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*.

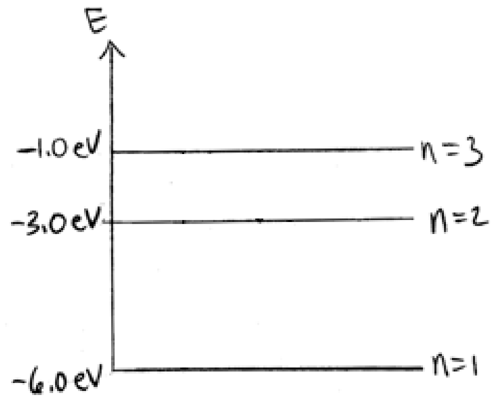
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 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) and 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

$n = 3 \rightarrow n = 1$

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

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

$n = 3 \rightarrow n = 2$

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

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

$n = 2 \rightarrow n = 1$

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

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

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

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

$$K = \frac{1}{2}\left(9.11\times10^{-31}\text{ kg}\right)\left(1.3\times10^{6}\text{ m/s}\right)^2 = 7.7\times10^{-19}\text{ J} = 4.8\text{ eV}$$

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:

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

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).

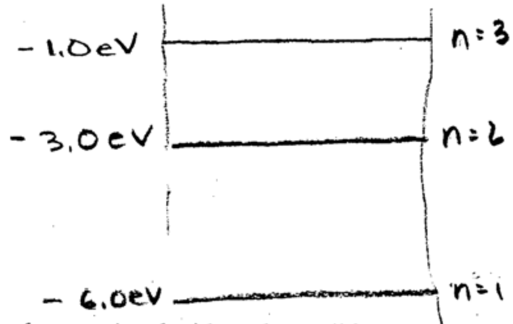
$\lambda_{n=2 \rightarrow n=1} = 413 \text{ nm}$

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

6. (10 points)

The allowed energies of a simple hypothetical atom are -6.0 eV, -3.0 eV, and -1.0 eV.

(a) Draw the atom's energy-level diagram. Label each level with the energy and the principal quantum number.



(b) Calculate the wavelengths associated with each possible transition between energy levels for the atom.

Transition $n=2$ to $n=3$

$E = \frac{hc}{\lambda}$

$2\text{eV} = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{2\text{eV}} = \frac{1.24\times10^3 \text{eV}\cdot\text{nm}}{2\text{eV}}$

$\boxed{= 620 \text{ nm}}$

$n=1$ to $n=2$

$3\text{eV} = \frac{hc}{\lambda}$

$\lambda = \frac{1.24\times10^3 \text{eV}\cdot\text{nm}}{3\text{eV}}$

$\boxed{\lambda = 413.33\text{nm}}$

$n=1$ to $n=3$

$5\text{eV} = \frac{hc}{\lambda}$

$\lambda = \frac{1.24\times10^3 \text{eV}\cdot\text{nm}}{5\text{eV}}$

$\boxed{\lambda = 248 \text{ nm}}$

(c) The atom is in the ground state when an electron traveling with a speed of 1.3×10^6 m/s collides with it. Can the electron excite the atom to the $n = 2$ state?

✓ Yes ____ No ____ It cannot be determined with the information given.

Justify your answer.

e^- $1.3\times10^6 \text{ m/s}$

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

Energy of e^- $= \frac{1}{2}(9.11\times10^{-31}\text{kg})(1.3\times10^6 \text{m/s})^2$

$= \frac{7.7\times10^{-9} \text{ J}}{1.6\times10^{-19} \text{ J/eV}} = 4.8\text{eV}$

The energy of the incoming electron is 4.8 eV which is greater than the 3 eV necessary to excite the atom to the $n=2$ state.

GO ON TO THE NEXT PAGE.

(d) Another electron excites the atom from the ground state to the $n = 2$ state. The atom then decays back to the ground state by emitting a photon.

i. Calculate the energy of the emitted photon in joules.

$E = 3\,eV \cdot 1.6 \times 10^{-19} \frac{J}{eV} = \boxed{4.8 \times 10^{-19}\,J}$

ii. In what region of the electromagnetic spectrum is the radiation?

_____ Radio _____ X-rays __✓__ Visible light

_____ It cannot be determined with the information given.

$E = hf$

$4.8 \times 10^{-19}\,J = (6.63 \times 10^{-34}\,J \cdot s)\,f$

$7.2 \times 10^{14}\,Hz = f$

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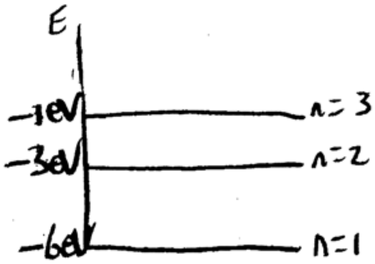
6. (10 points)

The allowed energies of a simple hypothetical atom are -6.0 eV, -3.0 eV, and -1.0 eV.

(a) Draw the atom's energy-level diagram. Label each level with the energy and the principal quantum number.



(b) Calculate the wavelengths associated with each possible transition between energy levels for the atom.

$E = \frac{hc}{\lambda}$ $2eV = \frac{1240}{\lambda}$ $\boxed{\lambda = 620\,nm}$

$5 = \frac{1240}{\lambda}$ $\boxed{\lambda = 248\,nm}$

$3 = \frac{1240}{\lambda}$ $\boxed{\lambda = 413\,nm}$

(c) The atom is in the ground state when an electron traveling with a speed of 1.3×10^6 m/s collides with it. Can the electron excite the atom to the $n = 2$ state?

____ Yes   X No   _____ It cannot be determined with the information given.

Justify your answer.

$\cancel{\lambda = \frac{h}{p} \quad p = mv \quad p = p' \quad 9.11 \times 10^{-31} \cdot 1.3 \times 10^{6}}$

$E = pc$ $p = mv$ $p = 1.3 \times 10^{6} \cdot 9.11 \times 10^{-31}$ $p = 1.18 \times 10^{-24}$

$E = 1.18 \times 10^{-24} \cdot 3 \times 10^{8}$ $E = 3.5 \times 10^{-16}\,J$

$E = \frac{hc}{\lambda}$ $3.5 \times 10^{-16} = \frac{1.99 \times 10^{-25}}{\lambda}$ $\lambda = 5.6 \times 10^{-10}\,m$

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(d) Another electron excites the atom from the ground state to the $n = 2$ state. The atom then decays back to the ground state by emitting a photon.

i. Calculate the energy of the emitted photon in joules.

$E = 3\,eV$ $\quad 1\,eV = 1.6\times10^{-19}\,J$

$\boxed{E = 4.8\times10^{-19}\,J}$

ii. In what region of the electromagnetic spectrum is the radiation?

_X_ Radio ____ X-rays ____ Visible light

____ It cannot be determined with the information given.

$E = \frac{hc}{\lambda}$ $\quad 4.8\times10^{-19} = \frac{1.99\times10^{-25}}{\lambda}$ $\quad \lambda = 4.1\times10^{-7}\,m$

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6. (10 points)

The allowed energies of a simple hypothetical atom are -6.0 eV, -3.0 eV, and -1.0 eV.

(a) Draw the atom's energy-level diagram. Label each level with the energy and the principal quantum number.

-6.0 eV 3

-3.0 eV 2

-1.0 eV 1

0

(b) Calculate the wavelengths associated with each possible transition between energy levels for the atom.

$E = hf$ $\quad \dfrac{(-6_{eV} - 3_{eV})}{h} = -\cancel{4}$

$\lambda = \dfrac{h}{mv}$ $\quad f\dfrac{(eV_1 - eV_2)}{h}$

$E = mc^2$

$-3_{eV} - 0_{eV} = -3eV$ (2 to 0)

$-6_{eV} - 0_{eV} = -6_{eV}$ (3 to 0)

$-6_{eV} - (-3_{eV}) = -3_{eV}$ (3 to 2)

$-6_{eV} - (-1_{eV}) = -5_{eV}$ (3 to 1)

$-3_{eV} - (-1)_{ev} = -2eV$ (2 to 1)

$-1_{eV} - 0ev = -1eV$ (1 to 0)

(c) The atom is in the ground state when an electron traveling with a speed of 1.3×10^6 m/s collides with it. Can the electron excite the atom to the $n = 2$ state?

✓ Yes ____ No ____ It cannot be determined with the information given.

Justify your answer.

$m_e = 9.11 \times 10^{-31}$ kg

$v = 1.3 \times 10^6$ m/s

$E = mc^2 = (9.11 \times 10^{-31})(1.3 \times 10^6)^2 = 1.53959 \times 10^{-18}$ J

$1eV = 1.6 \times 10^{-19}$ J

$1.53959 \times 10^{-18} \text{ J} \times \dfrac{1eV}{1.6 \times 10^{-19} \text{ J}} = 9.6224375 \text{ eV}$

$\boxed{\text{9.6 eV is greater that -3 eV.}}$

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(d) Another electron excites the atom from the ground state to the $n = 2$ state. The atom then decays back to the ground state by emitting a photon.

i. Calculate the energy of the emitted photon in joules.

$$3\,eV \times \frac{1.6 \times 10^{-19}\,J}{1\,eV} = \boxed{4.8 \times 10^{-19}\,J}$$

ii. In what region of the electromagnetic spectrum is the radiation?

_____ Radio ✓ X-rays _____ Visible light

_____ It cannot be determined with the information given.

GO ON TO THE NEXT PAGE.

Question 6

Overview

This question assessed students' understanding of the atomic structure of a hypothetical atom by drawing an energy-level diagram and associating possible light emissions with electron transitions between the energy levels.

Sample: B6A
Score: 10

All aspects of this solution are correct and clearly demonstrate the student's understanding.

Sample: B6B
Score: 6

Parts (a) and (b) earned full credit. No credit was earned for part (c), which applies the equation for photon energy to the electron. Part (d) i earned full credit. Part (d) ii has a correct calculation of wave length but chooses the wrong range for that wavelength and therefore earned no credit.

Sample: B6C
Score: 3

Part (a) earned no credit because the -6.0 eV energy level is not at the bottom of the diagram and the labeling of energy levels and principal quantum numbers is incorrect. No credit was earned for part (b). Part (c) lost 1 point for incorrect calculation of electron energy. Note that $E = mc^2$ is rest mass energy, not the kinetic energy. The transition energy is consistent with the student's energy-level diagram, and the conclusion is consistent with the two determined energies, so the other two points were earned. Full credit was awarded for part (d) i, which is also consistent with the incorrect energy-level diagram in part (a). No credit was earned for part (d) ii.