AP® PHYSICS
2011 SCORING GUIDELINES (Form B)

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 $10\ \text{m/s}^2$ 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) 3 points

For use of correct equation $\Delta E = hc/\lambda$ relating transition energy to wavelength — 1 point

$$\Delta E_B = \frac{1.24\times 10^3 \text{ eV}\bullet\text{nm}}{400 \text{ nm}} = 3.1 \text{ eV} \text{ (or } 5.0\times 10^{-19} \text{ J using } hc \text{ expressed in J}\bullet\text{m)}$$

$$\Delta E_C = \frac{1.24\times 10^3 \text{ eV}\bullet\text{nm}}{700 \text{ nm}} = 1.8 \text{ eV (or } 2.8\times 10^{-19} \text{ J)}$$

For recognition that $\Delta E_A = \Delta E_B + \Delta E_C$ — 1 point

$\Delta E_A = 3.1 \text{ eV} + 1.8 \text{ eV} = 4.9 \text{ eV}$ (or 7.8×10^{-19} J)

$\lambda_A = hc/\Delta E_A = \left(1.24\times 10^3 \text{ eV}\bullet\text{nm}\right)/4.9 \text{ eV}$

For a correct answer with units — 1 point

$\lambda_A = 253$ nm (or 255 nm using values in J)

The first two points could also be earned for derivation or recall of the relationship

$\frac{1}{\lambda_A} = \frac{1}{\lambda_B} + \frac{1}{\lambda_C}$, which gives a value of 255 nm.

(b) 2 points

For application of the photoelectric equation to the photon emitted during transition B — 1 point

$K_{max} = hf - \phi = \Delta E_B - \phi$

$K_{max} = 3.1 \text{ eV} - 2.46 \text{ eV}$ (or $5.0\times 10^{-19} \text{ J} - (2.46 \text{ eV})\left(1.6\times 10^{-19} \text{ J/eV}\right)$)

For a correct answer with units — 1 point

$K_{max} = 0.64$ eV (or 1.06×10^{-19} J)

(c) 3 points

For use of the relation $\lambda = h/p$ that relates de Broglie wavelength to momentum — 1 point

For use of $K = p^2/2m$ OR $p = mv$ and $K = mv^2/2$ — 1 point

Solving for p

$p = \sqrt{2mK_{max}}$

Substituting this expression for p into the equation for λ above

$\lambda = h/\sqrt{2mK_{max}}$

For correct substitutions including the value of K_{max} from part (b) — 1 point

$$\lambda = \left(6.63\times 10^{-34} \text{ J}\bullet\text{s}\right)\Big/\sqrt{2\left(9.11\times 10^{-31} \text{ kg}\right)(0.64 \text{ eV})\left(1.6\times 10^{-19} \text{ J/eV}\right)}$$

$\lambda = 1.54\times 10^{-9}$ m = 154 nm (or 151 nm using $K_{max} = 1.06\times 10^{-19}$ J)

Question 6 (continued)

Distribution of points

(d) 2 points

For an answer consistent with part (a) — 1 point

The correct answer is "*A* only" if part (a) was worked correctly. If part (a) was not worked correctly, the answer must be consistent with the values calculated in (a), unless the values were correctly recalculated.

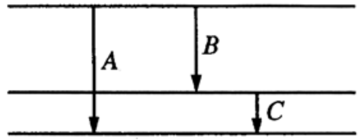
For an appropriate justification — 1 point

Example: From part (a) $\Delta E_A = 4.9\text{ eV}$. This energy is large enough to overcome the 2.46 eV work function, so electrons will be ejected from the metal. From part (a) $\Delta E_C = 1.8\text{ eV}$. This energy is not large enough to overcome the 2.46 eV work function, so electrons will not be ejected from the metal.

The justification point could also be earned by

(1) calculating the longest wavelength photon (505 nm) that could eject an electron from a metal having the given work function and comparing it with the wavelengths of the two transitions *A* and *C*, OR

(2) calculating the smallest frequency photon ($5.95 \times 10^{14}\text{ Hz}$) that could eject an electron from a metal having the given work function and comparing it with the frequencies of the two transitions *A* and *C*.



6. (10 points)

The figure above shows the energy-level diagram for a hypothetical simple atom. The wavelength of the radiation emitted when an electron undergoes transition *B* is 400 nm, and for transition *C* it is 700 nm.

(a) Calculate the wavelength of the radiation emitted when an electron makes transition *A*.

$$E_B = \frac{hc}{\lambda_B} = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{400\times10^{-9}} = 4.97\times10^{-19}\,J$$

$$E_c = \frac{hc}{\lambda_c} = \frac{6.63\times10^{-34}\times3.0\times10^{8}}{700\times10^{-9}} = 2.84\times10^{-19}\,J$$

$$E_A = E_B + E_c = (4.97 + 2.84)\times10^{-19}$$

$$= 7.81\times10^{-19}\,J$$

The photon emitted during transition *B* is then incident on a metal surface of work function 2.46 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

$$KE_{max} = hf - \phi$$

$$= E_B - \phi$$

$$= 4.97\times10^{-19} - 2.46(1.6\times10^{-19})$$

$$= 1.04\times10^{-19}\,J$$

(c) Calculate the de Broglie wavelength of the ejected electron.

$$\lambda = \frac{h}{p} \qquad KE_{max} = \frac{1}{2}mv^2$$

$$v = \sqrt{2\times1.04\times10^{-19}/(9.11\times10^{-31})}$$

$$p = mv$$

$$v = 4.78\times10^{5}\,m/s$$

$$p = 9.11\times10^{-31}\times9.78\times10^{5} = 4.35\times10^{-25}$$

$$\lambda = \frac{6.63\times10^{-34}}{4.35\times10^{-25}} = 1.52\times10^{-9}\,m$$

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(d) Photons emitted during which of transitions *A* and *C*, when incident on the metal surface, will also result in electrons being ejected from the metal?

✓ *A* only ____ *C* only ____ Both *A* and *C* ____ Neither *A* nor *C*

Justify your answer.

Minimum energy required to eject electron from metal

$= \phi$

$\phi = 2.46(1.6\times10^{-19})$

$= 3.94\times10^{-19}$ J

$E_A = 7.81\times10^{-19}$ J $> 3.94\times10^{-19}$ J

$E_c = 2.84\times10^{-19}$ J $< 3.94\times10^{-19}$ J

Therefore, only photons emitted during transition A will be able to liberate electrons from the metal.

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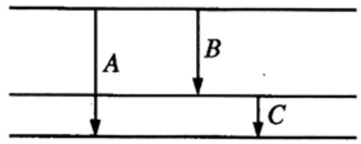

6. (10 points)

The figure above shows the energy-level diagram for a hypothetical simple atom. The wavelength of the radiation emitted when an electron undergoes transition B is 400 nm, and for transition C it is 700 nm.

(a) Calculate the wavelength of the radiation emitted when an electron makes transition A.

$E = hf \quad v = f\lambda \quad E = \frac{hc}{\lambda}$

$E_B = h\frac{c}{\lambda_B}$

$= (6.63\times10^{-34})\frac{(3.00\times10^{8})}{400\times10^{-9}}$

$= 4.973\times10^{-19}$

$E_C = h\frac{c}{\lambda_C}$

$= 2.841\times10^{-19}$

$E_A = E_B + E_C = 7.814\times10^{-19}$

$E_A = h\frac{c}{\lambda_A}$

$\lambda_A = \frac{hc}{E_A} = 254.5\text{ nm}$

$\approx 255\text{ nm}$

The photon emitted during transition B is then incident on a metal surface of work function 2.46 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

$K_{max} = hf - \phi$

$= \frac{E_A}{e} - 2.46$

$= \frac{7.814\times10^{-19}}{1.60\times10^{-19}} - 2.46$

$= 4.88 - 2.46 = 2.42\text{ eV}$

$= 3.87\times10^{-19}\text{ J}$

(c) Calculate the de Broglie wavelength of the ejected electron.

$E = pc \quad \lambda = \frac{h}{p}$

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

$\lambda = \frac{h}{(\frac{E}{c})} = \frac{hc}{E} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{3.87\times10^{-19}}$

$= 514\text{ nm}$

GO ON TO THE NEXT PAGE.

(d) Photons emitted during which of transitions *A* and *C*, when incident on the metal surface, will also result in electrons being ejected from the metal?

✓ *A* only ____ *C* only ____ Both *A* and *C* ____ Neither *A* nor *C*

Justify your answer.

$\phi = 2.46 eV = 2.46 \times (1.60 \times 10^{-19})$

$= 3.936 \times 10^{-19} J$

$(7.814 \times 10^{-19}) E_A > \phi$

$(2.841 \times 10^{-19}) E_c < \phi$

The work function is the energy required for electrons to be ejected from the metal surface. Only photons from transition A has enough energy to be ejected from the metal surface.

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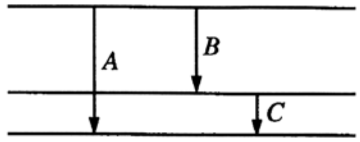

6. (10 points)

The figure above shows the energy-level diagram for a hypothetical simple atom. The wavelength of the radiation emitted when an electron undergoes transition B is 400 nm, and for transition C it is 700 nm.

(a) Calculate the wavelength of the radiation emitted when an electron makes transition A.

[redacted]

$\lambda_A = 400\text{nm} + 700\text{ nm}$

$= \underline{1100\text{ nm}}$ (0 dp)

The photon emitted during transition B is then incident on a metal surface of work function 2.46 eV.

(b) Calculate the maximum kinetic energy of the electron ejected from the metal by the photon.

$E = \phi + K_{max}$

$\frac{hc}{\lambda} = \phi + K_{max}$

$K_{max} = \frac{(4.14\times10^{-15}\text{ eV}\cdot\text{s})(3.00\times10^{8}\text{ ms}^{-1})}{(400\times10^{-9}\text{ m})} - 2.46\text{eV}$

$= 0.645\text{eV}$

[redacted]

$\approx$ [redacted] $\underline{6.45\times10^{-1}\text{ eV}}$ (3sf)

(c) Calculate the de Broglie wavelength of the ejected electron.

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

$=$ [redacted] $\frac{6.63\times10^{-34}\text{ J}\cdot\text{s}}{(9.11\times10^{-31}\text{ kg})(6.45\times10^{-1}\times1.60\times10^{-19}\text{ J})}$

$= 7.05205\times10^{14}\text{ m}$

$\approx \underline{7.05\times10^{14}\text{ m}}$ (3sf)

GO ON TO THE NEXT PAGE.

(d) Photons emitted during which of transitions A and C, when incident on the metal surface, will also result in electrons being ejected from the metal?

____ A only   ____ C only   ✓ Both A and C ____ Neither A nor C

Justify your answer.

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

$\frac{hc}{\lambda_{max}} = \phi$

$\frac{(4.14 \times 10^{-15}\ eV \cdot s)(3.00 \times 10^{8}\ ms^{-1})}{\lambda_{max}} = 6.45 \times 10^{-1}\ eV$

$\lambda_{max} = 1.92558 \times 10^{-6}\ m$

$\approx 192 \times 10\ nm$ (3sf)

As the maximum wavelength for the emission of electrons is 192×10 nm, and the transitions of both A and C give off wavelengths less than this, they both can result in the ejection of electrons from the metal.

Question 6

Sample: B6A
Score: 9

All aspects of this response clearly demonstrate the student's understanding. The only point not earned was for not finding the wavelength in part (a).

Sample: B6B
Score: 6

Parts (a) received full credit. Part (b) used the wrong energy transition and earned no credit. Part (c) earned 1 point for recognizing the de Broglie relationship, but no other credit was earned. Part (d) earned full credit.

Sample: B6C
Score: 3

Part (a) received no credit. Part (b) received full credit. Part (c) earned 1 point for recognizing the de Broglie relationship, but no other credit was earned. Part (d) earned no credit.