



## AP<sup>®</sup> Physics C 1993 Scoring Guidelines

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Mech 1.

(a) 3 points

Using the expression for the energy stored in a spring:

$$U = \frac{1}{2} kx^2 \quad 1 \text{ point}$$

Substituting:

$$U = \frac{1}{2} \left( 400 \frac{\text{N}}{\text{m}} \right) (0.5 \text{ m})^2 \quad 1 \text{ point}$$

$$U = 50 \text{ J} \quad 1 \text{ point}$$

(b) 5 points

For recognition of conservation of energy or work-energy theorem 1 point

$$\text{Kinetic energy of block C: } K = \frac{1}{2} m_C v_C^2 \quad 1 \text{ point}$$

$$\text{Work done (or energy dissipated by) friction: } W_f = \mu F_N d \quad 1 \text{ point}$$

$$K = U - W_f$$

$$\frac{1}{2} m_C v_C^2 = U - \mu m_C g d \quad 1 \text{ point}$$

Solving for  $v_C$ :

$$v_C = \sqrt{\frac{2}{m_C} (U - \mu m_C g d)}$$

Substituting:

$$v_C = \sqrt{\frac{2}{4 \text{ kg}} (50 \text{ J} - (0.4)(4 \text{ kg})(10 \text{ m/s}^2)(0.5 \text{ m}))}$$

$$v_C = 4.58 \text{ m/s} \quad 1 \text{ point}$$

(Full credit also awarded for correct alternate solution computing  $\int F_{\text{net}} dx$ , where  $F_{\text{net}} = kx - \mu F_N$ , to find the kinetic energy, and then computing the speed.)

Mech 1. (continued)

(c) 3 points

For any statement of conservation of momentum

1 point

$$m_C v_C = (m_C + m_D) v_f$$

1 point

Solving for  $v_f$ :

$$v_f = m_C v_C / (m_C + m_D)$$

Substituting:

$$v_f = (4 \text{ kg})(4.58 \text{ m/s}) / (4 \text{ kg} + 2 \text{ kg})$$

1 point

$$v_f = 3.05 \text{ m/s}$$

(d) 3 points

The blocks come to rest when all their kinetic energy  
has been dissipated, i.e.  $\Delta KE = \text{Work done by}$   
frictional force

1 point

$$\frac{1}{2}(m_C + m_D) v_f^2 = \mu(m_C + m_D) g d$$

1 point

Solving for  $d$ :

$$d = v_f^2 / 2\mu g$$

Substituting:

$$d = (3.05 \text{ m/s})^2 / (2)(0.4)(10 \text{ m/s}^2)$$

$$d = 1.16 \text{ m}$$

1 point

(Alternate Solution)

(Alternate Points)

$$\sum F = ma$$

(1 point)

$$a = \frac{\sum F}{m} = \frac{\mu(m_C + m_D)g}{(m_C + m_D)} = \mu g = (0.4)(10 \text{ m/s}^2) = 4 \text{ m/s}^2$$

$$v^2 = v_0^2 + 2ad \text{ (or other appropriate kinematic equations)}$$

(1 point)

$$d = \frac{v^2 - v_0^2}{2a} = \frac{0 - (3.05 \text{ m/s})^2}{2(-4 \text{ m/s}^2)} = 1.16 \text{ m}$$

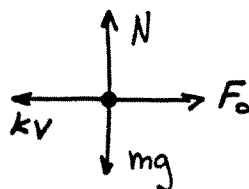
(1 point)

UNITS: For correct units on all answers

1 point

Mech 2.

(a) 3 points



1 point for  $F_0$  correctly drawn and labeled  
 1 point for  $kv$  correctly drawn and labeled  
 1 point for  $N$  and  $mg$  correctly drawn and labeled

1 point  
 1 point  
 1 point

(b) 3 points

$$F_{\text{net}} = ma$$

1 point

But  $F_{\text{net}} = F_0 - kv$ , therefore:

1 point

$$F_0 - kv = ma$$

Solving for  $a$ :

$$a = (F_0 - kv)/m$$

1 point

(c) 5 points

$$a = \frac{dv}{dt}$$

1 point

Using the equation from part b:

$$(1) \quad \frac{dv}{dt} = \frac{(F_0 - kv)}{m}$$

Re-arranging and integrating:

$$(2) \quad \int \frac{dv}{F_0 - kv} = \int \frac{1}{m} dt$$

1 point

Changing variables by letting  $u = F_0 - kv$ ,  $du = -k dv$ :

$$-\frac{1}{k} \int \frac{du}{u} = \int \frac{1}{m} dt$$

1 point

$$\ln(F_0 - kv) - \ln C = -\frac{k}{m} t, \text{ where } C \text{ is a constant}$$

$$v = \frac{1}{k} \left( F_0 - Ce^{-kt/m} \right)$$

Mech 2. (continued)

(c) (continued)

To evaluate  $C$ , use initial conditions  $t = 0$ ,  $v = 0$ 

1 point

$$C = F_0$$

$$\text{so } v = \frac{F_0}{k} \left( 1 - e^{-kt/m} \right)$$

1 point

Equation (2) can also be integrated using limits 0 and  $v$  for the left-hand side and 0 and  $t$  for the right-hand side to obtain the same answer for full credit.

(Alternate Method to solve equation (1))

(Alternate points)

Recognizing that the solution will be in exponential form, try:

$$v = Ae^{Bt} + C, \text{ where } A, B, \text{ and } C \text{ are constants}$$

(1 point)

Substituting into equation (1)

$$ABe^{Bt} = \frac{F_0}{m} - \frac{k}{m} (Ae^{Bt} + C)$$

$$ABe^{Bt} = \left( \frac{F_0}{m} - \frac{kC}{m} \right) - \frac{kA}{m} e^{Bt}$$

(1 point)

Equating coefficients to evaluate  $B$  and  $C$ ,

$$B = -\frac{k}{m}, \quad C = \frac{F_0}{k}$$

$$\text{Therefore, } v = Ae^{-kt/m} + \frac{F_0}{k}$$

To evaluate  $A$ , use initial conditions  $t = 0$ ,  $v = 0$ 

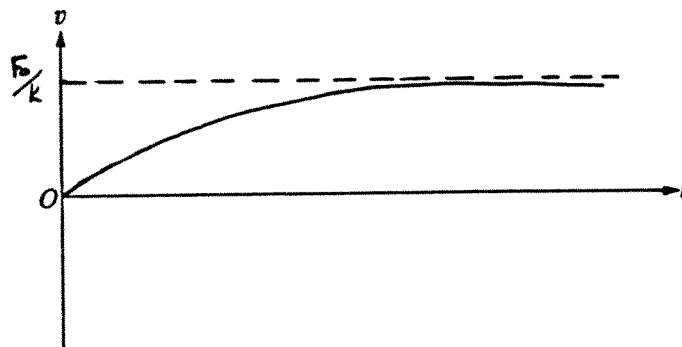
(1 point)

$$A = -\frac{F_0}{k}$$

$$\text{so } v = \frac{F_0}{k} \left( 1 - e^{-kt/m} \right)$$

(1 point)

(d) 2 points

For correct maximum value  $F_0/k$ 

1 point

For correct shape of curve

1 point

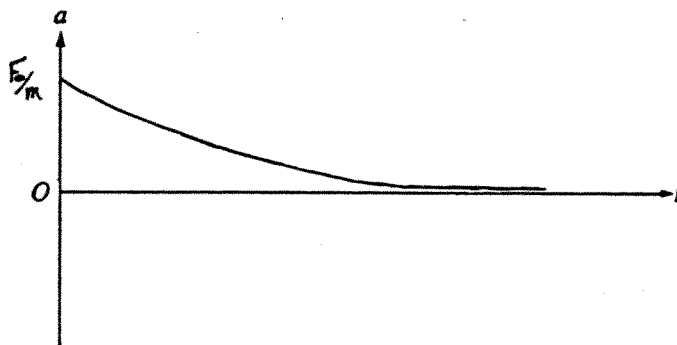
Mech 2. (continued)

(e) 2 points

Differentiating the expression for velocity from part (c)  
to get the expression for acceleration:

$$a = \frac{dv}{dt} = \frac{F_0}{k} \left[ 0 - (-k/m) e^{-kt/m} \right]$$

$$a = \frac{F_0}{m} e^{-kt/m}$$

For correct initial value  $F_0/m$ 

1 point

For correct shape of curve

1 point

(Alternate Solution)

From part (b):

$$a = \frac{1}{m} (F_0 - kv)$$

Substituting for  $v$  from part (c):

$$a = \frac{F_0}{m} - \frac{k}{m} \frac{F_0}{k} (1 - e^{-kt/m})$$

$$a = \frac{F_0}{m} e^{-kt/m}$$

Mech 3.

(a) 4 points

$$\tau = rF$$

1 point

$$\sum \tau = 0 \quad (\text{or } \tau_{\text{cw}} = \tau_{\text{ccw}})$$

1 point

Summing torques about the right end of the rod:

$$F_a \ell - Mg \left( \frac{\ell}{2} \right) = 0, \text{ where } F_a \text{ is force exerted by axis}$$

1 point

$$F_a = \frac{Mg}{2}$$

 $F_a$  is directed upward

1 point

(Alternate Solution for last two points)

(Alternate Points)

Sum torques about any other axis and also use  $\sum F = 0$ .

For example, summing torques about left end of rod:

$$Mg \left( \frac{\ell}{2} \right) - F_t \ell = 0, \text{ where } F_t \text{ is force exerted by thread}$$

$$F_t = \frac{Mg}{2}$$

(1 point)

$$\sum F = 0, \text{ so } F_t + F_a - Mg = 0$$

$$F_a = Mg - F_t = Mg - \frac{Mg}{2}$$

$$F_a = \frac{Mg}{2}$$

 $F_a$  is directed upward

(1 point)

(b) 2 points

Using  $\sum \tau = I\alpha$  and calculating the torque about the axis end of the rod:

1 point

$$Mg \frac{\ell}{2} = M \frac{\ell^2}{3} \alpha$$

Solving for  $\alpha$ :

$$\alpha = \frac{3}{2} \frac{g}{\ell}$$

1 point

## 1993 Physics C Solutions

Distribution  
of Points

Mech 3. (continued)

(c) 2 points

Using the relation between translational and angular acceleration:

$$a = \alpha r$$

1 point

Substituting  $r = \frac{\ell}{2}$  and  $\alpha$  from previous part:

$$a = \frac{3}{2} \frac{g}{\ell} \frac{\ell}{2}$$

$$a = \frac{3}{4} g$$

1 point

(d) 3 points

Using Newton's Second Law:

$$\sum F = Ma$$

1 point

$$\text{but } \sum F = Mg - F_r$$

1 point

$$\text{so } Mg - F_r = Ma$$

Substituting  $a = \frac{3}{4}g$  and solving for  $F_r$ :

$$F_r = \frac{1}{4} Mg$$

1 point

(e) 4 points

Using conservation of energy the increase in kinetic energy of rotation  $K_{\text{rot}}$  is equal to the decrease in potential energy  $\Delta U$ 

1 point

$$\Delta K_{\text{rot}} = \Delta U$$

$$\Delta K_{\text{rot}} = \frac{1}{2} I \omega^2$$

1 point

$$\Delta U = mgh \\ = Mg \frac{\ell}{2} \sin \theta$$

1 point

$$\frac{1}{2} I \omega^2 = Mg \frac{\ell}{2} \sin \theta$$

Solving for  $\omega$ :

$$\omega = \sqrt{\frac{Mg\ell}{I} \sin \theta}$$

Substituting  $I = M\ell^2/3$ 

$$\omega = \sqrt{\frac{3g}{\ell} \sin \theta}$$

1 point



## 1993 Physics C Solutions

Distribution  
of Points

Mech 3. (continued)

(e) (continued)

(Alternate Solution)

(Alternate points)

Work done by gravitational force  $W_g$  equals the increase in kinetic energy of rotation  $K_{\text{rot}}$

(1 point)

$$W_g = \int Mg \frac{\ell}{2} \cos \theta \, d\theta$$

(1 point)

$$= \frac{Mg\ell}{2} \sin \theta$$

$$\Delta K_{\text{rot}} = \frac{1}{2} I \omega^2$$

(1 point)

$$\frac{1}{2} I \omega^2 = Mg \frac{\ell}{2} \sin \theta$$

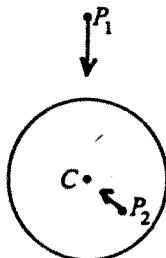
Substituting  $I = M\ell^2/3$  and solving for  $\omega$ :

$$\omega = \sqrt{\frac{3g}{\ell} \sin \theta}$$

(1 point)

E &amp; M 1.

(a) 2 points



1 point for each correct vector

2 points

(If both vectors are reversed from correct directions, then partial credit of 1 point awarded)

(b) i. 4 points

Gauss's Law:

$$\oint \mathbf{E} \cdot d\mathbf{A} = Q_{\text{encl}}/\epsilon_0 \quad (\text{or } 4\pi k Q_{\text{encl}})$$

1 point

For  $r > R$ , using a Gaussian surface that is a cylinder of radius  $r$  and length  $\ell$ :

$$\oint \mathbf{E} \cdot d\mathbf{A} = E(2\pi r\ell)$$

1 point

$$Q_{\text{encl}} = \rho(\pi R^2 \ell)$$

1 point

$$E(2\pi r\ell) = \rho(\pi R^2 \ell)/\epsilon_0$$

$$E = \frac{\rho R^2}{2\epsilon_0 r} \quad \left( \text{or } \frac{2\pi k \rho R^2}{r} \right)$$

1 point

(b) ii. 2 points

For  $r < R$ , using a similar Gaussian surface as above:

$$E(2\pi r\ell) = \rho(\pi r^2 \ell)/\epsilon_0$$

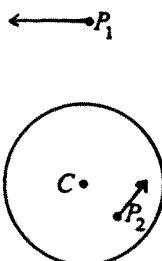
1 point

$$E = \frac{\rho r}{2\epsilon_0} \quad (\text{or } 2\pi k \rho r)$$

1 point

E &amp; M 1. (continued)

(c) 3 points



1 point for first correct vector

1 point

2 points for second correct vector

2 points

(If vectors are reversed from correct directions or if circular lines of force with counterclockwise arrows shown, then partial credit of 1 point awarded.)

(d) 4 points

Ampere's Law:

$$\oint \mathbf{B} \cdot d\mathbf{l} = \mu_0 I_{\text{encl}}, \text{ where } I_{\text{encl}} \text{ is the current enclosed by the closed loop of integration (i.e. the current density times the area)}$$

1 point

For  $r < R$ , integrating over a loop of radius  $r$ :

$$\oint \mathbf{B} \cdot d\mathbf{l} = B(2\pi r)$$

1 point

$$I_{\text{encl}} = \left( \frac{I}{\pi R^2} \right) \pi r^2 = I \frac{r^2}{R^2}$$

1 point

$$B(2\pi r) = \mu_0 I \frac{r^2}{R^2}$$

$$B = \frac{\mu_0 I}{2\pi} \frac{r}{R^2} \quad \left( \text{or } \frac{\mu_0 J r}{2} \right)$$

1 point

E &amp; M 2.

(a) i. 2 points

Using the expression for the flux of a uniform field:

$$\Phi = \mathbf{B} \cdot \mathbf{A}$$

1 point

Substituting:

$$\Phi = abB_0$$

1 point

(a) ii. 1 point

Using the expression relating the emf and flux:

$$\xi = - \frac{d\Phi}{dt}$$

Both the field and area are constant, so  $\xi = \text{zero}$ 

1 point

(a) iii. 1 point

Since there is no emf there is no current in the loop,  
and thus no magnetic force exerted on the loop.

1 point

(b) 2 points



2 points

When  $\omega t = \pi/2$ ,  $B = B_0 \cos \pi/2 = \text{zero}$ , i.e. the field has been decreasing, and is about to change direction. The induced current will be in a direction to oppose this change, i.e. clockwise.

(c) i. 4 points

Calculating the flux:

$$\Phi = abB_0 \cos \omega t$$

1 point

Calculating the emf:

$$\xi = - \frac{d\Phi}{dt} \quad (\text{negative sign not required})$$

1 point

$$= ab\omega B_0 \sin \omega t$$

Using Ohm's Law:

$$I = \xi/R$$

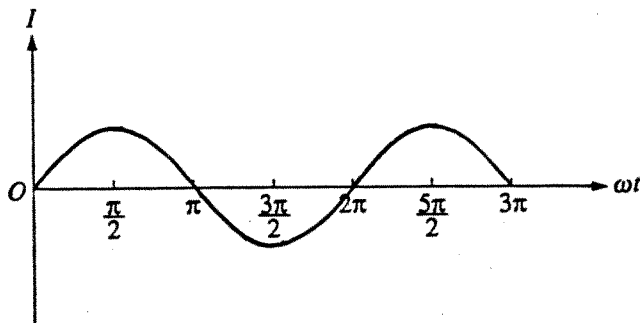
1 point

$$I = \frac{ab\omega B_0}{R} \sin \omega t$$

1 point

E &amp; M 2. (continued)

(c) ii. 3 points

For a graph showing a period of  $2\pi$ 

1 point

For a graph consistent with answer to (c)i.

1 point

For correct orientation of current at  $\pi/2$  consistent with answer to (b) (i.e., graph positive at  $\pi/2$  if clockwise current in (b); graph negative at  $\pi/2$  if counterclockwise current in (b)).

1 point

(c) iii. 2 points

The maximum value of the current occurs when  $\sin \omega t = 1$ .

$$I_{\max} = \frac{ab\omega B_0}{R}$$

For indicating the coefficient of the sin (or cos) term in (c)i.

1 point

For the correct answer (i.e. the coefficient in (c)i. must be correct)

1 point

## 1993 Physics C Solutions

Distribution  
of Points

E &amp; M 3.

(a) 2 points

The force due to the magnetic field provides the centripetal force that causes the ion to move in the semicircle.

$F = q\mathbf{v} \times \mathbf{B}$ , so by the right-hand rule the magnetic field must point into the page (or in the  $-z$  direction).

For field being perpendicular to the page 1 point

For direction into the page or in the  $-z$  direction 1 point

(b) 1 point

Between the plates, the electric field must exert a force opposite to that of the magnetic field.

The magnetic force is to the right, and  $F_{\text{elec}} = qE$ , so the electric field should point toward the left.

Therefore, plate K should have a positive polarity with respect to plate L. 1 point

(c) 2 points

Using the relation between the electric field and potential difference for parallel plates:

$E = V/d$  1 point

Substituting:

$$E = (1500 \text{ V})/(0.012 \text{ m})$$

$E = 1.25 \times 10^5 \text{ V/m}$  1 point

(d) 4 points

For a particle to pass between the plates undeflected, the forces due to the electric and magnetic fields  $F_E$  and  $F_B$  respectively must be equal in magnitude and in opposite directions.

$F_E = qE$  1 point

$F_B = qvB$  1 point

Therefore,  $qE = qvB$

Solving for  $v$ :

$$v = E/B = (1.25 \times 10^5 \text{ V/m})/(0.20 \text{ T})$$

$v = 6.25 \times 10^5 \text{ m/s}$  1 point

E &amp; M 3. (continued)

(e) 3 points

The centripetal force  $F_c$  is equal to the force  $qvB$  due to the magnetic field.

1 point

$$F_c = \frac{mv^2}{R}$$

1 point

$$\frac{mv^2}{R} = qvB$$

Solving for  $m$ :

$$m = qBR/v$$

Substituting:

$$m = (1.6 \times 10^{-19} \text{ C})(0.20 \text{ T})(0.50 \text{ m})/(6.25 \times 10^5 \text{ m/s})$$

$$m = 2.56 \times 10^{-26} \text{ kg}$$

1 point

(f) 2 points

Substituting  $2q$  into the force equation from part (e) and solving for the new radius  $R'$ :

1 point

$$R' = \frac{mv}{2qB}$$

Substituting the expression for  $m$  from part (e):

$$R' = \frac{v}{2qB} \frac{qBR}{v} = R/2$$

$$R' = 0.25 \text{ m}$$

1 point

UNITS: Additional 1 point awarded if all units are correct

1 point