AP · COLLEGE BOARD AP PHYSICS · FRAMEWORKS FIRST EXAMINED IN 2025

AP Physics

One practice exam for each of the four AP Physics courses, in the format the College Board sets since 2025: single-select multiple choice, then four free-response questions built on the four named task types — mathematical routines, translation between representations, experimental design, and qualitative/quantitative translation.

PAPERS	QUESTIONS	TOTAL MARKS	FIGURES
4	**40**	**224**	**21**

EVERY PAPER IN THIS FILE

1 AP Physics 1 · Algebra-Based — 10 questions · 53 marks · 70 minutes
Kinematics, translational dynamics, work and energy, linear momentum, torque and rotational dynamics, rotational energy and momentum, oscillations, and fluids.

2 AP Physics 2 · Algebra-Based — 10 questions · 54 marks · 70 minutes
Thermodynamics, electric force, field and potential, circuits, magnetism and electromagnetism, geometric optics, waves and physical optics, and modern physics.

3 AP Physics C · Mechanics — 10 questions · 55 marks · 70 minutes
Calculus-based mechanics: kinematics, translational dynamics including velocity-dependent forces, work and energy, momentum, torque and rotational dynamics, rotational energy and momentum, and oscillations.

4 AP Physics C · Electricity and Magnetism — 10 questions · 62 marks · 70 minutes
Calculus-based electromagnetism: charge and Gauss's law, electric potential, conductors and capacitors, circuits including RC transients, magnetic fields and Ampère's law, and electromagnetic induction.

ASSESSMENT

Every AP Physics exam has two sections of equal weight. Section I is single-select multiple choice with four options and no penalty for a wrong answer. Section II is free response, scored in points, and every question is built on one of four published task types. A table of equations and a table of constants are supplied for both sections, so nothing on an AP exam tests whether you can recall a formula.

DEMAND

Written to the standard the free-response rubrics actually apply. A numerical answer that appears without the symbolic expression behind it earns partial credit at best; a claim without reasoning earns nothing at all, however correct the claim is. The C courses are set at calculus level throughout — moments of inertia by integration, drag and RC problems as differential equations — because that is what separates them from Physics 1 and 2.

> *Written by GioPhysics from the published course frameworks. These are practice exams in the style of AP Physics; they are not College Board materials, contain no released exam questions, and the official course and exam descriptions remain the authority. AP is a trademark of the College Board, which is not affiliated with and does not endorse GioPhysics.*
>
> College Board AP Physics course and exam descriptions — https://apcentral.collegeboard.org/courses

AP Physics 1 · Algebra-Based

Kinematics, translational dynamics, work and energy, linear momentum, torque and rotational dynamics, rotational energy and momentum, oscillations, and fluids.

SUGGESTED TIME	TOTAL MARKS	QUESTIONS	MULTIPLE CHOICE
70 minutes	**53**	**10**	**6**

SECTION **AP 1 · AP Physics 1: Algebra-Based**

IN THE FORMAT OF Section I (single-select multiple choice) and Section II (four free-response task types)

DEMAND **Routine 3 · Demanding 5 · Discriminating 2**

Written to the standard the free-response rubrics actually apply. A numerical answer that appears without the symbolic expression behind it earns partial credit at best; a claim without reasoning earns nothing at all, however correct the claim is. The C courses are set at calculus level throughout — moments of inertia by integration, drag and RC problems as differential equations — because that is what separates them from Physics 1 and 2.

SYLLABUS POINTS 1 · 2 · 3 · 4 · 5 · 6 · 7 · 8

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.

AP Physics 1 · Algebra-Based

Answer all questions. 53 marks in 70 minutes.

1 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 1 **[1]**

An object moves along a straight line. Its velocity increases uniformly from 0 to 8.0 m/s during the first 4.0 s, stays at 8.0 m/s for the next 3.0 s, then decreases uniformly to 0 during the final 2.0 s. What total distance does the object travel?

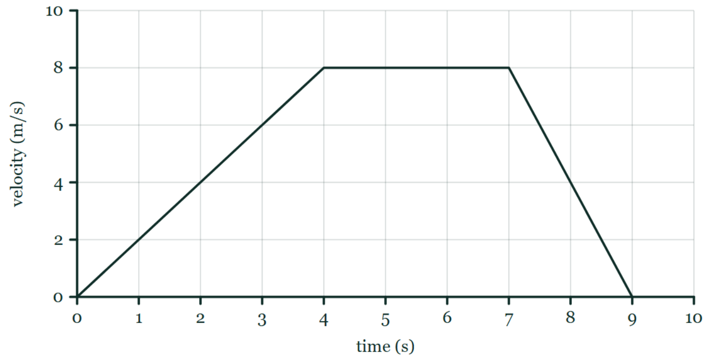

Fig. 1.1 *A velocity–time graph on a gridded pair of axes. The horizontal axis is time in seconds, marked at every second from 0 to 10; the vertical axis is velocity in metres per second, marked 0, 2, 4, 6, 8 and 10. The plotted line is a straight rise from the origin to 8.0 m/s at 4.0 s, then a horizontal segment held at 8.0 m/s until 7.0 s, then a straight fall back to zero at 9.0 s.*

A 40 m

B 48 m

C 56 m

D 72 m

Answer

2 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 2 **[1]**

A person of mass m stands on a bathroom scale in an elevator. The elevator is moving downward and slowing down. What does the scale read?

A less than mg

B exactly mg

C greater than mg

D zero

Answer

3 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 3 **[1]**

A car traveling at speed v brakes to rest in a distance d. Assuming the same constant braking force, what distance is required to bring the same car to rest from a speed of 2v?

A d√2

B 2d

C 4d

D 8d

Answer

---

4 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 4 **[1]**

A 0.50 kg ball moving at 4.0 m/s to the right collides head-on with a 1.5 kg ball moving at 2.0 m/s to the left. The two balls stick together. What is the velocity of the combined object immediately after the collision?

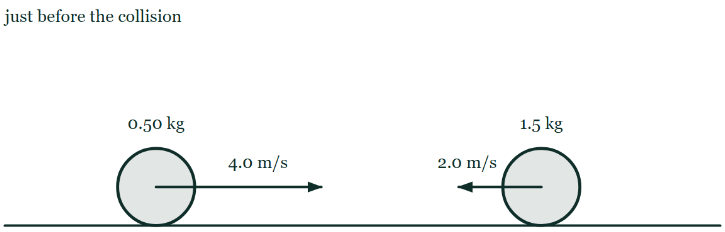

Fig. 4.1 *Two balls of equal size rest on a straight horizontal track, well apart from one another. The left-hand ball is labelled 0.50 kg and carries a horizontal arrow drawn from its centre pointing to the right, labelled 4.0 m/s. The right-hand ball is labelled 1.5 kg and carries a horizontal arrow drawn from its centre pointing to the left, labelled 2.0 m/s, so the two arrows point towards each other along the same line. A note on the figure states that this is the instant just before the collision.*

A 0.50 m/s to the left

B 0.50 m/s to the right

C 2.5 m/s to the left

D 2.5 m/s to the right

Answer

---

5 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 5 · 6 **[1]**

A solid disk and a thin hoop have the same mass and the same radius. Both are released from rest at the top of the same incline and roll down without slipping. Which reaches the bottom first?

A the disk, because a smaller fraction of its energy goes into rotation

B the hoop, because its mass is farther from the axis

C neither — they arrive together, because they have the same mass

D neither — they arrive together, because gravity acts equally on both

Answer

---

6 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 8 **[1]**

A solid block of density 600 kg/m^3 floats at rest in water of density 1000 kg/m^3. What fraction of the block's volume is below the surface?

A 0.40

B 0.60

C 1.00

D 1.67

Answer

---

7 ALGEBRA

FREE RESPONSE · MATHEMATICAL ROUTINES · DEMANDING · 2 · 3 **[12]**

A block of mass m is released from rest at a height h on an incline that makes an angle θ with the horizontal. The coefficient of kinetic friction between the block and the incline is μ. The block slides down the incline and then continues onto a horizontal surface with the same coefficient of kinetic friction.

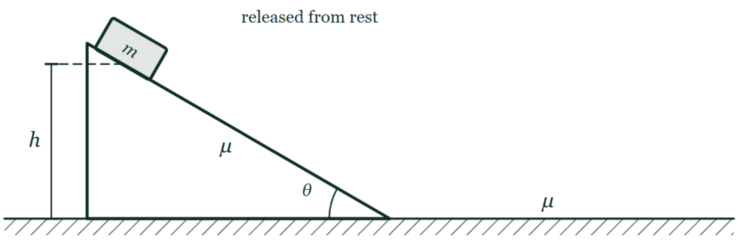

Fig. 7.1 *A wedge-shaped incline stands on a horizontal floor with its sloping face rising from right to left, and the angle between the sloping face and the floor at the foot of the slope is marked θ. A block labelled m rests on the sloping face near the top and is noted as released from rest, with a dimension line to the left of the wedge marking its height h above the floor. The symbol μ is printed on the wedge below the sloping face and again on the floor beyond the foot of the slope, showing that the same coefficient of kinetic friction applies to both surfaces, which run into one another at the bottom of the incline.*

(a) DERIVE **[4]**

Derive an expression for the speed of the block at the bottom of the incline, in terms of m, h, θ, μ and physical constants.

(b) CALCULATE **[3]**

Calculate the speed of the block at the bottom of the incline for $m = 2.0$ kg, $h = 1.5$ m, $\theta = 30°$, and $\mu = 0.25$.

(c) DETERMINE **[3]**

Determine the distance the block travels along the horizontal surface before coming to rest.

(d) JUSTIFY **[2]**

A student claims that doubling the mass of the block would double the distance found in part (c). Justify why the student is incorrect, referring to your expression.

8 ALGEBRA

FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 1 **[12]**

A cart moves along a straight horizontal track. Its velocity as a function of time is described as follows: from t = 0 to t = 2.0 s the velocity is constant at +3.0 m/s; from t = 2.0 s to t = 5.0 s the velocity decreases uniformly from +3.0 m/s to −3.0 m/s; from t = 5.0 s to t = 7.0 s the velocity is constant at −3.0 m/s.

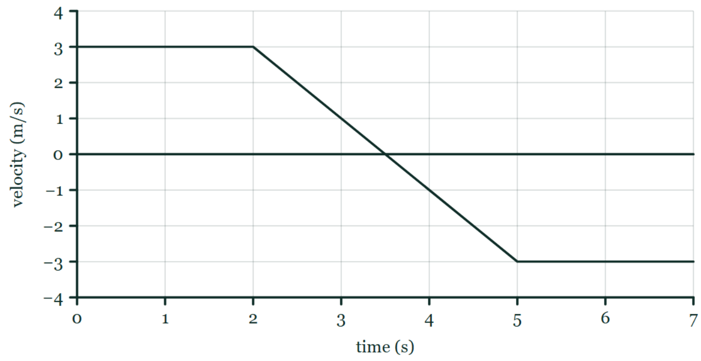

Fig. 8.1 *The cart's velocity–time graph. The time axis is drawn horizontally through velocity zero and is marked in seconds from 1 to 7; the vertical velocity axis is marked in metres per second from −4 to +4. The plotted line runs horizontally at +3.0 m/s from t = 0 to t = 2.0 s, then falls as a single straight sloping segment, passing through zero, to −3.0 m/s at t = 5.0 s, and then runs horizontally at −3.0 m/s until t = 7.0 s.*

(a) SKETCH **[3]**

Sketch a graph of the cart's acceleration as a function of time from t = 0 to t = 7.0 s. Label the value of the acceleration on each interval.

(b) DETERMINE **[3]**

Determine the time at which the cart is farthest from its starting point, and determine that distance.

(c) SKETCH **[3]**

Sketch a graph of the cart's position as a function of time over the same interval, taking the starting position as zero.

(d) DESCRIBE **[3]**

Describe the motion of the cart in words, making clear the difference between the interval in which it is slowing down and the interval in which it is speeding up.

---

9 ALGEBRA

FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DISCRIMINATING · 2 **[12]**

A student is given a wooden block, a horizontal board of the same material, a set of known masses, a spring scale, a meter stick, and a stopwatch. The student wants to determine the coefficient of kinetic friction μ between the block and the board.

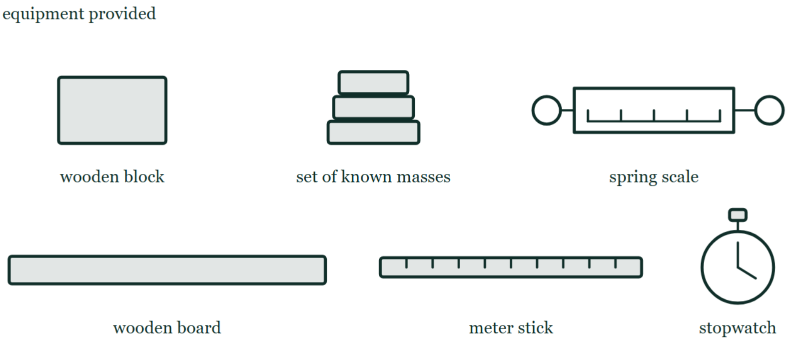

Fig. 9.1 *The equipment provided, drawn as six separate labelled items laid out side by side rather than as an assembled apparatus: a rectangular wooden block; a set of known masses drawn as a stack of three flat slabs; a spring scale drawn as a barrel with a graduated face and a ring at each end for pulling and for attaching; a long flat wooden board; a meter stick divided by evenly spaced marks; and a stopwatch drawn as a circular dial with two hands and a button on top.*

(a) DESCRIBE **[4]**

Describe an experimental procedure the student could use to collect the data needed. Include the quantity that is deliberately varied, the quantity measured in response, and at least two quantities held constant.

(b) DESCRIBE **[3]**

Describe how the student should graph the data so that the coefficient of friction can be determined from a straight line, and state what quantity the slope of that line represents.

(c) DETERMINE **[3]**

The student's best-fit line has a slope of 0.32 when friction force is plotted against normal force, and a vertical intercept of +0.15 N rather than zero. Determine the coefficient of kinetic friction, and explain what the non-zero intercept suggests about the experiment.

(d) EXPLAIN **[2]**

Explain why taking the slope of the best-fit line gives a more reliable value for μ than calculating f/N from a single pair of readings.

---

10 ALGEBRA

FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 3 · 5 · 6 **[11]**

A solid sphere and a block have the same mass. Both are released from rest at the same height at the top of an incline. The sphere rolls down without slipping. The block slides down a frictionless section of the same incline. The moment of inertia of a solid sphere about its center is $(2/5)MR^2$.

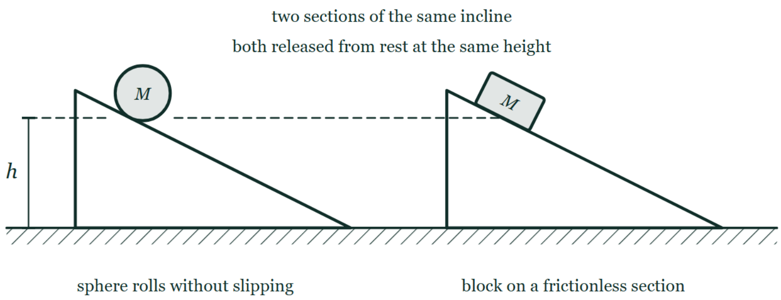

Fig. 10.1 *Two identical wedge-shaped inclines stand side by side on the same horizontal floor, labelled as two sections of the same incline. A solid sphere of mass M rests on the sloping face of the left wedge, and a block of mass M rests at the same point up the sloping face of the right wedge. A dashed horizontal line runs across the figure at the level of both objects, and a dimension line at the far left marks their common release height h above the floor. A note states that both are released from rest at the same height; a label under the left ramp reads that the sphere rolls without slipping, and one under the right ramp that the block is on a frictionless section.*

(a) INDICATE **[1]**

Indicate which object reaches the bottom of the incline with the greater translational speed, or whether they arrive with the same speed. No justification is required in this part.

(b) DERIVE **[4]**

Derive expressions for the translational speed of each object at the bottom of the incline, in terms of g and the height h.

(c) JUSTIFY **[2]**

Use your expressions to justify the answer you gave in part (a).

(d) EXPLAIN **[4]**

Explain, without using equations, why the sphere arrives more slowly, and explain why the answer does not depend on the mass or the radius of the sphere.

MARK SCHEME

AP Physics 1 · Algebra-Based — 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 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 1 **[1]**

An object moves along a straight line. Its velocity increases uniformly from 0 to 8.0 m/s during the first 4.0 s, stays at 8.0 m/s for the next 3.0 s, then decreases uniformly to 0 during the final 2.0 s. What total distance does the object travel?

KEY **B** **48 m**

The distance is the area under the velocity–time graph: a triangle of 16 m, a rectangle of 24 m, and a triangle of 8 m, giving 48 m. C treats the final stage as a rectangle rather than a triangle, and A drops it altogether. D multiplies 8.0 by the whole 9.0 s, treating the graph as if the object moved at its maximum speed throughout.

SP1

---

2 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 2 **[1]**

A person of mass m stands on a bathroom scale in an elevator. The elevator is moving downward and slowing down. What does the scale read?

KEY **C** **greater than mg**

A is chosen by almost everyone who reasons from the direction of motion rather than the direction of the acceleration. Moving down while slowing down means the acceleration points upward, so the normal force must exceed the weight.

SP2

---

3 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 3 **[1]**

A car traveling at speed v brakes to rest in a distance d. Assuming the same constant braking force, what distance is required to bring the same car to rest from a speed of 2v?

KEY **C** **4d**

B is the answer of a candidate reasoning proportionally without noticing that kinetic energy goes as v^2. The work–energy theorem gives $Fd = \frac{1}{2}mv^2$, so $d \propto v^2$.

SP2

---

4 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 4 **[1]**

A 0.50 kg ball moving at 4.0 m/s to the right collides head-on with a 1.5 kg ball moving at 2.0 m/s to the left. The two balls stick together. What is the velocity of the combined object immediately after the collision?

KEY **A** **0.50 m/s to the left**

Total momentum is $(0.50)(+4.0) + (1.5)(-2.0) = -1.0$ kg·m/s, and the combined mass is 2.0 kg. B gets the size right and the sign wrong, which on a real exam is a wrong answer, not a near miss.

SP2

---

5 MULTIPLE CHOICE · DEMANDING · 5 · 6 **[1]**

ALGEBRA

A solid disk and a thin hoop have the same mass and the same radius. Both are released from rest at the top of the same incline and roll down without slipping. Which reaches the bottom first?

KEY **A** **the disk, because a smaller fraction of its energy goes into rotation**

C and D are the answers of a candidate applying the free-fall result, where mass genuinely does cancel. It does cancel here too — but the rotational inertia does not, and the hoop's larger I/MR^2 leaves less of the released energy available as translational kinetic energy.

SP3

---

6 MULTIPLE CHOICE · ROUTINE · 8 **[1]**

ALGEBRA

A solid block of density 600 kg/m^3 floats at rest in water of density 1000 kg/m^3. What fraction of the block's volume is below the surface?

KEY **B** **0.60**

A is the fraction above the surface. D inverts the ratio and should be rejected on sight — a fraction of a volume cannot exceed 1.

SP2

---

7 ALGEBRA

FREE RESPONSE · MATHEMATICAL ROUTINES · DEMANDING · 2 · 3 **[12]**

A block of mass m is released from rest at a height h on an incline that makes an angle θ with the horizontal. The coefficient of kinetic friction between the block and the incline is μ. The block slides down the incline and then continues onto a horizontal surface with the same coefficient of kinetic friction.

(a) DERIVE · SP2 **[4]**

Derive an expression for the speed of the block at the bottom of the incline, in terms of m, h, θ, μ and physical constants.

1. 1 point: uses energy conservation with a friction term, $\Delta K = mgh - f \cdot L$
2. 1 point: identifies the distance along the incline as $L = h / \sin\theta$ and the friction force as $f = \mu mg \cos\theta$
3. 1 point: friction work $= \mu mg \cos\theta \cdot (h / \sin\theta) = \mu mgh \cot\theta$
4. 1 point: $v = \sqrt{2gh(1 - \mu \cot\theta)}$, with m correctly cancelling

A numerical answer with no symbolic expression scores at most one point on this task type. The expression is the task.

(b) CALCULATE · SP2 **[3]**

Calculate the speed of the block at the bottom of the incline for m = 2.0 kg, h = 1.5 m, θ = 30°, and μ = 0.25.

1. 1 point: $\cot 30° = 1.73$, so $1 - 0.25(1.73) = 0.567$
2. 1 point: $v = \sqrt{2 \times 9.8 \times 1.5 \times 0.567}$
3. 1 point: $v = 4.1$ m/s, with unit

(c) DETERMINE · SP2 **[3]**

Determine the distance the block travels along the horizontal surface before coming to rest.

1. 1 point: on the horizontal surface the only horizontal force is friction, μmg
2. 1 point: $\frac{1}{2}mv^2 = \mu mg \cdot d$, so $d = v^2/(2\mu g)$
3. 1 point: $d = 16.7 / (2 \times 0.25 \times 9.8) = 3.4$ m

(d) JUSTIFY · SP3 **[2]**

A student claims that doubling the mass of the block would double the distance found in part (c). Justify why the student is incorrect, referring to your expression.

1. 1 point: mass appears in both the kinetic energy and the friction force and cancels from $d = v^2/(2\mu g)$
2. 1 point: v itself is also independent of m, so the distance is unchanged when the mass is doubled

8 ALGEBRA

FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 1 **[12]**

A cart moves along a straight horizontal track. Its velocity as a function of time is described as follows: from $t = 0$ to $t = 2.0$ s the velocity is constant at $+3.0$ m/s; from $t = 2.0$ s to $t = 5.0$ s the velocity decreases uniformly from $+3.0$ m/s to -3.0 m/s; from $t = 5.0$ s to $t = 7.0$ s the velocity is constant at -3.0 m/s.

(a) SKETCH · SP1 **[3]**

Sketch a graph of the cart's acceleration as a function of time from $t = 0$ to $t = 7.0$ s. Label the value of the acceleration on each interval.

1. 1 point: $a = 0$ on $0 \le t < 2.0$ s and on $5.0\text{ s} < t \le 7.0$ s
2. 1 point: a constant and negative between 2.0 s and 5.0 s
3. 1 point: value stated as -2.0 m/s^2, from $(-3.0 - 3.0)/(5.0 - 2.0)$

(b) DETERMINE · SP2 **[3]**

Determine the time at which the cart is farthest from its starting point, and determine that distance.

1. 1 point: the cart is farthest away when the velocity changes sign, at $t = 3.5$ s
2. 1 point: area under the graph from 0 to 3.5 s = $(3.0)(2.0) + \frac{1}{2}(1.5)(3.0)$
3. 1 point: distance = $6.0 + 2.25 = 8.25$ m

The point most often lost is the first. Candidates look for where the acceleration changes rather than where the velocity crosses zero, and place the maximum at t = 5.0 s.

(c) SKETCH · SP1 **[3]**

Sketch a graph of the cart's position as a function of time over the same interval, taking the starting position as zero.

1. 1 point: straight line of positive constant slope from the origin to (2.0 s, 6.0 m)
2. 1 point: curve that flattens to a maximum at $t = 3.5$ s and then falls, with curvature downward throughout 2.0–5.0 s
3. 1 point: straight line of constant negative slope after $t = 5.0$ s

(d) DESCRIBE · SP3 **[3]**

Describe the motion of the cart in words, making clear the difference between the interval in which it is slowing down and the interval in which it is speeding up.

1. 1 point: moves in the positive direction at constant speed for the first 2.0 s
2. 1 point: from 2.0 s to 3.5 s it still moves in the positive direction but slows, because velocity and acceleration have opposite signs
3. 1 point: from 3.5 s onward it moves in the negative direction and speeds up until 5.0 s, because velocity and acceleration now have the same sign, then travels at constant speed

The distinction is the whole point of the question: a negative acceleration slows an object down only while the object is moving forward.

9 FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DISCRIMINATING · 2 **[12]**

ALGEBRA

A student is given a wooden block, a horizontal board of the same material, a set of known masses, a spring scale, a meter stick, and a stopwatch. The student wants to determine the coefficient of kinetic friction μ between the block and the board.

(a) DESCRIBE · SP4 **[4]**

Describe an experimental procedure the student could use to collect the data needed. Include the quantity that is deliberately varied, the quantity measured in response, and at least two quantities held constant.

1. 1 point: pull the block along the board with the spring scale at constant velocity, so that the applied force equals the friction force
2. 1 point: vary the total mass by adding known masses on top of the block — this is the independent variable
3. 1 point: record the spring-scale reading for each total mass — this is the dependent variable
4. 1 point: hold constant the surfaces in contact and the surface area, and keep the pull horizontal for every trial

"At constant velocity" is worth a point on its own. If the block accelerates, the scale reading exceeds the friction force and every value of μ comes out too large.

(b) DESCRIBE · SP4 **[3]**

Describe how the student should graph the data so that the coefficient of friction can be determined from a straight line, and state what quantity the slope of that line represents.

1. 1 point: plot the friction force (spring-scale reading) on the vertical axis against the normal force, or against the total mass, on the horizontal axis
2. 1 point: the relationship $f = \mu N$ is linear through the origin
3. 1 point: the slope equals μ if the horizontal axis is the normal force, or μg if the horizontal axis is the mass

(c) DETERMINE · SP4 **[3]**

The student's best-fit line has a slope of 0.32 when friction force is plotted against normal force, and a vertical intercept of +0.15 N rather than zero. Determine the coefficient of kinetic friction, and explain what the non-zero intercept suggests about the experiment.

1. 1 point: $\mu = 0.32$, the slope, which is dimensionless
2. 1 point: the model predicts an intercept of zero, since zero normal force means zero friction
3. 1 point: a positive intercept indicates a systematic error — for example the spring scale reads high at zero, or the pull was not horizontal, adding a constant component to every reading

Reading μ from a single data point instead of from the slope scores nothing here. The design of the graph is what the task type is assessing.

(d) EXPLAIN · SP4 **[2]**

Explain why taking the slope of the best-fit line gives a more reliable value for μ than calculating f/N from a single pair of readings.

1. 1 point: the slope uses every data point, so random errors in individual readings tend to average out
2. 1 point: a systematic offset such as the intercept above shifts a single-point ratio but does not change the slope, so the slope is insensitive to it

10 FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 3 · 5 · 6 **[11]**

ALGEBRA

A solid sphere and a block have the same mass. Both are released from rest at the same height at the top of an incline. The sphere rolls down without slipping. The block slides down a frictionless section of the same incline. The moment of inertia of a solid sphere about its center is $(2/5)MR^2$.

(a) INDICATE · SP3 **[1]**

Indicate which object reaches the bottom of the incline with the greater translational speed, or whether they arrive with the same speed. No justification is required in this part.

1. 1 point: the block

(b) DERIVE · SP2 **[4]**

Derive expressions for the translational speed of each object at the bottom of the incline, in terms of g and the height h.

1. 1 point: block — $Mgh = \frac{1}{2}Mv^2$, so $v = \sqrt{2gh}$
2. 1 point: sphere — energy is shared between translation and rotation, $Mgh = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$
3. 1 point: applies the rolling condition $\omega = v/R$ and substitutes $I = (2/5)MR^2$, giving $Mgh = (7/10)Mv^2$
4. 1 point: $v = \sqrt{10gh/7}$

(c) JUSTIFY · SP3 **[2]**

Use your expressions to justify the answer you gave in part (a).

1. 1 point: compares the coefficients — $10/7 = 1.43$ is smaller than 2, so the sphere's speed is smaller
2. 1 point: states the ratio explicitly, $v_{sphere} / v_{block} = \sqrt{5/7} = 0.85$

(d) EXPLAIN · SP3 **[4]**

Explain, without using equations, why the sphere arrives more slowly, and explain why the answer does not depend on the mass or the radius of the sphere.

1. 1 point: both objects convert the same gravitational potential energy per unit mass
2. 1 point: the sphere must also spin as it moves, so part of that energy goes into rotational kinetic energy and less is left for translation
3. 1 point: the mass appears in every energy term and cancels, so it cannot affect the result
4. 1 point: the radius cancels because the rolling condition ties ω to v through the same R that appears in the moment of inertia — only the shape factor 2/5 survives

   The last point is the hardest on the exam and is the reason this task type exists: the candidate has to say in words what the algebra in part (b) did, and identify which symbol survived the cancellation and why.

AP · COLLEGE BOARD AP PHYSICS · FRAMEWORKS FIRST EXAMINED IN 2025

AP Physics 2 · Algebra-Based

Thermodynamics, electric force, field and potential, circuits, magnetism and electromagnetism, geometric optics, waves and physical optics, and modern physics.

SUGGESTED TIME	TOTAL MARKS	QUESTIONS	MULTIPLE CHOICE
70 minutes	**54**	**10**	**6**

SECTION — **AP 2 · AP Physics 2: Algebra-Based**

IN THE FORMAT OF — Section I (single-select multiple choice) and Section II (four free-response task types)

DEMAND — **Routine 3 · Demanding 5 · Discriminating 2**

Written to the standard the free-response rubrics actually apply. A numerical answer that appears without the symbolic expression behind it earns partial credit at best; a claim without reasoning earns nothing at all, however correct the claim is. The C courses are set at calculus level throughout — moments of inertia by integration, drag and RC problems as differential equations — because that is what separates them from Physics 1 and 2.

SYLLABUS POINTS — 9 · 10 · 11 · 12 · 13 · 14 · 15

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.

THE PAPER

AP Physics 2 · Algebra-Based

Answer all questions. 54 marks in 70 minutes.

1 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 9 **[1]**

An ideal gas expands at a constant pressure of 2.0×10^5 Pa from a volume of 1.0×10^{-3} m^3 to 3.0×10^{-3} m^3. How much work is done by the gas?

A 200 J

B 400 J

C 600 J

D 800 J

Answer

2 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 10 **[1]**

Two point charges, +Q and −Q, are held a distance d apart. What are the electric field and the electric potential at the midpoint between them, taking the potential to be zero at infinity?

A field zero, potential zero

B field zero, potential non-zero

C field non-zero, potential zero

D field non-zero, potential non-zero

Answer

3 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 11 **[1]**

Three identical light bulbs are connected to a battery of negligible internal resistance: bulb X is in series with a parallel combination of bulbs Y and Z. Bulb Z then burns out, breaking its branch. What happens to the brightness of bulb X?

A It becomes brighter.

B It becomes dimmer.

C It is unchanged.

D It goes out.

Answer

4 ALGEBRA

[1]

A straight wire of length 0.25 m carries a current of 3.0 A at right angles to a uniform magnetic field of magnitude 0.40 T. What is the magnitude of the magnetic force on the wire?

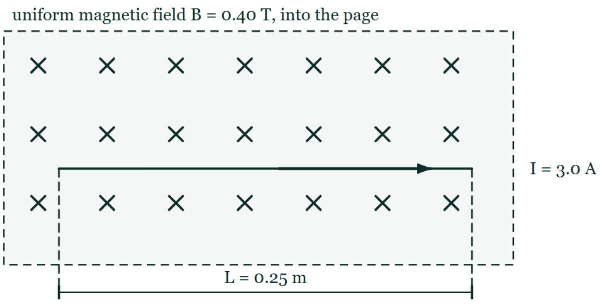

Figure 1 *A rectangular region of uniform magnetic field is shown by a grid of small crosses, marking a field of magnitude 0.40 T directed into the page. A straight wire lies horizontally across the region, in the plane of the page and therefore at right angles to the field, and an arrow drawn along the wire shows the conventional current of 3.0 A flowing to the right. A dimension line below the region, with projection lines dropped from each end of the wire, marks the length of wire lying in the field as L = 0.25 m. No force is shown.*

A 0.030 N

B 0.30 N

C 3.0 N

D 4.8 N

Answer

5 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 13

[1]

An object is placed 10 cm in front of a converging lens of focal length 15 cm. Which describes the image?

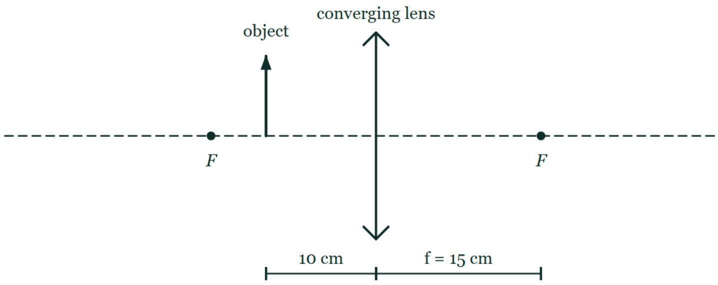

Figure 2 *A converging lens, drawn as a vertical line with outward-pointing arrowheads at each end, stands on a horizontal dashed principal axis. A focal point F is marked by a dot on the axis on each side of the lens, and the distance from the centre of the lens to the focal point on the far side is labelled f = 15 cm. A short upright arrow labelled "object" stands on the axis on the near side, and the distance from it to the centre of the lens is marked 10 cm, so the object lies between the focal point and the lens. No construction rays and no image are drawn.*

A real, inverted, and 30 cm from the lens

B real, inverted, and 6.0 cm from the lens

C virtual, upright, and 30 cm from the lens

D virtual, upright, and 6.0 cm from the lens

Answer

---

6 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 15

[1]

A nucleus of ${}^{238}_{92}U$ decays to ${}^{234}_{90}Th$. What particle is emitted?

A an alpha particle

B a beta-minus particle

C a beta-plus particle

D a gamma photon

Answer

---

7 ALGEBRA

FREE RESPONSE · MATHEMATICAL ROUTINES · DEMANDING · 9 **[12]**

A fixed quantity of a monatomic ideal gas is taken around the closed cycle A → B → C → D → A. State A is at pressure 2.0×10^5 Pa and volume 1.0×10^{-3} m³. The gas expands at constant pressure to state B at 3.0×10^{-3} m³. It is then cooled at constant volume to state C at 1.0×10^5 Pa. It is compressed at constant pressure to state D at 1.0×10^{-3} m³, and finally warmed at constant volume back to state A.

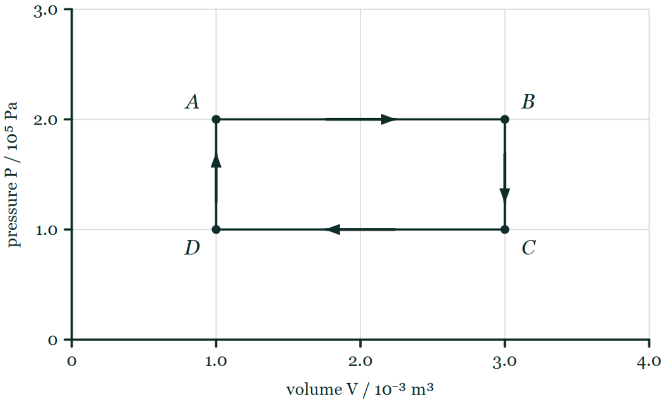

Figure 3 *A pressure-volume graph with a faint grid. The horizontal axis is volume V in units of 10^{-3} m³, marked from 0 to 4.0; the vertical axis is pressure P in units of 10^5 Pa, marked from 0 to 3.0. Four states are plotted as dots at the corners of a rectangle and labelled: A at V = 1.0 and P = 2.0, B at V = 3.0 and P = 2.0, C directly below B at P = 1.0, and D directly below A at P = 1.0. Straight lines join A to B to C to D and back to A, and an arrow on each side shows the order in which the gas is taken round the closed cycle.*

(a) CALCULATE **[2]**

Calculate the work done by the gas during the process A → B.

(b) DETERMINE **[4]**

Determine the change in internal energy of the gas during A → B, and hence the thermal energy added to the gas.

(c) DETERMINE **[3]**

Determine the net work done by the gas in one complete cycle.

(d) EXPLAIN **[3]**

Explain why the change in internal energy of the gas over one complete cycle is zero, and state what this implies about the net thermal energy exchanged with the surroundings.

---

8 ALGEBRA

FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 10 **[12]**

Two point charges are fixed on a horizontal line: a charge +2q at the origin, and a charge −q at a distance d to the right of it.

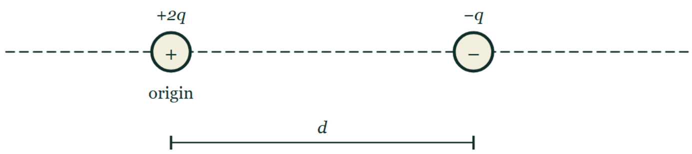

Figure 4 *Two point charges rest on a long horizontal dashed line that extends well beyond both of them. On the left, at a point labelled "origin", is a circle containing a plus sign, labelled +2q. A distance to the right of it is a circle containing a minus sign, labelled −q, and that separation is marked d by a dimension line drawn between the two centres below the charges. Nothing else is marked anywhere on the line, in either direction.*

(a) SKETCH **[3]**

Sketch the electric field lines in the region around the two charges. Indicate the direction of each line with an arrow.

(b) DETERMINE **[4]**

Determine the location on the line through the two charges at which the net electric field is zero. Indicate whether it lies to the left of +2q, between the charges, or to the right of −q, and justify that region before calculating.

(c) DETERMINE **[3]**

Determine whether there is a point on the line between the two charges at which the electric potential is zero, and if so, where.

(d) EXPLAIN **[2]**

Explain why the point where the field is zero and the point where the potential is zero are in different places.

9 ALGEBRA

FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DISCRIMINATING · 13 **[12]**

A student is given a converging lens of unknown focal length, an illuminated object, a screen, an optical bench and a meter stick. The student measures the object distance u and the corresponding image distance v for several positions of the lens.

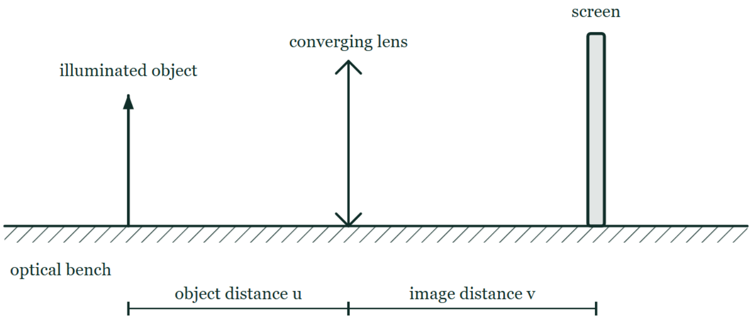

Figure 5 *An elevation view of an optical bench, drawn as a hatched horizontal rail labelled as carrying a metre scale. Standing on the rail, from left to right, are an illuminated object shown as an upright arrow, a converging lens drawn as a vertical line with outward-pointing arrowheads at each end, and a flat screen shown as a narrow upright board. Two dimension lines below the bench measure the object distance u, from the object to the centre of the lens, and the image distance v, from the centre of the lens to the screen.*

The student's measurements

u / cm	20.0	25.0	30.0	40.0	50.0
v / cm	60.0	37.5	30.0	24.0	21.4
1/u / cm^{-1}	0.0500	0.0400	0.0333	0.0250	0.0200
1/v / cm^{-1}	0.0167	0.0267	0.0333	0.0417	0.0467

(a) DESCRIBE **[3]**

Describe how the student should obtain each value of v so that the measurement is as accurate as possible.

(b) DESCRIBE **[4]**

The thin lens equation is $1/u + 1/v = 1/f$. Describe how the student should plot the data to obtain a straight line, and state what the slope and the intercepts of that line represent.

(c) DETERMINE **[3]**

Use the data to determine the focal length of the lens.

(d) EXPLAIN **[2]**

The student notices that the point at u = 20.0 cm lies slightly further from the best-fit line than the others. Explain why the measurement of v is least precise for small object distances, and describe one change that would improve it.

10 ALGEBRA **[12]**

Three identical bulbs, each of resistance R, are connected to a battery of e.m.f. ε and negligible internal resistance. Bulb X is connected in series with a parallel combination of bulbs Y and Z. The brightness of a bulb is determined by the power it dissipates.

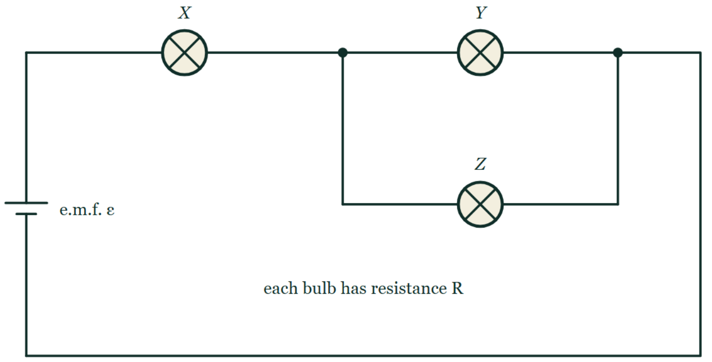

Figure 6 *A circuit diagram drawn as a rectangular loop. A cell of e.m.f. ε sits in the left-hand side of the loop. Following the wire from the cell along the top of the loop, it passes through bulb X and then reaches a junction dot where the circuit divides into two parallel branches: bulb Y lies on the upper branch, while a wire dropping from the junction carries bulb Z along a lower branch. The two branches rejoin at a second junction dot, after which a single wire runs down the right-hand side and back along the bottom to the cell. A note on the figure states that each bulb has resistance R.*

(a) INDICATE **[1]**

Indicate which bulb or bulbs are brightest in the original circuit. No justification is required in this part.

(b) DERIVE **[4]**

Derive expressions for the power dissipated by bulb X and by bulb Y in the original circuit, in terms of ε and R.

(c) DETERMINE **[3]**

Bulb Z now burns out, breaking its branch of the circuit. Determine the new power dissipated by bulb X, and state whether X becomes brighter, dimmer, or stays the same.

(d) EXPLAIN **[4]**

Explain, without using equations, why bulb X becomes dimmer while bulb Y becomes brighter when bulb Z burns out.

MARK SCHEME

AP Physics 2 · Algebra-Based — 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 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 9 **[1]**

An ideal gas expands at a constant pressure of 2.0×10^5 Pa from a volume of 1.0×10^{-3} m³ to 3.0×10^{-3} m³. How much work is done by the gas?

KEY **B** **400 J**

C uses the final volume rather than the change in volume. Work at constant pressure is the area under the isobar, PΔV, and only the change matters.

SP2

---

2 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 10 **[1]**

Two point charges, +Q and −Q, are held a distance d apart. What are the electric field and the electric potential at the midpoint between them, taking the potential to be zero at infinity?

KEY **C** **field non-zero, potential zero**

A is the commonest answer and gets exactly one of the two wrong. The field contributions are vectors that both point from the positive charge towards the negative one, so they add; the potentials are scalars of equal size and opposite sign, so they cancel.

SP1

---

3 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 11 **[1]**

Three identical light bulbs are connected to a battery of negligible internal resistance: bulb X is in series with a parallel combination of bulbs Y and Z. Bulb Z then burns out, breaking its branch. What happens to the brightness of bulb X?

KEY **B** **It becomes dimmer.**

Removing Z raises the total resistance of the circuit from 1.5R to 2R, so the current through X falls and X dims. A is chosen by candidates who reason that "fewer bulbs means more current for each", which is true for bulb Y's share but not for the total.

SP3

---

4 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 12 **[1]**

A straight wire of length 0.25 m carries a current of 3.0 A at right angles to a uniform magnetic field of magnitude 0.40 T. What is the magnitude of the magnetic force on the wire?

KEY **B** **0.30 N**

$F = BIL = 0.40 \times 3.0 \times 0.25 = 0.30$ N. A and C are decimal-place slips of the kind that survive on an exam where no working is seen, which is why the item is worth doing carefully rather than quickly. D multiplies all three numbers and then adds the field again.

SP2

---

5 ALGEBRA

MULTIPLE CHOICE · DEMANDING · 13 **[1]**

An object is placed 10 cm in front of a converging lens of focal length 15 cm. Which describes the image?

KEY **C** **virtual, upright, and 30 cm from the lens**

The object is inside the focal length, so the image must be virtual and upright — a candidate who checks that first can discard A and B without calculating. Solving $1/v = 1/15 - 1/10$ gives $v = -30$ cm, and the negative sign is the confirmation, not an error.

SP2

---

6 ALGEBRA

MULTIPLE CHOICE · ROUTINE · 15 **[1]**

A nucleus of $^{238}_{92}U$ decays to $^{234}_{90}Th$. What particle is emitted?

KEY **A** **an alpha particle**

The mass number falls by 4 and the atomic number by 2, which only an alpha particle can do. D leaves both numbers unchanged.

SP2

---

7 ALGEBRA

FREE RESPONSE · MATHEMATICAL ROUTINES · DEMANDING · 9 **[12]**

A fixed quantity of a monatomic ideal gas is taken around the closed cycle A → B → C → D → A. State A is at pressure 2.0×10^5 Pa and volume 1.0×10^{-3} m³. The gas expands at constant pressure to state B at 3.0×10^{-3} m³. It is then cooled at constant volume to state C at 1.0×10^5 Pa. It is compressed at constant pressure to state D at 1.0×10^{-3} m³, and finally warmed at constant volume back to state A.

(a) CALCULATE · SP2 **[2]**

Calculate the work done by the gas during the process A → B.

1 1 point: $W = P\Delta V$ for a constant-pressure process

2 1 point: $W = 2.0 \times 10^5 \times 2.0 \times 10^{-3} = 400$ J, done by the gas

(b) DETERMINE · SP2 **[4]**

Determine the change in internal energy of the gas during A → B, and hence the thermal energy added to the gas.

1 1 point: for a monatomic ideal gas $\Delta U = (3/2)nR\Delta T = (3/2)\Delta(PV)$

2 1 point: $\Delta(PV) = 2.0 \times 10^5\,(3.0 \times 10^{-3} - 1.0 \times 10^{-3}) = 400$ J, so $\Delta U = 600$ J

3 1 point: applies the first law, $Q = \Delta U + W_{by}$

4 1 point: $Q = 600 + 400 = 1000$ J added to the gas

(c) DETERMINE · SP2 **[3]**

Determine the net work done by the gas in one complete cycle.

1 1 point: net work is the area enclosed by the cycle on the PV diagram

2 1 point: area $= (2.0 \times 10^5 - 1.0 \times 10^5)(3.0 \times 10^{-3} - 1.0 \times 10^{-3})$

3 1 point: net work = 200 J, done by the gas because the cycle is traversed clockwise

(d) EXPLAIN · SP3 **[3]**

Explain why the change in internal energy of the gas over one complete cycle is zero, and state what this implies about the net thermal energy exchanged with the surroundings.

1 1 point: internal energy is a function of state and depends only on the temperature

2 1 point: the gas returns to state A, so its temperature — and hence its internal energy — is the same as at the start, giving $\Delta U = 0$ for the cycle

3 1 point: by the first law the net thermal energy added must equal the net work done by the gas, 200 J

8 FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 10 **[12]**

ALGEBRA

Two point charges are fixed on a horizontal line: a charge $+2q$ at the origin, and a charge $-q$ at a distance d to the right of it.

(a) SKETCH · SP1 **[3]**

Sketch the electric field lines in the region around the two charges. Indicate the direction of each line with an arrow.

1 1 point: lines begin on the positive charge and end on the negative charge, with arrows pointing away from $+2q$ and towards $-q$

2 1 point: twice as many lines leave $+2q$ as arrive at $-q$, with the surplus continuing outward to large distances

3 1 point: lines meet both charges radially and never cross one another

(b) DETERMINE · SP2 **[4]**

Determine the location on the line through the two charges at which the net electric field is zero. Indicate whether it lies to the left of $+2q$, between the charges, or to the right of $-q$, and justify that region before calculating.

1 1 point: the null point must lie beyond the smaller charge, to the right of $-q$, because only there do the two fields oppose and the weaker charge is closer

2 1 point: sets $k(2q)/(d + x)^2 = kq/x^2$, where x is measured from $-q$

3 1 point: $2x^2 = (d + x)^2$, so $x\sqrt{2} = d + x$

4 1 point: $x = d/(\sqrt{2} - 1) = 2.4d$ to the right of $-q$

Choosing the region before calculating is worth a point in its own right. A candidate who sets up the equation between the charges finds no physical solution and loses the whole part.

(c) DETERMINE · SP2 **[3]**

Determine whether there is a point on the line between the two charges at which the electric potential is zero, and if so, where.

1 1 point: potentials are scalars, so a zero requires $k(2q)/r_1 = kq/r_2$ with $r_1 + r_2 = d$

2 1 point: $2r_2 = r_1$, so $r_2 = d/3$

3 1 point: the potential is zero at a distance $d/3$ to the left of $-q$ (that is, $2d/3$ from $+2q$)

(d) EXPLAIN · SP3 **[2]**

Explain why the point where the field is zero and the point where the potential is zero are in different places.

1 1 point: the field is a vector sum, so it vanishes where two contributions are equal in magnitude and opposite in direction — which can only happen outside the pair

2 1 point: the potential is a scalar sum, so it vanishes where two contributions of opposite sign are equal in magnitude, which happens between the charges; the two conditions are different, so the points differ

9 FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DISCRIMINATING · 13 **[12]**

ALGEBRA

A student is given a converging lens of unknown focal length, an illuminated object, a screen, an optical bench and a meter stick. The student measures the object distance u and the corresponding image distance v for several positions of the lens.

(a) DESCRIBE · SP4 **[3]**

Describe how the student should obtain each value of v so that the measurement is as accurate as possible.

1. 1 point: move the screen until the image of the object is as sharp as possible, then measure from the centre of the lens to the screen
2. 1 point: approach the sharpest position from both directions and take the midpoint of the range over which the image looks focused
3. 1 point: measure with the meter stick parallel to the bench and the eye directly above the scale, to avoid parallax

The second point is the one that separates a well-designed optics experiment from a rough one. The image looks acceptably sharp over a range of screen positions, and taking the middle of that range is what makes the reading reproducible.

(b) DESCRIBE · SP4 **[4]**

The thin lens equation is $1/u + 1/v = 1/f$. Describe how the student should plot the data to obtain a straight line, and state what the slope and the intercepts of that line represent.

1. 1 point: plot $1/v$ on the vertical axis against $1/u$ on the horizontal axis
2. 1 point: rearranged, $1/v = -(1/u) + 1/f$, which has the form $y = mx + c$
3. 1 point: the slope is -1
4. 1 point: both intercepts equal $1/f$

(c) DETERMINE · SP2 **[3]**

Use the data to determine the focal length of the lens.

1. 1 point: adds $1/u$ and $1/v$ for any row — for example $0.0500 + 0.0167 = 0.0667\ \text{cm}^{-1}$
2. 1 point: confirms the sum is the same for every row, so $1/f = 0.0667\ \text{cm}^{-1}$
3. 1 point: $f = 15.0$ cm

(d) EXPLAIN · SP4 **[2]**

The student notices that the point at $u = 20.0$ cm lies slightly further from the best-fit line than the others. Explain why the measurement of v is least precise for small object distances, and describe one change that would improve it.

1. 1 point: at small u the image distance is large, the image is highly magnified and dim, and the range of screen positions over which it looks sharp is widest — so the uncertainty in v is greatest
2. 1 point: improvement — use a brighter object, work in a darkened room, or take repeated determinations of the sharpest position and average them

10 ALGEBRA

FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 11 **[12]**

Three identical bulbs, each of resistance R, are connected to a battery of e.m.f. ε and negligible internal resistance. Bulb X is connected in series with a parallel combination of bulbs Y and Z. The brightness of a bulb is determined by the power it dissipates.

(a) INDICATE · SP3 **[1]**

Indicate which bulb or bulbs are brightest in the original circuit. No justification is required in this part.

1 1 point: bulb X

(b) DERIVE · SP2 **[4]**

Derive expressions for the power dissipated by bulb X and by bulb Y in the original circuit, in terms of ε and R.

1 1 point: parallel pair has resistance $R/2$, so the total resistance is $3R/2$

2 1 point: current through X is $I = \varepsilon/(3R/2) = 2\varepsilon/(3R)$

3 1 point: $P_X = I^2R = 4\varepsilon^2/(9R)$

4 1 point: current through Y is half of I, so $P_Y = (\varepsilon/(3R))^2R = \varepsilon^2/(9R)$

(c) DETERMINE · SP2 **[3]**

Bulb Z now burns out, breaking its branch of the circuit. Determine the new power dissipated by bulb X, and state whether X becomes brighter, dimmer, or stays the same.

1 1 point: with Z's branch broken, X and Y are in series and the total resistance is 2R

2 1 point: $I = \varepsilon/(2R)$, so $P_X = \varepsilon^2/(4R)$

3 1 point: $\varepsilon^2/(4R)$ is less than $4\varepsilon^2/(9R)$, so X becomes dimmer

(d) EXPLAIN · SP3 **[4]**

Explain, without using equations, why bulb X becomes dimmer while bulb Y becomes brighter when bulb Z burns out.

1 1 point: removing one of two parallel branches raises the resistance of that section, and so raises the total resistance of the circuit

2 1 point: a higher total resistance means a smaller current from the battery, and bulb X carries the whole of that current, so X dissipates less power and dims

3 1 point: bulb Y previously carried only half of the current through X, because the current divided between two identical branches

4 1 point: now Y carries all of the current, and although that total current is smaller than before, it is larger than the half-share Y used to have — so Y brightens

The final point is the one this task type exists to test. Both effects work against each other, and a candidate has to see that the increase from carrying the full current outweighs the decrease in the total current.

AP Physics C · Mechanics

Calculus-based mechanics: kinematics, translational dynamics including velocity-dependent forces, work and energy, momentum, torque and rotational dynamics, rotational energy and momentum, and oscillations.

SUGGESTED TIME	TOTAL MARKS	QUESTIONS	MULTIPLE CHOICE
70 minutes	**55**	**10**	**6**

SECTION **AP C:M · AP Physics C: Mechanics**

IN THE FORMAT OF Section I (single-select multiple choice) and Section II (four free-response task types)

DEMAND **Routine 2 · Demanding 5 · Discriminating 3**

Written to the standard the free-response rubrics actually apply. A numerical answer that appears without the symbolic expression behind it earns partial credit at best; a claim without reasoning earns nothing at all, however correct the claim is. The C courses are set at calculus level throughout — moments of inertia by integration, drag and RC problems as differential equations — because that is what separates them from Physics 1 and 2.

SYLLABUS POINTS 1 · 2 · 3 · 4 · 5 · 6 · 7

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.

THE PAPER

AP Physics C · Mechanics

Answer all questions. 55 marks in 70 minutes.

---

1 CALCULUS

MULTIPLE CHOICE · ROUTINE · 1 **[1]**

A particle moves along the x-axis with acceleration $a(t) = 6t$, where a is in m/s^2 and t is in seconds. At $t = 0$ the particle is at rest at the origin. What is its position at $t = 2.0$ s?

A 4.0 m

B 8.0 m

C 12 m

D 24 m

Answer

---

2 CALCULUS

MULTIPLE CHOICE · DEMANDING · 2 **[1]**

An object of mass m falls from rest through a fluid that exerts a resistive force of magnitude bv, where v is the speed. What is the terminal speed?

A $b/(mg)$

B mg/b

C $\sqrt{(mg/b)}$

D mgb

Answer

---

3 CALCULUS

MULTIPLE CHOICE · ROUTINE · 3 **[1]**

A single force $F(x) = 4x^2$ acts on an object as it moves along the x-axis, where F is in newtons and x in metres. How much work does this force do on the object as it moves from $x = 0$ to $x = 3.0$ m?

A 12 J

B 36 J

C 54 J

D 108 J

Answer

---

4 MULTIPLE CHOICE · DEMANDING · 5 **[1]**

CALCULUS

A uniform thin rod of mass M and length L rotates about an axis perpendicular to the rod through one end. What is its moment of inertia about that axis?

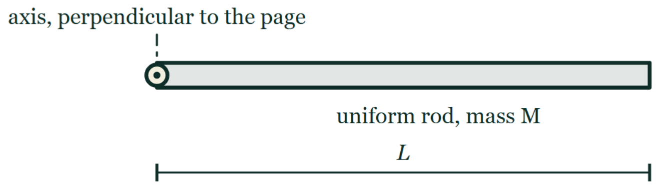

Fig. 4.1 *A uniform thin rod is drawn horizontally across the figure and labelled as having mass M. At its left-hand end a small circle with a dot at its centre marks the axis of rotation, which is perpendicular both to the rod and to the page; a short dashed leader connects that symbol to the words "axis, perpendicular to the page". A dimension line beneath the rod, with a tick at each end, runs from the axis to the far end of the rod and is labelled L.*

A $ML^2/12$

B $ML^2/6$

C $ML^2/3$

D ML^2

Answer

---

5 MULTIPLE CHOICE · DEMANDING · 6 **[1]**

CALCULUS

A figure skater spinning with her arms extended pulls her arms in close to her body. Which of the following is true?

A Her angular momentum and her kinetic energy both stay the same.

B Her angular momentum stays the same and her kinetic energy increases.

C Her angular momentum increases and her kinetic energy stays the same.

D Her angular momentum and her kinetic energy both increase.

Answer

---

6 MULTIPLE CHOICE · DEMANDING · 7 **[1]**

CALCULUS

A particle of mass m moves in a potential $U(x) = \frac{1}{2}kx^4$. Which statement about its motion for small oscillations about $x = 0$ is correct?

A The motion is simple harmonic with angular frequency $\sqrt{(k/m)}$.

B The motion is simple harmonic with angular frequency $\sqrt{(2k/m)}$.

C The motion is periodic but not simple harmonic, and its period depends on the amplitude.

D The motion is not periodic.

Answer

---

7 FREE RESPONSE · MATHEMATICAL ROUTINES · DISCRIMINATING · 5 · 6 **[13]**

CALCULUS

A uniform thin rod of mass M and length L is free to rotate in a vertical plane about a frictionless horizontal pivot at one end. The rod is held horizontal and released from rest.

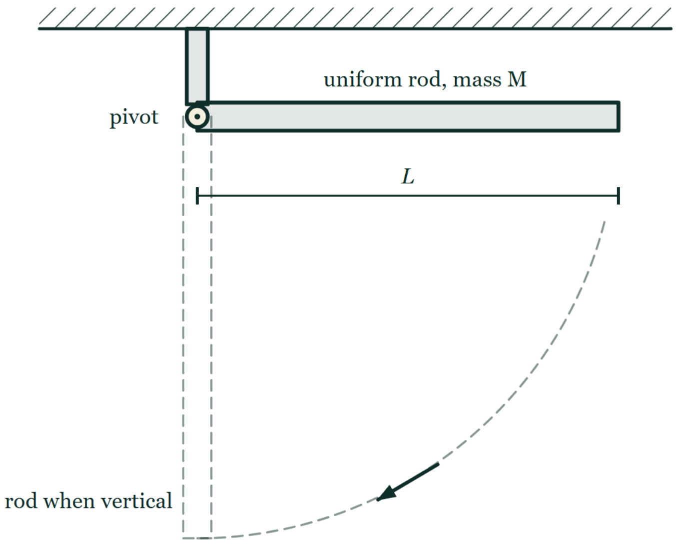

Fig. 7.1 *A uniform rod of mass M is held horizontal. Its left-hand end is carried on a hinge at the foot of a short post fixed to a hatched ceiling, and the word "pivot" labels that end. A dimension line below the rod, with a tick at each end, runs from the pivot to the free end and is labelled L. Directly below the pivot a dashed outline of the rod shows the position it will occupy when vertical, and a dashed arc from the free end down to that position, carrying a small arrow, shows the rod swinging down. No forces are marked on the rod.*

(a) DERIVE **[4]**

Using integration, derive the moment of inertia of the rod about the pivot. Show the mass element you use.

(b) DETERMINE **[3]**

Determine the angular acceleration of the rod at the instant it is released, while it is still horizontal.

(c) DERIVE **[3]**

Derive an expression for the angular speed of the rod when it reaches the vertical position.

(d) EXPLAIN **[3]**

Determine the linear acceleration of the free end of the rod at the instant of release, and explain how a point on the rod can have a downward acceleration greater than g.

8 CALCULUS

FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DISCRIMINATING · 3 · 7 **[12]**

A particle of mass m moves along the x-axis in a conservative field described by the potential energy function $U(x) = ax^4 - bx^2$, where a and b are positive constants.

(a) DERIVE **[2]**

Derive an expression for the force on the particle as a function of x.

(b) DETERMINE **[4]**

Determine the positions of all equilibrium points, and state for each whether it is stable or unstable.

(c) SKETCH **[3]**

Sketch a graph of U(x) against x, marking the equilibrium positions, and on the same axes indicate a total energy E for which the particle is confined to a region on one side of the origin only.

(d) DERIVE **[3]**

Derive an expression for the angular frequency of small oscillations of the particle about one of the stable equilibrium positions.

9 FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DEMANDING · 5 · 6 **[11]**

CALCULUS

A student wants to determine experimentally the moment of inertia I of a wheel that is free to rotate about a fixed horizontal axle. A light string is wound around a hub of known radius r on the axle, and a hanging mass m is attached to the free end. When released, the mass falls and the wheel rotates. Friction in the axle is not negligible.

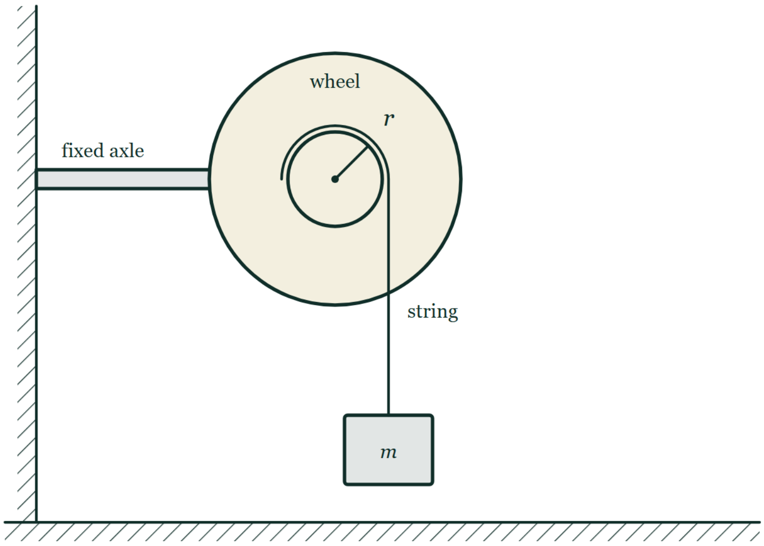

Fig. 9.1 *A large wheel is mounted on a fixed horizontal axle, carried on a bracket that runs out from a hatched vertical wall on the left. Concentric with the wheel and in front of it is a much smaller hub; a short line from the centre out to the hub's edge is labelled r. A string is wound over the top of the hub, leaves it tangentially on the right-hand side and hangs straight down to a rectangular block labelled m, which is suspended a short distance above a hatched horizontal floor.*

(a) DESCRIBE **[4]**

Describe a procedure for measuring the linear acceleration of the falling mass, and state the quantity the student should deliberately vary between trials.

(b) DERIVE **[4]**

Ignoring friction for this part, derive a relationship between the acceleration a of the hanging mass and the moment of inertia I, and describe how the student should plot the data to obtain a straight line.

(c) EXPLAIN **[3]**

Explain how the presence of friction in the axle would affect the value of I obtained from the slope, and describe a modification to the analysis that would account for it.

---

10 CALCULUS

FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 2 **[13]**

A block of mass m slides on a frictionless horizontal surface with initial speed v_0 at $t = 0$. It experiences a resistive force from the surrounding air of magnitude bv, directed opposite to its velocity, where b is a positive constant.

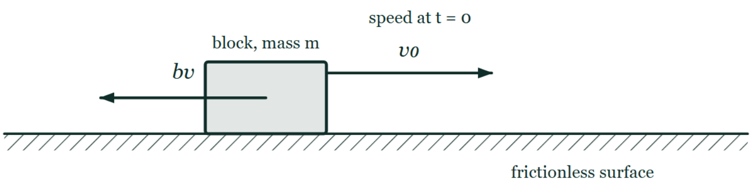

Fig. 10.1 *A rectangular block, labelled as having mass m, sits on a hatched horizontal surface that is marked "frictionless surface". Above the block an arrow points to the right, labelled v0 and annotated as the speed at t = 0. A second arrow begins at the centre of the block and points to the left, in the direction opposite to the motion, and is labelled bv for the resistive force the surrounding air exerts. No vertical forces are drawn, and no graph of the later motion is shown.*

(a) DERIVE **[4]**

Derive an expression for the speed of the block as a function of time.

(b) DETERMINE **[3]**

Determine the total distance travelled by the block before it comes to rest.

(c) SKETCH **[3]**

Sketch graphs of the speed and of the position of the block as functions of time, on separate axes.

(d) EXPLAIN **[3]**

Explain how the block can travel a finite total distance even though your expression predicts that its speed never reaches exactly zero.

MARK SCHEME

AP Physics C · Mechanics — 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 CALCULUS

MULTIPLE CHOICE · ROUTINE · 1 **[1]**

A particle moves along the x-axis with acceleration $a(t) = 6t$, where a is in m/s^2 and t is in seconds. At $t = 0$ the particle is at rest at the origin. What is its position at $t = 2.0$ s?

KEY **B** **8.0 m**

Integrating twice gives $v = 3t^2$ and $x = t^3$, so $x = 8.0$ m at $t = 2.0$ s. D is the answer of a candidate who evaluates a at $t = 2.0$ s to get 12 m/s^2 and then applies $x = \frac{1}{2}at^2$, which is only valid for constant acceleration — the whole point of the item is that this acceleration is not constant.

SP2

2 CALCULUS

MULTIPLE CHOICE · DEMANDING · 2 **[1]**

An object of mass m falls from rest through a fluid that exerts a resistive force of magnitude bv, where v is the speed. What is the terminal speed?

KEY **B** **mg/b**

C is the terminal speed for a resistive force proportional to v^2, and is the answer of a candidate who reaches for the more familiar quadratic drag law without reading the exponent given.

SP2

3 CALCULUS

MULTIPLE CHOICE · ROUTINE · 3 **[1]**

A single force $F(x) = 4x^2$ acts on an object as it moves along the x-axis, where F is in newtons and x in metres. How much work does this force do on the object as it moves from $x = 0$ to $x = 3.0$ m?

KEY **B** **36 J**

D is $F(3.0) \times 3.0 = 108$ J, the answer of a candidate who multiplies the final force by the distance instead of integrating. Since the force varies, the work is $\int_0^3 4x^2\,dx = (4/3)(27) = 36$ J.

SP2

4 CALCULUS

MULTIPLE CHOICE · DEMANDING · 5 **[1]**

A uniform thin rod of mass M and length L rotates about an axis perpendicular to the rod through one end. What is its moment of inertia about that axis?

KEY **C** **$ML^2/3$**

A is the moment of inertia about the centre. Applying the parallel-axis theorem, $I = ML^2/12 + M(L/2)^2 = ML^2/3$, and a candidate who quotes A has answered a different question.

SP2

5 CALCULUS

MULTIPLE CHOICE · DEMANDING · 6 **[1]**

A figure skater spinning with her arms extended pulls her arms in close to her body. Which of the following is true?

KEY **B** **Her angular momentum stays the same and her kinetic energy increases.**

A is the intuitive answer and is wrong about the energy. With $L = I\omega$ constant and I decreasing, $K = L^2/(2I)$ must rise — the skater does work pulling her arms inward against the centripetal requirement, and that work appears as kinetic energy.

SP3

6 MULTIPLE CHOICE · DEMANDING · 7 **[1]**

CALCULUS

A particle of mass m moves in a potential $U(x) = \frac{1}{2}kx^4$. Which statement about its motion for small oscillations about $x = 0$ is correct?

KEY **C** **The motion is periodic but not simple harmonic, and its period depends on the amplitude.**

The restoring force is $-dU/dx = -2kx^3$, which is not proportional to x, so the motion cannot be simple harmonic however small the amplitude. A and B are offered to candidates who assume any potential minimum gives SHM.

SP2

---

7 FREE RESPONSE · MATHEMATICAL ROUTINES · DISCRIMINATING · 5 · 6 **[13]**

CALCULUS

A uniform thin rod of mass M and length L is free to rotate in a vertical plane about a frictionless horizontal pivot at one end. The rod is held horizontal and released from rest.

(a) DERIVE · SP2 **[4]**

Using integration, derive the moment of inertia of the rod about the pivot. Show the mass element you use.

1. 1 point: takes a mass element $dm = (M/L)dx$ at distance x from the pivot
2. 1 point: writes $I = \int x^2\, dm = \int_0^L x^2(M/L)dx$
3. 1 point: evaluates the integral to $(M/L)(L^3/3)$
4. 1 point: $I = ML^2/3$

(b) DETERMINE · SP2 **[3]**

Determine the angular acceleration of the rod at the instant it is released, while it is still horizontal.

1. 1 point: the weight acts at the centre of mass, a distance L/2 from the pivot, giving $\tau = MgL/2$
2. 1 point: $\alpha = \tau/I = (MgL/2)/(ML^2/3)$
3. 1 point: $\alpha = 3g/(2L)$

(c) DERIVE · SP2 **[3]**

Derive an expression for the angular speed of the rod when it reaches the vertical position.

1. 1 point: the centre of mass falls a distance L/2, so the energy released is MgL/2
2. 1 point: sets $MgL/2 = \frac{1}{2}I\omega^2$ with $I = ML^2/3$
3. 1 point: $\omega = \sqrt{3g/L}$

(d) EXPLAIN · SP3 **[3]**

Determine the linear acceleration of the free end of the rod at the instant of release, and explain how a point on the rod can have a downward acceleration greater than g.

1. 1 point: $a = \alpha L = 3g/2$, which is 1.5g
2. 1 point: the rod is a rigid body, not a free particle — the pivot exerts a force on it, so the net force on the rod is not simply its weight
3. 1 point: the pivot pushes down on the rod (or, equivalently, the inner part of the rod is accelerating more slowly than g and the rod's rigidity transmits this as a downward force on the outer part), allowing the far end to accelerate faster than free fall

   A coin balanced on the end of such a rod is left behind when the rod is released — the classic demonstration this part is set on, and the point candidates find hardest to accept.

---

8 FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DISCRIMINATING · 3 · 7 **[12]**

CALCULUS

A particle of mass m moves along the x-axis in a conservative field described by the potential energy function $U(x) = ax^4 - bx^2$, where a and b are positive constants.

(a) DERIVE · SP2 **[2]**

Derive an expression for the force on the particle as a function of x.

1. 1 point: uses $F = -dU/dx$
2. 1 point: $F = -4ax^3 + 2bx$

(b) DETERMINE · SP2 **[4]**

Determine the positions of all equilibrium points, and state for each whether it is stable or unstable.

1. 1 point: equilibrium requires $F = 0$, so $2bx = 4ax^3$
2. 1 point: $x = 0$ and $x = \pm\sqrt{(b/2a)}$
3. 1 point: $x = 0$ is unstable — U has a local maximum there, since $d^2U/dx^2 = -2b < 0$
4. 1 point: $x = \pm\sqrt{(b/2a)}$ are stable, since $d^2U/dx^2 = 12ax^2 - 2b = 4b > 0$ at those points

(c) SKETCH · SP1 **[3]**

Sketch a graph of U(x) against x, marking the equilibrium positions, and on the same axes indicate a total energy E for which the particle is confined to a region on one side of the origin only.

1. 1 point: symmetric double-well curve, with $U \to +\infty$ as $x \to \pm\infty$ and a local maximum of $U = 0$ at $x = 0$
2. 1 point: minima marked at $x = \pm\sqrt{(b/2a)}$, with U negative there
3. 1 point: a horizontal line drawn at a negative energy E, between the minimum value of U and zero, with the two turning points on one side identified

(d) DERIVE · SP2 **[3]**

Derive an expression for the angular frequency of small oscillations of the particle about one of the stable equilibrium positions.

1. 1 point: for small displacements about a minimum, the effective spring constant is $k_{eff} = d^2U/dx^2$ evaluated at that point
2. 1 point: $k_{eff} = 12a(b/2a) - 2b = 4b$
3. 1 point: $\omega = \sqrt{(k_{eff}/m)} = 2\sqrt{(b/m)}$

The constant a drops out entirely, which is worth remarking on: it sets where the minimum sits but not how stiff the well is at the bottom.

9 FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DEMANDING · 5 · 6 **[11]**

CALCULUS

A student wants to determine experimentally the moment of inertia I of a wheel that is free to rotate about a fixed horizontal axle. A light string is wound around a hub of known radius r on the axle, and a hanging mass m is attached to the free end. When released, the mass falls and the wheel rotates. Friction in the axle is not negligible.

(a) DESCRIBE · SP4 **[4]**

Describe a procedure for measuring the linear acceleration of the falling mass, and state the quantity the student should deliberately vary between trials.

1. 1 point: release the mass from rest from a measured height h and time the fall with a stopwatch or photogate
2. 1 point: obtain the acceleration from $h = ½at^2$, repeating each trial and averaging the time
3. 1 point: vary the hanging mass m between trials, keeping the hub radius and the wheel unchanged
4. 1 point: use a photogate or video rather than a hand-operated stopwatch where possible, since the fall times are short and reaction time is a significant fraction of them

(b) DERIVE · SP4 **[4]**

Ignoring friction for this part, derive a relationship between the acceleration a of the hanging mass and the moment of inertia I, and describe how the student should plot the data to obtain a straight line.

1. 1 point: for the hanging mass, $mg - T = ma$; for the wheel, $Tr = I\alpha$ with $\alpha = a/r$
2. 1 point: eliminating T gives $mg = ma + Ia/r^2$, so $a = mg/(m + I/r^2)$
3. 1 point: rearranges to a linear form — for example $1/a = (I/r^2)(1/(mg)) + 1/g$
4. 1 point: plot 1/a against 1/m; the slope is $I/(gr^2)$ and the vertical intercept is 1/g

Choosing which reciprocal to plot is the substance of the task. Plotting a against m gives a curve and no usable gradient.

(c) EXPLAIN · SP4 **[3]**

Explain how the presence of friction in the axle would affect the value of I obtained from the slope, and describe a modification to the analysis that would account for it.

1. 1 point: a frictional torque opposes the rotation, so every measured acceleration is smaller than the frictionless model predicts
2. 1 point: the analysis attributes that reduction entirely to rotational inertia, so the value of I obtained is too large
3. 1 point: include a constant frictional torque τ_f in the wheel's equation, $Tr - \tau_f = I\alpha$, which adds a constant term to the linearised relationship and can be found from the intercept — or measure the torque needed to keep the wheel turning at constant speed and subtract it

10 FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 2 **[13]**

CALCULUS

A block of mass m slides on a frictionless horizontal surface with initial speed v_0 at $t = 0$. It experiences a resistive force from the surrounding air of magnitude bv, directed opposite to its velocity, where b is a positive constant.

(a) DERIVE · SP2 **[4]**

Derive an expression for the speed of the block as a function of time.

1. 1 point: Newton's second law gives $m\,dv/dt = -bv$
2. 1 point: separates variables, $dv/v = -(b/m)dt$
3. 1 point: integrates from v_0 at $t = 0$ to v at t, giving $\ln(v/v_0) = -bt/m$
4. 1 point: $v(t) = v_0e^{-bt/m}$

(b) DETERMINE · SP2 **[3]**

Determine the total distance travelled by the block before it comes to rest.

1. 1 point: $x = \int_0^\infty v_0e^{-bt/m}\,dt$
2. 1 point: evaluates to $v_0(m/b)[-e^{-bt/m}]_0^\infty$
3. 1 point: $x = mv_0/b$, a finite distance

(c) SKETCH · SP1 **[3]**

Sketch graphs of the speed and of the position of the block as functions of time, on separate axes.

1. 1 point: speed starts at v_0, decreases, is concave up, and approaches zero asymptotically without reaching it
2. 1 point: position starts at zero with initial slope v_0 and increases
3. 1 point: position approaches the horizontal asymptote $x = mv_0/b$

(d) EXPLAIN · SP3 **[3]**

Explain how the block can travel a finite total distance even though your expression predicts that its speed never reaches exactly zero.

1. 1 point: as the block slows, the resistive force also falls in proportion, so the deceleration decreases and the block never quite stops within the model
2. 1 point: the distance covered in each successive interval of time falls off exponentially
3. 1 point: the sum of those ever-smaller contributions converges, so the total distance is finite even though the time taken is unbounded — a physical situation in which "never stops" and "travels a finite distance" are both true

   This is the part of the task type that carries no equations at all in the rubric. A candidate who re-derives part (b) instead of explaining it earns nothing here.

AP · COLLEGE BOARD AP PHYSICS · FRAMEWORKS FIRST EXAMINED IN 2025

AP Physics C · Electricity and Magnetism

Calculus-based electromagnetism: charge and Gauss's law, electric potential, conductors and capacitors, circuits including RC transients, magnetic fields and Ampère's law, and electromagnetic induction.

SUGGESTED TIME	TOTAL MARKS	QUESTIONS	MULTIPLE CHOICE
70 minutes	**62**	**10**	**6**

SECTION **AP C:E&M · AP Physics C: Electricity and Magnetism**

IN THE FORMAT OF Section I (single-select multiple choice) and Section II (four free-response task types)

DEMAND **Routine 2 · Demanding 6 · Discriminating 2**

Written to the standard the free-response rubrics actually apply. A numerical answer that appears without the symbolic expression behind it earns partial credit at best; a claim without reasoning earns nothing at all, however correct the claim is. The C courses are set at calculus level throughout — moments of inertia by integration, drag and RC problems as differential equations — because that is what separates them from Physics 1 and 2.

SYLLABUS POINTS 8 · 9 · 10 · 11 · 12 · 13

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.

THE PAPER

AP Physics C · Electricity and Magnetism

Answer all questions. 62 marks in 70 minutes.

---

1 MULTIPLE CHOICE · DEMANDING · 8 **[1]**

CALCULUS

A solid conducting sphere of radius R carries a total charge Q distributed on its surface. What is the magnitude of the electric field at a distance r from the centre, where $r < R$?

A zero

B $Qr/(4\pi\varepsilon_0 R^3)$

C $Q/(4\pi\varepsilon_0 r^2)$

D $Q/(4\pi\varepsilon_0 R^2)$

Answer

2 MULTIPLE CHOICE · DEMANDING · 10 **[1]**

CALCULUS

A parallel-plate capacitor is charged by a battery and the battery is then disconnected. A dielectric slab of dielectric constant $\kappa > 1$ is inserted, filling the space between the plates. What happens to the charge on the plates and to the potential difference across them?

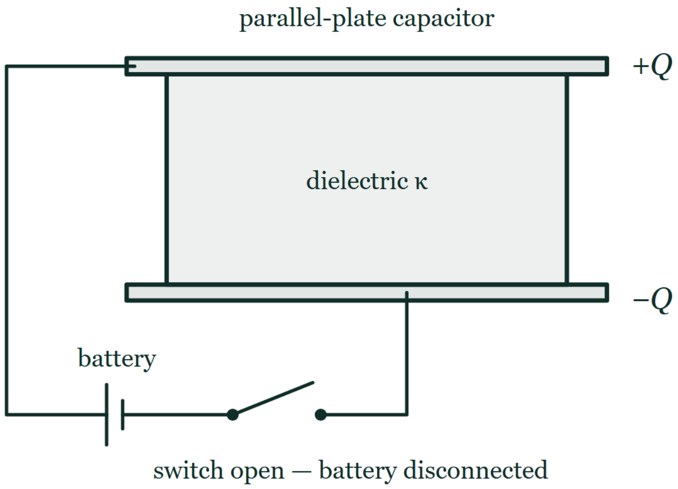

Fig. 2.1 *Two long horizontal plates, one directly above the other, form a parallel-plate capacitor; the upper plate is marked +Q at its right-hand end and the lower plate is marked -Q. A lightly shaded slab labelled "dielectric" with the constant k fills the whole space between the plates. A wire leaves the left-hand end of the upper plate, runs left and then down, passes through a battery and then an open switch along the bottom of the figure, and rises again to meet the underside of the lower plate. The switch is drawn open and labelled to show that the battery has been disconnected.*

A charge unchanged, potential difference decreases

B charge unchanged, potential difference increases

C charge increases, potential difference unchanged

D charge decreases, potential difference unchanged

Answer

---

3 MULTIPLE CHOICE · ROUTINE · 11 **[1]**

CALCULUS

In a series RC circuit connected to a battery of e.m.f. ε at $t = 0$ with the capacitor initially uncharged, what are the current immediately after the switch is closed and a long time later?

A ε/R immediately, and zero a long time later

B zero immediately, and ε/R a long time later

C ε/R at both times

D zero at both times

Answer

---

4 MULTIPLE CHOICE · ROUTINE · 12 **[1]**

CALCULUS

A long solenoid has n turns per unit length and carries a current I. Using Ampère's law, what is the magnitude of the magnetic field well inside the solenoid, far from its ends?

A $\mu_0 I/(2\pi r)$

B $\mu_0 nI$

C $\mu_0 nI/2$

D $\mu_0 I/(2R)$

Answer

---

5 MULTIPLE CHOICE · DEMANDING · 13 **[1]**

CALCULUS

A circular loop of wire lies in the plane of the page in a uniform magnetic field directed into the page. The magnitude of the field is increasing with time. What is the direction of the induced current in the loop?

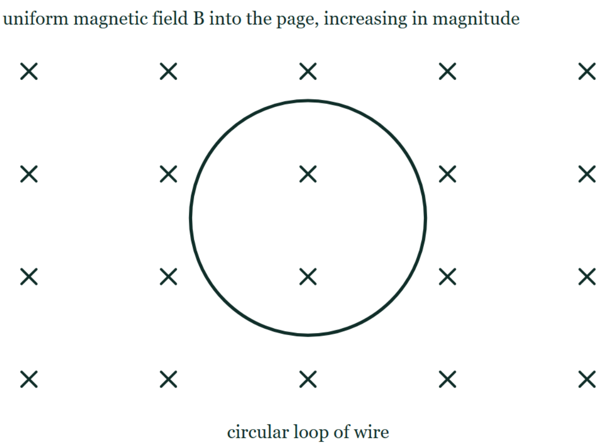

Fig. 5.1 *A single circle, labelled as a circular loop of wire, lies in the plane of the page. Small crosses are spaced in an even grid over the whole area of the figure, both inside the loop and all around it, showing a uniform magnetic field directed into the page; the caption to the field states that its magnitude is increasing with time. Nothing is drawn on the loop itself: no arrow, no current direction and no terminals are marked.*

A clockwise, because the induced current opposes the field

B counterclockwise, because the induced current opposes the increase in flux into the page

C clockwise, because the induced current reinforces the increase in flux

D there is no induced current, because the loop is not moving

Answer

---

6 MULTIPLE CHOICE · DEMANDING · 9 **[1]**

CALCULUS

In a region of space the electric potential is given by $V(x) = 3x^2 - 2x$, where V is in volts and x in metres. What is the x-component of the electric field at x = 2.0 m?

A −10 V/m

B −8.0 V/m

C +8.0 V/m

D +10 V/m

Answer

---

7 FREE RESPONSE · MATHEMATICAL ROUTINES · DISCRIMINATING · 8 · 9 **[14]**

CALCULUS

An insulating sphere of radius R carries a volume charge density that varies with distance from the centre as $\rho(r) = \rho_0 r/R$ for $r \le R$, where ρ_0 is a positive constant. There is no charge outside the sphere.

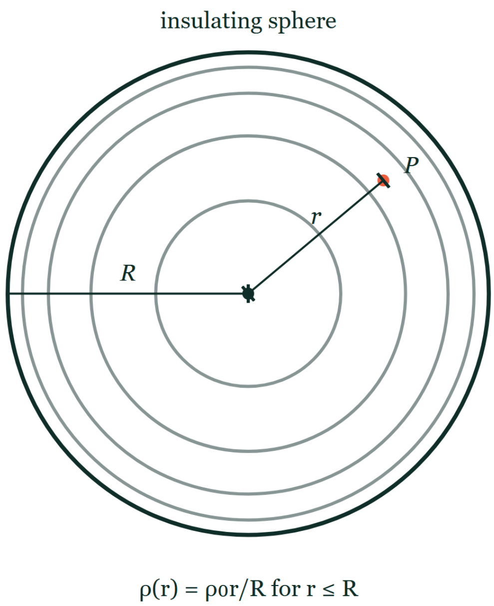

Fig. 7.1 *A large circle represents the insulating sphere. Inside it, faint concentric rings are drawn at intervals that get smaller towards the outside, indicating that the charge density increases with distance from the centre. A dimension line from the centre out to the surface, tick-marked at both ends, is labelled R. A second, shorter dimension line runs from the centre to a small marked point P inside the sphere and is labelled r. Below the sphere the density is written as a function of radius, proportional to r divided by R. No Gaussian surface is drawn.*

(a) DERIVE **[3]**

Derive an expression for the total charge Q on the sphere.

(b) DERIVE **[4]**

Using Gauss's law, derive an expression for the magnitude of the electric field at a distance r from the centre, for $r < R$.

(c) DERIVE **[3]**

Derive an expression for the magnitude of the electric field at a distance r from the centre, for $r > R$, and verify that your two expressions agree at $r = R$.

(d) DERIVE **[4]**

Derive an expression for the electric potential at the centre of the sphere, taking the potential to be zero at infinity.

---

8 CALCULUS

FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 10 · 11 **[15]**

A capacitor of capacitance C, initially uncharged, is connected in series with a resistor of resistance R and a battery of e.m.f. ε. The switch is closed at $t = 0$.

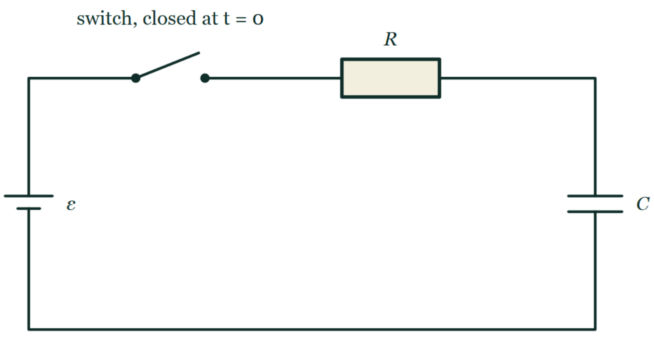

Fig. 8.1 *A single-loop circuit drawn as a rectangle. A cell of e.m.f. epsilon sits in the left-hand side of the loop, with its long positive plate uppermost. Along the top wire, reading from the left, come an open switch labelled S with the note that it is closed at t = 0, and then a rectangular resistor labelled R. A capacitor labelled C, drawn as two equal parallel plates, sits in the right-hand side of the loop. Everything is in series round the one loop: there are no branches and no junction dots anywhere in the circuit.*

(a) DERIVE **[4]**

Write the loop equation for the circuit and derive an expression for the charge on the capacitor as a function of time.

(b) SKETCH **[4]**

On separate axes, sketch the charge on the capacitor and the current in the circuit as functions of time. Label the initial value and the asymptotic value on each.

(c) DETERMINE **[3]**

Determine the time, as a multiple of RC, at which the capacitor holds half of its final charge.

(d) EXPLAIN **[4]**

The total energy delivered by the battery over the whole charging process is $C\varepsilon^2$, but only $\frac{1}{2}C\varepsilon^2$ is stored in the capacitor. Explain where the remaining energy goes, and explain why this fraction does not depend on the value of R.

9 CALCULUS

FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DEMANDING · 10 · 11 **[13]**

A student is given a capacitor of unknown capacitance, a resistor of known resistance R = 47 kΩ, a battery, a switch, a voltmeter of very high resistance and a stopwatch. The student wants to determine the capacitance.

(a) DESCRIBE **[4]**

Describe a procedure the student could use, and state which quantities should be recorded.

(b) DESCRIBE **[3]**

Describe how the student should linearise the data, and state what the slope of the resulting graph represents.

(c) DETERMINE **[3]**

The student's graph of ln(V/V) against t has a slope of $-0.43\ s^{-1}$. Determine the capacitance.

(d) EXPLAIN **[3]**

Explain why plotting ln V against t is preferable to determining the time constant by reading off the time at which V has fallen to 37% of its initial value.

A conducting rod of mass m and length L slides without friction on two long horizontal parallel rails separated by L. The rails are joined at one end by a resistor of resistance R, and the whole apparatus sits in a uniform magnetic field of magnitude B directed vertically, perpendicular to the plane of the rails. The rod is given an initial speed v_0 to the right at t = 0 and then released. The rod and rails have negligible resistance.

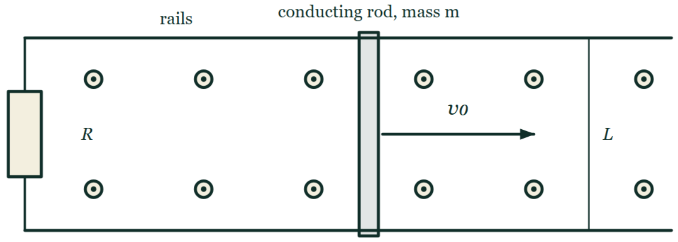

Fig. 10.1 *The apparatus is seen from above. Two long parallel horizontal rails run across the figure, joined at their left-hand ends by a resistor labelled R, and open at the right-hand end. A short bar lying across the rails, drawn solid, is the conducting rod of mass m. An arrow starting at the rod points to the right and is labelled v0. A tick-marked dimension line drawn between the rails to the right of the rod is labelled L for their separation. Dots in an even grid cover the whole area, marking a uniform magnetic field pointing out of the page, that is vertically upward from the horizontal plane of the rails. No induced current or force is drawn.*

(a) DERIVE **[3]**

Derive expressions for the e.m.f. induced in the circuit and the current in the resistor when the rod moves with speed v.

(b) DERIVE **[4]**

Derive an expression for the speed of the rod as a function of time.

(c) DETERMINE **[3]**

Determine the total energy dissipated in the resistor from t = 0 until the rod has effectively stopped, and determine the total distance the rod travels.

(d) EXPLAIN **[4]**

Explain, without deriving anything further, why the rod slows down, and explain what would be observed instead if the resistor were replaced by a superconducting wire of zero resistance.

MARK SCHEME

AP Physics C · Electricity and Magnetism — 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 · DEMANDING · 8 **[1]**

CALCULUS

A solid conducting sphere of radius R carries a total charge Q distributed on its surface. What is the magnitude of the electric field at a distance r from the centre, where $r < R$?

KEY **A** **zero**

B is the field inside a uniformly charged insulating sphere and is the trap: the word conducting is what decides the answer. A Gaussian surface inside a conductor in electrostatic equilibrium encloses no charge, so the field is zero.

SP2

2 MULTIPLE CHOICE · DEMANDING · 10 **[1]**

CALCULUS

A parallel-plate capacitor is charged by a battery and the battery is then disconnected. A dielectric slab of dielectric constant $\kappa > 1$ is inserted, filling the space between the plates. What happens to the charge on the plates and to the potential difference across them?

KEY **A** **charge unchanged, potential difference decreases**

C is the correct answer to the same question with the battery still connected, and telling the two cases apart is the entire item. With the battery removed the charge has nowhere to go, so Q is fixed; C rises by κ, and V = Q/C therefore falls.

SP3

3 MULTIPLE CHOICE · ROUTINE · 11 **[1]**

CALCULUS

In a series RC circuit connected to a battery of e.m.f. ε at t = 0 with the capacitor initially uncharged, what are the current immediately after the switch is closed and a long time later?

KEY **A** **ε/R immediately, and zero a long time later**

B is the answer for an inductor rather than a capacitor. An uncharged capacitor has no potential difference across it, so at the first instant it behaves as a wire; once charged to ε it blocks any further current.

SP2

4 MULTIPLE CHOICE · ROUTINE · 12 **[1]**

CALCULUS

A long solenoid has n turns per unit length and carries a current I. Using Ampère's law, what is the magnitude of the magnetic field well inside the solenoid, far from its ends?

KEY **B** **$\mu_0 nI$**

A is the field of a long straight wire and D that at the centre of a single loop. C is the field at the very end of a solenoid, which is a genuinely different situation from the one described.

SP2

5 MULTIPLE CHOICE · DEMANDING · 13 **[1]**

CALCULUS

A circular loop of wire lies in the plane of the page in a uniform magnetic field directed into the page. The magnitude of the field is increasing with time. What is the direction of the induced current in the loop?

KEY **B** **counterclockwise, because the induced current opposes the increase in flux into the page**

D confuses motional e.m.f. with Faraday's law in general — a stationary loop in a changing field has an induced e.m.f. A gets the reasoning half right: the induced current opposes the change in flux, not the field itself, and here that requires a counterclockwise current producing flux out of the page.

SP3

---

6 MULTIPLE CHOICE · DEMANDING · 9 **[1]**

CALCULUS

In a region of space the electric potential is given by $V(x) = 3x^2 - 2x$, where V is in volts and x in metres. What is the x-component of the electric field at x = 2.0 m?

KEY **A** **−10 V/m**

D omits the minus sign in $E = -dV/dx$, which is the commonest single error on this topic. C evaluates V rather than its derivative.

SP2

---

7 FREE RESPONSE · MATHEMATICAL ROUTINES · DISCRIMINATING · 8 · 9 **[14]**

CALCULUS

An insulating sphere of radius R carries a volume charge density that varies with distance from the centre as $\rho(r) = \rho_0 r/R$ for $r \le R$, where ρ_0 is a positive constant. There is no charge outside the sphere.

(a) DERIVE · SP2 **[3]**

Derive an expression for the total charge Q on the sphere.

1. 1 point: uses a spherical shell of volume $dV = 4\pi r^2 dr$ as the element of integration
2. 1 point: $Q = \int_0^R \rho_0(r/R)4\pi r^2\, dr = (4\pi\rho_0/R)\int_0^R r^3\, dr$
3. 1 point: $Q = \pi\rho_0 R^3$

(b) DERIVE · SP2 **[4]**

Using Gauss's law, derive an expression for the magnitude of the electric field at a distance r from the centre, for r < R.

1. 1 point: chooses a concentric spherical Gaussian surface of radius r and states that E is radial and constant on it, so $\oint E\cdot dA = E(4\pi r^2)$
2. 1 point: computes the enclosed charge by integrating, $q_{enc} = (4\pi\rho_0/R)(r^4/4) = \pi\rho_0 r^4/R$
3. 1 point: sets $E(4\pi r^2) = q_{enc}/\varepsilon_0$
4. 1 point: $E = \rho_0 r^2/(4\varepsilon_0 R)$

Treating the enclosed charge as $Q(r/R)^3$ — correct only for a uniform sphere — is the single commonest error here and costs three of the four points.

(c) DERIVE · SP2 **[3]**

Derive an expression for the magnitude of the electric field at a distance r from the centre, for r > R, and verify that your two expressions agree at r = R.

1. 1 point: outside the sphere the whole charge is enclosed, so $E = Q/(4\pi\varepsilon_0 r^2) = \rho_0 R^3/(4\varepsilon_0 r^2)$
2. 1 point: substitutes r = R into the inside expression to get $\rho_0 R/(4\varepsilon_0)$
3. 1 point: substitutes r = R into the outside expression to get the same value, confirming the field is continuous at the surface

(d) DERIVE · SP2 **[4]**

Derive an expression for the electric potential at the centre of the sphere, taking the potential to be zero at infinity.

1. 1 point: $V(0) = \int_0^\infty E\, dr$, splitting the integral at r = R
2. 1 point: outside contribution $\int_R^\infty \rho_0 R^3/(4\varepsilon_0 r^2)\, dr = \rho_0 R^2/(4\varepsilon_0)$
3. 1 point: inside contribution $\int_0^R \rho_0 r^2/(4\varepsilon_0 R)\, dr = \rho_0 R^2/(12\varepsilon_0)$
4. 1 point: $V(0) = \rho_0 R^2/(4\varepsilon_0) + \rho_0 R^2/(12\varepsilon_0) = \rho_0 R^2/(3\varepsilon_0)$

8 FREE RESPONSE · TRANSLATION BETWEEN REPRESENTATIONS · DEMANDING · 10 · 11 **[15]**

CALCULUS A capacitor of capacitance C, initially uncharged, is connected in series with a resistor of resistance R and a battery of e.m.f. ε. The switch is closed at $t = 0$.

(a) DERIVE · SP2 **[4]**

Write the loop equation for the circuit and derive an expression for the charge on the capacitor as a function of time.

1. 1 point: $\varepsilon - IR - q/C = 0$ with $I = dq/dt$
2. 1 point: separates variables, $dq/(\varepsilon C - q) = dt/(RC)$
3. 1 point: integrates with $q = 0$ at $t = 0$
4. 1 point: $q(t) = \varepsilon C(1 - e^{(-t/RC)})$

(b) SKETCH · SP1 **[4]**

On separate axes, sketch the charge on the capacitor and the current in the circuit as functions of time. Label the initial value and the asymptotic value on each.

1. 1 point: charge rises from zero, concave down, approaching the asymptote $q = \varepsilon C$
2. 1 point: εC labelled on the charge graph
3. 1 point: current starts at ε/R and decays, concave up, approaching zero
4. 1 point: ε/R labelled on the current graph

(c) DETERMINE · SP2 **[3]**

Determine the time, as a multiple of RC, at which the capacitor holds half of its final charge.

1. 1 point: sets $\varepsilon C(1 - e^{(-t/RC)}) = \frac{1}{2}\varepsilon C$
2. 1 point: $e^{(-t/RC)} = \frac{1}{2}$, so $t/RC = \ln 2$
3. 1 point: $t = 0.69RC$

(d) EXPLAIN · SP3 **[4]**

The total energy delivered by the battery over the whole charging process is $C\varepsilon^2$, but only $\frac{1}{2}C\varepsilon^2$ is stored in the capacitor. Explain where the remaining energy goes, and explain why this fraction does not depend on the value of R.

1. 1 point: the difference, $\frac{1}{2}C\varepsilon^2$, is dissipated as thermal energy in the resistor
2. 1 point: the battery moves the full charge εC through the full potential difference ε, while the capacitor's stored energy is the integral of $q/C\, dq$, which averages to half that
3. 1 point: a larger R makes the current smaller but the process correspondingly longer
4. 1 point: the two effects cancel exactly in $\int I^2R\, dt$, so the dissipated energy is $\frac{1}{2}C\varepsilon^2$ whatever the resistance

The independence from R is one of the most surprising results in the topic and one of the best-discriminating parts available. Candidates who say only "energy is lost in the resistor" earn one point of four.

9 FREE RESPONSE · EXPERIMENTAL DESIGN AND ANALYSIS · DEMANDING · 10 · 11 **[13]**

CALCULUS

A student is given a capacitor of unknown capacitance, a resistor of known resistance $R = 47\ \text{k}\Omega$, a battery, a switch, a voltmeter of very high resistance and a stopwatch. The student wants to determine the capacitance.

(a) DESCRIBE · SP4 **[4]**

Describe a procedure the student could use, and state which quantities should be recorded.

1. 1 point: charge the capacitor fully through the battery, then disconnect the battery and discharge it through the known resistor
2. 1 point: record the voltmeter reading V at measured time intervals t from the start of the discharge
3. 1 point: repeat the whole discharge several times and average the readings at each time
4. 1 point: states why the voltmeter must have a very high resistance — otherwise it provides a parallel discharge path and shortens the time constant

(b) DESCRIBE · SP4 **[3]**

Describe how the student should linearise the data, and state what the slope of the resulting graph represents.

1. 1 point: $V = V_0 e^{(-t/RC)}$, so $\ln V = \ln V_0 - t/(RC)$
2. 1 point: plot $\ln V$ on the vertical axis against t on the horizontal axis to obtain a straight line
3. 1 point: the slope is $-1/(RC)$, so $C = -1/(R \times \text{slope})$

(c) DETERMINE · SP2 **[3]**

The student's graph of $\ln(V/V)$ against t has a slope of $-0.43\ \text{s}^{-1}$. Determine the capacitance.

1. 1 point: $RC = 1/0.43 = 2.33\ \text{s}$
2. 1 point: $C = 2.33 / 47 \times 10^3$
3. 1 point: $C = 5.0 \times 10^{-5}\ \text{F}$ (50 μF)

(d) EXPLAIN · SP4 **[3]**

Explain why plotting $\ln V$ against t is preferable to determining the time constant by reading off the time at which V has fallen to 37% of its initial value.

1. 1 point: the single-point method relies on two readings only, V_0 and one other, so an error in either propagates directly into the answer
2. 1 point: the graph uses every data point, so random errors average out and the slope is better determined
3. 1 point: the straightness of the line is itself a test that the discharge really is exponential, which the single-point method assumes without checking

10 FREE RESPONSE · QUALITATIVE/QUANTITATIVE TRANSLATION · DISCRIMINATING · 13 **[14]**

CALCULUS

A conducting rod of mass m and length L slides without friction on two long horizontal parallel rails separated by L. The rails are joined at one end by a resistor of resistance R, and the whole apparatus sits in a uniform magnetic field of magnitude B directed vertically, perpendicular to the plane of the rails. The rod is given an initial speed v_0 to the right at t = 0 and then released. The rod and rails have negligible resistance.

(a) DERIVE · SP2 **[3]**

Derive expressions for the e.m.f. induced in the circuit and the current in the resistor when the rod moves with speed v.

1. 1 point: the flux through the circuit changes as the enclosed area changes, $\varepsilon = -d\Phi/dt = -BL(dx/dt)$
2. 1 point: magnitude of the e.m.f. is BLv
3. 1 point: $I = BLv/R$

(b) DERIVE · SP2 **[4]**

Derive an expression for the speed of the rod as a function of time.

1. 1 point: the force on the current-carrying rod is $F = BIL = B^2L^2v/R$, directed opposite to the motion by Lenz's law
2. 1 point: $m\,dv/dt = -B^2L^2v/R$
3. 1 point: separates and integrates from v_0 at t = 0
4. 1 point: $v(t) = v_0 e^{-B^2L^2t/(mR)}$

(c) DETERMINE · SP2 **[3]**

Determine the total energy dissipated in the resistor from t = 0 until the rod has effectively stopped, and determine the total distance the rod travels.

1. 1 point: the only energy source is the rod's kinetic energy, and it all ends up in the resistor, so the total dissipated energy is $\frac{1}{2}mv_0^2$
2. 1 point: distance $x = \int_0^\infty v\,dt = v_0\,mR/(B^2L^2)$
3. 1 point: states both results with correct symbols

(d) EXPLAIN · SP3 **[4]**

Explain, without deriving anything further, why the rod slows down, and explain what would be observed instead if the resistor were replaced by a superconducting wire of zero resistance.

1. 1 point: the motion changes the flux through the circuit, which drives a current
2. 1 point: by Lenz's law that current is in the direction whose magnetic force opposes the motion, so the rod decelerates — the kinetic energy is transferred to the resistor as thermal energy
3. 1 point: with zero resistance the current, and hence the retarding force, would become arbitrarily large for any non-zero speed
4. 1 point: so the rod would stop almost immediately, and in the idealised limit the flux through the circuit cannot change at all — which is the behaviour that makes a superconducting loop hold its flux fixed

The final point rewards a candidate who recognises that R appearing in a denominator is a signal to ask what happens in the limit, rather than one who simply repeats the derivation with R = 0.

THE CHEAPEST MARKS ON ANY PAPER

What the command words are asking for

Every board publishes these and marks to them. A candidate who explains where the question said state has spent four minutes earning one mark; one who states where it said explain has earned none.

Calculate	Perform mathematical steps to arrive at a final answer, including an algebraic expression, correctly substituted numbers, and units.
Derive	Perform a series of mathematical steps from a fundamental law or relationship to arrive at the desired result.
Describe	Provide the relevant characteristics of a specified topic.
Determine	Arrive at a conclusion after reasoning, observation, or applying mathematical routines.
Explain	Provide information about how or why a relationship, situation or outcome occurs, using evidence and reasoning.
Indicate	Select the correct option from those provided, before giving any reasoning that is asked for.
Justify	Provide evidence to support or defend a claim, and reasoning to explain how that evidence supports the claim.
Sketch	Draw a shape or trend line, without requiring exact plotted values.

WHAT IS BEING TESTED

AP assessment objectives

Every AP Physics exam has two sections of equal weight. Section I is single-select multiple choice with four options and no penalty for a wrong answer. Section II is free response, scored in points, and every question is built on one of four published task types. A table of equations and a table of constants are supplied for both sections, so nothing on an AP exam tests whether you can recall a formula.

SP1 21 MARKS · 9%	**Creating representations** Describe, create and use models, diagrams, graphs and free-body diagrams to represent a physical situation.
SP2 120 MARKS · 54%	**Mathematical routines** Determine and apply mathematical relationships, working symbolically before substituting, and check the reasonableness of a result.
SP3 41 MARKS · 18%	**Scientific questioning and argumentation** Make and justify a claim with evidence and reasoning, and evaluate the claims and reasoning of others.
SP4 42 MARKS · 19%	**Experimental method and data analysis** Design an experimental procedure, identify and control variables, analyse data including linearisation, and evaluate sources of error.

> *Written by GioPhysics from the published course frameworks. These are practice exams in the style of AP Physics; they are not College Board materials, contain no released exam questions, and the official course and exam descriptions remain the authority. AP is a trademark of the College Board, which is not affiliated with and does not endorse GioPhysics.*
>
> College Board AP Physics course and exam descriptions — https://apcentral.collegeboard.org/courses