3.5 Further Mechanics: Momentum, Impulse and Collisions Depth: 30-minute Pack

EDEXCEL 9FM0 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

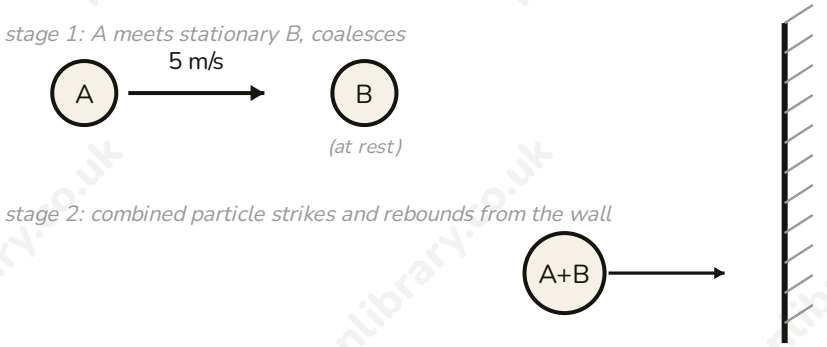
Key results: momentum, impulse and Newton's law of restitution

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Unless a question states otherwise, take g = 9.8 m/s^2, model each object as a particle, and take all strings as light and inextensible, all pulleys and surfaces as smooth, and all spheres as smooth (so there is no friction, and no tangential impulse, at any point of contact). The impulse-momentum principle states that the impulse J exerted on a particle of mass m equals its change in momentum, J = m*(v - u); when a force F varies with time t, the impulse delivered over an interval is the integral of F with respect to t over that interval. Provided no external horizontal force acts on a system of colliding or jerked particles, total momentum is conserved: m1*u1 + m2*u2 = m1*v1 + m2*v2, with velocities signed along the line of centres (or along the string). Newton's experimental law of restitution states that the speed of separation is e times the speed of approach, v2 - v1 = -e*(u2 - u1), where 0 <= e <= 1 is the coefficient of restitution between the two surfaces; e = 1 gives a perfectly elastic collision (no kinetic energy lost) and e = 0 gives a perfectly inelastic collision (the particles coalesce, or move off together immediately after a string jerks taut). The loss in kinetic energy due to a direct collision is m1*m2*(1-e^2)*(u1-u2)^2 / (2*(m1+m2)). When a sphere strikes a fixed smooth surface obliquely, the component of its velocity parallel to the surface is unchanged by the impact, while the component perpendicular to the surface obeys Newton's law of restitution.

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1 A particle A of mass 3 kg, moving with speed 5 m/s, collides directly with a stationary particle B of mass 2 kg, and the two particles coalesce on impact to form a single combined particle. This combined particle then travels on and strikes a fixed smooth wall at right angles, rebounding with coefficient of restitution 0.4 between the combined particle and the wall.



(a) Find the common speed of the combined particle immediately after the first collision (with B). **(2)**

(b) Find the speed of the combined particle immediately after it rebounds from the wall. **(2)**

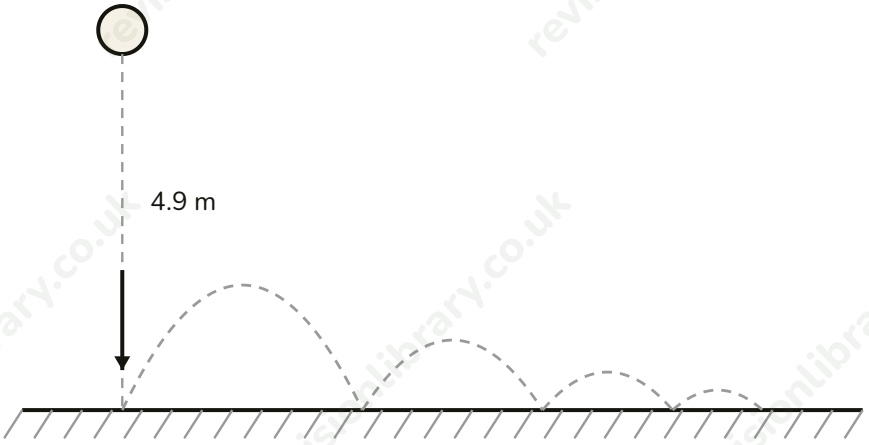
(c) Find the total loss in kinetic energy, from immediately before the first collision to immediately after the rebound from the wall. **(3)**

(d) Find, to 3 significant figures, the percentage of the original kinetic energy that has been lost overall. **(2)**

(Total for Question 1 is 9 marks)

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2 A ball is released from rest at a height of 4.9 m above smooth horizontal ground and allowed to bounce repeatedly. The coefficient of restitution between the ball and the ground is e = 0.5. Air resistance is negligible, and g = 9.8 m/s^2 throughout this question.



(a) Show that the ball takes exactly 1 second to fall to the ground for the first time, and find its speed immediately before this first impact. **(3)**

(b) Show that the time taken for the ball to rise to its highest point after the nth bounce, and fall back to the ground again, is $2*e^n$ seconds. **(3)**

(c) Hence find, as an exact number of seconds, the total time from the ball's release until it comes to rest. **(3)**

(Total for Question 2 is 9 marks)

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3 A particle P of mass 7 kg is moving with speed 9 m/s along a smooth horizontal straight line. It collides directly with a particle Q of mass 3 kg, which is moving along the same line with velocity -8 m/s (a negative value means moving in the opposite direction to P). After the collision P and Q coalesce.

(a) Find the common velocity of the combined particle after the collision. **(3)**

(b) Find the magnitude of the impulse exerted by Q on P. **(2)**

(c) Find the kinetic energy lost in the collision. **(3)**

(d) The contact between P and Q lasts 0.5 s. Find the magnitude of the average force between them, to 3 significant figures. **(2)**

(Total for Question 3 is 10 marks)

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Mark scheme · 3.5 Further Mechanics: Momentum, Impulse and Collisions Depth: 30-minute Pack

Question 1

(a) momentum equation: 3(5) + 2(0) = (3+2)v **M1**

(a) v = 3 m/s, cao **A1**

(a) Answer: 3 m/s

(b) speed after = e x (speed before) = 0.4 x 3, using their speed from part (a) (ft) **M1**

(b) 1.2 m/s (moving away from the wall), cao **A1**

(b) Answer: 1.2 m/s, away from the wall

(c) KE initial (before any collision) = $0.5(3)(5^2)$, since B is at rest **M1**

(c) KE final (after the wall rebound) = $0.5(5)(1.2^2)$, using their speeds from parts (a) and (b) (ft) **M1**

(c) total loss = 37.5 - 3.6 = 33.9 J, cao **A1**

(c) Answer: 33.9 J

(d) percentage = (33.9/37.5) x 100, using their total loss from part (c) (ft) **M1**

(d) 90.4% (awrt 3 s.f.), cao **A1**

(d) Answer: 90.4% (3 s.f.)

Question 2

(a) uses $h = 0.5*g*t^2$ with h=4.9, g=9.8, i.e. $4.9 = 4.9*t^2$ **M1**

(a) t = 1 s, cso **A1**

(a) speed = g*t = 9.8*1 = 9.8 m/s, cao **A1**

(a) Answer: t = 1 s; speed = 9.8 m/s

(b) recognises the speed immediately after the nth bounce is e^n x 9.8, since each bounce multiplies the impact speed by e, starting from the first impact speed of 9.8 m/s **M1**

(b) uses the fact that, in free flight under gravity with no resistance, the time to rise to the peak equals the time to fall back, so the total flight time is 2 x (speed just after the bounce)/g **M1**

(b) = $2*(e^n*9.8)/9.8 = 2*e^n$ seconds, cso **A1**

(b) Answer: Time between the nth and (n+1)th bounce = $2*e^n$ seconds

(c) total time = (time of first fall) + sum from n=1 to infinity of $2*e^n$, using their results from parts (a) and (b) (ft) **M1**

(c) recognises this as an infinite geometric series with first term 2e and common ratio e, and uses sum to infinity = 2e/(1-e) **M1**

(c) total time = 1 + 2(0.5)/(1-0.5) = 1+2 = 3 seconds, cao **A1**

(c) Answer: Total time = 3 seconds

Question 3

(a) conservation of momentum: m1 u1 + m2 u2 = (m1 + m2) v **M1**

(a) 63 + (-24) = 10v **A1**

(a) v = 39/10 m/s **A1**

(a) Answer: 39/10 m/s

(b) change of momentum of P **M1**

(b) 7(39/10 - 9) = -357/10 N s **A1**

(b) Answer: 357/10 N s

(c) KE before - KE after **M1**

(c) 759/2 - 1521/20 **A1**

(c) 6069/20 J **A1**

(c) Answer: 6069/20 J

(d) force = impulse/time **M1**

(d) 71.4 N **A1**

(d) Answer: 71.4 N

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