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INTERNATIONAL A LEVEL MATHEMATICS • MECHANICS 2

Mechanics 2

Exam Questions by Topic

Pearson Edexcel International Advanced Level (WME02/01) • Calculator allowed • Take $g = 9.8\,\text{m}\,\text{s}^{-2}$

Multi-step exam questions at the difficulty of the real WME02 paper, with a full mark scheme

Chapters (tap a chapter to jump to it)		Qs	Marks	Page	My score
1	**Projectiles** Horizontal projection, projection at any angle, the equation of the path	10	84	2	
2	**Variable Acceleration** Calculus for motion in a line and in $\mathbf{i}, \mathbf{j}$ form	10	85	28	
3	**Centres of Mass** Particles, laminas, frameworks, suspended and tilting bodies	10	81	54	
4	**Work and Energy** Work done, kinetic and potential energy, the work–energy principle, power	10	82	80	
5	**Impulses and Collisions** Impulse as a vector, Newton's law of restitution, loss of kinetic energy	10	82	106	
6	**Statics of Rigid Bodies** Rods and ladders in equilibrium, friction, hinge forces	10	81	132	

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CHAPTER 1 • KEY SKILLS

1 Projectiles

Specification M2: Projectiles • 10 questions • 84 marks • about 101 minutes

1 Components

Speed U at angle α above the horizontal: $U\cos\alpha$ across and $U\sin\alpha$ up. $\tan\alpha = \frac{3}{4}$ gives $\cos\alpha = \frac{4}{5}$, $\sin\alpha = \frac{3}{5}$

2 Horizontal motion

No horizontal force: the horizontal velocity stays $U\cos\alpha$, so $x = (U\cos\alpha)t$

3 Vertical motion

Acceleration $9.8\,\text{m s}^{-2}$ downwards: use suvat with up positive and $a = -9.8$. A point below the start has $s < 0$

4 Time of flight

Set the vertical displacement equal to its final value and solve for t in one equation. Reject the negative root.

5 Greatest height

The vertical component of velocity is zero at the top: $0 = (U\sin\alpha)^2 - 2gh$. The speed there is $U\cos\alpha$, not 0.

6 Velocity at an instant

$v_x = U\cos\alpha$, $v_y = U\sin\alpha - gt$. Speed $= \sqrt{v_x^2 + v_y^2}$; direction $\tan\theta = \frac{|v_y|}{v_x}$, above or below the horizontal.

7 Speed conditions

Speed $\leqslant k$ means $v_y^2 \leqslant k^2 - v_x^2$, a condition on the vertical component only.

8 Equation of the path

$y = x\tan\alpha - \frac{gx^2}{2U^2\cos^2\alpha}$ and $\frac{1}{\cos^2\alpha} = \sec^2\alpha = 1 + \tan^2\alpha$ give a quadratic in $\tan\alpha$

9 Vectors

Velocity $(p\mathbf{i} + q\mathbf{j})$: horizontal part p, vertical part q. Perpendicular directions: gradients multiply to -1

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	7	6	6	6	7	11	10	10	10	11
1 Components		•		•		•	•	•	•	
2 Horizontal motion	•	•	•		•		•	•	•	•
3 Vertical motion	•	•	•	•		•	•		•	•
4 Time of flight	•	•				•			•	•
5 Greatest height		•		•		•			•	
6 Velocity at an instant	•		•	•		•	•			•
7 Speed conditions				•						
8 Equation of the path					•			•		
9 Vectors			•			•				•
Interleaved: constant acceleration and vectors (M1)	•		•			•	•			•
Interleaved: quadratics and inequalities (P1)				•	•	•		•		•
Interleaved: trigonometric identities, exact values (P2, P3)		•			•			•	•	

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. Write R(→) and R(↑) before each equation and keep up as positive. Take $g = 9.8\,\text{m s}^{-2}$ and give answers to 2 or 3 significant figures, not as fractions. A speed is a magnitude; a direction needs an angle and a reference line.

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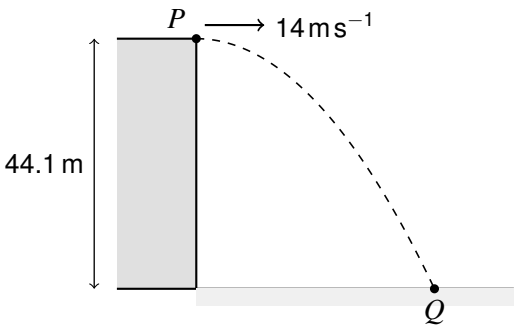

Figure 1

A stone is thrown horizontally with speed $14\,\text{m}\,\text{s}^{-1}$ from a point P at the top of a vertical cliff. The point P is 44.1 m above the sea. The stone hits the sea at the point Q, as shown in Figure 1. The stone is modelled as a particle moving freely under gravity.

(a) Find the time taken by the stone to travel from P to Q.

(2)

(b) Find the horizontal distance from the foot of the cliff to Q.

(1)

(c) Find the speed of the stone as it hits the sea, and the angle its direction of motion makes with the horizontal at this instant.

(4)

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Question 1 continued

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(Total for Question 1 is 7 marks)

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2. A ball is projected from a point O on horizontal ground with speed $35\,\text{m}\,\text{s}^{-1}$ at an angle of elevation α, where $\tan\alpha = \frac{3}{4}$. The ball moves freely under gravity until it hits the ground at the point A.

(a) Find the greatest height above the ground reached by the ball.

(3)

(b) Find the distance OA.

(3)

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Question 2 continued

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3. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are horizontal and vertically upward unit vectors respectively.]*

A particle P is projected from a fixed point O with velocity $(9.8\mathbf{i} + 14.7\mathbf{j})\,\text{m s}^{-1}$ and moves freely under gravity.

(a) Find the time after projection at which P is moving in a direction 45° below the horizontal.

(3)

(b) Find the position vector of P relative to O at this time.

(3)

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Question 3 continued

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4. A particle is projected from a point on horizontal ground with speed $30\,\text{m}\,\text{s}^{-1}$ at an angle of 60° above the horizontal, and moves freely under gravity until it hits the ground.

(a) Find the least speed of the particle during its flight.

(2)

(b) Find the length of time for which the speed of the particle is less than or equal to $25\,\text{m}\,\text{s}^{-1}$

(4)

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Question 4 continued

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(Total for Question 4 is 6 marks)

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5. A particle is projected from a point O with speed U at an angle α above the horizontal and moves freely under gravity. When the particle has moved a horizontal distance x from O, its height above O is y.

(a) Show that $y = x\tan\alpha - \frac{gx^2}{2U^2}\left(1+\tan^2\alpha\right)$

(4)

A particle is projected from O with speed $28\,\text{m}\,\text{s}^{-1}$ and passes through the point which is 40 m horizontally from O and 10 m above O.

(b) Find the two possible values of α, giving your answers to the nearest 0.1°

(3)

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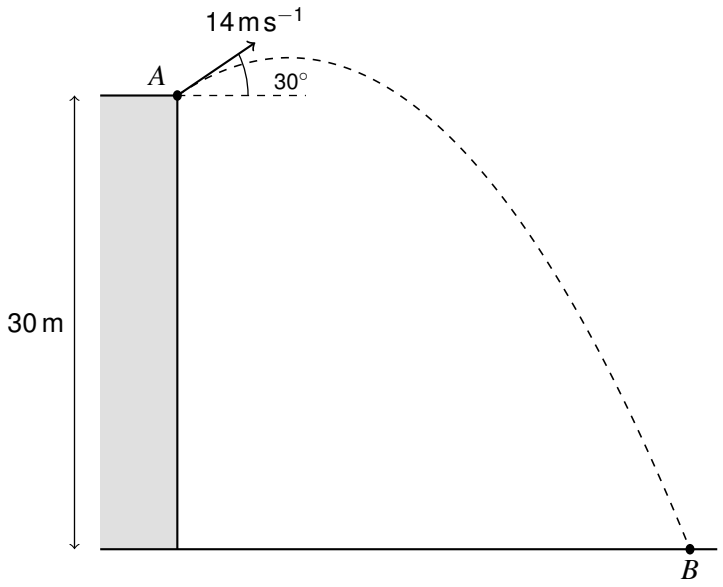

Figure 2

A ball is projected from a point A which is 30 m above horizontal ground, with speed 14 m s^{-1} at an angle of 30° above the horizontal. The ball moves freely under gravity and hits the ground at the point B, as shown in Figure 2.

(a) Find the greatest height above the ground reached by the ball.

(2)

(b) Find the time taken by the ball to travel from A to B.

(3)

(c) Show that the ball hits the ground with speed 28 m s^{-1}

(2)

At the point C on its path, the ball is moving perpendicular to its initial direction of motion.

(d) Find the height of C above the ground.

(4)

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Question 6 continued

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Question 6 continued

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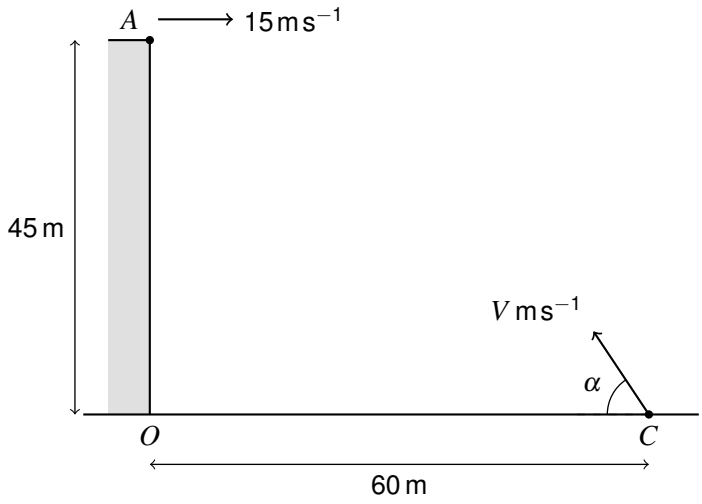

Figure 3

A ball A is projected horizontally with speed $15\,\text{m s}^{-1}$ from the top of a vertical tower OA of height 45 m. At the same instant, a second ball B is projected from the point C on horizontal ground, where $OC = 60$ m, with speed $V\,\text{m s}^{-1}$ at an angle α above the horizontal, towards the tower, as shown in Figure 3. The balls move freely under gravity in the same vertical plane and collide 2 s after they are projected.

(a) Find the height above the ground at which the balls collide.

(2)

(b) By considering the horizontal motion of the balls, show that $V\cos\alpha = 15$

(2)

(c) Find the value of V and the value of α.

(4)

(d) Determine whether B is moving upwards or downwards at the instant of the collision.

(2)

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Question 7 continued

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Question 7 continued

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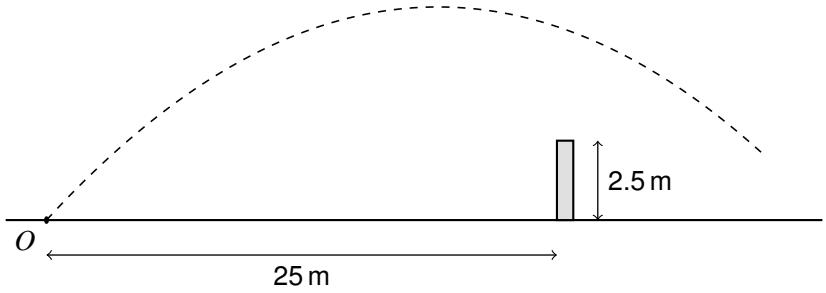

Figure 4

A ball is kicked from a point O on horizontal ground with speed $20\,\text{m}\,\text{s}^{-1}$ at an angle α above the horizontal. A vertical wall of height 2.5 m stands 25 m from O, as shown in Figure 4. The ball moves freely under gravity in a vertical plane perpendicular to the wall, and the wall is modelled as having no thickness.

(a) Show that, when the ball is a horizontal distance x m from O, its height y m above the ground is given by

$$y = x\tan\alpha - \frac{49x^2}{4000}\left(1+\tan^2\alpha\right)$$

(3)

(b) Show that the ball passes over the wall only if $49\tan^2\alpha - 160\tan\alpha + 65 < 0$

(4)

(c) Hence find the range of values of α for which the ball passes over the wall, giving the limits to the nearest 0.1°

(3)

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Question 8 continued

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Question 8 continued

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9. A particle is projected from a point O on horizontal ground with speed U at an angle α above the horizontal, where $0 < \alpha < \frac{\pi}{2}$. It moves freely under gravity until it hits the ground.

(a) Show that the time of flight is $\dfrac{2U\sin\alpha}{g}$

(2)

(b) Show that the horizontal distance from O to the point where the particle lands is $\dfrac{U^2\sin 2\alpha}{g}$

(2)

A stone is thrown from O with speed $21\,\text{m}\,\text{s}^{-1}$ and lands 22.5 m from O.

(c) Find the two possible angles of projection.

(3)

(d) Show that the ratio of the greatest heights reached for these two angles is $\left(7-4\sqrt{3}\right) : 1$

(3)

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Question 9 continued

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Question 9 continued

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10. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are horizontal and vertically upward unit vectors respectively.]*

Two particles P and Q are projected at the same instant from a point O on horizontal ground. The initial velocity of P is $(3\mathbf{i}+12\mathbf{j})\,\mathrm{m\,s^{-1}}$ and the initial velocity of Q is $(2\mathbf{i}+4\mathbf{j})\,\mathrm{m\,s^{-1}}$. The particles move freely under gravity, and each comes to rest when it hits the ground.

(a) Find the distance between P and Q at the instant Q hits the ground.

(4)

(b) Show that the directions of motion of P and Q are perpendicular when $(9.8t)^2 - 16(9.8t) + 54 = 0$, where t seconds is the time after projection.

(4)

(c) Hence find the time at which the directions of motion of P and Q are perpendicular, explaining why only one root of the equation in part (b) is valid.

(3)

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Question 10 continued

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Question 10 continued

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TOTAL FOR CHAPTER 1 IS 84 MARKS

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CHAPTER 2 • KEY SKILLS

2 Variable Acceleration

Specification M2: Variable acceleration • 10 questions • 85 marks • about 102 minutes

1 Differentiating

$v = \frac{dx}{dt}$ and $a = \frac{dv}{dt}$. Go down from displacement to velocity to acceleration.

2 Integrating

$v = \int a\,dt$ and $x = \int v\,dt$. Find each constant from the given conditions at once.

3 Rest and turning

At rest: $v = 0$. The particle changes direction where v changes sign. Solve the quadratic with working shown.

4 Distance travelled

Split the time at each instant of rest and add the sizes of the displacements: distance is never negative.

5 Greatest speed

Greatest or least velocity where $a = 0$; also check the end points of the interval. Speed is $|v|$.

6 Vectors

Differentiate or integrate each component separately. The constant of integration is a vector, e.g. $\mathbf{c} = 2\mathbf{i} + \mathbf{j}$

7 Direction of motion

The direction of motion is the direction of $\mathbf{v}$, not $\mathbf{r}$. Parallel to $\mathbf{i}$: the $\mathbf{j}$ part of $\mathbf{v}$ is 0.

8 Magnitudes and forces

Speed $= |\mathbf{v}|$; $\mathbf{F} = m\mathbf{a}$. Give a vector when a vector is asked for, and a magnitude when a magnitude is asked for.

9 Constant acceleration

suvat comes from integrating a constant a. It must not be used when the acceleration depends on t.

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	7	6	6	7	6	11	11	10	10	11
1 Differentiating	•		•				•	•	•	
2 Integrating		•		•	•	•	•	•	•	•
3 Rest and turning	•					•				
4 Distance travelled	•	•				•		•	•	
5 Greatest speed		•				•		•	•	
6 Vectors			•	•			•			•
7 Direction of motion			•				•			
8 Magnitudes and forces			•	•			•			•
9 Constant acceleration					•					
Interleaved: quadratics and cubics, factor theorem (P1, P2)	•					•	•			•
Interleaved: exponentials, logarithms and chain rule (P3)								•	•	
Interleaved: $F = ma$ and relative position (M1)							•			•

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. When the acceleration depends on t, use calculus, never suvat: suvat earns no marks. Include and find every constant of integration. Read whether a vector or a magnitude is asked for.

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1. A particle P moves along a straight line. At time t seconds, $t \geqslant 0$, the displacement of P from a fixed point O on the line is x metres, where

$$x = t^3 - 9t^2 + 24t$$

(a) Find the values of t when P is instantaneously at rest.

(3)

(b) Find the acceleration of P when $t = 5$

(1)

(c) Find the total distance travelled by P in the interval $0 \leqslant t \leqslant 4$

(3)

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Question 1 continued

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2. A particle P moves along a straight line. At time t seconds, the acceleration of P is $(6-2t)\,\mathrm{m\,s^{-2}}$, in the direction of increasing x. When $t = 0$, P is at the point O and is moving with velocity $5\,\mathrm{m\,s^{-1}}$ in the direction of increasing x.

(a) Find the greatest velocity of P in the interval $0 \leqslant t \leqslant 6$

(3)

(b) Find the displacement of P from O when $t = 6$

(3)

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Question 2 continued

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3. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are perpendicular horizontal unit vectors and position vectors are given relative to a fixed origin* O*.]*

A particle P moves in a horizontal plane. At time t seconds, the position vector of P is $\mathbf{r}$ metres, where

$$\mathbf{r} = \left(t^3 - 3t\right)\mathbf{i} + \left(2t^2 - 8t\right)\mathbf{j}$$

(a) Find the velocity of P at the instant when P is moving parallel to the vector $\mathbf{i}$

(3)

(b) Find the acceleration of P at this instant.

(2)

(c) Find the speed of P when $t = 0$

(1)

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Question 3 continued

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4. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are horizontal unit vectors directed due east and due north respectively, and position vectors are given relative to a fixed origin* O*.]*

A remote-controlled boat is modelled as a particle B moving on the surface of a lake. At time t seconds after it is switched on, its acceleration is $(6t\mathbf{i} - 4\mathbf{j})\,\text{m s}^{-2}$. When $t = 0$, B has velocity $(-3\mathbf{i} + 8\mathbf{j})\,\text{m s}^{-1}$ and is at the point with position vector $(2\mathbf{i} + \mathbf{j})\,\text{m}$.

(a) Find an expression for the velocity of B at time t seconds.

(2)

(b) Find the time at which B is moving due north.

(2)

(c) Find the distance of B from O when $t = 3$

(3)

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Question 4 continued

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5. A particle moves along a straight line with constant acceleration $a\,\text{m s}^{-2}$. At time $t = 0$ it passes through a fixed point O on the line with velocity $u\,\text{m s}^{-1}$. At time t seconds its velocity is $v\,\text{m s}^{-1}$ and its displacement from O is s metres.

(a) By integration, show that $v = u + at$ and $s = ut + \frac{1}{2}at^2$

(4)

(b) Hence show that $v^2 = u^2 + 2as$

(1)

(c) Explain why these formulae cannot be used for a particle whose acceleration at time t seconds is $3t\,\text{m s}^{-2}$

(1)

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Question 5 continued

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6. A particle P moves along a straight line. At time t seconds, $t \geqslant 0$, the acceleration of P is $(2t-7)\,\text{m s}^{-2}$. When $t = 0$, P is at the point O and is moving with velocity $10\,\text{m s}^{-1}$

(a) Show that the velocity of P at time t seconds is $\left(t^2 - 7t + 10\right)\,\text{m s}^{-1}$

(2)

(b) Find the values of t when P is instantaneously at rest.

(2)

(c) Find the total distance travelled by P in the interval $0 \leqslant t \leqslant 6$

(5)

(d) Find the greatest speed of P in the interval between the two times when it is at rest.

(2)

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Question 6 continued

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7. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are perpendicular horizontal unit vectors and position vectors are given relative to a fixed origin* O*.]*

A particle P of mass 2 kg moves in a horizontal plane. At time t seconds, $t \geqslant 0$, the velocity of P is $\mathbf{v}\,\text{m s}^{-1}$, where

$$\mathbf{v} = (t+1)\mathbf{i} + \left(t^2 - 5\right)\mathbf{j}$$

(a) Find the magnitude of the resultant force acting on P when $t = 2$

(3)

(b) Find the speed of P at the instant when it is moving in the direction of the vector $(\mathbf{i} + \mathbf{j})$

(4)

When $t = 0$, P is at O.

(c) Find the distance of P from O at the instant, after $t = 0$, when P crosses the line through O parallel to $\mathbf{i}$

(4)

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Question 7 continued

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Question 7 continued

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8. A cyclist starts from rest at the point O and moves along a straight horizontal road. At time t seconds after leaving O, the speed of the cyclist is $v\,\text{m s}^{-1}$, where

$$v = 6 - 6e^{-\frac{1}{2}t}$$

The cyclist is modelled as a particle.

(a) Find the acceleration of the cyclist when $t = 0$

(2)

(b) Explain why the speed of the cyclist is always less than $6\,\text{m s}^{-1}$

(1)

(c) Find the distance travelled by the cyclist in the first 4 seconds.

(4)

(d) Find the exact time at which the speed of the cyclist is $5\,\text{m s}^{-1}$

(2)

(e) State one limitation of this model of the motion of the cyclist.

(1)

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Question 8 continued

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9. A particle P moves along a straight line, starting from rest at the point O at time $t = 0$. At time t seconds, the velocity of P is $v\,\text{m s}^{-1}$, where

$$v = \begin{cases} 4t - t^2 & 0 \leqslant t \leqslant 3 \\ \dfrac{27}{t^2} & t > 3 \end{cases}$$

(a) Find the greatest speed of P in the interval $0 \leqslant t \leqslant 3$

(2)

(b) Show that the acceleration of P does not change suddenly at $t = 3$

(2)

(c) Find the distance travelled by P from $t = 0$ to $t = 6$

(4)

(d) Show that P never reaches the point which is 18 m from O.

(2)

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Question 9 continued

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10. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are perpendicular horizontal unit vectors and position vectors are given relative to a fixed origin* O*.]*

At time t seconds, $t \geqslant 0$, the velocity of a particle P is $\left[\left(3t^2 - 4\right)\mathbf{i} + 2t\mathbf{j}\right]$ m s^{-1}, and P is at O when $t = 0$. A second particle Q moves with constant velocity $(3\mathbf{i} + \mathbf{j})$ m s^{-1} and is at the point with position vector $(-6\mathbf{i} + 2\mathbf{j})$ m when $t = 0$.

(a) Find the position vector of P at time t seconds.

(3)

(b) Show that P and Q collide, and find the position vector of the point of collision.

(4)

(c) Show that P and Q have the same $\mathbf{i}$ component of position when $t = 1$, and find the distance between them at this time.

(2)

(d) Find the speed of P at the instant of the collision.

(2)

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Question 10 continued

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TOTAL FOR CHAPTER 2 IS 85 MARKS

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CHAPTER 3 • KEY SKILLS

3 Centres of Mass

Specification M2: Centres of mass • 10 questions • 81 marks • about 97 minutes

1 Particles

$\bar{x} = \frac{\sum mx}{\sum m}$ and $\bar{y} = \frac{\sum my}{\sum m}$, or $\bar{\mathbf{r}} = \frac{\sum m\mathbf{r}}{\sum m}$. Coordinates must be measured from the same origin.

2 Standard laminas

Rectangle: its centre. Triangle: $\frac{2}{3}$ of the way along a median from the vertex. Semicircle: $\frac{4r}{3\pi}$ from the diameter.

3 Composite laminas

Mass $\propto$ area for a uniform lamina. Make a table of masses and distances; a removed part has a negative mass.

4 Frameworks

For uniform rods or wire, mass $\propto$ length, acting at each midpoint. Do not assume rods have equal masses.

5 Different densities

Mass = (mass per unit area) $\times$ area. Attached particles add their own mass at their own point.

6 Freely suspended

The centre of mass hangs vertically below the point of suspension: find the angle from $\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$

7 Extra forces

Take moments about the point of suspension. Distances are measured perpendicular to each force's line of action.

8 Toppling

On the point of toppling about a corner, the centre of mass is vertically above that corner: $\tan\theta = \frac{\bar{x}}{\bar{y}}$ from that corner.

9 Symmetry

Use an axis of symmetry for one coordinate and moments for the other, and state which you used.

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	6	6	6	6	6	10	10	10	10	11
1 Particles	•		•	•				•		
2 Standard laminas		•		•		•	•		•	•
3 Composite laminas		•			•	•	•		•	•
4 Frameworks			•					•		
5 Different densities				•			•	•		
6 Freely suspended				•		•	•	•	•	
7 Extra forces						•	•			
8 Toppling					•					•
9 Symmetry		•			•	•	•		•	
Interleaved: moments and friction (M1)						•	•	•		•
Interleaved: trigonometry and exact values (P1, P2)				•	•	•		•	•	•
Interleaved: straight lines and algebra (P1)	•	•	•					•	•	

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. Mark your axes on the diagram and keep every term in terms of a. Use a table of mass ratios and distances. For a hanging body, draw the line from the point of suspension to the centre of mass and say which angle you have found.

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1. Three particles of masses 2 kg, 3 kg and 5 kg are placed at the points with coordinates $(1, 2)$, $(4, -1)$ and (p, q) respectively. The centre of mass of the three particles is at the point $(3, 1)$.

(a) Find the value of p and the value of q.

(4)

A fourth particle, of mass M kg, is placed at the origin.

(b) Show that, for every value of M, the centre of mass of the four particles lies on the line $x = 3y$

(2)

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Question 1 continued

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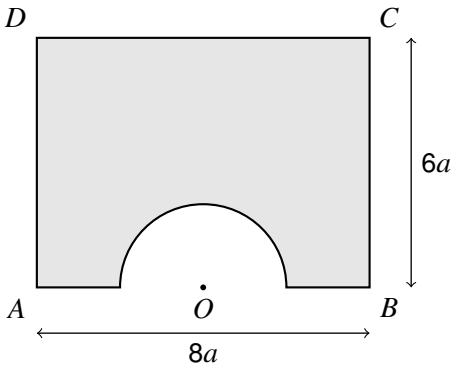

Figure 1

A uniform lamina is formed by removing a semicircle of radius $2a$ from a rectangle $ABCD$, where $AB = 8a$ and $BC = 6a$. The diameter of the semicircle lies along AB and its centre is the midpoint O of AB, as shown in Figure 1.

(a) Show that the centre of mass of the lamina is a distance $\dfrac{208a}{3(24-\pi)}$ from AB.

(5)

(b) State the distance of the centre of mass of the lamina from AD.

(1)

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Question 2 continued

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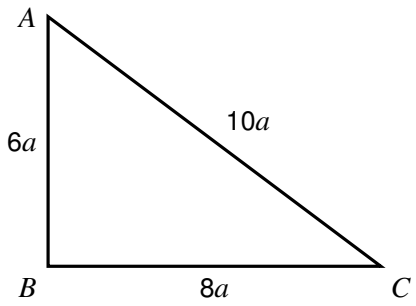

Figure 2

A uniform wire of total mass 12 kg is bent into the shape of a triangle ABC, with $AB = 6a$, $BC = 8a$ and $CA = 10a$, so that angle $ABC = 90^\circ$, as shown in Figure 2.

(a) Find the distance of the centre of mass of the framework from AB and from BC.

(4)

A particle of mass m kg is attached to the framework at A. The centre of mass of the loaded framework is equidistant from AB and BC.

(b) Find the value of m.

(2)

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Question 3 continued

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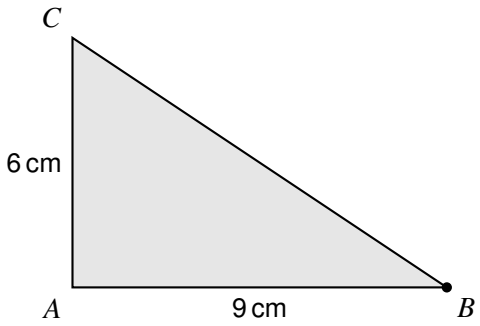

Figure 3

A uniform triangular lamina ABC, of mass $2M$, has $AB = 9$ cm, $AC = 6$ cm and angle $BAC = 90°$. A particle of mass M is attached to the lamina at B, as shown in Figure 3.

(a) Find the distance of the centre of mass of the loaded lamina from AC and from AB.

(4)

The loaded lamina is freely suspended from C and hangs in equilibrium.

(b) Find the angle between CA and the vertical, giving your answer to the nearest 0.1°

(2)

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Question 4 continued

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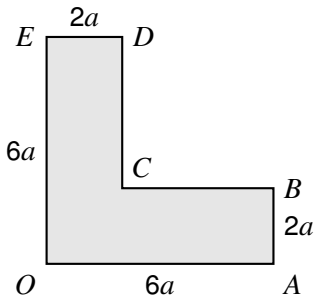

Figure 4

A uniform L-shaped lamina $OABCDE$ has $OA = OE = 6a$ and $AB = DE = 2a$, with all its angles right angles, as shown in Figure 4.

(a) Find the distance of the centre of mass of the lamina from OA and from OE.

(3)

The lamina is placed in a vertical plane with OA along a line of greatest slope of a rough plane inclined at an angle θ to the horizontal, with O below A. The plane is rough enough to prevent sliding.

(b) Find the greatest value of θ for which the lamina does not topple.

(3)

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Question 5 continued

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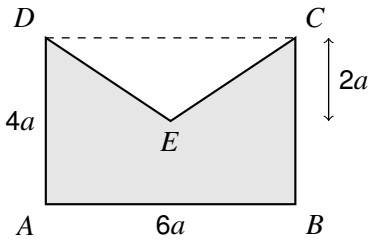

Figure 5

A uniform lamina $ABCED$ is formed by removing the triangle DCE from a rectangle $ABCD$, where $AB = 6a$ and $BC = 4a$. The point E is $2a$ from DC and lies on the perpendicular bisector of DC, as shown in Figure 5. The mass of the lamina is M.

(a) Show that the centre of mass of the lamina is a distance $\frac{14}{9}a$ from AB.

(4)

The lamina is freely suspended from A and hangs in equilibrium.

(b) Find the angle between AB and the vertical, giving your answer to the nearest degree.

(3)

The lamina is now suspended from A by a light string and is held in equilibrium, with AB horizontal and AD vertical, by a horizontal force of magnitude F applied at D, in the plane of the lamina.

(c) Find F in terms of M and g.

(3)

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Question 6 continued

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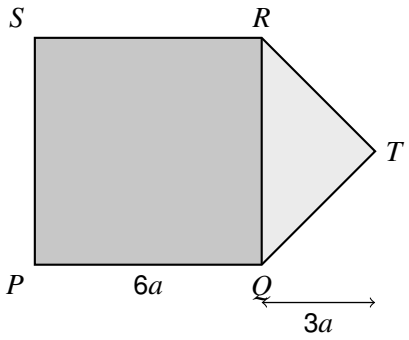

Figure 6

A lamina is formed by joining a square $PQRS$ of side $6a$ to an isosceles triangle QTR along QR, as shown in Figure 6. The perpendicular distance of T from QR is $3a$. The square and the triangle are each uniform, but the mass per unit area of the square is twice the mass per unit area of the triangle. The total mass of the lamina is M.

(a) Show that the centre of mass of the lamina is a distance $\frac{31}{9}a$ from PS.

(4)

The lamina is freely suspended from P and hangs in equilibrium.

(b) Find the angle between PQ and the vertical, giving your answer to the nearest degree.

(3)

The lamina is instead held in a vertical plane, with PQ horizontal and below SR, by two light vertical strings attached at P and at Q.

(c) Find, in terms of M and g, the tension in each string.

(3)

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Question 7 continued

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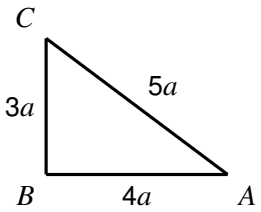

Figure 7

A framework ABC is made from three uniform rods AB, BC and CA, rigidly joined at their ends to form a triangle with $AB = 4a$, $BC = 3a$ and $CA = 5a$, as shown in Figure 7. The masses of AB, BC and CA are $2m$, m and $3m$ respectively.

(a) Show that the centre of mass of the framework is a distance $\frac{5}{3}a$ from BC and a distance a from AB.

(4)

The framework is suspended from the point D on AB by a single vertical string and hangs in equilibrium with AB horizontal.

(b) Find the distance AD.

(2)

A particle of mass km is now attached to the framework at C. The loaded framework is freely suspended from A and hangs in equilibrium with AB at an angle θ to the vertical, where $\tan\theta = \frac{3}{5}$

(c) Find the value of k.

(4)

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Question 8 continued

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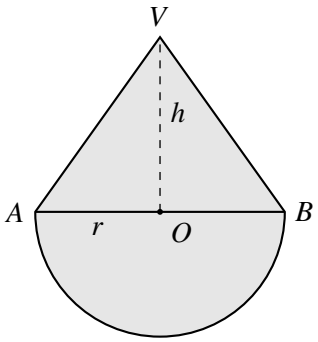

Figure 8

A uniform lamina is formed by joining a semicircle of radius r, with diameter AB and centre O, to an isosceles triangle ABV with $VA = VB$, along their common edge AB. The height of the triangle is h, as shown in Figure 8.

(a) Show that the distance of the centre of mass of the lamina from O, measured towards V, is

$$\frac{2\left(h^2 - 2r^2\right)}{3(2h + \pi r)}$$

(4)

(b) Find h in terms of r when the centre of mass of the lamina is at O.

(2)

(c) For this value of h, explain why the lamina can rest in equilibrium with any point of its curved edge in contact with a horizontal table.

(1)

Given instead that $h = 2r$, the lamina is freely suspended from A and hangs in equilibrium.

(d) Find the angle between AB and the vertical, giving your answer to the nearest 0.1°

(3)

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Question 9 continued

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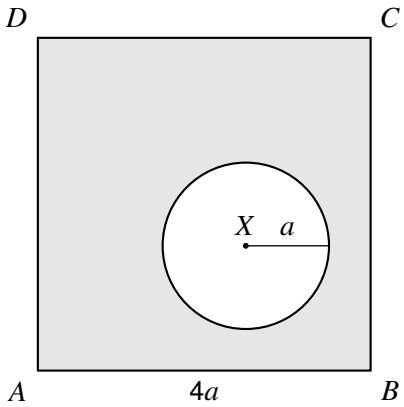

Figure 9

A uniform lamina is formed by cutting a circular hole of radius a from a square $ABCD$ of side $4a$. The centre X of the hole is a distance $2.5a$ from AD and $1.5a$ from AB, as shown in Figure 9.

(a) Show that the centre of mass of the lamina is a distance $\frac{(64-5\pi)a}{2(16-\pi)}$ from AD, and find its distance from AB.

(4)

The lamina is placed in a vertical plane with AB along a line of greatest slope of a rough plane inclined at an angle θ to the horizontal, with A below B. The angle θ is slowly increased.

(b) Assuming that the lamina does not slide, find the value of θ at which it is about to topple.

(3)

The coefficient of friction between the lamina and the plane is 0.9

(c) Determine whether the lamina slides or topples first as θ is increased, giving a reason.

(3)

(d) State how you have used the modelling assumption that the lamina is rigid.

(1)

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Question 10 continued

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(Total for Question 10 is 11 marks)

TOTAL FOR CHAPTER 3 IS 81 MARKS

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CHAPTER 4 • KEY SKILLS

4 Work and Energy

Specification M2: Work and energy • 10 questions • 82 marks • about 98 minutes

1 Work done

Work = force × distance moved in the direction of the force. A force at θ to the motion does work $F\cos\theta \times d$

2 Work against gravity

Raising a mass m through a vertical height h takes mgh. On a slope, $h = d\sin\alpha$

3 Energy

Kinetic energy $\frac{1}{2}mv^2$; potential energy mgh. Change in kinetic energy is $\frac{1}{2}m\left(v^2-u^2\right)$, not $\frac{1}{2}m(v-u)^2$

4 Work–energy principle

Work done by driving forces − work against resistances = change in KE + change in PE. Count gravity once only.

5 Conservation

With no work against resistances, KE + PE is constant. The path and the angle do not matter.

6 Friction

Work against friction = $\mu R \times d$, with R from resolving perpendicular to the surface (cosine on a slope).

7 Power

$P = Fv$, where F is the driving force. 1 kW = 1000 W. Average power $= \dfrac{\text{work done}}{\text{time}}$

8 Greatest speed

At the greatest speed $a = 0$: driving force = resistance + weight component.

9 Varying resistance

With resistance kv and power P: $\dfrac{P}{v} - kv = ma$. At the greatest speed, a quadratic in v.

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	6	6	6	6	6	11	10	10	10	11
1 Work done	●				●	●	●	●		●
2 Work against gravity	●			●		●	●	●		
3 Energy			●	●	●	●	●	●		●
4 Work–energy principle				●	●	●	●	●		●
5 Conservation			●					●		
6 Friction	●			●	●		●	●		
7 Power	●	●				●			●	●
8 Greatest speed		●				●			●	
9 Varying resistance									●	
Interleaved: $F = ma$, friction and connected particles (M1)		●			●	●	●		●	●
Interleaved: projectiles (Chapter 1)			●					●		
Interleaved: quadratics and simultaneous equations (P1)						●		●	●	

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. When a question says “use the work–energy principle”, suvat earns no marks. Write one equation with every energy and work term, counting gravity once. Convert kW to W and give answers to 2 or 3 significant figures.

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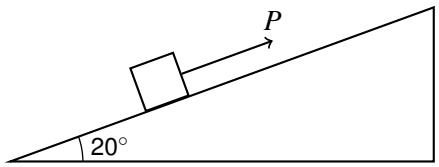

Figure 1

A package of mass 5 kg is pushed at constant speed for 4 m up a line of greatest slope of a rough plane inclined at 20° to the horizontal, by a force acting up the slope parallel to the line of greatest slope, as shown in Figure 1. The coefficient of friction between the package and the plane is 0.3. The package is modelled as a particle.

(a) Find the work done against friction.

(3)

(b) Find the total work done by the pushing force.

(2)

(c) The package takes 8 s to move the 4 m. Find the average rate at which the pushing force does work.

(1)

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Question 1 continued

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2. A cyclist and her bicycle have a combined mass of 80 kg. She rides along a straight road, working at a constant rate of 240 W. The resistance to her motion is modelled as a constant force of magnitude 30 N.

(a) Find her greatest possible speed on horizontal ground.

(2)

(b) Find her acceleration on horizontal ground at the instant when her speed is $5\,\mathrm{m\,s^{-1}}$

(2)

She later rides up a hill inclined at an angle α to the horizontal, where $\sin\alpha = \frac{1}{40}$, at a constant speed of $4\,\mathrm{m\,s^{-1}}$. The resistance is unchanged.

(c) Find the rate at which she is now working.

(2)

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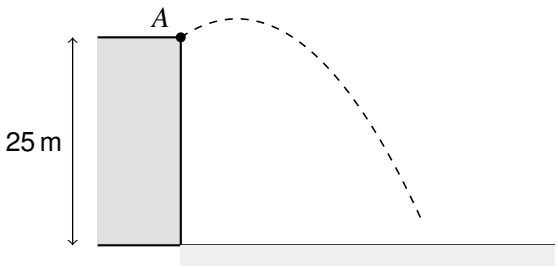

Figure 2

A stone is thrown from a point A at the top of a vertical cliff, 25 m above the sea, with speed $12\,\text{m}\,\text{s}^{-1}$, as shown in Figure 2. The stone moves freely under gravity.

(a) Use the principle of conservation of mechanical energy to find the speed of the stone as it hits the sea.

(3)

(b) Find the speed of the stone when it is 10 m above the sea.

(2)

(c) Explain why the angle at which the stone is thrown was not needed.

(1)

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Question 3 continued

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4. A particle of mass 2 kg is projected with speed $12\,\text{m}\,\text{s}^{-1}$ from the point A, up a line of greatest slope of a rough plane inclined at an angle α to the horizontal, where $\tan\alpha = \frac{3}{4}$. The coefficient of friction between the particle and the plane is 0.25. The particle comes to instantaneous rest at the point B.

(a) Use the work–energy principle to find the distance AB.

(5)

(b) Find the work done against friction as the particle moves from A to B.

(1)

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Question 4 continued

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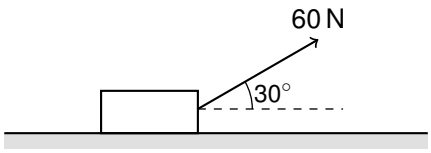

Figure 3

A sledge of mass 15 kg is pulled from rest across rough horizontal snow by a rope inclined at 30° above the horizontal, as shown in Figure 3. The tension in the rope is 60 N and the coefficient of friction between the sledge and the snow is 0.2. The sledge is modelled as a particle and the rope as light.

(a) Find the work done by the tension in the rope as the sledge moves 20 m.

(2)

(b) Use the work–energy principle to find the speed of the sledge after it has moved 20 m.

(4)

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Question 5 continued

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6. A car of mass 1200 kg moves along a straight road. The resistance to motion is modelled as a constant force of magnitude R newtons, and the engine works at a constant rate of P watts. On a horizontal road the greatest possible speed of the car is $40\,\text{m s}^{-1}$. When the car moves up a road inclined at an angle α to the horizontal, where $\sin\alpha = \frac{1}{20}$, its greatest possible speed is $25\,\text{m s}^{-1}$

(a) Show that $R = 980$ and find the value of P.

(5)

(b) Find the acceleration of the car on the horizontal road at the instant when its speed is $28\,\text{m s}^{-1}$

(3)

The car later moves down the inclined road with the engine switched off. The resistance is unchanged.

(c) Use the work–energy principle to find the distance the car travels while its speed falls from $25\,\text{m s}^{-1}$ to $15\,\text{m s}^{-1}$

(3)

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Question 6 continued

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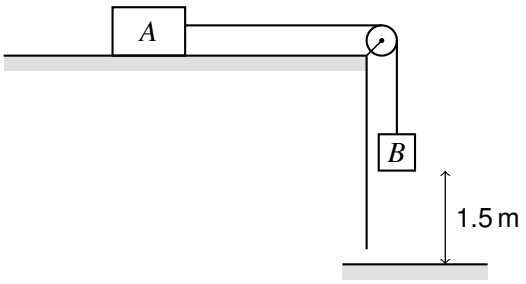

Figure 4

A particle A of mass 3 kg rests on a rough horizontal table. It is attached to a light inextensible string which passes over a small smooth pulley at the edge of the table. The other end of the string is attached to a particle B of mass 2 kg, which hangs 1.5 m above the floor, as shown in Figure 4. The coefficient of friction between A and the table is 0.4. The system is released from rest with the string taut, and A does not reach the pulley.

(a) Find the work done against friction as B falls 1.5 m.

(2)

(b) Use the work–energy principle to find the speed of B at the instant it reaches the floor.

(4)

B does not rebound.

(c) Use the work–energy principle to find the further distance moved by A before it comes to rest.

(3)

(d) State how you have used the fact that the pulley is smooth.

(1)

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Question 7 continued

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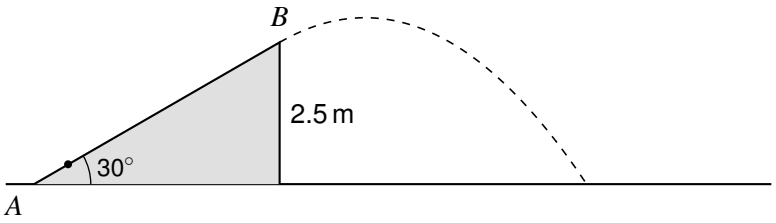

Figure 5

A ramp AB is a rough plane of length 5 m inclined at 30° to the horizontal, with A on horizontal ground and B 2.5 m above the ground. A particle P of mass 0.5 kg is projected from A with speed $10\,\text{m}\,\text{s}^{-1}$ up the line of greatest slope AB. The coefficient of friction between P and the ramp is 0.2. After leaving the ramp at B, P moves freely under gravity until it hits the ground, as shown in Figure 5.

(a) Find the work done against friction as P moves from A to B.

(2)

(b) Use the work–energy principle to find the speed of P at B.

(3)

(c) Use the principle of conservation of mechanical energy to find the speed of P as it hits the ground.

(2)

(d) Find the time taken by P to travel from B to the ground.

(3)

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Question 8 continued

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9. A car of mass 800 kg moves along a straight road. The engine of the car works at a constant rate of 30 kW. The resistance to motion of the car is modelled as a force of magnitude kv newtons, where $v\,\text{m s}^{-1}$ is the speed of the car and k is a constant. The greatest possible speed of the car on a horizontal road is $50\,\text{m s}^{-1}$

(a) Find the value of k.

(2)

(b) Find the acceleration of the car on a horizontal road when its speed is $20\,\text{m s}^{-1}$

(3)

The car moves up a road inclined at an angle α to the horizontal, where $\sin\alpha = \frac{1}{16}$, with the engine working at the same rate.

(c) Find the greatest possible speed of the car up this road.

(4)

(d) Suggest one reason why the model of the resistance may need refining.

(1)

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Question 9 continued

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10. A van of mass 1500 kg tows a trailer of mass 500 kg up a straight road inclined at an angle α to the horizontal, where $\sin\alpha = \frac{1}{14}$. The trailer is attached to the van by a light rigid towbar parallel to the road. The resistances to the motion of the van and of the trailer are constant forces of magnitude 400 N and 200 N respectively. The engine of the van works at a constant rate of 45 kW.

(a) Find the acceleration of the van and trailer at the instant when their speed is $15\,\text{m}\,\text{s}^{-1}$

(3)

(b) Find the tension in the towbar at this instant.

(2)

At this instant the towbar breaks.

(c) Use the work–energy principle to find the distance the trailer travels up the road before coming to rest.

(3)

(d) Find the acceleration of the van immediately after the towbar breaks.

(2)

(e) Explain why the van's acceleration in part (d) does not remain constant.

(1)

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Question 10 continued

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Question 10 continued

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TOTAL FOR CHAPTER 4 IS 82 MARKS

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CHAPTER 5 • KEY SKILLS

5 Impulses and Collisions

Specification M2: Impulses and collisions • 10 questions • 82 marks • about 98 minutes

1 Impulse as a vector

$\mathbf{I} = m\mathbf{v} - m\mathbf{u}$ (after minus before). Its magnitude is $|\mathbf{I}|$; give a vector only when a vector is asked for.

2 Impulse at an angle

Draw the triangle $m\mathbf{u} + \mathbf{I} = m\mathbf{v}$ and use the cosine rule, or resolve parallel and perpendicular to $\mathbf{u}$

3 Conservation of momentum

Total momentum before = total momentum after. Draw before and after diagrams and choose a positive direction.

4 Newton's law of restitution

Speed of separation = $e\times$ speed of approach, with $0 \leqslant e \leqslant 1$. Use it as a relationship, not a remembered formula.

5 Smooth wall

A sphere hitting a wall at speed u rebounds at eu. The impulse on it is $m(u+eu)$: the direction changes.

6 Kinetic energy lost

Total KE before $-$ total KE after, with $\frac{1}{2}mv^2$ for every particle. Not $\frac{1}{2}m(v-u)^2$

7 Further collisions

They collide again only if the one behind is faster. Equal speeds: no further collision. A wall turns a particle round.

8 Successive impacts

Tabulate times and distances for each particle between impacts, then form one equation for where they meet.

9 Using $0 \leqslant e \leqslant 1$

The range of e (or of a mass ratio) decides directions and gives inequalities.

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	6	6	6	6	6	11	10	10	10	11
1 Impulse as a vector	•								•	
2 Impulse at an angle					•				•	
3 Conservation of momentum		•		•		•	•	•		•
4 Newton's law of restitution		•		•		•	•	•		•
5 Smooth wall			•				•	•		
6 Kinetic energy lost		•	•			•				
7 Further collisions							•	•		•
8 Successive impacts								•		•
9 Using $0 \leqslant e \leqslant 1$						•	•			•
Interleaved: momentum and impulse in one dimension (M1)		•	•	•		•	•	•		•
Interleaved: vectors, cosine rule, scalar product (P1, M1)	•				•				•	
Interleaved: inequalities and quadratics (P1)						•	•		•	•

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. Draw a diagram before and after every collision, with arrows for the directions and the masses written in. Write the impact law in words first. Give the magnitude of an impulse as a positive value in N s.

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1. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are perpendicular horizontal unit vectors.]*

A hockey puck of mass 0.4 kg slides across smooth horizontal ice with velocity $(5\mathbf{i} - 3\mathbf{j})\,\text{m s}^{-1}$. It is struck by a stick, and immediately afterwards its velocity is $(2\mathbf{i} + 4\mathbf{j})\,\text{m s}^{-1}$. The puck is modelled as a particle.

(a) Find the magnitude of the impulse exerted on the puck by the stick.

(3)

(b) Find the angle between the direction of this impulse and the direction in which the puck was moving before it was struck.

(3)

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Question 1 continued

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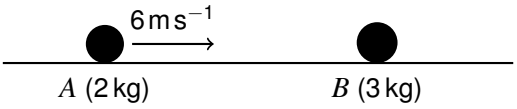

Figure 1

A small smooth sphere A of mass 2 kg moves with speed 6 m s^{-1} on a smooth horizontal surface and collides directly with a small smooth sphere B of mass 3 kg, which is at rest, as shown in Figure 1. The coefficient of restitution between the spheres is $\frac{1}{2}$

(a) Find the speeds of A and B immediately after the collision.

(4)

(b) Find the kinetic energy lost in the collision.

(2)

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Question 2 continued

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3. A small ball of mass 0.5 kg moves on a smooth horizontal floor with speed $8\,\text{m}\,\text{s}^{-1}$, perpendicular to a fixed smooth vertical wall. The ball strikes the wall and rebounds. The coefficient of restitution between the ball and the wall is 0.6

(a) Find the magnitude of the impulse exerted on the ball by the wall.

(3)

(b) Find the kinetic energy lost in the impact.

(2)

(c) State what the value 0.6 tells you about whether kinetic energy is lost in the impact.

(1)

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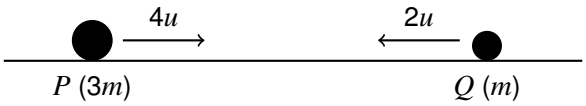

Figure 2

Figure 2 shows a particle P of mass $3m$, moving with speed $4u$, about to collide directly with a particle Q of mass m, which is moving with speed $2u$ in the opposite direction. In the collision, Q is turned back and leaves with speed $4u$

(a) Find the speed and direction of motion of P immediately after the collision.

(3)

(b) Find the coefficient of restitution between P and Q.

(3)

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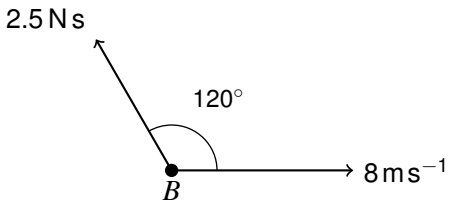

Figure 3

A ball B of mass 0.25 kg is moving horizontally with speed 8 m s^{-1} when it is given an impulse of magnitude 2.5 N s. The impulse acts in the horizontal plane at an angle of 120° to the direction of motion of B, as shown in Figure 3.

(a) Find the speed of B immediately after the impulse.

(4)

(b) Find the angle through which the direction of motion of B is turned by the impulse.

(2)

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Question 5 continued

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6. Two small smooth spheres P and Q, of masses $3m$ and $5m$, are moving towards each other in the same straight line on a smooth horizontal surface, with speeds $2u$ and u respectively. They collide directly. The coefficient of restitution between P and Q is e.

(a) Find, in terms of e and u, the velocities of P and Q immediately after the collision, taking the original direction of motion of P as positive.

(6)

(b) Show that the direction of motion of P is reversed if $e > \frac{1}{15}$

(2)

The total kinetic energy lost in the collision is $\frac{15}{2}mu^2$

(c) Find the value of e.

(3)

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Question 6 continued

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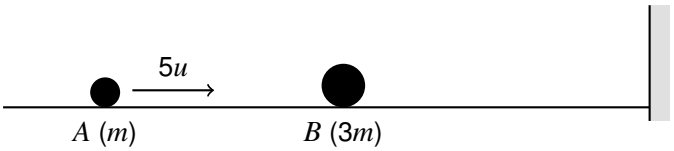

Figure 4

Two small smooth spheres A and B, of masses m and $3m$, lie on a smooth horizontal floor in a straight line perpendicular to a fixed smooth vertical wall, with B between A and the wall. B is at rest and A is moving towards B with speed $5u$, as shown in Figure 4. The coefficient of restitution between A and B is $\frac{3}{5}$

(a) Find the speeds of A and B immediately after they collide.

(4)

(b) State the direction of motion of A after the collision.

(1)

B then hits the wall and rebounds. The coefficient of restitution between B and the wall is f, where $f > 0$

(c) Find, in terms of m, u and f, the magnitude of the impulse exerted on B by the wall.

(2)

(d) Show that A and B collide again if and only if $f > \frac{1}{2}$

(3)

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Question 7 continued

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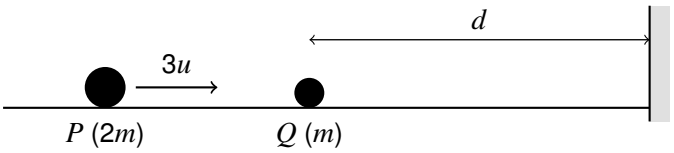

Figure 5

A small smooth sphere P of mass $2m$ moves with speed $3u$ on a smooth horizontal floor towards a small smooth sphere Q of mass m, which is at rest at a distance d from a fixed smooth vertical wall. The spheres move in a line perpendicular to the wall, as shown in Figure 5. The coefficient of restitution between P and Q is $\frac{1}{2}$

(a) Find the speeds of P and Q immediately after they collide.

(4)

Q hits the wall and rebounds. The coefficient of restitution between Q and the wall is f, where $f > 0$

(b) Show that P and Q collide for the second time at a distance $\dfrac{fd}{2f+1}$ from the wall.

(4)

(c) Given that the second collision is at a distance $\frac{1}{4}d$ from the wall, find the value of f.

(2)

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Question 8 continued

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9. *[In this question,* $\mathbf{i}$ *and* $\mathbf{j}$ *are perpendicular horizontal unit vectors.]*

A particle P of mass 0.5 kg is moving with velocity $(4\mathbf{i}+3\mathbf{j})\,\text{m s}^{-1}$ when it receives an impulse $\lambda(\mathbf{i}-2\mathbf{j})\,\text{N s}$, where λ is a non-zero constant.

(a) Find, in terms of λ, the velocity of P immediately after the impulse.

(2)

The speed of P is the same immediately before and immediately after the impulse.

(b) Show that $\lambda = 0.4$

(4)

(c) Find the magnitude of the impulse.

(1)

(d) Find the angle through which the direction of motion of P is turned by the impulse.

(3)

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Question 9 continued

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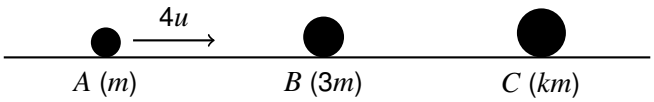

Figure 6

Three small smooth spheres A, B and C, of masses m, $3m$ and km respectively, lie in a straight line on a smooth horizontal surface, as shown in Figure 6. B and C are at rest. A is projected towards B with speed $4u$ and collides directly with B. The coefficient of restitution between each pair of spheres is $\frac{1}{2}$

(a) Find the velocities of A and B immediately after their collision.

(4)

B then collides directly with C.

(b) Find, in terms of k and u, the velocities of B and C immediately after this collision.

(4)

(c) Find the range of values of k for which there is a further collision between A and B.

(3)

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TOTAL FOR CHAPTER 5 IS 82 MARKS

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CHAPTER 6 • KEY SKILLS

6 Statics of Rigid Bodies

Specification M2: Statics of rigid bodies • 10 questions • 81 marks • about 97 minutes

1 Three equations

Resolve in two perpendicular directions and take moments about one point. Each equation must be dimensionally correct.

2 Moments of angled forces

Moment = force $\times$ perpendicular distance. A force T at θ to a rod at distance d from A: moment $Td\sin\theta$

3 Choosing the point

Take moments about a point where unknown forces act (a hinge or a contact) so they do not appear.

4 Hinges

Give the hinge force components X and Y. Magnitude $\sqrt{X^2+Y^2}$; direction from $\tan^{-1}\frac{Y}{X}$, then the angle asked for.

5 Smooth contacts

A smooth wall gives a horizontal reaction; a smooth peg gives a reaction perpendicular to the rod.

6 Rough contacts

Friction acts along the surface, opposing the motion that would happen. Limiting: $F = \mu R$

7 Ladders

Foot on rough ground: friction towards the wall. A rough wall adds an upward friction at the top when the ladder is about to slip down.

8 Inequalities

In equilibrium $F \leqslant \mu R$, so $\mu \geqslant \frac{F}{R}$. The limiting case gives the end of a range.

9 Accuracy

Keep exact values until the end: premature rounding gives answers such as 0.131 for 0.13

Skills map every skill above is tested at least once; interleaved skills come from GCSE or other chapters

Skill	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Marks	6	6	6	6	6	10	10	10	10	11
1 Three equations	●	●	●	●	●	●	●	●	●	●
2 Moments of angled forces	●	●	●	●	●	●	●	●	●	●
3 Choosing the point	●	●	●	●		●	●	●	●	●
4 Hinges	●						●	●		
5 Smooth contacts			●		●					●
6 Rough contacts			●	●	●	●			●	●
7 Ladders					●	●				●
8 Inequalities				●		●		●	●	●
9 Accuracy		●	●				●	●	●	
Interleaved: moments, friction and statics of a particle (M1)	●	●	●	●	●	●	●	●	●	●
Interleaved: centres of mass (Chapter 3)		●								
Interleaved: trigonometry, exact values and surds (P1, P2)	●	●			●	●	●	●	●	

Exam difficulty. Questions 1 to 5 check each skill on its own. Questions 6 to 10 are multi-step questions built like the last questions on a real WME02 paper, where one part leads into the next and skills from different topics are combined.

Must learn. Draw every force on the diagram, including both components at a hinge and friction at each rough contact. State what you are taking moments about. Read whether an angle is to be measured from the horizontal, the vertical or the rod.

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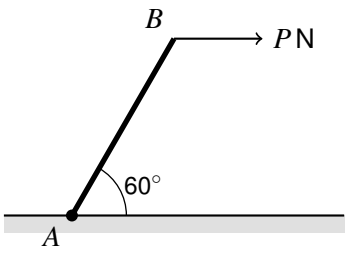

Figure 1

A uniform rod AB, of length 2 m and weight 50 N, is freely hinged at A to a point on horizontal ground. The rod is held in equilibrium at an angle of 60° to the horizontal by a horizontal force of magnitude P newtons applied at B, as shown in Figure 1. The force acts in the vertical plane containing the rod.

(a) Find the value of P.

(3)

(b) Find the magnitude of the force exerted on the rod by the hinge.

(2)

(c) Explain why the force exerted by the hinge does not act along the rod.

(1)

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Question 1 continued

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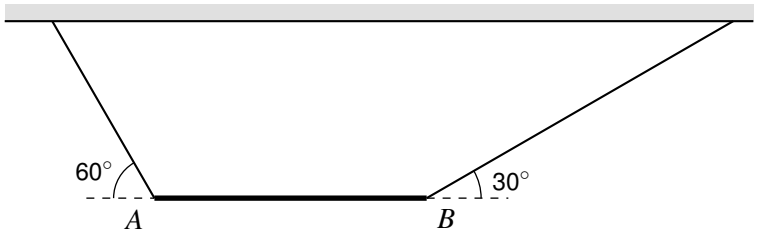

Figure 2

A non-uniform rod AB, of length 4 m and weight 60 N, hangs in equilibrium in a horizontal position, supported by two light strings attached at A and B. The string at A makes an angle of 60° with the rod and the string at B makes an angle of 30° with the rod, as shown in Figure 2. The strings and the rod lie in a vertical plane.

(a) Find the tension in each string.

(4)

(b) Find the distance of the centre of mass of the rod from A.

(2)

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Question 2 continued

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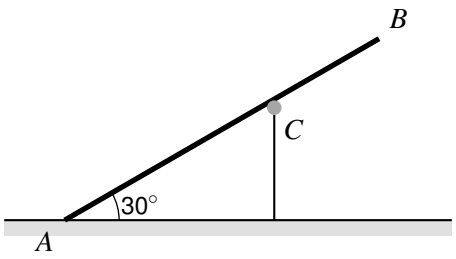

Figure 3

A uniform rod AB, of length 6 m and weight 100 N, rests with the end A on rough horizontal ground and with the rod in contact with a small smooth peg C, where $AC = 4$ m. The rod is inclined at 30° to the horizontal, as shown in Figure 3, and is in limiting equilibrium.

(a) Find the magnitude of the force exerted on the rod by the peg.

(3)

(b) Find the coefficient of friction between the rod and the ground.

(3)

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Question 3 continued

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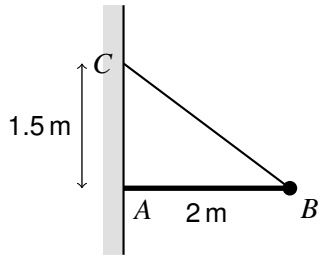

Figure 4

A uniform rod AB, of length 2 m and weight 30 N, rests in a horizontal position with the end A against a rough vertical wall. A particle of weight 10 N is attached to the rod at B. The rod is held in equilibrium by a light string attached at B and to the point C on the wall, 1.5 m vertically above A, as shown in Figure 4. The rod and the string lie in a vertical plane perpendicular to the wall.

(a) Find the tension in the string.

(3)

(b) Find the least possible value of the coefficient of friction between the rod and the wall.

(3)

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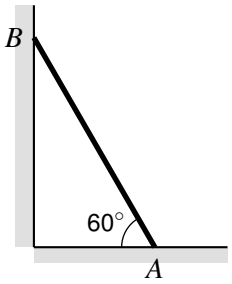

Figure 5

A uniform ladder AB, of length 4 m and mass 20 kg, rests with the end A on rough horizontal ground and the end B against a smooth vertical wall. The ladder makes an angle of 60° with the ground, as shown in Figure 5, and lies in a vertical plane perpendicular to the wall.

(a) Find the magnitude of the reaction exerted on the ladder by the wall.

(3)

(b) Find the least possible value of the coefficient of friction between the ladder and the ground.

(3)

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Question 5 continued

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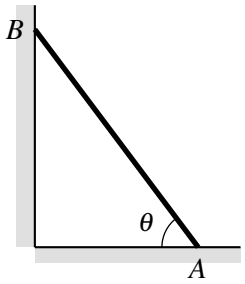

Figure 6

A uniform ladder AB, of length $2a$ and weight W, rests with its end A on rough horizontal ground and its end B against a rough vertical wall. The ladder makes an angle θ with the ground, as shown in Figure 6, and lies in a vertical plane perpendicular to the wall. The coefficient of friction between the ladder and the ground and between the ladder and the wall is μ. The ladder is about to slip.

(a) Show that $\tan\theta = \dfrac{1-\mu^2}{2\mu}$

(6)

(b) Given that $\mu = \frac{1}{3}$, find the value of θ.

(2)

(c) With $\mu = \frac{1}{3}$, explain why the ladder cannot rest in equilibrium at 45° to the ground.

(2)

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Question 6 continued

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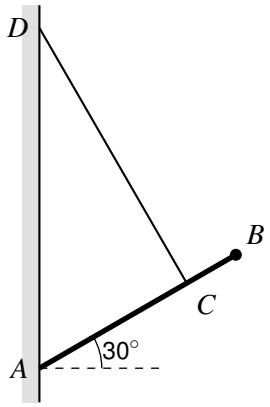

Figure 7

A uniform rod AB, of length $4a$ and weight W, is freely hinged at A to a vertical wall. A particle of weight $2W$ is attached to the rod at B. The rod is held in equilibrium at 30° above the horizontal by a light string attached to the rod at C, where $AC = 3a$, and to the point D on the wall vertically above A. The string is perpendicular to the rod, as shown in Figure 7, and the rod and string lie in a vertical plane perpendicular to the wall.

(a) Show that the tension in the string is $\frac{5\sqrt{3}}{3}W$

(4)

(b) Find, in terms of W, the magnitude of the force exerted on the rod by the hinge.

(4)

(c) Find the angle between the force exerted by the hinge and the rod, giving your answer to the nearest 0.1°

(2)

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Question 7 continued

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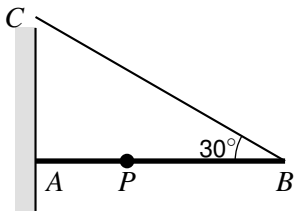

Figure 8

A uniform rod AB, of length $2a$ and weight W, is freely hinged at A to a vertical wall. The rod is held in a horizontal position by a light string attached at B and to the point C on the wall vertically above A, with angle $ABC = 30^\circ$. A particle of weight W is attached to the rod at the point P, where $AP = x$ and $0 \leqslant x \leqslant 2a$, as shown in Figure 8.

(a) Show that the tension in the string is $\dfrac{W(a+x)}{a}$

(3)

(b) Find, in terms of W, a and x, the horizontal and vertical components of the force exerted on the rod by the hinge.

(4)

(c) Explain why the force exerted by the hinge can never act along the rod.

(1)

(d) Find the exact value of x for which the force exerted by the hinge acts at 45° to the rod.

(2)

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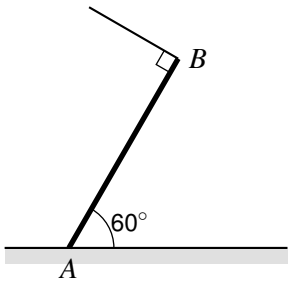

Figure 9

A uniform rod AB, of length $2a$ and weight W, rests with the end A on rough horizontal ground. The rod is held in equilibrium at 60° to the horizontal by a light string attached at B. The string is perpendicular to the rod, as shown in Figure 9, and the rod and string lie in a vertical plane. The rod is on the point of slipping.

(a) Find, in terms of W, the tension in the string.

(3)

(b) Show that the coefficient of friction between the rod and the ground is $\frac{\sqrt{3}}{7}$

(4)

A particle of weight W is now attached to the rod at B. The string is adjusted so that it remains perpendicular to the rod and the rod remains at 60° to the horizontal.

(c) Determine whether the rod can remain in equilibrium.

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Question 9 continued

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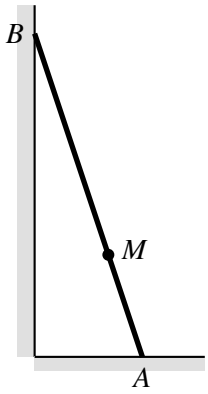

Figure 10

A uniform ladder AB, of length 6 m and mass 20 kg, rests with the end A on rough horizontal ground and the end B against a smooth vertical wall. The ladder makes an angle α with the ground, where $\tan\alpha = 3$, and lies in a vertical plane perpendicular to the wall. The coefficient of friction between the ladder and the ground is 0.25. A man of mass 80 kg climbs up the ladder, as shown in Figure 10. The man is modelled as a particle M.

(a) Find the greatest distance from A that the man can climb before the ladder slips.

(5)

To allow the man to reach the top of the ladder, a horizontal force of magnitude P newtons, towards the wall, is applied to the ladder at A.

(b) Find the least value of P.

(5)

(c) State one way in which modelling the man as a particle affects your answers.

(1)

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Question 10 continued

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Question 10 continued

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(Total for Question 10 is 11 marks)

TOTAL FOR CHAPTER 6 IS 81 MARKS

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