

**Question 1 (Marks 20)**

A car travels in a straight line, with a displacement described by the equation

$$s = 4t^2 + 1, \text{ where } t \text{ is the time, in seconds, and } s \text{ is the car's displacement, in metres.}$$

- (a) Find:
- (i) The displacement of the car at  $t = 0$ ;
  - (ii) The instantaneous velocity of the car at any time  $t$ ;
  - (iii) The instantaneous acceleration of the car at any time  $t$ ;
- (b) How long does it take the car to accelerate to a speed of  $50 \text{ km h}^{-1}$ ?
- (c) What is the car's displacement when it has a speed of  $50 \text{ km h}^{-1}$ ?
- (d) After accelerating to  $50 \text{ km h}^{-1}$ , the car travels with a constant speed around a curve in the road with a radius of 30 m.
- (i) Draw a diagram showing the path of the car around the curve and the direction of the velocity and acceleration vectors of the car at any moment, as it is rounding the curve.
  - (ii) What is the centripetal acceleration of the car as it rounds the curve?
- (e) As the car is rounding the curve, a passenger drops an apple core from the car window. You may neglect air resistance. Assume that the height from which the core is dropped is 1.4 m, and that the passenger drops the apple core with a velocity of zero with respect to the motion of the car.
- (i) With what velocity does the apple core move at the instant it is dropped (relative to the original location of the car)? (*Remember that for a velocity you need to have both a magnitude and a direction.*)
  - (ii) Assume that the apple core does not collide with anything until it hits level ground, after falling 1.4 metres. How long does the apple core take to hit the ground?
  - (iii) How far from the point on the ground where the apple was dropped does it hit the ground?
  - (iv) What is the magnitude and direction of the velocity of the apple core immediately before it hits the ground? Draw a sketch of the  $x$ - and  $y$ - velocity vectors, together with their resultant vector. Clearly mark on your diagram the angle that the resultant makes with the horizontal.

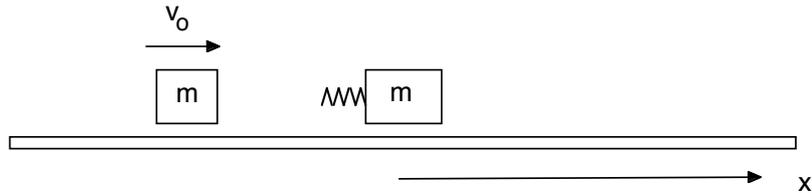
**Question 2 [Marks 10]**

- (a) The Moon's nearly circular orbit about the Earth has a radius of 384,000 km and a period of 27.3 days. Assuming that the Moon's orbit about the Earth is circular:
- Draw a diagram showing the force(s) acting on the Moon due to the gravitational attraction of the Earth.
  - Calculate the acceleration of the Moon, and give the direction of this acceleration.
- (b) A centrifuge rotor has a mass of 0.100 kg, a radius of 0.0500 m, and a moment of inertia of  $1.25 \times 10^{-4} \text{ kg m}^2$ . The rotor is accelerated from rest to 20,000 revolutions per minute in 5.0 minutes.
- Assuming that the acceleration is constant, what is the angular acceleration of the rotor during this period?
  - Calculate the average tangential acceleration of the outer edge of the rotor during this period.
  - Through how many revolutions has the centrifuge rotor turned during its acceleration period?
  - Calculate the rotational kinetic energy of the rotor when it has accelerated and reached its final constant angular velocity of 20,000 revolutions per minute.
  - Calculate the centripetal acceleration of the rotor when it has an angular speed of 10,000 revolutions per minute.
  - Calculate the total acceleration of the rotor when it has an angular speed of 10,000 revolutions per minute. Give both magnitude and direction.

**Question 3 (Marks 20)**

- (i) Under what conditions is mechanical energy conserved?  
(ii) Under what conditions is momentum conserved?

Two small objects with mass  $m$  move without friction or air resistance in the  $x$  direction. (We may imagine them as sliders on an air track apparatus but, as they are small, they may be treated as particles in this question.) To one of them is attached an ideal spring with spring constant  $k$ . Initially, the one on the left travels at  $v_0$  and the other is stationary.



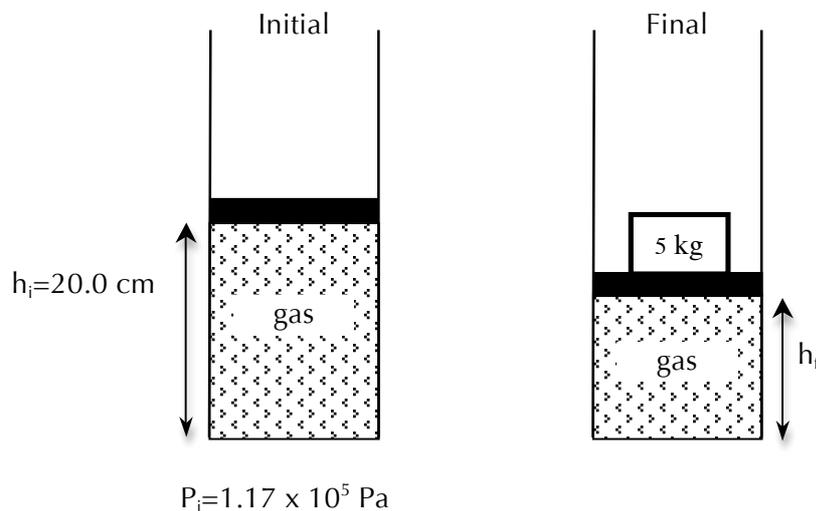
- (iii) Explaining your reasoning, derive an expression for the maximum compression of the spring. (Hint: at the instant when the spring is maximally compressed, what is the relative velocity of the two masses?)
- (iv) After the collision, the particle on the left has velocity  $v$  to the right and that on the right velocity  $V$  to the right. Explaining your reasoning and showing all working, derive expressions for  $V$  and  $v$ .
- (v) How many solutions did you get for part (iv)? In no more than three clear sentences, comment on its/ their significance.
- (vi) State the definition of the centre of mass of a collection of particles. If your definition is an equation, define the terms.
- (vii) Using the definition of centre of mass explicitly, derive an expression for the velocity of the centre of mass of the two mass system for the states before the collision and after the collision.
- (viii) Comment on your answer to part (vii).

**Question 4 [Marks 25]**

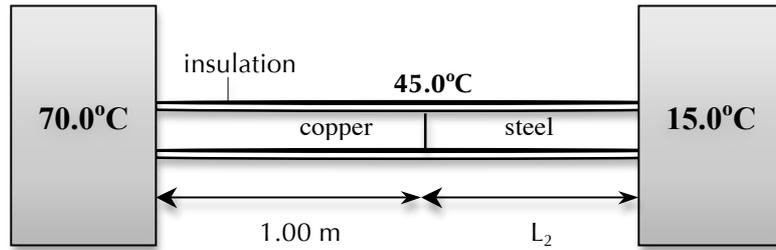
*Specific Heats and Thermal conductivities of selected metals*

Substance	Specific Heat $c$ , ( $\text{Jkg}^{-1}\text{K}^{-1}$ )	Thermal conductivity $k$ , ( $\text{Wm}^{-1}\text{K}^{-1}$ )
Aluminium	910	205.0
Brass	377	109.0
Copper	390	385.0
Lead	130	34.7
Steel	456	50.2

- (a) A piston is set up as shown below. The cylinder is filled with an ideal monatomic gas. The surface area of the piston is  $12.0 \text{ cm}^2$ . The piston is initially  $20.0 \text{ cm}$  above the base of the cylinder and the absolute initial pressure,  $P_i = 1.17 \times 10^5 \text{ Pa}$ .

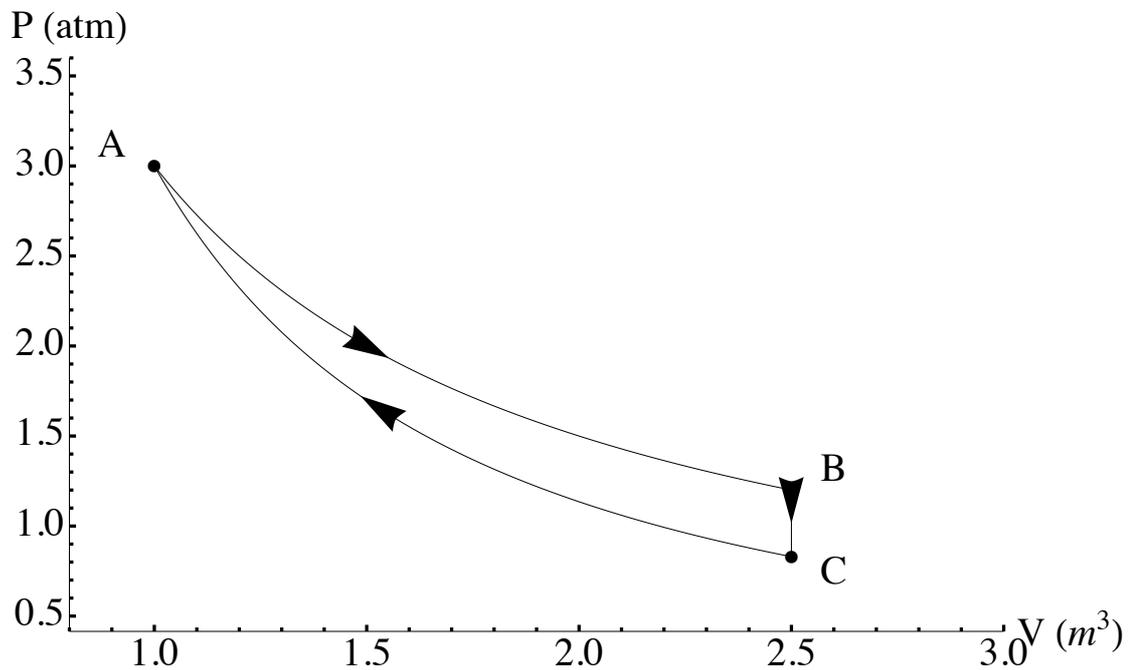


- (i) How many degrees of freedom does the gas filling the cylinder have?
- (ii) What pressure is exerted on the gas when a  $5.00 \text{ kg}$  block is placed on the piston?
- (iii) The piston is left for long enough for it to return to thermal equilibrium with its surroundings, what is the height of the piston above the cylinder?
- (b) A long rod, insulated to prevent heat loss along its sides, has one end maintained at  $70.0^\circ \text{C}$  and the other end at  $15.0^\circ \text{C}$ . The rod consists of a  $1.00 \text{ m}$  section of copper (with one end at  $70.0^\circ \text{C}$ ) joined end to end to a length  $L_2$  of steel. Both sections of the rod have cross sectional areas of  $10.00 \text{ cm}^2$ . The temperature of the copper-steel junction is  $45.0^\circ \text{C}$  after a steady state has been set up.



The diagram is not to scale.

- (i) What is the rate of heat flow from the hot end of the rod to the cold end?
- (ii) What is the length  $L_2$  of the steel section?
- (c) The figure shows a thermodynamic process followed by an ideal diatomic gas. Process  $A \rightarrow B$  is isothermal with  $278\text{ kJ}$  of heat energy entering the system, process  $B \rightarrow C$  is isovolumetric with  $233\text{ kJ}$  of heat energy leaving the system and process  $C \rightarrow A$  is adiabatic. Point A has  $V = 1.0\text{ m}^3$  and  $P = 3.0\text{ atm}$ , point B has  $V = 2.5\text{ m}^3$  and  $P = 1.2\text{ atm}$  and point C has  $V = 2.5\text{ m}^3$  and  $P = 0.83\text{ atm}$ .



- (i) What is the change in internal energy as the gas goes from A to B?
- (ii) What is the change in internal energy as the gas goes from B to C?
- (iii) How much work is done on the gas as it goes from C to A?

**Question 5 [Marks 25]**

- (a) A 5.00 kg block is attached to a spring with spring constant  $k = 125 \text{ N/m}$ . The block is pulled from its equilibrium position at  $x = 0$  to a position at  $x = +0.687 \text{ m}$  and released from rest. The block then executes simple harmonic motion along the  $x$ -axis. Showing all your reasoning, calculate:
- The magnitude of the acceleration of the block upon release at  $x = +0.687 \text{ m}$
  - The period of the oscillations
  - The work done by the spring force between  $x = 0.687 \text{ m}$  and  $x = 0$
  - Sketch a displacement time graph for two oscillations showing how the position of the block varies with time. Include numbers on your axes.
  - On the same graph sketch what would happen if a small damping force, proportional to the velocity, was applied to the spring.
- (b) Two loudspeakers S1 and S2, placed 5.0 m apart, are driven in phase by an audio oscillator. A boy stands at point P, which is 12.0 m from S1 and 13.0 m from S2. A right angle triangle is formed by P, S1 and S2. The wave from S2 arrives at point P two periods later than the wave from S1. The speed of sound is 350 m/s.
- Calculate the frequency of the oscillator
  - The boy walks away from S1 along the S1-P line, until destructive interference occurs. At that point the wave from S2 arrives 1.5 periods later than the wave from S1. Set up an equation (but do not solve it) to calculate the new distance of the boy from S1.
- (c) A man is travelling on a bicycle at 10.0 m/s along a straight road that runs close to and parallel to railroad tracks. He hears the whistle of a train that is behind him. The frequency of the train whistle is 600 Hz, but the frequency the man hears is 558 Hz. Take velocity of sound to be 340 m/s.
- What frequency is heard by a stationary observer, located between the train and the man on the bicycle?
  - What is the speed of the train and is it travelling towards or away from the man on the bicycle?