AP® Physics C
1995 Scoring Guidelines

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1995

Mechanics 1 Scoring Guide

Solutions	Distribution of points

Note: For this solution, vector quantities to the right are defined as positive.

(a) 3 points

For a correct expression relating impulse and force — 1 point

$I = \int_{t_1}^{t_2} F\,dt$ OR $F\,\Delta t$

For any indication that the impulse is the area under the curve — 1 point

$I = 2\left(\frac{1}{2}\right)(2 \times 10^3\ \text{N})(4 \times 10^{-3}\ \text{s}) + (2 \times 10^3\ \text{N})(2 \times 10^{-3}\ \text{s})$

For the correct answer — 1 point

$I = 12\ \text{N} \cdot \text{s}$

(b) 3 points

For a correct expression relating impulse and momentum — 1 point

$I = \int_{v_1}^{v_2} m\,dv$ OR Δp

For a correct expression for the impulse in terms of the mass and speed of the ball — 1 point

$I = m_b(v_{bf} - v_{bi})$

Since the ball is initially at rest, $v_{bi} = 0$.

Substituting and solving for v_{bf}:

$v_{bf} = I/m_b$

$v_{bf} = (12\ \text{N} \cdot \text{s})/(5\ \text{kg})$

For the correct answer — 1 point

$v_{bf} = 2.4\ \text{m/s}$

Solutions	Distribution of points

(c)

i. 2 points

For either an expression for the impulse on the cube, with an indication that the value for the cube is equal and opposite that of the ball, or conservation of momentum — 1 point

$I = m_c(v_{cf} - v_{ci})$ and $I = -12\ \text{N}\cdot\text{s}$

OR $m_c v_{ci} = m_b v_{bf} + m_c v_{cf}$

Solving for the speed of the cube after the collision:

$v_{cf} = (I + m_c v_{ci})/m_c$ OR $v_{cf} = (m_c v_{ci} - m_b v_{bf})/m_c$

$v_{cf} = [-12\ \text{N}\cdot\text{s} + (0.5\ \text{kg})(26\ \text{m/s})]/(0.5\ \text{kg})$

OR $= [(0.5\ \text{kg})(26\ \text{m/s}) - (5\text{kg})(2.4\ \text{m/s})]/(0.5\ \text{kg})$

For a correct answer — 1 point

$v_{cf} = 2\ \text{m/s}$

ii. 1 point

The speed obtained above has a positive value, so the cube is moving to the right. — 1 point

(d) 3 points

For a correct expression for the kinetic energy dissipated — 1 point

$\Delta K = K_{cf} + K_{bf} - K_{ci}$

For a correct general expression for kinetic energy: — 1 point

$$K = \frac{1}{2}mv^2$$

$$\Delta K = \frac{1}{2}\left(m_c v_{cf}^2 + m_b v_{bf}^2 - m_c v_{ci}^2\right)$$

$$= \frac{1}{2}\left[(0.5\text{kg})(26\ \text{m/s})^2 + (5\ \text{kg})(2.4\ \text{m/s})^2 - (0.5\ \text{kg})(2\ \text{m/s})^2\right]$$

For the correct answer — 1 point

$\Delta K = 154\ \text{J}$

Solutions	Distribution of points
(e) 3 points	
Both objects take the same amount of time to reach the floor.	
For the kinematic equation for the vertical motion $y = v_{yi}t + \frac{1}{2}gt^2$ The initial velocity is zero. Solving for t: $t = \sqrt{2y/g}$ $= \sqrt{2(1.2\text{ m})/(10\text{ m/s}^2)} = \sqrt{0.24\text{ s}^2}$ $t = 0.5\text{ s}$	1 point
For a correct expression for horizontal motion with no acceleration $x = v_x t$ Applying this equation to the two objects: $x_b = (2.4\text{ m/s})(0.5\text{ s}) = 1.2\text{ m}$ $x_c = (2\text{ m/s})(0.5\text{ s}) = 1\text{ m}$	1 point
$\Delta x = x_b - x_c$ For the correct answer $\Delta x = 0.2\text{ m}$	1 point

Mechanics 2 Scoring Guide

Solutions	Distribution of points

(a)

i. 3 points

The minimum occurs when $\left.\dfrac{dU}{dr}\right|_{r_0} = 0$.

For realizing that one must take the derivative of U	1 point
For setting the derivative equal to zero	1 point

Evaluating the derivative:

$$\left.\frac{dU}{dr}\right|_{r_0} = \frac{a}{b} + \left.\frac{(-1)ab}{r^2}\right|_{r_0} = 0$$

$$\frac{a}{b} - \frac{ab}{r_0^2} = 0$$

Solving for r_0:

$$\frac{a}{b} = \frac{ab}{r_0^2}$$

$$r_0^2 = b^2$$

For the correct answer	1 point

$r_0 = b$

ii. 1 point

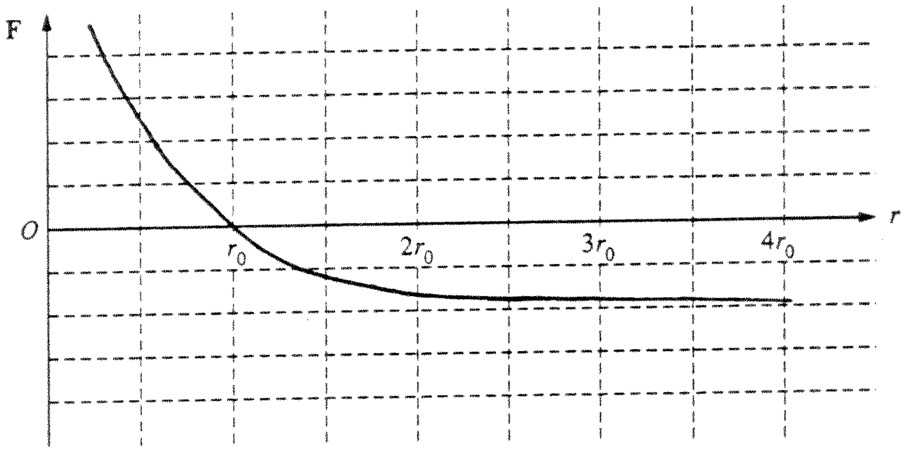
The minimum potential energy is found by evaluating $U(r_0)$.

$$U_0 = U(r_0) = a\left(\frac{b}{b} + \frac{b}{b}\right)$$

For the correct answer	1 point

$U_0 = 2a$

Solutions	Distribution of points
(b) 3 points	
Using the relationship $F = -\frac{dU}{dr}$, the shape of the graph can be determined from the general expression for $\frac{dU}{dr}$ found in part (a)i, or qualitatively from the slope of the $U(r)$ graph.	



For a positive force for $r < r_0$, smooth and monotonically decreasing as r increases, that does not cross the y axis	1 point
For a zero force at $r = r_0$, with the curve passing smoothly through the x axis	1 point
For a negative force for $r > r_0$, smooth and monotonic, that approaches a constant value	1 point

(In the absence of credit for the graph, indicating that $F = -\frac{dU}{dr}$ received 1 point.)

Solutions	Distribution of points
(c) 4 points	
For indicating that energy is conserved	1 point
$E = K + U = \text{constant}$	
For recognizing that the initial kinetic energy is zero	1 point
$U\left(\frac{r_0}{2}\right) = \frac{1}{2}mv^2 + U(r_0)$	
For evaluating $U\left(\frac{r_0}{2}\right)$	1 point
$U\left(\frac{r_0}{2}\right) = a\left(\frac{b}{2b} + \frac{2b}{b}\right) = \frac{5a}{2}$	
Substituting:	
$\frac{1}{2}mv^2 = \frac{5a}{2} - 2a = \frac{a}{2}$	
Solving for the speed:	
$v = \sqrt{a/m}$	
For using $U_0 = 2a$ from part (a)ii, and substituting for a	1 point
$v = \sqrt{U_0/2m}$	
(d) 2 points	
By conservation of energy, the particle will again come to rest (instantaneously have zero velocity) at a point r_1 where its potential energy equals that at $r_0/2$.	
$U(r_1) = U\left(\frac{r_0}{2}\right)$	2 points
(Some students interpreted "at rest" to mean permanently at rest. Full credit was awarded for saying that the particle never comes to rest.)	
(e) 2 points	
The particle will oscillate, with the end points of the motion being $r_0/2$ and r_1.	
For indicating that the particle will oscillate	1 point
For indicating, implicitly or explicitly, that energy is not lost	1 point

Mechanics 3 Scoring Guide

Solutions	Distribution of points
(a) 3 points	
For a correct expression for centripetal acceleration	1 point
$a = \dfrac{v^2}{r}$ OR $\omega^2 r$	
For expressing v or ω in terms of given quantities	1 point
$v = \dfrac{2\pi r}{T}$ OR $\omega = \dfrac{2\pi}{T}$	
For the correct answer	1 point
$a_a = \dfrac{4\pi^2 r_a}{T^2}$	
(b) 4 points	
The centripetal force on star A is due to the gravitational force exerted by star B.	
For a correct expression for the centripetal force on star A	1 point
$F_c = M_a a_a$ OR $M_a v_a^2 / r_a$	
For a correct expression for the gravitational force:	
$F_G = \dfrac{GM_a M_b}{r^2}$	1 point
For using $r = r_a + r_b$	1 point
For setting F_c and F_G equal	1 point
$M_a \dfrac{4\pi^2 r_a}{T^2} = \dfrac{GM_b M_a}{(r_a + r_b)^2}$	
Solving for M_b:	
$M_b = \dfrac{4\pi^2 r_a (r_a + r_b)^2}{GT^2}$	

(c) 2 points

The same calculations as above can be performed with the roles of star A and star B switched.

For realization of this symmetry	1 point
For the correct answer	1 point

$$M_a = \frac{4\pi^2 r_b (r_a + r_b)^2}{GT^2}$$

(Alternate solution) — *(Alternate points)*

Writing the expression for the center of mass with respect to point P:

$$\frac{-M_a r_a + M_b r_b}{M_a + M_b} = 0$$

For the simplified version of this equation (1 point)

$$M_a r_a = M_b r_b$$

$$M_a = M_b \frac{r_b}{r_a}$$

Substituting the expression for M_b from part (b) to obtain the final answer (1 point)

$$M_a = \frac{4\pi^2 r_b (r_a + r_b)^2}{GT^2}$$

(d) 3 points

$$I = \sum mr^2$$

For indicating that $I \propto mr^2$	1 point
For knowing that in this case the constant of proportionality is 1 for each star.	1 point
For the correct answer	1 point

$$I = M_a r_a^2 + M_b r_b^2$$

Solutions	Distribution of points
(e) 3 points	
For indicating that the total angular momentum is the sum of the individual stars' momenta	1 point
$L = L_a + L_b$	
For a correct general expression for angular momentum	1 point
$L = mvr$ OR $I\omega$	
$L = M_a v_a r_a + M_b v_b r_b$ OR $\left(M_a r_a^2 + M_b r_b^2\right)\omega$	
$L = M_a \frac{2\pi r_a}{T} r_a + M_b \frac{2\pi r_b}{T} r_b$ OR $\left(M_a r_a^2 + M_b r_b^2\right)\frac{2\pi}{T}$	
For the correct answer	1 point
$L = \frac{2\pi}{T}\left(M_a r_a^2 + M_b r_b^2\right)$	

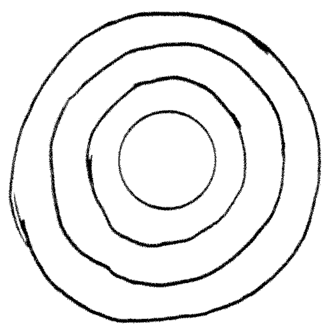
Electricity & Magnetism 1 Scoring Guide

Solutions	Distribution of points
(a) 4 points	
For a correct statement of Gauss' law $\epsilon_0 \oint \mathbf{E} \cdot \mathbf{dA} = q_{enc}$	1 point
For correctly evaluating the flux $\epsilon_0 E\,(2\pi r\,\ell) = q$	1 point
For correctly evaluating the enclosed charge $\epsilon_0 E\,(2\pi r\,\ell) = \lambda \ell$	1 point
For the correct answer $E = \dfrac{\lambda}{2\pi \epsilon_0 r}$	1 point

(Since the question did not refer to the radial variable r at this point, which seemed to cause a misunderstanding for some students, full credit was awarded for using a instead of r.)

(b)

i. 2 points



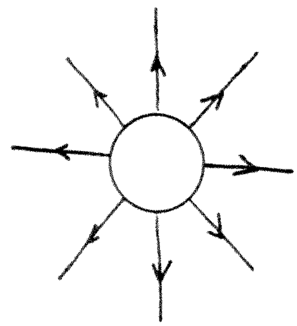
For drawing one concentric circle	1 point
For additional concentric circles	1 point

(One point was deducted from earned points for any extraneous lines or for arrowheads drawn on the circles. Some students indicated that equipotential lines ran coaxial to the cylinder, and received full credit.)

Solutions | **Distribution of points**

(b) (continued)

ii. 2 points



For drawing radial field lines — 1 point

For indicating that the field is directed outward — 1 point

(c)

i. 3 points

For any statement relating the potential difference to the summation of the electric field over a distance — 1 point

$$\Delta V = -\int \mathbf{E} \cdot d\boldsymbol{\ell}$$

$$V_C - V_D = -\int_D^C \mathbf{E} \cdot d\boldsymbol{\ell} = \int_C^D \mathbf{E} \cdot \mathbf{dr}$$

For correctly substituting for the electric field — 1 point

$$V_C - V_D = \int_C^D \frac{\lambda}{2\pi \epsilon_0} \frac{dr}{r}$$

$$= \frac{\lambda}{2\pi \epsilon_0} \int_a^{3a} \frac{dr}{r}$$

$$= \frac{\lambda}{2\pi \epsilon_0} \ln r \Big|_a^{3a}$$

For the correct answer — 1 point

$$V_C - V_D = \frac{\lambda}{2\pi \epsilon_0} \ln 3$$

Solutions	Distribution of points
(c) (continued)	
ii. 1 point	
For a correct equation for the work	1 point
$W = Q\,\Delta V$ OR $\dfrac{Q\lambda}{2\pi\epsilon_0}\ln 3$	
(d) 3 points	
For recognition of the need to use Gauss' law to determine the total charge from the charge density	1 point
$\epsilon_0 \oint \mathbf{E}\cdot\mathbf{dA} = \int \rho\, dV$	
For correct substitutions	1 point
$\epsilon_0 E\,(2\pi r\ell) = \int_0^r \rho_0 (r/a)^{1/2}\,(2\pi r\ell)dr$	
$\epsilon_0 E(2\pi r\ell) = \dfrac{2\pi\ell\rho_0}{\sqrt{a}}\int_0^r r^{3/2}\,dr$	
$= \dfrac{4}{5}\dfrac{\pi\ell\rho_0}{\sqrt{a}}\, r^{5/2}$	
For the correct answer	1 point
$E = \dfrac{2}{5}\dfrac{\rho_0}{\epsilon_0\sqrt{a}}\, r^{3/2}$	

Electricity & Magnetism 2 Scoring Guide

Solutions	Distribution of points
(a) 2 points	
For the expression for the capacitance of a capacitor with a dielectric $C = \frac{\kappa \epsilon_0 A}{d}$ (This point also awarded for any indication of the knowledge that the capacitance is different with and without the dielectric, e.g. $C = \kappa C_0$)	1 point
Solving for the dielectric constant and substituting: $\kappa = \frac{Cd}{\epsilon_0 A} = \frac{(5 \times 10^{-8}\ \mathrm{F})(1 \times 10^{-3}\ \mathrm{m})}{(8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2})(1\ \mathrm{m^2})}$	
For the correct answer $\kappa = 5.65$	1 point
(b)	
i. 2 points	
Just after the switch is closed, the voltage across the capacitor is zero, that is all the voltage appears across the resistor. For a statement of Ohm's Law $I = \frac{V}{R} = \frac{30\ \mathrm{V}}{2 \times 10^6\ \Omega}$	1 point
For the correct answer $I = 1.5 \times 10^{-5}\ \mathrm{A}$	1 point
ii. 2 points	
For the correct expression for the time constant $\tau = RC$; $\tau = (2 \times 10^6\ \Omega)(5 \times 10^{-8}\ \mathrm{F})$	1 point
For the correct answer $\tau = 1 \times 10^{-1}\ \mathrm{s}$	1 point

Solutions	Distribution of points

iii. 2 points

When the capacitor is fully charged, the potential across it is 30 volts.

$$V_c = \frac{Q}{C}$$
$$Q = CV$$
$$= (5 \times 10^{-8}\ \text{F})(30\ \text{V})$$

For a correct expression relating the relevant quantities, and correct substitutions — 1 point

$Q = 1.5 \times 10^{-6}$ C, and is negative charge

For correctly indicating the sign of the charge — 1 point

iv. 2 points

For any correct expression for the energy stored in a capacitor — 1 point

$$U = \frac{1}{2}CV^2 \quad \text{OR} \quad \frac{1}{2}QV \quad \text{OR} \quad \frac{1}{2}\frac{Q^2}{C}$$

$$= \frac{1}{2}(5 \times 10^{-8}\ \text{F})(30\ \text{V})^2$$

For the correct answer — 1 point

$U = 2.25 \times 10^{-5}$ J

(c) 2 points

For correctly using the new capacitance (for which $\kappa = 1$) — 1 point

$$C_n = \frac{C}{\kappa}$$

For indicating that the charge on the plates is unchanged — 1 point

Substituting into the expression for the voltage:

$$V_n = \frac{\kappa Q}{C}$$

$$= \frac{(5.65)(1.5 \times 10^{-6}\ \text{C})}{(5 \times 10^{-8}\ \text{F})}$$

$V_n = 170$ V

Solutions	Distribution of points

(c) (continued)

(Alternate solution)	*(Alternate points)*
For a correct expression for the new voltage across the capacitor	(1 point)
$V_n = \kappa V_0$	
For correctly substituting values	(1 point)
$V_n = (5.65)(30\ \text{V})$	
$V_n = 170\ \text{V}$	

(d) 2 points

Since $U = \dfrac{1}{2}\dfrac{Q^2}{C}$, and Q does not change, $U_n = \kappa U$. The energy stored in the capacitor has increased. The increase came from the work that had to be done to remove the dielectric from the capacitor.

For any indication that the energy increases	1 point
For indicating that work is done in removing the dielectric	1 point

UNITS POINT - For four correct units (The dielectric constant must have no units and the time constant must be expressed in seconds to be included as correct .)	1 point

Electricity & Magnetism 3 Scoring Guide

Solutions	Distribution of points
(a) 3 points	
For a correct general expression for the emf induced in the loop (with or without a negative sign)	1 point
$\varepsilon = -\dfrac{d\phi}{dt}$	
For any indication that $\phi = BA$	1 point
The magnetic field is constant, therefore the magnitude of the emf is:	
$\varepsilon = B\dfrac{dA}{dt}$	
Taking the derivative of the expression for the area, $A = Hx$:	
$\dfrac{dA}{dt} = H\dfrac{dx}{dt} = Hv_0$	
For a correct answer (obtained by substituting for $\dfrac{dA}{dt}$)	1 point
$\varepsilon = BHv_0$	
(b) 2 points	
For a correct expression for Ohm's law	1 point
$I = \dfrac{\varepsilon}{R}$	
For a correct answer	1 point
$I = \dfrac{BHv_0}{R}$	
(c) 2 points	
For any indication that the induced current creates a magnetic field that opposes the applied field, or a reference to Lenz's law	1 point
The induced current must be clockwise. (Just giving this answer earns both points.)	1 point

Electricity & Magnetism 3 Scoring Guide

Solutions	Distribution of points
(d) 4 points	
For the expression for the magnetic force on a current element	1 point
$\mathbf{F} = I\,d\boldsymbol{\ell} \times \mathbf{B}$ or $I\ell B$	

The contributions from the top and bottom sections of the loop cancel, so only the contribution from the right side remains. This force opposes the motion of the loop. Therefore:

$F = -IHB$

Generalizing the expression for the current from part (b) gives $I = \dfrac{BH\upsilon}{R}$.

Substituting for I to get the expression for the force: (1 point)

$$F = -\frac{B^2H^2\upsilon}{R}$$

Substituting, using Newton's second law, $F = ma$:

$$ma = -\frac{B^2H^2\upsilon}{R}$$

For substituting $a = \dfrac{d\upsilon}{dt}$ (1 point)

$$m\frac{d\upsilon}{dt} = -\frac{B^2H^2\upsilon}{R}$$

Re-arranging terms and integrating:

$$\int_{\upsilon_0}^{\upsilon}\frac{d\upsilon}{\upsilon} = -\int_0^t \frac{B^2H^2}{mR}dt$$

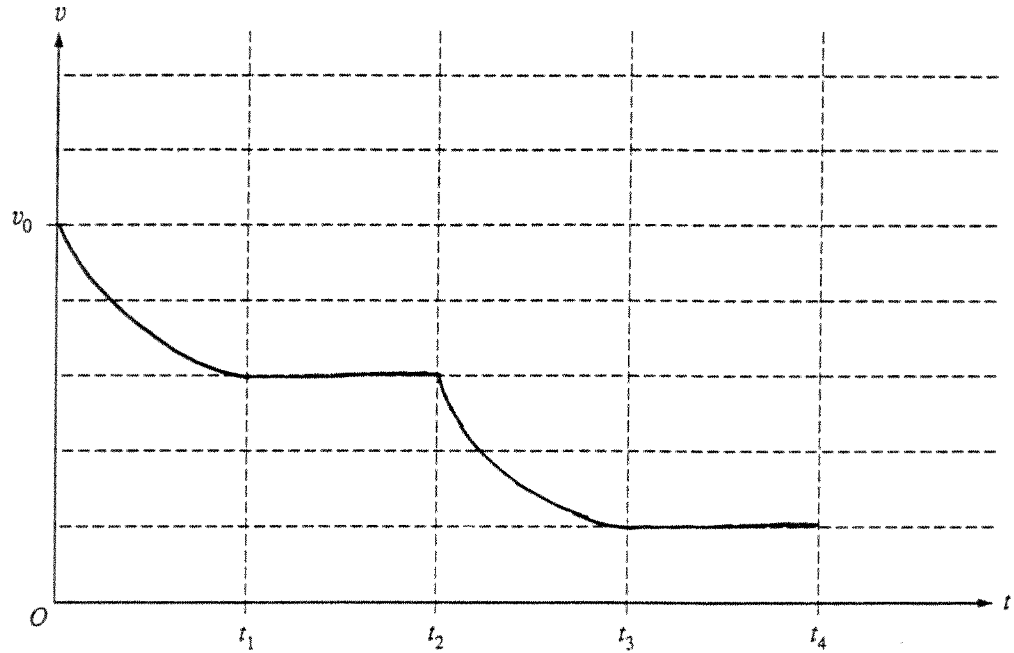
$$\ln\frac{\upsilon}{\upsilon_0} = -\frac{B^2H^2}{mR}t$$

For the correct answer (1 point)

$$\upsilon = \upsilon_0 e^{-B^2H^2t/mR}$$

Solutions **Distribution of points**

(e) 4 points



For the first segment starting at v_0 and curving appropriately	1 point
For both the second and fourth segments horizontal and non-zero	1 point
For the third segment curved appropriately	1 point
For all four segments drawn as a continuous curve with abrupt changes in slope at t_1, t_2, and t_3	1 point