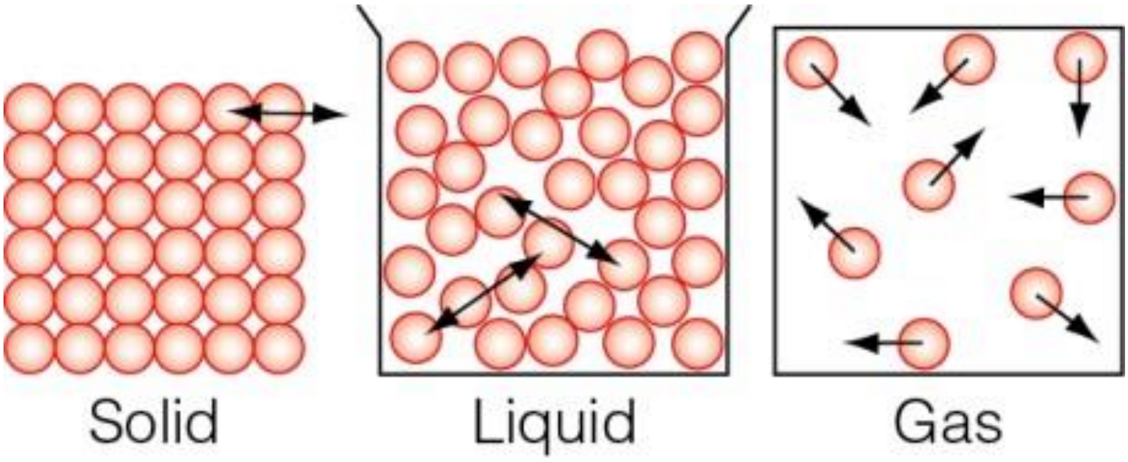
Page 329 Test yourself on prior knowledge

1



2 Conduction involves the transfer of the vibration of particles from hot nearest neighbour to colder nearest neighbours, and convection involves the translation of hotter, faster-moving particles from somewhere hot to somewhere colder.

3 Particles of water moving fast, and perpendicular to the surface of the tea, can escape the surface, lowering the overall average kinetic energy of the water particles in the tea, lowering its temperature.

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1 Thermodynamics deals with the macroscopic (large-scale) behaviour of a system, in terms of energies involved with the system, such as the internal energy, the thermal energy and the work done on or by the system.

2 Increasing its temperature (heating it) OR by doing work on it (compressing it).

3 $\Delta U = \Delta Q - \Delta W$

so $\Delta W = \Delta Q - \Delta U$

$= 1247 \text{ kJ} - 1864 \text{ kJ}$

$= -617 \text{ kJ}$

The negative sign indicates that, rather than the gas doing work, work is done on the gas.

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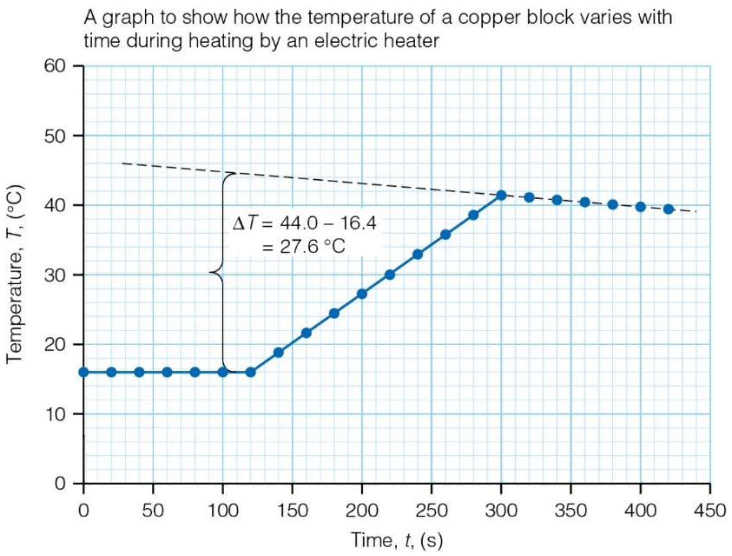
Page 334–335 Activity

Measuring the specific heat capacity of a metal block

1



2 From graph, $\Delta T = 44.0 - 16.4 = 27.6°C$

3 Specific heat capacity is calculated from $Q = mc\Delta\theta$, where Q is the amount of thermal energy supplied.

If we assume that the experiment is 100 % efficient, and all the electrical energy supplied from the heater is converted into thermal energy of the copper block then:

$Q = VIt = 12.0\ V \times 4.0\ A \times 180\ s = 8640\ J$

The mass of the block, m = 0.814 kg and $\Delta\theta = 27.6$ K so:

$$c = \frac{Q}{m \times \Delta\theta}$$

$$= \frac{8640\ \mathrm{J}}{0.814\ \mathrm{kg} \times 27.6\ \mathrm{K}}$$

$= 384.6\ J\ kg^{-1}\ K^{-1} \approx 380\ J\ kg^{-1}\ K^{-1}$ (2 sf)

4 Efficiency of transfer of electrical energy into thermal energy will never be 100 %. Some thermal energy will be lost to the surroundings.

5 Repeating the experiment would give a range of different values for *c*. These could be averaged and the range used to estimate an uncertainty in the value.

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6

Error	Random or systematic	Way that the error could be removed
Measuring the time using a stopwatch	Systematic	Use datalogger with appropriate sensor to measure both temperature and time.
Measuring the pd using a voltmeter	Systematic	More precise voltmeter. Repeated readings and averaging.
Measuring the current using an ammeter	Systematic	More precise ammeter. Repeated readings and averaging.
Measuring the mass of the block using an electronic balance	Systematic	More precise balance. Repeated readings and averaging.
Measuring the temperature of the block using a thermometer	Systematic	More precise thermometer. Repeated readings and averaging.
The thermal energy escaping to the surroundings	Random	Full thermal lagging of the block.
The residual heat left in the heater after it has been switched off	Systematic	Use of calorimetric cooling curve technique. Repeated readings and averaging.

Page 335 Test yourself

4 **a)** $Q = P \times t$

$= 750\text{ W} \times 150\text{ s} = 112\,500\text{ J} \approx 110\,000\text{ J}$ (2 sf)

$\Delta\theta = Q/(mc)$

$= 112\,500 / (0.42\text{ kg} \times 4200\text{ J kg}^{-1}\text{ K}^{-1})$

$= 63.8\text{ K}$

Final temperature of tea = 17°C + 63.8°C = 80.8°C ≈ 81°C (2 sf)

(Note: 1 degree Celsius is equal to 1 Kelvin.)

b) Some of Q is used changing the state of the water from liquid to gas, so not all the thermal energy goes into heating all the water in the tea. This will reduce the final temperature of the tea.

c) $\Delta\theta = 80.8°\text{C} - 71.0°\text{C} = 9.8°\text{C}$

So $Q = mc\Delta\theta$

$= 0.42\text{ kg} \times 4200\text{ J kg}^{-1}\text{ K}^{-1} \times 9.8°\text{C}$

$= 17\,287.2\text{ J} = 17\,000\text{ J}$ (to 2 sf)

d) $m = Q / (c\Delta\theta)$

$= 17\,287.2\text{ J} / (4000\text{ J kg}^{-1}\text{ K}^{-1} \times (71.0 - 5.5))$

$= 0.066\text{ kg}$

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5 a) m = ρ × V

= 1.2 kg m^{-3} × 24 000 m^3

= 28 800 kg

b) Δθ = 16°C – 5.0°C = 11°C

So Q = mcΔθ

= 28 800 kg × 1000 J kg^{-1} K^{-1} × 11°C

= 3.17 × 10^8 J = 3.2 × 10^8 J (to 2 sf)

c) Total power = 14.7 kW × 4 = 58 800 W

So t = Q/P

= 3.17 × 10^8 J / 58 800 W

= 5391 s = 90 mins (to 2 sf)

d) Some thermal energy will be lost via conduction through the material of the dome.

6 a) m = ρ × V

= 1 g cm^{-3} × (240 × 60 × 60) cm^3

= 864 kg ≈ 860 kg (2 sf)

b) Q = mcΔθ

= 864 kg × 4200 J kg^{-1} K^{-1} × (25.5 – 9.5)°C

= 58 060 800 J

c) Rate of fall of temperature = rate heater causes temperature to rise when functioning

$$\frac{\Delta\theta}{\Delta t} = \frac{Q}{mc\Delta t} = \frac{P}{mc}$$

= 100 W / (864 kg × 4200 J kg^{-1} K^{-1})

= 2.75 × 10^{-5} K s^{-1}

2.75 × 10^{-5} K s^{-1} × 3600 s = 0.099 K hr^{-1} ≈ 0.1°C hr^{-1}.

d) $k = \frac{\Delta\theta/\Delta t}{\theta_w - \theta_s} = \frac{0.099\ \mathrm{K\ hr^{-1}}}{(25.5-15.0)°\mathrm{C}}$ = – 0.0094 hr^{-1}

e) $\frac{\Delta\theta}{\Delta t}$ = – 0.0094 hr^{-1} × (25.5 – 8)°C = 0.1645°C hr^{-1}

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7 Q = ml_f

= 12.5 × 10^{-3} kg × 334 × 10^{-3} J kg^{-1}

= 4175 J ≈ 4180 J (3 sf)

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8 $Q = ml_f$

$= 4.2 \times 10^{-3}$ kg $\times 23 \times 10^3$ J kg^{-1}

$= 96.6$ J

So time taken, $t = Q/P = 96.6$ J / 18 W = 5.36 s ≈ 5.4 s (2 sf)

9 a) $Q = mc\Delta\theta$

$= 1.5$ kg $\times 4200$ J kg^{-1} K^{-1} $\times (100 - 20)$°C

$= 5.04 \times 10^5$ J

b) $t = Q/P$

$= 5.04 \times 10^5$ J / 2.7×10^3 W

$= 186.6$ s (190 s to 2 sf)

c) $m = Q/l_v = (P \times t) / l_v$

$= (2.7 \times 10^3$ W $\times 25$ s$) / 2260 \times 10^3$ J kg^{-1}

$= 0.030$ kg

10 a) $V_1I_1t = m_1l_v + E$ and $V_2I_2t = m_2l_v + E$

so $V_1I_1t - m_1l_v = V_2I_2t - m_2l_v$

$m_2l_v - m_1l_v = V_2I_2t - V_1I_1t$

$$l_v = \frac{(V_2I_2 - V_1I_1)t}{m_2 - m_1}$$

b) $l_v = \dfrac{(12.00\ \text{V} \times 3.00\ \text{A} - 8.00\ \text{V} \times 2.41\ \text{A}) \times 600\ \text{s}}{(10.3 \times 10^{-3} - 5.8 \times 10^{-3})\ \text{kg}}$

$= 2.23 \times 10^6$ J kg^{-1} $= 2.2 \times 10^6$ J kg^{-1} (2 sf)

11 a) A suitable diagram showing a test tube containing stearic acid, inside a small water bath with thermometer probes in the stearic acid and the water bath.

b) Thermal energy lost by the water $= mc\Delta\theta$

$= 25 \times 10^{-3}$ kg $\times 4200$ J kg^{-1}K^{-1} $\times (95 - 18)$ °C = 8085 J in 600 s

So P, rate at which energy is lost is 8085 J / 600 s = 13 W

c) i) $c = \dfrac{Pt}{m\Delta\theta}$

Using readings from portion of graph over which stearic acid is solid:

$c = \dfrac{13\ \text{W} \times (600 - 300)\ \text{s}}{4 \times 10^{-3}\text{g} \times (65 - 20)\text{°C}} = 21667$ J kg^{-1} K^{-1}

ii) $l_f = \dfrac{Pt}{m}$

Using the portion of the graph over which the temperature of the stearic acid is almost constant:

$l_f = \dfrac{13\ \text{W} \times (245 - 180)\ \text{s}}{4 \times 10^{-3}\text{g}} = 211250$ J kg^{-1}

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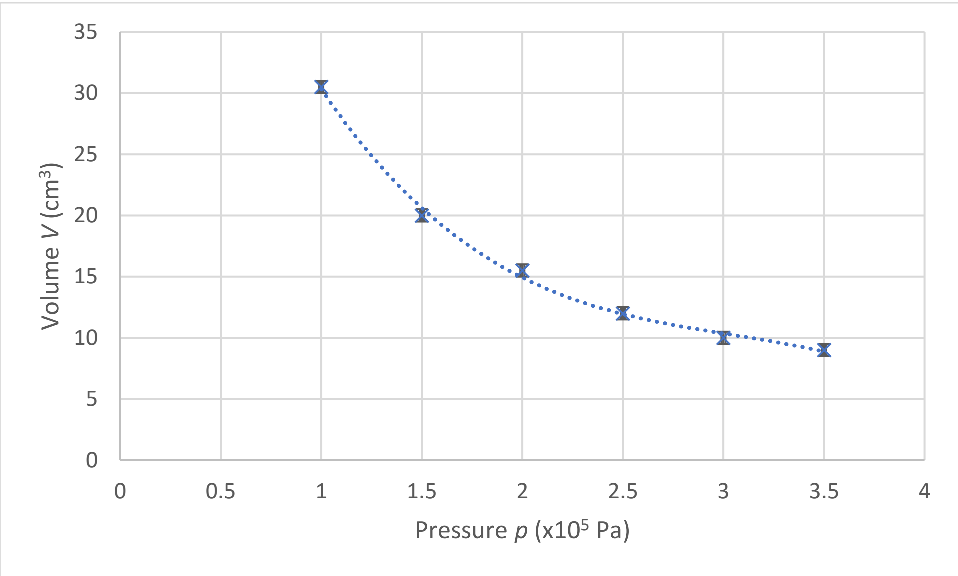
Pages 339–340 Required practical 8

Investigating Boyle's (constant temperature) law

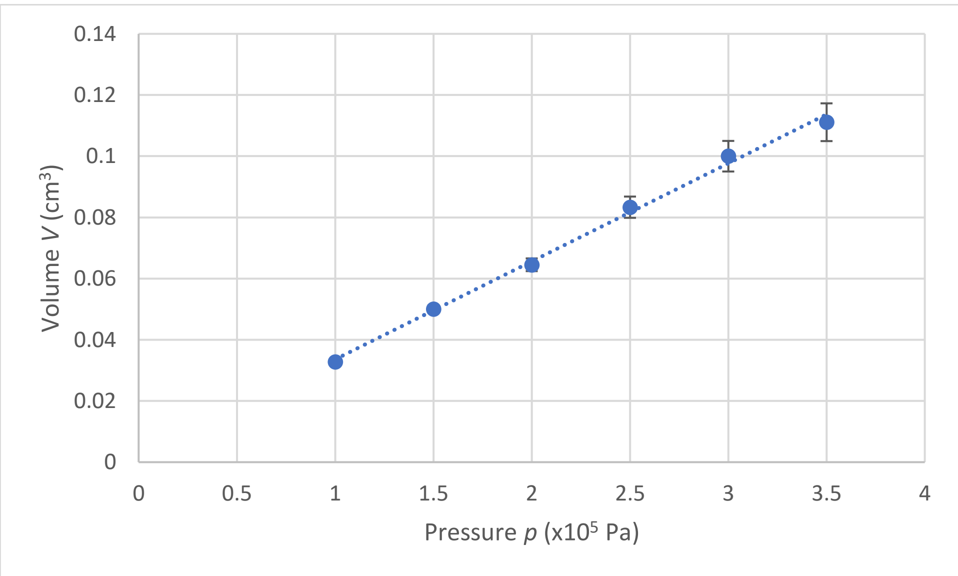
1

pressure, p, (× 10^5 Pa); (±0.01 × 10^5 Pa)	volume, V, (cm^3); (±0.5 cm^3)	1/V, (cm^{-3})	p x V, (× 10^5 Pa cm)
1.0	30.5	0.033	30.5
1.5	20.0	0.050	30.0
2.0	15.5	0.065	31.0
2.5	12.0	0.083	30.0
3.0	10.0	0.100	30.0
3.5	9.0	0.111	31.5

2



3



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4 Excel calculates the gradient of the graph of 1/V against p to be 0.0324 $cm^{-3}/(\times 10^5 Pa)$
This is 1/k, so k = 30.7 × 10^5 Pa cm^3 = 3.09 N m

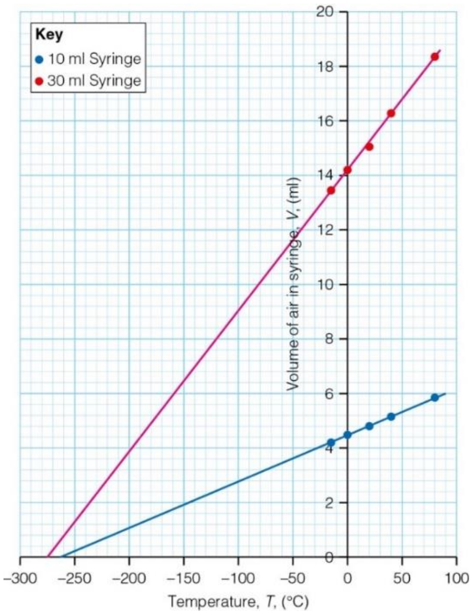
The largest uncertainty on the graph gives a value of about 6%, therefore the uncertainty in k is ± 0.19 N m.

5 The value of V is also dependent on the temperature of the apparatus. Compressing the air does work on the gas increasing its internal energy and hence the temperature. Allowing the apparatus to come to thermal equilibrium reduces this systematic error.

Page 342 Required practical 8

Investigation of Charles' law for a gas

1



2 Examining the graph gives a value of absolute zero in the range of –265 to – 275°C.

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12 p_1 = 2.5 MPa; $V_1 = 6.0 \times 10^{-3}$ m^3; T_1 = 273.15 + 5 °C = 278.15 K

p_2 = 0.1 MPa; V_2 = ?; T_2 = 273.15 + 20 °C = 293.15 K

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

$$V_2 = \frac{p_1V_1T_2}{T_1p_2}$$

$$= \frac{2.5 \text{ MPa} \times 6.0 \times 10^{-3} \text{m}^3 \times 293.15 \text{ K}}{278.15 \text{ K} \times 0.1 \text{ MPa}}$$

= 0.158 m^3

13 If p remains constant, $V \propto T$, so if V doubles, T doubles. T is in Kelvin.

24°C = 297.15 K, hence T_2 must be 594.3 K = 321.15°C.

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14 a) The volume remains constant, so $p \propto T$ and

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$\Rightarrow T_2 = \frac{p_2 T_1}{p_1} = \frac{2.4 \times 10^5 \text{Pa} \times (16+273.15)°\text{C}}{1.5 \times 10^5 \text{Pa}}$$

= 462.54 K ≈ 190°C (2 sf)

b) The water will boil, producing a large quantity of steam, increasing the pressure at a greater rate.

15 The temperature remains constant, so the air obeys Boyle's Law where:

$P_1V_1 = p_2V_2$

$$\Rightarrow V_2 = \frac{p_1 V_1}{p_2}$$

$$= \frac{(1+2.5) \text{ atm} \times 22 \times 10^{-3} \text{ m}^3}{1 \text{ atm}}$$

$= 77 \times 10^{-3}$ m^3

16 $p_1 = 1.5 \times 10^6$ Pa; $V_1 = 150$ cm^3; $T_1 = 273.15 + 100$ °C = 373.15 K

$p_2 = 1.0 \times 10^5$ Pa; V_2 = ?; $T_2 = 273.15 + 6.5$ °C = 279.65 K

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$V_2 = \frac{p_1 V_1 T_2}{T_1 p_2}$$

$$= \frac{1.5 \times 10^6 \text{Pa} \times 150 \text{ cm}^3 \times 279.65 \text{ K}}{373.15 \text{ K} \times 1.0 \times 10^5 \text{ Pa}}$$

= 1686 cm^3 ≈ 1700 cm^3 (2 sf)

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17 $$V = \frac{nRT}{p}$$

$$= \frac{1.5 \text{ mol} \times 8.31 \text{ J mol}^{-1}\text{K}^{-1} \times 312 \text{ K}}{1.7 \times 10^5 \text{Pa}}$$

= 0.023 m^3

18 $$n = \frac{pV}{RT}$$

$$= \frac{1.2 \times 10^5 \text{Pa} \times 0.85 \text{ m}^3}{8.31 \text{ J mol}^{-1}\text{K}^{-1} \times (18+273) \text{ K}}$$

= 42.2 moles ≈ 42 moles (2 sf)

19 a) $$p = \frac{nRT}{V}$$

$$= \frac{0.15 \text{ mol} \times 8.31 \text{ J mol}^{-1}\text{K}^{-1} \times 293 \text{ K}}{8.2 \times 10^{-4} \text{m}^3}$$

$= 4.45 \times 10^5$ Pa

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b) Assuming that the volume of the tyre does not increase:

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

$$= \frac{5.45 \times 10^5\ \mathrm{Pa} \times 8.2 \times 10^{-4}\ \mathrm{m}^3}{0.15\ \mathrm{mol} \times 8.31\ \mathrm{J\ mol^{-1}K^{-1}}}$$

$= 358.5$ K ≈ 85°C (2 sf)

20 a) D

b) A

c) C

21 $V = \frac{nRT}{p}$

$$= \frac{1\ \mathrm{mol} \times 8.31\ \mathrm{J\ mol^{-1}K^{-1}} \times 273\mathrm{K}}{1.01 \times 10^5 \mathrm{Pa}}$$

$= 0.0225\ \mathrm{m}^3$

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

$$= \frac{1.01 \times 10^5\ \mathrm{Pa} \times 2.45 \times 10^{-2}\ \mathrm{m}^3}{1\ \mathrm{mol} \times 8.31\ \mathrm{J\ mol^{-1}K^{-1}}}$$

$= 297.8$ K

Quantity	Standard temperature and pressure (STP)	Room temperature and pressure (RTP)
Temperature, T/K	273	297.8
Pressure, $p/10^5$ Pa	1.01	1.01
Volume, V/m^3	2.25×10^{-2}	2.45×10^{-2}

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Pages 346–347 Activity

The ideal gas equation and Mount Kilimanjaro

1 For 1.0 kg of air on the surrounding plains, at a temperature of (273 + 30) K = 303 K and 90 kPa
Volume = mass/density

= 1.0 kg / 1.03 kg m^{-3}

= 0.97 m^3

On the surrounding plains:

p_1 = 90 kPa; V_1 = 0.97 m^3; T_1 = 303 K

At the summit:

p_2 = 50 kPa; V_2 = ?; T_2 = (273 — 6.8) K = 266 K

Using the ideal gas combined gas law:

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_1}$$

$$V_2 = \frac{p_1V_1T_2}{T_1p_2}$$

$$= \frac{90\text{ kPa} \times 0.97\text{ m}^3 \times 266\text{ K}}{303\text{ K} \times 50\text{ kPa}}$$

= 1.53 m^3 ≈ 1.5 m^3 (2 sf)

This is the volume of 1 kg of air at the top of Mount Kilimanjaro, thus the density of the air at the summit is:

$\rho = \frac{m}{V} = \frac{1.0}{1.53}$ = 0.65 kg m^{-3}

2 On the surrounding plains, using the ideal gas equation, $pV = nRT$, 1 mole of air has a volume of:

$V_1 = \frac{nRT_1}{p_1} = \frac{1 \times 8.31\text{ J mol}^{-1}\text{K}^{-1} \times 303\text{ K}}{90 \times 10^3\text{Pa}}$ = 0.028 m^3 = 280 litres

At the summit:

$V_2 = \frac{nRT_2}{p_2} = \frac{1 \times 8.31\text{ J mol}^{-1}\text{K}^{-1} \times 266\text{ K}}{50 \times 10^3\text{Pa}}$ = 0.044 m^3 = 440 litres

So, 6 litre capacity lungs contain:

a) (On the plains) no. of oxygen molecules of air in 6 litres

= $0.21 \times 6.02 \times 10^{23} \times \frac{6\text{ l}}{280\text{ l}} = 2.71 \times 10^{21}$ molecules

b) (At the summit) no. of oxygen molecules of air in 6 litres

= $0.21 \times 6.02 \times 10^{23} \times \frac{6\text{ l}}{440\text{ l}} = 1.72 \times 10^{21}$ molecules

This is only 63 % of the plains-level value and will lead to some form of altitude sickness.

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22 a) $F = N\frac{\Delta p}{\Delta t}$

$= 2.6 \times 10^{24}$ atoms $\times \frac{1.33 \times 10^{-22} \text{kg m s}^{-1}}{1s}$

$= 345.8$ N ≈ 350 N (2 sf)

b) $p = \frac{F}{A}$

$= \frac{345.8 \text{ N}}{7.4 \times 10^{-4} \text{m}^2}$

$= 467297$ Pa ≈ 4.7×10^5 Pa (2 sf)

23 a) Circumference = $2\pi r$

$\Rightarrow r = C/2\pi = 70/2\pi = 11.1$ cm

Volume, $V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(11.1 \times 10^{-2} \text{ m})^3 = 5.73 \times 10^{-3} \text{ m}^3$ (3 sf)

Number of moles of gas, $n = \frac{pV}{RT} = \frac{6.9 \times 10^5 \text{Pa} \times 5.7 \times 10^{-3} \text{m}^3}{8.31 \text{ J mol}^{-1} \times 300 \text{ K}}$ = 1.58 ≈ 1.6 (2 sf)

Mass of air, $m = n \times M_m = 1.58 \times 29 \times 10^{-3}$ kg mol^{-1} = 0.0458 kg

b) Density of air in football, $\rho = \frac{m}{V} = \frac{0.0458 \text{ kg}}{5.7 \times 10^{-3} \text{m}^3}$ = 7.99 ≈ 8.0 kg m^{-3} (2 sf)

$p = \frac{1}{3}(c_{rms})^2$

$\Rightarrow c_{rms} = \sqrt{\frac{3p}{\rho}}$

$= \sqrt{\frac{3 \times 6.9 \times 10^5 \text{Pa}}{8.0 \text{ kg m}^{-3}}}$

$= 497$ m s^{-1} ≈ 500 m s^{-1} (2 sf)

24 a) $R = \frac{pV}{nT}$

$= \frac{1.01 \times 10^6 \text{ Pa} \times 0.067 \text{ m}^3}{3 \times 273 \text{ K}}$

$= 8.26$ J mol^{-1} K^{-1} ≈ 8.3 J mol^{-1} K^{-1} (2 sf)

b) $k = \frac{R}{N_A}$

$= \frac{8.26 \text{ J mol}^{-1}\text{K}^{-1}}{6.02 \times 10^{23}}$

$= 1.4 \times 10^{-23}$ J K

c) $E_k = \frac{3}{2}kT$

$= \frac{3}{2} \times 1.37 \times 10^{-23}$ J K^{-1} $\times$ 273 K

$= 5.6 \times 10^{-21}$ J

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25 Points needed:

- KE and therefore average velocity of particles increases with T
- Therefore momentum change on each collision each greater
- Molecules take less time to travel between walls/to the wall and back
- Number of collisions per second increases with T
- Momentum change per second depends on momentum change per collision and number of collisions per second – both of these are greater, increasing the force on the walls, and thus the pressure

Assumptions:

- All particles are similar
- Newton's Laws of Motion are obeyed
- Volume of particles << Volume of container
- Motion is random
- All collisions are totally elastic
- No intermolecular forces

26 a) $p = \frac{nRT}{V} = \frac{M}{M_m} \times \frac{RT}{V}$

$= \frac{42\text{ g}}{4.0\text{ g}} \times \frac{8.31\text{ J mol}^{-1}\text{K}^{-1} \times (273+20)\text{K}}{3.0 \times 10^{-3}\text{m}^3}$

$= 8.5 \times 10^6$ Pa

b) $N = nN_A = \frac{M}{M_m} \times N_A$

$= \frac{42\text{ g}}{4.0\text{ g}} \times 6.02 \times 10^{23}$

$= 6.3 \times 10^{24}$ molecules

c) $pV = \frac{1}{3}Nm(c_{rms})^2 \Rightarrow c_{rms} = \sqrt{\frac{3pV}{Nm}}$

$= \sqrt{\frac{3 \times 8.5 \times 10^6\text{Pa} \times 3.0 \times 10^{-3}\text{m}^3}{6.3 \times 10^{24} \times \frac{4.0 \times 10^{-3}}{6.02 \times 10^{23}}\text{kg}}}$

$= 1352\text{ ms}^{-1} \approx 1400\text{ ms}^{-1}$ (2 sf)

d) p decreases as $p \propto T$

N remains constant

c_{rms} decreases as $c_{rms} \propto T$

Pages 353–356 Practice questions

1 C
2 B
3 A
4 D
5 B

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6 A
7 A
8 D
9 C
10 C

11 a) $Q_i = m_i c_i \Delta\theta_i$ [1]

$= 3.0 \text{ kg} \times 440 \text{ J kg}^{-1} \text{K}^{-1} \times (35 - 31)\ °\text{C}$

$= 5280$ J [1]

b) $Q_{freeze} = m_g \times l_f$

$= 25 \times 10^{-3} \text{ kg} \times 63 \times 10^3 \text{ J kg}^{-1}$

$= 1575$ J [1]

c) $Q_{freeze} + Q_{cooling} = Q_i$

$\Rightarrow Q_{cooling} = Q_i - Q_{freeze}$ [1]

$= 5280 \text{ J} - 1575 \text{ J} = 3705$ J [1]

$= m_g c_g \Delta\theta_g$

$$\Rightarrow c_g = \frac{3705 \text{ J}}{(25 \times 10^{-3} \text{ kg}) \times (1064\ °\text{C} - 35\ °\text{C})}$$

$= 144 \text{ J kg}^{-1} \text{ K}^{-1}$ [1]

d) No thermal energy is lost to the surroundings/specific heat capacity of gold is constant over a wide temperature range. [1]

12 a) $m_t c_t (40 - T) = m_a c_a (T - 5)$ [1]

$0.050 \text{ kg} \times 4250 \text{ J kg}^{-1} \text{ K}^{-1} (40 - T) = 0.12 \text{ kg} \times 900 \text{ J kg}^{-1} \text{ K}^{-1} (T - 5)$

$8500 - 212.5T = 108T - 540$

$\Rightarrow 9040 = 320.5\ T$ [1]

$\Rightarrow T = 28.2\ °\text{C} = 28\ °\text{C}$ (2 sf) [1]

b) Time to cool mould and tea to 0°C, $t = \frac{Q}{P} = \frac{m_t c_t \Delta\theta_t + m_m c_m \Delta\theta_t}{P}$

$$= \frac{(0.05 \text{ kg} \times 4250 \text{ J kg}^{-1} \text{ K}^{-1} \times 28.2\ °\text{C}) + (0.12 \text{ kg} \times 900 \text{ J kg}^{-1} \text{ K}^{-1} \times 28.2\ °\text{C})}{32 \text{ W}} = 282 \text{ s [1]}$$

Time to freeze tea $= \frac{m_t l_f}{P} = \frac{0.05 \text{ kg} \times 3.38 \times 10^5 \text{ J kg}^{-1}}{32 \text{ W}} = 528$ s [1]

Total time to freeze = 282 s + 528 s = 810 s (13.5 minutes) [1]

We have assumed that the mould remains in thermal equilibrium with the tea as it freezes. [1]

13 a) Per second: $\Delta\theta = \frac{Q}{mc} = \frac{15 \times 10^3 \text{ J}}{0.24 \text{ kg} \times 4200 \text{ J kg}^{-1} \text{ K}^{-1}} = 14.8\ °\text{C}$ [1]

so output temperature = 5°C + 14.8 °C = 19.8 °C (or 20 °C to 2 sf) [1]

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b) $t = \frac{mc\Delta\theta}{P}$ [1]

$= \frac{0.24\text{ kg} \times 4200\text{ J kg}^{-1}\text{ K}^{-1} \times (80-35)°\text{C}}{15 \times 10^3\text{ W}} = 3.0\text{ s}$ [1]

14 a) $n = \frac{pV}{RT} = \frac{1.4 \times 10^5\text{ Pa} \times 0.09\text{ m}^3}{8.31\text{ J mol}^{-1} \times 285\text{ K}}$ = 5.32 moles (or 5.3 to 2 sf) [1]

b) $p_2 = \frac{p_1 T_2}{T_1}$ [1]

$= \frac{1.4 \times 10^5\text{Pa} \times 363\text{ K}}{285\text{ K}} = 1.78 \times 10^5\text{ Pa}$ = 1.8×10^5 Pa (2 sf) [1]

c) Mass of nitrogen in tyre = 0.028 kg mol^{-1} × 5.32 moles = 0.149 kg [1]

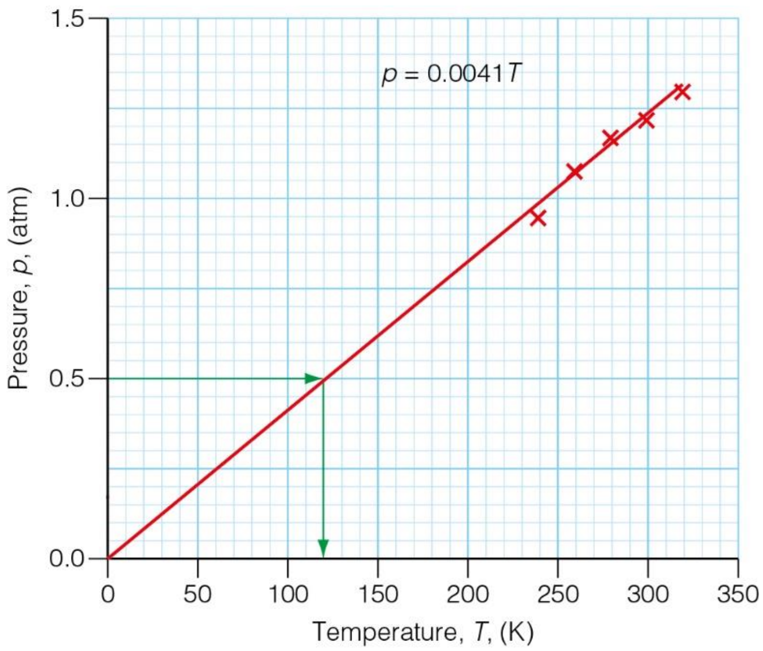
density $\rho = \frac{m}{V} = \frac{0.149\text{ kg}}{0.09\text{ m}^3} = 1.65\text{ kg m}^{-3}$ [1]

$c_{rms} = \sqrt{\frac{3p}{\rho}} = \sqrt{\frac{3 \times 1.78 \times 10^5\text{ Pa}}{1.65\text{ kg m}^{-3}}} = 568.9\text{ m s}^{-1}$ = 570 m s^{-1} (2 sf) [1]

d) Similarity: move in random directions/no intermolecular forces/obey Newton's Laws. [1]

Difference: velocity / kinetic energy / hit walls with different forces. [1]

15 a) [1 mark for correct scale, 1 mark for points plotted correctly, 1 mark for line of best fit through (0,0)]



b) As pV = nRT, gradient of pT graph = nR/V [1]

So, n = gradient × V/R [1]

$= 0.0041 \times \frac{0.055\text{ m}^3}{8.31\text{ Jmol}^{-1}}$ $= 2.7 \times 10^{-5}$ moles (using Excel calculated gradient) [1]

c) T = 120–128 K as measured from graph intercept at 0.50 atm. [1]

d) $E_k = \frac{3}{2}kT$ [1]

$= \frac{3}{2} \times 1.37 \times 10^{-23}\text{ J K}^{-1} \times 124\text{ K} = 2.55 \times 10^{-21}\text{ J}$ (or similar, using answer to (c)) [1]

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e) $U = NE_k = nN_AE_k$ [1]

$= 2.7 \times 10^{-5} \times 6.02 \times 10^{23} \times 2.55 \times 10^{-21}$ J = 0.041 J (or similar, using answer to (d)) [1]

16 a) 2 or 3 points from list = [1], 4 or 5 points = [2]

- Molecules have negligible volume
- Collisions are elastic
- Gas cannot be liquefied
- There are no intermolecular forces (apart from during collisions)
- Gas obeys gas laws at all temperatures/pressures [2]

b) $n = \frac{pV}{RT}$ [1]

$= \frac{2.02 \times 10^5 \text{ Pa} \times 3.3 \times 10^{-4} \text{ m}^3}{8.31 \text{ J mol}^{-1} \times 300 \text{ K}}$ = 0.027 moles [1]

c) $\rho = \frac{nM_m}{V}$ [1]

$= \frac{0.027 \text{ moles} \times 0.084 \text{ kg mol}^{-1}}{3.3 \times 10^{-4} \text{ m}^3}$ [1]

= 687 kg m^{-3} = 6.9 kg m^{-3} (2 sf) [1]

d) $V_2 = \frac{p_1V_1T_2}{T_1p_2}$

$= \frac{2.02 \times 10^5 \text{ Pa} \times 3.3 \times 10^{-4} \text{ m}^3 \times 266 \text{ K}}{300 \text{ K} \times 0.5 \times 10^5 \text{ Pa}}$

= 1.18×10^{-3} m^3 = 1.2×10^{-3} m^3 (2 sf) [1]

Pages 356–357 Stretch and challenge

17 a) pressure × volume = constant, for constant mass and temperature

b) initial pressure in air column = (A + 100) mmHg

where A = atmospheric pressure in mmHg

second pressure in air column = (A − 100) mmHg

The volume of trapped air is proportional to the length of the air column, so applying Boyle's Law gives (A + 100) × (400) = (A − 100) × (520)

400A + 40000 = 520A – 52000

$A = \frac{92000}{120}$ = 767 mmHg

c) i) force = pressure × area

area = $4\pi R^2 = 5.15 \times 10^{14}$ m^2

force = $(101 \times 10^3$ Pa$) \times (5.15 \times 10^{14}$ m$^2) = 5.2 \times 10^{19}$ N

ii) W = mg so divide result from part **i)** by g = 9.8 m s^{-2}

mass = 5.3×10^{18} kg

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iii) Number of molecules, N = Avogadro Number × Number of moles

$$N = 6.02 \times 10^{23} \times \frac{5.3 \times 10^{18}\ \text{kg}}{0.030\ \text{kg mol}^{-1}}$$

$N = 1.06 \times 10^{44}$ molecules

iv) Volume, V = mass / density

$$= \frac{5.3 \times 10^{18}\ \text{kg}}{1.2\ \text{kg m}^{-3}}$$

$= 4.4 \times 10^{18}\ \text{m}^3$

Height, h $= \frac{\text{volume}}{\text{surface area of earth}}$

$$= \frac{4.4 \times 10^{18}\ \text{m}^3}{4 \times \pi \times (6.4 \times 10^6\ \text{m})^2}$$

= 8600 m

d) The air is compressible and the air at the ground is compressed due to the weight of the air above it. We have used the density of air at ground level for the calculations but it is less at higher levels so volume is greater than that calculated and hence height is also larger.

e) The value for the mass obtained is good because the weight of the air (and hence the mass) is independent of whether or not it is compressed, (as long as the height is not so great that g reduces significantly – reasonable to think this applies here as 200 km < 6400 km).

18 Let T be the original temperature:

Heat gained by thermometer = heat lost by water

$20\ \text{J K}^{-1} \times (50 - 18)\ °\text{C} = (T - 50)\ °\text{C} \times 4200\ \text{J kg}^{-1}\ \text{K}^{-1} \times 0.25\ \text{kg}$

$640 = (T - 50) \times 1050$

$\Rightarrow T = 50.0 + (640 / 1050)$

$= 50.6\ °\text{C}$

19 a) Wind drives water vapour from the clothes. This causes more water to evaporate, which cools the remaining water in the clothes. (Sufficient cooling will extract sufficient latent heat of fusion from the water to cause freezing of the water.)

b) If mass M freezes and mass m evaporates:

Heat extracted from M, $E_M = (333 \times 10^3\ \text{J kg}^{-1} \times M)$ J

Energy absorbed by m, $E_m = (2500 \times 10^3\ \text{J kg}^{-1} \times m)$ J

Equating these two expressions:

333M = 2500m

$$\frac{M}{m} = \frac{2500}{333}$$

$$\frac{M}{m+M} = \frac{2500}{2500 + 333} = 0.882$$

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20 Let m be the mass of the bullet and v be the speed of the bullet.

80% kinetic energy of bullet = thermal energy heating bullet + thermal energy melting bullet

$\frac{4}{5}(\frac{1}{2}mv^2) = (m \times 0.12 \times 10^3\ J\ kg^{-1}\ K^{-1} \times (600 - 320)\ K) + (m \times 21 \times 10^3\ K\ kg^{-1})$

$v^2 = \frac{5}{2}(3.36 \times 10^4 + 21 \times 10^3)$

$v = 370\ m\ s^{-1}$

21 a) Thermal energy to raise temperature of water from 20°C to 100°C = $m \times 4200\ J\ kg^{-1}\ K^{-1} \times 80\ K$

Thermal energy required to boil the water at 100°C = ml_v

Thermal energy supplied per sec, P

$P = \frac{m\ kg \times 4200\ J\ kg^{-1}\ K^{-1} \times 80\ K}{180\ s} = \frac{m \times 4200 \times 4}{9}$

In 1200 s, the energy supplied is:

$1200 \times P = m \times l_v$

$P = \frac{ml_v}{1200}$

Hence $\frac{ml_v}{1200} = \frac{m \times 4200 \times 4}{9}$

$l_v = 2.24 \times 10^6\ J\ kg^{-1}$

Assumption: the thermal capacity of the kettle is negligible.

b) i) Atmospheric pressure, $p = 1.01 \times 10^5$ Pa

ii) $W_{atmosphere} = \int p dV$

$$= 1.01 \times 10^5\ Pa \times 0.10\ m \times \pi \times \left(\frac{0.24\ m}{2}\right)^2 = 457\ J$$

iii) 100°C

(Because the change has happened slowly allowing thermal equilibrium to be maintained.)

iv) Since the volume of gas has halved while the pressure and temperature remained constant, half of the gas has condensed to water.

$\Delta Q_c = -\Delta U - \Delta W = -l_v\Delta m - W_{atmosphere}$

$= -(2.24 \times 10^6\ J\ kg^{-1}) \times 0.5 \times (0.37 \times 10^{-3}\ kg) - 457\ J$

$= -414\ J - 457\ J = -871\ J$

(Negative sign because heat is transferred to the surroundings)

c) i) height reached is given by $\frac{1}{2}mv^2 = mgh$

but $\frac{1}{2}mv^2 = \frac{3}{2}kT$

and $m = \frac{M_m}{N_A} = \frac{0.032\ kg}{6.02 \times 10^{23}}$

so $h = \frac{3kT}{2mg} = \frac{3}{2} \times \frac{1.38 \times 10^{-23}\ J\ K^{-1} \times 283\ K}{\left(0.032\ kg/6.02 \times 10^{23}\right) \times 9.81\ N\ kg^{-1}} = 1.1 \times 10^4\ m$

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ii) $\frac{3}{2}kT_S = \frac{GmM_E}{R_E}$

$T_S = \frac{2}{3k} \times \left(\frac{GmM_E}{R_E}\right)$

Using $M_E = 5.97 \times 10^{24}$ kg and $R_E = 6.37 \times 10^6$ m

$= \frac{2 \times 6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}} \times \left(\frac{0.032\ \mathrm{kg}}{6.02 \times 10^{23}}\right) \times 5.97 \times 10^{24}\ \mathrm{kg}}{3 \times 1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}} \times 6.37 \times 10^6\ \mathrm{m}}$

$= 1.60 \times 10^5$ K

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