

Friday 6 June 2025 – Afternoon

A Level Further Mathematics B (MEI)

Y431/01 Mechanics Minor

Time allowed: 1 hour 15 minutes



You must have:

- the Printed Answer Booklet
- the Formulae Booklet for Further Mathematics B (MEI)
- a scientific or graphical calculator



QP

INSTRUCTIONS

- Use black ink. You can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided in the **Printed Answer Booklet**. If you need extra space, use the lined page at the end of the Printed Answer Booklet. The question numbers must be clearly shown.
- Fill in the boxes on the front of the Printed Answer Booklet.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.
- Give your final answers to a degree of accuracy that is appropriate to the context.
- The acceleration due to gravity is denoted by $g \text{ m s}^{-2}$. When a numerical value is needed use $g = 9.8$ unless a different value is specified in the question.
- Do **not** send this Question Paper for marking. Keep it in the centre or recycle it.

INFORMATION

- The total mark for this paper is **60**.
- The marks for each question are shown in brackets [].
- This document has **8** pages.

ADVICE

- Read each question carefully before you start your answer.

- 1** Particles A and B move towards each other on a smooth horizontal surface. Particle A has speed 3 m s^{-1} and particle B has speed 8 m s^{-1} .

After they collide directly, A and B move away from each other, A with a speed of 5.2 m s^{-1} and B with a speed of $v \text{ m s}^{-1}$. The collision between A and B is perfectly elastic.

- (a)** Find the value of v . **[1]**
- (b)** State the kinetic energy lost in the collision between A and B. **[1]**

Two different particles, C and D, move on a smooth horizontal surface. Particle C has a speed of 6.4 m s^{-1} towards D and particle D has a speed of 1.9 m s^{-1} away from C.

After they collide directly, the particles move away from each other. The speed of C after the collision is 0.2 m s^{-1} . The coefficient of restitution between C and D is 0.8.

You are given that the mass of C is 3.5 kg.

- (c)** Determine the mass of D. **[4]**

- 2 (a) (i) State the dimensions of force. [1]
- (ii) State the dimensions of energy. [1]

The surface tension, S , of a liquid can be defined as force per unit length. It can **also** be defined as energy per unit area.

- (b) Show that these two definitions of surface tension are dimensionally consistent with one another. [2]

When a droplet of liquid is placed on a non-absorbent horizontal surface, the maximum height h m of the droplet is modelled by the formula

$$h = \lambda S^\alpha g^\beta \rho^\gamma,$$

where

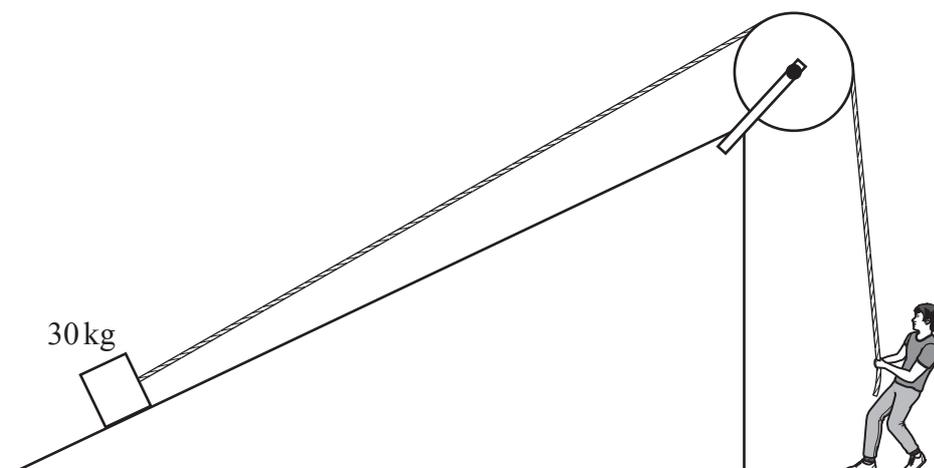
- λ is a dimensionless constant,
- S is the surface tension of the liquid in N m^{-1} ,
- g is the acceleration due to gravity in m s^{-2} ,
- ρ is the density of the liquid in kg m^{-3} .

- (c) Use dimensional analysis to determine the values of α , β and γ . [4]

At room temperature, water has a density of 1 g cm^{-3} and a surface tension of 0.073 N m^{-1} . When a small droplet of water is placed on a non-absorbent horizontal surface, it has maximum height 0.53 cm .

- (d) Find the value of λ . [2]

- 3 The diagram shows a crate of mass 30 kg on a smooth inclined plane. One end of a light inextensible rope is attached to the crate. The rope passes over a smooth pulley which is fixed at the top of the plane. The other end of the rope is held by a worker.



At first, the crate is at rest at a point A on the plane. The worker pulls continuously on the rope so that the crate moves up the plane.

Subsequently, the crate comes to rest, in equilibrium with the rope taut, at a point B on the plane. The vertical distance between A and B is 3.5 m.

- (a) Calculate the work done by the tension in the rope as the crate moves from A to B. [1]

At a point C, which is between A and B on the plane, the rope makes an angle of 12° with AB. The crate passes through C with a speed of 0.8 m s^{-1} . The tension in the rope when the crate is at C is 206 N.

- (b) Calculate the power of the tension in the rope when the crate is at C. [2]

The worker now lets the crate slide back down to A, starting from rest at B. While moving from B to A, 894 J of work is done against the tension in the rope.

- (c) Calculate the speed of the crate when it reaches A. [2]

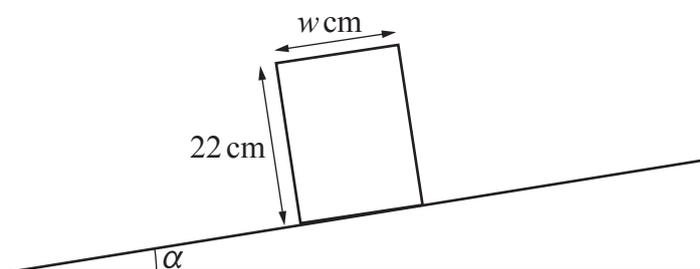
- (d) State **one** limitation of the model that could affect the answer to part (c). [1]

- 4 A block of mass m kg rests on a rough plane inclined at an angle α to the horizontal. The coefficient of friction between the block and the plane is μ . At first the block is in equilibrium, and then α is gradually increased.

- (a) Assuming that the block does not topple first, show that at the point of sliding $\mu = \tan \alpha$. [2]

The block is modelled as a uniform rectangular prism whose cross section has width w cm and height 22 cm. **Fig. 4.1** shows the block placed on the inclined plane so that the cross section contains a line of greatest slope.

Fig. 4.1



The coefficient of friction between the block and the plane is 0.6.

At first, the block is in equilibrium. As α is increased, equilibrium is broken by the block sliding, rather than toppling.

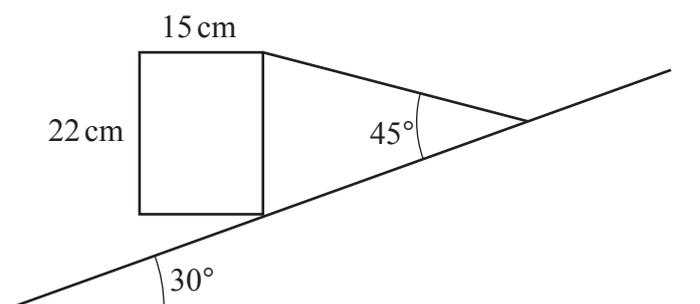
(b) Determine the range of possible values of w . [3]

For the remainder of the question you are given that $w = 15$, $m = 10$ and $\alpha = 30^\circ$.

One end of a light inextensible string is attached to one of the top edges of the block. The other end of the string is attached to a point further up the inclined plane.

The string makes an angle of 45° with the inclined plane so that the block is held in equilibrium with its base horizontal, as shown in **Fig. 4.2**. Both the string and the centre of mass of the block lie in the same vertical plane as a line of greatest slope.

Fig. 4.2

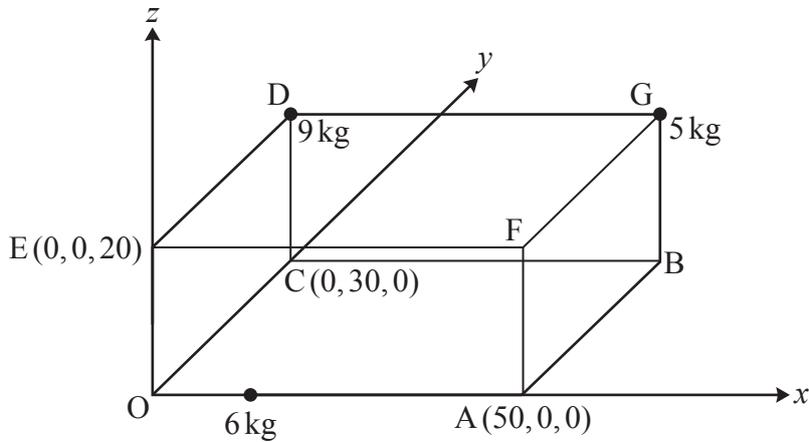


(c) Determine the tension in the string. [3]

(d) Determine the angle between the inclined plane and the total contact force that the inclined plane exerts on the block. [6]

- 5 The diagram shows a cuboid frame OABCDEFG where O is the origin of the coordinate system in which the points A, C and E have coordinates $(50, 0, 0)$, $(0, 30, 0)$ and $(0, 0, 20)$ respectively.

The frame is made of 12 light inextensible rods.



Three particles are attached to the frame as follows:

- A particle of mass 9 kg at D.
- A particle of mass 5 kg at G.
- A particle of mass 6 kg at the point $(\lambda, 0, 0)$ on OA, where $0 \leq \lambda \leq 50$.

The centre of mass of the frame with the three particles attached lies at $(\bar{x}, \bar{y}, \bar{z})$.

(a) Show that $\bar{y} = 21$ and $\bar{z} = 14$. [2]

(b) Find the range of possible values of \bar{x} . [3]

For the remainder of the question, you are given that the particle of mass 6 kg is fixed at A.

The frame is now suspended by two light vertical wires, one attached at O and the other at C. The frame hangs in equilibrium with OC horizontal.

(c) Find the tension in each of the two wires. [3]

(d) Calculate the angle that the plane OABC makes with the downward vertical. [2]

The wire attached to C snaps, and the frame is left suspended in equilibrium only by the vertical wire attached at O.

(e) Calculate the angle that OA now makes with the downward vertical. [2]

- 6 In this question the unit vectors \mathbf{i} and \mathbf{j} are directed horizontally.

Two skaters, Amos and Beth, move on a horizontal ice rink. The masses of Amos and Beth are 70 kg and 50 kg respectively.

At first Amos and Beth move as a single body with velocity $4\mathbf{i} \text{ m s}^{-1}$. Amos then exerts an impulse on Beth of $(35\mathbf{i} + 70\mathbf{j}) \text{ N s}$ so that they move apart with different speeds.

- (a) Determine Beth's speed after separation. [3]
- (b) Determine the total gain in kinetic energy of the two skaters. [3]

On another occasion Amos and Beth are moving as a single body with velocity $(3.5\mathbf{i} + 2.5\mathbf{j}) \text{ m s}^{-1}$.

Amos exerts an impulse on Beth so that they move apart with equal speeds, and Amos travels in the \mathbf{i} direction.

- (c) Determine the possible speeds of the skaters after separation. [6]

END OF QUESTION PAPER

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