AP® PHYSICS
2012 SCORING GUIDELINES

General Notes About 2012 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 in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an 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 sheets. 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 owing 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 eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 7

10 points total | **Distribution of points**

(a) 2 points

For correct substitution of the momentum value into the de Broglie wavelength relationship — 1 point

$$\lambda = \frac{h}{p} = \frac{\left(6.63 \times 10^{-34}\ \text{J•s}\right)}{\left(5.5 \times 10^{-20}\ \text{kg•m/s}\right)}$$

For a correct answer, with units — 1 point

$\lambda = 1.2 \times 10^{-14}\ \text{m}$

(b) 2 points

For correct substitution of the momentum into an equation to compute the speed of the proton and substituting the speed into the equation for kinetic energy — 1 point

$$\upsilon = \frac{p}{m_p} = \frac{5.5 \times 10^{-20}\ \text{kg•m/s}}{1.67 \times 10^{-27}\ \text{kg}} = 3.3 \times 10^{7}\ \text{m/s}$$

$$K = \frac{1}{2}m\upsilon^2 = \frac{1}{2}\left(1.67 \times 10^{-27}\ \text{kg}\right)\left(3.3 \times 10^{7}\ \text{m/s}\right)^2$$

For a correct answer, with units — 1 point

$K = 9.1 \times 10^{-13}\ \text{J}$ (or $9.0 \times 10^{-13}\ \text{J}$, depending on earlier rounding)

Alternate solution — *Alternate points*

Derive formula for kinetic energy

$$K = \frac{1}{2}m\upsilon^2 = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m}$$

For using $K = \dfrac{p^2}{2m}$ *to find the kinetic energy* — *1 point*

$$K = \frac{\left(5.5 \times 10^{-20}\ \text{kg•m/s}\right)^2}{(2)\left(1.67 \times 10^{-27}\ \text{kg}\right)}$$

For a correct answer, with units — *1 point*

$K = 9.1 \times 10^{-13}\ \text{J}$

Question 7 (continued)

Distribution of points

(c) 3 points

For an attempt to apply conservation of energy to the system — 1 point

$U_1 + K_1 = U_2 + K_2$

U_1 is approximately zero (the proton is initially far away from the uranium nucleus)

$K_2 = 0$ (the proton is instantaneously at rest)

Therefore $K_1 = U_2$

For any correct expression that shows the electrostatic potential energy of the system at the proton's closest approach equal to the kinetic energy determined in part (b), using either symbols or values from the problem — 1 point

$$K_1 = U_2 = \frac{kq_1q_2}{r} = \frac{k(92e)(e)}{D}$$

$$K_1 = \frac{92ke^2}{D}$$

$$D = \frac{92ke^2}{K} = \frac{(92)\left(9 \times 10^9 \text{ N•m}^2/\text{C}^2\right)\left(1.6 \times 10^{-19} \text{ C}\right)^2}{\left(9.06 \times 10^{-13} \text{ J}\right)}$$

For a correct answer, with units — 1 point

$D = 2.3 \times 10^{-14}$ m

(d) 3 points

For selecting "Greater" — 1 point

For using the mass-energy relationship $E = mc^2$ in an attempt to solve for the mass defect of the uranium decaying into the daughter particles plus excess energy — 1 point

$E = \Delta mc^2$

$$\Delta m = \frac{E}{c^2} = \frac{\left(2.5 \times 10^{-11} \text{ J}\right)}{\left(3.0 \times 10^8 \text{ m/s}\right)^2}$$

For an answer with any proper units of mass — 1 point

$\Delta m = 2.8 \times 10^{-28}$ kg or $\Delta m = 0.17$ amu

7. (10 points)

The momentum of a particular proton is 5.5×10^{-20} kg•m/s. Relativistic effects can be ignored throughout this question.

(a) Calculate the de Broglie wavelength of the proton.

$\lambda = \frac{h}{p}$

$\lambda = \frac{6.63\times10^{-34}}{5.5\times10^{-20}}$

$\lambda = 1.2\times10^{-14}$ m

(b) Calculate the kinetic energy of the proton.

$p = mv$

$5.5\times10^{-20} = 1.67\times10^{-27} v$

$v = 3.3\times10^{7}$ m/s

$KE = \frac{1}{2}mv^2$

$KE = \frac{1}{2}(1.67\times10^{-27})(3.3\times10^{7})^2$

$KE = 9.1\times10^{-13}$ J

The proton is directed toward a very distant stationary uranium nucleus, $^{235}_{92}U$. The proton reaches a distance D from the center of the nucleus and then reverses direction. Assume that the nucleus is heavy enough to remain stationary during the interaction.

(c) Calculate the value of D.

U has 92 protons

$TE_0 = TE_f$

$KE_{p_0} + \cancel{KE_{n_0}} + \cancel{U_{E_0}} = \cancel{KE_{p_f}} + \cancel{KE_{nf}} + U_{E_f}$

$9.1\times10^{-13} = \frac{kq \cdot q_2}{r}$

$9.1\times10^{-13} = \frac{9\times10^{9}(1.6\times10^{-19})(92\cdot1.6\times10^{-19})}{D}$

$9.1\times10^{-13} D = 2.1\times10^{-26}$

$D = 2.3\times10^{-14}$ m

(d) After the proton has moved away, the $^{235}_{92}U$ nucleus spontaneously fissions into $^{148}_{57}La$ and $^{84}_{35}Br$, along with three neutrons. As a result, 2.5×10^{-11} J of energy is released. Indicate whether the mass of the $^{235}_{92}U$ nucleus is greater or less than the mass of the fission products.

____ Greater ✓ Less

Calculate the mass difference.

$E = \Delta m c^2$

$2.5\times10^{-11} = \Delta m (3\times10^{8})^2$

2.7×10^{-28} kg $= \Delta m$

$\Delta m = 2.7\times10^{-28}$ kg

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7. (10 points)

The momentum of a particular proton is 5.5×10^{-20} kg•m/s. Relativistic effects can be ignored throughout this question.

(a) Calculate the de Broglie wavelength of the proton.

$\lambda = \frac{h}{p}$ $\quad \lambda = \frac{6.63 \times 10^{-34}}{5.5 \times 10^{-20}}$ $\quad \boxed{\lambda = 1.21 \times 10^{-14} m}$

(b) Calculate the kinetic energy of the proton.

$KE = \frac{1}{2}mv^2$

$KE = \frac{1}{2}(1.67 \times 10^{-27})(3 \times 10^{8^2})$

$\boxed{KE = 7.52 \times 10^{-11} J}$

The proton is directed toward a very distant stationary uranium nucleus, ${}^{235}_{92}U$. The proton reaches a distance D from the center of the nucleus and then reverses direction. Assume that the nucleus is heavy enough to remain stationary during the interaction.

(c) Calculate the value of D.

(U) ← proton

$D = \frac{m_1 + m_2}{2}$ $\quad D = \frac{(92) + (1.67 \times 10^{-27})}{2}$

$\boxed{D = \approx 46m}$

(d) After the proton has moved away, the ${}^{235}_{92}U$ nucleus spontaneously fissions into ${}^{148}_{57}La$ and ${}^{84}_{35}Br$, along with three neutrons. As a result, 2.5×10^{-11} J of energy is released. Indicate whether the mass of the ${}^{235}_{92}U$ nucleus is greater or less than the mass of the fission products.

X Greater ____ Less

Calculate the mass difference.

$E = mc^2$

$2.5 \times 10^{-11} = m(3 \times 10^{8^2})$

$\boxed{\text{mass difference} = 2.78 \times 10^{-28} kg}$

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7. (10 points)

The momentum of a particular proton is 5.5×10^{-20} kg•m/s. Relativistic effects can be ignored throughout this question.

(a) Calculate the de Broglie wavelength of the proton.

$\lambda = \frac{h}{p}$

$\lambda = \frac{6.63 \times 10^{-34}}{5.5 \times 10^{-20}}$

$\lambda = 1.205 \times 10^{-14}$

$p = mv$

$5.5 \times 10^{-20} = 1.67 \times 10^{-27} \cdot v$

$v = 32934131.74$ m/s

(b) Calculate the kinetic energy of the proton.

$KE = \frac{1}{2} m v^2$ $m = 1.67 \times 10^{-27}$

$KE = 9.057 \times 10^{-13}$

The proton is directed toward a very distant stationary uranium nucleus, $^{235}_{92}U$. The proton reaches a distance D from the center of the nucleus and then reverses direction. Assume that the nucleus is heavy enough to remain stationary during the interaction.

(c) Calculate the value of D.

$q_u = 92(1.6 \times 10^{-19} C)$

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

$(1-D)$ original distance − final distance

$d = 1-D$

$V_0 = 32934131.74$

$V_f = 0$

$a = ?$

$0 = 32934131.74^2 + 2a(1-D)$

$a = \frac{-32934131.74^2}{2(1-D)} = \frac{-5.42 \times 10^{14}}{1-D}$

$F = \frac{k q_u q_p}{D^2}$

$ma = \frac{1.3392 \times 10^{-7}}{D^2}$

$ma = 1.67 \times 10^{-27} \left(\frac{-5.4233 \times 10^{14}}{(1-D)}\right)$

$D^2 \left(\frac{-5.4233 \times 10^{14}}{(1-D)}\right) = 8.0192 \times 10$

$\frac{-5.4233 \times 10^{14} D^2}{D^2 - D^3} = 8.0192 \times 10^{1}$

use graphing calc to find D

(d) After the proton has moved away, the $^{235}_{92}U$ nucleus spontaneously fissions into $^{148}_{57}La$ and $^{84}_{35}Br$, along with three neutrons. As a result, 2.5×10^{-11} J of energy is released. Indicate whether the mass of the $^{235}_{92}U$ nucleus is greater or less than the mass of the fission products.

____ Greater ✓ Less

Calculate the mass difference.

$\Delta E = (\Delta m) c^2$

$2.5 \times 10^{-11} = \Delta m c^2$

$\Delta = 8.\overline{33} \times 10^{-20}$ kg

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Question 7

Overview

This question assessed students' understanding of the wave nature of protons, nuclear collision, and the energy involved in spontaneous nuclear fission.

Sample: B7-A
Score: 9

This response is a good example of a very clean and well-organized solution. Only 1 point was lost, because the incorrect answer is chosen in part (d).

Sample: B7-B
Score: 5

Full credit was earned in part (a). No points were awarded in part (b), because the student uses the speed of light as the proton's speed in the kinetic energy expression. In part (c) no credit was earned. Full credit was earned in part (d).

Sample: B7-C
Score: 3

This response earned 1 of the 2 points in part (a). The scoring guidelines call for a correct answer with units, and the units are missing here. In part (b), again, 1 of the 2 points was lost because of the lack of units in the answer. No credit was earned in part (c), because the student incorrectly attempts to use dynamics and kinematics to calculate the distance D. Instead, energy must be used to correctly solve this problem. One point was earned in part (d) for the use of $E = mc^2$ to relate mass to energy.