AP® Physics C
1998 Scoring Guidelines

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1998 Physics C Solutions

Distribution of points

Mech. 1 (15 points)

(a)

i. 1 point

For correct answer — 1 point

$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{0.30\,\text{m} - 0.10\,\text{m}}{0.30\,\text{s} - 0.10\,\text{s}} = 1.00\,\text{m/s}$$

ii. 1 point

For correct answer — 1 point

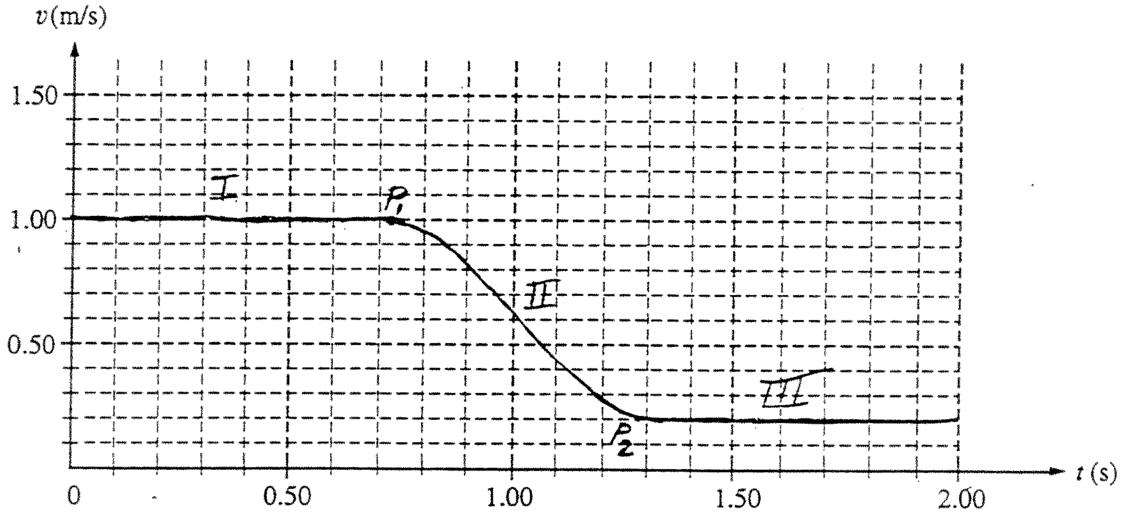
$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{0.99\,\text{m} - 0.87\,\text{m}}{1.10\,\text{s} - 0.90\,\text{s}} = 0.60\,\text{m/s}$$

iii. 1 point

For correct answer — 1 point

$$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{1.18\,\text{m} - 1.14\,\text{m}}{1.90\,\text{s} - 1.70\,\text{s}} = 0.20\,\text{m/s}$$

(b) 3 points



For line I horizontal at $v = 1.00$ m/s or at answer obtained for (a)i. — 1 point

For line II with monotonic, negative slope between points P_1 and P_2, P_1 at (0.70 - 0.80, 1.00) or (0.70 - 0.80, answer to (a)i.), and P_2 at (1.20 - 1.30, 0.20) or (1.20 - 1.30, answer to (a)iii.) — 1 point

(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at $v = 0.20$ m/s or at answer obtained for (a)iii. — 1 point

Mech. 1 (continued)

(c)

i. 3 points

For any statement of conservation of momentum or energy — 1 point

For proper conservation of momentum or energy equation — 1 point

Method 1: Conservation of momentum

$$m_A v_{Ai} = m_A v_{Af} + m_B v_B$$

$$(0.90\text{ kg})(1.00\text{ m/s}) = (0.90\text{ kg})(0.20\text{ m/s}) + (0.60\text{ kg})v_B$$

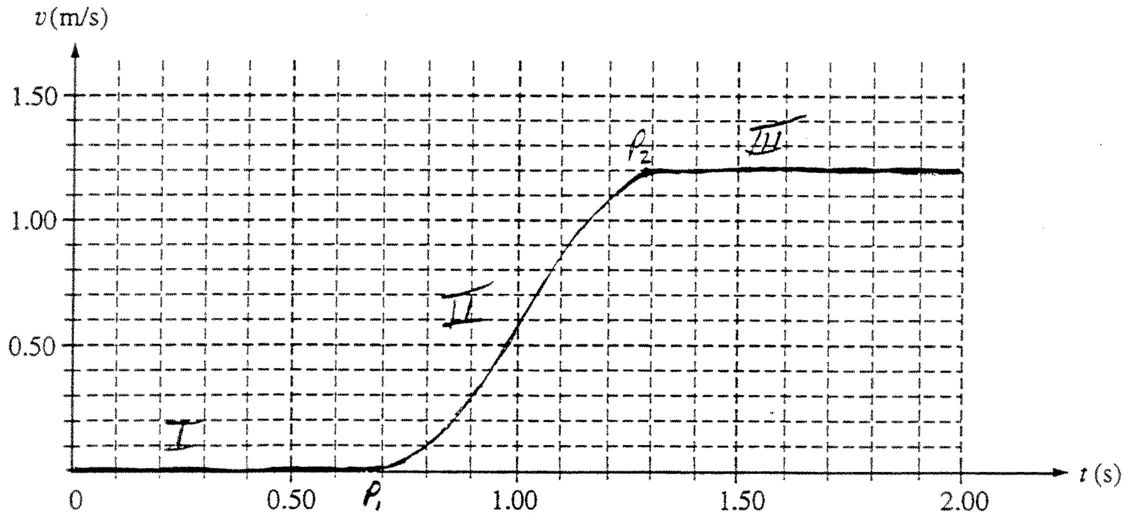
Method 2: Recognize from part (d) that energy is also conserved.

$$\frac{1}{2}m_A v_{Ai}^2 = \frac{1}{2}m_A v_{Af}^2 + \frac{1}{2}m_B v_B^2$$

$$\frac{1}{2}(0.90\text{ kg})(1.00\text{ m/s})^2 = \frac{1}{2}(0.90\text{ kg})(0.20\text{ m/s})^2 + \frac{1}{2}(0.60\text{ kg})v_B^2$$

For correct answer — 1 point

$v_B = 1.2$ m/s



For line I horizontal at $v = 0$ — 1 point

For line II with monotonic, positive slope between points P_1 and P_2,

P_1 at (0.70 - 0.80, 0), and

P_2 at (1.20 - 1.30, 1.20) or (1.20 - 1.30, answer to (c)i.) — 1 point

(This line may be straight, which is consistent with the data, or slightly curved as shown, which is consistent with the behavior of springs)

For line III horizontal at $v = 1.20$ m/s or at answer obtained for (c)i. — 1 point

(d)

i. 2 points

For correct answer Yes, the collision is elastic.	1 point
For any reasonable justification Examples: The final kinetic energy equals the initial kinetic energy. The spring force is conservative meaning the total energy stored equals the total energy released. The compressed spring stores and releases energy in equal amounts.	1 point

(The justification point was not awarded if student answered "no" to the question.)

ii. 1 point

For any reasonable explanation Examples: The compressed spring stores maximum amount of kinetic energy. At time t = 1 s, there is maximum kinetic energy stored as potential energy. At time t = 1 s, the spring has maximum potential or elastic energy.	1 point

1998 Physics C Solutions

Distribution of points

Mech. 2 (15 points)

(a)

i. 3 points

For a statement that momentum is conserved <u>or</u> $p_i = p_f$ — 1 point

$m\upsilon_0 = (3m)\upsilon_f$

For the correct final speed — 1 point

$\upsilon_f = \dfrac{\upsilon_0}{3}$

For correct substitutions and answer — 1 point

$K_{after} = \dfrac{1}{2}M\upsilon^2 = \dfrac{1}{2}(3m)\left(\dfrac{\upsilon_0}{3}\right)^2 = \dfrac{m\upsilon_0^2}{6}$

(1 point awarded for $K_{after} = \dfrac{1}{2}(3m)\upsilon_f^2$ if student found wrong υ_f or could not find υ_f.)

ii. 2 points

$\Delta K = K_{after} - K_{before} = \dfrac{m\upsilon_0^2}{6} - \dfrac{m\upsilon_0^2}{2}$

For correct sign of answer — 1 point

For correct magnitude of answer — 1 point

$\Delta K = -\dfrac{m\upsilon_0{}^2}{3}$

(2 points awarded for any wrong answer from (a)i. minus $\dfrac{1}{2}m\upsilon_0^2$.)

(1 point awarded for $\dfrac{1}{2}m\upsilon_0^2$ minus any wrong answer from (a)i.)

(b)

i. 2 points

For correct substitutions into the center of mass equation — 1 point

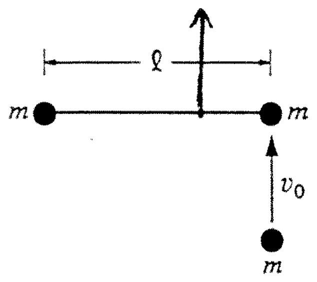
$r_{cm} = \dfrac{\Sigma m_i r_i}{\Sigma m_i} = \dfrac{m(0) + 2m(\ell)}{m + 2m}$

For correct answer — 1 point

$r_{cm} = \dfrac{2}{3}\ell$

Mech. 2 (continued)

ii. 1 point



For vertical arrow anywhere on diagram or in answer space — 1 point

iii. 1 point

Linear momentum is conserved.

$\mathbf{p}_i = \mathbf{p}_f$

$m\upsilon_0 + 3m(0) = (3m)\upsilon_f$

For correct answer — 1 point

$\upsilon_f = \dfrac{\upsilon_0}{3}$

iv. 3 points

Angular momentum is conserved.

$L_{\text{before}} = L_{\text{after}}$

For determining the angular momenta about the center of mass — 1 point

$L_{before} = m\upsilon_0 R\sin\theta = m\upsilon_0\left(\dfrac{1}{3}\ell\right)$

$L_{after} = \omega I$

For determining the moment of inertia — 1 point

$I = \Sigma mr^2 = m\left(\dfrac{2}{3}\ell\right)^2 + 2m\left(\dfrac{1}{3}\ell\right)^2 = \dfrac{2}{3}m\ell^2$

Substituting into $L_{\text{before}} = L_{\text{after}}$,

$m\upsilon_0\left(\dfrac{1}{3}\ell\right) = \dfrac{2}{3}m\ell^2\omega$

For correct answer — 1 point

$\omega = \dfrac{\upsilon_0}{2\ell}$

Distribution of points

Mech. 2 (continued)

v. 3 points

$$K_i = \frac{1}{2}m\upsilon_0^2$$

For recognizing that final kinetic energy is translational plus rotational — 1 point

$$K_f = \frac{1}{2}m\upsilon_f^2 + \frac{1}{2}I\omega^2$$

For correct substiutions and final kinetic energy — 1 point

$$K_f = \frac{1}{2}(3m)\left(\frac{\upsilon_0}{3}\right)^2 + \frac{1}{2}\left(\frac{2}{3}m\ell\quad\right)\left(\frac{\upsilon_0}{2\ell}\right)^2 = \frac{1}{4}m\upsilon_0^2$$

$$\Delta K = K_f - K_i = \frac{1}{4}m\upsilon_0^2 - \frac{1}{2}m\upsilon_0^2$$

For correct answer — 1 point

$$\Delta K = -\frac{1}{4}m\upsilon_0{}^2$$

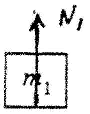
(Correct answer point awarded for either positive or negative sign.)

1998 Physics C Solutions | **Distribution of points**

Mech. 3 (15 points)

(a) 5 points

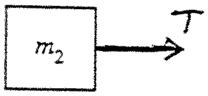
For each correct vector -- ½ point
For each correct magnitude -- ½ point
If the score for part (a) contained an odd number of half-points, the total score was truncated by dropping one half-point.

i. 

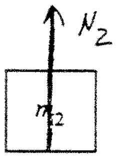
$N_1 = m_1 g$ — 1 point

ii. 

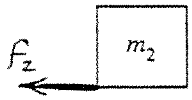
$f_1 = 0$ — 1 point

iii. 

$T = Mg$ — 1 point

iv. 

$N_2 = (m_1 + m_2)g$ — 1 point

v. 

$f_2 = Mg$ — 1 point

(b) 3 points

For expression for the maximum frictional force — 1 point
$f_{2(\max)} = \mu_{s2} N_2 = \mu_{s2}(m_1 + m_2)g$

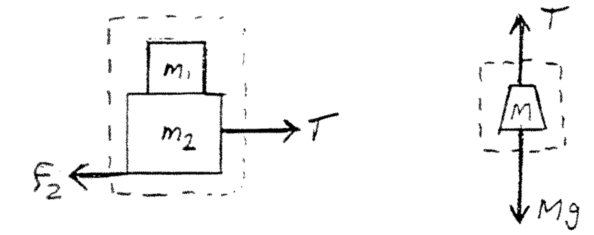
For equating this force to the tension $T = Mg$ — 1 point
$Mg = \mu_{s2}(m_1 + m_2)g$

For the correct answer — 1 point
$M = \mu_{s2}(m_1 + m_2)$

Distribution of points

Mech. 3 (continued)

(c) 3 points



For correctly applying Newton's second law to the hanging block — 1 point

$\Sigma F = ma$

$Mg - T = Ma$ (equation 1)

For correctly applying Newton's second law to the system of the two blocks on the plane — 1 point

$\Sigma F = (m_1 + m_2)a$

$T - f_2 = (m_1 + m_2)a$ (equation 2)

For combining equations 1 and 2 to eliminate T, substituting for f_2 and solving for a — 1 point

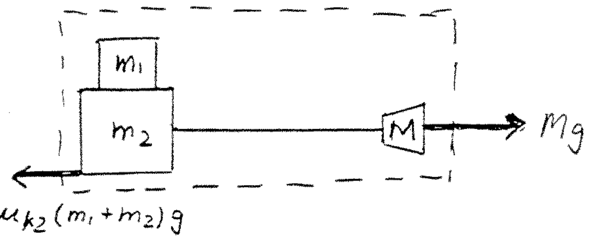
For example, solve each equation for T and set them equal.

$f_2 + (m_1 + m_2)a = Mg - Ma$

$\mu_{k2}(m_1 + m_2)g + (m_1 + m_2)a = Mg - Ma$

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

(Alternate solution) — *(Alternate points)*



Apply Newton's second law to the three-block system, realizing that the pulley acts only to change the direction of the force produced by the tension in the string.

$\Sigma F = m_s a$

For correct substitutions in left side of equation above — *1 point*

For correct substitutions in right side of equation above — *1 point*

$Mg - \mu_{k2}(m_1 + m_2)g = (M + m_1 + m_2)a$

For correct solution for a — *1 point*

$$a = \left[\frac{M - \mu_{k2}(m_1 + m_2)}{M + m_1 + m_2}\right]g$$

Mech. 3 (continued)

(d)

i. 2 points

$$a_1 = \frac{f_1}{m_1}$$

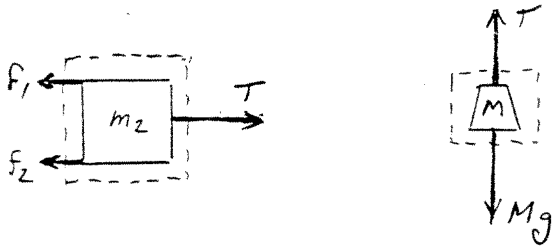
For correct value of f_1 — 1 point

$$f_1 = \mu_{k1} m_1 g$$

For correct answer — 1 point

$$a_1 = \frac{\mu_{k1} m_1 g}{m_1} = \mu_{k1} g$$

ii. 2 points



Apply Newton's second law to the hanging block.

$\Sigma F = ma$

$Mg - T = Ma_2$ (equation 1)

For correctly applying Newton's second law to block 2 — 1 point

$\Sigma F = ma$

$T - f_1 - f_2 = m_2 a_2$ (equation 2)

For combining equations 1 and 2 to eliminate T, substituting for the frictional forces and solving for a_2. — 1 point

For example, solve each equation for T and set them equal.

$$f_1 + f_2 + m_2 a_2 = Mg - Ma_2$$

$$Ma_2 + m_2 a_2 = Mg - \mu_{k1} m_1 g - \mu_{k2}(m_1 + m_2) g$$

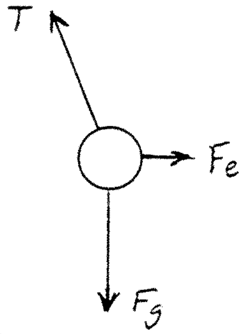
$$a_2 = \left[\frac{M - \mu_{k1} m_1 - \mu_{k2}(m_1 + m_2)}{M + m_2}\right] g$$

1998 Physics C Solutions

E & M 1 (15 points)

Distribution of points

(a) 4 points



For magnitudes of electric and gravitational forces, F_g and F_e — 1 point

For equating F_g and F_e to components of T — 1 point

$T\cos\theta = F_g = mg$

$$T\sin\theta = F_e = \frac{kQ_AQ_B}{r^2}$$

Eliminate T between these two equations and solve for Q_B.
For example from 1st equation,

$$T = \frac{(0.025\text{ kg})(9.8\text{ m/s}^2)}{\cos 20°} = 0.26\text{ N}$$

Substituting into the 2nd equation,

$$(0.26\text{ N})\sin 20° = \frac{(9\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2)(120\times10^{-6}\text{ C})Q_B}{(1.5\text{m})^2}$$

For proper substitutions — 1 point

For the correct answer — 1 point

$Q = 1.86\times10^{-7}$ C (or 1.9×10^{-7} C)

(b) 2 points

For correct answer — 1 point

The new equilibrium angle will be less than 20° (or it decreases).

For reasonable justification that indicates charges moved on conductor so positive charge is farther apart <u>or</u> that indicates that F_e is smaller. — 1 point

Example:

The conductor allows charges to move. Positive charge will be on the far side of B from A and with a greater distance the electric force will be smaller.

Distribution of points

E & M 1 (continued)

(c) 3 points

Using Gauss's law

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{q}{\varepsilon_0}$$

For evaluation of integral in equation above — 1 point

For correct expression for charge enclosed — 1 point

$$E(2\pi r\ell) = \frac{\lambda\ell}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi r\varepsilon_0} = \frac{0.10 \times 10^{-6}\ \text{C/m}}{2\pi r\left(8.85 \times 10^{-12}\ \text{C}^2/\text{N}\cdot\text{m}^2\right)}$$

For either of the two expressions above for E — 1 point

$$E = \frac{1.8 \times 10^3}{r}\ \text{N/C}$$

(d) 2 points

$F = qE$

For proper substitutions in equation above — 1 point

$$F = \left(120 \times 10^{-6}\ \text{C}\right)\left(\frac{1.8 \times 10^3}{1.5}\right)\text{N/C}$$

For correct answer — 1 point

$F = 0.14$ N

(e) 4 points

For expression for work, such as $W = q\Delta V$ or $\int qE\,dr$ — 1 point

For integral with proper limits — 1 point

For the proper evaluation of integral and substitution — 1 point

For example,

$$W = \int_a^b \mathbf{F} \cdot d\mathbf{s} = -\int_a^b qE\,dr = -q\int_{1.5}^{3} \frac{1.8 \times 10^3}{r}dr$$

$$W = -(120 \times 10^{-6})\left(1.8 \times 10^3\right)\int_{1.5}^{0.3} \frac{1}{r}dr = -.216[\ln r]_{1.5}^{0.3} = -.216(\ln 0.3 - \ln 1.5)$$

For the correct answer — 1 point

$W = 0.35$ J

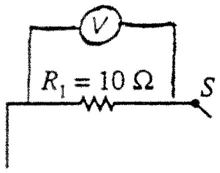
Alternately, one could find ΔV using a similar integral and then use $W = q\Delta V$, with assignment of points similar to the above to maximum of 4 points.

1998 Physics C Solutions

Distribution of points

E & M 2 (15 points)

(a) 2 points



For correct placement of voltmeter — 2 points

(b) 3 points

For correct application of Ohm's law — 1 point

$$I = \frac{\mathcal{E}}{R_1 + R_2} = \frac{20\text{ V}}{30\ \Omega}$$

For correct value of current — 1 point

$$I = \frac{2}{3}\text{ A}$$

For correct value of voltage across R_1 — 1 point

$$V_1 = IR = \frac{2}{3}\text{A} \times 10\ \Omega = 6.67\text{ V}$$

(Alternate solution using voltage divider) — *(Alternate points)*

For voltage divider equation — *1 point*

$$V = \frac{R_1}{R_1 + R_2}\mathcal{E}$$

For correct substitution — *1 point*

$$V = \frac{10\ \Omega}{10\ \Omega + 20\ \Omega} \times 20\text{ V}$$

For correct answer — *1 point*

$V = 6.67$ V

(c)

i. 2 points

For correct answer — 2 points

$V = 0$

(1 point awarded for stating that no current flows)

ii. 1 point

$Q = CV$

For correct substitutions and answer — 1 point

$Q = 15\,\mu\text{F} \times 20\text{V} = 300\,\mu\text{C}$

E & M 2 (continued)

(d) 2 points

For correct answer — 2 points

$V = 0$

(1 point awarded for no current or realization of new initial conditions)

(e)

i. 2 points

For correct application of Ohm's law and answer — 2 points

$$I = \frac{\mathcal{E}}{R_1 + R_2} = \frac{20\ \text{V}}{30\ \Omega} = \frac{2}{3}\text{A}$$

(1 point awarded for $\frac{20\ \text{V}}{10\ \Omega}$)

ii. 1 point

For correct substitution in energy equation and correct answer — 1 point

$$U_L = \tfrac{1}{2}LI^2 = \tfrac{1}{2}(2\ \text{H})\left(\tfrac{2}{3}\ \text{A}\right)^2 = 0.444\ \text{J}$$

(1 point also awarded if incorrect current in (e)i. (except zero) was substituted and answer was consistent with this current.)

(f) 2 points

For correct equation — 2 points

$$\mathcal{E} - I(R_1 + R_2) - L\frac{dI}{dt} = 0$$

(1 point only awarded if one sign incorrect)

One point was subtracted from the final score for two or more wrong or absent units for parts where the answer was given, except where the answer was zero, in which case units were not counted.

1998 Physics C Solutions

Distribution of points

E & M 3 (15 points)

(a) 4 points

Using Newton's 2nd law along the ramp,
$F_g \sin\theta - F_m = ma$, where F_g = force of gravity, and F_m = magnetic force

At constant speed, $a = 0$, so
$F_g \sin\theta - F_m = 0$

For the following expression for F_m — 1 point
$F_m = F_g \sin\theta$

For substituting $F_g = mg$ — 1 point
$F_m = mg \sin\theta$

For substituting $F_m = I\ell B$ — 1 point
$I\ell B = mg \sin\theta$

For correct answer — 1 point
$I = \dfrac{mg\sin\theta}{\ell B}$

(b) 4 points

$|\mathcal{E}| = \left|-\dfrac{d\phi_M}{dt}\right|$

For correct expression for ϕ_M — 1 point
$\phi_M = B\ell x$

For the time deriviative of ϕ_M — 1 point
$\dfrac{d\phi_M}{dt} = B\ell \upsilon$

For correct use of Ohm's law to find current — 1 point
$\mathcal{E} = IR$
$I = \dfrac{\mathcal{E}}{R} = \dfrac{B\ell\upsilon}{R}$

For equating this expression to the expression for I from part (a) and solving for υ — 1 point
$\dfrac{B\ell\upsilon}{R} = \dfrac{mg\sin\theta}{B\ell}$
$\upsilon = \dfrac{mgR\sin\theta}{B^2\ell^2}$

Distribution of points

E & M 3 (continued)

(c) 2 points

For correct expression for power — 1 point

$P = I^2 R$

For correction substitution of the expression for I from part (a) — 1 point

$$P = \frac{(m^2 g^2 \sin^2\theta)R}{B^2\ell^2}$$

(d) 3 points

For either of the following two expressions — 1 point

$$m\frac{dv}{dt} = mg\sin\theta - I\ell B$$

$$\frac{dv}{dt} = g\sin\theta - \frac{B^2\ell^2 v}{mR}$$

For rearranging terms in either expression to set up intergral — 1 point

For example,

$$\frac{dv}{g\sin\theta - \frac{B^2\ell^2 v}{mR}} = dt$$

For integrating this expression, and applying $v(0) = 0$ to get answer — 1 point

$$v(t) = \frac{mRg\sin\theta}{B^2\ell^2}\left[1 - \exp\left(-\frac{B^2\ell^2 t}{mR}\right)\right]$$

(e) 2 points

For correct answer — 1 point

Yes, the final speed of the bar decreases

For any reasonable justification — 1 point

For example;

Since the two resistors are in parallel across the emf in the bar, the new effective resistance is $\frac{R}{2}$. And since $v = \frac{mgR\sin\theta}{B^2\ell^2}$ from part (b), then if R decreases, the speed decreases.