AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2008 SCORING GUIDELINES

General Notes About 2008 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 1 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

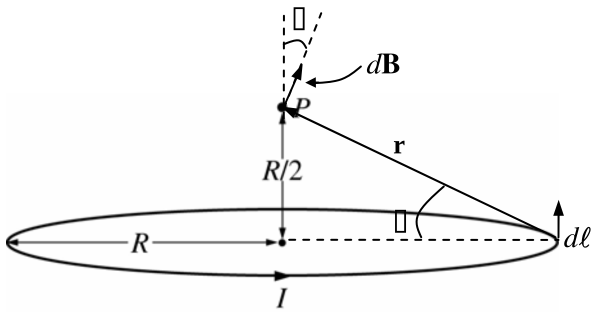
15 points total **Distribution of points**

(a)

(i) 1 point

For indicating that the magnetic field B_1 at point P is toward the top of the page — 1 point

(ii) 6 points



(In plane of loop and tangent to it.)

For using the Biot-Savart law — 1 point

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\,d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$$

For correctly indicating or applying the fact that $d\ell$ is perpendicular to $\mathbf{r}$ — 1 point

$$dB = \frac{\mu_0}{4\pi}\frac{I\,d\ell\,r\sin\theta}{r^3} = \frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2}$$

For recognizing that the net horizontal component will be zero, so that just the vertical components are summed — 1 point

$B_1 = \int dB_{vert} = \int dB\cos\alpha = \int \frac{R}{r}dB$, where α is the elevation angle of the vector $\mathbf{r}$

For the correct expression for r — 1 point

$$r = \sqrt{R^2 + \frac{R^2}{4}} = \frac{\sqrt{5}}{2}R$$

$$B_1 = \int \frac{R}{r}dB = \int \frac{R}{r}\frac{\mu_0}{4\pi}\frac{I\,d\ell}{r^2} = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}\int d\ell$$

For the correct calculation of $\int d\ell$ — 1 point

$\int d\ell = \int_0^{2\pi} R\,d\beta = 2\pi R$, where β is the angle around the loop

For a correct final expression — 1 point

$$B_1 = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}\int d\ell = \frac{\mu_0 IR}{4\pi\left(\frac{\sqrt{5}}{2}R\right)^3}2\pi R = \frac{4}{5\sqrt{5}}\frac{\mu_0 I}{R}$$

Question 3 (continued)

	Distribution of points
(b) 2 points	
For recognizing that B_{net} is the vector sum of the field generated by the first loop and the field generated by the second loop	1 point
For recognizing that the B field from top loop is in the same direction and has the same magnitude as that from the bottom loop	1 point
$B_{net} = 2B_1 = \dfrac{8}{5\sqrt{5}}\dfrac{\mu_0 I}{R}$	
(c) 2 points	
For identifying B as B_{net} in a correct expression for magnetic flux	1 point
$\phi = \int \mathbf{B} \cdot d\mathbf{A} = \int B_{net}dA = B_{net}A$	
For correctly substituting the area as s^2	1 point
$\phi = B_{net}s^2$	
(d) 4 points	
For using Faraday's law with ϕ identified as magnetic flux	1 point
$\mathcal{E} = -\dfrac{d\phi}{dt}$ with some work showing understanding of ϕ	
For recognizing that there is an angular dependence	1 point
$\phi = B_{net}s^2\cos\theta$	
For correctly relating the angle to the angular velocity	1 point
$\phi = B_{net}s^2\cos\omega t$	
For the correct final expression	1 point
$\mathcal{E} = -B_{net}\dfrac{d}{dt}\left(s^2\cos\omega t\right) = B_{net}s^2\omega\sin\omega t$	

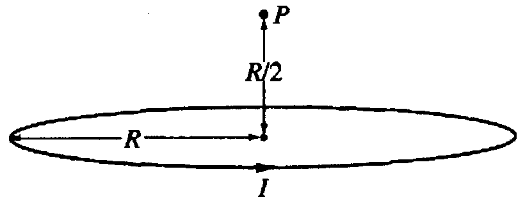


Figure 1

E&M. 3.

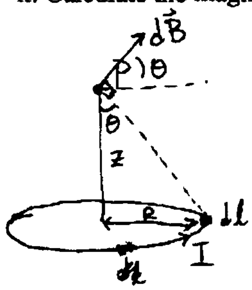
The circular loop of wire in Figure 1 above has a radius of R and carries a current I. Point P is a distance of $R/2$ above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R, I, and fundamental constants.

(a)

i. State the direction of the magnetic field B_1 at point P due to the current in the loop.

Upwards, by right hand rule.

ii. Calculate the magnitude of the magnetic field B_1 at point P.



Taking each dl segment on the loop,

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}, \quad \text{where } r^2 = R^2 + z^2$$

Since it is symetrical, we only take $\vec{B}$ field from the z-component.

$$dB_z = \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}\sin\theta = \frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}\cdot\frac{R}{r}$$

By integrating,

$$B_z = \int_0^{2\pi R} \frac{\mu_0}{4\pi}\frac{IR}{(R^2+z^2)^{3/2}}\,dl = \frac{\mu_0 I R^2}{2(R^2+z^2)^{3/2}}$$

when $z = R/2$

$$B_z = \frac{\mu_0 I R^2}{2\left(R^2+\frac{R^2}{4}\right)^{3/2}} = \cancel{\frac{\mu_0 I}{2R}\cdot\frac{1}{\ }\times\left(\frac{4}{5}\right)^{3/2}}\ \frac{\mu_0 I}{2R}\left(\frac{4}{5}\right)^{3/2} = \cancel{\frac{4\mu_0 I}{R\cdot 5^{3/2}}}$$

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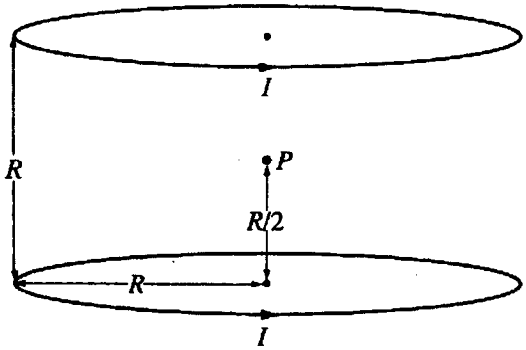

Figure 2

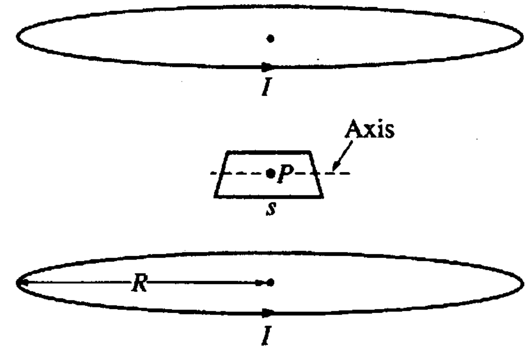

Figure 3

A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

(b) Determine the magnitude of the net magnetic field B_{net} at point P.

$$B_{net} = 2B_z = \frac{\mu_0 I}{R}\left(\frac{4}{5}\right)^{3/2}$$

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net}.

(c) In terms of B_{net} and s, determine the magnetic flux through the square loop.

$$\Phi_B = B_{net} \cdot A = B_{net} s^2$$

(d) The square loop is now rotated about an axis in its plane at an angular speed ω. In terms of B_{net}, s, and ω, calculate the induced emf in the loop as a function of time t, assuming that the loop is horizontal at $t = 0$.

$$\Phi_B = B_{net} s^2 \cdot \cancel{\sin} \cos\theta = B_{net} s^2 \cos(\omega t)$$

By Faraday's Law;

$$|\mathcal{E}| = -\frac{d\Phi_B}{dt} = \cancel{B_{net}\,\omega s^2 \cos}\ \ \omega B_{net} s^2 \sin(\omega t)$$

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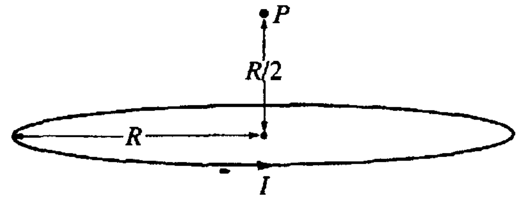


Figure 1

E&M. 3.

The circular loop of wire in Figure 1 above has a radius of R and carries a current I. Point P is a distance of $R/2$ above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R, I, and fundamental constants.

(a)

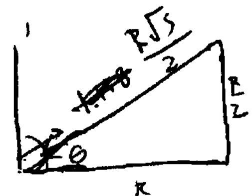
i. State the direction of the magnetic field B_1 at point P due to the current in the loop.

up

the right hand rule!

ii. Calculate the magnitude of the magnetic field B_1 at point P.

$$\int dB = \int \frac{\mu_0}{4\pi} \frac{I\, dl \times r}{r^3}$$



$\frac{5R^2}{4}$

for the crossproduct

$$B = \frac{\mu_0}{4\pi} \cdot \frac{I}{\left(\frac{5}{4}R^2\right)} \cdot 2\pi R \cdot \sin\left(\arctan\left(\frac{R}{2}/R\right)\right)$$

$\cancel{\oint B \cdot dl = \mu_0 I}$

$$\frac{\mu_0}{\cancel{2}}\, I \cdot \frac{1}{r} \cdot \frac{\cancel{4}^{2}}{5} \cdot \frac{\sqrt{5}}{5}$$

$$\boxed{\frac{\mu_0 I}{r} \cdot \frac{\sqrt{5}}{25}}$$

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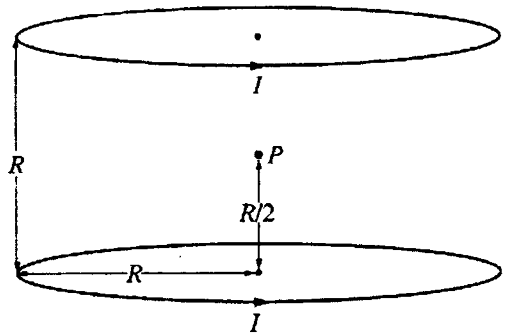

Figure 2

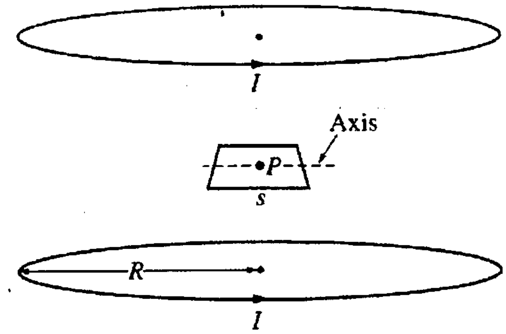

Figure 3

A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

(b) Determine the magnitude of the net magnetic field B_{net} at point P.

the magnetic field of the new loop is equal ~~to~~ that of the first one; therefore, ~~the~~ this will result in a doubled magnetic field from in 3.a.ii

$$\boxed{\frac{\mu_0 I}{r} \cdot \frac{2\sqrt{5}}{25}}$$

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net}.

(c) In terms of B_{net} and s, determine the magnetic flux through the square loop. $\phi_m = \int B \cdot dA$

$$\boxed{B_{net} \cdot s^2}$$

(d) The square loop is now rotated about an axis in its plane at an angular speed ω. In terms of B_{net}, s, and ω, calculate the induced emf in the loop as a function of time t, assuming that the loop is horizontal at $t = 0$.

magnetic flux at an angle θ with the original plane

$$\varepsilon = -\frac{d\phi_m}{dt}$$

$$B_{net} s^2 \sin(\omega t)$$

the induced emf

$$\cancel{-B_{net} s^2 \cos\theta} \quad \boxed{-\omega B_{net} s^2 \cos(\omega t)}$$

ϕ

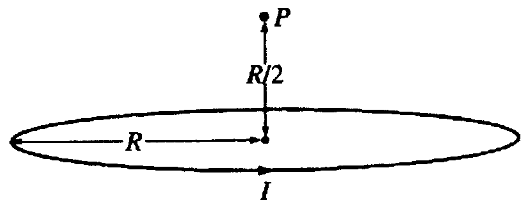

Figure 1

E&M. 3.

The circular loop of wire in Figure 1 above has a radius of R and carries a current I. Point P is a distance of $R/2$ above the center of the loop. Express algebraic answers to parts (a) and (b) in terms of R, I, and fundamental constants.

(a)

i. State the direction of the magnetic field B_1 at point P due to the current in the loop.

Towards the center of the loop.

ii. Calculate the magnitude of the magnetic field B_1 at point P.

$$F = qvB \sin\theta$$

$$\oint B\, dl = \mu_0 I$$

$$Bl = \mu_0 I$$

$$B(R/2) = \mu_0 I$$

$$B = \frac{\mu_0 I}{R/2}$$

$$\boxed{B = \frac{2\mu_0 I}{R} \text{ Teslas}}$$

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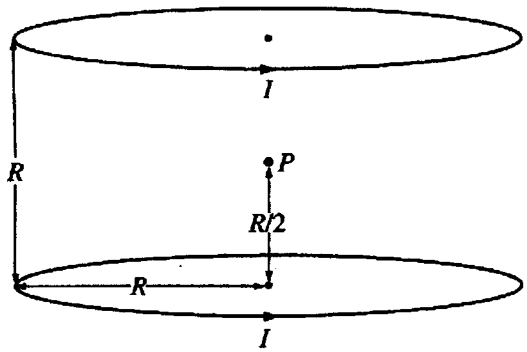

Figure 2

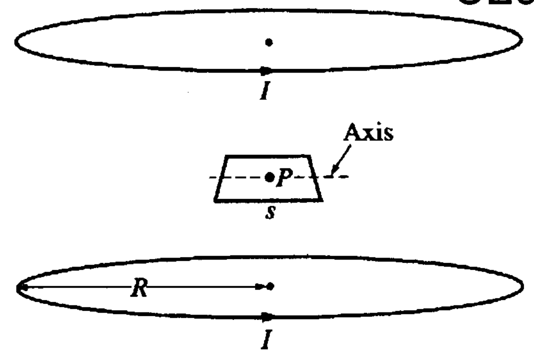

Figure 3

A second identical loop also carrying a current I is added at a distance of R above the first loop, as shown in Figure 2 above.

(b) Determine the magnitude of the net magnetic field B_{net} at point P.

$$B_1 = \frac{2\mu_0 I}{R} \qquad B_2 = \frac{2\mu_0 I}{R}$$

$$B_{net} = \frac{2\mu_0 I}{R} + \frac{2\mu_0 I}{R} = \frac{4\mu_0 I}{R} \text{ Teslas}$$

A small square loop of wire in which each side has a length s is now placed at point P with its plane parallel to the plane of each loop, as shown in Figure 3 above. For parts (c) and (d), assume that the magnetic field between the two circular loops is uniform in the region of the square loop and has magnitude B_{net}.

(c) In terms of B_{net} and s, determine the magnetic flux through the square loop.

$$\Phi = \oint B\,dA \qquad A = s^2$$

$$\Phi = BA\cancel{\cos\theta}$$

$$\boxed{\Phi = B_{net}\, s^2 \text{ Webers}}$$

(d) The square loop is now rotated about an axis in its plane at an angular speed ω. In terms of B_{net}, s, and ω, calculate the induced emf in the loop as a function of time t, assuming that the loop is horizontal at $t = 0$.

$$\mathcal{E}_{mf} = \frac{-d\Phi}{dt} \qquad \Phi = \oint B\,dA$$

$$\mathcal{E} = -\frac{d(\oint B\,dA)}{dt}$$

$$\mathcal{E} = -BAt\cos\theta$$

$$\mathcal{E} = -B_{net}\, s^2 t \cos\theta$$

volts

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Question 3

Overview

The intent of this question was to assess students' understanding of a magnetic field, including its vector nature. Parts (a) and (b) required a calculation using the Biot-Savart law and an application of the principle of superposition. Parts (c) and (d) addressed the concept of magnetic flux, both with the loop fixed perpendicular to a magnetic field, and with the orientation of the loop varying with respect to the direction of the magnetic field.

Sample: CE3A
Score: 15

The student catches a trigonometry function error in part (d) that would have cost 1 point for an incorrect final expression.

Sample: CE3B
Score: 11

Part (a)(i) is correct. Three points were earned in part (a)(ii) for using the Biot-Savart law, a correct expression for the value of r (most easily seen in the diagram), and correctly evaluating $\int d\ell$. Parts (b) and (c) earned full credit. Part (d) lost 1 point for an incorrect final answer, since the use of sine and cosine are reversed.

Sample: CE3C
Score: 6

No points were earned in part (a), while parts (b) and (c) received full credit. Two points were earned in part (d) for using Faraday's law with ϕ as a magnetic flux and for recognizing an angular dependence.