



## AP<sup>®</sup> Physics C 1988 Scoring Guidelines

**The materials included in these files are intended for use by AP teachers for course and exam preparation in the classroom; permission for any other use must be sought from the Advanced Placement Program<sup>®</sup>. Teachers may reproduce them, in whole or in part, in limited quantities, for face-to-face teaching purposes but may not mass distribute the materials, electronically or otherwise. These materials and any copies made of them may not be resold, and the copyright notices must be retained as they appear here. This permission does not apply to any third-party copyrights contained herein.**

These materials were produced by Educational Testing Service<sup>®</sup> (ETS<sup>®</sup>), which develops and administers the examinations of the Advanced Placement Program for the College Board. The College Board and Educational Testing Service (ETS) are dedicated to the principle of equal opportunity, and their programs, services, and employment policies are guided by that principle.

The College Board is a national nonprofit membership association dedicated to preparing, inspiring, and connecting students to college and opportunity. Founded in 1900, the association is composed of more than 4,200 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges, through major programs and services in college admission, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT<sup>®</sup>, the PSAT/NMSQT<sup>®</sup>, and the Advanced Placement Program<sup>®</sup> (AP<sup>®</sup>). The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

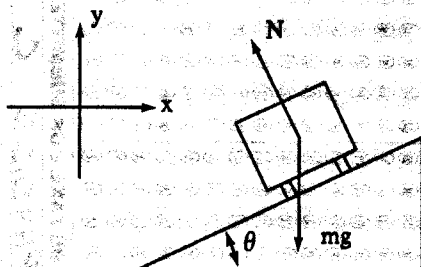
Copyright © 2002 by College Entrance Examination Board. All rights reserved. College Board, Advanced Placement Program, AP, SAT, and the acorn logo are registered trademarks of the College Entrance Examination Board. APIEL is a trademark owned by the College Entrance Examination Board. PSAT/NMSQT is a registered trademark jointly owned by the College Entrance Examination Board and the National Merit Scholarship Corporation. Educational Testing Service and ETS are registered trademarks of Educational Testing Service.

**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

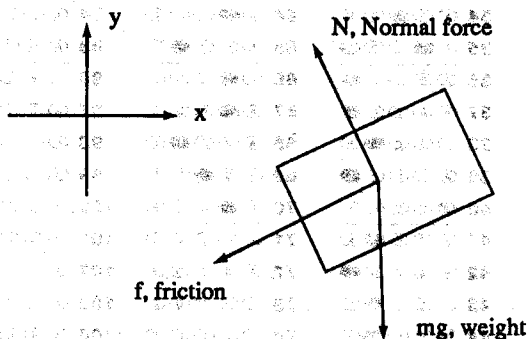
Eliminate  $N$ :  $\tan \theta = \frac{v^2}{gr}$

1 point

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

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:

$$\sum F_y = N \cos \theta - f \sin \theta - mg = 0$$

$$\sum F_x = N \sin \theta + f \cos \theta = \frac{mv^2}{r}$$

2 points

 For solving for  $N, f$ :

$$N = \frac{mv^2}{r} \sin \theta + mg \cos \theta$$

$$f = \frac{mv^2}{r} \cos \theta - mg \sin \theta$$

2 points

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

1 point

$$\mu_{\min} = 0.32 \quad (\text{correct calculation})$$

1 point

Mech 2. (a) 4 points

 For linear force relation:  $F = kx$ 

1 point

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

2 points

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

1 point

(b) 2 points

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

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

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

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

1 point

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

1 point

(c) 3 points

$$|\Delta K| = |\Delta U| = \text{area under force graph from } B \text{ to } C$$

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

$$K_{\text{init.}} = \frac{1}{2} m v_0^2 \quad 1 \text{ point}$$

$$3 \text{ J} = \frac{1}{2} (5 \text{ kg}) v_0^2 \quad 1 \text{ point}$$

$$v_0 \approx 1.1 \text{ m/s} \quad 1 \text{ point}$$

(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

$$k_{\text{net}} = F_{\text{net}} / \Delta x = 40 \text{ N} / (0.05 \text{ m}) = 800 \text{ N/m}$$

$$k_2 = k_{\text{net}} - k_1$$

OR

$$F = k_1 \Delta x_1 + k_2 \Delta x_2$$

$$60 \text{ N} = 200 \text{ N/m} (0.15 \text{ m}) + k_2 (0.05 \text{ m})$$

$$k_2 = 600 \text{ N/m}$$

2 points

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

$$I_{2R} = 4I \quad 1 \text{ point}$$

(b) 2 points

For recognition of requirement of coupling between the disks:

$$R \Delta \theta_R = 2R \Delta \theta_{2R} \quad \text{OR} \quad v_R = v_{2R}, \text{ for outer edges} \quad 1 \text{ point}$$

$$R \omega_R = 2R \omega_{2R}$$

$$R \alpha t^2 = 2R \alpha_{2R} t^2$$

$$R \alpha t = 2R \alpha_{2R} t$$

$$\alpha_{2R} = \frac{1}{2} \alpha \quad 1 \text{ point}$$

**Solutions****Distribution  
of points****(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:

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

$$T = \frac{I\alpha}{R}$$

1 point

**(d) 3 points**

For recognition that two torques act on the smaller disk

1 point

$$\Gamma_{\text{net}} = \Gamma_{\text{applied}} - TR = I\alpha$$

1 point

$$\Gamma_{\text{applied}} = I\alpha + TR = I\alpha + \frac{I\alpha}{R} R = 2I\alpha$$

1 point

**(e) 3 points**

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

1 point

$$\omega = \alpha t$$

1 point

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

1 point

# SOLUTIONS AND SCORING GUIDES

## SECTION II

### 1988 AP Physics C Examination: Electricity and Magnetism

#### Solutions

#### Distribution of points

**E & M 1. (a)** 3 points

$$V = \frac{1}{4\pi\epsilon_0} \frac{Q}{a} \text{ or } \frac{kQ}{a} \quad 2 \text{ points}$$

$$Q = 4\pi\epsilon_0 aV \text{ or } \frac{aV}{k} \quad 1 \text{ point}$$

**(b)** 4 points

$$\text{For Gauss's law: } \oint \vec{E} \cdot d\vec{S} = Q_{\text{net}}/\epsilon_0 \text{ or } 4\pi kQ_{\text{net}} \quad 1 \text{ point}$$

$$\oint \vec{E} \cdot d\vec{S} = E4\pi r^2 \quad 1 \text{ point}$$

For using  $Q_{\text{net}} = Q$  from (a) above 1 point

$$E = \frac{Va}{r^2} \text{ or } \frac{Q}{4\pi\epsilon_0 r^2} \text{ or } \frac{kQ}{r^2} \quad 1 \text{ point}$$

**(c)** 5 points

$$\Delta V = V_a - V_b = - \int_b^a \vec{E} \cdot d\vec{l} \quad 1 \text{ point}$$

For correct use of limits on integral 1 point

$$\Delta V = - \int_b^a \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} dr \text{ or } - \int_b^a \frac{kQ}{r^2} dr \quad 1 \text{ point}$$

$$\int \frac{1}{r^2} dr = -\frac{1}{r} \quad 1 \text{ point}$$

$$\Delta V = \frac{Q}{4\pi\epsilon_0} \left( \frac{1}{a} - \frac{1}{b} \right) \text{ or } kQ \left( \frac{1}{a} - \frac{1}{b} \right)$$

$$\Delta V = \frac{V(b-a)}{b} \text{ or equivalent} \quad 1 \text{ point}$$

Alternate solution:

(Alternate points)

For recognition that  $\vec{E}$  is unchanged by addition of the shell for  $a \leq r \leq b$

(1 point)

Therefore  $V = \frac{1}{4\pi\epsilon_0} \frac{Q}{r} \left( \text{or } \frac{kQ}{r} \right) + \text{Constant}$ ,  
for  $a \leq r \leq b$

(2 points)

$$\Delta V = V_a - V_b$$

(1 point)

$$\Delta V = \frac{1}{4\pi\epsilon_0} Q \left( \frac{1}{a} - \frac{1}{b} \right) \text{ or } kQ \left( \frac{1}{a} - \frac{1}{b} \right)$$

$$\Delta V = \frac{V(b-a)}{b} \text{ or equivalent}$$

(1 point)

**Solutions**

**Distribution of points**

(d) 3 points

$$Q = C \Delta V$$

1 point

$$4\pi\epsilon_0 Va = C V \frac{(b-a)}{b}$$

1 point

$$C = \frac{4\pi\epsilon_0 ab}{b-a}$$

1 point

**E & M 2. (a) 4 points**

For correct treatment of series and parallel resistances:

$$8\Omega + 4\Omega = 12\Omega$$

$$\frac{1}{12\Omega} + \frac{1}{4\Omega} = \frac{4}{12\Omega} = \frac{1}{3\Omega}$$

$$9\Omega + 3\Omega = 12\Omega$$

2 points

For correct application of Ohm's law:

$$I = V/R = \frac{120\text{ V}}{12\Omega} \text{ or equivalent}$$

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

$$I_{8\Omega} = I_{(8+4)\Omega} = \frac{30\text{ V}}{12\Omega} = 2.5\text{ A}$$

1 point

Alternate solution:

(Alternate points)

$$I_{8\Omega} = I_{(8+4)\Omega} = \frac{1}{4} I_{9\Omega}$$

(2 points)

$$I_{8\Omega} = 2.5\text{ A}$$

(1 point)

Alternate solution for (a) and (b):

(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

$$U = \frac{1}{2} CV^2 \text{ or equivalent}$$

1 point

$$U = 1500\text{ }\mu\text{J}$$

1 point

(e) 4 points

For determining the correct equivalent circuit

1 point

For recognizing that  $U_{8\Omega} =$  a fraction of  $U_{\text{total}}$ 

$$U_{8\Omega} = \frac{1}{4} \cdot \frac{2}{3} U_{\text{total}}$$

$$= 250 \mu\text{J}$$

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 &amp; M 3. (a) 4 points

$$\text{Ampere's law: } \oint \vec{B} \cdot d\vec{\ell} = \mu_0 \sum I$$

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

$$\text{Faraday's law: } \mathcal{E} = - \frac{d\Phi_B}{dt} \text{ or equivalent}$$

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

$$E = \frac{\mu_0 ni r_2}{2t}$$

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

$$E = \frac{\mu_0 ni r_1}{2t r_3}$$

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.