Answers: Thermal Physics - 1

Exercise A

1 0 K is the lowest temperature as at this temperature the internal energy of a substance is at its minimum value. The kinetic energy of all the atoms or molecules is zero - they have stopped moving. [1]

2 Increases the internal energy of the substance [1] as the electrostatic potential increases when a substance changes phase (from solid to liquid, or from liquid to gas). [1]

3 Increase the temperature of the substance. [1]

Change the phase of the substance from solid to liquid, or from liquid to gas. [1]

4 The average kinetic energy of the atoms or molecules in 1.0 kg of water at 0 °C is the same as the average kinetic energy of the atoms or molecules in 1.0 kg of ice at 0 °C.

However, the atoms or molecules in 1.0 kg of water have a higher electrostatic potential energy. [1]

As the internal energy is the sum of the kinetic and potential energies of the atoms or molecules within the substance. The water has a higher internal energy. [1]

5 When the water vapour condenses there is a decrease in the electrostatic potential energy of the particles in the water. [1]

This energy is transferred from the water to the window. [1]

Exercise B

1 a Use of $E = mc\Delta\theta$ [1]

Water: $E = 1.0 \times 4200 \times 20 = 84000$ J [1]

b Aluminium: $E = 0.600 \times 904 \times 20 = 10800$ J [1]

c Lead: $E = 4.2 \times 10^{-6} \times 129 \times 20 = 10.8$ mJ [1]

2 Appropriate diagram [2]

Measurements: Current [1]

Potential difference [1]

Initial temperature [1]

Final temperature [1]

Time [1]

3 Change in GPE is converted into thermal energy. [1]

Loss in GPE = $mg\Delta h = 1.0 \times 9.81 \times 450 = 4400\,J$ [1]

$E = mc\Delta\theta$ Therefore $\Delta\theta = \frac{E}{mc} = \frac{4400}{1.0 \times 4200} = 1.0°C$ [1]

4 $c = \frac{IVt}{m\Delta\theta}$ [1]

$c = \frac{2.0 \times 12 \times (5.0 \times 60)}{0.500 \times 32}$ [1]

$c = 450\,J\,kg^{-1}\,K^{-1}$ this corresponds to iron in Table 1 [1]

5 From $E = mc\Delta\theta$; $P = mc\frac{\Delta\theta}{\Delta t}$ [1]

From the graph $\frac{\Delta\theta}{\Delta t}$ = gradient [1]

Gradient = $0.75\,°C\,s^{-1} \pm 0.04\,°C\,s^{-1}$ [1]

$P = mc\frac{\Delta\theta}{\Delta t} = mc$ gradient and therefore

$c = \frac{P}{m \times \text{gradient}}$ [1]

$c = \frac{60}{0.030 \times 0.75} = 270\,J\,kg^{-1}\,K^{-1}$ +/− $200\,J\,kg^{-1}\,K^{-1}$ [1]

6 Drop in kinetic energy of car

$= \frac{1}{2}mv^2 = \frac{1}{2} \times 1500 \times 20^2 = 300\,kJ$ [1]

As there are two discs the energy dissipated by each disc = 150 kJ [1]

$E = mc\Delta\theta$ therefore $\Delta\theta = \frac{E}{mc} = \frac{150000}{8.0 \times 500} = 38\,°C$ [1]

Exercise C

1 $E = mL_f$ [1]

$E = 2.5 \times 88000 = 220\,kJ$ [1]

2 There is a greater change in internal energy changing phase from liquid to gas than from solid to liquid. [1]

3 $E = mL_f$ [1]

$E = 0.050 \times 398000 = 20\,kJ$ [1]

4 Energy transferred to the water = $Pt = 24 \times (60 \times 20)$ = 28800 J [1]

$E = mL_v$, $m = \frac{E}{L_v}$ [1]

$m = \frac{28800}{2.26 \times 10^6} = 0.013\,kg$ [1]

5 a $\frac{E}{\Delta t} = mc\frac{\Delta\theta}{\Delta t}$ [1]

$\frac{E}{\Delta t} = 0.060 \times 904 \times \frac{640}{16}$ [1]

$\frac{E}{\Delta t} = 2200\,W$ [1]

b $E = mL_f$ [1]

$E = 0.060 \times 398000 = 24000\,J$ [1]

6 Kinetic energy of bullet = $\frac{1}{2}mv^2 = \frac{1}{2} \times 0.008 \times 400^2$
$= 640\,J$ [1]

Energy required to heat the bullet to its melting point (327 °C):

$E = mc\Delta\theta = 0.008 \times 129 \times (327 - 20) = 296\,J$ [1]

Energy required to melt the lead = $E = mL_f$
$= 0.008 \times 23000 = 184\,J$ [1]

Energy remaining = $640 - (296 + 184) = 160\,J$ [1]

$E = mc\Delta\theta$ Therefore $\Delta\theta = \frac{E}{mc} = \frac{160}{0.008 \times 129} = 160\,°C$ [1]

Therefore final temperature of lead = $160 + 327$
$= 490\,°C$ [1]

Exercise D

1 $N = n \times N_A = 3.0 \times 6.02 \times 10^{23}$ [1]

$N = 1.8 \times 10^{24}$ atoms or molecules [1]

2 The number of atoms in 1 mol of silicon is the same as the number of atoms in 1 mol of aluminium. [1]

However, the atoms have a different mass (silicon atoms have a greater mass than aluminium atoms). [1]

3 Initial momentum = mu and final momentum = $-mu$ [1]

Therefore change in momentum, $\Delta p = 2\,mu$ [1]

4 a $N = n \times N_A$ therefore $n = \frac{N}{N_A}$

$n = \frac{N}{N_A} = \frac{2.0 \times 10^{24}}{6.02 \times 10^{23}} = 3.3\,\text{mol}$ [1]

b $n = \frac{N}{N_A} = \frac{1.5 \times 10^{17}}{6.02 \times 10^{23}} = 2.5 \times 10^{-7}\,\text{mol}$ [1]

c $n = \frac{N}{N_A} = \frac{2.0 \times 10^{24}}{6.02 \times 10^{23}} = 3.3\,\text{mol}$ [1]

5 a $m = n \times M = \frac{N}{N_A} \times M$ therefore $N = \frac{m \times N_A}{M}$ [1]

$= \frac{1.0 \times 6.02 \times 10^{23}}{64 \times 10^{-3}} = 9.4 \times 10^{24}$ [1]

b $m = n \times M = \frac{N}{N_A} \times M$

Find m when $N = 1$ [1]

$M = \frac{1}{6.02 \times 10^{23}} \times 235 \times 10^{-3} = 3.9 \times 10^{-25}\,\text{kg}$

6 Mass of lead, density = $\frac{\text{mass}}{\text{volume}}$ therefore

mass = density × volume [1]

mass = $11340 \times 0.20 = 2300\,\text{kg}$ [1]

Number of atoms = $\frac{2300}{3.46 \times 10^{-25}} = 6.6 \times 10^{27}$ atoms [1]

$n = \frac{N}{N_A} = \frac{6.6 \times 10^{27}}{6.02 \times 10^{23}} = 11 \times 10^3\,\text{mol}$ [1]

Exercise E

1 $pV = nRT$ therefore $p = \frac{nRT}{V}$ [1]

$p = \frac{60 \times 8.31 \times 250}{60000} = 2.1\,\text{Pa}$ [1]

2 **a** $p \propto \frac{1}{V}$ therefore if V is doubled, p halves. [1]

b $p \propto \frac{1}{V}$ therefore if V reduces by a factor of 3,

p increases by a factor of 3. [1]

3 $\frac{p}{T}$ = constant [1]

Initially: $\frac{300000}{293} = 1020\,\text{Pa}\,\text{K}^{-1}$ [1]

p = constant $\times T$

After the change $p = 1020 \times 393 = 401000\,\text{Pa}$ [1]

Therefore the change = 101 000 Pa [1]

4 Graph of p against $\frac{1}{V}$ with axis labelled (including units)

Points plotted correctly [1]

Line of best fit drawn [1]

Determination of gradient = 48 000 +/− 2000 [1]

Gradient = nRT therefore $n = \frac{\text{gradient}}{RT}$

$n = \frac{48000}{8.31 \times 293} = 20\,\text{mol}$ [1]

5 $pV = nRT$ therefore $V = \frac{nRT}{p}$ [1]

$V = \frac{1 \times 8.31 \times 273}{100000}$ [1]

$V = 0.023\,m^3$ [1]

6 $pV = nRT$ therefore $n = \frac{pV}{RT}$ [1]

$n = \frac{50000 \times 0.25}{8.31 \times 288}$ [1]

$n = 5.2\,mol$ [1]

$N = n \times N_A = 5.2 \times 6.02 \times 10^{23}$

$= 3.1 \times 10^{24}$ particles (atoms or molecules) [1]

7 $pV = nRT$ therefore $n = \frac{RT}{pV}$ [1]

Temperature of air inside the lungs – 300 K

Volume of the lungs – 5800 ml → 0.0058 m³ [1]

Pressure in the lungs – atmospheric pressure = 100000 Pa

$n = \frac{8.31 \times 300}{100000 \times 0.0058}$ [1] – mark awarded for using your estimates

$n = 4.3\,\text{mol}$ [1]

Exercise F

1 Mean speed $= \dfrac{100+200+150+50}{4} = 125\ \mathrm{m\,s^{-1}}$ [1]

Mean square speed $= \dfrac{100^2+200^2+150^2+50^2}{4}$

$= 19000\ \mathrm{m^2\,s^{-2}}$ [1]

Root mean square speed $= \sqrt{19000} = 140\ \mathrm{m\,s^{-1}}$ [1]

2 Particles gain kinetic energy as the temperature increases [1]

Therefore the speeds of the particles increases [1]

3 $pV = \frac{1}{3}Nm\overline{c^2}$ therefore $V = \dfrac{\frac{1}{3}Nm\overline{c^2}}{p}$ [1]

$V = \dfrac{\frac{1}{3}\times 4.0\times 10^{25}\times 4.7\times 10^{-26}\times 450^2}{800000}$ [1]

$V = 0.16\ \mathrm{m^3}$ [1]

4 $pV = \frac{1}{3}Nm\overline{c^2}$ therefore $p = \dfrac{\frac{1}{3}Nm\overline{c^2}}{V}$ [1]

$p = \dfrac{\frac{1}{3}\times 4.0\times 10^{25}\times 4.7\times 10^{-26}\times 600^2}{0.16}$ [1]

$p = 1.4\ \mathrm{MPa}$ [1]

5 **a** $N = n\times N_A = 2.0\times 6.02\times 10^{23}$

$= 1.2\times 10^{24}$ molecules [1]

b mass of molecule $= \dfrac{M}{N} = \dfrac{0.032}{1.2\times 10^{24}}$

$= 2.7\times 10^{-26}\ \mathrm{kg}$ [1]

c $pV = \frac{1}{3}Nm\overline{c^2}$ therefore $\overline{c^2} = \dfrac{pV}{\frac{1}{3}Nm}$ [1]

$\overline{c^2} = \dfrac{140000\times 0.020}{\frac{1}{3}\times 1.2\times 10^{24}\times 2.7\times 10^{-26}}$ [1]

$\overline{c^2} = 260000\ \mathrm{m^2\,s^{-2}}$ [1]

$c_{r.m.s.} = \sqrt{260000} = 510\ \mathrm{m\,s^{-1}}$ [1]