AP® Physics B
2009 Scoring Guidelines
Form B

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AP® PHYSICS
2009 SCORING GUIDELINES

General Notes About 2009 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point and a student's solution contains the application of that equation to the problem, but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics Exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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Question 1

15 points total **Distribution of points**

(a) 4 points

For any indication that the centripetal force on the small disk equals the weight of the hanging objects — 1 point

For using the correct expression for the centripetal acceleration — 1 point

$$\frac{m_1 v^2}{r} = m_2 g$$

For the correct expression for the speed of the disk in terms of the period — 1 point

$v = 2\pi r / P$

$$\frac{m_1}{r}\left(\frac{2\pi r}{P}\right)^2 = m_2 g$$

For a correct expression relating m_2 and P in terms of the specified quantities — 1 point

$$\frac{4\pi^2 m_1 r}{P^2} = m_2 g$$

$$P = 2\pi\sqrt{\frac{m_1 r}{m_2 g}}$$

(b) 2 points

For listing two quantities, one of which is correct, consistent with equation obtained in part (a) — 1 point

For having both quantities correct, consistent with equation obtained in part (a) — 1 point

For example: $1/P^2$ and m_2, P^2 and $1/m_2$, P and $1/\sqrt{m_2}$

(c) 4 points

Using the example of $1/P^2$ and m_2

m_2 (kg)	0.020	0.040	0.060	0.080
P (s)	1.40	1.05	0.80	0.75
$1/P^2$	0.51	0.91	1.6	1.8

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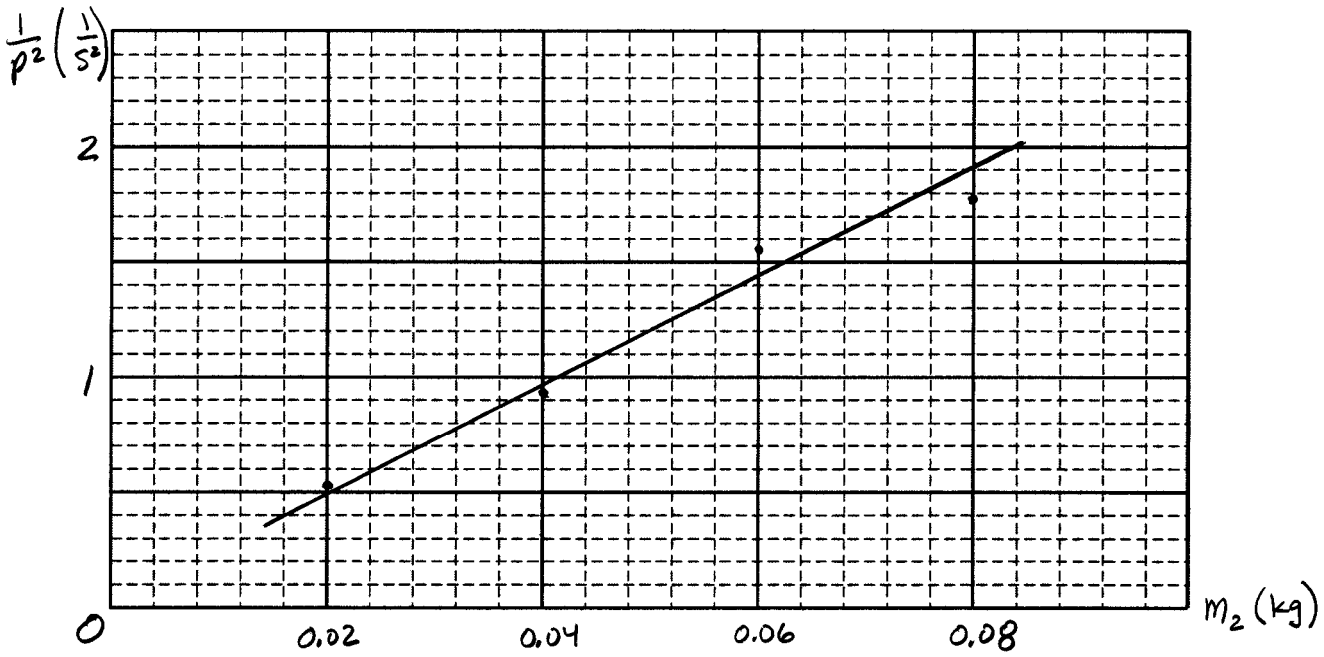
Question 1 (continued)

Distribution of points

(c) (continued)



For correctly labeling both axes 1 point
For correctly scaling both axes 1 point
For a reasonably correct plotting of the data 1 point
For a reasonably correct best-fit line 1 point

(d) 5 points

For associating the slope of the line with the correct coefficient for the quantities graphed 1 point

For the example graph given, $\frac{1}{P^2} = \frac{m_2 g}{4\pi^2 m_1 r}$, so slope $= \frac{g}{4\pi^2 m_1 r}$

For a correct method of calculating the slope, including substitution of points on the line 1 point
For a correct substitution of given values (i.e., all values except the points from the line) 1 point
For example:

$$g = (\text{slope})\left(4\pi^2 m_1 r\right) = \frac{\left(2\ \text{s}^{-2} - 0.4\ \text{s}^{-2}\right)}{(0.084\ \text{kg} - 0.016\ \text{kg})}\left(4\pi^2\right)(0.012\ \text{kg})(0.80\ \text{m})$$

For a reasonable numerical value 1 point
For correct units 1 point
$g = 8.9\ \text{m/s}^2$

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Question 2

15 points total **Distribution of points**

(a) 6 points

The solution starts with the expression for the force between point charges.

$F = \frac{kq_1q_2}{r^2}$

For having equal contributions to the force from each charge on the x axis (e.g., by including a factor of 2 in the calculation) 1 point

For using the correct distance between charges 1 point

$r^2 = y_A^2 + x_B^2$

For including only the y component of the forces, since the x components cancel (e.g., by including $\sin\theta$ in the equation, where θ is the angle between the x axis and the line connecting particle A and either of the other two particles) 1 point

For correctly determining the angle θ from the geometry 1 point

For example: $\theta = \tan^{-1}(y_A/x_B)$

These elements combine to yield the following expression.

$F = 2\frac{kq_Aq_B}{y_A^2 + x_B^2}\sin\left[\tan^{-1}(y_A/x_B)\right]$

$F = 2\frac{\left(9.0\times10^9\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(0.20\times10^{-9}\ \text{C}\right)\left(0.30\times10^{-9}\ \text{C}\right)}{(0.030\ \text{m})^2 + (0.040\ \text{m})^2}\sin\left[\tan^{-1}\left(\frac{0.030\ \text{m}}{0.040\ \text{m}}\right)\right]$

For the correct numerical answer 1 point

$F = 2.59\times10^{-7}\ \text{N}$

For correctly indicating that the force is in the negative y direction 1 point

(b) 2 points

For any indication that particle A will move toward the origin after release 1 point

For any indication that the particle goes past the origin, then reverses direction 1 point

For example: The particle oscillates between $y = \pm 0.030$ m

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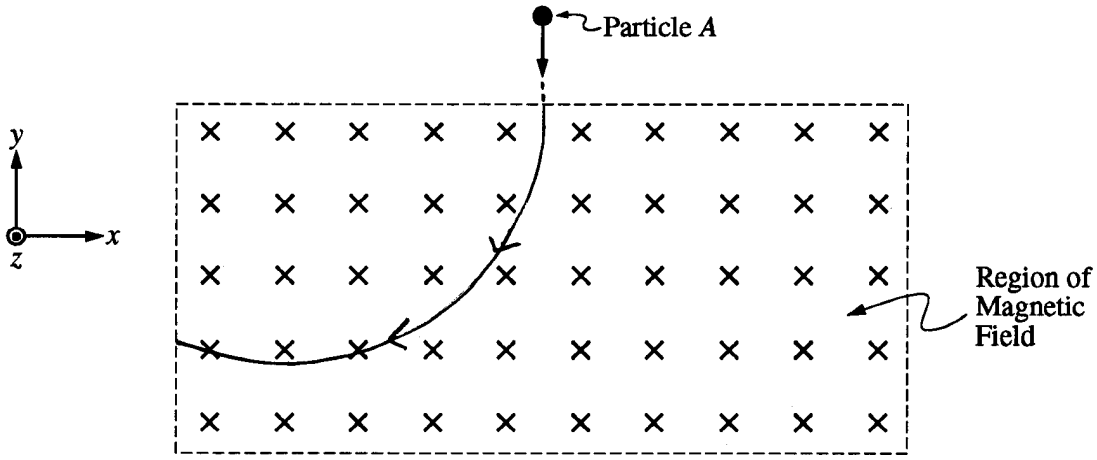
Question 2 (continued)

Distribution of points

(c) 2 points



For any path that (1) is an arc of a circle whose center lies on the line defining the side of the field where the particle enters and (2) goes completely through the field region — 1 point

For the path curving to the left — 1 point

(d) 2 points

For the correct expression for the force on a particle moving perpendicular to a magnetic field — 1 point

$F = qvB\sin\theta = qvB$

$F = \left(0.20 \times 10^{-9}\ \text{C}\right)(6000\ \text{m/s})(0.50\ \text{T})$

For the correct answer — 1 point

$F = \left(6.0 \times 10^{-7}\ \text{N}\right)$

(e) 3 points

For equating the expression for the electric and magnetic forces on the particle — 1 point

$qE = qvB$

$E = vB$

$E = (6000\ \text{m/s})(0.50\ \text{T})$

For the correct numerical answer — 1 point

$E = 3000\ \text{N/C}$

For correctly indicating that the field is in the negative x direction — 1 point

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Question 3

15 points total **Distribution of points**

(a) 3 points

For a meaningful use of the correct expression for flow rate, Av (e.g., an attempt to substitute for volume and speed) 1 point

For relating the flow rates at points A and B 1 point

$A_A v_A = A_B v_B$

$v_A = A_B v_B / A_A = \left(0.50 \times 10^{-4}\ \text{m}^2\right)(8.2\ \text{m/s}) \Big/ \left(1.0 \times 10^{-4}\ \text{m}^2\right)$

For the correct answer 1 point

$v_A = 4.1\ \text{m/s}$

(b) 5 points

For applying Bernoulli's equation to this situation 1 point

$P_A + \rho g y_A + \frac{1}{2}\rho v_A^2 = P_B + \rho g y_B + \frac{1}{2}\rho v_B^2$

$P_A = P_B + \rho g (y_B - y_A) + \frac{1}{2}\rho\left(v_B^2 - v_A^2\right)$

For using atmospheric pressure $\left(1.0 \times 10^5\ \text{Pa}\right)$ for the pressure at point B 1 point

For correctly substituting values for y_A and y_B 1 point

For correctly substituting values for v_A and v_B consistent with the work in part (a) 1 point

$P_A = \left(1.0 \times 10^5\ \text{Pa}\right) + \left(1000\ \text{kg/m}^3\right)\left(9.8\ \text{m/s}^2\right)(0.50\ \text{m} - 0)$

$+ \frac{1}{2}\left(1000\ \text{kg/m}^3\right)\left([8.2\ \text{m/s}]^2 - [4.1\ \text{m/s}]^2\right)$

For correct units for the answer 1 point

$P_A = 1.3 \times 10^5\ \text{N/m}^2$ (or Pa)

(c) 2 points

For correctly relating the initial speed and the maximum height 1 point

$v^2 = {v_0}^2 + 2a(x - x_0)$ OR $\frac{1}{2}mv^2 = mgh$

$v_B^2 = 2gh$

$h = v_B^2 / 2g = (8.2\ \text{m/s})^2 \big/ 2\left(9.8\ \text{m/s}^2\right)$

For the correct answer with correct units 1 point

$h = 3.4\ \text{m}$

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Question 3 (continued)

Distribution of points

(d) 5 points

For correctly analyzing the vertical motion with constant acceleration, to find the time for the water to reach maximum height — 1 point

$v = v_0 + at$

$0 = v_{By} + gt$

$v_{By} = gt$

For the correct vertical component of speed — 1 point

$v_{By} = v_B \sin\theta$

$t = v_{By}/g = v_B \sin\theta / g$

For correctly analyzing the horizontal motion with constant speed — 1 point

$x = v_{Bx}(2t)$

For the correct horizontal component of speed — 1 point

$v_{Bx} = v_B \cos\theta$

$x = v_B \cos\theta (2v_B \sin\theta / g) = 2v_B^2 \cos\theta \sin\theta / g$

$x = 2(8.2 \text{ m/s})^2 \cos 60° \sin 60° / (9.8 \text{ m/s}^2)$

For the correct answer with units — 1 point

$x = 5.9$ m (or 5.8 m using $g = 10 \text{ m/s}^2$)

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Question 4

15 points total **Distribution of points**

(a) 2 points

For a correct expression for the pressure due to the weight of the piston 1 point
For including atmospheric pressure 1 point
$P = P_{atm} + (mg/A)$

Notes:
The second point was also awarded for stating the assumption that the cylinder is in a vacuum.
A numeric value for atmospheric pressure instead of a variable in the equation was acceptable.

(b) 2 points

For combining resistors in parallel 1 point
$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$\frac{1}{R_{eq}} = \frac{1}{R_0} + \frac{1}{R_0} + \frac{1}{R_0} = \frac{3}{R_0}$

For the correct answer 1 point
$R_{eq} = R_0/3$

(c) 3 points

For correctly relating the change in internal energy of the gas to the energy provided by the circuit 1 point
$\Delta U = P_{cir}t$

For a correct relationship for the power delivered by the circuit in terms of voltage difference and resistance 1 point
$P_{cir} = \mathcal{E}^2/R_{eq}$

$\Delta U = \left(\mathcal{E}^2 \Big/ \frac{R_0}{3}\right)t$

For the correct answer 1 point
$\Delta U = 3\mathcal{E}^2 t/R_0$

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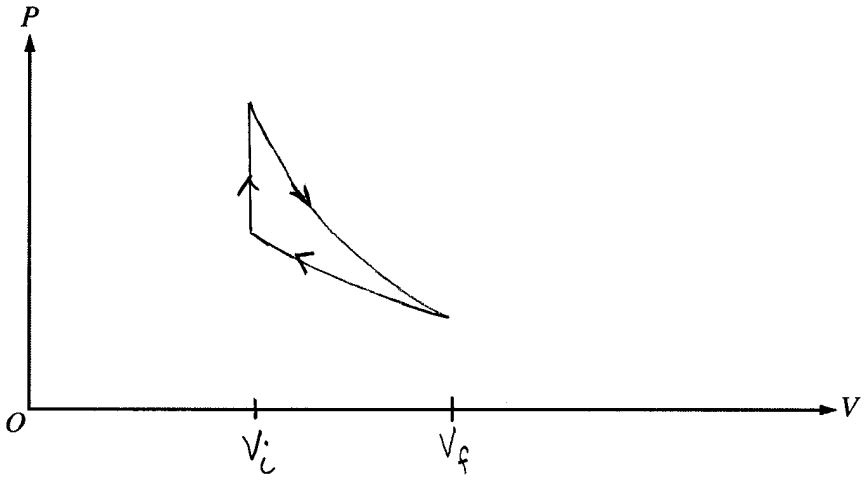
Question 4 (continued)

Distribution of points

(d) 3 points

For indicating that the temperature decreases	1 point
Justifying using the first law of thermodynamics: $\Delta U = Q + W$	
For indicating that $Q = 0$ (the definition of an adiabatic process)	1 point
For indicating that negative work is done on the piston, so applying the first law gives a net loss of energy in the gas and thus the internal energy decreases	1 point
Since the internal energy is proportional to temperature, the temperature must also decrease.	

(e) 5 points



For a vertical straight segment	1 point
One point for each curved segment from one end of the straight line to a point at a lower pressure and higher volume	2 points
(Only the segments were scored. Presence or correctness of arrowheads was not considered.)	
For correctly labeling V_i	1 point
For correctly labeling V_f	1 point

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Question 5

10 points total **Distribution of points**

(a) 2 points

Using the relationship for the speed of light inside a material: $n = c/v$

For correct substitutions 1 point

$v_{oil} = c/n = \left(3.00 \times 10^{8} \text{ m/s}\right)/1.7$

For the correct answer 1 point

$v_{oil} = 1.8 \times 10^{8} \text{ m/s}$

(b) 2 points

For using the relationship for the wavelength of light inside a material, which can be derived as follows: 1 point

$f_{oil} = f_{air}$, and $f = v/\lambda$

$v_{oil}/\lambda_{oil} = v_{air}/\lambda_{air}$

$(c/n)/\lambda_{oil} = c/\lambda_{air}$

$\lambda_{oil} = \lambda_{air}/n$

For correct substitutions 1 point

$\lambda_{oil} = \left(5.2 \times 10^{-7} \text{ m}\right)/1.7$

$\lambda_{oil} = 3.1 \times 10^{-7} \text{ m}$

(c) 3 points

There is a 180° phase shift when light is reflected at the lower interface, so for constructive interference the path length in the film must be an odd multiple of a half wavelength.

For any indication of the phase shift (e.g., a description as above or a $\lambda_{oil}/2$ correction in an equation such as $2t + \lambda_{oil}/2 = \lambda_{oil}$, where t is the thickness of the film) 1 point

For work that correctly accounts for constructive interference (e.g., a description as in the first statement above for the net path length, or correct factors of λ in an equation as in the second statement above) 1 point

$2t = \lambda_{oil}/2$

For substituting the correct value for the wavelength 1 point

$t = \lambda_{oil}/4 = \left(3.1 \times 10^{-7} \text{ m}\right)/4$

$t = 7.8 \times 10^{-8} \text{ m}$

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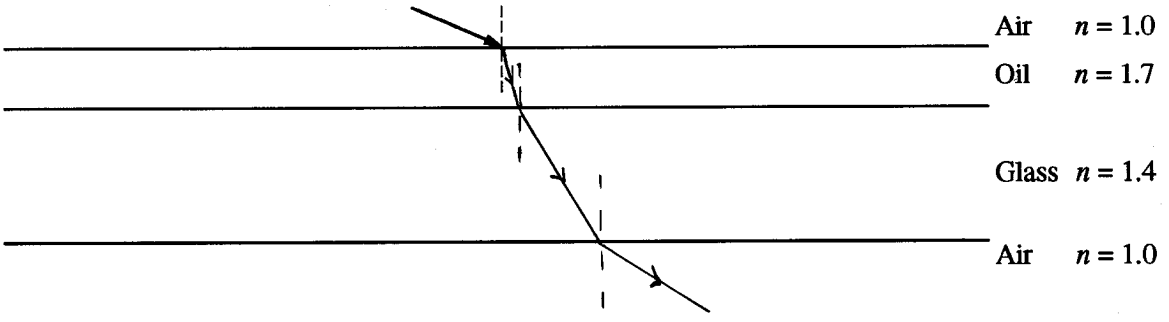
Question 5 (continued)

Distribution of points

(d) 3 points



For a ray at the first interface that bends toward the normal — 1 point
For a ray at the second interface that bends away from the normal — 1 point
For a ray at the third interface that bends away from the normal (This ray does not have to be parallel to the initial ray.) — 1 point

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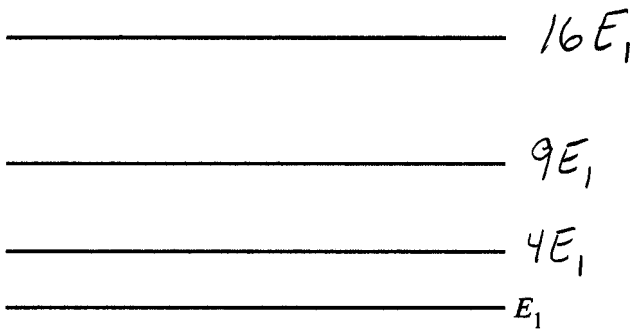
Question 6

10 points total **Distribution of points**

(a) 3 points



Note: Energy levels not drawn to scale.

The given equation, $E_n = n^2 E_1$, is used to calculate the other energies

One point for each correctly labeled energy level 3 points

(b) 2 points

From the relationship between frequency and energy, $\Delta E = hf$, it is seen that the smallest frequency corresponds to the smallest energy difference.

For a correct determination of the energy difference 1 point

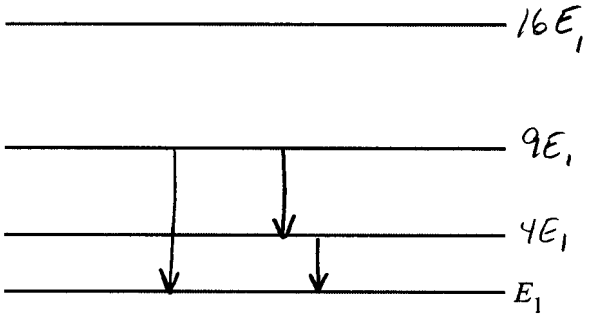
$\Delta E = 4E_1 - E_1 = 3E_1$

For a correct relationship between the minimum energy difference and the frequency 1 point

$hf = 3E_1$

$f = 3E_1/h$

(c) 2 points



Note: Energy levels not drawn to scale.

For the transition from $9E_1$ to E_1 1 point

For the pair of transitions from $9E_1$ to $4E_1$ and $4E_1$ to E_1 1 point

One point earned for this part was deducted for one extraneous line, and two or more extraneous lines resulted in no credit for this part.

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Question 6 (continued)

Distribution of points

(d) 3 points

For a correct relationship between the maximum energy difference and the frequency 1 point

$hf = 9E_1 - E_1 = 8E_1$

$f = 8E_1/h$

For a correct relationship between the wavelength and frequency of the light 1 point

$f = c/\lambda$

A single equation that directly relates energy and wavelength could earn both points.

$c/\lambda = 8E_1/h$

For the correct answer 1 point

$\lambda = hc/8E_1$

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