

Exercise walk-through

5.2

Ideal gases and molecular kinetic energy (129–132, CP14)

Pearson Edexcel · International A-Level · Physics

Temperature is not internal energy

Temperature

Relates to average random molecular kinetic energy.

A small and a large sample can have the same temperature.

Internal energy

Total random kinetic and intermolecular potential energy.

Depends on amount and state.
Whole-object motion is separate.

Period and energy test different properties

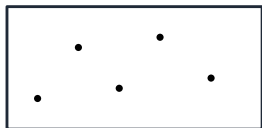
Relationship	Interpretation
Spring: $T = 2\pi\sqrt{m/k_s}$	Period depends on mass and stiffness.
Small-angle pendulum: $T = 2\pi\sqrt{l/g}$	State the small-angle condition.
$E_{\text{total}} = \frac{1}{2}k_s A_0^2$; $E_k = \frac{1}{2}k_s(A_0^2 - x^2)$	Kinetic energy versus displacement is a downward parabola.
a - x gradient $= -\omega^2$	Take the square root of the negative gradient to find ω .

Check yourself

Question	Explanation
Constant temperature but increasing internal energy? Why remove background?	Molecular arrangements and potential energy can change during phase change. It does not obey the test source's distance or time-decay model.
a - x gradient -25 s^{-2} ?	$\omega = \sqrt{25 \text{ s}^{-2}} = 5.0 \text{ rad/s}$. The negative sign indicates restoring acceleration.

Exercise 2.1

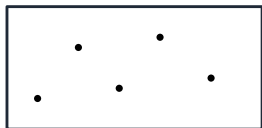
2.1 A sealed rigid vessel contains gas at 1.2×10^5 Pa and 27°C . Find its pressure at 87°C . Explain why a Celsius ratio fails. [4]



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27 to 87°C

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2.1 Fixed N and V give p/T constant. Convert temperatures to 300K and 360K .

$$p_2 = p_1 \frac{T_2}{T_1} = 1.2 \times 10^5 \text{ Pa} \frac{360 \text{ K}}{300 \text{ K}} = 1.44 \times 10^5 \text{ Pa}$$

Pressure. Gas-law proportionality uses absolute temperature; Celsius has an offset zero.

Exercise 2.2

2.2 Gas occupies $3.0 \times 10^{-3} \text{ m}^3$ at $2.0 \times 10^5 \text{ Pa}$ and 300 K . Find its molecule number using $k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$. Distinguish molecule number from amount in moles. [3]



$$\begin{aligned} p &= 2.0 \times 10^5 \text{ Pa} \\ V &= 3.0 \times 10^{-3} \text{ m}^3 \\ T &= 300 \text{ K} \end{aligned}$$

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2.2 Use the molecule form of the ideal-gas equation.

$$N = \frac{pV}{k_B T} = \frac{(2.0 \times 10^5 \text{ Pa})(3.0 \times 10^{-3} \text{ m}^3)}{(1.38 \times 10^{-23} \text{ J K}^{-1})(300 \text{ K})} = 1.45 \times 10^{23}$$

Molecule count; N counts individual particles, whereas amount in moles is N/N_A .

Exercise 2.3

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2.3 From $\frac{1}{2}m_0c_{rms}^2 = \frac{3}{2}k_B T$, RMS speed is inversely proportional to square root of molecule mass at equal T .

$$\frac{c_l}{c_h} = \sqrt{\frac{m_h}{m_l}} = \sqrt{\frac{9m}{m}} = 3$$

Ratio 3:1. Mean translational kinetic energies are equal.

Exercise 3.1

3.1 A spherical gas vessel has internal diameter 0.20 m, pressure 1.5×10^5 Pa and temperature 290 K. Molecule mass is 4.65×10^{-26} kg. Find gas mass and RMS speed. Use $k_B = 1.38 \times 10^{-23} \text{ J K}^{-1}$. [6]



$D = 0.20 \text{ m}$
 $p = 1.5 \times 10^5 \text{ Pa}$
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$$\begin{aligned} D &= 0.20 \text{ m} \\ p &= 1.5 \times 10^5 \text{ Pa} \\ T &= 290 \text{ K} \end{aligned}$$

3.1 Radius is half diameter; first calculate volume.

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(0.10 \text{ m})^3 = 4.19 \times 10^{-3} \text{ m}^3$$

$$N = \frac{pV}{k_B T} = \frac{(1.5 \times 10^5 \text{ Pa})(4.1888 \times 10^{-3} \text{ m}^3)}{(1.38 \times 10^{-23} \text{ J K}^{-1})(290 \text{ K})} = 1.57 \times 10^{23}$$

Count.

$$m_g = Nm_0 = (1.5700 \times 10^{23})(4.65 \times 10^{-26} \text{ kg}) = 7.30 \times 10^{-3} \text{ kg}$$

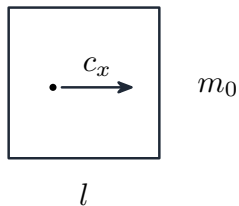
Gas mass. Use mean molecular kinetic energy to find RMS speed.

$$c_{rms} = \sqrt{\frac{3k_B T}{m_0}} = \sqrt{\frac{3(1.38 \times 10^{-23} \text{ J K}^{-1})(290 \text{ K})}{4.65 \times 10^{-26} \text{ kg}}} = 508 \text{ m s}^{-1}$$

Speed and unit.

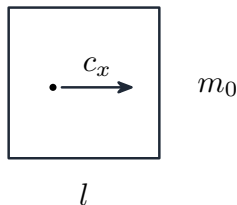
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3.2 A particle of mass m_0 moves in a cube of side l . Derive the ideal-gas pressure relation from its wall collisions and isotropic random motion. Combine it with $pV = Nk_B T$ to obtain mean translational kinetic energy. State two ideal-gas assumptions. [7]



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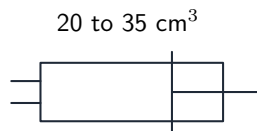
3.2 Elastic collision gives momentum transfer $2m_0c_x$. The return interval to the same wall is $2l/c_x$; mean force is $m_0c_x^2/l$. Sum N molecules, divide by wall area and use equal squared components in 3 directions:

$$pV = Nm_0\langle c_x^2 \rangle = \frac{1}{3}Nm_0\langle c^2 \rangle$$

Equating with $Nk_B T$ gives $\frac{1}{2}m_0\langle c^2 \rangle = \frac{3}{2}k_B T$. Negligible particle volume; negligible forces between particles except elastic collisions.

Exercise 3.3

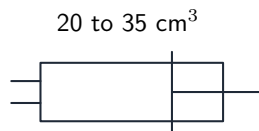
3.3 A syringe pressure gauge reads 80 kPa above atmospheric pressure 100 kPa at syringe volume 20 cm^3 . Connecting tubing adds 5 cm^3 . Find the gauge reading at syringe volume 35 cm^3 after equilibration. Explain two controls and the direction of error if the final gas is still warmer than initially. [6]



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3.3 Use absolute pressure and total connected volume.

$$p_{2,abs} = p_{1,abs} \frac{V_{1,total}}{V_{2,total}} = 180 \text{ kPa} \frac{(20 + 5) \text{ cm}^3}{(35 + 5) \text{ cm}^3} = 112.5 \text{ kPa}$$

Absolute result.

$$p_{2,g} = p_{2,abs} - p_{atm} = (112.5 - 100) \text{ kPa} = 12.5 \text{ kPa}$$

Gauge result. Keep the same sealed amount of gas; change volume slowly and wait for thermal equilibration. If final gas remains warmer, pressure is higher than this isothermal prediction.