Note that these are answers to the exam questions, not complete solutions. Answers provided to questions requiring explanations do not represent complete solutions, and would not necessarily receive the full marks allocated on the exam paper. Many marks are given on the exam for ‘working’ (i.e. for showing that you understand the relevant physics), and a numerical answer alone is not always sufficient to gain full marks.

**Question 1**

(a) Mass per second = \( \rho Av \)

(b) \( F = \frac{dp}{dt} = \frac{d(mv)}{dt} = \frac{(dm/dt)v}{v} = \rho Av^2. \)

(c) \( 1.84 \times 10^6 \) N.

(d) \( 5.5 \times 10^8 \) W.

(e) \( 1.11 \times 10^6 \) N.

(f) \( 0.26. \) This assumes that the tyres are on the verge of slipping, so that the static friction force takes its maximum possible value.

(g) This is a small value of \( \mu_s. \) Assuming that the tyres do not skid is possibly a bad assumption. Alternatively, perhaps the static friction was not at its maximum value.

**Question 2**

(a) N m rad\(^{-1}\), or (alternatively) kg m\(^2\) s\(^{-2}\) rad\(^{-1}\).

(b) Proof required.

(c) The expression follows from \( \tau = I\alpha \) and \( \tau = -K\theta. \)

(d) Proof required. The appropriate comparison to make here is with the case of a mass oscillating linearly at the end of a spring. Use the expression for the period of oscillation and argue by analogy between the equations \( -K\theta = I\alpha \) and \( -kx = ma. \)

(e) \( 1.4 \times 10^{-4} \) Nm rad\(^{-1}\).

**Question 3**

(a) \( 0.225 \) N.

(b) \( 1.0 \) rad/s.
(c) 0.60 m/s (tangentially!)

(d) \(|a_{\text{total}}| = 0.67\text{m/s}^2\) at an angle of 26.6° from the radial direction. The total (linear) acceleration is the vector sum of the centripetal acceleration and the tangential linear acceleration.

(e) 0.33 rad/s.

**Question 4**

(a) The ‘proper length’ is the length measured in the rest frame of the object being measured. Here, \(L\) is the proper length.

(b) Answer: B.

**Question 5**

(a) Proof required. Use \(E = \gamma E_0 = \gamma m_0 c^2\).

(b) 14.3 mm.

**Question 6**

(a) Proof required. Note that the orbital speed should be \(7.66 \times 10^3\) m/s, and not \(8.3 \times 10^3\) m/s as printed on the exam paper.

(b) 2.40 \(\times\) \(10^{12}\) J.

(c) The change in gravitational energy is \(3 \times 10^{11}\) J.

(d) The total energy required is \(2.7 \times 10^{12}\) J, which is equal to the final kinetic energy plus the increase in gravitational potential energy. This assumes that the initial kinetic energy is zero, which may not be the best assumption. (Why?)

**Question 7**

(a) (i) Proof required. Hint: show that \(\rho_{\text{hot air}} V g = \rho_{\text{air}}, 20^\circ C V g - m_{\text{load}} g\).

(ii) Temperature is 379 K.

(b) (i) 74 N. Remember that atmospheric pressure pushes on both sides of the plug.

(ii) 13.6 litres per second.

**Question 8**

(a) Possible for situations I, II, III but not IV. Explanation required. Use an expression for the allowed frequencies of a wave on a string with two fixed ends, and the fact that the speed of the waves on a string is \(v = \sqrt{T/\mu}\), where \(T\) is the tension and \(\mu\) is the linear mass density.
(b) (i) 5 cm.
(ii) 40 cm.
(iii) 12 m/s.
(iv) 0.033 s.
(v) Either of the following:

\[ y = 5 \cos[(15.7)x + (188)t - 0.64] \]
\[ y = 5 \sin[(15.7)x + (188)t + 0.93], \]

where \( x \) is given in metres and \( t \) is in seconds. Don’t forget the phase shift!

(c) Beat frequency is 156 Hz.

**Question 9**

(a) \( 4.18 \times 10^5 \) J. First, heat the ice from -10\(^\circ\)C to 0\(^\circ\)C. Then, supply energy to change the phase from ice to water (latent heat). Finally, heat to 15\(^\circ\)C.

(b) \( 3.56 \times 10^5 \) J.

(c) \( 2256 \) kJ.

(d) Graph shows a horizontal line (parallel to the V axis) at a pressure of 1 atm, between the initial and final volumes. Note that 1 litre is equivalent to 0.001 m\(^3\).

(e) \( 1.69 \times 10^5 \) J. (Area under the p-V graph.)

(Answers compiled by J.Richmond)