3.6 Further Mechanics and Thermal Physics: 1-hour Pack

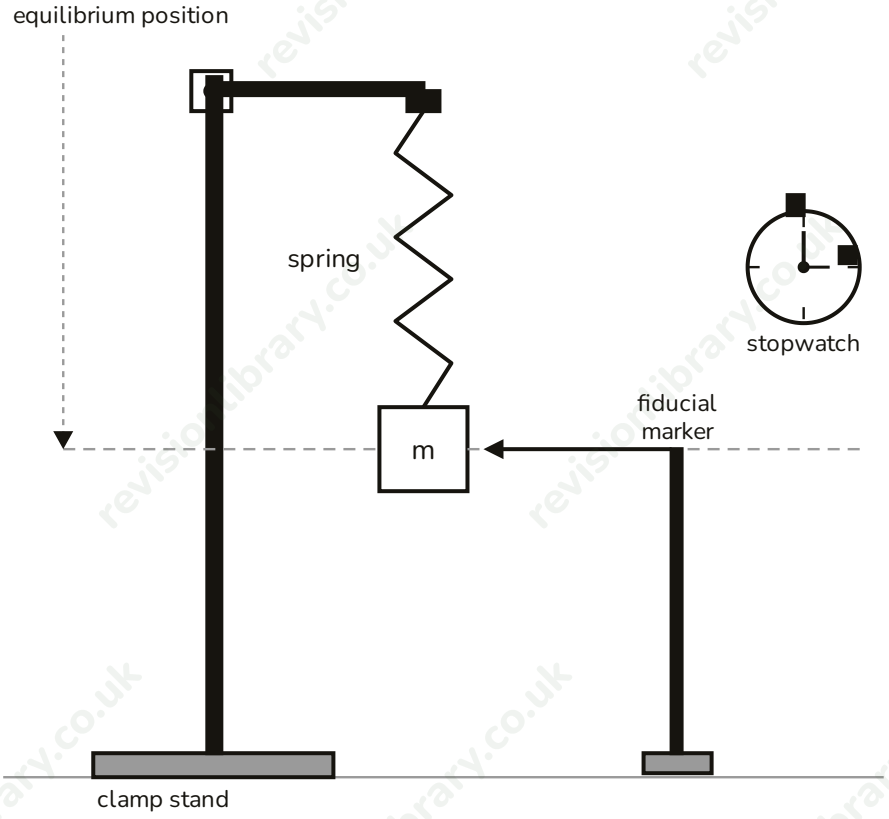
AQA 7408 · Calculator allowed · about 60 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 REQUIRED PRACTICAL. A student carries out the required practical investigation into simple harmonic motion, using a mass-spring system to determine the spring constant k from the relationship $T^2 = (4pi^2/k) \times m$, where T is the period of oscillation and m is the mass attached to the spring.



(a) Describe how the student should measure the period of oscillation of the mass-spring system accurately, including how random error in each timing is reduced. **(3)**

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(b) The student obtains the following processed data for a graph of T^2 (s^2) against m (kg): at m = 0.10 kg, T^2 = 0.247 s^2; at m = 0.50 kg, T^2 = 1.234 s^2. Using these two points, calculate the gradient of the graph of T^2 against m, and hence determine the spring constant k. **(5)**

(c) Explain how the student could reduce the percentage uncertainty in the final value obtained for k. **(2)**

(Total for Question 1 is 10 marks)

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2 A Ferris wheel cabin of mass 380 kg moves at constant speed in a vertical circle of radius 22 m, completing one revolution every 40 s. Take g = 9.81 m/s^2.

(a) Calculate the angular velocity of the cabin. **(2)**

(b) Calculate the linear speed of the cabin. **(2)**

(c) Calculate the centripetal acceleration of the cabin. **(2)**

(d) Calculate the force exerted by the wheel structure on the cabin at the bottom and at the top of the circle. **(4)**

(Total for Question 2 is 10 marks)

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3 A container of volume 0.020 m^3 holds 5.4 x 10^{24} molecules of nitrogen gas at a pressure of 2.0 x 10^5 Pa. Each nitrogen molecule has a mass of 4.65 x 10^{-26} kg. Use the Physics Equations Sheet where needed ($pV = (1/3) \times N \times m \times \langle c^2 \rangle$; average molecular kinetic energy $E_k = (3/2) \times k \times T$, with the Boltzmann constant k = 1.38 x 10^{-23} J/K).

(a) State two assumptions of the kinetic theory model of an ideal gas. **(2)**

(b) Using $pV = (1/3) \times N \times m \times \langle c^2 \rangle$, calculate the root-mean-square speed of the nitrogen molecules. **(4)**

(c) Using $E_k = (3/2) \times k \times T$, calculate the average translational kinetic energy of a gas molecule at a temperature of 300 K. **(3)**

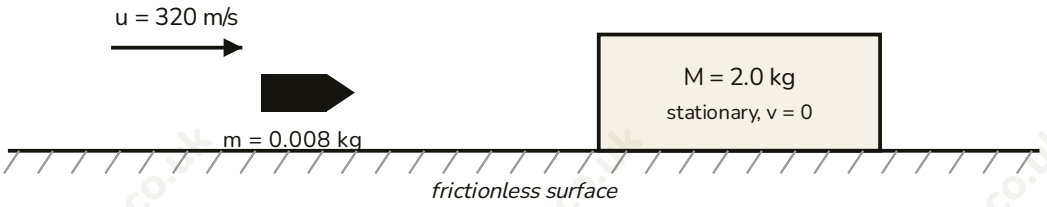
(d) A second container at the same temperature holds hydrogen gas instead of nitrogen. Without further calculation, explain which gas has the higher root-mean-square speed, and why. **(2)**

(Total for Question 3 is 11 marks)

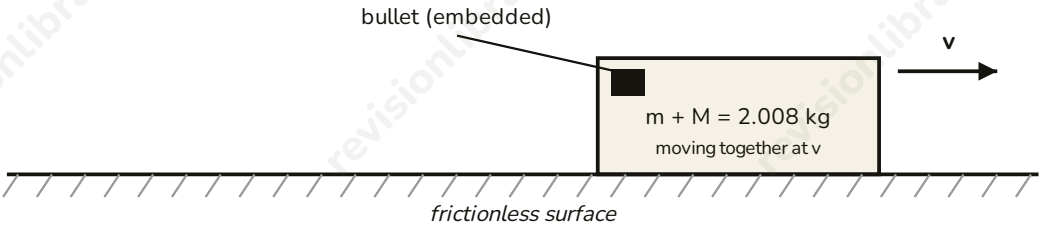
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4 A bullet of mass 8.0 g (0.008 kg) travelling horizontally at 320 m/s embeds itself in a stationary wooden block of mass 2.0 kg that is free to move. Use the Physics Equations Sheet where needed.

Before impact



After impact (bullet embedded in block)



(a) Calculate the common velocity of the bullet and block immediately after the bullet embeds itself in the block. **(3)**

(b) Calculate the kinetic energy of the bullet immediately before the impact, and the kinetic energy of the bullet-block system immediately after the impact. Hence calculate the loss of kinetic energy during the collision. **(3)**

(c) Assume the lost kinetic energy is converted into internal (thermal) energy shared between the bullet and the region of wood it embeds in, with half of this energy absorbed by the bullet. The specific heat capacity of the bullet material is 130 J/(kg K). Estimate the rise in temperature of the bullet. **(3)**

(Total for Question 4 is 9 marks)

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5 REQUIRED PRACTICAL. A student determines g using a simple pendulum. For each length, the time for 20 complete oscillations is measured and divided by 20 to give the period T. The results are given below.

L (m): 0.40, 0.60, 0.80, 1.00

T (s): 1.27, 1.55, 1.79, 2.01

(a) Explain why the student times 20 oscillations and divides by 20, rather than timing a single oscillation. **(2)**

(b) Calculate T^2 for the length L = 1.00 m. **(2)**

(c) Using the data for L = 0.40 m and L = 1.00 m, calculate the gradient of a graph of T^2 (y-axis) against L (x-axis). **(3)**

(d) Given that $T^2 = (4 \pi^2 / g) L$, use your gradient to calculate the experimental value of g. **(2)**

(e) Suggest one reason why this experimental value of g differs from the accepted value of 9.81 m/s^2. **(2)**

(Total for Question 5 is 11 marks)

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Mark scheme · 3.6 Further Mechanics and Thermal Physics: 1-hour Pack

Question 1

(a) use a fiducial marker (fixed reference point) at the equilibrium position, viewed at eye level, to judge when the mass passes through the same point each time and avoid parallax error, oe **B1**

(a) time a large number of oscillations (e.g. 20) rather than one, then divide the total time by the number of oscillations, to reduce the percentage/random error in the period, oe **B1**

(a) repeat each timing (e.g. three times) and calculate a mean value of T, oe **B1**

(a) Answer: Use a fiducial marker to define one full oscillation, time 20 oscillations rather than one and divide by 20, and repeat and average the timings.

(b) gradient = (change in T^2)/(change in m), using the two given data points **M1**

(b) correct substitution: gradient = (1.234 - 0.247)/(0.50 - 0.10) **M1**

(b) gradient = 2.47 s^2/kg (awrt) **A1**

(b) gradient = 4pi^2/k rearranged to k = 4pi^2/gradient, with correct substitution, ft **M1**

(b) k = 16.0 N/m (awrt), cao **A1**

(b) Answer: gradient = 2.47 s^2/kg (approx); k = 16.0 N/m

(c) use a wider range of masses (larger spread of m values), which increases the range spanned by the data and reduces the percentage uncertainty in the gradient, oe **B1**

(c) take measurements at more values of m across the range and draw a line of best fit, rather than using only two points, to average out random error, oe **B1**

(c) Answer: Use a larger range of masses and take more data points, drawing a line of best fit rather than joining just two points, to reduce the percentage uncertainty in the gradient.

Question 2

(a) $\omega = 2\pi / T = 2\pi / 40$ **M1**

(a) ω = 0.157 rad/s cao **A1**

(a) Answer: 0.157 rad/s

(b) v = ω r = 0.157 x 22 **M1**

(b) v = 3.46 m/s cao **A1**

(b) Answer: 3.46 m/s

(c) use $a = \omega^2 r = 0.157^2 \times 22$ (or v^2/r) **M1**

(c) a = 0.543 m/s^2 cao **A1**

(c) Answer: 0.543 m/s^2

(d) at the bottom: N - mg = m a(centripetal), so N = mg + m a **M1**

(d) N(bottom) = 380 x 9.81 + 380 x 0.543 = 3934 N cao **A1**

(d) at the top: mg - N = m a(centripetal), so N = mg - m a **M1**

(d) N(top) = 3728 - 206 = 3522 N cao **A1**

(d) Answer: N(bottom) = 3934 N, N(top) = 3522 N

Question 3

(a) any one correct assumption, e.g. molecules undergo perfectly elastic collisions with each other and the container walls, oe **B1**

(a) any other correct assumption, e.g. the volume of the molecules is negligible compared with the volume of the container; the duration of a collision is negligible compared with the time between collisions; there are negligible intermolecular forces except during collisions; molecules move in continuous random motion, oe (any two distinct assumptions for 2 marks) **B1**

(a) Answer: Any two of: collisions are perfectly elastic; molecular volume is negligible compared to the container volume; collision time is negligible compared to time between collisions; negligible forces between molecules except during collisions; molecules move in continuous random motion.

(b) rearranged correctly to $\langle c^2 \rangle = 3pV/(Nm)$ **M1**

(b) correct substitution of all given values **M1**

(b) $\langle c^2 \rangle = 4.78 \times 10^4$ m^2/s^2 (awrt), ecf allowed to next mark **A1**

(b) $c_{rms} = \sqrt{\langle c^2 \rangle}$ = 219 m/s (awrt), cao, unit given **A1**

(b) Answer: c_{rms} = 219 m/s (3 s.f.)

(c) correct substitution into $E_k = (3/2) \times k \times T$ **M1**

(c) correct arithmetic combination, e.g. $1.5 \times 1.38 \times 10^{-23} = 2.07 \times 10^{-23}$ **M1**

(c) $E_k = 6.21 \times 10^{-21}$ J (awrt), cao, unit given **A1**

(c) Answer: 6.21×10^{-21} J (3 s.f.)

(d) hydrogen has the higher rms speed, oe **B1**

(d) at the same temperature both gases have the same average kinetic energy per molecule ($E_k = (3/2)kT$ depends only on T); since $E_k = 1/2 \times m \times \langle c^2 \rangle$, the much smaller mass of a hydrogen molecule (compared to nitrogen) means $\langle c^2 \rangle$ (and hence rms speed) must be greater to give the same E_k, oe **B1**

(d) Answer: Hydrogen has the higher rms speed, because at the same temperature both gases have equal average molecular kinetic energy, and the lower mass of hydrogen molecules means they must move faster to have the same kinetic energy.

Question 4

(a) conservation of momentum applied: m_bullet x u = (m_bullet + M_block) x v, oe **M1**

(a) correct substitution: 0.008 x 320 = (0.008 + 2.0) x v **M1**

(a) v = 1.27 m/s (awrt), cao **A1**

(a) Answer: 1.27 m/s (3 s.f.)

(b) KE before = $1/2 \times 0.008 \times 320^2$ = 409.6 J (awrt), cao **M1**

(b) KE after = $1/2 \times 2.008 \times v^2$ = 1.63 J (awrt), ft from (a) **M1**

(b) KE loss = 408 J (awrt), ft **A1**

(b) Answer: KE before = 409.6 J; KE after = 1.63 J; KE lost = 408 J (3 s.f.)

(c) energy absorbed by bullet = half of KE loss = 204 J (awrt), ft from (b) **M1**

(c) correct substitution into deltaT = Q/(m x c), using the bullet's mass (0.008 kg) **M1**

(c) deltaT = 196 K (or °C) (awrt), cao, ft **A1**

(c) Answer: Approximately 196 K rise in temperature (3 s.f.)

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Question 5

(a) the fixed reaction-time uncertainty in starting/stopping the stopwatch is spread over a much longer total time **B1**

(a) this reduces the percentage uncertainty in the value obtained for a single period, compared with timing one oscillation directly oe **B1**

(a) Answer: Timing 20 oscillations and dividing by 20 spreads the fixed reaction-time uncertainty of the stopwatch over a much longer total time, reducing the percentage uncertainty in the period of a single oscillation.

(b) $T^2 = 2.01^2$ **M1**

(b) $T^2 = 4.04\ s^2$ cao **A1**

(b) Answer: 4.04 s^2

(c) T^2 at L=0.40 is $1.27^2 = 1.61\ s^2$; T^2 at L=1.00 is $2.01^2 = 4.04\ s^2$ **M1**

(c) gradient = (4.04 - 1.61) / (1.00 - 0.40) **M1**

(c) gradient = 4.05 s^2/m cao **A1**

(c) Answer: 4.05 s^2/m

(d) $g = 4\pi^2$ / gradient **M1**

(d) g = 9.76 m/s^2 cao (accept 9.75 from the rounded gradient 4.05) **A1**

(d) Answer: 9.76 m/s^2 (9.75 m/s^2 if the rounded gradient 4.05 is used)

(e) a valid systematic error, e.g. the amplitude of swing was too large so the small-angle approximation (needed for $T = 2\pi\sqrt{L/g}$) no longer holds accurately; or the length was measured to the centre of the bob incorrectly (e.g. omitting half the bob diameter), giving a consistent error in L; or air resistance/timing reaction delay introduced a small systematic effect oe (1 mark for a plausible source, 1 mark for linking it to the direction/nature of the discrepancy) **B2**

(e) Answer: A plausible cause is a systematic error, such as the pendulum being swung with too large an amplitude (breaking the small-angle approximation used in the formula) or the length being measured incorrectly (e.g. not including the radius of the bob to its centre of mass).

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