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 6

10 points total | **Distribution of points**

(a) 3 points

For correctly expressing frequency in terms of speed of light and wavelength, either with symbols or numerical values — 1 point

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^{8}\text{ m/s}}{1.5 \times 10^{-8}\text{ m}} = 2.0 \times 10^{16}\text{ Hz}$$

For substituting the expression for frequency into the equation for the energy of a photon — 1 point

$$E = hf = (6.63 \times 10^{-34}\text{ J} \cdot \text{s})(2.0 \times 10^{16}\text{ Hz})$$

For the correct answer with correct units — 1 point

$$E = 1.33 \times 10^{-17}\text{ J} = 82.7\text{ eV}$$

Alternate solution — *Alternate points*

For correctly expressing the momentum of the photon in terms of Planck's constant and the wavelength, either with symbols or numerical values — *1 point*

$$\lambda = \frac{h}{p} \quad \text{or} \quad p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}\text{ J} \cdot \text{s}}{1.5 \times 10^{-8}\text{ m}} = 4.42 \times 10^{-26}\text{ kg•m/s}$$

For substituting the expression for the momentum into the energy-momentum relationship for a photon — *1 point*

$$E = pc = (4.42 \times 10^{-26}\text{ N} \cdot \text{s})(3.0 \times 10^{8}\text{ m/s})$$

For the correct answer with correct units — *1 point*

$$E = 1.33 \times 10^{-17}\text{ J} = 82.7\text{ eV}$$

(b) 4 points

The kinetic energy of a massive particle is given by

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

For substituting the energy in joules from part (a) as the kinetic energy to calculate the speed of the electron — 1 point

$$1.33 \times 10^{-17}\text{ J} = \frac{1}{2}(9.11 \times 10^{-31}\text{ kg})v^2$$

$$v = 5.4 \times 10^{6}\text{ m/s}$$

For calculating the momentum of the electron using the speed calculated above — 1 point

$$p = mv = (9.11 \times 10^{-31}\text{ kg})(5.4 \times 10^{6}\text{ m/s})$$

For substituting the momentum into the equation for the deBroglie wavelength — 1 point

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}\text{ J•s}}{(9.11 \times 10^{-31}\text{ kg})(5.4 \times 10^{6}\text{ m/s})}$$

For the correct answer with correct units — 1 point

$$\lambda = 1.35 \times 10^{-10}\text{ m}$$

Question 6 (continued)

Distribution of points

(c) 3 points

The expected answer is a description of an experiment in which a beam of electrons is aimed at either a single slit, a double slit, a diffraction grating, or a crystal. The student must also describe the interference pattern of maxima and minima appearing on a screen as evidence of the wave nature of the electron.

For using a beam of electrons (NOT a single electron)	1 point
For aiming the electron beam at one of the objects noted above	1 point
For indicating that the resultant is an interference pattern (a drawing was acceptable)	1 point

Notes:

If the experiment description is completely correct except that it includes a beam of light instead of electrons, it earned two of the three possible points.

No points were earned for merely naming an experiment, either in reference to commonly known experimenters ("Davisson–Germer experiment") or pieces of equipment ("double-slit experiment").

6. (10 points)

A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.

(a) Calculate the energy of the photon.

$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34}(3 \times 10^{8} \frac{m}{s})}{1.5 \times 10^{-8} m} = \boxed{1.326 \times 10^{-17} J = E_{photon}}$

(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.

$1.326 \times 10^{-17} J = KE = \frac{1}{2} mv^2 = \frac{1}{2}(9.11 \times 10^{-31} kg) v^2$

$v = 5.395 \times 10^{6} m/s$

$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{(9.11 \times 10^{-31})(5.395 \times 10^{6} m/s)} = \boxed{1.349 \times 10^{-10} m = \lambda}$

(c) Describe an experiment that illustrates the wave properties of this electron.

an experiment that describes the wave properties of an electron is the Double-Slit experiment. This experiment ~~...~~ prove that electrons spread out like light ~~of~~ rays do, and will not be found in some areas if forced through small ~~...~~ slits, because they experience destructive interfearance

B6B

6. (10 points)

A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.

(a) Calculate the energy of the photon.

$E_{ph} = \frac{hc}{\lambda}$ $\quad \frac{1.99 \times 10^{-25} \text{ J}\cdot\text{m}}{1.5 \times 10^{-8} \text{ m}} = 1.33 \times 10^{-17} \text{ J}$

(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.

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

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

$\lambda = 1.35 \times 10^{-10}$ m

$KE = E_{ph}$

$\frac{1}{2}mv^2 = 1.33 \times 10^{-17}$

$\frac{1}{2}(9.11 \times 10^{-31})\, v^2 = 1.33 \times 10^{-17}$

$v = 5.39 \times 10^{6}$

(c) Describe an experiment that illustrates the wave properties of this electron.

Rutherford experiment

6. **(10 points)**

A photon with a wavelength of 1.5×10^{-8} m is emitted from an ultraviolet source into a vacuum.

(a) Calculate the energy of the photon.

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

$1.5\times10^{-8} = \frac{6.63\times10^{-34}}{p}$

$p = 4.42\times10^{-26}$

$E = pc$

$E = 4.42\times10^{-26}(3.00\times10^{8})$

$E = 1.326\times10^{-17}\,J$

(b) Calculate the de Broglie wavelength of an electron with kinetic energy equal to the energy of the photon.

$1.3\lambda\; K_{max} = hf - \phi$

$1.326\times10^{-17} = 6.63\times10^{-34} f - \phi$

$\frac{1.326\times10^{-17} + \phi}{6.63\times10^{-34}} = f$

(c) Describe an experiment that illustrates the wave properties of this electron.

The de Broglie experiment

Question 6

Overview

This was a 10-point question intended to test student knowledge of topics in modern physics: specifically, the energy of a photon and wave-particle duality. In part (a) students were given the wavelength of a photon and asked to calculate its energy. In part (b) students were asked to calculate the de Broglie wavelength of an electron with the same kinetic energy as the photon in part (a). In part (c) students were asked to describe an experiment that would demonstrate the wave nature of the electron.

Sample: B6A
Score: 10

This response contains typical correct solutions to parts (a) and (b). The description of the experiment in part (c) is correct and includes all of the necessary components.

Sample: B6B
Score: 7

Parts (a) and (b) earned full credit. Even though the substitution of momentum in part (b) is not explicitly written in the expression for the wavelength, the correct equations and correct answer are acceptable for credit. Part (c) earned nothing.

Sample: B6C
Score: 3

Part (a) uses the alternate solution and earned full credit. None of the remaining work is correct.