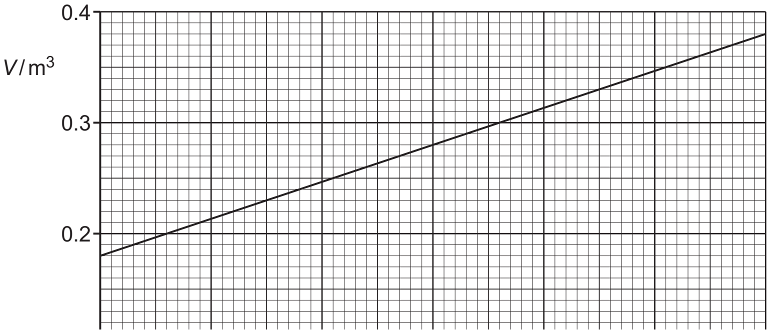
Determine the change in temperature ΔT of Q.

Question 3

Question 3

(b) Nitrogen may be assumed to be an ideal gas. A fixed amount of nitrogen gas is contained at a constant pressure of 1.6×10^5 Pa.

The variation of the volume V of the gas with the temperature θ of the gas is shown in Fig. 3.1.



Question 3

Question 3

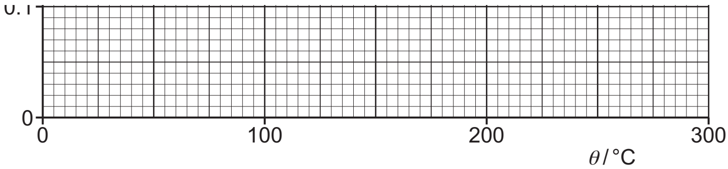


Fig. 3.1

(i) The temperature of the nitrogen gas is increased from 0 °C to 210 °C. Determine the work done on the gas.

Question 3

Question 3

Question 3

(ii) Determine the number N of molecules of nitrogen gas.

Question 3

(iii) The mass of a nitrogen molecule is 4.7×10^{-26} kg.

Calculate the root-mean-square (r.m.s.) speed of a nitrogen molecule at 210 °C.

Question 3

[Total: 12]

Solution 3

(a)(i)

Mark scheme

- (P and Q are at the) same temperature
- no net transfer of thermal energy (between P and Q)

Solution 3

(a)(ii) Worked steps

Two materials are heated together, so they share the same temperature rise and the energy supplied is split between them.

- $Q = mc\Delta T$ for each, added: $Q = (m_1 c_1 + m_2 c_2)\,\Delta T$.
- $24 \times 10^3 = (0.54 \times 390 \times \Delta T) + (0.37 \times 910 \times \Delta T)$
- The bracket is $210.6 + 336.7 = 547.3$ J K^{-1}.
- $\Delta T = \dfrac{24 \times 10^3}{547.3} = 44$ K

Solution 3

Both masses take the same ΔT because they are in **thermal equilibrium** — that is the physics the question is testing, and it is why the two terms factorise. Solving them separately and adding the answers is the usual mistake.

Mark scheme

- $\mathrm{Q} = \mathrm{mc}\Delta\mathrm{T}$
- $24 \times 103 = (0.54 \times 390 \times \Delta\mathrm{T}) + (0.37 \times 910 \times \Delta\mathrm{T})$
- $\Delta\mathrm{T} = 44\,\mathrm{K}$

Solution 3

(b)(i) Worked steps

At constant pressure the work done is pressure times the change in volume, and the sign follows the direction of that change.

- $W = p\Delta V$
- $\Delta V = 0.18 - 0.32 = -0.14$ m^3
- $W = 1.6 \times 10^5 \times (-0.14) = -2.2 \times 10^4$ J

Solution 3

Subtract in the order **final minus initial**. The gas was compressed, so ΔV is negative and the work done *by* the gas is negative — work was done *on* it. Quoting a positive number here throws away the sign the question is asking about.

Mark scheme

- work done = pΔV
- = (1.6 × 105) × (0.18 – 0.32)
- = –2.2 × 104 J

Solution 3

(b)(ii) Worked steps

Use the equation of state written per molecule, since the question asks for a number of molecules rather than moles.

- $pV = NkT$, so $N = \dfrac{pV}{kT}$
- $N = \dfrac{1.6 \times 10^5 \times 0.18}{1.38 \times 10^{-23} \times 273}$
- $N = 7.6 \times 10^{24}$

Solution 3

Two traps: use the state that goes with the volume you substitute (here the 0.18 m^3 one), and put the temperature in **kelvin**. Using R instead of k answers a different question — it gives moles, and would need multiplying by the Avogadro constant.

Mark scheme

- pV = NkT
- N = (1.6 × 105 × 0.18) / (1.38 × 10–23 × 273)
- = 7.6 × 1024

Solution 3

(b)(iii) Worked steps

Mean kinetic energy connects to temperature, and from it to the r.m.s. speed.

- $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$, so $c_{\text{r.m.s.}} = \sqrt{\dfrac{3kT}{m}}$
- $T = 210 + 273 = 483$ K
- $c_{\text{r.m.s.}} = \sqrt{\dfrac{3 \times 1.38 \times 10^{-23} \times 483}{4.7 \times 10^{-26}}}$
- $c_{\text{r.m.s.}} = 650\ \text{m}\,\text{s}^{-1}$

Solution 3

The mass in this formula is the mass of **one molecule**, not of the gas — the units are the check: $\mathrm{J\,K^{-1}} \times \mathrm{K}$ over kg gives $\mathrm{m^2\,s^{-2}}$, and the square root is a speed. And convert 210 °C to kelvin; using 210 gives 430 $\mathrm{m\ s^{-1}}$, which is the marked wrong answer for this question.

Mark scheme

- $½m<c2> = (3\,/\,2)kT$
- r.m.s. speed $= \sqrt{}[(3 \times 1.38 \times 10–23 \times (210 + 273)\,/\,(4.7 \times 10–26)]$
- $= 650$ m s–1
- 9702/42
- February/March 2025

Question 8

9702/42 M23 ▪ Q8 ▪ 11 marks

Plutonium-238 ($^{238}_{94}\text{Pu}$) is unstable and undergoes alpha decay.

(a) Complete the equation to show the decay of plutonium-238.

$$^{238}_{94}\text{Pu} \rightarrow \ \ldots^{\cdots}\,\text{U} + \ \ldots^{\cdots}\,\alpha$$

[2]

Question 8

9702/42 M23 ▪ Q8 ▪ 11 marks

Plutonium-238 ($^{238}_{94}$Pu) is unstable and undergoes alpha decay.

(b)(i) Calculate the initial number N_0 of nuclei of plutonium-238 in the power source. **[1]**

(b)(ii) Determine the initial activity of the source. Give a unit with your answer. **[2]**

(b)(iii) Use your answer in **(b)(ii)** to determine the initial power output from the source due to the decay of plutonium-238. **[2]**

(b)(iv) The space probe will continue to function until the power output from the plutonium in the source decreases to 65.3% of its initial value.

Calculate the time, in years, for which the space probe will function. **[2]**

Question 8

9702/42 M23 ▪ Q8 ▪ 11 marks

Plutonium-238 ($^{238}_{94}$Pu) is unstable and undergoes alpha decay.

(c) An alternative power source uses energy generated from the radioactive decay of polonium-210. This isotope has a half-life of 0.378 years. The mass of the isotope needed for the same initial power output as in (b) is 3.37 g.

Suggest one advantage and one disadvantage of using polonium-210 as the source of energy. **[2]**

Solution 8

(a)

Mark scheme

- 234, 92 for the uranium nucleus
- 4, 2 for the alpha particle

Solution 8

(b)(i) Worked steps

Know. The number of nuclei is the mass of the sample divided by the mass of one nucleus, and one plutonium-238 nucleus has a mass of 238 u.

Equation. $N_0 = \dfrac{M}{238u}$, with $u = 1.66 \times 10^{-27}$ kg.

Substitute. $N_0 = \dfrac{0.874}{238 \times 1.66 \times 10^{-27}}$.

Answer. $N_0 = 2.21 \times 10^{24}$ nuclei.

Solution 8

Check. A gram of anything holds of order 10^{21}–10^{24} atoms, so this is the right size. Using 238 g mol^{-1} and the Avogadro constant gives the same number.

Mark scheme

- $N_0 = 0.874/(238 \times 1.66 \times 10^{-27})$
- $= 2.21 \times 10^{24}$

Solution 8

(b)(ii) Worked steps

Know. Activity is the number of decays per second, $A = \lambda N$, and the decay constant comes from the half-life: $\lambda = \dfrac{\ln 2}{t_{1/2}}$.

Equation. $A = \dfrac{\ln 2}{t_{1/2}} N_0$, with $t_{1/2}$ **in seconds**.

Substitute. $t_{1/2} = 87.7 \times 365 \times 24 \times 3600 = 2.77 \times 10^9$ s, so
$A = \dfrac{0.693}{2.77 \times 10^9} \times 2.21 \times 10^{24}$.

Answer. $A = 5.5 \times 10^{14}$ Bq — the unit is required, and the becquerel is one decay per second.

Solution 8

Check. Converting the half-life to seconds is the whole question: leaving it in years gives an answer 3×10^7 times too large.

Mark scheme

- $A = \lambda N$
- $= \frac{\ln 2}{87.7 \times 365 \times 24 \times 3600} \times 2.21 \times 10^{24}$
- $= 5.54 \times 10^{14}$ Bq

Solution 8

(b)(iii)

Worked steps

Know. Each decay releases 5.59 MeV, and power is energy per second — which is exactly what an activity in becquerels gives you.
Equation. $P = A \times E_{\text{per decay}}$, with the energy converted to joules: 1 MeV $= 1.60 \times 10^{-13}$ J.
Substitute. $P = 5.54 \times 10^{14} \times 5.59 \times 1.60 \times 10^{-13}$.
Answer. $P = 496$ W, about half a kilowatt.
Check. Activity is *per second* already, so no extra time factor belongs here. If you find yourself multiplying by a number of seconds, you have double-counted.

Mark scheme

- power $= 5.54 \times 10^{14} \times 5.59 \times 10^{6} \times 1.60 \times 10^{-19}$
- $= 496$ W

Solution 8

(b)(iv) Worked steps

Know. The power output falls in proportion to the number of nuclei left, so it decays exponentially with the same half-life: $P = P_0 e^{-\lambda t}$.

Equation. $\dfrac{P}{P_0} = e^{-\lambda t}$, so $t = -\dfrac{\ln(P/P_0)}{\lambda}$.

Substitute. $\ln(0.653) = -0.426$, and $\lambda = \dfrac{\ln 2}{87.7} = 7.90 \times 10^{-3}$ per **year** — the half-life may stay in years here, provided the answer is wanted in years.

Solution 8

Answer. $t = \dfrac{0.426}{7.90 \times 10^{-3}} = 54$ years.

Check. 65.3% is more than half, so the answer must be **less** than one half-life of 87.7 years. It is.

Mark scheme

- $65.3 = 100e^{-\frac{\ln 2}{87.7}t}$
- $\ln 0.653 = -(\ln 2/87.7)t$
- $t = 53.9$ years

Solution 8

(c)

Mark scheme

- advantage: less mass so less energy needed to launch probe
- disadvantage: half-life shorter so will not provide power for as long