Past-paper walk-through

Power ▪ 3.5

eXercise

Questions in this set

- 2019 Q4
- 2018 Q2
- 2018 Q3
- 2017 Q1

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 4

2019 ▪ Q4

[Diagram: A circuit consisting of a battery connected in series with a resistor labeled R_1 and a motor. The motor's output shaft (shown as a spring/coil symbol) connects via a string over to a block of mass M, which hangs at a height H above the ground, as indicated by a vertical double-headed arrow labeled H between the block and the ground.]

A motor is a device that when connected to a battery converts electrical energy into mechanical energy. The motor shown above is used to lift a block of mass M at constant speed from the ground to a height H above the ground in a time interval Δt. The motor has constant resistance and is connected in series with a resistor of resistance R_1 and a battery.

Question 4

Mechanical power, the rate at which mechanical work is done on the block, increases if the potential difference (voltage drop) between the two terminals of the motor increases.

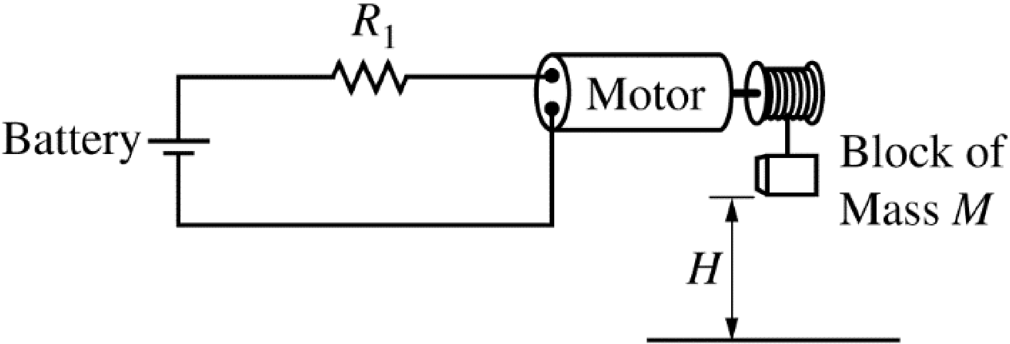
(a) Determine an expression for the mechanical power in terms of M, H, Δt, and physical constants, as appropriate.

(b) Without M or H being changed, the time interval Δt can be decreased by adding one resistor of resistance R_2, where $R_2 > R_1$, to the circuit shown above. How should the resistor of resistance R_2 be added to the circuit to decrease Δt?

$I_{nparallelwiththebattery}$ $I_{nparallelwith}$ R_1 $I_{nparallelwiththemotor}$ $I_{nserieswiththebattery,}$ R_1, and the motor

In a clear, coherent, paragraph-length response that may also contain figures and/or equations, justify why your selection would decrease Δt.

Question 4



Solution 4

(a)

Mark scheme

- Mechanical power $P = W/\Delta t$, where the work done lifting the block at constant speed equals its gain in gravitational potential energy, $W = MgH$. So $P = \dfrac{MgH}{\Delta t}$. Points: 1 for an expression implying energy-based reasoning (e.g. simply writing MgH for the work/energy transferred, as opposed to a kinematics-based approach); 1 for the fully correct expression for mechanical power, $P = MgH/\Delta t$.

Solution 4

(b) Mark scheme

- Correct answer: connect R_2 IN PARALLEL WITH R_1 (not with the battery, not with the motor, not in series with everything). Note: if the wrong option is selected, the justification may still earn credit. Full justification: the work required to lift the block is fixed, $W = MgH$, so decreasing Δt requires increasing the mechanical power $P = MgH/\Delta t$ delivered by/to the motor – i.e. increasing the potential difference (and current) across/through the motor. By Kirchhoff's loop rule around the single loop (battery, R_1, motor), increasing the potential difference across the motor requires DEcreasing the potential difference across R_1. Adding R_2 in parallel with R_1 decreases the equivalent resistance of that parallel combination, which (for the fixed EMF and now-lower total series resistance)

Solution 4

increases the total circuit current; since the motor is in series and carries the same current as the rest of the loop, more current – and a higher potential difference and higher power – flows through the motor, decreasing Δt. Points (5 total): 1 for correctly asserting that power must increase for Δt to decrease (equal work done in less time requires a faster rate of energy transfer); 1 for a correct assertion that current increases as the circuit's total resistance decreases (alternate: potential difference across the parallel resistors decreases as their combined resistance decreases); 1 for connecting that current specifically THROUGH THE MOTOR increases because it equals the total series current (alternate: potential difference specifically across the motor increases because the potential difference across the parallel R_1/R_2 section decreases, via Kirchhoff's loop rule); 1 for a justification that placing R_2 in parallel with R_1 decreases the equivalent resistance of that combination; 1 for an overall logical, relevant, internally consistent

Solution 4

paragraph-length argument that follows the published paragraph-response requirements.

Question 2

2018 ▪ Q2

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.
[Table — "Dough Cylinder" | A (m^2) | ℓ (m) | ΔV (V) | R (Ω) | (two extra blank columns provided for student-added quantities): 1 | 0.00049 | 0.030 | 1.02 | 23.6 2 | 0.00049 | 0.050 | 2.34 | 31.5 3 | 0.00053 | 0.080 | 3.58 | 61.2 4 | 0.00057 | 0.150 | 6.21 | 105]

(a)(i) Indicate below which quantities could be graphed to determine a value for the resistivity of the dough cylinders. You may use the remaining columns in the table

Question 2

above, as needed, to record any quantities (including units) that are not already in the table.

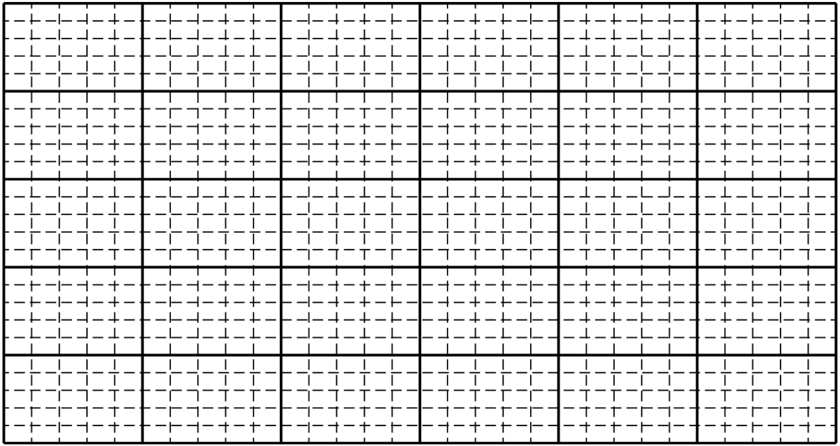
Vertical Axis: ______________________________ Horizontal Axis: ______________________________

(a)(ii) On the grid below, plot the appropriate quantities to determine the resistivity of the dough cylinders. Clearly scale and label all axes, including units as appropriate.

[Figure: a blank grid (graph paper) for plotting.]

(a)(iii) Use the above graph to estimate a value for the resistivity of the dough cylinders.

Question 2



Question 2

Dough Cylinder	A (m^2)	ℓ (m)	ΔV (V)	R (Ω)		
1	0.00049	0.030	1.02	23.6		
2	0.00049	0.050	2.34	31.5		
3	0.00053	0.080	3.58	61.2		
4	0.00057	0.150	6.21	105		

Question 2

2018 ▪ Q2

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.

[Table — "Dough Cylinder" | A (m^2) | ℓ (m) | ΔV (V) | R (Ω) | (two extra blank columns provided for student-added quantities): 1 | 0.00049 | 0.030 | 1.02 | 23.6 2 | 0.00049 | 0.050 | 2.34 | 31.5 3 | 0.00053 | 0.080 | 3.58 | 61.2 4 | 0.00057 | 0.150 | 6.21 | 105]

(b) Another group of students perform the experiment described in part (a) but shape the dough into long rectangular shapes instead of cylinders. Will this change affect the value of the resistivity determined by the second group of students?

_____ Yes _____ No

Question 2

Briefly justify your reasoning.

Question 2

2018 ▪ Q2

A group of students prepare a large batch of conductive dough (a soft substance that can conduct electricity) and then mold the dough into several cylinders with various cross-sectional areas A and lengths ℓ. Each student applies a potential difference ΔV across the ends of a dough cylinder and determines the resistance R of the cylinder. The results of their experiments are shown in the table below.

[Table — "Dough Cylinder" | A (m^2) | ℓ (m) | ΔV (V) | R (Ω) | (two extra blank columns provided for student-added quantities): 1 | 0.00049 | 0.030 | 1.02 | 23.6 2 | 0.00049 | 0.050 | 2.34 | 31.5 3 | 0.00053 | 0.080 | 3.58 | 61.2 4 | 0.00057 | 0.150 | 6.21 | 105]

(c) Describe an experimental procedure to determine whether or not the resistivity of the dough cylinders depends on the temperature of the dough. Give enough detail so that another student could replicate the experiment. As needed, include a diagram of

Question 2

the experimental setup. Assume equipment usually found in a school physics laboratory is available.

Solution 2

(a)(i)

Mark scheme

- Resistivity ρ is related to resistance by $R = \rho\ell/A$, so plotting R (vertical axis) versus ℓ/A (horizontal axis) gives a line through the origin with slope ρ – and the table already provides an ℓ/A column. (Equivalently, plotting RA vertically against ℓ horizontally, etc., using only quantities derived from R, ℓ, and A.) Scoring (2 points, 1 each): (1) choosing quantities derived from R, ℓ, and A only; (2) choosing two quantities that, when graphed together, can be used to determine the resistivity (i.e., whose slope or intercept yields ρ).

Solution 2

(a)(ii) Mark scheme

- Plot R (Ω) on the vertical axis against ℓ/A (m^{-1}) on the horizontal axis using the four data points (61, 23.6), (102, 31.5), (151, 61.2), (263, 105.0); the points fall approximately on a straight line through the origin, consistent with $R = \rho(\ell/A)$. Scale each axis so the data spans at least half the grid (e.g. 0-300 m^{-1} horizontally, 0-120 Ω vertically), label both axes with units, and plot the four points. Scoring (3 points, 1 each; only awarded if the graphed quantities match the choice in part (a)(i)): (1) a linear scale on both axes where the plotted data use at least half the grid; (2) both axes labeled, with units as appropriate; (3) data points plotted that represent the appropriate trend for the chosen quantities (here, a linear/direct-proportion trend).

Solution 2

(a)(iii)

Mark scheme

- The resistivity is the slope of the R vs. ℓ/A graph. Using the plotted line (or a calculator fit to the data), the slope – and hence the resistivity – is $\rho \approx 0.42\ \Omega \cdot \mathrm{m}$ (accepted range ± 0.03). Scoring (2 points, 1 each): (1) correctly using the slope of the graph to find the resistivity, or stating that a calculator was used to find the appropriate value from the graph/data; (2) a correct resistivity value, $\rho = 0.42\ \Omega \cdot \mathrm{m}$ (± 0.03), calculated from the graph or data.

Solution 2

(b)

Mark scheme

- Correct answer: 'No.' Resistivity is an intrinsic material property – it does not depend on the shape into which the material is formed (only resistance $R = \rho\ell/A$ depends on shape, via ℓ and A). Scoring (1 point): for indicating that resistivity depends only on the material, not its shape. Note: if the wrong option is selected, the explanation is not graded.

Solution 2

(c) Mark scheme

- Example procedure: Make two dough cylinders of the same length and cross-sectional area. Keep one cylinder at room temperature, and heat the other cylinder on a hot plate to a different temperature, e.g. 30°C (measured with a thermometer). Apply the same voltage across each cylinder (measured with a voltmeter), and measure the current through each cylinder with an ammeter; use $R = \Delta V/I$ and $\rho = RA/\ell$ to compare resistivities at the two temperatures. Scoring (4 points, 1 each): (1) explicitly or implicitly controlling all variables (e.g. length and cross-sectional area) except temperature; (2) a plausible way to change the temperature of the dough; (3) indicating that the temperature will be varied (i.e., at least two different temperature values are tested/compared); (4) a valid

Solution 2

and feasible experiment in which resistance, or voltage and current, are appropriately measured.

Question 3

2018 ▪ Q3

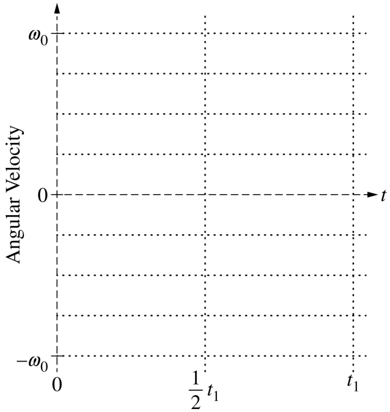
The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.
[Figure: a thin horizontal disk mounted on a vertical axle through its center, shown in a simple side-view sketch.]
(a)(i) On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.
[Figure: a blank graph grid, vertical axis "Angular Velocity" marked from $-\omega_0$ to ω_0 (with 0 in the middle), horizontal axis t marked 0 and t_1, dotted gridlines, for the student to sketch a curve.]
(a)(ii) On the grid at right below, sketch the disk's angular acceleration as a function of time t from $t = 0$ until the disk comes to rest at time $t = t_1$.

Question 3

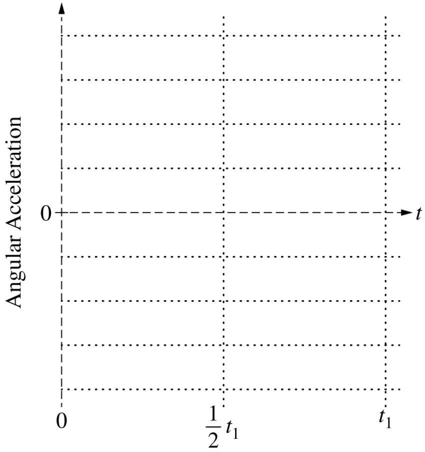
[Figure: a blank graph grid, vertical axis "Angular Acceleration", horizontal axis t marked 0 and t_1, dotted gridlines, for the student to sketch a curve.]

Question 3

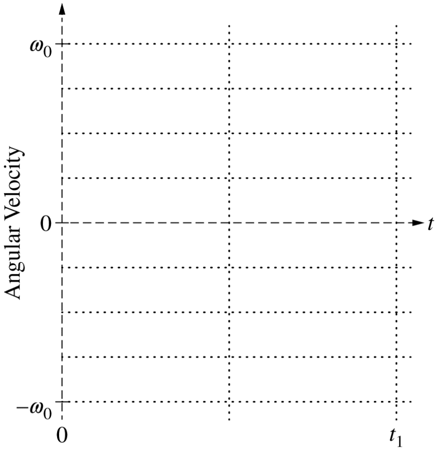
ii. On the grid at right below, sketch the dis
from $t = 0$ to $t = t_1$.



Question 3



Question 3



Question 3

2018 ▪ Q3

The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

[Figure: a thin horizontal disk mounted on a vertical axle through its center, shown in a simple side-view sketch.]

(b) The magnitude of the frictional torque exerted on the disk is τ_0. Derive an equation for the rotational inertia *I* of the disk in terms of τ_0, ω_0, t_1, and physical constants, as appropriate.

Question 3

2018 ▪ Q3

The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

[Figure: a thin horizontal disk mounted on a vertical axle through its center, shown in a simple side-view sketch.]

(c)(i) On the grid at left below, sketch a graph that could represent the disk's angular velocity as a function of time from $t = 0$ to $t = t_1$, which is the time at which the disk came to rest in part (a).

[Figure: a blank graph grid like part (a)'s left grid, vertical axis "Angular Velocity" (from $-\omega_0$ to ω_0), horizontal axis t marked 0, $\frac{1}{2}t_1$, and t_1.]

(c)(ii) On the grid at right below, sketch the disk's angular acceleration as a function of time from $t = 0$ to $t = t_1$.

Question 3

[Figure: a blank graph grid like part (a)'s right grid, vertical axis "Angular Acceleration", horizontal axis t marked 0, $\frac{1}{2}t_1$, and t_1.]

Question 3

2018 ▪ Q3

The disk shown above spins about the axle at its center. A student's experiments reveal that, while the disk is spinning, friction between the axle and the disk exerts a constant torque on the disk.

[Figure: a thin horizontal disk mounted on a vertical axle through its center, shown in a simple side-view sketch.]

(d) The student is trying to mathematically model the magnitude τ of the torque exerted by the axle on the disk when the oil is present at times $t > \frac{1}{2}t_1$. The student writes down the following two equations, each of which includes a positive constant (C_1 or C_2) with appropriate units.

(1) $\tau = C_1\left(t - \frac{1}{2}t_1\right)$ (for $t > \frac{1}{2}t_1$)

(2) $\tau = \dfrac{C_2}{\left(t + \frac{1}{2}t_1\right)}$ (for $t > \frac{1}{2}t_1$)

Question 3

Which equation better mathematically models this experiment?

$E^{quation(1)}$ $E^{quation(2)}$

Briefly explain why the equation you selected is plausible and why the other equation is not plausible.

Solution 3

(a)(i) Mark scheme

- The disk starts with angular velocity $+\omega_0$ at $t = 0$, and a constant frictional torque decelerates it uniformly to rest at $t = t_1$, so the angular-velocity-vs-time graph is a straight line with negative slope, starting at ω_0 and reaching zero exactly at t_1 (not going negative). Scoring (2 points, 1 each): (1) a curve with angular velocity $+\omega_0$ at $t = 0$ that decreases to zero at $t = t_1$; (2) a curve that is a straight line with negative slope showing the angular velocity approaching zero (a positive slope is also acceptable if the initial angular velocity on the graph is drawn negative).

Solution 3

(a)(ii)

Mark scheme

- Because the frictional torque (and hence the rotational inertia I times angular acceleration) is constant while the disk is spinning, the angular acceleration is a constant, negative value from $t = 0$ to $t = t_1$ – a horizontal line below the time axis. Scoring (2 points, 1 each): (1) a curve that is negative for the entire time interval; (2) a curve that is a constant, nonzero function of time.

Solution 3

(b) Mark scheme

- Using the rotational form of Newton's second law and a rotational kinematics equation: $\tau_0 = I\alpha$ and $\alpha = \Delta\omega/\Delta t = (0-\omega_0)/t_1 = -\omega_0/t_1$. Combining: $I = \dfrac{\tau_0 t_1}{\omega_0}$. Scoring (3 points, 1 each): (1) using an equation for the rotational version of Newton's second law ($\tau = I\alpha$); (2) using an angular kinematics equation, $\alpha = \Delta\omega/\Delta t$; (3) a correct final answer in terms of τ_0, ω_0, t_1, derived from first principles, $I = \tau_0 t_1/\omega_0$ (the point is still earned if a minus sign appears, e.g. from using $-\tau_0$ or $-\omega_0$). Alternate solution using angular momentum/rotational impulse earns the same 3 points: (1) defining and using

Solution 3

angular momentum $L = I\omega$; (2) using rotational impulse $\Delta L = \tau \Delta t$; (3) the same correct answer $I = \tau_0 t_1 / \omega_0$.

Solution 3

(c)(i) Mark scheme

- For $0 \leq t \leq \frac{1}{2}t_1$ the graph is identical to part (a)(i) – a straight line from $+\omega_0$ decreasing at the same constant rate. At $t = \frac{1}{2}t_1$ oil begins reducing the friction, so the curve changes slope/curvature there and continues decreasing, but now at a DECREASING rate (concave, flattening out) because the frictional torque is shrinking as more oil reaches the surface; the disk has NOT stopped by $t = t_1$ (it approaches but does not reach zero). Scoring (3 points, 1 each): (1) a curve with a clear change of slope or curvature at $\frac{1}{2}t_1$, showing a decrease in speed thereafter; (2) a curve that indicates slowing at a decreasing rate between $\frac{1}{2}t_1$ and t_1; (3) a curve that does not reach zero at or before time t_1.

Solution 3

(c)(ii)

Mark scheme

- From 0 to $\frac{1}{2}t_1$ the angular acceleration is the same constant negative value as in part (a)(ii). After $\frac{1}{2}t_1$, as the oil reduces friction, the magnitude of the (still negative) angular acceleration decreases over time (approaching zero asymptotically, or possibly reaching zero at or before t_1 and remaining zero thereafter). Scoring (1 point): for a curve with decreasing magnitude between times $\frac{1}{2}t_1$ and t_1. Note: the acceleration may reach zero at or before t_1; if so, it must remain zero for the remaining time.

Solution 3

(d)

Mark scheme

- Correct answer: 'Equation (2).' As more oil reaches the axle-disk interface, the frictional torque should decrease over time. Equation (2), $\tau = C_2/(t + \frac{1}{2}t_1)$, decreases as t increases, matching this physical behavior. Equation (1), $\tau = C_1(t - \frac{1}{2}t_1)$, instead increases as t increases, so it is not plausible. Scoring (1 point): for stating that Equation (2) is plausible because the frictional torque decreases with increasing time, whereas in Equation (1) the torque increases with increasing time. Note: if the wrong equation is selected, the explanation is not graded.

Question 1

2017 ▪ Q1

[Figure: Three circuit diagrams side by side, each showing a battery with a "+" terminal on the left post and a "−" terminal on the right post. Circuit 1: the battery is connected to a single lightbulb, labeled A. Circuit 2: the battery is connected to two lightbulbs, labeled B and C, wired in parallel (both bulbs connected across the battery terminals via separate branches). Circuit 3: the battery is connected to two lightbulbs, labeled D and E, wired in series (one loop through both bulbs in sequence).]
In the three circuits shown above, the batteries are all identical, and the lightbulbs are all identical. In circuit 1 a single lightbulb is connected to the battery. In circuits 2 and 3, two lightbulbs are connected to the battery in different ways, as shown. The lightbulbs are labeled A–E.

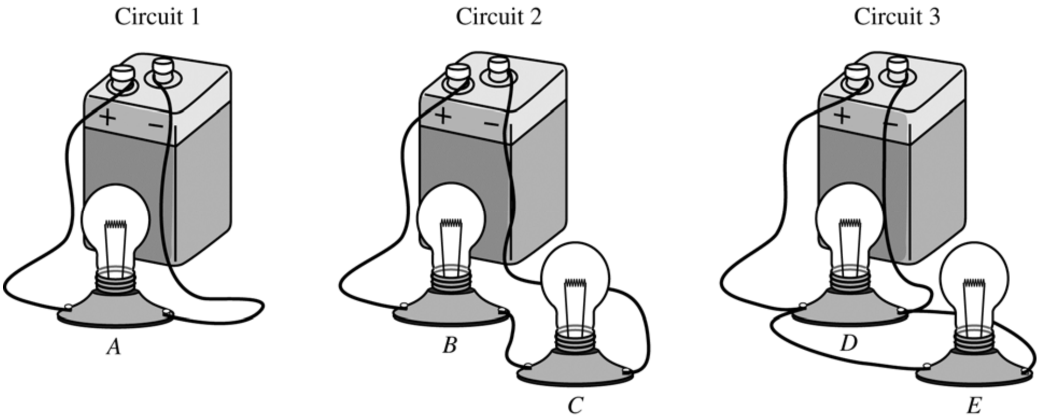
Question 1

(a) Rank the magnitudes of the potential differences across lightbulbs A, B, C, D, and E from largest to smallest. If any lightbulbs have the same potential difference across them, state that explicitly.

Ranking:

Briefly explain how you determined your ranking.

Question 1



Question 1

2017 ▪ Q1

[Figure: Three circuit diagrams side by side, each showing a battery with a "+" terminal on the left post and a "−" terminal on the right post. Circuit 1: the battery is connected to a single lightbulb, labeled A. Circuit 2: the battery is connected to two lightbulbs, labeled B and C, wired in parallel (both bulbs connected across the battery terminals via separate branches). Circuit 3: the battery is connected to two lightbulbs, labeled D and E, wired in series (one loop through both bulbs in sequence).]

In the three circuits shown above, the batteries are all identical, and the lightbulbs are all identical. In circuit 1 a single lightbulb is connected to the battery. In circuits 2 and 3, two lightbulbs are connected to the battery in different ways, as shown. The lightbulbs are labeled A–E.

(b) The batteries all start with an identical amount of usable energy and are all connected to the lightbulbs in the circuits at the same time.

Question 1

In which circuit will the battery run out of usable energy first?
_____ Circuit 1 _____ Circuit 2 _____ Circuit 3
In which circuit will the battery run out of usable energy last?
_____ Circuit 1 _____ Circuit 2 _____ Circuit 3
In a clear, coherent paragraph-length response that may also contain equations and drawings, explain your reasoning.

Solution 1

(a) Mark scheme

- Ranking: $A = D = E > B = C$. Reasoning: Bulbs A, D, and E are each connected directly across the battery terminals (each forms a complete loop through only itself and the battery), so by Kirchhoff's voltage law each has the full battery potential difference ΔV across it. Bulbs B and C are identical and in series with each other, forming the second branch across the battery, so the battery's ΔV splits equally between them: each gets $\Delta V_{battery}/2$. Therefore $A = D = E$ (full battery voltage) is greater than $B = C$ (half battery voltage). Points: 1 pt for correctly ranking $A = D = E$ with a valid explanation (each directly across the battery); 1 pt for correctly ranking $B = C$ with a valid explanation (same current

Solution 1

through the series pair, or the loop voltage splits equally between identical series bulbs). The ranking itself must be correct to earn credit for either explanation.

Solution 1

(b) Mark scheme

- Correct answer: the battery in Circuit 3 runs out of usable energy first; the battery in Circuit 2 runs out last. Reasoning: battery power is $P = I\Delta V$; since all three batteries have the same ΔV, the order in which they "die" follows the ranking of current, which follows the ranking of equivalent resistance each battery drives (lower resistance $\rightarrow$ more current $\rightarrow$ more power $\rightarrow$ shorter life). Circuit 3 has two loops (parallel paths), giving the lowest overall resistance, the most current, and the most power, so its battery runs out first. Circuit 2 is a single loop with two bulbs in series, giving the highest overall resistance, the least current, and the least power, so its battery runs out last; Circuit 1 is in between. Points: 1 pt for indicating that all three circuits draw different amounts of power (may

Solution 1

address only two circuits); 1 pt for explaining, using potential difference or resistance reasoning, that the battery in Circuit 2 delivers the least power; 1 pt for explaining, using potential difference or resistance reasoning, that the battery in Circuit 3 delivers the most power; 1 pt for an implicit or explicit statement that greater power results in shorter battery life; 1 pt for a logical, relevant, internally consistent paragraph-length argument that follows the published paragraph-response requirements.