Please check the examination details below before entering your candidate information

Candidate surname StemUp Model Solution | Other names

Centre Number | Candidate Number

Pearson Edexcel International Advanced Level

Monday 2 June 2025

Afternoon (Time: 1 hour 30 minutes) | Paper reference **WME02/01**

Mathematics

International Advanced Subsidiary/Advanced Level
Mechanics M2

You must have:
Mathematical Formulae and Statistical Tables (Yellow), calculator

Total Marks

Candidates may use any calculator permitted by Pearson regulations. Calculators must not have the facility for symbolic algebra manipulation, differentiation and integration, or have retrievable mathematical formulae stored in them.

Instructions:

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- **Fill in the boxes** at the top of this page with your name, centre number and candidate number.
- Answer **all** questions and ensure that your answers to parts of questions are clearly labelled.
- Answer the questions in the spaces provided
  – *there may be more space than you need.*
- You should show sufficient working to make your methods clear. Answers without working may not gain full credit.
- Whenever a numerical value of g is required, take $g = 9.8\,\text{m}\,\text{s}^{-2}$, and give your answer to either 2 significant figures or 3 significant figures.

Information:

- A booklet 'Mathematical Formulae and Statistical Tables' is provided.
- There are 7 questions in this question paper. The total mark for this paper is 75.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*

Advice:

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.
- If you change your mind about an answer, cross it out and put your new answer and any working underneath.

Turn over ▶

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1: **In this question you must show all stages of your working.**
Solutions relying on calculator technology are not acceptable.

A particle P moves along the x-axis.
At time $t = 0$, P is at rest at the origin O.
At time t seconds, $t \geqslant 0$, the acceleration of P, in the positive x direction, is

$$k(3 - t^2)\,\text{m s}^{-2}$$

where k is a positive constant.

Given that when $t = 1.5$, the speed of P is $13.5\,\text{m s}^{-1}$

(a) show that $k = 4$

(3)

The displacement of P from O is s metres in the positive x direction.

(b) Show that

$$s = \frac{1}{3}t^2(18 - t^2)$$

(2)

(c) Find the total distance that P moves before it returns to O.

(4)

(a) $v = \int k(3 - t^2)\,dt = k\left(3t - \frac{1}{3}t^3\right) + C$

$t = 0, v = 0 \Rightarrow C = 0$

$t = 1.5, v = 13.5$: $k\left(3 \times 1.5 - \frac{1}{3} \times 1.5^3\right) = 13.5$

$k(4.5 - 1.125) = 13.5 \Rightarrow 3.375k = 13.5$

$k = 4$ as required

(b) $s = \int 4\left(3t - \frac{1}{3}t^3\right)\,dt = 4\left(\frac{3}{2}t^2 - \frac{1}{12}t^4\right) + D = 6t^2 - \frac{1}{3}t^4 + D$

$t = 0, s = 0 \Rightarrow D = 0$

$s = 6t^2 - \frac{1}{3}t^4 = \frac{1}{3}t^2(18 - t^2)$ as required

(c) $v = 0$: $4\left(3t - \frac{1}{3}t^3\right) = 0 \Rightarrow 4t\left(3 - \frac{1}{3}t^2\right) = 0$

$t^2 = 9 \Rightarrow t = 3 \quad (t > 0)$

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Question 1 continued

P moves in the positive direction for $0 < t < 3$, then returns.

When $t = 3$: $s = \frac{1}{3} \times 9 \times (18 - 9) = 27$

Returns to O when $s = 0$, i.e. $t^2 = 18$

Total distance = 27 + 27 = 54 m

(Total for Question 1 is 9 marks)

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2: **In this question you must show all stages of your working.**
Solutions relying on calculator technology are not acceptable.

[*In this question,* **i** *and* **j** *are horizontal unit vectors.*]

A particle P of mass 3 kg is moving on a smooth horizontal plane.

At time t seconds, where $1 \leqslant t \leqslant 4$, the position vector, **r** metres, of P relative to a fixed origin is given by $\mathbf{r} = 4t^{\frac{1}{2}}\,\mathbf{i} - 3t\,\mathbf{j}$.

At the instant when $t = 4$, P receives an impulse $(6\mathbf{i} - 3\mathbf{j})$ N s.

Find the speed of P immediately after the impulse is received.

(7)

$v = \frac{dr}{dt} = 2t^{-\frac{1}{2}}i - 3j$

$t = 4$: $v = 2 \times 4^{-\frac{1}{2}}\, i - 3j = (i - 3j)\ m\ s^{-1}$

Impulse = change in momentum:

$6i - 3j = 3(v - (i - 3j))$

$v - (i - 3j) = 2i - j$

$v = 3i - 4j$

Speed $= \sqrt{(3^2 + (-4)^2)} = \sqrt{25}$

Speed $= 5\ m\ s^{-1}$

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Question 2 continued

(Total for Question 2 is 7 marks)

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3: [*The distance of the centre of mass of a semicircular arc of radius r is* $\frac{2r}{\pi}$ *from its centre.*]

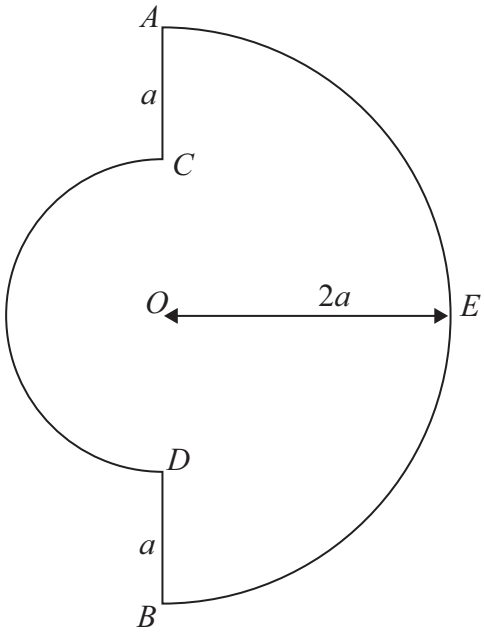


Figure 1

A uniform rigid wire **framework**, shown in Figure 1, consists of two wire semicircular arcs AB and CD, both with centre O, joined by two straight pieces of wire, AC and DB.

Arc AB has radius $2a$, arc CD has radius a, $AC = DB = a$, and $ACDB$ is a straight line.

The framework lies in a single plane.

(a) Show that the centre of mass of the framework is a distance $\frac{6a}{(3\pi + 2)}$ from AB.

(5)

The point E is on the arc AB and the angle AOE is a right angle.

The framework is freely suspended from A.

The framework hangs at rest in a vertical plane with ***AE*** making an angle θ with the downward vertical.

(b) Find the exact value of $\tan\theta$, simplifying your answer.

(5)

(a) Take moments about AB (distances measured towards E positive).

	arc AB	arc CD	AC + DB	framework
Mass ratio	$\pi(2a) = 2\pi a$	πa	$2a$	$3\pi a + 2a$
Distance	$\frac{2(2a)}{\pi} = \frac{4a}{\pi}$	$-\frac{2a}{\pi}$	0	d

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Question 3 continued

$2\pi a \times \frac{4a}{\pi} - \pi a \times \frac{2a}{\pi} + 2a \times 0 = (3\pi a + 2a)d$

$8a^2 - 2a^2 = a(3\pi + 2)d$

$6a^2 = a(3\pi + 2)d$

$d = \frac{6a}{(3\pi + 2)}$ as required

(b) By symmetry G lies on OE with $OG = d = \frac{6a}{3\pi + 2}$

Suspended from A, so AG is vertical. $OA = OE = 2a$ and angle $AOE = 90°$, so angle $OAE = 45°$. Let angle $OAG = \alpha$:

$\tan \alpha = \frac{OG}{OA} = \frac{6a}{(3\pi + 2)} \div 2a = \frac{3}{3\pi + 2}$

θ = angle $GAE = 45° - \alpha$

$\tan \theta = \tan(45° - \alpha) = \frac{\tan 45° - \tan \alpha}{1 + \tan 45° \tan \alpha} = \frac{1 - \tan \alpha}{1 + \tan \alpha}$

$\tan \theta = \left(1 - \frac{3}{3\pi + 2}\right) \div \left(1 + \frac{3}{3\pi + 2}\right)$

$\tan \theta = \frac{3\pi + 2 - 3}{3\pi + 2 + 3}$

$\tan \theta = \frac{3\pi - 1}{3\pi + 5}$



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Question 3 continued

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Question 3 continued

(Total for Question 3 is 10 marks)



4: A rough plane is inclined to the horizontal at an angle α, where $\sin\alpha = \frac{1}{7}$

A car of mass 750 kg moves up a line of greatest slope of the plane. The total resistance to the motion of the car from non-gravitational forces is 200 N. The engine of the car is working at a constant rate of 20 kW.

(a) Find the constant speed, in m s^{-1}, at which the car could move up the slope.

(4)

(b) Find the acceleration of the car at the instant when it is moving up the slope at $10\,\text{m s}^{-1}$

(4)

At this instant, the car is at the point A and the engine of the car is switched off.

The total resistance to the motion of the car from non-gravitational forces remains at 200 N.

Using the work-energy principle,

(c) find how far up the slope from A the car would travel before coming to rest.

(4)

(a) At constant speed v the driving force is $F = \frac{20\,000}{v}$

Resolving parallel to the slope ($a = 0$):

$F - 750g \sin\alpha - 200 = 0$

$\frac{20\,000}{v} - 750 \times 9.8 \times \frac{1}{7} - 200 = 0$

$\frac{20\,000}{v} = 1050 + 200 = 1250$

$v = 16\ \text{m s}^{-1}$

(b) $D = \frac{20\,000}{10} = 2000\ \text{N}$

N2L up the slope: $D - 750g \sin\alpha - 200 = 750a$

$2000 - 1050 - 200 = 750a$

$750 = 750a$

$a = 1\ \text{m s}^{-2}$

(c) Let the car travel d m up the slope from A.

Loss in KE = gain in PE + work done against resistance

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Question 4 continued

$\frac{1}{2} \times 750 \times 10^2 = 750g \times d \sin\alpha + 200d$

$37\,500 = 750 \times 9.8 \times \frac{1}{7} \times d + 200d$

$37\,500 = 1050d + 200d = 1250d$

$d = 30\ m$

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Question 4 continued

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Question 4 continued

(Total for Question 4 is 12 marks)

5: A particle P of mass $2m$ and a particle Q of mass m are at rest on a smooth horizontal plane. Particle P is projected with speed u along the plane towards Q and the particles collide. The coefficient of restitution between the particles is e, where $e > 0$

(a) Show that the speed of Q after the collision is $\frac{2(1+e)u}{3}$

(5)

The total loss of kinetic energy due to the collision is $k(1-e^2)mu^2$, where k is a constant.

(b) Find the value of k.

(5)

The magnitude of the impulse of Q on P in the collision is $\frac{8mu}{9}$

(c) Find the value of e.

(2)

After the collision, Q goes on to hit a vertical wall which is fixed at right angles to the direction of motion of Q. The coefficient of restitution between Q and the wall is f.

After Q has hit the wall, Q has the same speed as P.

(d) Find the value of f.

(3)

(a) Direction of u positive. After the collision P has velocity v_P, Q has velocity v_Q.

CLM: $2m(u) + m(0) = 2mv_P + mv_Q \Rightarrow 2u = 2v_P + v_Q$ (1)

NEL: $v_Q - v_P = eu \Rightarrow v_P = v_Q - eu$ (2)

Sub (2) into (1): $2u = 2v_Q - 2eu + v_Q$

$3v_Q = 2u + 2eu$

Speed of Q $= v_Q = \frac{2(1+e)u}{3}$ as required

(b) $v_P = \frac{2(1+e)u}{3} - eu = \frac{u}{3}(2-e)$

KE after $= \frac{1}{2}(2m)\left(\frac{u}{3}(2-e)\right)^2 + \frac{1}{2}m\left(\frac{2(1+e)u}{3}\right)^2$

$= \frac{mu^2}{9}[(2-e)^2 + 2(1+e)^2]$

$= \frac{mu^2}{9}(4 - 4e + e^2 + 2 + 4e + 2e^2) = \frac{mu^2}{9}(6 + 3e^2) = \frac{mu^2}{3}(2 + e^2)$

KE loss $= \frac{1}{2}(2m)u^2 - \frac{mu^2}{3}(2 + e^2) = \frac{mu^2}{3}(3 - 2 - e^2)$

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Question 5 continued

$= \frac{1}{3}(1 - e^2)mu^2$

$k = \frac{1}{3}$

(c) Impulse on Q = impulse of Q on P in magnitude:

$\frac{8mu}{9} = m \times \frac{2(1 + e)u}{3} - 0$

$1 + e = \frac{4}{3} \Rightarrow e = \frac{1}{3}$

(d) $e = \frac{1}{3}$: $v_Q = \frac{2}{3} \times \frac{4}{3}u = \frac{8u}{9}$, $v_P = \frac{u}{3}\left(2 - \frac{1}{3}\right) = \frac{5u}{9}$

Speed of Q after hitting the wall = $f \times \frac{8u}{9}$

$\frac{8uf}{9} = \frac{5u}{9}$

$f = \frac{5}{8}$

Question 5 continued

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Question 5 continued

(Total for Question 5 is 15 marks)

6:

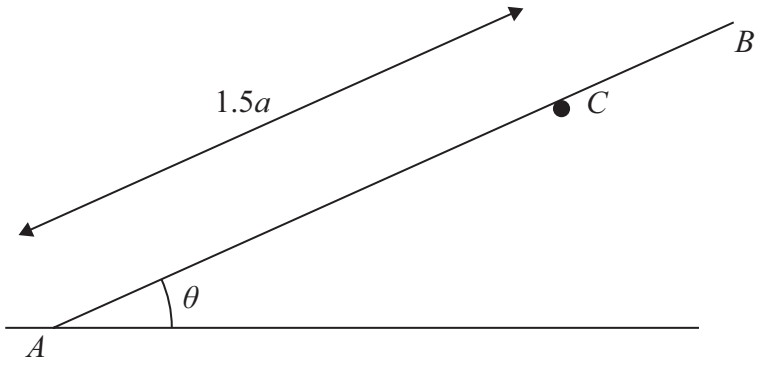


Figure 2

A uniform rod AB, of mass m and length $2a$, has its end A on a rough horizontal floor.

A smooth horizontal rail is fixed above the floor.

The rod rests in equilibrium against the rail at the point C, where $AC = 1.5a$.

The vertical plane containing the rod is at right angles to the rail.

The rod is inclined to the floor at an angle θ, as shown in Figure 2.

The magnitude of the normal reaction exerted on the rod at C is S.

(a) Show that $S = \dfrac{2mg\cos\theta}{3}$

(3)

The magnitude of the vertical component of the force exerted on the rod at A is V.

(b) Show that $V = \dfrac{mg}{3}(3 - 2\cos^2\theta)$

(3)

Given that the rod is in limiting equilibrium and the coefficient of friction between the rod and the floor is $\dfrac{4}{7}$

(c) show that

$$p\tan^2\theta + q\tan\theta + r = 0$$

where p, q and r are integers to be found.

(6)

(a) M(A): $S \times 1.5a = mg \times a\cos\theta$

$S = \dfrac{mga\cos\theta}{1.5a} = \dfrac{2mg\cos\theta}{3}$ as required

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Question 6 continued

(b) S is perpendicular to the rod, so its vertical component is S cos θ.

R(↑): $V + S\cos\theta = mg$

$$V = mg - \frac{2mg\cos\theta}{3} \times \cos\theta = mg - \frac{2mg\cos^2\theta}{3}$$

$$V = \frac{mg}{3}(3 - 2\cos^2\theta) \quad \text{as required}$$

(c) Friction at A acts horizontally, magnitude F. Limiting: $F = \frac{4}{7}V$

R(→): $F = S\sin\theta$

$$\frac{4}{7} \times \frac{mg}{3}(3 - 2\cos^2\theta) = \frac{2mg\cos\theta}{3} \times \sin\theta$$

$4(3 - 2\cos^2\theta) = 14\sin\theta\cos\theta$

Divide by $\cos^2\theta$: $12\sec^2\theta - 8 = 14\tan\theta$

$12(1 + \tan^2\theta) - 8 = 14\tan\theta$

$12\tan^2\theta - 14\tan\theta + 4 = 0$

$6\tan^2\theta - 7\tan\theta + 2 = 0$

$p = 6, \quad q = -7, \quad r = 2$

Question 6 continued

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Question 6 continued

(Total for Question 6 is 12 marks)

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7: A small stone is projected from a point O on horizontal ground.

The stone is projected with speed $20\,\text{m s}^{-1}$ at an angle α to the ground.

When the stone is 11 m above the ground

- the vertical velocity component of the stone has magnitude $V\,\text{m s}^{-1}$
- the horizontal velocity component of the stone has magnitude $2V\,\text{m s}^{-1}$

In a model of the motion

- the stone is modelled as a particle moving freely under gravity
- **the acceleration due to gravity is modelled as being $10\,\text{m s}^{-2}$**

Using the model and the principle of conservation of mechanical energy,

(a) show that $V = 6$

(4)

Figure 3 shows a plane fixed to the ground at an angle of 60°

The stone hits this plane at the point A.

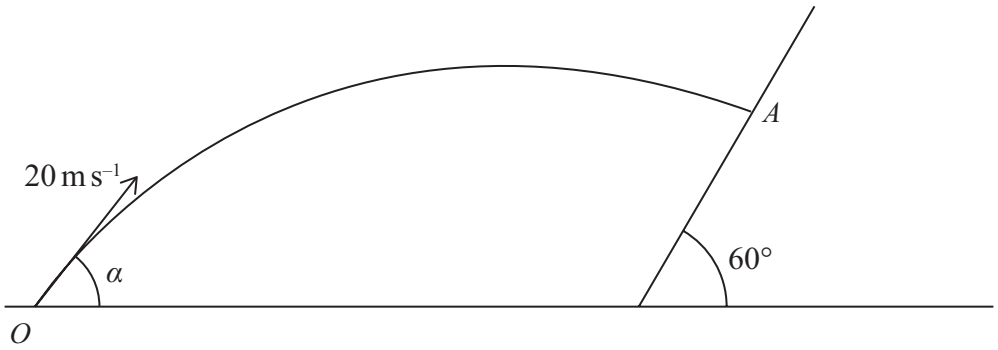


Figure 3

The direction of the motion of the stone is perpendicular to the plane at the instant the stone hits A.

Using the model,

(b) find the height of A above the ground, giving your answer to 2 significant figures.

(6)

(a) Conservation of mechanical energy from O to height 11 m:

$\frac{1}{2}m(20)^2 - \frac{1}{2}mv^2 = mg \times 11$, where $v^2 = V^2 + (2V)^2 = 5V^2$

$\frac{1}{2}m \times 400 - \frac{1}{2}m(V^2 + 4V^2) = 10m \times 11$

$200 - \frac{5}{2}V^2 = 110$

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Question 7 continued

$V^2 = 36 \Rightarrow V = 6$ as required

(b) Horizontal component of velocity is constant = $2V = 12$ m s^{-1}

At A the velocity is perpendicular to the plane, so it makes 30° with the horizontal (directed downwards). Speed at A = S:

$S \cos 30° = 12 \Rightarrow S = \frac{12}{\cos 30°} = 8\sqrt{3}, \quad S^2 = 192$

Energy from O to A, height H:

$\frac{1}{2}m(20)^2 - \frac{1}{2}mS^2 = mgH$

$200 - \frac{1}{2} \times 192 = 10H$

$10H = 104 \Rightarrow H = 10.4$

Height of A = 10 m (2 s.f.)



Question 7 continued

(Total for Question 7 is 10 marks)

TOTAL FOR PAPER IS 75 MARKS

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