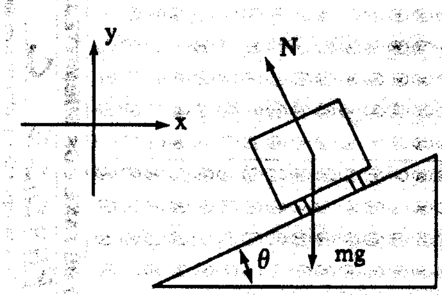
AP® Physics C
1988 Scoring Guidelines

SOLUTIONS AND SCORING GUIDES
SECTION II
1988 AP Physics C Examination: Mechanics

Solutions | **Distribution of points**

Mech 1. (a) 5 points



For Newton's 2nd law: $\sum \vec{F} = m\vec{a}$ — 1 point

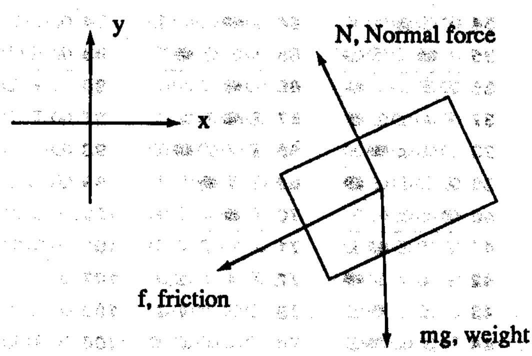
$\sum F_y = N\cos\theta - mg = 0$ — 1 point

$\sum F_x = N\sin\theta = \frac{mv^2}{r}$ — 1 point

Eliminate N: $\tan\theta = \frac{v^2}{gr}$ — 1 point

$v = \sqrt{gr\tan 15^\circ} = 16$ m/s — 1 point

(b) 4 points



1 point awarded for each force with correct label — 3 points

1 point awarded if no extraneous or incorrect forces are included. A pseudoforce is acceptable if it is correctly explained and used. — 1 point

Solutions | **Distribution of points**

(c) 6 points

For proper resolution of Newton's 2nd law:

$$\left.\begin{aligned}\sum F_y &= N\cos\theta - f\sin\theta - mg = 0\\ \sum F_x &= N\sin\theta + f\cos\theta = \frac{mv^2}{r}\end{aligned}\right\}$$ 2 points

For solving for N, f:

$$\left.\begin{aligned}N &= \frac{mv^2}{r}\sin\theta + mg\cos\theta\\ f &= \frac{mv^2}{r}\cos\theta - mg\sin\theta\end{aligned}\right\}$$ 2 points

$$\mu \geqslant \frac{f}{N} = \frac{v^2\cos\theta - rg\sin\theta}{v^2\sin\theta + rg\cos\theta}$$ 1 point

$\mu_{min} = 0.32$ (correct calculation) 1 point

Mech 2. (a) 4 points

For linear force relation: $F = kx$ 1 point

$20\text{ N} = k_1\,(0.10\text{ m})$ (Correct use of values from graph) 2 points

$k_1 = 200\text{ N/m}$ 1 point

(b) 2 points

$$|\Delta K| = \Delta U = \frac{1}{2}k_1(x_{AB})^2 = \frac{1}{2}(200\text{ N/m})(0.10\text{ m})^2$$

OR $|\Delta K| =$ area under graph $= \frac{1}{2}(20\text{ N})(0.10\text{ m})$

OR $|\Delta K| = \int_0^{0.1\text{ m}} k_1 x\,dx = (200\text{ N/m})\dfrac{(0.10\text{ m})^2}{2}$

OR $|\Delta K| = \bar{F}\,\Delta x = (10\text{ N})(0.1\text{ m})$

1 point (for any of the above)

$|\Delta K| = 1\text{ J}$ 1 point

(c) 3 points

$|\Delta K| = |\Delta U| =$ *area* under force graph from B to C

OR one of the equivalent methods in part (b) above 2 points

$|\Delta K| = 2\text{ J}$ 1 point

Solutions	Distribution of points
(d) 3 points	
$K_{\text{init.}} = \frac{1}{2} m v_0^2$	1 point
$3\text{ J} = \frac{1}{2}(5\text{ kg})\, v_0^2$	1 point
$v_0 \approx 1.1\text{ m/s}$	1 point
(e) 3 points	
$\frac{1}{2} m v_0^2 = \frac{1}{2} k_1 (x_{AC})^2 + \frac{1}{2} k_2 (x_{BC})^2$ $3\text{ J} = \frac{1}{2}(200\text{ N/m})(0.15\text{ m})^2 + \frac{1}{2} k_2 (0.05\text{ m})^2$ OR $k_{net} = F_{net} / \triangle x = 40\text{ N}/(0.05\text{ m}) = 800\text{ N/m}$ $k_2 = k_{net} - k_1$ OR $F = k_1 \triangle x_1 + k_2 \triangle x_2$ $60\text{ N} = 200\text{ N/m}\,(0.15\text{ m}) + k_2(0.05\text{ m})$	2 points
$k_2 = 600\text{ N/m}$	1 point
Mech 3. (a) 3 points	
For knowing that moment of inertia is proportional to mR^2	1 point
For using the same mass and $R \rightarrow 2R$	1 point
$I_{2R} = 4I$	1 point
(b) 2 points	
For recognition of requirement of coupling between the disks:	
$R\,\triangle\theta_R = 2R\,\triangle\theta_{2R}$ OR $v_R = v_{2R}$, for outer edges $R\omega_R = 2R\,\omega_{2R}$ $R\frac{\alpha t^2}{2} = 2R\frac{\alpha_{2R} t^2}{2}$ $R\,\alpha t = 2R\,\alpha_{2R} t$	1 point
$\alpha_{2R} = \frac{1}{2}\alpha$	1 point

(c) 4 points

Torque: $\Gamma_{2R} = I_{2R}\,\alpha_{2R}$ — 1 point

$= (4I)\left(\frac{1}{2}\alpha\right)$ — 1 point

Also: $\Gamma_{2R} = T(2R)$ — 1 point

Therefore: $T(2R) = (4I)\left(\frac{1}{2}\alpha\right)$

$T = \dfrac{I\alpha}{R}$ — 1 point

(d) 3 points

For recognition that two torques act on the smaller disk — 1 point

$\Gamma_{net} = \Gamma_{applied} - TR = I\alpha$ — 1 point

$\Gamma_{applied} = I\alpha + TR = I\alpha + \dfrac{I\alpha}{R}R = 2I\alpha$ — 1 point

(e) 3 points

$K_{rot} = \frac{1}{2}I\omega^2$ — 1 point

$\omega = \alpha t$ — 1 point

$K_{rot} = \frac{1}{2}I\alpha^2 t^2$ — 1 point

Solutions	Distribution of points
E & M 1. (a) 3 points	
$V = \frac{1}{4\pi\epsilon_0}\frac{Q}{a}$ or $\frac{kQ}{a}$	2 points
$Q = 4\pi\epsilon_0 aV$ or $\frac{aV}{k}$	1 point
(b) 4 points	
For Gauss's law: $\oint \vec{E} \cdot d\vec{S} = Q_{net}/\epsilon_0$ or $4\pi k Q_{net}$	1 point
$\oint \vec{E} \cdot d\vec{S} = E 4\pi r^2$	1 point
For using $Q_{net} = Q$ from (a) above	1 point
$E = \frac{Va}{r^2}$ or $\frac{Q}{4\pi\epsilon_0 r^2}$ or $\frac{kQ}{r^2}$	1 point
(c) 5 points	
$\Delta V = V_a - V_b = -\int_b^a \vec{E} \cdot d\vec{\ell}$	1 point
For correct use of limits on integral	1 point
$\Delta V = -\int_b^a \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}\,dr$ or $-\int_b^a \frac{kQ}{r^2}\,dr$	1 point
$\int \frac{1}{r^2}\,dr = -\frac{1}{r}$	1 point
$\Delta V = \frac{Q}{4\pi\epsilon_0}\left(\frac{1}{a} - \frac{1}{b}\right)$ or $kQ\left(\frac{1}{a} - \frac{1}{b}\right)$	
$\Delta V = \frac{V(b-a)}{b}$ or equivalent	1 point
<u>Alternate solution:</u>	(Alternate points)
For recognition that $\vec{E}$ is unchanged by addition of the shell for $a \leqslant r \leqslant b$	(1 point)
Therefore $V = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}\left(\text{or } \frac{kQ}{r}\right)$ + Constant, for $a \leqslant r \leqslant b$	(2 points)
$\Delta V = V_a - V_b$	(1 point)
$\Delta V = \frac{1}{4\pi\epsilon_0} Q\left(\frac{1}{a} - \frac{1}{b}\right)$ or $kQ\left(\frac{1}{a} - \frac{1}{b}\right)$	
$\Delta V = \frac{V(b-a)}{b}$ or equivalent	(1 point)

Solutions	Distribution of points
(d) 3 points	
$Q = C \Delta V$	1 point
$4\pi\epsilon_0 Va = C\, V_0 \dfrac{(b-a)}{b}$	1 point
$C = \dfrac{4\pi\epsilon_0 ab}{b-a}$	1 point
E & M 2. (a) 4 points	
For correct treatment of series and parallel resistances: $\left.\begin{array}{l} 8\,\Omega + 4\,\Omega = 12\,\Omega \\ \dfrac{1}{12\,\Omega} + \dfrac{1}{4\,\Omega} = \dfrac{4}{12\,\Omega} = \dfrac{1}{3\,\Omega} \\ 9\,\Omega + 3\,\Omega = 12\,\Omega \end{array}\right\}$	2 points
For correct application of Ohm's law:	
$I = V/R = \dfrac{120\text{ V}}{12\,\Omega}$ or equivalent	1 point
$I = 10\text{ A}$	1 point
(b) 3 points	
$V_{4\,\Omega} = V_{(8+4)\,\Omega} = V_{\text{parallel combination}} = (3\,\Omega)(10\text{ A}) = 30\text{ V}$	2 points
$I_{8\Omega} = I_{(8+4)\Omega} = \dfrac{30\text{ V}}{12\,\Omega} = 2.5\text{ A}$	1 point
<u>Alternate solution:</u>	(Alternate points)
$I_{8\Omega} = I_{(8+4)\Omega} = \dfrac{1}{4} I_{9\Omega}$	(2 points)
$I_{8\Omega} = 2.5\text{ A}$	(1 point)
<u>Alternate solution for (a) and (b):</u>	(Alternate points)
For applying Kirchoff's rules to 2 loops and 1 junction	(4 points)
For solving the equations for the 2 currents	(3 points)
(c) 2 points	
$V_{\text{cap}} = V_{\text{parallel } 4\Omega}$	1 point
$V_{\text{cap}} = (2.5\text{A})(4\Omega) = 10\text{V}$	1 point
(d) 2 points	
$U = \frac{1}{2} CV^2$ or equivalent	1 point
$U = 1500\ \mu\text{J}$	1 point

(e) 4 points

For determining the correct equivalent circuit	1 point
For recognizing that $U_{8\Omega}$ = a fraction of U_{total}; $U_{8\Omega} = \frac{1}{4} \cdot \frac{2}{3} U_{total} = 250\ \mu J$	3 points
Alternate solution:	(Alternate points)
For determining correct equivalent circuit	(1 point)
For use of integrals of the form $\int_0^\infty e^{-2t/RC}\,dt$	(1 point)
For successfully completing the calculation	(2 points)

E & M 3. (a) 4 points

Ampere's law: $\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \sum I$	1 point
$\int_a^b \vec{B} \cdot d\vec{\ell} + \int_b^c \vec{B} \cdot d\vec{\ell} + \int_c^d \vec{B} \cdot d\vec{\ell} + \int_d^a \vec{B} \cdot d\vec{\ell} = Bh + 0 + 0 + 0$	1 point
$\sum I = nhi$	1 point
$B = \mu_0 ni$	1 point

(b) 4 points

Faraday's law: $\mathcal{E} = -\frac{d\Phi_B}{dt}$ or equivalent	1 point
$\Phi_B = B\pi r_2^2$	1 point
$\frac{d\Phi_B}{dt} = \pi r_2^2 \frac{dB}{dt}$	
$\frac{dB}{dt} = \mu_0 n \frac{di}{dt} = -\frac{\mu_0 ni}{t}$	1 point
$\mathcal{E} = \frac{\mu_0 ni\pi r_2^2}{t}$	1 point

(c) 3 points

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell}$	1 point
$= E\,2\pi r_2$	1 point
$E = \frac{\mu_0 nir_2}{2t}$	1 point

(d) 2 points

$\mathcal{E} = -\frac{d}{dt}(B\pi r_1^2)$	1 point
$\mathcal{E} = \frac{\mu_0 ni\pi r_1^2}{t}$	1 point

(e) 2 points

$\mathcal{E} = \oint \vec{E} \cdot d\vec{\ell} = E\,2\pi r_3$	1 point
$E = \frac{\mu_0 nir_1^2}{2tr_3}$	1 point

year. Many students did not attempt it, presumably because their course did not cover enough modern physics. It is difficult, but not impossible, to cover all topics in the syllabus before the examination, and modern physics comes last in the usual schedule. Nevertheless, the Physics B course is a survey course, and modern physics topics are included.

Physics C, Comments

Mechanics

Mech 1. This problem, which dealt with an automobile rounding a curve, contained a standard first part with no friction present. The second part included frictional effects and was more challenging. This mix provided a broad distribution of scores and good discrimination of ability. A common pitfall noticed by Readers was that students resolved forces parallel and perpendicular to the road surface, which made a correct analysis far more difficult. Many students failed to recognize that the acceleration had only a horizontal component.

Mech 2. The double-spring problem had a good combination of several concepts—Hooke's law, a graphical analysis, the connection between force and potential energy, and work-energy. Students showed a multitude of approaches to parts (b), (c), and (e).

Mech 3. The so-called bicycle problem, two rotating disks coupled by a light chain, provided a good test of concepts of rotational kinematics and dynamics. It was evidently too difficult for some as there were many scores in the 0-3 range. Part of the apparent difficulty may stem from the unusual division of knowns and unknowns—the angular acceleration was a given rather than forces or torques.

Electricity and Magnetism

E&M 1. Students seem to expect a Gauss's law problem and are well prepared for standard problems. This question contained, in part, one of the usual ones, and most students had little trouble with Gauss's law. What gave them trouble was calculating the potential difference between the inner and outer conductors. There was a good spread of grades, and the question was discriminating in the middle and upper ranges.

E&M 2. A deceptively simple circuit problem gave students an opportunity to get all tangled up in applying Kirchhoff's rules, and many of them did so. The problem was cleverly designed to involve a minimum of calculation of equivalent resistances for parallel and series combinations, but the cleverness was missed by most because of errors or lack of insight.

E&M 3. Determining the magnetic field in a long solenoid is a standard Ampere's law problem, and this question couples that nicely with induced emf's and induced electric fields. Apparently, many students put this problem off until last and were not able to make much headway.