Past-paper walk-through

Temperature scales ▪ 14.2

eXercise

Questions in this set

- 9702/41 N25 Q4 ▪ 10 marks
- 9702/43 J24 Q2 ▪ 7 marks
- 9702/42 J23 Q2 ▪ 12 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 4

9702/41 N25 ▪ Q4 ▪ 10 marks

(a)(i) the Celsius temperature scale **[1]**

(a)(ii) the thermodynamic temperature scale. Give a unit with your answer. **[1]**

(b)(i) State what is indicated about the nature of the gas from the variation shown in Fig. 4.1. **[1]**

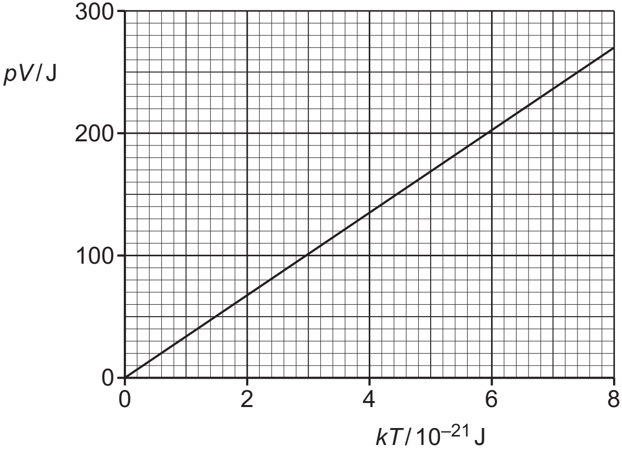
(b)(ii) Determine the number *N* of molecules of the gas in the sample. **[2]**

(b)(iii) Use your answer in (b)(ii) to determine the amount *n* of gas in the sample. **[1]**

(c) The root-mean-square (r.m.s.) speed of the molecules of the gas is 1900 m s^{-1} when pV is equal to 270 J.

Determine the mass, in u, of one molecule of the gas, where u is the unified atomic mass unit. **[4]**

Question 4



Solution 4

(a)(i)

Mark scheme

- temperature $= -273.15\ ^{\circ}\mathrm{C}$ **A1**

(a)(ii)

Mark scheme

- temperature $= 0\ \mathrm{K}$ **A1**

Solution 4

(b)(i)

Mark scheme

- gas is ideal **B1**

Solution 4

(b)(ii) Worked steps

Use the equation of state written **per molecule**, because the question asks for a number of molecules.

- $pV = NkT$, so $N = \dfrac{pV}{kT}$
- $N = \dfrac{270}{8.0 \times 10^{-21}}$
- $N = 3.4 \times 10^{22}$

Solution 4

The product pV is given directly as 270 J, so there is nothing to multiply out — and kT is the mean energy scale of the gas, which the earlier part supplied. A number of molecules has **no unit**.

Mark scheme

- $pV = NkT$ **C1**
- $N = 270 / (8.0 \times 10–21)$
- $= 3.4 \times 1022$ **A1**

Solution 4

(b)(iii) Worked steps

The amount in moles is the number of molecules divided by the number in one mole.

- $n = \dfrac{N}{N_A} = \dfrac{3.4 \times 10^{22}}{6.02 \times 10^{23}}$
- $n = 0.056$ mol

Solution 4

Divide, do not multiply: there are far more molecules in a mole than in this sample, so the answer must be well under 1. Carry your own N forward from (b)(ii).

Mark scheme

- n $= (3.4 \times 1022) / (6.02 \times 1023)$
- $= 0.056$ mol **A1**

Solution 4

(c) Worked steps

Kinetic theory links pV to the molecules' mean square speed, and everything else in that equation is now known.

- $pV = \frac{1}{3}Nm\langle c^2\rangle$, so $m = \dfrac{3pV}{N\langle c^2\rangle}$
- $\langle c^2\rangle = c^2_{\text{r.m.s.}} = 1900^2 = 3.61 \times 10^6\ \text{m}^2\,\text{s}^{-2}$
- $m = \dfrac{3 \times 270}{3.4 \times 10^{22} \times 3.61 \times 10^6} = 6.6 \times 10^{-27}\ \text{kg}$
- Convert to unified atomic mass units by dividing by 1.66×10^{-27} kg: $m = \dfrac{6.6 \times 10^{-27}}{1.66 \times 10^{-27}} = 4.0\ \text{u}$

Solution 4

Four marks for four steps: the kinetic-theory equation, squaring the r.m.s. speed, the mass in kilograms, and the conversion to u. Do the conversion — an answer left in kilograms answers a different question.

A sense-check that also tells you something: 4.0 u is helium, which is exactly the kind of light monatomic gas that has an r.m.s. speed near 1900 m s^{-1} at a few hundred kelvin.

Mark scheme

- ½ $m<c2> = (3 / 2)$ kT **C1**
- ½ × m × 19002 = 1.5 × 8.0 × 10–21
- (m = 6.65 × 10–27 kg) **C1**
- m = (6.65 × 10–27) / (1.66 × 10–27) **C1**
- = 4.0 u **A1**

Question 2

9702/43 J24 ▪ Q2 ▪ 7 marks

(a)(i) State the magnitude and unit of absolute zero on the thermodynamic temperature scale. **[1]**

(a)(ii) Explain why temperature measured using a laboratory liquid-in-glass thermometer does not give a measurement of thermodynamic temperature. **[1]**

(b)(i) Explain how Fig. 2.2 shows that platinum is a suitable metal for use in a resistance thermometer. **[2]**

(b)(ii) Suggest a reason why a platinum resistance thermometer is **not** suitable for measuring a rapidly changing temperature. **[1]**

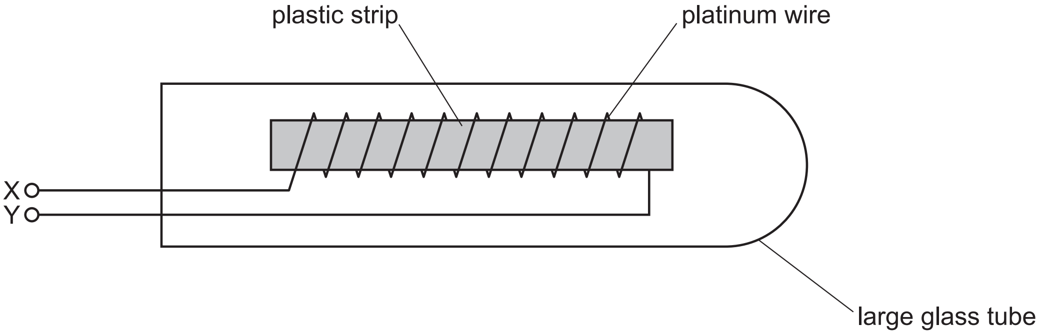
(b)(iii) Suggest a type of thermometer that is suitable for measuring a rapidly changing temperature. **[1]**

(c) A negative temperature coefficient thermistor may be used as a type of resistance thermometer.

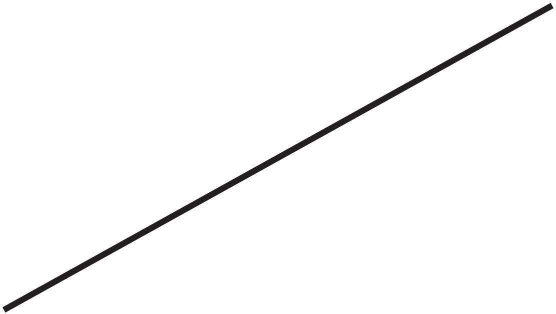
Question 2

State **one** way in which the variation with temperature of the resistance of a thermistor differs from that of a platinum wire. **[1]**

Question 2



Question 2



Solution 2

(a)(i)

Mark scheme

- 0 K

(a)(ii)

Mark scheme

- (measurement) depends on properties of the liquid

Solution 2

(b)(i)

Mark scheme

- resistivity varies with temperature
- variation with temperature is linear
- unique value of resistivity for each (different value of) temperature

Any two points, 1 mark each

Solution 2

(b)(ii)

Mark scheme

- thermometer has high heat capacity/specific heat capacity
- **or**
- energy transfer needed for thermometer to reach correct temperature
- **or**
- thermometer takes time to reach the correct temperature

Solution 2

(b)(iii)

Mark scheme

- thermocouple

Solution 2

(c)

Mark scheme

- (variation is) inverse
- **or**
- (variation is) non-linear

Question 2

9702/42 J23 ▪ Q2 ▪ 12 marks

(a)(i) State what is meant by an ideal gas. **[2]**

(a)(ii) State the temperature, in degrees Celsius, of absolute zero. **[1]**

(b)(i) the number of molecules of the gas in the vessel **[3]**

(b)(ii) the mass of one molecule of the gas **[1]**

(b)(iii) the root-mean-square (r.m.s.) speed v of the molecules of the gas. **[3]**

(c) The gas in (b) is now cooled gradually to absolute zero.

On Fig. 2.1, sketch the variation with thermodynamic temperature T of the r.m.s. speed of the molecules of the gas. **[2]**

Solution 2

(a)(i)

Mark scheme

- (gas that obeys) $pV \propto T$ (for all values of p, V and T)
- where T is thermodynamic temperature

(a)(ii)

Mark scheme

- temperature $= -273.15$ °C

Solution 2

(b)(i) Worked steps

Know. Counting **molecules** rather than moles means using the Boltzmann constant form of the equation of state.

Equation. $pV = NkT$, so $N = \dfrac{pV}{kT}$.

Convert. The temperature must be thermodynamic: $227\ ^\circ\text{C} = 227 + 273 = 500$ K.

Substitute. $N = \dfrac{(1.37 \times 10^5)(0.640)}{(1.38 \times 10^{-23})(500)}$.

Answer. $N = 1.27 \times 10^{25}$.

Solution 2

Check. The conversion to kelvin is a mark in itself. Using 227 would give a number more than twice as large, and no amount of correct algebra afterwards recovers it.

Mark scheme

- $pV = NkT$
- $N = (1.37 \times 10^5 \times 0.640)/(1.38 \times 10^{-23} \times (227 + 273))$
- $= 1.27 \times 10^{25}$

Solution 2

(b)(ii) Worked steps

Know. The total mass of the gas is shared equally among all its molecules, so divide.

Equation. $m = \dfrac{\text{total mass}}{N}$.

Substitute. $m = \dfrac{0.0424}{1.27 \times 10^{25}}$.

Answer. $m = 3.34 \times 10^{-27}$ kg.

Solution 2

Check. That is about twice the mass of a hydrogen atom, so the gas is plausibly hydrogen molecules. A molecular mass coming out near 10^{-3} kg means the mass in kilograms was divided by a number of **moles** instead of a number of molecules.

Mark scheme

- mass $= 0.0424/(1.27 \times 10^{25})$
- $= 3.34 \times 10^{-27}$ kg

Solution 2

(b)(iii) Worked steps

Know. The average translational kinetic energy of a molecule depends only on temperature. Set the mechanical expression equal to the thermal one.

Equation. $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$, so $v = \sqrt{\dfrac{3kT}{m}}$ where v is the r.m.s. speed.

Substitute. $v = \sqrt{\dfrac{3(1.38 \times 10^{-23})(500)}{3.34 \times 10^{-27}}}$.

Answer. $v = 2490$ m s^{-1}.

Check. Take the square root at the end: $\langle c^2\rangle$ comes out as 6.2×10^6, and quoting that is quoting a **squared** speed. The same answer follows from $pV = \frac{1}{3}(Nm)\langle c^2\rangle$ with Nm the total mass of gas, which avoids parts (b)(i) and (b)(ii) entirely. **Mark scheme**

Solution 2

- $\frac{1}{2}m\langle c^2\rangle = (3/2)kT$
- $3.34 \times 10^{-27} \times v^2 = 3 \times 1.38 \times 10^{-23} \times 500$
- $v = 2490$ m s^{-1}
- **or**
- $pV = \frac{1}{3}(Nm)\langle c^2\rangle$ and $Nm =$ mass of gas
- $0.0424 \times v^2 = 3 \times 1.37 \times 10^5 \times 0.640$
- $v = 2490$ m s^{-1}

Solution 2

(c) Worked steps

Know. From $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$, the r.m.s. speed is proportional to $\sqrt{T}$, not to T.
Two fixed points. At $T = 0$ the molecules have no translational kinetic energy, so the line starts at the **origin**. At $T = 500$ K it passes through the speed found in (b)(iii).
Shape. A square-root curve: rising throughout, but with a gradient that gets **shallower** as the temperature increases.

Solution 2

Check. A straight line through the origin is the error to avoid. It would say that doubling the temperature doubles the speed, whereas doubling the temperature multiplies the speed by only $\sqrt{2}$.

Mark scheme

- sketch: line from (0, 0) to (500, v)
- line with decreasing positive gradient throughout