CollegeBoard
Advanced Placement Program

AP® Physics B
2006 Scoring Guidelines
Form B

General Notes About 2006 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 1 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. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

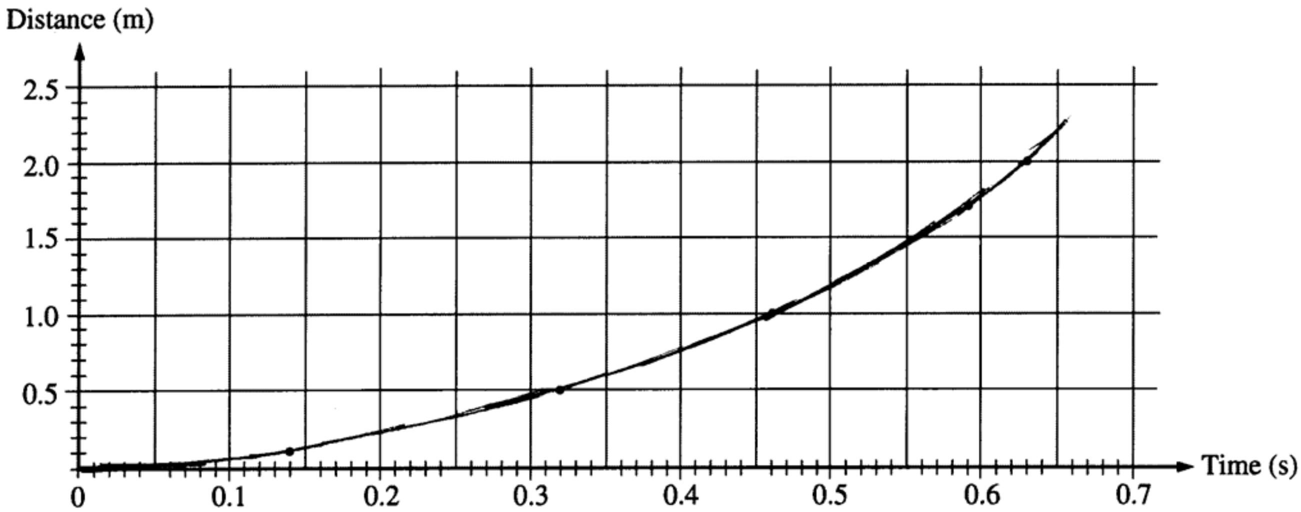
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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.

Question 1

15 points total **Distribution of points**

(a) 3 points



For a line that is close to all of the data points	1 point
For a smooth curve	1 point
For a nonlinear curve that is concave up	1 point

(b) 2 points

Distance and time are related by the equation $D = \frac{1}{2}gt^2$

For a correct pair of quantities, expressed in terms of D and t, that will yield a straight line — 2 points

Examples: D and t^2 OR $\sqrt{D}$ and t

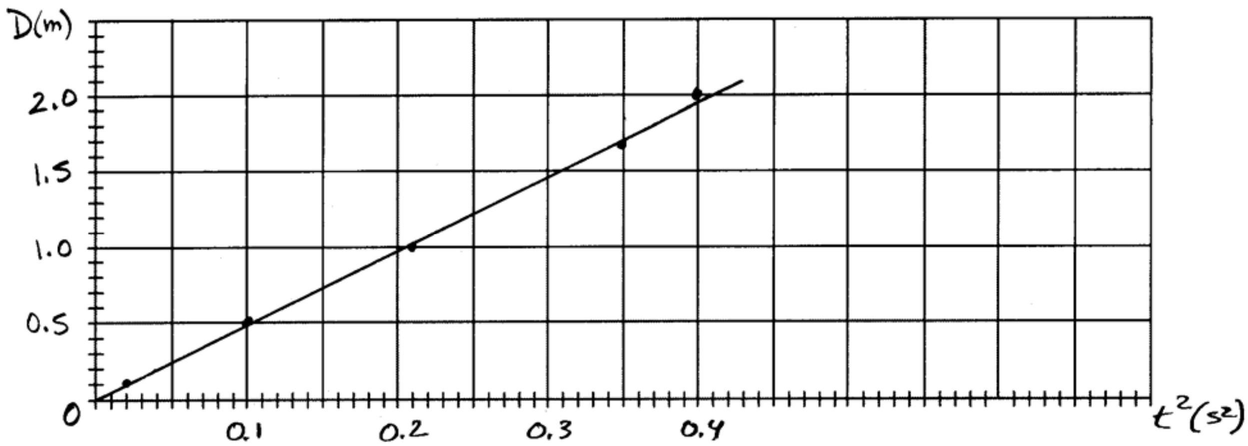
Question 1 (continued)

Distribution of points

(c) 4 points

For correctly scaling and labeling the horizontal axis for a quantity cited in part (b)	1 point
For correctly scaling and labeling the vertical axis for a quantity cited in part (b)	1 point
For a reasonably correct plotting of the data	1 point
For a reasonably straight line through the data points	1 point

Example graphing D versus t^2:



Note: If part (b) contains incorrect variables and they are correctly graphed in part (c), a maximum of 2 points could be earned.

(d) 3 points

For determining the slope of the line drawn on the graph — 1 point

Using the example graph above, slope $= \dfrac{(2.0 - 0.1)\ \text{m}}{(0.41 - 0.02)\ \text{s}^2} = \dfrac{1.9\ \text{m}}{0.39\ \text{s}^2} = 4.9\ \text{m/s}^2$

For an expression relating g to the slope — 1 point

In the example given, $D = \dfrac{1}{2}gt^2$, so $\dfrac{1}{2}g =$ slope

For a value of g in the range $9\text{-}11\ \text{m/s}^2$ — 1 point

In the example given, $g = 2\left(4.9\ \text{m/s}^2\right) = 9.8\ \text{m/s}^2$

(e) 3 points

For a good, specific improvement — 2 points

For an explanation of how this would improve accuracy — 1 point

Example: Do several trials for each value of D and take averages. This reduces personal and random error.

One point could be earned for less appropriate or less specific answers, for example "do trials in a vacuum" or "cut down on air resistance."

Question 2

15 points total	**Distribution of points**

(a) 4 points

For any use of conservation of energy	1 point
For example, initially the small block has only potential energy, and it is all converted to kinetic energy when it reaches the bottom of the ramp.	
For a correct expression for the initial potential energy	1 point
For a correct expression for the kinetic energy at the bottom of the ramp	1 point
$Mgh = \frac{1}{2}M(3.5v_0)^2$	
For the correct answer	1 point
$h = \frac{3.5^2}{2}\frac{v_0^2}{g}$ or equivalent	

(b) 4 points

For any use of conservation of momentum	1 point
For a correct expression for the initial momentum of the blocks	1 point
For a correct expression for the final momentum of the blocks	1 point
$M(3.5v_0) = Mv + (1.5M)(2v_0)$	
$v = 3.5v_0 - 3v_0$	
For the correct answer	1 point
$v = 0.5v_0$	

(c) 4 points

For a correct relationship between friction and the acceleration of the block	1 point
$\sum F = ma = f_{fric}$	
For a correct kinematic equation relating acceleration and distance that does not contain time	1 point
$v_f^2 = v_i^2 - 2aD$	
For using the correct initial speed of the block	1 point
$0 = 4v_0^2 - 2aD$	
$a = 2v_0^2/D$	
Substituting expressions for *a* and *f* into the first equation above	
$(1.5M)2v_0^2/D = \mu(1.5M)g$	
For the correct answer	1 point
$\mu = 2v_0^2/Dg$	

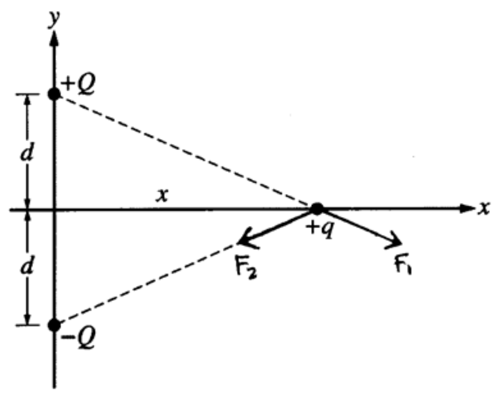
Question 2 (continued)

	Distribution of points
(c) (continued)	
Alternate solution	*Alternate points*
For any indication that the work done on the block as it slides is equal to its initial kinetic energy	*1 point*
$f_{fric}d = \frac{1}{2}mv_i^2$	
For a correct expression for the work done on the block	*1 point*
For a correct expression for the initial kinetic energy of the block	*1 point*
$\mu(1.5M)gD = \frac{1}{2}(1.5M)(2v_0)^2$	
For the correct answer	*1 point*
$\mu = \dfrac{2v_0^2}{Dg}$	
(d) 3 points	
For indicating that the collision is inelastic	1 point
For indicating that the reason it is inelastic is because the change in kinetic energy is not zero, or because kinetic energy is lost in the collision	1 point
For showing that the change in kinetic energy is not zero	1 point
$\Delta K = K_f - K_i = \left[\frac{1}{2}M(0.5v_0)^2 + \frac{1}{2}(1.5M)(2v_0)^2\right] - \frac{1}{2}M(3.5v_0)^2$	
$\Delta K = -3Mv_0^2$	

Question 3

15 points total **Distribution of points**

(a) 2 points



For indicating the correct direction for the force due to the $+Q$ charge (F_1 as drawn above) 1 point

For indicating the correct direction for the force due to the $-Q$ charge (F_2 as drawn above) 1 point

(b) 6 points

For any indication that the magnitudes of F_1 and F_2 are the same 1 point

The x-components of F_1 and F_2 cancel.

For any indication that the magnitude of the net force is the sum of the y-components of F_1 and F_2, which are equal 1 point

Example: $F_{total} = F_1 \cos\theta + F_2 \cos\theta = 2F\cos\theta$, where θ is the angle between the y-axis and the dashed lines in the figure

For a correct expression for $\cos\theta$ 1 point

$$\cos\theta = \frac{d}{\sqrt{x^2 + d^2}}$$

For a correct substitution for F into the above expression for F_{total} 1 point

$$F = \frac{kqQ}{r^2} = \frac{kqQ}{x^2 + d^2}$$

$$F_{total} = 2\frac{kqQ}{x^2 + d^2}\frac{d}{\sqrt{x^2 + d^2}}$$

For the correct magnitude of the total force 1 point

$$F_{total} = \frac{2kqQd}{\left(x^2 + d^2\right)^{3/2}} \quad \text{or equivalent}$$

For indicating the correct direction for the total force, e.g., negative y-direction, toward the bottom of the page, etc. 1 point

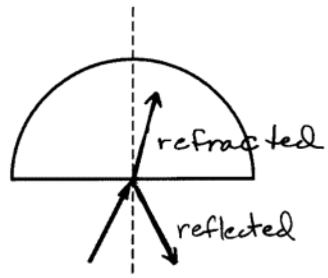
Question 3 (continued)

	Distribution of points
(c) 2 points	
The field can be found from the force. $E = F_{total}/q$	
For the correct magnitude of the electric field $E = \dfrac{2kQd}{\left(x^2 + d^2\right)^{3/2}}$	1 point
For indicating the correct direction for the electric field, e.g., negative *y*-direction, toward the bottom of the page, etc.	1 point
(d) 2 points	
The total potential is the sum of the individual point charge potentials. $V = V_1 + V_2 = \dfrac{kQ}{\sqrt{x^2 + d^2}} + \dfrac{-kQ}{\sqrt{x^2 + d^2}}$	
For indicating that the electric potential is zero *Note: One point partial credit could be earned for only recognizing that the potentials from the two charges must be added.*	2 points
(e) 3 points	
For any indication that as x gets large, the hypotenuse and x are approximately equal or d is negligible compared to x	1 point
For indicating that the above implies that $\sqrt{x^2 + d^2} \approx x$	1 point
For indicating that substituting the approximate equality into the answer from part (b) yields $F_{total} = \dfrac{2kqQd}{x^3}$	1 point

Question 4

15 points total **Distribution of points**

(a)



(i) 2 points

For drawing a reflected ray at approximately the same angle to the normal as the incident ray — 1 point
For clearly indicating that this is the reflected ray — 1 point

(ii) 4 points

Snell's law is used to find the angle of refraction
$n_1 \sin\theta_1 = n_2 \sin\theta_2$
For correctly substituting values into Snell's law — 1 point
$1.0 \sin 27° = 1.51 \sin\theta_2$
$\sin\theta_2 = \sin 27°/1.51 = 0.30$
For the correct value of the angle — 1 point
$\theta_2 = 17.5°$
For drawing a ray at approximately the correct angle — 1 point
For clearly indicating that this is the refracted ray — 1 point

(iii) 1 point

The speed in the block can be determined using the definition of index of refraction.
$\upsilon = c/n = \left(3.00 \times 10^8 \text{ m/s}\right)/1.51$
For the correct answer — 1 point
$\upsilon = 1.99 \times 10^8 \text{ m/s}$

Question 4 (continued)

Distribution of points

(a) (continued)

(iv) 2 points

For a statement that the frequency is the same in the two materials, or an equation that is an application of that fact — 1 point

$$\left.\begin{aligned} f &= \frac{v_{\text{air}}}{\lambda_{\text{air}}} = \frac{v_{\text{plastic}}}{\lambda_{\text{plastic}}} \\ \lambda_{\text{plastic}} &= \frac{v_{\text{plastic}}\lambda_{\text{air}}}{v_{\text{air}}} \end{aligned}\right\} \quad \text{OR} \quad \lambda_{plastic} = \frac{\lambda_{air}}{n}$$

$$\lambda_{\text{plastic}} = \frac{1.99\times10^8 \text{ m/s}}{3\times10^8 \text{ m/s}}(650 \text{ nm}) \quad \text{OR} \quad \lambda_{plastic} = \frac{650 \text{ nm}}{1.51}$$

For the correct answer with units — 1 point

$\lambda_{\text{plastic}} = 431$ nm OR 430 nm

(b) 2 points

The following points were only awarded if rays were shown or described in part (a)

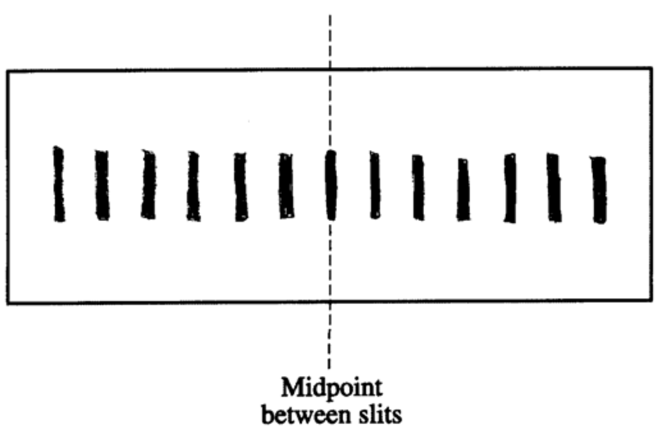
For indicating that the angle of reflection does not change — 1 point

For indicating that the angle of refraction becomes smaller — 1 point

(c)

(i) 2 points

Example in which the dark lines in the drawn pattern represent the bright bands of blue light



For indicating a central peak in the pattern — 1 point

For having approximately even spacing between maxima — 1 point

A sketch of the intensity graph was also acceptable

Question 4 (continued)

	Distribution of points
(c) (continued)	
(ii) 2 points	
For using an appropriate formula (or combination of formulas) and correctly substituting	1 point
For example	
$x_m \approx \dfrac{m\lambda L}{d}$	
$x_m \approx \dfrac{(1)\left(450 \times 10^{-9}\ \text{m}\right)(1.4\ \text{m})}{0.15 \times 10^{-3}\ \text{m}}$	
For the correct answer	1 point
$x = 4.2\ \text{mm}$	

Question 5

10 points total | **Distribution of points**

(a)

(i) 2 points

From the ideal gas law, $PV/T =$ a constant

Points A and B are on the isothermal, so they are at the same temperature.

Therefore, $P_B V_B = P_A V_A$

$P_B 2V_0 = P_A V_0$

For the correct answer — 1 point

$\frac{P_B}{P_A} = \frac{1}{2}$

For a correct justification (such as the reasoning shown above) — 1 point

(ii) 2 points

Points C and B are at the same pressure.

Therefore, $\frac{P_C}{P_A} = \frac{P_B}{P_A}$

For the correct answer — 1 point

$\frac{P_C}{P_A} = \frac{1}{2}$

For a correct justification (such as the reasoning shown above) — 1 point

(iii) 2 points

Points A and B are on the isothermal, so they are at the same temperature.

For the correct answer — 1 point

$\frac{T_B}{T_A} = 1$

For a correct justification (such as the reasoning shown above) — 1 point

Question 5 (continued)

	Distribution of points
(a) (continued)	
(iv) 2 points	
Points C and A are at the same volume. Therefore, from the ideal gas law $\dfrac{P_C}{P_A} = \dfrac{T_C}{T_A}$.	
$\dfrac{P_C}{P_A} = \dfrac{1}{2}$, which was determined in part (ii) above	
For the correct answer	1 point
$\dfrac{T_C}{T_A} = \dfrac{1}{2}$	
For a correct justification (such as the reasoning shown above)	1 point
(b) 1 point	
For a correct explanation	1 point
Internal energy depends only on the temperature. Since step I is isothermal there is no change in temperature and thus no change in internal energy	
(c) 1 point	
For a correct explanation	1 point
$W = -P\Delta V$. In step III there is no change in volume, and thus no work done.	

Question 6

10 points total	**Distribution of points**

(a) 1 point

For a correct expression for kinetic energy	1 point
$K = mv^2/2$	
<u>Note</u>: *This point was only awarded if no extraneous energy formulas were used.*	

(b) 2 points

For using the correct expression for de Broglie wavelength	1 point
$\lambda = h/p$	
For the correct answer in terms of the given quantities	1 point
$\lambda = h/mv$	

(c) 2 points

For a correct expression for the total energy of the electron and positron	1 point
$E_{total} = 2\left(mv^2/2 + mc^2\right)$	
Can also add that since $v << c$, $E_{total} \approx 2mc^2$	
The two photons share this energy equally.	
For the correct answer	1 point
$E_{photon} = mv^2/2 + mc^2$ OR $E_{photon} \approx mc^2$	

(d) 3 points

For using the given expression for the photon energy	1 point
$E_{photon} = hf$	
For expressing the energy in terms of the wavelength	1 point
$f = c/\lambda$ so $E_{photon} = hc/\lambda$	
Substituting the energy obtained in part (c)	
$mv^2/2 + mc^2 = hc/\lambda$ OR $mc^2 = hc/\lambda$	
For the correct answer	1 point
$\lambda = 2hc/\left(mv^2 + 2mc^2\right)$ OR $\lambda = h/mc$	

(e) 2 points

For any indication that conservation of momentum applies	1 point
For a correct explanation of why conservation of momentum requires two photons	1 point
Example: since the total momentum of the electron and positron was zero, the total momentum of the products must be zero. Since a photon cannot have zero momentum, two photons traveling in opposite directions are required.	
<u>Note</u>: *Only 1 point total was awarded for attempts to explain using Newton's third law.*	