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CENTRE NUMBER

CANDIDATE NUMBER

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FURTHER MATHEMATICS **9231/33**

Paper 3 Further Mechanics **May/June 2026**

1 hour 30 minutes

You must answer on the question paper.

You will need: List of formulae (MF19)

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen. Do **not** use correction fluid or tape.
- Do **not** write on any bar codes.
- If additional space is needed, you should use the lined page at the end of this booklet; the question number or numbers must be clearly shown.
- You should use a calculator where appropriate.
- You must show all necessary working clearly; no marks will be given for unsupported answers from a calculator.
- Give non-exact numerical answers correct to 3 significant figures, or 1 decimal place for angles in degrees, unless a different level of accuracy is specified in the question.
- Where a numerical value for the acceleration due to gravity (g) is needed, use $10\,\text{m}\,\text{s}^{-2}$.

INFORMATION

- The total mark for this paper is 50.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **16** pages. Any blank pages are indicated.

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1 A particle P of mass m is moving in a horizontal circle with constant angular speed ω on the smooth inner surface of a hemispherical shell of radius a. The plane of the circular motion is at a height $h = \frac{1}{3}a$ above the lowest point on the shell. The angle between the vertical and the normal reaction of the surface on P is θ.

Find ω in terms of a and g. [5]

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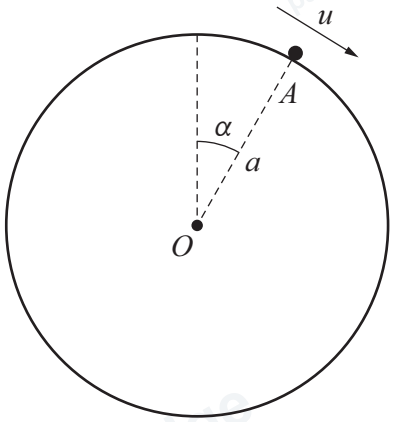
2 A particle P of mass m is moving in a straight horizontal line towards a fixed point A on the line. The particle is subject to a resistive force that is inversely proportional to the square of the distance between P and A. Initially, the distance between P and A is d and the speed of P is u. When the distance between P and A is $\frac{1}{2}d$, the particle has lost $\frac{3}{4}$ of its kinetic energy.

Find, in terms of d, the minimum distance of P from A. [6]

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A fixed smooth solid sphere has centre O and radius a. A particle of mass m is projected perpendicular to OA in a downward direction with speed u from the point A on the outer surface of the sphere, where OA makes an angle α with the upward vertical through O (see diagram).

The particle moves in part of a vertical circle on the surface of the sphere. It loses contact with the sphere at the point B, where OB makes an angle β with the upward vertical through O. The speed of the particle at the point B is v.

Given that the ratio of u to v is 2 : 3 find the ratio $\cos\alpha : \cos\beta$. [5]

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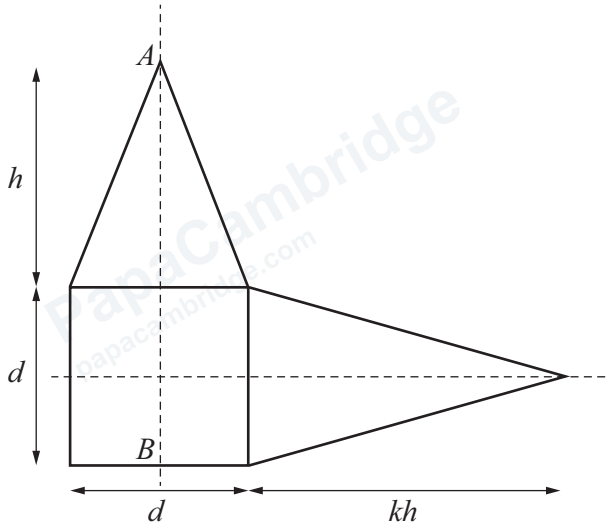
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An object consists of a uniform solid cube of side length d, and two uniform solid square-based pyramids. The cube and the pyramids are made of the same material.

One pyramid, of base length d and height h, is fixed to the top face of the cube so that the base of this pyramid and the face of the cube coincide. Point A is at the top vertex of this pyramid. Point B is in the centre of the bottom face of the cube, vertically below A. The second pyramid, of base length d and height kh, is fixed to a vertical face of the cube so that the base of this pyramid and the vertical face of the cube coincide (see diagram, which shows a cross-section, including the axes of symmetry).

(a) Find an expression for the distance of the centre of mass of the object from AB in terms of h, k, and d. [4]

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The object is placed on a horizontal plane so that the bottom face of the cube that contains point B is in contact with the plane. It is given that the object is on the point of toppling.

(b) Find the value of h in terms of k and d. [3]

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(c) Given that $h = 1.5d$, find the value of k. [2]

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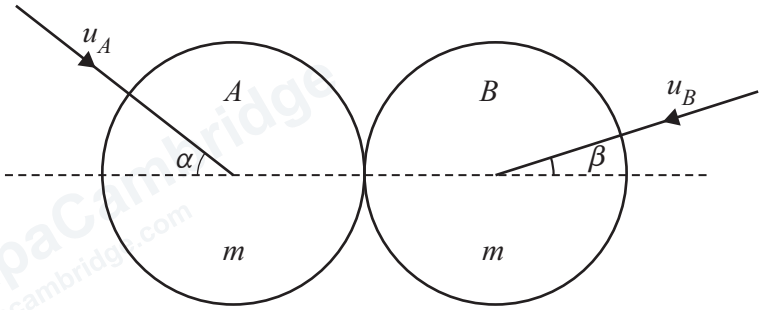
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Two uniform smooth spheres A and B of equal radii and equal masses m are moving with speeds u_A and u_B respectively on a smooth horizontal surface when they collide. Immediately before the collision, the direction of motion of A makes an angle α with the line of centres, and the direction of motion of B makes an angle β with the line of centres (see diagram). Immediately after the collision, the direction of motion of A makes an angle θ with the line of centres, and the direction of motion of B makes an angle φ with the line of centres. It is given that $\cos\alpha = \cos\varphi = \frac{4}{5}$ and $\cos\beta = \frac{24}{25}$ and $\cos\theta = \frac{3}{5}$.

(a) Find the percentage loss in the kinetic energy of A. [2]

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(b) Find the value of the coefficient of restitution between the spheres. [4]

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6 A smooth plane is inclined at an angle θ to the horizontal, where $\sin\theta = \frac{4}{5}$. One end of a light elastic spring, with natural length $10a$ and modulus of elasticity $1.6mg$, is attached to a fixed point O on the plane. The other end of the spring is attached to a particle P of mass $0.2m$. The point O and the particle P lie on the same line of greatest slope of the plane, with P above O. The particle P is at rest.

(a) Show that the distance OP is $9a$. [3]

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A particle Q of mass $0.3m$ is held on the plane on the line of greatest slope through O, at a distance $10a$ above P. The particle Q is released from rest. The particle Q then collides and coalesces with particle P.

(b) Find, in terms of a and g, the speed of the combined particle immediately after the collision. [4]

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(c) As a result of the collision, the spring is further compressed. Find, in terms of a, the minimum distance of the combined particle from O. [4]

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7 At time $t = 0$ s, a particle P is projected from a point O on horizontal ground. The initial velocity of P is $25\,\text{m s}^{-1}$ at an angle α above the horizontal, where $\sin\alpha = \frac{4}{5}$. At time $t = T$ s, a second particle Q is projected vertically upwards from the horizontal ground directly below the point where P will reach its greatest height. The initial velocity of Q is also $25\,\text{m s}^{-1}$. Both particles move freely under gravity. The two particles collide when Q is travelling upwards and at the point where P reaches its greatest height.

(a) Show that the two particles collide 2 seconds after P is projected. [1]

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(b) Find the value of T. [3]

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(c) As a result of the collision, the trajectory of P changes, but the horizontal component of its velocity remains unchanged. Immediately after the collision, the speed of P is $v\,\text{m}\,\text{s}^{-1}$, at an angle θ above the horizontal.

Find, in terms of $\tan\theta$, the greatest height of P above the ground after the collision. [4]

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