3.6 Further Mechanics and Thermal Physics: 30-minute Pack

Total Marks

AQA 7408 · Calculator allowed · about 30 minutes

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 A fixed mass of an ideal gas occupies a volume of 2.40×10^{-3} m^3 at a pressure of 1.05×10^5 Pa and a temperature of 290 K. Use the Physics Equations Sheet where needed ($pV = nRT$, with $R = 8.31$ J/(mol K); $N = n \times N_A$, with $N_A = 6.02 \times 10^{23}$ /mol).

(a) State Boyle's law. **(1)**

(b) The gas is compressed to a volume of 1.60×10^{-3} m^3 and heated to a temperature of 340 K. Using $pV = nRT$, calculate the new pressure of the gas. **(4)**

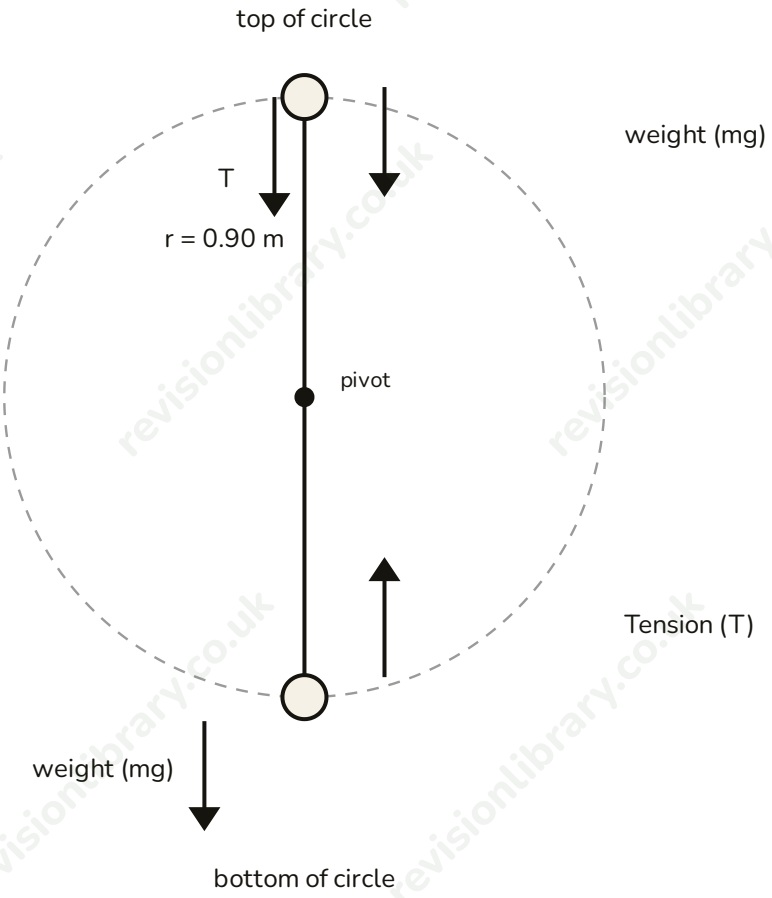
(c) Using the initial conditions ($p = 1.05 \times 10^5$ Pa, $V = 2.40 \times 10^{-3}$ m^3, $T = 290$ K), calculate the number of moles of gas present, and hence the number of gas molecules. **(3)**

(Total for Question 1 is 8 marks)

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2 A bucket of water of mass 0.60 kg is swung in a vertical circle of radius 0.90 m at the end of a light rope. Take g = 9.81 m/s^2. Use the Physics Equations Sheet where needed.

Bucket swung in a vertical circle



(a) State the condition, in terms of the tension in the rope, for the water to just remain in the bucket as it passes the top of the circle. **(1)**

(b) Show that the minimum speed of the bucket at the top of the circle, for the water to just stay in, is about 3.0 m/s. **(3)**

(c) The bucket passes the bottom of the circle with speed 4.5 m/s. Calculate the tension in the rope at this point. **(4)**

(d) State and explain the effect on the tension at the bottom of the circle if the bucket were instead swung faster. **(2)**

(Total for Question 2 is 10 marks)

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3 A footbridge over a river in a town centre is found to sway noticeably when large groups of people cross it walking in step. Engineers are considering two possible modifications: (i) fitting mechanical dampers to the structure, or (ii) redesigning the bridge to change its natural frequency of vibration. Discuss, using your knowledge of forced oscillations, resonance and damping, how each approach would help to reduce unwanted large-amplitude oscillations of the bridge, and evaluate which approach you consider to be more effective.

(Total for Question 3 is 6 marks)

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Mark scheme · 3.6 Further Mechanics and Thermal Physics: 30-minute Pack

Question 1

(a) for a fixed mass of gas at constant temperature, the pressure is inversely proportional to the volume (pV = constant), oe **B1**

(a) Answer: For a fixed mass of gas at constant temperature, pressure is inversely proportional to volume (pV = constant).

(b) recognises that n and R are constant, so p1V1/T1 = p2V2/T2, oe **M1**

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

(b) correctly rearranged to make p2 the subject **M1**

(b) p2 = 1.85 x 10^5 Pa (awrt), cao **A1**

(b) Answer: 1.85 x 10^5 Pa (3 s.f.)

(c) correct substitution into n = pV/RT **M1**

(c) n = 0.105 mol (awrt) **A1**

(c) N = n x N_A = 6.30 x 10^{22} molecules (awrt), ft **A1**

(c) Answer: n = 0.105 mol; N = 6.30 x 10^{22} molecules

Question 2

(a) at the limiting condition, the contact force of the bucket on the water is zero, so weight alone provides the water's centripetal force; in the ideal common-radius model the rope tension is also zero, but it acts on the bucket and is distinct from the contact force on the water, oe **B1**

(a) Answer: Tension = 0 N (weight alone provides the centripetal force)

(b) at minimum speed, mg = mv^2/r (tension = 0), oe **M1**

(b) rearranged to v = $\sqrt{g \times r}$ **M1**

(b) cso: v = $\sqrt{9.81 \times 0.90}$ = 2.97 m/s, rounding to about 3.0 m/s as given **A1**

(b) Answer: v = 2.97 m/s (approx 3.0 m/s, as given)

(c) at the bottom, T - mg = mv^2/r, oe **M1**

(c) centripetal term calculated: mv^2/r = 0.60 x 4.5^2/0.90 = 13.5 N **M1**

(c) weight term calculated: mg = 0.60 x 9.81 = 5.89 N (awrt), and added to centripetal term **M1**

(c) T = 19.4 N (awrt), cao **A1**

(c) Answer: 19.4 N (3 s.f.)

(d) the tension would be greater (increase), oe **B1**

(d) a higher speed requires a greater centripetal force (F = mv^2/r increases with v^2), and this extra force must be provided by additional tension (beyond that supporting the weight), oe **B1**

(d) Answer: Tension increases, because a greater speed requires a greater centripetal force, which the rope must supply in addition to supporting the weight of the bucket.

Question 3

Level 3 A detailed and coherent discussion that explains resonance occurring when the driving frequency (footsteps) matches (or is close to) the natural frequency of the bridge, causing a large amplitude of forced oscillation; explains that dampers increase the degree of damping, dissipating vibrational energy as heat and reducing (and broadening) the amplitude peak at resonance; explains that changing the bridge's natural frequency (e.g. by altering its stiffness or mass) moves the resonant frequency away from typical walking frequencies so resonance is avoided; a reasoned, well-justified evaluation is given comparing the two approaches, using correct physics terminology throughout. **5-6**

Level 2 A reasonable discussion showing understanding of resonance, with at least one of the two modifications (damping or changing natural frequency) explained correctly and linked to a reduction in amplitude; the evaluation may be brief, one-sided, or only partially justified; generally correct physics with some gaps in detail or terminology. **3-4**

Level 1 Basic, largely unlinked statements about resonance and/or damping are made, with limited explanation and little or no reference to the bridge context; no meaningful evaluation attempted. **1-2**

Level 0 No relevant content, or the answer does not relate to the question. **0**

Indicative content:

- Resonance occurs when the frequency of a periodic driving force (the footsteps of people walking in step) matches, or is very close to, the natural frequency of the bridge, producing a maximum amplitude of oscillation.
- With little damping present, the amplitude of oscillation at resonance can become very large, which explains the noticeable swaying.
- Fitting dampers increases the degree of damping in the system, dissipating vibrational energy as heat (internal energy); this reduces the amplitude of oscillation at resonance and broadens (flattens) the resonance peak, so the response is less sensitive to the exact driving frequency.
- Changing the structure (its mass and/or stiffness) alters the bridge's natural frequency, so that it no longer coincides with the typical range of frequencies produced by pedestrians walking, meaning resonance is not driven under normal use.
- Evaluation: changing the natural frequency removes the risk of resonance for expected walking frequencies but may not protect against a wider range of driving frequencies (e.g. running, wind gusts, or unusual crowd behaviour); dampers reduce the amplitude across a whole range of driving frequencies, giving more general protection.
- A well-justified conclusion might argue that using dampers (or a combination of both approaches) is the more robust practical solution, since pedestrian step frequency cannot be precisely controlled, whereas changing natural frequency alone only guards against resonance at one specific frequency.

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