AP® PHYSICS B
2007 SCORING GUIDELINES

General Notes About 2007 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 and 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 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 7

Distribution of points

(a) 3 points

Using the relationship between mass and energy

$E = m_e c^2$

For correct substitutions of the positron mass and the speed of light — 1 point

For the correct value of energy in joules — 1 point

$E = \left(9.11 \times 10^{-31}\ \text{kg}\right)\left(3.00 \times 10^{8}\ \text{m/s}\right)^2 = 8.20 \times 10^{-14}\ \text{J}$

For using the correct factor to convert from joules to eVs — 1 point

$E = 8.20 \times 10^{-14}\ \text{J} / 1.60 \times 10^{-19}\ \text{J/eV}$

$E = 5.12 \times 10^{5}\ \text{eV}$

(b) 1 point

Since the electron and positron have the same mass, the energy before annihilation is twice the value found in part (a). That energy goes into creating the two photons of equal energy, so each photon has the energy equivalent of one of the particles.

For any indication that this is the same numerical answer as in part (a) — 1 point

$E_\gamma = 5.12 \times 10^{5}\ \text{eV}$

<u>Note:</u> *Full credit was earned if the student's answer to part (a) was zero and the correct calculation shown for part (a) was done here.*

(c) 3 points

For a correct equation relating energy and wavelength — 1 point

$E_\gamma = hf = \dfrac{hc}{\lambda}$

For substituting the value of energy from part (b), either in eV or joules — 1 point

For substituting a value of h or hc in units that are consistent with those of the energy used — 1 point

$\lambda = hc/E_\gamma = \left(1.24 \times 10^{3}\ \text{eV}\bullet\text{nm}\right)/\left(5.12 \times 10^{5}\ \text{eV}\right)$

$\lambda = 2.42 \times 10^{-3}\ \text{nm} = 2.42 \times 10^{-12}\ \text{m}$

Alternate solution — *Alternate points*

Using the relationship between wavelength and momentum

$\lambda = h/p$

For substituting values for h and p (but not earned if $p = mv$ was used) — *1 point*

For using the value of p from part (d) — *1 point*

For substituting a value of h in units that are consistent with those of the momentum used — *1 point*

$\lambda = \left(6.63 \times 10^{-34}\ \text{J}\bullet\text{s}\right)/\left(2.73 \times 10^{-22}\ \text{kg}\bullet\text{m/s}\right)$

$\lambda = 2.42 \times 10^{-3}\ \text{nm} = 2.42 \times 10^{-12}\ \text{m}$

Question 7 (continued)

	Distribution of points
(d) 2 points	
$\lambda = h/p$	
For correct substitutions, using the value of λ determined in (c)	1 point
$p = h/\lambda = \dfrac{6.63 \times 10^{-34}\ \text{J}\bullet\text{s}}{2.42 \times 10^{-12}\ \text{m}}$ or $\dfrac{4.14 \times 10^{-5}\ \text{eV}\bullet\text{s}}{2.42 \times 10^{-12}\ \text{m}}$	
For correct units in the final answer	1 point
$p = 2.74 \times 10^{-22}\ \text{kg}\bullet\text{m/s}$ (or N•s or J•s/m) or $0.0017\ \text{eV}\bullet\text{s/m}$	
Alternate solution	*Alternate points*
$E = pc$	
For substituting the value of energy from part (b)	*1 point*
$p = \dfrac{E}{c} = \dfrac{\left(8.20 \times 10^{-14}\ \text{J}\right)}{3.00 \times 10^{8}\ \text{m/s}}$ *OR* $\dfrac{\left(5.12 \times 10^{5}\ \text{eV}\right)}{3.00 \times 10^{8}\ \text{m/s}}$	
For correct units in the final answer	*1 point*
$p = 2.73 \times 10^{-22}\ \text{kg}\bullet\text{m/s}$ (or N•s or J•s/m) or $0.0017\ \text{eV}\bullet\text{s/m}$	
(e) 1 point	
For indicating that the total momentum is zero	1 point

7. (10 points)

It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron-positron pair before annihilation is negligible compared to the energy of the photons created.

(a) Calculate, in eV, the rest energy of a positron.

$q = 1.6\times10^{-19}C$
$m = 9.11\times10^{-31}kg$

$E = mc^2$
$E = (9.11\times10^{-31}kg)(3\times10^8 m/s)^2$
$E = 8.199\times10^{-14}J \cdot \frac{1eV}{1.6\times10^{-19}J} = 5.12\times10^5 eV$

(b) Determine, in eV, the energy each emitted photon must have.

Total energy $= 2$ (E from above)
$= 2(5.12\times10^5 eV$
$= 1.024\times10^6 eV$ for total ($\frac{1}{2}$ of this per photon)
energy of 1 photon $= 5.12\times10^5 eV$

(c) Calculate the wavelength of each created photon.

$\frac{hc}{\lambda} = E \qquad \lambda = \frac{hc}{E} = \frac{1240 eVnm}{5.12\times10^5 eV} = \boxed{2.42\times10^{-12}m \quad \lambda = 2.42\,pm}$

since the energies of the positron + electron are the same, so is that of both photons

(d) Calculate the magnitude of the momentum of each photon.

$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}J\cdot s}{2.42\times10^{-12}m} = 2.74\times10^{-22} N\cdot s$

The momentums of each photon is the same, but the other is -2.74×10^{-22} N·s because it travels in the opposite direction

(e) Determine the total momentum of the two-photon system.

The total momentum is zero because the two photons have equal and opposite momentums

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7. (10 points)

It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron-positron pair before annihilation is negligible compared to the energy of the photons created.

(a) Calculate, in eV, the rest energy of a positron.

$E = (9.11\times10^{-31})\ (3\times10^{8})^2 = 8.199\times10^{-14}\,J \times \frac{1eV}{1.6\times10^{-19}J}$

$= 512\ 000\ eV$

(b) Determine, in eV, the energy each emitted photon must have.

$E = mc^2 \qquad E = (1.67\times10^{-27})\ (3\times10^{8})^2$

$E = 1.503\times10^{-10} \times \frac{1eV}{1.6\times10^{-19}J}$

$E = 9.4\times10^{8}\,eV$

(c) Calculate the wavelength of each created photon.

$E = \frac{hc}{\lambda} \qquad \lambda = \frac{hc}{E} \qquad \lambda = \frac{6.63\times10^{-34}\cdot 3\times10^{8}}{1.503\times10^{-10}}$

$\lambda = 1.32\times10^{-15}\,m$

(d) Calculate the magnitude of the momentum of each photon.

$p = mv \qquad p = (1.67\times10^{-27})\ (3\times10^{8})$

$= 5.01\times10^{-19}\ N/s$

(e) Determine the total momentum of the two-photon system.

$p_{TOT} = 0$ the momentum of each photon is equal in magnitude but opposite in force, so they cancel each other out

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7. (10 points)

It is possible for an electron and a positron to orbit around their stationary center of mass until they annihilate each other, creating two photons of equal energy moving in opposite directions. A positron is a particle that has the same mass as an electron and equal but opposite charge. The amount of kinetic energy of the electron-positron pair before annihilation is negligible compared to the energy of the photons created.

(a) Calculate, in eV, the rest energy of a positron.

$Q = 1.6 \times 10^{-19}\,C$

$m = 9.11 \times 10^{-31}$

$E = 0J$

(b) Determine, in eV, the energy each emitted photon must have.

$E = hf$

$E = 15J$

(c) Calculate the wavelength of each created photon. $c = \lambda f$

$c = \lambda f$

$E = hf$

$E = h\dfrac{c}{\lambda}$

$15 = (4.14 \times 10^{-15})\dfrac{(3 \times 10^{8})}{\lambda}$

$\boxed{\lambda = 8.28 \times 10^{-8}\,m}$

(d) Calculate the magnitude of the momentum of each photon.

$p = \dfrac{E}{c}$

$p = \dfrac{15}{3 \times 10^{8}} = \boxed{5 \times 10^{-8}\,kg \cdot \dfrac{m}{s}}$

(e) Determine the total momentum of the two-photon system.

$p = mv + mv$

$p = (5 \times 10^{-8})(5 \times 10^{-8})$

$p = 1 \times 10^{-7}\,kg \cdot \dfrac{m}{s}$

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Question 7

Overview

The final 10-point question on the exam evaluated students' understanding of some basic ideas in modern physics: mass-energy equivalence and the conservation of energy; the relationships among photon energy, photon momentum, and the corresponding wavelength; and conservation of the total momentum of an isolated system.

Sample: 7A
Score: 10

This student writes explicit reasoning for most of the parts, in addition to the needed calculations.

Sample: 7B
Score: 7

Part (a) earned full credit, but part (b) repeats the calculation with the proton mass and earned nothing. Part (c) earned full credit for a correct calculation with the incorrect value from part (b). Part (d) earned nothing, and part (e) earned full credit.

Sample: 7C
Score: 4

Parts (a) and (b) earned nothing. Part (c) got the points for a correct expression and for substituting the energy from part (b) but uses a value of h in eV and lost the consistency point. Part (d) earned full credit for correctly using an incorrect value from part (b). Part (e) earned nothing.