General Notes About 2009 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point and a student's solution contains the application of that equation to the problem, but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 3

15 points total | **Distribution of points**

(a) 4 points

Using the expression for the magnitude of the induced emf

$$|\mathcal{E}| = \left|-\frac{d\phi_m}{dt}\right|$$

For recognizing that the area is constant in time — 1 point

$$|\mathcal{E}| = A\left|\frac{dB}{dt}\right|$$

For correctly taking the time derivative of the magnetic field — 1 point

$$\left|\frac{dB}{dt}\right| = \frac{d}{dt}(at+b) = a$$

For a correct expression for the emf — 1 point

For a positive value for the magnitude of the emf — 1 point

$$|\mathcal{E}| = aL^2$$

(b)

(i) 2 points

The resistors are in series, so the total current flows through both of them.

$$I = \frac{\mathcal{E}}{R_{tot}}$$

For correctly calculating the resistance of the two resistors in series — 1 point

$$R_{tot} = \sum R_i = 2R_0$$

For correctly substituting the value of the emf from part (a) — 1 point

$$I = \frac{aL^2}{2R_0}$$

Alternate solution: | *Alternate Points*

$$I_2 = \frac{\mathcal{E}_2}{R_2}$$

The resistors have equal resistance, so the emf across each is half the total emf.

For correctly substituting the emf across bulb 2, consistent with the answer to part (a) — *1 point*

$$I_2 = \frac{\left(aL^2/2\right)}{R_2}$$

For correctly substituting the resistance of bulb 2 — *1 point*

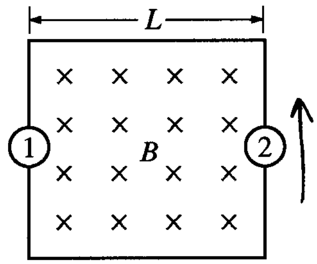
$$I_2 = \frac{\left(aL^2/2\right)}{R_0} = \frac{aL^2}{2R_0}$$

Question 3 (continued)

Distribution of points

(b) (continued)

(ii) 1 point



For indicating that current flows upward in bulb 2 or counterclockwise around the loop — 1 point

(c) 2 points

$P_1 = I_1V_1 = I_1^2R_1 = V_1^2/R_1$

For substituting one correct value into one of the above expressions — 1 point
For substituting a second correct value in the chosen expression — 1 point

$$P = \left(\frac{aL^2}{2R_0}\right)\left(\frac{aL^2}{2}\right) \quad \text{OR} \quad P = \left(\frac{aL^2}{2R_0}\right)^2 R_0 \quad \text{OR} \quad P = \left(\frac{aL^2}{2}\right)^2 \Big/ R_0$$

$$P = a^2L^4/4R_0$$

(d) 4 points

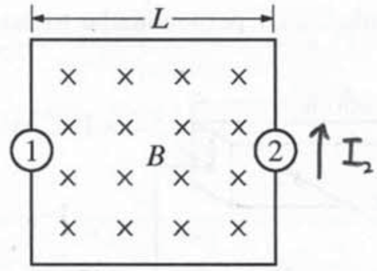
For indicating that bulb 1 is brighter — 1 point
For any indication that the emf is the same as in the original circuit (since there is no flux through the added loop) — 1 point
For stating that adding a bulb in parallel with bulb 2 decreases the overall resistance of the circuit — 1 point
For stating that decreasing the overall resistance increases the overall current, which is equal to the current in bulb 1 — 1 point

(e) 2 points

For indicating that bulb 1 is the same brightness as in the original circuit — 1 point
For a complete and correct justification — 1 point
Examples:

Since each loop has half the area, each has half the original emf. But each also has half the resistance. This means the current and thus the power in bulb 1 is the same.

The two loops are essentially identical. Separately, the flux through each loop would create an emf that is counterclockwise. Since these emfs are in opposite directions in the central wire, the net effect is that there is no emf in that wire. Therefore the situation is equivalent to the original one.



E&M. 3.

A square conducting loop of side L contains two identical lightbulbs, 1 and 2, as shown above. There is a magnetic field directed into the page in the region inside the loop with magnitude as a function of time t given by $B(t) = at + b$, where a and b are positive constants. The lightbulbs each have constant resistance R_0. Express all answers in terms of the given quantities and fundamental constants.

(a) Derive an expression for the magnitude of the emf generated in the loop.

$$\mathcal{E} = \frac{d\Phi}{dt} = \frac{A\,dB}{dt} = L^2 \frac{d}{dt}(at+b) = \boxed{L^2 a}$$

(b)

i. Determine an expression for the current through bulb 2.

$$I = \frac{\mathcal{E}}{r} = \boxed{\frac{L^2 a}{2R_0}}$$

ii. Indicate on the diagram above the direction of the current through bulb 2.

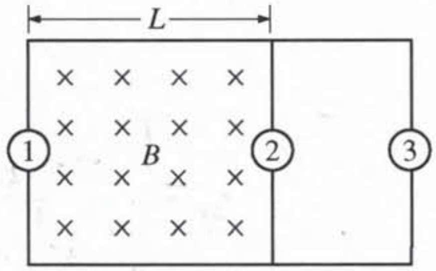
Lenz's Law

(c) Derive an expression for the power dissipated in bulb 1.

$$P = I^2 R = \left(\frac{L^2 a}{2R_0}\right)^2 R_0 = \frac{L^4 a^2}{4R_0^{\cancel{2}}} \cdot \cancel{R_0}$$

$$\boxed{P = \frac{L^4 a^2}{4R_0}}$$

Another identical bulb 3 is now connected in parallel with bulb 2, but it is entirely outside the magnetic field, as shown below.



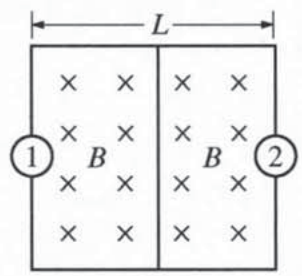
(d) How does the brightness of bulb 1 compare to what it was in the previous circuit?

__✓__ Brighter ____ Dimmer ____ The same

Justify your answer.

Since the area enclosed is the same, the EMF generated is also the same. However, the addition of bulb 3 reduces the resistance of the circuit, so I_T increases. This means P_1 increases as well, raising the brightness of the bulb.

Now the portion of the circuit containing bulb 3 is removed, and a wire is added to connect the midpoints of the top and bottom of the original loop, as shown below.

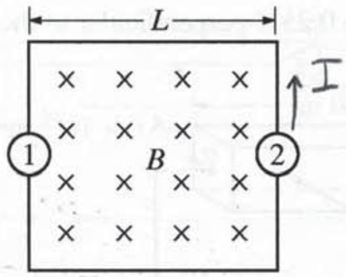


(e) How does the brightness of bulb 1 compare to what it was in the first circuit?

____ Brighter ____ Dimmer __✓__ The same

Justify your answer.

The areas enclosed by each of the two conducting loops are half the initial area, so the EMF generated is also half ($\mathcal{E} = A\frac{dB}{dt}$). However, the resistance in each loop is also halved. Because $I = \frac{\mathcal{E}}{R}$, the current through bulb 1 is the same, so the power ($P = I^2R$) is the same as well.



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(a) Derive an expression for the magnitude of the emf generated in the loop.

$$V = \frac{d\phi}{dt} = \frac{dBL^2}{dt} = aL^2$$

(b)

i. Determine an expression for the current through bulb 2.

The bulbs are connected in series. Therefore, the equivalent resistance $R_{eq} = 2R_o$.

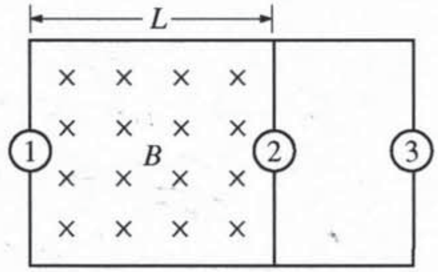
$I_{eq} = \frac{V}{R_{eq}} = \frac{aL^2}{2R_o}$. The currents flowing through the bulbs are equal ~~constant~~. The current through bulb 2 equals $I_{eq} = \frac{aL^2}{2R_o}$.

ii. Indicate on the diagram above the direction of the current through bulb 2.

(c) Derive an expression for the power dissipated in bulb 1.

$$P = IV = \frac{V^2}{R_o} = \frac{(aL^2)^2}{R_o} = \frac{a^2L^4}{R_o}$$

Another identical bulb 3 is now connected in parallel with bulb 2, but it is entirely outside the magnetic field, as shown below.



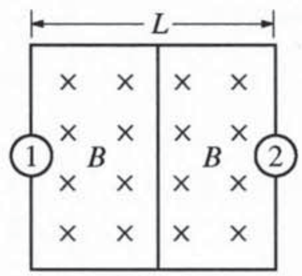
(d) How does the brightness of bulb 1 compare to what it was in the previous circuit?

____ Brighter ____ Dimmer ✓ The same

Justify your answer.

Current is induced only on the portion of the frame which is influenced by the changing magnetic field. No current flows through bulb 3, so no electrical energy is lost to bulb 3.

Now the portion of the circuit containing bulb 3 is removed, and a wire is added to connect the midpoints of the top and bottom of the original loop, as shown below.

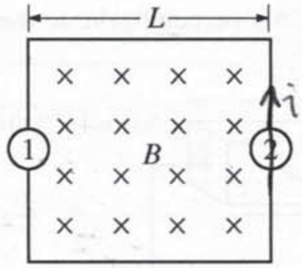


(e) How does the brightness of bulb 1 compare to what it was in the first circuit?

____ Brighter ____ Dimmer ✓ The same

Justify your answer.

If we consider the loop as two seperate half-loops, the emf induced on each half-loop is $V = \frac{d\phi}{dt} = \frac{dB \cdot \frac{L^2}{2}}{dt} = \frac{aL^2}{2}$. The two half-loops induce currents on the wire through the midpoints that have equal magnitudes and opposite directions. Therefore, no current flows through the midsegment and the situation does not change.



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(a) Derive an expression for the magnitude of the emf generated in the loop.

$$\Phi_B = \oint B \cdot dA = BA = (at+b)(L^2)$$

$$\mathcal{E} = -\frac{d\Phi_B}{dt} \quad \frac{d\Phi_B}{dt} = (L^2)(a) \quad \boxed{\mathcal{E} = -L^2 a}$$

(b)

i. Determine an expression for the current through bulb 2.

$$V = IR$$

$$-L^2 a = IR_0$$

$$\boxed{I = -\frac{L^2 a}{R_0}}$$

ii. Indicate on the diagram above the direction of the current through bulb 2.

(c) Derive an expression for the power dissipated in bulb 1.

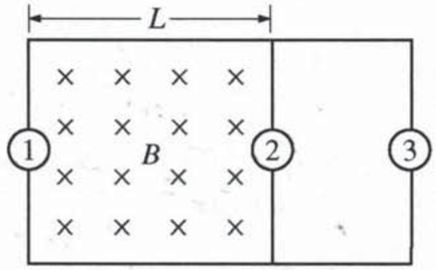
$$P = IV \qquad \boxed{P = \frac{-L^2 a}{R_0}}$$

$$V = IR$$

$$I = V/R$$

$$P = V^2/R$$

Another identical bulb 3 is now connected in parallel with bulb 2, but it is entirely outside the magnetic field, as shown below.



(d) How does the brightness of bulb 1 compare to what it was in the previous circuit?

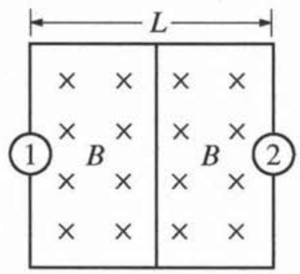
____ Brighter   _X_ Dimmer   ____ The same

Justify your answer.

$I_{eq} = I_1 + I_2 + I_3$

The current will now be split between 3 bulbs instead of 2.

Now the portion of the circuit containing bulb 3 is removed, and a wire is added to connect the midpoints of the top and bottom of the original loop, as shown below.



(e) How does the brightness of bulb 1 compare to what it was in the first circuit?

____ Brighter   ____ Dimmer   _X_ The same

Justify your answer.

The third wire does not contain anything with resistance so it does not affect the two bulbs.

Question 3

Overview

This question assessed students' understanding of induced emf and its effect in various circuits. Some parts of the problem also assessed students' mastery of simple circuits.

Sample: CE-3A
Score: 15

This response earned the maximum number of points and has nice explanations for parts (d) and (e).

Sample: CE-3B
Score: 10

The response earned 4 points in part (a) and 3 points in part (b). There is a nice explanation in part (b). In part (c) the student does not account for the fact that only half the voltage is across bulb 1, so 1 point was lost. No points were earned for part (d). Part (e) is also very nicely written and earned both points.

Sample: CE-3C
Score: 7

The answer in part (a) should be positive, so 1 point was lost. In part (b) the direction of the current is correct, but the incorrect resistance is used, so again 1 point was lost. In part (c) the student does not account for the fact that only half the voltage is across bulb 1 and earned only 1 point. Part (d) earned no points, and part (e) earned 1 point for checking "The same."