AP® Physics C
1994 Scoring Guidelines

1994 Physics C Solutions

Distribution of Points

Mech 1.

(a) 3 points

For the correct expression for the energy stored in a spring:
$U = \frac{1}{2}kx^2$ — 1 point

For substituting the correct values:
$U = \frac{1}{2}(200\ \mathrm{N/m})(0.4\ \mathrm{m})^2$ — 1 point

For the correct answer (including units):
$U = 16\ \mathrm{J}$ — 1 point

(b) 3 points

For applying conservation of energy — 1 point
Kinetic energy of ball/block combination = energy stored in spring
For a correct expression for kinetic energy — 1 point

$\frac{1}{2}Mv_1{}^2 = U$

$v_1 = \sqrt{2U/M}$

$= \sqrt{2\,(16\ \mathrm{J})/(2.1\ \mathrm{kg})}$

For the correct answer:
$v_1 = 3.9\ \mathrm{m/s}$ — 1 point

(c) 3 points

For applying conservation of momentum — 1 point
For a correct expression for momentum — 1 point

$mv = Mv_1$

$v = Mv_1/m$

$= (2.1\ \mathrm{kg})(3.9\ \mathrm{m/s})/(0.1\ \mathrm{kg})$

For the correct answer:
$v = 81.9\ \mathrm{m/s}$ — 1 point

(d) 2 points

For indicating that the maximum compression of the spring will be less than 0.4 meters. — 1 point

For a correct explanation referring to the motion of the blocks or their kinetic energy — 1 point
Some examples:
The 0.8-kg block will begin to move before the spring can compress as much, due to the force that the spring exerts on it.
The kinetic energy of the center of mass of the system in this case is non-zero, so some of the initial energy must remain as kinetic energy. Less energy is available as potential energy, so the spring compression is less.

Distribution of Points

Mech 1. (cont.)

(e) 4 points

Two principles must be applied to calculate the velocity of the 0.8 kg block at the instant the spring is no longer compressed: conservation of momentum and conservation of energy.

For indicating conservation of momentum is applicable — 1 point

$Mv_1 = Mv_2 + M_2 v_3$

For substituting: $(2.1 \text{ kg})(3.9 \text{ m/s})$ $[\text{or } 8.2 \text{ kg} \cdot \text{m/s}^2] = (2.1 \text{ kg})v_2 + (8 \text{ kg})v_3$ — 1 point

For indicating conservation of energy is applicable — 1 point

$\frac{1}{2}Mv_1^2 = \frac{1}{2}Mv_2^2 + \frac{1}{2}M_2 v_3^2$

For substituting:

$\frac{1}{2}(2.1 \text{ kg})(3.9 \text{ m/s})^2$ $[\text{or } 16 \text{ J}] = \frac{1}{2}(2.1 \text{ kg})v_2^2 + \frac{1}{2}(8 \text{ kg})v_3^2$ — 1 point

The equation $3.9 \text{ m/s} = v_3 - v_2$ or $-(v_2 - v_3)$, which can be obtained from the two equations above, was accepted as a substitute equation, but only if one of those equations was also present.

Distribution of Points

Mech 2.

(a) 4 points

$$K_{\text{total}} = K_{\text{translational}} + K_{\text{rotational}}$$

For a correct expression for translational kinetic energy — 1 point
For a correct expression for rotational kinetic energy — 1 point

$$K_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

For substituting $\omega = \dfrac{v}{r}$ — 1 point

$$K_{\text{total}} = \frac{1}{2}mv^2 + \frac{1}{2}\left(\frac{2}{5}mr^2\right)\left(\frac{v^2}{r^2}\right) = \frac{7}{10}mv^2$$

$$= \frac{7}{10}(25\text{ kg})(10\text{ m/s})^2$$

$K_{\text{total}} = 1{,}750\text{ J}$ — 1 point

In the absence of other credit, one point was awarded for indicating that the total kinetic energy is the sum of translational and rotational kinetic energies.

(b)
i. 4 points

For an indication that conservation of energy is applicable — 1 point

$K_{\text{total}}(\text{leaving incline}) = K_{\text{total}}(\text{bottom of incline}) - U$

For correct use of $U = mgh$ — 1 point

$$\frac{7}{10}mv^2 = K_{\text{total}}(\text{bottom of incline}) - mgh$$

$$= 1{,}750\text{ J} - (25\text{ kg})(10\text{ m/s}^2)(3\text{ m})$$

$$= 1{,}000\text{ J}$$

$$v = \sqrt{\frac{10}{7}(1{,}000\text{ J})/(25\text{ kg})}$$

For correct substitutions — 1 point

$v = 7.56\text{ m/s}$ — 1 point

Full credit could be earned for this part if rotation was omitted both here and in (a). If rotation was included in (a) but omitted here, or if translation was included in (a) but omitted here, a maximum of 2 points could be earned.

The statement $\frac{1}{2}mv^2 = mgh$ or $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$ was awarded 1 point.

The statement $v_f^2 = v_0^2 - 2gh$ was accepted as equivalent to the energy equation without rotation.

Distribution of Points

Mech 2. (cont.)

(b) (cont.)
ii. 1 point

As it leaves the top of the incline the sphere's velocity will be directed parallel to the incline, i.e. at 25° above the horizontal.
For any clear indication that student realized this fact — 1 point

(c) 4 points

For a correct kinematic equation for the vertical motion, indicating use of the component of the velocity — 1 point

$$y_f = y_0 + v_{0y}t + \frac{1}{2}gt^2 \quad \left(\text{or } v_y^2 = v_{0y}^2 - 2g(y - y_0)\right)$$

For recognizing that $y_f - y_0 = -3$ m, or otherwise correctly accounting for the difference in height — 1 point

Substituting the appropriate values:
$y_f = 0$, $y_0 = 3$ m, $v_{0y} = 7.56$ m/s (sin 25°), $g = -10$ m/s,
and solving the quadratic equation:
$t_2 = 1.16$ s, -0.52 s, where the positive solution is the applicable one.
(Separate calculations for appropriate intervals could also be done, and added to obtain $t_2 = 1.16$ s.)

For a correct equation for the horizontal distance, indicating use of the component of the velocity — 1 point

$x = v_{0x}t = v_0 \cos 25°\, t$
$\quad = (7.56 \text{ m/s}) \cos 25° \ (1.157 \text{ s})$
$x = 7.93$ m — 1 point

(d) 2 points

For indicating that the speed of the sphere as it leaves the top of the incline would be less than in (b). — 1 point

For a correct explanation — 1 point
For example:
All of the potential energy gained is at the loss of the translational kinetic energy.

Distribution of Points

Mech 3.

(a) 3 points

Using the general relationship between potential energy and force:
$U = \int F\, dR$

$$U = \int_{\infty}^{r} \frac{GM_e m}{R^2}\, dR$$

For correct limits on the integral	1 point
For an expression in which the force is proportional to $1/R^2$	1 point
For having the remainder of the force expression correct	1 point

1 point was awarded for the expression $F = \dfrac{GM_e m}{R^2}$ in the absence of any other correct work.

(b) 2 points

The total energy of the satellite at point A is the sum of the kinetic and potential energies.

$$E_A = \frac{1}{2} m v_0^{\,2} - \frac{GM_e m}{a}$$

For a correct expression for the kinetic energy (with v_0)	1 point
For a correct expression for the potential energy (with a)	1 point

(c) 2 points

For a correct expression for angular momentum:

$L = I\omega$ OR mvr OR $\mathbf{p} \times \mathbf{r}$	1 point
For correctly substituting $v = v_0$ and $r = a$	1 point

$L = mv_0 a$

(d) 3 points

For any indication of use of conservation of angular momentum:	1 point
For correctly substituting velocities and radii	1 point

$mv_B b = mv_0 a$

For the correct solution:

$v_B = \dfrac{v_0 a}{b}$	1 point

Distribution of Points

Mech 3. (cont.)

(d) (cont.)

(Alternate solution) — (Alternate points)

For any indication of use of conservation of energy — (1 point)

For correctly substituting velocities and radii — (1 point)

$$\frac{1}{2}mv_0^2 - \frac{GM_em}{a} = \frac{1}{2}mv_B^2 - \frac{GM_em}{b}$$

For the correct answer (i.e. solving the equation for v or v^2)

$$v_B = \left[v_0^2 + 2GM_e\left(\frac{1}{b} - \frac{1}{a}\right)\right]^{1/2}$$ (1 point)

(e) 3 points

In a circular orbit, the centripetal force is provided by gravity.

For any expression of Newton's second Law, $F = ma$ — 1 point

For the correct expression for the centripetal acceleration, $a = \dfrac{v^2}{r}$ — 1 point

$$\frac{mv^2}{a} = \frac{GM_em}{a^2}$$

For the correct answer, with $r = a$

$$v = \sqrt{\frac{GM_e}{a}}$$ 1 point

(f) 2 points

The work done is equal to the change in the total energy of the satellite.
Since the potential energy remains constant, the change in total energy is equal to the change in kinetic energy.

For any indication that the work equals the change in kinetic energy — 1 point

$$W = \Delta K = \frac{1}{2}m\left(v^2 - v_0^2\right)$$

For the correct answer with all substitutions made:

$$W = \frac{1}{2}m\left(\frac{GM_e}{a} - v_0^2\right)$$ 1 point

Distribution of Points

E & M 1.

(a) 4 points

For a correct expression for the potential:

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r} \text{ or } \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$ 1 point

Since all of the charge is at the same distance, simply substitute the total charge and the appropriate distance.

For correct expressions for calculating the total charge:

$Q = \lambda\ell$ 1 point

$\ell = 2\pi R$ 1 point

$$V = \frac{1}{4\pi\varepsilon_0}\frac{2\pi R\lambda}{R}$$

For a correct answer:

$$V = \frac{\lambda}{2\varepsilon_0} \text{ OR } 2\pi k\lambda$$ 1 point

(b) 2 points

The electric field from each infinitesimal piece of the ring is canceled by the field from a piece on the opposite side of the ring.

Therefore, $E = 0$. 2 points

(c) 2 points

The total charge on the rod is simply the charge per unit length times the length of the rod.

$Q = \lambda\ell$

For using the correct expression for the length of the rod:

$\ell = 2R\theta$ 1 point

For the correct answer:

$Q = 2\theta\lambda R$ 1 point

(d) 2 points

Once again, since all of the charge is at the same distance, simply substitute the total charge and the appropriate distance in the expression for the potential.

For using the answer to (c) for the total charge 1 point

$$V = \frac{1}{4\pi\varepsilon_0}\frac{2\theta\lambda R}{R}$$

For the correct answer:

$$V = \frac{\theta\lambda}{2\pi\varepsilon_0} \text{ OR } 2k\theta\lambda$$ 1 point

E & M 1. (cont.)

(e) 5 points

For a correct expression for the electric field:

$$E = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{R^2} \text{ or } \frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$$ 1 point

Since all the charge is at the same distance, calculating the electric field requires integration over the angle only. Also, the vertical components of the field cancel, so the integration can be limited to the horizontal components.

$dq = \lambda R\ d\phi$ 1 point

For including the $\cos\phi$ term in the horizontal component 1 point

$$E = \frac{1}{4\pi\varepsilon_0}\int_{-\theta}^{\theta}\frac{\lambda R}{R^2}\cos\phi\, d\phi$$

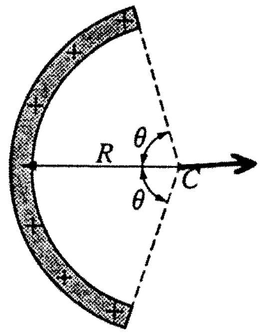
$$= \frac{1}{4\pi\varepsilon_0}\frac{\lambda}{R}\sin\phi\Big|_{-\theta}^{\theta}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{\lambda}{R}\left(\sin\theta - \sin(-\theta)\right)$$

For a correct expression for the electric field:

$$E = \frac{\lambda\sin\theta}{2\pi\varepsilon_0 R} \text{ OR } \frac{2k\lambda\sin\theta}{R}$$ 1 point

For correctly indicating the direction of the field 1 point



Distribution of Points

E & M 2.

(a)
i. 1 point

The shuttle end is negative. 1 point
Due to the motion of the wire, the free electrons in it have a velocity to the right. Using the right-hand rule, the force on the electrons due to the magnetic field is toward the shuttle.

ii. 2 points

Electrons in the wire stop moving when the force due to the electric field created by the difference in charge between the ends of the wire counteracts the magnetic force.

$qE = qvB$

$E = vB$

The emf V (potential difference between the ends of the wire) is the electric field multiplied by the length ℓ of the wire.

$V = vB\ell$ 1 point

$= (7{,}600 \text{ m/s})(3.3 \times 10^{-5} \text{ T})(20 \times 10^3 \text{ m})$

$V = 5{,}016 \text{ V}$ 1 point

(b) 2 points

For using Ohm's Law:

$I = V/R$ 1 point

$= (5{,}016 \text{ V})/(10{,}000\ \Omega)$

$I = 0.5016 \text{ A}$ 1 point

(c)
i. 2 points

For a correct expression for the magnetic force on a current:

$\mathbf{F} = I\, d\boldsymbol{\ell} \times \mathbf{B}$ 1 point

The current is perpendicular to the field, so the magnitude of the force is:

$F = I\ell B$

$= (0.5016 \text{ A})(20 \times 10^3 \text{ m})(3.3 \times 10^{-5} \text{ T})$

$F = 0.331 \text{ N}$ 1 point

(If a student used 20 m for the length of the tether instead of 20×10^3 m in both (a) and (c), only one answer point was lost.)

ii. 1 point

By the right-hand rule, the direction of the magnetic force is opposite the shuttle's velocity. 1 point

Distribution of Points

E & M 2. (cont.)

(d) 4 points

The change in the shuttle's energy is equal to the energy dissipated due to the resistance of the wire.

$\Delta U = Pt$	1 point
$P = I^2 R$	1 point
$\Delta U = I^2 Rt$	
For correct substitution:	
$\Delta U = (0.5016\ \text{A})^2\ (10{,}000\ \Omega)\ (7\ \text{d})\ (24\ \text{h/d})\ (60\ \text{min/h})\ (60\ \text{s/min})$	1 point
$\Delta U = 1.52 \times 10^9\ \text{J}$	1 point

(Alternate solution) (Alternate points)

The change in energy equals the work done on the shuttle.

$\Delta E = \mathbf{F} \cdot \mathbf{d}$	(1 point)
$\mathbf{F} \cdot \mathbf{d} = Fvt$	(1 point)
For correct substitution:	
$\Delta E = (0.33\ \text{N})(7{,}600\ \text{m/s})(7\ \text{d})(24\ \text{hr/d})(60\ \text{min/hr})(60\ \text{s/min})$	(1 point)
$\Delta E = 1.5 \times 10^9\ \text{J}$	(1 point)

(e) 2 points

If current was forced to flow the other way, the direction of the magnetic force on the current would be reversed. This force would do work on the shuttle, and the resulting gain of energy would cause an increase in the radius of the orbit (it would "boost" the orbit).

For correctly indicating that the radius would increase	1 point
For a correct explanation of the cause	1 point

For correct units in three answers and no incorrect units	1 point

Distribution of Points

E & M 3.

(a)

i. 4 points

For a correct expression for Ampere's Law:

$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I_{enc}$ — 1 point

For indicating the correct path of integration, either by drawing a circle on the figure or using $2\pi r$ in Ampere's Law — 1 point

The enclosed current is the current per unit area for the inner conductor multiplied by the area inside the distance r.

$$I_{enc} = \frac{I}{\pi a^2}\pi r^2 = \frac{Ir^2}{a^2}$$ 1 point

$$B(2\pi r) = \mu_0 \frac{Ir^2}{a^2}$$

$$B = \frac{\mu_0 Ir}{2\pi a^2}$$ 1 point

ii. 2 points

For $a < r < b$, the enclosed current is the total current in the inner conductor: $I_{enc} = I$ — 1 point

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

$$B = \frac{\mu_0 I}{2\pi R}$$ 1 point

(b) 1 point

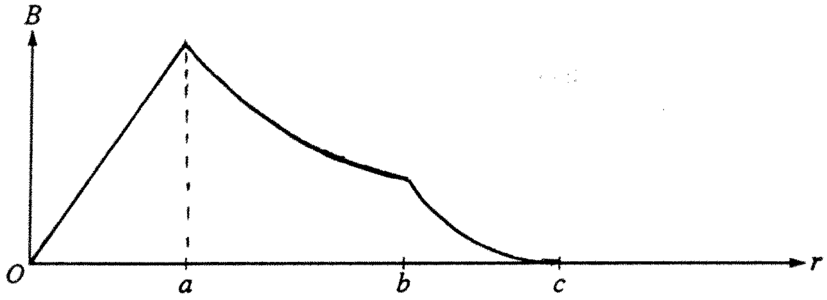
For $r > c$, the net current enclosed is zero.

Therefore, the field is also zero. — 1 point

Distribution of Points

E & M 3. (cont.)

(c) 4 points



For a linear increase for $0 < r < a$ (or answer consistent with (a)i) — 1 point
For a $1/r$ decrease for $a < r < b$ (or answer consistent with (a)ii) — 1 point
For any decreasing function for $b < r < c$ — 1 point
For a zero function for $r > c$ (or answer consistent with (b)) — 1 point

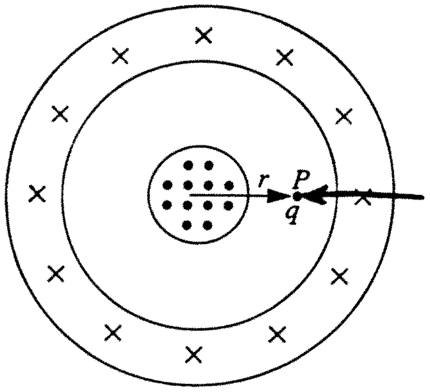
A maximum of three points could be earned if the graph was discontinuous

(d)
i. 2 points

For a correct expression for the magnetic force on a moving point charge:
$\mathbf{F} = q\mathbf{v} \times \mathbf{B}$ or $F = qvB$ — 1 point
Substituting the expression for B from (a)i:

$$F = \frac{qv\mu_0 I}{2\pi R}$$ — 1 point

ii. 1 point



Cross Section

For correctly indicating the direction of the force — 1 point

Distribution of Points

E & M 3. (cont.)

(e) 1 point

The answers to (d) would not change. — 1 point

Only the current inside the radius r has any effect on the magnetic field and hence the charge.