AP® Physics B
2011 Scoring Guidelines

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AP® PHYSICS
2011 SCORING GUIDELINES

General Notes About 2011 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 earned. 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 earn 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 earned. 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*.

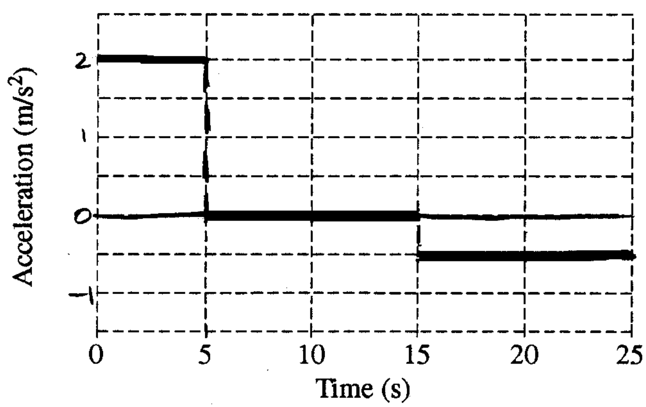
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 earn 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 using a linear scale on the vertical axis	1 point
For showing horizontal lines in the three appropriate time frames	1 point
For having the correct acceleration values for segments *B* and *C*	1 point

(The correct value for segment *A* is accounted for in the answer point in part (d).)

$a = \Delta v/\Delta t$ (or the slope of the velocity versus time curve)

For segment *A*: $a = (10\,\text{m/s} - 0\,\text{m/s})/(5\text{ s} - 0\text{ s}) = 2\,\text{m/s}^2$

For segment *B*: slope is zero, so acceleration is zero

For segment *C*: $a = (5\,\text{m/s} - 10\,\text{m/s})/(25\text{ s} - 15\text{ s}) = -0.5\,\text{m/s}^2$

(b) 2 points

$x = x_0 + v_0 t + (1/2)at^2$, where $x_0 = 0$

For substituting $v_0 = 0$ and $t = 5$ s into the equation above	1 point
For substituting the value on the graph of the constant acceleration between 0 and 5 s or an explicit calculation of $2\,\text{m/s}^2$	1 point

$x = (1/2)(2\ \text{m/s}^2)(5\text{ s})^2$

$x = 25$ m

Alternate solution — *Alternate points*

Position is the area under the velocity versus time curve.

For correctly substituting into the expression for the area under the curve	*1 point*

$x = (1/2)(10\,\text{m/s})(5\text{ s})$

For the correct answer	*1 point*

$x = 25$ m

Question 1 (continued)

	Distribution of points
(c) 2 points	
For selecting segment *B*	1 point
For an appropriate justification	1 point
Example: $F_{net} = ma = m(\Delta v/\Delta t)$, the velocity is constant for this segment, so $\Delta v = 0$; therefore, $F_{net} = 0$.	
(d) 2 points	
For using Newton's second law	1 point
$F_{net} = ma$	
$F_{net} = (0.40\ \text{kg})\left(2\ \text{m/s}^2\right)$	
For the correct answer	1 point
$F_{net} = 0.80\ \text{N}$	
(e) 2 points	
For using the work-energy theorem	1 point
$W = F\Delta r\cos\theta$	
To move in a straight line, the net force must be in the direction of motion, so $\theta = 0°$.	
$W = F_{net}d$	
For substituting the value of the position determined in from part (b), which is equal to the displacement, to determine the work done for segment *A*	1 point
For segment *A*, $W_A = (0.8\ \text{N})(25\ \text{m}) = 20\ \text{J}$	
For segment *B*, $W_B = (0\ \text{N})(10\ \text{m/s})(10\ \text{s}) = 0\ \text{J}$	
$W_{tot} = W_A + W_B = 20\ \text{J} + 0\ \text{J} = 20\ \text{J}$	
Alternate solution	*Alternate points*
$W = \Delta K$	
$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$	
For correct substitutions into the equation above	*1 point*
$W = \frac{1}{2}(0.40\ \text{kg})(10\ \text{m/s})^2 - \frac{1}{2}(0.40\ \text{kg})(0\ \text{m/s})^2$	
For the correct answer	*1 point*
$W = 20\ \text{J}$	

Question 1 (continued)

	Distribution of points
(f) 3 points	
For selecting "Negative"	1 point
For an appropriate explanation using kinematic or dynamic principles	1 point
Examples:	
The velocity is decreasing, so the kinetic energy is also decreasing.	
The acceleration is negative; therefore, the direction of the net force is opposite to the direction of the displacement.	
For connecting the explanation to the work done	1 point
Units	1 point
For correct units on at least two parts with a calculated numerical answer and no incorrect units	1 point

Question 2

15 points total | **Distribution of points**

(a)

i. 3 points

For writing the appropriate expression for the electric potential, given the spherical symmetry of the situation — 1 point

$V = \frac{kq}{r}$

The electric field inside a conducting sphere in equilibrium is zero, so the potential inside the sphere is constant, uniform, and equal to the potential at the surface.

$V = \frac{kq}{R_1}$

For correct substitutions — 1 point

$V = \frac{\left(9.0 \times 10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9}\ \text{C}\right)}{0.12\ \text{m}}$

For the correct answer — 1 point

$V = 480\ \text{V}$

ii. 2 points

For writing the appropriate expression for the electric potential — 1 point

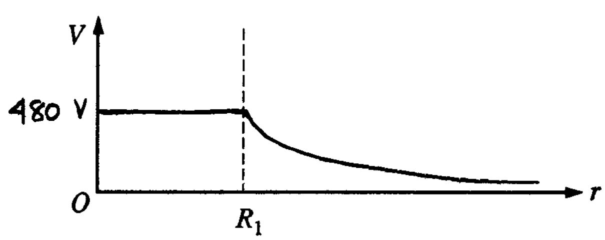
$V = \frac{kq}{r}$

$V = \frac{\left(9.0 \times 10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9}\ \text{C}\right)}{0.24\ \text{m}}$

For the correct answer calculated from a correct expression showing substitutions — 1 point

$V = 240\ \text{V}$

(b) 3 points



For labeling the potential at $r = 0$ with the value from part (a) i — 1 point

For drawing a horizontal line from $r = 0$ to $r = R_1$ that is continuous with the other part of the graph — 1 point

For drawing a reasonable curve for the $1/r$ dependence in the region beyond R_1 — 1 point

Question 2 (continued)

Distribution of points

(c)

i. 2 points

$r = 0.10 \text{ m} < 0.12 \text{ m} = R_1$

There is no electric field inside a conducting sphere in equilibrium.

For the correct answer — 2 points

$E = 0 \text{ N/C}$

ii. 2 points

$r = 0.24 \text{ m} > 0.12 \text{ m} = R_1$, so the charge can be treated as a point charge at the center of the sphere.

For writing the appropriate expression for the electric field — 1 point

$$E = \frac{kq}{r^2}$$

$$E = \frac{\left(9.0 \times 10^9 \text{ N}\bullet\text{m}^2/\text{C}^2\right)\left(6.4 \times 10^{-9} \text{ C}\right)}{(0.24 \text{ m})^2}$$

For the correct answer — 1 point

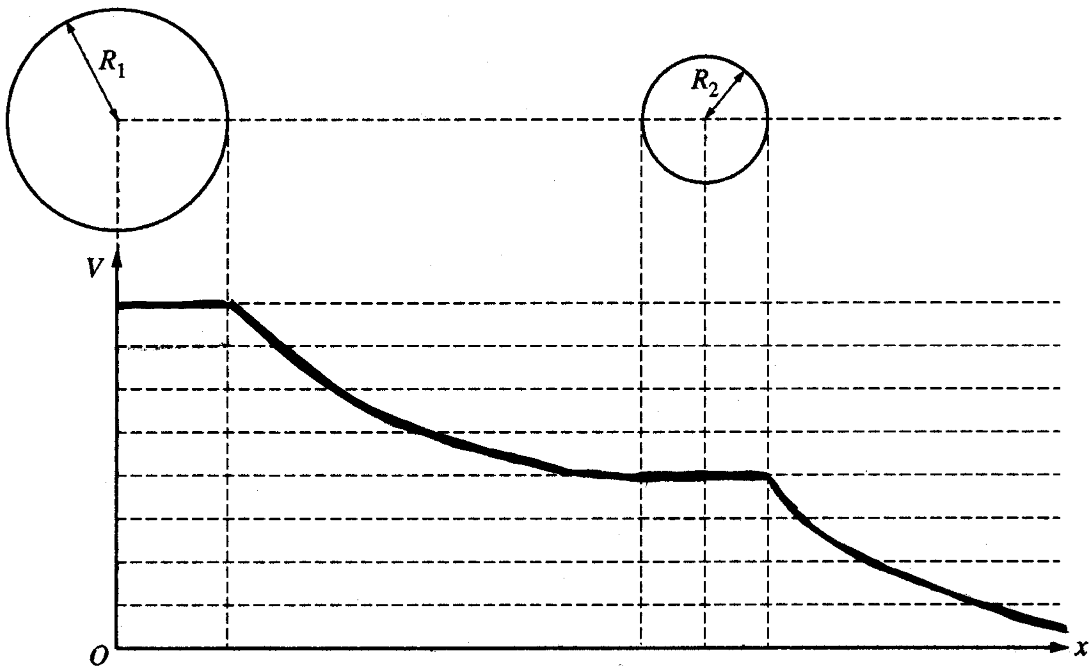
$E = 1000 \text{ N/C}$

Question 2 (continued)

Distribution of points

(d) 2 points

Sample Sketch



For a horizontal line inside the second sphere, with a nonzero value and continuous with the parts of the graph on either side — 1 point

For $1/r$ curves in the regions on either side of the second sphere, with the curve in the region to the right at lower values than the curve to the left — 1 point

Note: Except for the stipulation above for the $1/r$ curves, the relative values of the potentials of the two spheres are not scored. The sample graph shows an acceptable answer that does not include exact relative values.

Units point

For correct units in parts (a) ii and (c) ii — 1 point

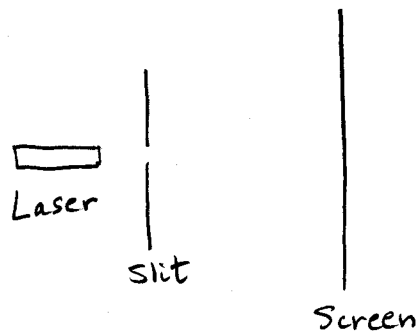
Question 3

15 points total **Distribution of points**

(a) 2 points

For selection of a length-measuring device (meter stick or metric ruler)	1 point
For selection of a light source (laser pointer or filament lamp AND prism)	1 point

(b) 2 points



For a sketch of the equipment selected in part (a), including slit (meter stick or ruler not required)	1 point
For labeling all the selected equipment, including the slit	1 point

(c) 4 points

In the scoring of this part, the following aspects of the response earn points:

For shining the laser light through the slit	1 point
For using the meter stick or ruler to measure at least one distance to be used in the calculation	1 point
For measuring the distance from the slit to the screen or wall	1 point
For making reference to some interference pattern formed on the screen or wall	1 point

Example:

Set up the equipment as shown in the diagram. Shine the laser light through the slit to form a diffraction pattern on the screen. Using the meter stick, measure the distance L between the slit and the screen. Using the metric ruler, measure the width Δx of the central bright maximum on the screen.

Question 3 (continued)

	Distribution of points
(d) 5 points	
In the scoring for this part, the following aspects of the explanation earn points:	
For including correct expressions for single-slit diffraction, such as the following:	1 point
$x_m = \dfrac{m\lambda L}{d}$ AND some indication that this is valid only for the small angle approximation, such as saying that $L >> x_m$ OR $m\lambda = d\sin\theta$ AND $\tan\theta = x_m/L$	
For solving for a correct expression for *d*	1 point
For using the measurements described in part (c)	1 point
For correctly identifying *m*, consistent with a single-slit diffraction pattern	2 points

Example:

Because $L >> x_m$, the relationship that applies is $x_m = \dfrac{m\lambda L}{d}$, where x_1 is the distance from the center of the diffraction pattern to the first minimum. This is half the width Δx measured in part (c). *L* is the distance between the slit and the screen. The final expression for *d* is $d = \dfrac{2\lambda L}{\Delta x}$.

(e) 2 points	
For indicating that the central bright maximum gets narrower or that the fringes get closer together	1 point
For indicating in the explanation that since *x* is proportional to $1/d$, if *d* increases, then *x* decreases	1 point

Question 4

10 points total — **Distribution of points**

(a) 2 points

For any statement indicating that the total weight is the sum of three terms, that of the beaker, ball, and water — 1 point

$W_{tot} = W_{beaker} + W_{ball} + W_{water}$

For calculating W_{water} — 1 point

$\rho = m/V$, so $m = \rho V$

$W_{water} = m_{water}g = \rho_{water}V_{water}g$

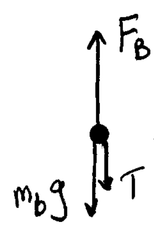
$W_{water} = \left(1000\ \text{kg/m}^3\right)\left(5.0 \times 10^{-3}\ \text{m}^3\right)\left(9.8\ \text{m/s}^2\right) = 49\ \text{N}$

$W_{water} = 49\ \text{N}$

$W_{tot} = 2.0\ \text{N} + 3.0\ \text{N} + 49\ \text{N}$

$W_{tot} = 54\ \text{N}$ (or 55 N using $g = 10\ \text{m/s}^2$)

(b) 3 points



One point for each of the three correctly drawn and appropriately labeled forces — 3 points
One point deducted for any extraneous forces or forces not drawn near the object

(c) 1 point

$\Sigma F_y = ma_y$

The ball is in equilibrium, so $a_y = 0$.

$\Sigma F_y = F_B - T - m_b g = 0$

$F_B = T + m_b g$

$F_B = 4.0\ \text{N} + 3.0\ \text{N}$

For the correct answer — 1 point

$F_B = 7.0\ \text{N}$

Question 4 (continued)

	Distribution of points
(d) 2 points	
$P = \rho g h$	
For correct substitutions	1 point
$P = \left(1000 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(0.20 \text{ m})$	
For the correct answer with units	1 point
$P = 1960 \text{ Pa}$ (or 2000 Pa using $g = 10 \text{ m/s}^2$)	
(e) 2 points	
For selecting "Lower"	1 point
For an appropriate justification	1 point
Example: Less fluid is displaced by the rubber ball because less of the ball's volume is submerged in the water.	

Question 5

15 points total | **Distribution of points**

(a) 4 points

$\Sigma F_y = F_E - F_g = ma_y$

The sphere is in equilibrium, so $a_y = 0$.

For setting the electrical force equal to the gravitational force — 1 point

$F_E = F_g$

For correct substitutions for F_E and F_g — 1 point

$qE = mg$

Note: If the solution starts with the equation above, the first 2 points are earned.

For substituting into the equation above the relationship $E = V/L$ — 1 point

$q\dfrac{V}{L} = mg$

For the correct final expression for q — 1 point

$q = mgL/V$

Note: The points for substitution of expressions for F_E, F_g, and E are earned only if the solution starts with an indication that the electric and gravitational forces are equal in magnitude.

Alternate solution: — *Alternate points*

For setting the amount of gravitational potential energy lost equal to the amount of electrical potential energy gained — *1 point*

$\left|\Delta U_g\right| = \left|\Delta U_E\right|$

For substituting mgL for $\left|\Delta U_g\right|$ — *1 point*

Substituting qV for $\left|\Delta U_E\right|$ — *1 point*

$mgL = qV$

For the correct final expression for q — *1 point*

$q = mgL/V$

Note: The points for the substitution of expressions for $\left|\Delta U_g\right|$ *and* $\left|\Delta U_E\right|$ *are earned only if the solution starts with an indication of conservation of energy between gravitational and electric potential energy.*

(b) 1 point

For an appropriate physical explanation — 1 point

Example: The gap can be explained by the quantization of electric charge. There are no spheres with charges between the values of 3.2×10^{-19} C and 1.6×10^{-19} C , the difference being the electron charge, the smallest charge that can exist.

Note: Answers that refer to the fact that charge is quantized earn this point.

Question 5 (continued)

	Distribution of points
(c) 3 points	
From part (a), $q = mgL/V$	
$m = \dfrac{qV}{gL}$	
For selecting a correct data point (V, q) from the graph, such as $\left(500\text{ V}, 9.6\times10^{-19}\text{ C}\right)$	1 point
Note: This point is earned for the use of any correct data point from the graph. Many students used the point $\left(500\text{ V}, 1.0\times10^{-18}\text{ C}\right)$, which is acceptable.	
For substituting the data point value into a correct expression for m	1 point
$m = \dfrac{\left(9.6\times10^{-19}\text{ C}\right)(500\text{ V})}{\left(9.8\text{ m/s}^2\right)(0.050\text{ m})}$	
For the correct value of m with correct units	1 point
$m = 9.8\times10^{-16}\text{ kg}$ (or an equivalent correct value using a different data point or using $g = 10\text{ m/s}^2$)	

(d)

When the sphere enters the magnetic field, the upward electric force and the downward gravitational force do not change in magnitude or direction, so they still cancel each other. The resultant force on the sphere is then due to the magnetic force only.

i. 1 point	
For an indication that the sphere moves in a circular arc or a curved path	1 point
ii. 2 points	
For stating that if q is positive, then when the sphere enters the magnetic field it will move toward the right (or counterclockwise); however, if q is negative, it will move toward the left (or clockwise).	2 points

Notes:

One point only is earned if the description mentions that the sphere would move either left or right depending on its charge but does not link a positive charge to moving right and a negative charge to moving left.

One point only is also earned if the description mentions either that if q is positive the sphere would move to the right or that if q is negative the sphere would move to the left but does not mention both.

Question 5 (continued)

Distribution of points

(e) 4 points

$\Sigma F = F_B = ma_c$

For an indication that it is the magnetic force F_B that provides the centripetal force — 1 point

For a correct substitution for the magnetic force $F_B = qvB$ — 1 point

For a correct substitution for the centripetal force $ma_c = mv^2/r$ — 1 point

Note: The two substitution points are earned only if the solution starts with an indication that the centripetal force is due to the magnetic force.

$qvB = m\dfrac{v^2}{r}$

Note: If a response starts with the equation above, 3 points are earned.

$B = \dfrac{mv}{qr}$

For an indication that the radius r must be smaller than $L/2$ to prevent the sphere from reaching the bottom of the plate, so $r_{max} = L/2$ — 1 point

Because B is inversely proportional to r, the value r_{max} corresponds to the minimum value of B needed.

$B_{min} = \dfrac{2mv}{qL}$

Question 5

Overview

This question assessed students' understanding of the behavior of an electrically charged object traveling at constant speed, in both electric and magnetic uniform fields.

Sample: B5A
Score: 13

The response earned full credit for part (a). No points were earned for part (b) because the student does not reference charge quantization. Parts (c) and (d) earned full credit. In part (e) 1 point was lost for substituting L instead of $L/2$ for the radius.

Sample: B5B
Score: 9

The response earned full credit in part (a). No credit was earned in part (b). Full credit was earned in part (c). No credit was earned for part (d) i because of the reference to straight-line motion. Full credit was earned for part (d) ii. No points were earned in part (e), which incorrectly equates the magnetic and gravitational forces.

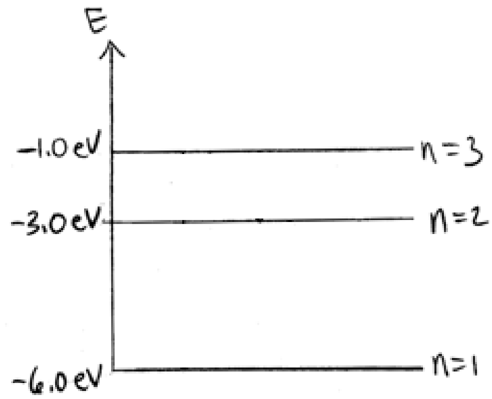
Sample: B5C
Score: 5

The response earned no points in part (a) because the solution does not start with equating the electrostatic and gravitational forces. No points were earned in part (b) because the student does not reference charge quantization. Part (c) earned 1 point for the use of a data point from the graph. Part (d) i earned full credit. Part (d) ii did not earn any points because the response does not indicate how to determine the sign of the charge. Part (e) lost 1 point for substituting L instead of $L/2$ for the radius.

Question 6

10 points total **Distribution of points**

(a) 2 points



Note: Figure not to scale

For a correct energy-level diagram with horizontal lines and −6 eV at the bottom — 1 point

Note: The energy-level diagram does not need to be drawn to scale in order to earn this point.

For correct labeling of energy levels and quantum numbers (e.g., $n = 1$ correlated with −6 eV) <u>and</u> no other incorrect energy levels shown — 1 point

(b) 3 points

For correctly relating photon energy to wavelength — 1 point

$E = hc/\lambda$ OR $E = hf$ and $c = \lambda f$ OR $E = pc$ and $p = h/f$

The energy in these equations is equal to the change in energy for each transition, so the wavelength of a photon for each transition becomes $\lambda = hc/\Delta E$, where the value of hc is given on the equation sheet.

For the indication that there are three possible transitions — 1 point

For the substitution of correct values of ΔE in all attempted transitions — 1 point

$n = 3 \rightarrow n = 1$

$$\Delta E = -1 \text{ eV} - (-6 \text{ eV}) = 5 \text{ eV}$$

$$\lambda_{n=3\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{5.0 \text{ eV}} = 248 \text{ nm}$$

$n = 3 \rightarrow n = 2$

$$\Delta E = -1 \text{ eV} - (-3 \text{ eV}) = 2 \text{ eV}$$

$$\lambda_{n=3\rightarrow n=2} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{2.0 \text{ eV}} = 620 \text{ nm}$$

$n = 2 \rightarrow n = 1$

$$\Delta E = -3 \text{ eV} - (-6 \text{ eV}) = 3 \text{ eV}$$

$$\lambda_{n=2\rightarrow n=1} = \frac{1.24 \times 10^3 \text{ eV}\cdot\text{nm}}{3.0 \text{ eV}} = 413 \text{ nm}$$

Question 6 (continued)

Distribution of points

(c) 3 points

For selecting "Yes," along with a statement that the kinetic energy of the electron is greater than the transition energy. (Note: The selection of "yes" with no justification does not earn this point.) — 1 point

Points are earned for an appropriate justification as follows:

For a correct calculation of the electron's kinetic energy — 1 point

For an identification of the energy needed for the transition from ground state to the first excited state (Note: This point is earned for explicit mention of the needed excitation energy, either 3 eV or a value consistent with the energy-level diagram shown in part (a).) — 1 point

Example:

To excite the atom in the ground state ($n = 1$) to the first excited state ($n = 2$), the incident electron must have a kinetic energy at least equal to the $n = 1 \rightarrow n = 2$ transition energy, which is $\Delta E = -3\text{ eV} - (-6\text{ eV}) = 3\text{ eV}$.

The kinetic energy of the incident electron is

$$K = \frac{1}{2}m_e v^2$$

$$K = \frac{1}{2}\left(9.11 \times 10^{-31}\text{ kg}\right)\left(1.3 \times 10^{6}\text{ m/s}\right)^2 = 7.7 \times 10^{-19}\text{ J} = 4.8\text{ eV}$$

Since the kinetic energy of the electron is greater than the transition energy, the electron can excite the atom to the $n = 2$ state.

Note: Credit is earned for a "No" response with complete justification only if the justification is consistent with any errors in the energy-level diagram or in the calculation of kinetic energy.

Note: Full credit can also be earned for an answer that (1) calculates the speed of an electron having a kinetic energy equal to that of the energy required to raise the atom from the ground state to the first excited state and (2) then shows that that speed is less than the speed of the electron given in the question, thus concluding that the electron can excite the atom from the ground state to the first excited state.

Question 6 (continued)

Distribution of points

(d)

i. 1 point

The energy of the emitted photon for the $n = 2 \rightarrow n = 1$ transition is calculated in part (b).

$\Delta E = -3\text{ eV} - (-6\text{ eV}) = 3\text{ eV}$

Converting this value to joules:

$$\Delta E = 3\text{ eV}\left(\frac{1.60 \times 10^{-19}\text{ J}}{1\text{ eV}}\right)$$

For the correct answer — 1 point

$\Delta E = 4.8 \times 10^{-19}\text{ J}$

Note: This point is also awarded for an answer consistent with the energy-level diagram shown in part (a).

ii. 1 point

For selecting "Visible Light" only — 1 point

The wavelength for the $n = 2 \rightarrow n = 1$ transition is found in part (b).

$\lambda_{n=2\rightarrow n=1} = 413\text{ nm}$

A wavelength of 413 nm is the wavelength for violet in the visible light region of the electromagnetic spectrum.