AP® Physics C
1996 Scoring Guidelines

AP® Physics C
1996 Scoring Guidelines

The materials included in these files are intended for use by AP teachers for course and exam preparation in the classroom; permission for any other use must be sought from the Advanced Placement Program®. Teachers may reproduce them, in whole or in part, in limited quantities, for face-to-face teaching purposes but may not mass distribute the materials, electronically or otherwise. These materials and any copies made of them may not be resold, and the copyright notices must be retained as they appear here. This permission does not apply to any third-party copyrights contained herein.

Mechanics 1 Scoring Guide (15 points)

Solutions — **Distribution of points**

(a) 2 points

Mass (kg)	Average Time for Ten Vibrations (s)	Period T (s)	T^2 (s^2)
0.10	8.86	.886	.785
0.20	10.6	1.06	1.12
0.30	13.5	1.35	1.82
0.40	14.7	1.47	2.16
0.50	17.7	1.77	3.13

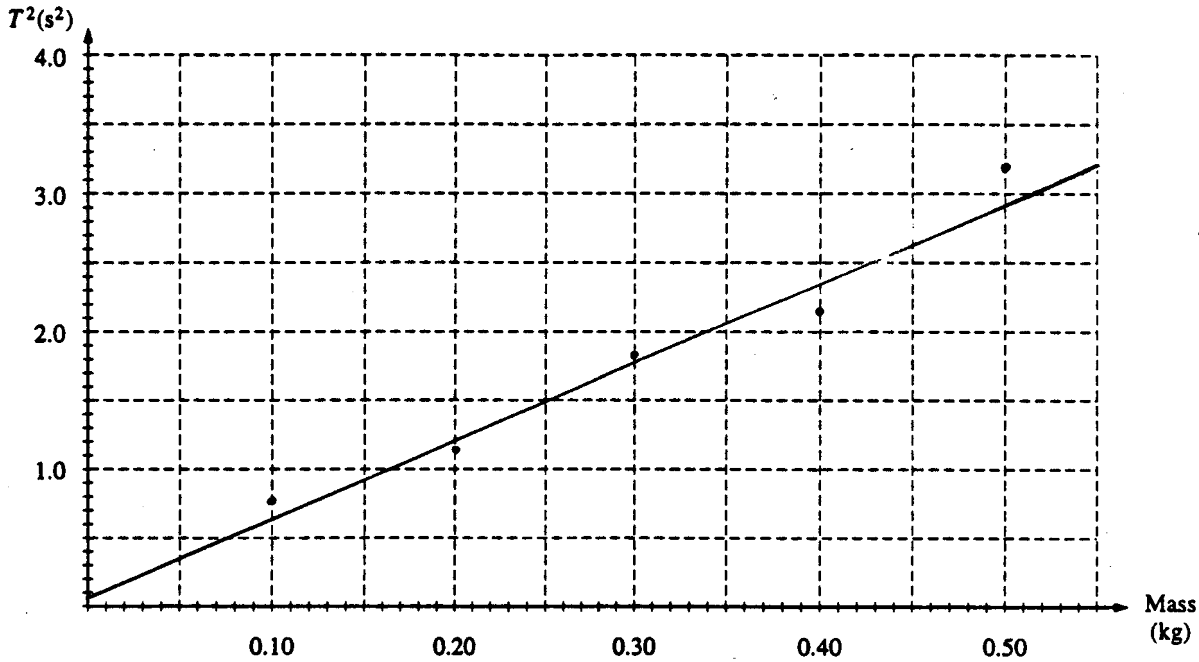
For recording the correct values for the period — 1 point

For recording the correct values for the square of the period — 1 point

Solutions **Distribution of points**

(b) 3 points

The following shows the correctly graphed data and a sample of an acceptable line to fit the data.



For correctly plotting the values of T^2	1 point
For drawing a straight line that is not horizontal or vertical	1 point
For drawing a straight line consistent with the data, having at least one point above and one point below the line	1 point

(c) 2 points

The period is $T = (16.1\ \text{s})/(10) = 1.61\ \text{s}$. Thus $T^2 = 2.59\ \text{s}^2$.

For a value of mass for this period that is consistent with the graph	1 point
On the sample graph given, the corresponding mass as read from the straight-line fit is 0.45 kg.	
For an answer expressed with 2 or 3 significant figures	1 point

Solutions	**Distribution of points**

(d) 2 points

For recognizing this is simple harmonic motion and using the equation for the period of a spring , $T = 2\pi\sqrt{m/k}$ — 1 point

For solving the equation for k — 1 point

$k = 4\pi^2 m/T^2$

The ratio m/T^2 is the inverse of the slope of the straight-line fit.

(Alternate solution) — *(Alternate points)*

For attaching one or more masses to the bar and measuring the force and displacement at equilibrium — *1 point*

For indicating that the force constant can be determined from a graph of force versus displacement or the equation $k = F/x$ — *1 point*

(e) 2 points

For indicating that this device can be used in space — 1 point

For explaining that the period of oscillation is independent of the effects of gravity — 1 point

(f) 3 points

For indicating that the gravitational force equals the net force on the shuttle — 1 point

$$F_G = \frac{GmM_e}{r^2} = ma$$

For solving for the acceleration — 1 point

$$a = \frac{GM_e}{r^2}$$

$$r = \left(6.4 \times 10^6 \text{ m/s}\right) + \left(0.3 \times 10^6 \text{ m/s}\right) = 6.7 \times 10^6 \text{ m/s}$$

$$a = \left(6.65 \times 10^{-11} \frac{\text{m}^3}{\text{kg}\cdot\text{s}^2}\right)\left(6.0 \times 10^{24}\text{kg}\right)\Big/\left(6.7 \times 10^6\text{m}\right)^2$$

For the correct answer — 1 point

$a = 8.9 \text{ m/s}^2$

(g) 1 point

For explaining that all objects aboard the shuttle are accelerating toward the Earth at the same rate as the shuttle, or that they are all in "free-fall". — 1 point

Without a contact force counteracting the force of gravity, there is no sensation of weight.

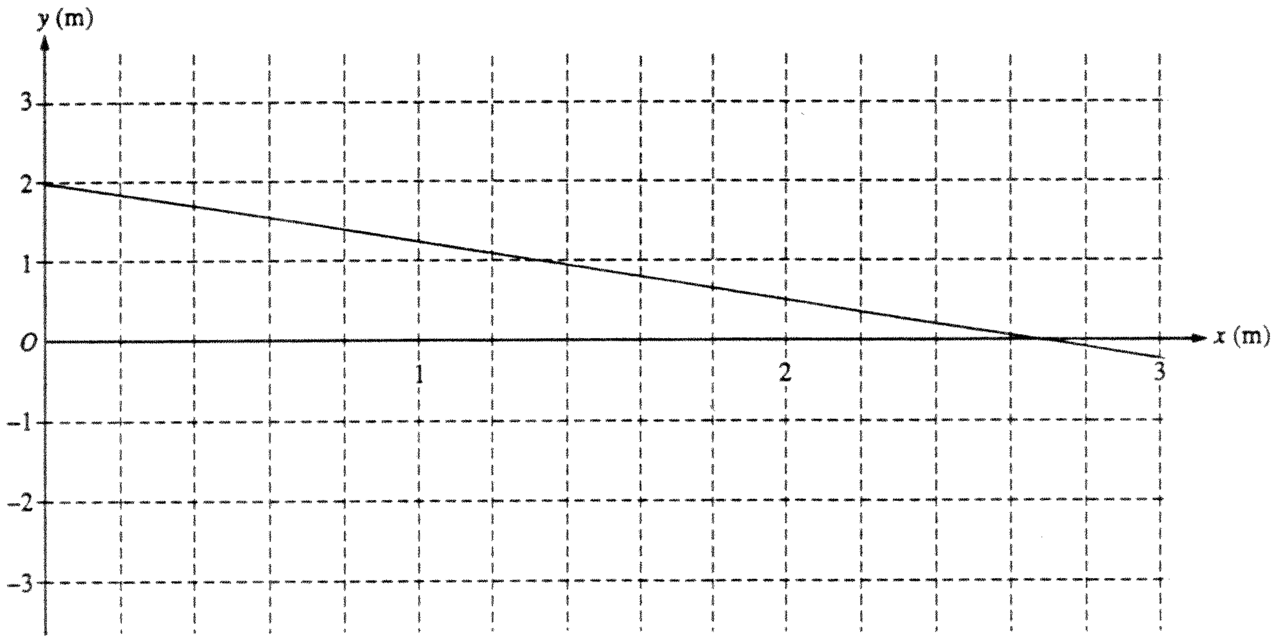
Mechanics 2 Scoring Guide (15 points)

Solutions	Distribution of points
(a) 3 points	
For indicating, via an equation or a free-body diagram, that the net force is the sum of gravity and the normal force exerted by the platform	1 point
Using Newton's second law:	
$mg - N = ma_v$	
Solving for the force exerted by the platform:	
$N = m(g - a_v)$	
For correctly substituting both accelerations	1 point
$N = (300\ \text{kg})(10\ \text{m/s}^2 - 1.5\ \text{m/s}^2)$	
For the correct answer	1 point
$N = 2550\ \text{N}$ (or 2490 N if using $9.8\ \text{m/s}^2$)	
(b) 2 points	
For indicating that the frictional force is the only horizontal force exerted	1 point
$f = ma_h$	
$f = (300\ \text{kg})(2\ \text{m/s}^2)$	
For the correct answer	1 point
$f = 600\ \text{N}$	
(c) 3 points	
Expressing the frictional force in terms of the normal force:	
$f = \mu N$	
$\mu = f/N$	
For correctly substituting the frictional force from part (b)	1 point
For correctly substituting the normal force from part (a)	1 point
$\mu = (600\ \text{N})/(2550\ \text{N})$	
For the correct answer, with no units	1 point
$\mu = 0.24$	

Solutions	**Distribution of points**
(d) 4 points	
For writing the equation for the vertical motion, and indicating that $a_v = -1.5\ \text{m/s}^2$	1 point
$y = y_0 + \frac{1}{2}(-1.5)t^2$	
For indicating that $y_0 = 2$	1 point
For writing the equation for the horizontal motion, and indicating that $a_h = 2\ \text{m/s}^2$	1 point
$x = \frac{1}{2}(2)t^2$	
The relationship between x and y can be obtained by combining the equations for the horizontal and vertical motions, eliminating t^2.	
For a correct equation relating y and x	1 point
$y = 2 - 0.75x$	
Note: Alternate methods that derive this equation from a relationship between the components of acceleration or velocity could also receive full credit.	

Solutions | **Distribution of points**

(e) 3 points



For a straight line with a negative slope, extending at least to $x = 1$ m	1 point
For a y-intercept at 2 m	1 point
For an x-intercept at $2\frac{2}{3}$ m or a slope of $-\frac{3}{4}$	1 point

Note: Credit was only awarded for showing the items above on the graph. Students were expected to show an understanding of the physics of the situation, and thus were not awarded full credit for graphing an incorrect equation from part (d).

Mechanics 3 Scoring Guide (15 points)

Solutions	Distribution of points

(a) 2 points

Beginning with the integral expression for rotational inertia:

$$I_r = \int r^2 dm$$

For a correct expression for the mass element dm — 1 point

$$dm = \frac{M}{\ell} dr$$

For correct limits on the integral — 1 point

$$I_r = \int_{-\ell/2}^{\ell/2} \frac{M}{\ell} r^2 dr$$

$$I_r = \frac{M}{\ell} \frac{r^3}{3} \Big|_{-\ell/2}^{\ell/2} = \frac{2M}{\ell} \frac{1}{3} \frac{\ell^3}{2^3}$$

$$I_r = \frac{M\ell^2}{12}$$

(Alternate solution) — *(Alternate Points)*

For correctly using the parallel axis theorem — *1 point*

$$I_{end} = I_{cm} + mr^2$$

$$I_{end} = \frac{1}{3} M\ell^2$$

Solving for I_{cm}:

$$I_{cm} = I_{end} - mr^2$$

For the correct substitutions — *1 point*

$$I_{cm} = \frac{1}{3} M\ell^2 - M\frac{\ell^2}{4}$$

$$I_r = \frac{M\ell^2}{12}$$

Solutions	**Distribution of points**

(b) 2 points

For adding terms for the rod and the hoop to obtain the total rotational inertia — 1 point

$I = I_r + I_h$

For the correct expressions for each of the terms — 1 point

$$I = \frac{M\ell^2}{12} + M\frac{\ell^2}{4}$$

$$I = \frac{M\ell^2}{3}$$

(c), (d), and (e) 8 points

The solutions to these three parts are highly connected, and so points for the various principles involved in their solution were awarded independent of the part in which they appeared.

For use of Newton's second law — 1 point

$\mathbf{F}_{net} = m\mathbf{a}$

For expressing the net force on the cat as the difference between the tension in the rope and the cat's weight — 1 point

$F_{net} = |Mg - T|$

Taking down as the positive direction for the acceleration:

$Ma = Mg - T$

For the torque equation for the rotation of the rod-hoop assembly — 1 point

$\tau = I\alpha$

For the correct torque exerted by the rope — 1 point

$$\tau = T\frac{\ell}{2}$$

For the correct relationship between the angular and the linear accelerations — 1 point

$\alpha = \alpha/R$ or $\alpha = a/(\ell/2)$

Solutions | **Distribution of points**

(c), (d), and (e) (continued)

Example solution for part (c):

Substituting the torque from the rope, the angular acceleration, and the rotational inertia in the torque equation:

$$T\frac{\ell}{2} = \frac{M\ell^2}{3}\,\frac{2a}{\ell}$$

Solving for the acceleration:

$$a = \frac{3}{4}\frac{T}{M}$$

Substituting a in the Newton's law equation and solving for T:

$$\frac{3}{4}T = Mg - T$$

$$\frac{7}{4}T = Mg$$

For the correct answer — 1 point

$$T = \frac{4}{7}Mg$$

Example solution for part (d):
Using the torque equation:

$$\tau = T\frac{\ell}{2} = I\alpha$$

$$\alpha = \frac{T\ell}{2I}$$

Substituting for T and I:

$$\alpha = \frac{\ell}{2}\left(\frac{4}{7}Mg\right)\left(\frac{3}{M\ell^2}\right)$$

For the correct answer — 1 point

$$\alpha = \frac{6}{7}\frac{g}{\ell}$$

Solutions	**Distribution of points**

(c), (d), and (e) (continued)

Example solution for part (e):

$$a = \alpha\left(\frac{\ell}{2}\right)$$

Substituting for α:

$$a = \left(\frac{6}{7}\frac{g}{\ell}\right)\left(\frac{\ell}{2}\right)$$

For the correct answer — 1 point

$$a = \frac{3}{7}g$$

(f) 3 points

For a correct expression for the angular momentum of the cat — 1 point

$$L = Mv\frac{\ell}{2} \quad \text{or} \quad Mvr$$

For a kinematic equation that allows calculation of the speed v of the cat — 1 point

$$v^2 = v_0^2 + 2ad$$

$$v^2 = 2aH = 2\left(\frac{3}{7}g\right)\left(\frac{5\ell}{3}\right) = \frac{10}{7}g\ell$$

For the correct answer — 1 point

$$L = \frac{M\ell}{2}\sqrt{\frac{10}{7}g\ell} \quad \text{or} \quad M\sqrt{2aH}\,\frac{\ell}{2}$$

Electricity & Magnetism 1 Scoring Guide (15 points)

Solutions	**Distribution of points**
(a) 3 points	
The sphere is metal; therefore the charge resides on the outer surface. This means that it can be treated as a point charge at the center of the sphere.	
For using the expression for the potential of a point charge	2 points
$V_0 = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q_0}{a}$	
For the correct answer	1 point
$Q_0 = 4\pi\varepsilon_0 V_0 a$	
(b)	
i. 1 point	
For indicating that the charge on the inner surface of the shell is $-Q_0$	1 point
The electric field inside a conductor is zero; therefore the inner surface of the shell must carry a charge equal and opposite to that of the sphere to cancel the field from the sphere.	
ii. 1 point	
For indicating that the charge on the outer surface of the shell is Q_0	1 point
The net charge on the shell is zero, so the charge on the outer surface must cancel that on the inner surface.	

Solutions	Distribution of points
(c)	
i. 1 point	
The magnitude of the electric field is zero. There is no electric field inside a conductor. A zero field has no direction.	1 point
ii. 2 points	
Only the charge inside the region contributes to the field. It can be treated as a point charge at the center of the sphere.	
$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q_0}{r^2}$	1 point
The field is directed radially outward.	1 point
iii. 1 point	
The magnitude of the electric field is zero. There is no electric field inside a conductor. A zero field has no direction.	1 point
iv. 2 points	
This situation is equivalent to that in (ii).	
$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{Q_0}{r^2}$	1 point
The field is directed radially outward.	1 point
(d) 2 points	
For indicating that the sphere does exert a force on the shell while it is being assembled.	1 point
For explaining that the charges induced on the inner and outer surfaces appear as the shell is being assembled, and the fact that the negative charge is closer means that there is a net attractive force	1 point

Solutions | **Distribution of points**

(e) 2 points

For correctly integrating the electric field to find the potential — 1 point

$$V = \frac{1}{4\pi\varepsilon_0}\left(-\int_{\infty}^{2b}\frac{Q_0}{r^2}dr - \int_{b}^{a}\frac{Q_0}{r^2}dr\right)$$

$$V = \frac{Q_0}{4\pi\varepsilon_0}\left(\frac{1}{r}\bigg|_{\infty}^{2b} + \frac{1}{r}\bigg|_{b}^{a}\right)$$

$$V = \frac{Q_0}{4\pi\varepsilon_0}\left(\frac{1}{2b} + \frac{1}{a} - \frac{1}{b}\right)$$

$$V = \frac{Q_0}{4\pi\varepsilon_0}\left(\frac{1}{a} - \frac{1}{2b}\right)$$

$$V = \frac{Q_0}{4\pi\varepsilon_0}\left(\frac{2b-a}{2ab}\right)$$

For the correct answer — 1 point

$$V = V_0\left(\frac{2b-a}{2b}\right)$$

Note: Alternately, the first point could also be obtained by the superposition of potentials on the sphere due to the three charge distributions: on the surface of the sphere, on the inside surface of the shell, and on the outside surface of the shell.

Electricity & Magnetism 2 Scoring Guide (15 points)

Solutions	**Distribution of points**
(a) 4 points	
There are many strategies for working through this part. Points were awarded for the following key concepts.	
For correctly calculating the total charge in the circuit (200 μC)	1 point
For the realization that the charge is conserved	1 point
For the realization that the final voltages on the capacitors are equal or that the capacitors are connected in parallel	1 point
For the correct final charges on the capacitors ($Q_1 = 50\ \mu C$, $Q_2 = 150\ \mu C$)	1 point

Example:
Calculating the total charge:
$Q_0 = C_1\ V_0 = (4\ \mu F)(50\ V) = 200\ \mu C$
At equilibrium, the voltage is the same across both capacitors.
$V_1 = V_2$

$$\frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

The charge in the circuit is conserved.

$$Q_1 + Q_2 = Q_0$$

At this point, one can realize that there is a 1 to 3 capacitance ratio and that the total charge must be similarly divided, or one can solve the two simultaneous equations.

$$Q_1 = \frac{Q_0 C_1}{C_2 + C_1} = \frac{(200\ \mu C)(4\ \mu F)}{(12\ \mu F) + (4\ \mu F)}$$

$$Q_1 = 50\ \mu C$$

$$Q_2 = Q_0 - Q_1 = (200\ \mu C) - (50\ \mu C)$$

$$Q_2 = 150\ \mu C$$

Solutions	**Distribution of points**

(b) 3 points

Using the equation for the energy stored in a capacitor:

$$U = \frac{1}{2}CV^2$$

Calculating the initial energy:

$$U_i = \frac{1}{2}C_1 V_0^2 \qquad \text{1 point}$$

$$U_i = \frac{1}{2}(4\ \mu\text{F})(50\ \text{V})^2 = 5000\ \mu\text{J}$$

Calculating the final energy (either by the method below that uses the answers from part (a) or an equivalent method):

$$U = \frac{1}{2}\frac{Q^2}{C}$$

$$U_f = \frac{1}{2}\frac{Q_1^2}{C_1} + \frac{1}{2}\frac{Q_2^2}{C_2} \qquad \text{(or equivalent)} \qquad \text{1 point}$$

$$U_f = \frac{1}{2}\left(\frac{(50\ \mu\text{C})^2}{4\ \mu\text{F}} + \frac{(150\ \mu\text{C})^2}{12\ \mu\text{F}}\right) = 1250\ \mu\text{J}$$

$$\Delta U = U_f - U_i = -3750\ \mu\text{J} \qquad \text{1 point}$$

(Point was awarded for either a positive or negative value)

(c) 2 points

For recognizing the general form of the Kirchoff loop rule for this circuit — 1 point

$$\mathcal{E} - IR - V_2 = 0$$

The three quantities required for substitution:

1) The emf is supplied by the initially charged capacitor.

$$\mathcal{E} = V_1 = \frac{Q_1}{C_1}$$

2) Using the fact that the total charge is the sum of the charges on the capacitors, $Q_1 + Q_2 = Q_0 = V_0C_1$, the voltage V_2 can be determined.

$$V_2 = \frac{Q_2}{C_2} = \frac{V_0C_1 - Q_1}{C_2}$$

3) Capacitor C_1 is discharging, so $I = -\frac{dQ_1}{dt}$

Making these three substitutions in the loop equation:

$$\frac{Q_1}{C_1} + \frac{dQ_1}{dt}R - \frac{V_0C_1 - Q_1}{C_2} = 0 \qquad \text{1 point}$$

Note: Full credit was awarded if $I = +\frac{dQ_1}{dt}$ was used.

Solutions — **Distribution of points**

(d) 3 points

For the appropriate equation for power that allows use of the given current — 1 point

$P = I^2 R$

For substituting the expression for the current — 1 point

$P = \left(I_0 e^{-t/\tau}\right)^2 R$

For the correct answer — 1 point

$P = I_0^2 R e^{-2t/\tau}$ or $\overset{35}{\cancel{0.25}}\, e^{-t/\left(1.5 \times 10^{-4}\right)}$

(e) 3 points

For recognizing that the energy dissipated is equal to the difference in stored energy calculated in part (b) — 3 points

$\Delta U = 3750\ \mu\text{J}$

(Alternate solution) — *(Alternate Points)*

For recognizing that the energy dissipated is the integral of the power — *1 point*

$\Delta U = \int P\, dt$

For correctly setting up the integral, including limits — *1 point*

$$\Delta U = I_0^2 R \int_0^{\infty} e^{-2t/\tau}\, dt$$

$$\Delta U = I_0^2 R \left(-\frac{\tau}{2}\right) e^{-2t/\tau}\Big|_0^{\infty} = I_0^2 R \left(-\frac{\tau}{2}\right)(0-1)$$

$$\Delta U = (0.5\ \text{A})^2 (100\ \Omega) \frac{\left(3 \times 10^{-4}\ \text{s}\right)}{2}$$

For the correct answer — *1 point*

$\Delta U = 3750\ \mu\text{J}$

Electricity & Magnetism 3 Scoring Guide (15 points)

Solutions	**Distribution of points**

(a) 4 points

Using the given equation:

$$\oint \mathbf{E}\cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$$

For any indication that $d\phi_m = A\,dB$ — 1 point

For recognizing that the path of integration is a circle of radius r concentric with the solenoid axis, giving a factor of $2\pi r$ for the path length — 1 point

For recognition that the contributing flux is within this circle, giving a factor of πr^2 for the area enclosed — 1 point

Making these substitutions:

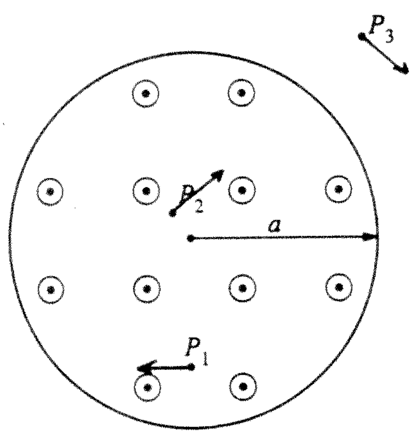
$$E(2\pi r) = \frac{d}{dt}(BA)$$

$$E(2\pi r) = \pi r^2 \frac{dB}{dt}$$

For the correct answer (either positive or negative) — 1 point

$$E = \frac{r}{2}\frac{dB}{dt}$$

(b) 3 points



For all three vectors reasonably tangent to circles concentric with the solenoid and clockwise — 3 points

Note: 2 points were awarded if all three vectors were reasonably tangent but at least one was counterclockwise. 2 points were awarded if the vectors at P_1 and P_2 were correct but the one at P_3 was missing or incorrect. 1 point was awarded if the vectors at P_1 and P_2 were reasonably tangent but counterclockwise and the one at P_3 was missing. Any other incorrect responses received no credit.

Solutions	**Distribution of points**

(c) 4 points

This calculation is the same as that in part (a), except that the contributing flux exists only inside the radius a.

For any indication that $d\phi_m = A\,dB$	1 point
For recognizing that the path of integration is a circle of radius r concentric with the solenoid axis, giving a factor of $2\pi r$ for the path length	1 point
For recognition that the contributing flux is within this circle, giving a factor of πa^2 for the area enclosed	1 point

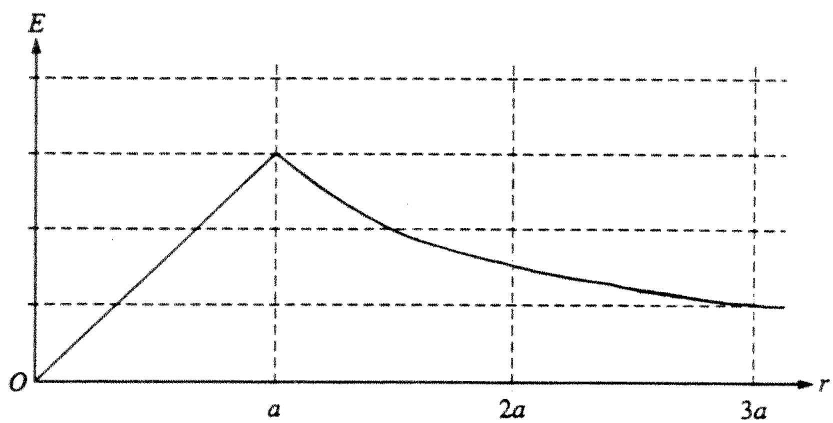
Making these substitutions:

$$E(2\pi r) = \pi a^2 \frac{dB}{dt}$$

For the correct answer (either positive or negative)	1 point

$$E = \frac{a^2}{2r}\frac{dB}{dt}$$

(d) 4 points



For indicating that $E = 0$ at $r = 0$	1 point
For a reasonably linear graph with positive slope for the region $0 < r < a$	1 point
For a continuous graph at $r = a$, with a change in slope	1 point
For a graph in the region $r > a$ with a continuous negative slope, that does not reach $E = 0$ before $r = 3a$	1 point