

University Physics I · Midterm Examination

Calculus-based mechanics through energy: units, uncertainty and dimensional reasoning; motion in one and two dimensions; force models built from system boundaries and connector constraints; work done by variable forces; and potential-energy landscapes analysed with an explicit system and reference level. Every written question is set so that the model has to be built before anything can be substituted.

SUGGESTED TIME	TOTAL MARKS	QUESTIONS	MULTIPLE CHOICE
90 minutes	73	13	8

SECTION

UPI · Midterm · University Physics I — Midterm examination

IN THE FORMAT OF

A university midterm: conceptual multiple choice, structured problems, a data-analysis question and an extended derivation

DEMAND

Recall 1 · Routine 5 · Demanding 6 · Discriminating 1

Pitched at what a strong course grade requires rather than at what a homework set rehearses. Routine substitutions carry few marks; most sit on problems that have to be set up before they can be solved, on derivations from a named law, and on checking a result against its limits. Every paper still opens with entry points, so you can tell which marks you should be securing first.

COURSE UNITS

UPI-01 · UPI-02 · UPI-03 · UPI-04 · UPI-05 · UPI-06 · UPI-07

INSTRUCTIONS

- Answer all questions in the spaces provided.
- Show your working. Method marks are awarded even where the final answer is wrong.
- Give your answers to a sensible number of significant figures, with a unit.
- The mark scheme for this paper follows the last question.

Written by GioPhysics from its own University Physics course maps. These are practice examinations in a university style: they are not the examinations of any university, contain no past-paper questions, and carry no academic credit. For a course you are taking, your instructor's syllabus and past papers remain the authority.

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University Physics I · Midterm Examination

Answer all questions. 73 marks in 90 minutes.

1 MULTIPLE CHOICE · ROUTINE · UPI-01.02 [1]

CORE COURSE

A heavy, flexible rope of length L hangs freely from a hook. A small sideways flick at its lower end sends a pulse up the rope. A student proposes that the time t for the pulse to reach the hook depends only on L , the gravitational acceleration g (in m/s^2) and the rope's mass per unit length μ (in kg/m), in the form $t = C L^a g^b \mu^c$, where C is a dimensionless constant. Which exponents does dimensional analysis require?

- A $a = \frac{1}{2}, b = -\frac{1}{2}, c = 0$
- B $a = \frac{1}{2}, b = -\frac{1}{2}, c = \frac{1}{2}$
- C $a = -\frac{1}{2}, b = \frac{1}{2}, c = 0$
- D $a = \frac{1}{2}, b = \frac{1}{2}, c = 0$

Answer

2 MULTIPLE CHOICE · ROUTINE · UPI-01.03 [1]

CORE COURSE

To find the average speed of a trolley, a student measures the distance between two marks on a bench as $(1.250 \pm 0.005) \text{ m}$ and times the trolley between the marks as $(0.50 \pm 0.02) \text{ s}$. Which result is reported correctly?

- A $(2.500 \pm 0.025) \text{ m/s}$
- B $(2.50 \pm 0.25) \text{ m/s}$
- C $(2.50 \pm 0.01) \text{ m/s}$
- D $(2.5 \pm 0.1) \text{ m/s}$

Answer

3 MULTIPLE CHOICE · ROUTINE · UPI-02.01 · UPI-02.07 [1]

CORE COURSE

A cart moves along a straight track with velocity $v(t) = (6.0 - 2.0t) \text{ m/s}$, where t is in seconds, for $0 \leq t \leq 5.0 \text{ s}$. What distance does the cart travel in this interval?

- A 5.0 m
- B 9.0 m
- C 13 m
- D 30 m

Answer

4CORE
COURSE

MULTIPLE CHOICE · ROUTINE · UPI-03.03

[1]

A survey drone flies at 12.0 m/s relative to the air. A steady wind blows towards the east at 5.0 m/s relative to the ground. The pilot points the drone so that its path over the ground runs due north. What is the drone's speed relative to the ground?

- A 7.0 m/s
- B 10.9 m/s
- C 13.0 m/s
- D 17.0 m/s

Answer

5CORE
COURSE

MULTIPLE CHOICE · RECALL · UPI-04.04

[1]

A small magnet is held motionless on a vertical steel door. The door attracts it horizontally, and friction stops it sliding down. Which force is the Newton's-third-law partner of the upward friction force that the door exerts on the magnet?

- A The weight of the magnet: the downward gravitational force of the Earth on the magnet
- B The normal force that the door exerts on the magnet
- C The downward friction force that the magnet exerts on the door
- D The magnetic attraction that the door exerts on the magnet

Answer

6CORE
COURSE

MULTIPLE CHOICE · ROUTINE · UPI-05.04

[1]

A 62.0 kg passenger stands on bathroom scales in a lift. The lift is moving downwards and slowing down at 1.40 m/s^2 . What do the scales read? Take $g = 9.81 \text{ m/s}^2$.

- A 695 N
- B 608 N
- C 521 N
- D 86.8 N

Answer

7CORE
COURSE

MULTIPLE CHOICE · DEMANDING · UPI-03.05 · UPI-05.05

[1]

A child on a playground swing is at the highest point of her swing, momentarily at rest, with the taut ropes at an angle to the vertical. Treat the child as a particle on a light rope of fixed length. What is the direction of her acceleration at that instant?

- A She has no acceleration, because her velocity is zero.
- B Vertically downwards, with magnitude g .
- C Along the rope, towards the pivot.
- D Perpendicular to the rope, along the arc towards the lowest point.

Answer

A particle moves along the x -axis under a single conservative force. Its potential energy is $U(x) = (3.0 \text{ J/m}^2)x^2 - (1.0 \text{ J/m}^3)x^3$, which has a minimum $U = 0$ at $x = 0$ and a maximum $U = 4.0 \text{ J}$ at $x = 2.0 \text{ m}$. The particle is released from rest at $x = -0.80 \text{ m}$. Which statement describes its subsequent motion?

- A** It oscillates between $x = -0.80 \text{ m}$ and $x = +0.80 \text{ m}$, because turning points lie equal distances either side of a minimum.
- B** It oscillates between $x = -0.80 \text{ m}$ and a turning point that lies between $x = +0.80 \text{ m}$ and $x = +2.0 \text{ m}$.
- C** It passes $x = +2.0 \text{ m}$ and moves off towards large positive x .
- D** It moves to $x = 0$, where U is least, and remains at rest there.

Answer

A campus fountain has its nozzle at ground level. The designer wants each jet of water to reach the highest point of its path exactly at the centre of a decorative ring, which is $H = 1.80$ m above the nozzle and $d = 3.00$ m from it horizontally. A low wall 0.60 m high stands 5.40 m horizontally from the nozzle, in the vertical plane of the jet, on the far side of the ring. Treat each parcel of water as a projectile launched from the nozzle at speed v_0 and angle θ above the horizontal, with no air resistance. Take $g = 9.81$ m/s².

(a) SHOW THAT

[3]

Show that the launch angle must satisfy $\tan \theta = 2H/d$.

(b) CALCULATE

[3]

Calculate the launch angle θ and the launch speed v_0 .

(c) EXPLAIN

[2]

Explain why the launch angle in (a) does not depend on g , whereas the launch speed in (b) does.

(d) DETERMINE

[2]

Determine the height of the jet as it passes the position of the wall, and state whether the jet clears the wall.

(e) PREDICT

[2]

In service, a partly blocked filter reduces the launch speed by 2.0% while the launch angle stays the same. Predict whether the jet still clears the wall, supporting your prediction with a calculation.

Block A, of mass $m_A = 4.00$ kg, rests on a horizontal bench. A light inextensible cord is tied to A and runs horizontally to a light, frictionless pulley fixed at the edge of the bench. From that pulley the cord hangs vertically downwards, passes under a second light, frictionless pulley that is free to move, and rises vertically to a hook fixed to the underside of the bench top, so the two vertical sections of cord are parallel. Load B, of mass $m_B = 6.00$ kg, hangs from the axle of the movable pulley. The coefficients of friction between A and the bench are $\mu_s = 0.50$ (static) and $\mu_k = 0.35$ (kinetic). The system is released from rest. Take $g = 9.81$ m/s².

(a) EXPLAIN

[2]

Explain why the magnitude of B's acceleration is half the magnitude of A's acceleration.

(b) DETERMINE

[3]

Determine the smallest mass of B that would set A in motion from rest, and hence confirm that A moves when the 6.00 kg load is used.

(c) DETERMINE

[5]

Determine the acceleration of A, the acceleration of B and the tension in the cord while the system is moving.

(d) EVALUATE

[3]

A student treats A and B together as a single system and writes $m_B g - \mu_k m_A g = (m_A + m_B)a$. Evaluate this equation as a model of the motion.

A loaded truck of mass $m = 1.80 \times 10^4$ kg loses its brakes on a mountain road and enters an emergency arrester bed at $v_0 = 25.0$ m/s. The bed is a straight lane of loose gravel that rises uphill at a constant angle $\theta = 5.0^\circ$ to the horizontal. The gravel gets deeper along the bed, and it exerts a resistive force on the truck, parallel to the slope and opposite to the motion, of magnitude $F = \mu(s)mg \cos \theta$, where s is the distance travelled along the bed and $\mu(s) = \mu_0 + \beta s$, with $\mu_0 = 0.20$ and $\beta = 5.0 \times 10^{-3} \text{ m}^{-1}$. Treat the truck as a particle and ignore air resistance. Take $g = 9.81 \text{ m/s}^2$.

(a) DERIVE

[3]

Starting from the definition of work, derive an expression for the work done on the truck by the gravel as the truck travels a distance s along the bed.

(b) SHOW THAT

[2]

Show that the stopping distance s satisfies $\frac{1}{2}v_0^2 = gs \sin \theta + g \cos \theta(\mu_0 s + \frac{1}{2}\beta s^2)$.

(c) CALCULATE

[2]

Calculate the stopping distance.

(d) DETERMINE

[2]

Determine the percentage of the truck's initial kinetic energy that is stored as gravitational potential energy and the percentage that is dissipated in the gravel.

(e) EVALUATE

[2]

A highway engineer argues that a heavier truck needs a longer arrester bed. Evaluate this argument, first within the model and then for a real bed.

A cyclist rides a bicycle fitted with a power meter along a level road on a windless day. At each of six steady speeds v she records the power P that she delivers to the rear wheel. A model of the total resistance on the rider and bicycle is $F = F_r + kv^2$, where F_r is a constant rolling resistance and kv^2 is aerodynamic drag, with k constant. Take $g = 9.81 \text{ m/s}^2$.

Steady-speed readings on a level road

Trial	Speed v (m/s)	Power P (W)
1	4.0	29
2	6.0	68
3	8.0	133
4	10.0	243
5	12.0	390
6	14.0	608

(a) **EXPLAIN**

[2]

Explain why, at a steady speed on a level road, the model predicts that $P = (F_r + kv^2)v$.

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(b) **DETERMINE**

[4]

By processing the data so that the model predicts a straight line, determine F_r and k .

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(c) **COMPARE**

[2]

A second student proposes that rolling resistance is negligible, so that $P = kv^3$. Compare how well this model and the two-term model account for the data.

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(d) **ESTIMATE**

[2]

Estimate the coefficient of rolling resistance $C_r = F_r/N$, where N is the normal force of the road on the bicycle and rider, stating the assumption you make.

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(e) DESCRIBE

[2]

Describe two changes to the procedure that would reduce the uncertainty in the value of F_r .

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13
CORE
COURSE

FREE RESPONSE · MODEL, SOLVE AND CHECK THE LIMITS · DISCRIMINATING · UPI-01.07 · UPI-07.03 · UPI-07.04 · UPI-07.05 · UPI-07.06

[17]

A snap-action switch is modelled as a slider of mass m that moves without friction along a straight horizontal rail, taken as the x -axis. A light spring of stiffness k and natural length L_0 joins the slider to a fixed pivot at perpendicular distance a from the rail, and the foot of that perpendicular is at $x = 0$. The pivot is closer to the rail than the spring's natural length, so $a < L_0$. Take the elastic potential energy of the spring to be zero at its natural length. Gravity and the normal force of the rail are perpendicular to the rail and do no work on the slider.

(a) DERIVE

[2]

Starting from the elastic potential energy of a spring, $\frac{1}{2}k \times (\text{extension})^2$, derive an expression for the potential energy $U(x)$ of the system when the slider is at position x .

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(b) DERIVE

[3]

Using the relation between a conservative force and its potential-energy function, derive an expression for the component $F_x(x)$ of the force on the slider along the rail.

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(c) DETERMINE

[2]

Determine all the equilibrium positions of the slider.

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(d) JUSTIFY

[2]

Justify, for each equilibrium position, whether it is stable or unstable.

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- (e) **SKETCH** [3]

Sketch $U(x)$ against x over a range that includes all the equilibrium positions, marking each position and the value of U there.

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- (f) **CALCULATE** [3]

For a switch with $k = 250 \text{ N/m}$, $L_0 = 50.0 \text{ mm}$, $a = 40.0 \text{ mm}$ and $m = 20.0 \text{ g}$, calculate the positions of the two stable states and the minimum speed the slider must have as it passes through one stable state if it is to reach the other.

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- (g) **PREDICT** [2]

The pivot is moved further from the rail until $a \geq L_0$. Predict how the switch now behaves, reasoning from the energy landscape.

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University Physics I · Midterm Examination — mark scheme

One line per mark, as an examiner would award them. A note under a part is the error that part is set to catch.

- 1** MULTIPLE CHOICE · ROUTINE · UPI-01.02 **[1]**
CORE COURSE
- A heavy, flexible rope of length L hangs freely from a hook. A small sideways flick at its lower end sends a pulse up the rope. A student proposes that the time t for the pulse to reach the hook depends only on L , the gravitational acceleration g (in m/s^2) and the rope's mass per unit length μ (in kg/m), in the form $t = C L^a g^b \mu^c$, where C is a dimensionless constant. Which exponents does dimensional analysis require?

KEY A $a = \frac{1}{2}$, $b = -\frac{1}{2}$, $c = 0$

Only μ contains the kilogram, so nothing else can cancel it and c must be 0; matching seconds then needs $b = -\frac{1}{2}$, and matching metres needs $a = \frac{1}{2}$, giving $t = C\sqrt{L/g}$. B is tempting because a heavier rope feels as though it ought to change the time, but a non-zero c leaves $\text{kg}^{\frac{1}{2}}$ uncanceled — and physically the tension at each height grows in proportion to μ , so the mass per unit length drops out of the pulse speed. C is what a candidate obtains by writing the dimensions of g as $\text{m}\cdot\text{s}^{-2}$ instead of $\text{m}\cdot\text{s}^{-2}$; matching seconds then gives $b = \frac{1}{2}$ and matching metres gives $a = -\frac{1}{2}$, and the resulting $\sqrt{g/L}$ has the dimensions of a frequency, s^{-1} , not of a time. D is $\sqrt{gL}$, which has the dimensions of a speed: it is what a candidate writes who remembers that wave speeds on hanging ropes look like $\sqrt{gL}$ and forgets that the question asks for a time.

U2

- 2** MULTIPLE CHOICE · ROUTINE · UPI-01.03 **[1]**
CORE COURSE
- To find the average speed of a trolley, a student measures the distance between two marks on a bench as $(1.250 \pm 0.005) \text{ m}$ and times the trolley between the marks as $(0.50 \pm 0.02) \text{ s}$. Which result is reported correctly?

KEY D $(2.5 \pm 0.1) \text{ m/s}$

For a quotient the fractional uncertainties combine: $0.005/1.250$ is 0.4 % and $0.02/0.50$ is 4 %, so the speed carries about 4 % of 2.5 m/s, which is $\pm 0.1 \text{ m/s}$ whether the two are added (0.11 m/s) or combined in quadrature (0.10 m/s); with a one-figure uncertainty the value is quoted to the same decimal place, 2.5 m/s. A adds the two absolute uncertainties, 0.005 m and 0.02 s, which have different units and cannot be added at all. B divides one uncertainty by the other, as though the uncertainty of a ratio were the ratio of the uncertainties. C propagates only the distance's 0.4 %, the tempting choice because the distance is written to more decimal places — but the timing uncertainty is ten times larger as a fraction and dominates the result.

U4

- 3** MULTIPLE CHOICE · ROUTINE · UPI-02.01 · UPI-02.07 **[1]**
CORE COURSE
- A cart moves along a straight track with velocity $v(t) = (6.0 - 2.0t) \text{ m/s}$, where t is in seconds, for $0 \leq t \leq 5.0 \text{ s}$. What distance does the cart travel in this interval?

KEY C **13 m**

The velocity changes sign at $t = 3.0 \text{ s}$, so the distance is the integral of the speed $|v|$: $\int_0^3 (6.0 - 2.0t) dt = 9.0 \text{ m}$ forwards, and $\int_3^5 (6.0 - 2.0t) dt = -4.0 \text{ m}$, which is 4.0 m backwards, for a total of 13 m. A is the displacement, $\int_0^5 v dt = 5.0 \text{ m}$, in which the return leg cancels part of the outward one. B counts only the outward leg — the answer of a candidate who finds the turning point and stops there. D multiplies the initial speed by the whole interval, as though the velocity were constant.

U3

4

CORE
COURSE

MULTIPLE CHOICE · ROUTINE · UPI-03.03

[1]

A survey drone flies at 12.0 m/s relative to the air. A steady wind blows towards the east at 5.0 m/s relative to the ground. The pilot points the drone so that its path over the ground runs due north. What is the drone's speed relative to the ground?

KEY **B 10.9 m/s**

The ground velocity is the vector sum of the velocity relative to the air and the wind velocity. To cancel the eastward wind the drone must head partly west, so its 12.0 m/s airspeed is the hypotenuse of a right triangle whose east-west leg is 5.0 m/s, and the northward ground speed is $\sqrt{(12.0^2 - 5.0^2)} = 10.9$ m/s. C treats 12.0 m/s as the northward leg and adds the wind at right angles, which is the ground speed if the drone points due north and is allowed to drift east — not the path the pilot is holding. A and D subtract and add the speeds as though the wind blew along the line of flight.

U3

5

CORE
COURSE

MULTIPLE CHOICE · RECALL · UPI-04.04

[1]

A small magnet is held motionless on a vertical steel door. The door attracts it horizontally, and friction stops it sliding down. Which force is the Newton's-third-law partner of the upward friction force that the door exerts on the magnet?

KEY **C The downward friction force that the magnet exerts on the door**

A third-law pair is one interaction seen from each side: the same type of force, acting on the two different objects involved. The door's friction on the magnet therefore partners the magnet's friction on the door, which points down. A is the tempting answer because the weight is equal and opposite to the friction force here — but both of those forces act on the magnet, and they balance because the magnet is in equilibrium, which is the first law at work, not the third; the weight's own partner is the magnet's gravitational pull on the Earth. B is tempting because the normal force and the friction are the two components of the single contact force the door exerts, so they feel like a matched pair; but both act on the magnet and they are perpendicular, not opposite. D is tempting because the magnetic attraction is what presses the magnet against the door and so makes the friction possible; but it too acts on the magnet, is horizontal, and belongs to the magnetic interaction, whose partner is the magnet's pull on the door.

U1

6

CORE
COURSE

MULTIPLE CHOICE · ROUTINE · UPI-05.04

[1]

A 62.0 kg passenger stands on bathroom scales in a lift. The lift is moving downwards and slowing down at 1.40 m/s². What do the scales read? Take $g = 9.81$ m/s².

KEY **A 695 N**

Slowing down while moving downwards means the acceleration points upwards. Taking up as positive, $N - mg = ma$, so $N = m(g + a) = 62.0 \times (9.81 + 1.40) = 695$ N. C is $m(g - a)$, the reading for a lift that is speeding up on the way down — the answer of a candidate who takes the direction of the acceleration from the direction of motion. B is the reading at rest or at constant velocity, and D is ma alone, as though the scales measured only the net force.

U3

7

CORE
COURSE

MULTIPLE CHOICE · DEMANDING · UPI-03.05 · UPI-05.05

[1]

A child on a playground swing is at the highest point of her swing, momentarily at rest, with the taut ropes at an angle to the vertical. Treat the child as a particle on a light rope of fixed length. What is the direction of her acceleration at that instant?

KEY D Perpendicular to the rope, along the arc towards the lowest point.

The radial component of acceleration is v^2/r , which is zero when $v = 0$, so the tension exactly balances the component of the weight along the rope, $T = mg \cos \theta$. What is left is the component $mg \sin \theta$ perpendicular to the rope, so the acceleration is $g \sin \theta$ along the tangent to the arc, towards the bottom of the swing. A confuses zero velocity with zero acceleration — she is at rest for an instant only. B would be right if the rope went slack; with the rope taut the tension is not zero, so gravity is not the only force. C is the reflex that circular motion means acceleration towards the centre, which holds only when the speed is not changing — here the speed is changing and the radial part has vanished.

U1

8

CORE
COURSE

MULTIPLE CHOICE · DEMANDING · UPI-07.05 · UPI-07.06

[1]

A particle moves along the x-axis under a single conservative force. Its potential energy is $U(x) = (3.0 \text{ J/m}^2)x^2 - (1.0 \text{ J/m}^3)x^3$, which has a minimum $U = 0$ at $x = 0$ and a maximum $U = 4.0 \text{ J}$ at $x = 2.0 \text{ m}$. The particle is released from rest at $x = -0.80 \text{ m}$. Which statement describes its subsequent motion?

KEY B It oscillates between $x = -0.80 \text{ m}$ and a turning point that lies between $x = +0.80 \text{ m}$ and $x = +2.0 \text{ m}$.

The total energy is fixed at $U(-0.80 \text{ m}) = 1.92 + 0.51 = 2.43 \text{ J}$. At $x = +0.80 \text{ m}$, $U = 1.92 - 0.51 = 1.41 \text{ J}$, which is less than 2.43 J , so the particle still has kinetic energy there and has not reached a turning point; and because 2.43 J is below the 4.0 J maximum it turns back before $x = 2.0 \text{ m}$ (at about $x = 1.15 \text{ m}$). A assumes the well is symmetric, but the x^3 term makes it shallower on the positive side. C tempts a candidate who sees the particle cross $x = 0$ with all 2.43 J as kinetic energy and supposes nothing can stop it, but U rises again beyond $x = 0$, and escaping past $x = 2.0 \text{ m}$ would need a total energy greater than 4.0 J . D confuses the position of least potential energy, where the speed is greatest, with a place where the particle stops; with no dissipation it passes through $x = 0$ at its maximum speed.

U1

9

CORE
COURSE

STRUCTURED · DEMANDING · UPI-03.02 · UPI-03.07 · UPI-03.08

[12]

A campus fountain has its nozzle at ground level. The designer wants each jet of water to reach the highest point of its path exactly at the centre of a decorative ring, which is $H = 1.80 \text{ m}$ above the nozzle and $d = 3.00 \text{ m}$ from it horizontally. A low wall 0.60 m high stands 5.40 m horizontally from the nozzle, in the vertical plane of the jet, on the far side of the ring. Treat each parcel of water as a projectile launched from the nozzle at speed v_0 and angle θ above the horizontal, with no air resistance. Take $g = 9.81 \text{ m/s}^2$.

(a) SHOW THAT · U2

[3]

Show that the launch angle must satisfy $\tan \theta = 2H/d$.

- 1 At the highest point the vertical velocity is zero, so the time to reach it is $t_1 = v_0 \sin \theta / g$ and the height is $H = (v_0 \sin \theta)^2 / (2g)$, equivalently $H = \frac{1}{2}gt_1^2$
- 2 The horizontal velocity is constant, so $d = (v_0 \cos \theta)t_1$
- 3 $\tan \theta = (v_0 \sin \theta) / (v_0 \cos \theta) = gt_1 / (d/t_1) = gt_1^2 / d = 2H/d$

Candidates who aim the nozzle straight at the ring write $\tan \theta = H/d$, treating the jet as though it travelled in a straight line. The factor of 2 is the whole content of the result, which is why it is given: the part rewards the route, not the answer.

- (b) **CALCULATE** · U3 [3]
- Calculate the launch angle θ and the launch speed v_0 .
- 1 $\tan \theta = 2 \times 1.80/3.00 = 1.20$, so $\theta = 50.2^\circ$
 - 2 Vertical component $v_0 \sin \theta = \sqrt{2gH} = \sqrt{2 \times 9.81 \times 1.80} = 5.94$ m/s; time to the top $t_1 = 5.94/9.81 = 0.606$ s, so horizontal component $v_0 \cos \theta = 3.00/0.606 = 4.95$ m/s
 - 3 $v_0 = \sqrt{5.94^2 + 4.95^2} = 7.74$ m/s
- The usual slip is to obtain 5.94 m/s from $\sqrt{2gH}$ and report it as the launch speed. It is only the vertical component; the horizontal component is fixed separately by the requirement that the top of the path lies 3.00 m away.*
- (c) **EXPLAIN** · U1 [2]
- Explain why the launch angle in (a) does not depend on g , whereas the launch speed in (b) does.
- 1 The path of a projectile is a parabola, and a parabola that starts at the nozzle and has its vertex at the point (d, H) is fixed by those two points alone, so its initial slope $\tan \theta = 2H/d$ is set by geometry
 - 2 g sets only how quickly the water travels along that parabola: a larger g needs larger velocity components for the same path ($v_0 \sin \theta = \sqrt{2gH}$), so $v_0 \propto \sqrt{g}$, leaving the direction unchanged
- The part catches candidates who offer 'g cancels in the algebra' as an explanation. The credit is for saying what g does and does not control — the time scale of the motion, not the shape of the path.*
- (d) **DETERMINE** · U3 [2]
- Determine the height of the jet as it passes the position of the wall, and state whether the jet clears the wall.
- 1 Using the symmetry of the parabola about $x = d$, $y = H[1 - ((x - d)/d)^2] = 1.80 \times [1 - (2.40/3.00)^2] = 0.648$ m (or, with unrounded components, $t = 5.40/4.952 = 1.090$ s and $y = 5.943t - 4.905t^2 = 0.648$ m; accept 0.64 m to 0.65 m from rounded intermediate values)
 - 2 0.648 m is greater than 0.60 m, so the jet clears the wall, but only by about 0.05 m (4.8 cm)
- Candidates who note that the jet lands at $2d = 6.00$ m and conclude that anything nearer is safe have ignored the height of the wall. The size of the margin, not the yes or no, is what part (e) depends on.*
- (e) **PREDICT** · U3 [2]
- In service, a partly blocked filter reduces the launch speed by 2.0 % while the launch angle stays the same. Predict whether the jet still clears the wall, supporting your prediction with a calculation.
- 1 The trajectory is $y = x \tan \theta - gx^2/(2v_0^2 \cos^2 \theta)$; at $x = 5.40$ m the first term is 6.48 m and the gravitational drop term is 5.83 m, which scales as $1/v_0^2$ and so grows by a factor $1/0.98^2 = 1.041$ to 6.07 m
 - 2 $y = 6.48 - 6.07 = 0.41$ m, below the 0.60 m wall, so the jet now strikes the wall: a 2 % loss of speed lowers the jet at the wall by about 0.24 m
- Most candidates expect a 2 % change in speed to change the height by about 2 %. At the wall the drop term nearly cancels the rise term, so their small difference is extremely sensitive to v_0 — the design weakness the question is set to expose.*

Block A, of mass $m_A = 4.00$ kg, rests on a horizontal bench. A light inextensible cord is tied to A and runs horizontally to a light, frictionless pulley fixed at the edge of the bench. From that pulley the cord hangs vertically downwards, passes under a second light, frictionless pulley that is free to move, and rises vertically to a hook fixed to the underside of the bench top, so the two vertical sections of cord are parallel. Load B, of mass $m_B = 6.00$ kg, hangs from the axle of the movable pulley. The coefficients of friction between A and the bench are $\mu_s = 0.50$ (static) and $\mu_k = 0.35$ (kinetic). The system is released from rest. Take $g = 9.81$ m/s².

(a) EXPLAIN · U1

[2]

Explain why the magnitude of B's acceleration is half the magnitude of A's acceleration.

- 1 If A moves a distance s towards the edge, the horizontal section of cord shortens by s , so, because the cord is inextensible, the combined length of the two vertical sections increases by s
- 2 That extra length is shared equally by the two vertical sections that support the movable pulley, so B descends $s/2$; differentiating twice with respect to time gives $a_B = a_A/2$

Candidates who assume that everything on one cord shares one acceleration are applying a rule that holds only for a cord over fixed pulleys. The relation has to be derived from the length of the cord, and a candidate who skips that step carries the wrong acceleration into every later part.

(b) DETERMINE · U2

[3]

Determine the smallest mass of B that would set A in motion from rest, and hence confirm that A moves when the 6.00 kg load is used.

- 1 With the system at rest, the light movable pulley is in equilibrium under two upward tensions and B's weight, so $2T = m_B g$
- 2 A stays at rest only if the friction it needs, which equals T , does not exceed $\mu_s m_A g = 0.50 \times 4.00 \times 9.81 = 19.6 \text{ N}$
- 3 Motion starts if $m_B g/2 > \mu_s m_A g$, that is $m_B > 2\mu_s m_A = 4.00 \text{ kg}$; 6.00 kg exceeds this (it would need $T = 29.4 \text{ N}$), so A moves

The common error is to compare B's whole weight, 58.9 N, with the maximum static friction. The movable pulley halves the pull the cord exerts on A, and a candidate who misses it predicts motion for any load above 2.00 kg.

(c) DETERMINE · U3

[5]

Determine the acceleration of A, the acceleration of B and the tension in the cord while the system is moving.

- 1 For A, horizontally: $T - \mu_k m_A g = m_A a_A$, where $\mu_k m_A g = 0.35 \times 4.00 \times 9.81 = 13.7 \text{ N}$
- 2 For B together with the movable pulley, vertically: $m_B g - 2T = m_B a_B$, with $a_B = a_A/2$
- 3 Eliminating T : $a_A = g(m_B - 2\mu_k m_A)/(2m_A + m_B/2) = 9.81 \times 3.20/11.00 = 2.85 \text{ m/s}^2$
- 4 $a_B = a_A/2 = 1.43 \text{ m/s}^2$, downwards
- 5 $T = \mu_k m_A g + m_A a_A = 13.7 \text{ N} + 11.4 \text{ N} = 25.1 \text{ N}$ (check on B with unrounded values: $58.86 \text{ N} - 2 \times 25.15 \text{ N} = 8.56 \text{ N}$, and $6.00 \text{ kg} \times 1.427 \text{ m/s}^2 = 8.56 \text{ N}$)

Two errors dominate: writing $m_B g - T = m_B a$ for B, which leaves out one of the two sections of cord holding the pulley up, and giving both bodies the same acceleration. Each produces a plausible-looking number, which is why substituting back into B's equation is worth doing.

(d) EVALUATE · U1

[3]

A student treats A and B together as a single system and writes $m_B g - \mu_k m_A g = (m_A + m_B)a$. Evaluate this equation as a model of the motion.

- 1 The equation gives both bodies one acceleration a , but $a_B = a_{A/2}$, and A accelerates horizontally while B accelerates vertically, so $(m_A + m_B)a$ is not the rate of change of the system's momentum
- 2 It treats the tension as internal and lets it cancel, but the hook and the fixed pulley lie outside the system and exert forces on the cord, so external forces are missing from the left-hand side (equally creditworthy: the cord pulls A with T but supports B with $2T$, so the tension forces do not cancel)
- 3 It predicts $a = 9.81 \times (6.00 - 1.40)/10.00 = 4.51 \text{ m/s}^2$, far above the correct 2.85 m/s^2 , so the equation is not a valid model of this arrangement

A system boundary is a free choice, but Newton's second law for a system then needs every external force on it and the acceleration of every part. Candidates who defend the equation because 'tension is internal' have not asked what the hook is doing.

11
CORE
COURSE

STRUCTURED · DEMANDING · UPI-06.02 · UPI-06.03 · UPI-07.01 · UPI-07.02 · UPI-07.07

[11]

A loaded truck of mass $m = 1.80 \times 10^4 \text{ kg}$ loses its brakes on a mountain road and enters an emergency arrester bed at $v_0 = 25.0 \text{ m/s}$. The bed is a straight lane of loose gravel that rises uphill at a constant angle $\theta = 5.0^\circ$ to the horizontal. The gravel gets deeper along the bed, and it exerts a resistive force on the truck, parallel to the slope and opposite to the motion, of magnitude $F = \mu(s)mg \cos \theta$, where s is the distance travelled along the bed and $\mu(s) = \mu_0 + \beta s$, with $\mu_0 = 0.20$ and $\beta = 5.0 \times 10^{-3} \text{ m}^{-1}$. Treat the truck as a particle and ignore air resistance. Take $g = 9.81 \text{ m/s}^2$.

(a) DERIVE · U2

[3]

Starting from the definition of work, derive an expression for the work done on the truck by the gravel as the truck travels a distance s along the bed.

- 1 The force varies with position, so $W = \int_0^s \mathbf{F} \cdot d\mathbf{s}'$ with the force antiparallel to the displacement: $W = -\int_0^s (\mu_0 + \beta s')mg \cos \theta ds'$
- 2 Integrating term by term: $W = -mg \cos \theta [\mu_0 s' + \frac{1}{2}\beta s'^2]$ evaluated from 0 to s
- 3 $W_{\text{gravel}} = -mg \cos \theta (\mu_0 s + \frac{1}{2}\beta s^2)$

Candidates who multiply the force at the entry point, or at the far end, by the distance have used the constant-force rule on a force that nearly triples along the bed. Setting up the integral, with its sign, is the point of the part.

(b) SHOW THAT · U2

[2]

Show that the stopping distance s satisfies $\frac{1}{2}v_0^2 = gs \sin \theta + g \cos \theta (\mu_0 s + \frac{1}{2}\beta s^2)$.

- 1 Gravity does work $-mgs \sin \theta$ as the truck rises a height $s \sin \theta$, and the normal force does no work because it is perpendicular to the displacement
- 2 The work-kinetic energy theorem, $W_{\text{net}} = 0 - \frac{1}{2}mv_0^2$, gives $-mgs \sin \theta - mg \cos \theta (\mu_0 s + \frac{1}{2}\beta s^2) = -\frac{1}{2}mv_0^2$, and dividing by m gives the stated result

Two errors recur: adding work by the normal force to the net work, and giving gravity's work the wrong sign so that it adds kinetic energy on an uphill slope. The stated result exposes both, since neither version reproduces it.

(c) CALCULATE · U3

[2]

Calculate the stopping distance.

- 1 With $g \sin \theta = 0.855 \text{ m/s}^2$ and $g \cos \theta = 9.77 \text{ m/s}^2$, the equation becomes $0.0244s^2 + 2.81s - 312.5 = 0$, with s in metres
- 2 The physical, positive root is $s = 69.4 \text{ m}$

The quadratic also has a root at -184 m , which candidates sometimes report as 184 m . It has no meaning here: s is measured forwards from the entry point, and the model only describes the truck while it is moving forwards.

(d) DETERMINE · U3

[2]

Determine the percentage of the truck's initial kinetic energy that is stored as gravitational potential energy and the percentage that is dissipated in the gravel.

- 1 Gravitational potential energy gained = $mgs \sin \theta = 1.80 \times 10^4 \times 0.855 \times 69.4 = 1.07 \times 10^6 \text{ J}$, which is 19.0 % of the initial kinetic energy $\frac{1}{2}mv_o^2 = 5.63 \times 10^6 \text{ J}$
- 2 The remaining $4.56 \times 10^6 \text{ J}$, 81.0 %, is dissipated by the gravel's nonconservative force as thermal energy and deformation of the bed

The part separates the conservative interaction, whose work is stored and could be returned, from the dissipative one. Candidates who say that all the kinetic energy is dissipated have treated the whole slope as friction.

(e) EVALUATE · U1

[2]

A highway engineer argues that a heavier truck needs a longer arrester bed. Evaluate this argument, first within the model and then for a real bed.

- 1 Within the model both forces along the slope, the gravel's resistance and the weight component, are proportional to m , so m cancels from the work-energy equation and the stopping distance is independent of mass: the model does not support the argument
- 2 A real bed has effects that do not scale with m — air resistance, set by the truck's size and speed, slows a heavier truck less and would lengthen its stop, while a heavier truck sinks deeper and meets a larger μ , which would shorten it — so the argument could hold only through such an unmodelled effect, and it must be tested rather than assumed

Candidates tend either to accept the argument on intuition ('more momentum to stop') or to reject it outright because 'mass cancels'. The credit goes to the answer that sees the cancellation as a consequence of the model's assumptions and names what would break it.

12
CORE
COURSE

DATA ANALYSIS · DEMANDING · UPI-01.08 · UPI-01.09 · UPI-05.06 · UPI-06.06

[12]

A cyclist rides a bicycle fitted with a power meter along a level road on a windless day. At each of six steady speeds v she records the power P that she delivers to the rear wheel. A model of the total resistance on the rider and bicycle is $F = F_r + kv^2$, where F_r is a constant rolling resistance and kv^2 is aerodynamic drag, with k constant. Take $g = 9.81 \text{ m/s}^2$.

(a) EXPLAIN · U1

[2]

Explain why, at a steady speed on a level road, the model predicts that $P = (F_r + kv^2)v$.

- 1 At constant velocity the acceleration is zero, so by Newton's second law the forward driving force equals the total resistive force $F_r + kv^2$
- 2 The power delivered by a force is $P = F \cdot v$; the driving force is parallel to the velocity, so $P = (F_r + kv^2)v$

Candidates often look for a change in kinetic energy to account for the power. At steady speed there is none: all of the power goes into doing work against the resistance.

- (b) DETERMINE · U4 [4]
- By processing the data so that the model predicts a straight line, determine F_r and k .
- 1 Rearranges the model to $P/v = F_r + kv^2$, so a graph of P/v against v^2 should be a straight line with gradient k and intercept F_r
 - 2 Calculates $P/v = 7.25, 11.3, 16.6, 24.3, 32.5$ and 43.4 N for $v^2 = 16, 36, 64, 100, 144$ and 196 m²/s²
 - 3 Gradient of a best-fit line through all six points: $k = 0.200$ kg/m (accept 0.19 to 0.21 kg/m)
 - 4 Intercept: $F_r = 4.0$ N (accept 3.5 to 4.5 N)
- Plotting P against v gives a curve from which neither constant can be read, and plotting P against v^3 discards the rolling term; dividing by v is the step being rewarded. A gradient taken from two neighbouring points rather than from a line through all six is the usual source of values outside the accepted range — neighbouring pairs give intercepts anywhere from 2.2 N to 5.7 N.*
- (c) COMPARE · U4 [2]
- A second student proposes that rolling resistance is negligible, so that $P = kv^3$. Compare how well this model and the two-term model account for the data.
- 1 In the pure-drag model P/v^3 should be constant, but it falls steadily from 0.453 kg/m at 4.0 m/s to 0.222 kg/m at 14.0 m/s: a systematic trend, not random scatter
 - 2 In the two-term model the values of P/v lie close to a straight line, with residuals within about ± 0.35 N that are scattered in sign with no systematic trend, and the intercept of 4.0 N is clearly not zero — at 4.0 m/s it is more than half of the 7.25 N total resistance — so the rolling term is needed, above all at low speed
- Judged only on the fastest trials, where drag dominates, $P = kv^3$ looks adequate. The comparison has to be made where the two models differ most, at low speed, and it has to rest on a trend rather than on one point.*
- (d) ESTIMATE · U4 [2]
- Estimate the coefficient of rolling resistance $C_r = F_r/N$, where N is the normal force of the road on the bicycle and rider, stating the assumption you make.
- 1 States a plausible combined mass for rider and bicycle, for example 80 kg (any value from 60 kg to 100 kg), so that on a level road $N = mg \approx 80 \times 9.81 = 785$ N
 - 2 $C_r = 4.0 \text{ N}/785 \text{ N} \approx 0.005$ (0.004 to 0.007 across the range of masses allowed)
- The mass is omitted deliberately. Candidates who stop because a datum is missing, rather than stating a reasonable value and carrying on, have misread what an estimate asks of them.*
- (e) DESCRIBE · U4 [2]
- Describe two changes to the procedure that would reduce the uncertainty in the value of F_r .
- 1 Add readings at lower speeds, for example 2.0 m/s to 4.0 m/s, where rolling resistance is the larger share of the total, so that the line is fixed close to its intercept rather than extrapolated to it
 - 2 Ride each speed on the same stretch of road in both directions, repeating and averaging, so that a slight gradient or breeze, which the model assumes absent, cancels instead of biasing the power readings
- 'Take more readings' or 'use a better power meter' earns nothing unless the answer says where the readings should be taken and why that helps. F_r is an intercept, so its uncertainty is governed by the low-speed end of the line.*

A snap-action switch is modelled as a slider of mass m that moves without friction along a straight horizontal rail, taken as the x -axis. A light spring of stiffness k and natural length L_0 joins the slider to a fixed pivot at perpendicular distance a from the rail, and the foot of that perpendicular is at $x = 0$. The pivot is closer to the rail than the spring's natural length, so $a < L_0$. Take the elastic potential energy of the spring to be zero at its natural length. Gravity and the normal force of the rail are perpendicular to the rail and do no work on the slider.

(a) DERIVE · U2 [2]

Starting from the elastic potential energy of a spring, $\frac{1}{2}k \times (\text{extension})^2$, derive an expression for the potential energy $U(x)$ of the system when the slider is at position x .

- 1 The spring runs from the pivot to the slider, so its length is $\sqrt{x^2 + a^2}$ and its extension is $\sqrt{x^2 + a^2} - L_0$ (negative when the spring is compressed)
- 2 Elastic potential energy $\frac{1}{2}k(\text{extension})^2$ gives $U(x) = \frac{1}{2}k(\sqrt{x^2 + a^2} - L_0)^2$

Candidates who write $U = \frac{1}{2}kx^2$ have taken the slider's position as the spring's extension. The spring is not aligned with the rail, and its extension has to come from the geometry.

(b) DERIVE · U2 [3]

Using the relation between a conservative force and its potential-energy function, derive an expression for the component $F_x(x)$ of the force on the slider along the rail.

- 1 For a conservative force in one dimension, $F_x = -dU/dx$
- 2 By the chain rule, $dU/dx = k(\sqrt{x^2 + a^2} - L_0) \times x/\sqrt{x^2 + a^2}$
- 3 $F_x = -kx(1 - L_0/\sqrt{x^2 + a^2})$

The chain-rule factor $x/\sqrt{x^2 + a^2}$ is the projection of the spring force onto the rail. Candidates who drop it obtain a force of $-k(a - L_0)$ at $x = 0$, which the left-right symmetry of the arrangement rules out.

(c) DETERMINE · U2 [2]

Determine all the equilibrium positions of the slider.

- 1 $F_x = 0$ requires either $x = 0$ or $\sqrt{x^2 + a^2} = L_0$
- 2 The equilibria are $x = 0$ and $x = \pm\sqrt{L_0^2 - a^2}$, the outer pair existing because $a < L_0$

Candidates commonly find only the symmetric pair, where the spring is at its natural length, and miss $x = 0$, where the spring is compressed but pushes straight across the rail and so exerts no force along it.

(d) JUSTIFY · U1 [2]

Justify, for each equilibrium position, whether it is stable or unstable.

- 1 At $x = \pm\sqrt{L_0^2 - a^2}$, $U = 0$, which is the least value U can take because it is $\frac{1}{2}k$ times a square, so these are minima of U and the equilibria are stable
- 2 At $x = 0$, $U = \frac{1}{2}k(L_0 - a)^2 > 0$ is a maximum between the two minima; equivalently, for small x , $F_x \approx kx(L_0/a - 1)$ has the same sign as x and pushes the slider away, so $x = 0$ is unstable

An equilibrium with a compressed spring feels as though it ought to be stable, because springs restore. Here the compressed spring pushes the slider sideways as soon as it is displaced, and the judgement has to rest on the shape of U or the sign of F_x , not on intuition about springs.

(e) SKETCH · U1

[3]

Sketch $U(x)$ against x over a range that includes all the equilibrium positions, marking each position and the value of U there.

- 1 A curve symmetric about $x = 0$ with two minima at $x = \pm\sqrt{(L_0^2 - a^2)}$, where it touches $U = 0$ without crossing below the axis
- 2 A smooth local maximum (zero slope, no cusp) at $x = 0$, marked at height $\frac{1}{2}k(L_0 - a)^2$
- 3 U rising without limit on both sides beyond the minima, growing roughly as $\frac{1}{2}kx^2$ once $|x|$ is much larger than L_0 , so that the whole curve is a double well that never falls below zero

Sketches that dip below the axis, or put a cusp at $x = 0$, show a candidate drawing a generic double well from memory instead of the function derived in (a). Every feature asked for can be read from $U(x)$ and $F_x(x)$ without further calculation.

(f) CALCULATE · U3

[3]

For a switch with $k = 250 \text{ N/m}$, $L_0 = 50.0 \text{ mm}$, $a = 40.0 \text{ mm}$ and $m = 20.0 \text{ g}$, calculate the positions of the two stable states and the minimum speed the slider must have as it passes through one stable state if it is to reach the other.

- 1 Stable states at $x = \pm\sqrt{(0.0500^2 - 0.0400^2)} \text{ m} = \pm 0.0300 \text{ m}$, that is $\pm 30.0 \text{ mm}$
- 2 Height of the energy barrier: $U(0) - 0 = \frac{1}{2} \times 250 \times (0.0500 - 0.0400)^2 = 1.25 \times 10^{-2} \text{ J}$
- 3 Conservation of mechanical energy, $\frac{1}{2}mv^2 = 1.25 \times 10^{-2} \text{ J}$, gives $v = \sqrt{(2 \times 1.25 \times 10^{-2}/0.0200)} = 1.12 \text{ m/s}$ (strictly, any speed greater than this)

The speed is set by the height of the barrier, not by the distance between the states. Candidates who use $\frac{1}{2}kx^2$ with $x = 30.0 \text{ mm}$ or $x = 60.0 \text{ mm}$ obtain 3.35 m/s or 6.71 m/s , treating the slider's displacement as the spring's extension again.

(g) PREDICT · U1

[2]

The pivot is moved further from the rail until $a \geq L_0$. Predict how the switch now behaves, reasoning from the energy landscape.

- 1 For $a \geq L_0$ the spring's length $\sqrt{(x^2 + a^2)}$ is never less than a , so the spring is never compressed; $\sqrt{(x^2 + a^2)} = L_0$ has no solution when $a > L_0$ and only $x = 0$ when $a = L_0$, so $x = 0$ is the only equilibrium: as a rises towards L_0 the outer minima at $\pm\sqrt{(L_0^2 - a^2)}$ move in to $x = 0$ and the barrier $\frac{1}{2}k(L_0 - a)^2$ shrinks to zero
- 2 U now rises steadily with $|x|$ from a single minimum at $x = 0$ (a very flat one when $a = L_0$), so $x = 0$ is stable: a displaced slider is always pushed back towards the centre and oscillates about it, so the switch loses its two latched states and no longer snaps

This is the limit check on the whole model: the positions from (c) and the barrier from (d) and (f) must vanish continuously as a approaches L_0 . Candidates who predict that the switch will 'snap harder' have not followed the landscape through the limit.

What the command words are asking for

Examiners mark to the command word as well as to the physics. An answer that explains where the question said state has spent time earning one mark; one that states a result where the question said derive has earned none, however correct the result.

State	Give the result, definition or law concisely. No justification is required.
Describe	Give the relevant features of a situation or process in words, precisely enough that someone else could reproduce it.
Explain	Give the physical reason a result or behaviour occurs, connecting it explicitly to the principle that governs it.
Calculate	Obtain a numerical value, showing the relation used, the substitution and the units of the result.
Determine	Obtain a result by any valid route the problem allows — analytic, graphical or numerical — with enough working to be followed.
Derive	Start from a named fundamental law or definition and reach the required result by explicit, justified steps.
Show that	Establish a result the question gives you. Every step must be shown, because the stated answer earns nothing on its own.
Estimate	Reach an order-of-magnitude value from stated, reasonable assumptions, and say what those assumptions are.
Sketch	Draw the shape of a graph or field with axes labelled and its key features marked — intercepts, asymptotes, turning points, limits. Exact scale is not required.
Justify	Support a claim or a choice with evidence, and with the reasoning that connects that evidence to the claim.
Evaluate	Weigh a model, argument or result against criteria, including its assumptions and domain of validity, and reach a stated judgement.
Compare	Identify the similarities and differences between two situations, models or results, relating each difference to its cause.
Predict	Say what will happen when a condition changes, reasoning from a principle rather than guessing, and give the reason.

WHAT IS BEING TESTED

University assessment objectives

Each course has the two papers a university course is examined by: a midterm on the first half of its units, and a cumulative final weighted towards the second half. Every paper combines short conceptual multiple-choice items with structured problems, a data or estimation question, and at least one extended derivation. Constants are given where a question needs them; a calculator and your own formula sheet are assumed.

U1 21 MARKS · 29%	Conceptual understanding Identify the governing principle and the conditions under which it holds, and reason qualitatively about what a result must look like before calculating it.
U2 19 MARKS · 26%	Mathematical modelling and derivation Translate a physical situation into mathematics: choose coordinates and approximations, set up the governing equations, solve them symbolically, and derive stated results from named laws.

U3

22 MARKS · 30%

Quantitative problem solving

Carry a multi-step calculation to a numerical result with correct units and sensible precision, and check it against dimensions, limiting cases and orders of magnitude.

U4

11 MARKS · 15%

Data, estimation and experimental reasoning

Analyse measurements and their uncertainties, linearise and fit data, estimate orders of magnitude from stated assumptions, and judge whether evidence supports a model.

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