AP® Physics B
2011 Scoring Guidelines
Form B

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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*.

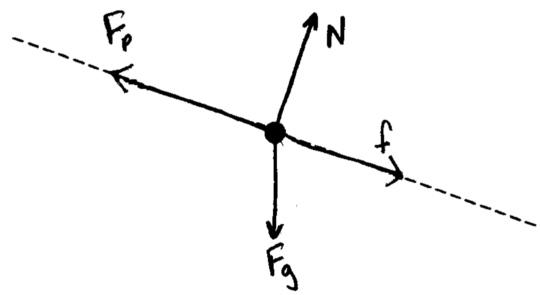
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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) 4 points



For each correct force on the dot for which the vector drawn has the correct direction and a correct label such as those in the figure above, 1 point was earned. — 4 points

No points were earned for an appropriately labeled force if the direction was incorrect.

1 earned point was deducted for each additional force or component.

(b) 2 points

Applying Newton's second law to the forces perpendicular to the plane

$\Sigma F_{\perp} = ma_{\perp}$, where $a_{\perp} = 0$

$N - F_g \cos\theta = 0$

$N - mg\cos\theta = 0$

For a correction expression for the normal force — 1 point

$N = mg\cos\theta$ (or $N = mg\sin\theta$, if $70°$ was clearly used for θ)

For correctly substituting the values of *m*, *g* and θ into the correct expression — 1 point

$N = (50\text{ kg})(9.8\text{ m/s}^2)\cos 20°$

$N = 460\text{ N}$ (or 470 N using $g = 10\text{ m/s}^2$)

(c) 2 points

For a correct expression for the component of the force of gravity parallel to the plane — 1 point

$F_{g_{||}} = F_g \sin\theta = mg\sin\theta$ (or $mg\cos\theta$, if $70°$ was clearly used for θ)

$F_{g_{||}} = (50\text{ kg})(9.8\text{ m/s}^2)\sin(20°)$

For a correct answer — 1 point

$F_{g_{||}} = 168\text{ N}$ (or 171 N using $g = 10\text{ m/s}^2$)

Question 1 (continued)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

For indicating $F_{g||} = \sqrt{F_g^{\,2} - F_{g\perp}^{\,2}}$ — *1 point*

$F_g = mg = (50\ \text{kg})(10\ \text{m/s}^2) = 500\ \text{N}$

$F_{g\perp} = mg\cos\theta = N = 460\ \text{N}$

For a correct answer — *1 point*

$F_{g_{||}} = 168\ \text{N}$ (or 171 N using $g = 10\ \text{m/s}^2$)

(d) 2 points

For a correct expression for the frictional force — 1 point

$f = \mu_K N$

For correct substitution of μ_K and the value of N from part (b) — 1 point

$f = (0.30)(460\ \text{N})$

$f = 138\ \text{N}$ (or 141 N using the $g = 10\ \text{m/s}^2$ result of $N = 470\ \text{N}$ from (b))

(e) 2 points

Applying Newton's second law to the forces parallel to the plane

$F_{\text{net}||} = \Sigma F_{||} = ma_{||}$, where $a_{||} = 0$ because the box is moving at constant speed

For indicating $F_{\text{net}||} = 0$ — 1 point

$F_{\text{net}||} = F_p - F_{g_{||}} - f = 0$

For correct substitutions of the answers from parts (c) and (d) into a correct expression — 1 point

$F_P = F_{g||} + f$

$F_p = 168\ \text{N} + 138\,\text{N}$

$F_p = 306\ \text{N}$ (or 312 N using the $g = 10\ \text{m/s}^2$ results of $F_{g_{||}} = 171\ \text{N}$ and $f = 141\ \text{N}$)

Question 1 (continued)

Distribution of points

(f) 2 points

For a correct expression relating work to force and distance — 1 point

$W = Fd\cos\phi$, where ϕ is the angle between **F** and **d**

(W = force times distance must be implied, not $W = mgh$. It was acceptable if ϕ was not explicitly included because $\cos\phi = \cos 0° = 1$.)

For correctly substituting the force from part (e) and $d = \dfrac{3.0\text{ m}}{\sin 20°}$ or 8.8 m — 1 point

$$W = 306\text{ N}\left(\frac{3.0\text{ m}}{\sin 20°}\right)$$

$W = 2684\text{ J}$ (or 2737 J using the $g = 10\text{ m/s}^2$ result of $F_p = 312\text{ N}$)

Units 1 point

For correct units on at least three answers and no incorrect units — 1 point

Question 2

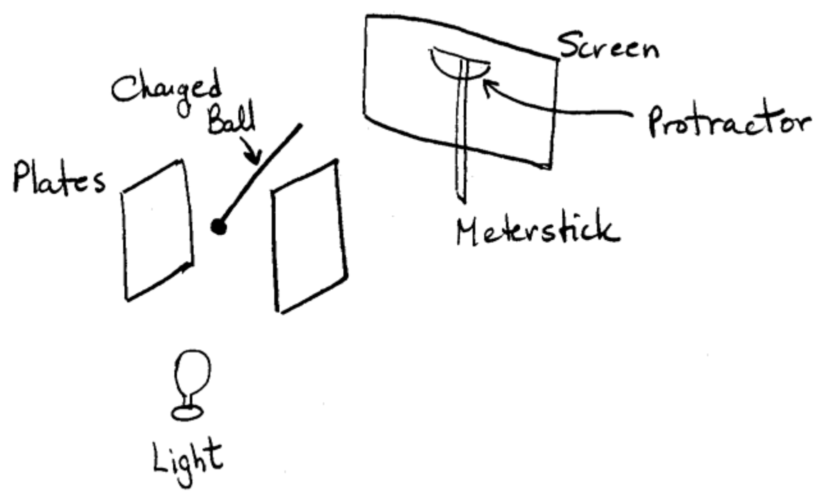
15 points total | **Distribution of points**

(a) 1 point

For checking any of the equipment listed — 1 point

(b) 3 points

Sample diagram



For including the plates and ball — 1 point
For including all objects checked, with the exception of measurement devices — 1 point
For clearly labeling each piece of equipment — 1 point

(c) 6 points

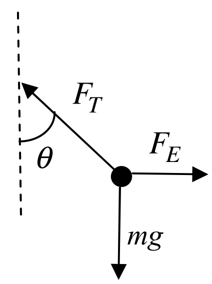
For an indication of the measurements to be taken — 1 point
For indicating the equipment associated with each measurement — 1 point
For using each object checked in part (a) — 1 point
For clearly describing each measurement — 1 point
For only including measurements relevant to determining the electric field or force — 1 point
For the entire procedure being complete and correct — 1 point
For example: Suspend the ball between the plates, and set up the screen perpendicular to the plates. Shine the light on the ball so the shadow falls on the screen. Using the meterstick as a vertical line, measure the angle of the string's shadow with the protractor.

Question 2 (continued)

Distribution of points

(d)

i. 3 points



For an indication of the relationship between forces that justifies the method for determining the electric field	1 point

$\sum F_{\text{net}} = 0$

$F_T \sin\theta = F_E$ and $F_T \cos\theta = mg$

The two equations above can be used to eliminate F_T and solve for F_E.

For a correct expression for the electrostatic force	1 point

$F_E = mg\tan\theta$

$E = F_E/q$

For an expression for the magnitude of the electric field	1 point

$E = mg\tan\theta/q$

ii. 1 point

For correctly explaining how to determine the field direction	1 point

For example: The force on a positive charge is in the same direction as the field. Therefore the direction of the field is in the direction of the ball's deflection.

iii. 1 point

For correctly explaining how to determine which plate is positive	1 point

For example: The electric field is directed from positive to negative charges. Once the direction of the field is determined, you know which plate is positively charged.

Question 3

15 points total | **Distribution of points**

(a) 2 points

For a correct relationship relating f to υ and λ — 1 point

$\upsilon = f\lambda$

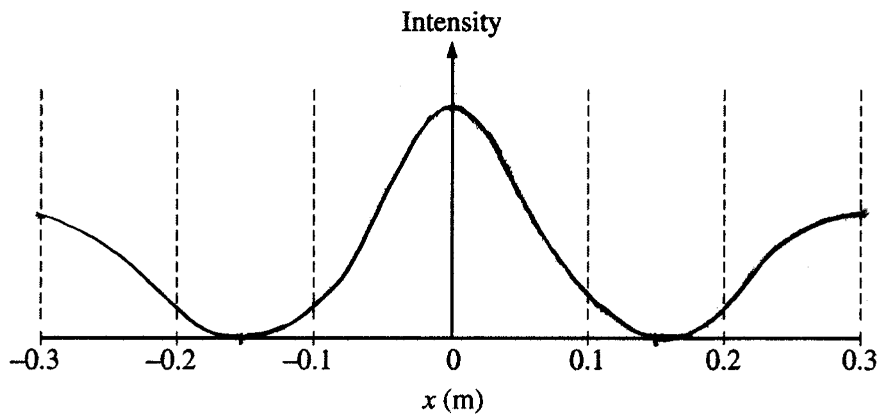
$f = \upsilon/\lambda$, where $\upsilon = c$

$f = \left(3\times10^{8}\ \text{m/s}\right)/\left(2.4\times10^{-2}\ \text{m}\right)$

For the correct answer with units — 1 point

$f = 1.25\times10^{10}\ \text{Hz}$

(b) 4 points



The position of the maxima on the screen for a double-slit interference pattern is found from $x_m \approx \dfrac{m\lambda L}{d}$, where L is the distance to the screen, d is the slit separation, λ is the wavelength, and m is an integer.

To calculate the distance from the central maximum to the first secondary maximum, let $m = 1$.

$$x_{m=1} = \frac{(1)\left(2.4\times10^{-2}\ \text{m}\right)(2.5\ \text{m})}{0.20\ \text{m}} = 0.30\ \text{m}$$

For the graph symmetric with multiple peaks — 1 point

For the central maximum at $x = 0$ — 1 point

For the first secondary maximum at either side at $x = \pm0.3$ m — 1 point

For a reasonable curved shape with minima about halfway between the central and the first secondary maxima — 1 point

Relative heights of the peaks are not considered in the scoring of this question because that was considered in part (c).

Question 3 (continued)

Distribution of points

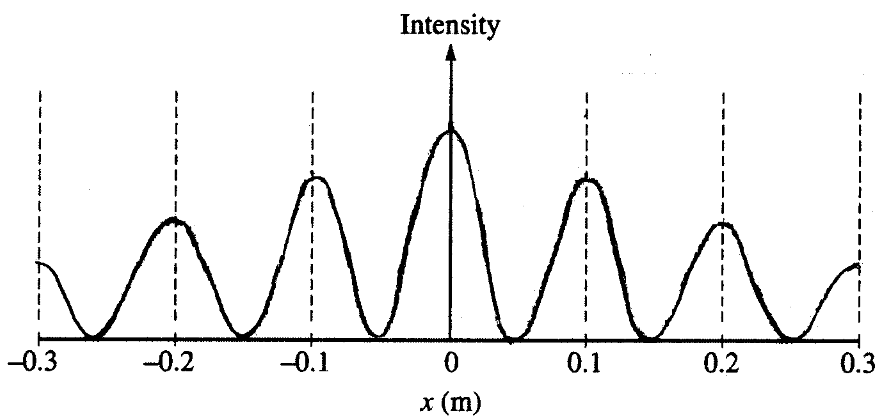
(c) 3 points

1 $x = 0.00$ m 3 $x = 0.15$ m 2 $x = 0.30$ m

For recognition that the intensity is greatest at $x = 0.00$ m — 1 point
For recognition that the intensity is least at $x = 0.15$ m — 1 point
For a correct justification of the correct answer — 1 point

Example: At $x = 0.00$ m, constructive interference between the light from the two slits arriving in phase results in a central maximum of greatest intensity. At $x = 0.15$ m, destructive interference between the light from the two slits arriving 180° out of phase ($1/2$ wavelength apart) results in a dark fringe of minimum intensity. At $x = 0.30$ m, constructive interference also occurs, but the double-slit pattern is modulated by the single-slit pattern so that the first bright fringe is not as bright (has less intensity) than the central maximum.

(d) 3 points



In the equation $x_m \approx \dfrac{m\lambda L}{d}$ for the positions of the maxima, $x_m \propto \lambda$, so when the wavelength is reduced to $\lambda/3$, the distance of each maxima from the center is $1/3$ the previous value.

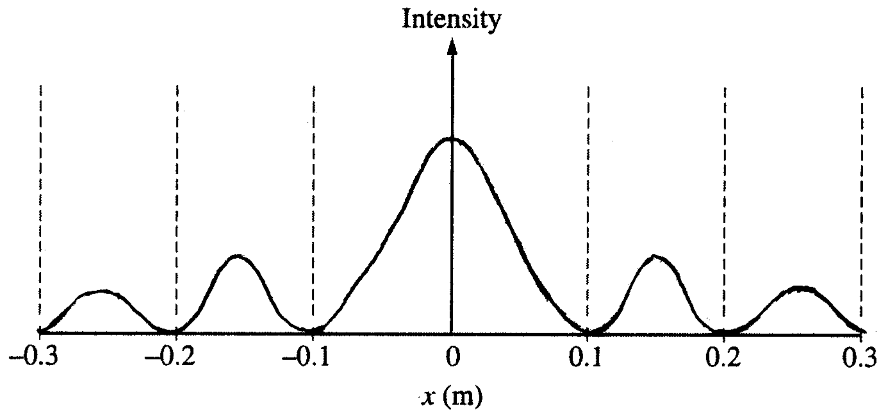
For $m = 1$, $x_{m=1} = (0.30\text{ m})/3 = 0.10\text{ m}$

For drawing more maxima than drawn in part (b) — 1 point
For showing the maxima at distances from the center that are $1/3$ the distances shown in part (b) (with $0,\ \pm 0.1,\ \pm 0.2,$ and ± 0.3 m being the actual correct values) — 1 point
For the maxima decreasing in height with increasing distance from the center — 1 point

Question 3 (continued)

Distribution of points

(e) 3 points



The position of the minima on the screen for a single-slit interference pattern is found from $x_{\min} \approx \dfrac{m\lambda L}{d}$, where L is the distance to the screen, d is the slit separation, λ is the wavelength, and m is an integer greater than 0.

The distance between successive minima is given by

$$\frac{\lambda L}{d} = \frac{\left(0.80\times 10^{-2}\ \text{m}\right)(2.5\ \text{m})}{0.20\ \text{m}} = 0.10\ \text{m}$$

For showing minima at $\pm 0.1, \pm 0.2, \pm 0.3$ m — 1 point

For the correct curved shape with maxima about midway between successive minima — 1 point

For maxima that decrease in height with increasing distance from the center (The actual relative heights of the maximum were not considered in awarding this point as long as the heights decreased with distance.) — 1 point

Question 4

10 points total | **Distribution of points**

(a) 3 points

For each correct force on the dot for which the vector drawn has the correct direction and a correct label such as those in the figure above, 1 point was earned. — 3 points

No points were earned for an appropriately labeled force if the direction was incorrect.

1 earned point was deducted for each additional force or components.

(b) 3 points

For recognition that the balloon is in equilibrium, so $\sum F_y = ma_y = 0$ — 1 point

For an expression for F_B that matches the free-body diagram — 1 point

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

$F_B = m_b g + T$

The 0.015 kg object is also in equilibrium, so $T - m_{obj} g = 0$

$T = m_{obj} g$

$F_B = m_b g + m_{obj} g$

$F_B = (0.005\ \text{kg} + 0.0150\ \text{kg})(9.8\ \text{m/s}^2)$

For a correct answer with units — 1 point

$F_B = 0.196\ \text{N}$ (or 0.20 N using $g = 10\ \text{m/s}^2$)

Question 4 (continued)

Distribution of points

(c) 2 points

The buoyant force equals the weight of the air displaced by the balloon, so the volume of the balloon equals the volume of that amount of air.

$F_B = m_{air}g$

$m_{air} = \rho_{air}V_b$

For a correct expression relating the buoyant force to the volume of the balloon — 1 point

$F_B = \rho_{air}V_b g$

$$V_b = \frac{F_B}{\rho_{air}g}$$

For correct substitutions of ρ_{air} and the value of F_B from part (b) — 1 point

$$V_b = \frac{0.196\text{ N}}{\left(1.29\text{ kg/m}^3\right)\left(9.8\text{ m/s}^2\right)} = 0.0155\text{ m}^3$$

(d) 2 points

For selecting "It swings toward the back of the car." — 1 point

For an appropriate explanation — 1 point

Examples:

The inertia of the hanging 0.015 kg object leaves it behind as the car accelerates out from under it.

As the car and the child holding the string accelerate forward, the hanging object must also accelerate forward. Thus the force exerted on the object by the string must have an unbalanced component in the forward direction. This can occur only if the object swings backward so that the string slants forward.

Question 5

15 points total | **Distribution of points**

(a)

i. 3 points

For the correct identification of the magnetic force on the positively charged particles as they enter region 1 — 1 point

$F_B = qvB_1$, directed toward the bottom of the page

For the correct identification of the electric force on the positively charged particles as they enter region 1 — 1 point

$F_E = qE$, directed toward the top of the page

$F_{net} = \sum F = qE - qvB = ma$

For the particle to move at constant velocity, $a = 0$

For the correct application of Newton's laws to obtain the equation needed to relate the speed of the particles to the electric and magnetic field strengths — 1 point

$qE - qvB_1 = 0$

$v = E/B_1$

ii. 2 points

For selecting "It curves toward the bottom of the page." — 1 point

For an appropriate explanation — 1 point

Example: The electric force $F_E = qE$, directed upward, is the same for all speeds of the particle. However, the magnetic force $F_B = qvB_1$, directed downward, increases with increasing speed. Therefore if the speed of the particle is greater than that in part (a)i, then $F_B > F_E$. The resultant force on the particle as it enters region 1 is toward the bottom of the page, causing the particle to curve in that direction.

The justification point could be earned only if the correct answer was selected.

(b) 2 points

$F_B = qvB_2$

For correctly substituting $v = E/B_1$ from part (a)i — 1 point

$$F_B = \frac{qEB_2}{B_1}$$

For correctly indicating that the direction is up or toward the top of the page — 1 point

Question 5 (continued)

Distribution of points

(c) 2 points

For including in the description that the force is constant — 1 point

For including in the description that the direction changes — 1 point

Example: The magnitude $F_B = qvB_2$ does not change because the particle is in a constant magnetic field B_2 and the angle between the velocity and magnetic force remains constant at $90°$. But as the particle curves the direction of its velocity changes, and the direction of the magnetic force also changes because it remains perpendicular to the velocity vector.

(d) 2 points

For an appropriate description that includes a statement that the path is circular — 2 points

Example: When the particle is in region 2, it moves toward the top of the page in a circular arc.

An explanation saying only that the path curved upward earned only 1 point.

One earned point was deducted for any incorrect statement. For example, "circular, out of the page" earned only 1 point.

(e) 4 points

For indicating that the net force provides the centripetal acceleration — 1 point

$$F_{net} = \frac{mv^2}{R}$$

For indicating that the net force is due to the magnetic field — 1 point

$$F_{net} = qvB_2$$

$$qvB_2 = \frac{mv^2}{R}$$

Substituting $v = \dfrac{E}{B_1}$, from part (a)i

$$qvB_2 = \frac{m}{R}\frac{E^2}{B_1^2}$$

For the correct answer — 1 point

$$\frac{q}{m} = \frac{E}{B_1 B_2 R}$$

For stating that R, a previously undefined quantity, is the radius of the circular arc in which the particle moves when in the magnetic field B_2 — 1 point

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

$$\Delta E_B = \frac{1.24\times10^3 \text{ eV}\bullet\text{nm}}{400 \text{ nm}} = 3.1 \text{ eV} \quad (\text{or } 5.0\times10^{-19} \text{ J using } hc \text{ expressed in J}\bullet\text{m})$$

$$\Delta E_C = \frac{1.24\times10^3 \text{ eV}\bullet\text{nm}}{700 \text{ nm}} = 1.8 \text{ eV} \quad (\text{or } 2.8\times10^{-19} \text{ J})$$

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

$$\Delta E_A = 3.1 \text{ eV} + 1.8 \text{ eV} = 4.9 \text{ eV} \quad (\text{or } 7.8\times10^{-19} \text{ J})$$

$$\lambda_A = hc/\Delta E_A = \left(1.24\times10^3 \text{ eV}\bullet\text{nm}\right)/4.9 \text{ eV}$$

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

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

$$K_{max} = 3.1 \text{ eV} - 2.46 \text{ eV} \quad \left(\text{or } 5.0\times10^{-19} \text{ J} - (2.46 \text{ eV})\left(1.6\times10^{-19} \text{ J/eV}\right)\right)$$

For a correct answer with units — 1 point

$$K_{max} = 0.64 \text{ eV} \quad (\text{or } 1.06\times10^{-19} \text{ J})$$

(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

$$\lambda = \left(6.63\times10^{-34} \text{ J}\bullet\text{s}\right)/\sqrt{2\left(9.11\times10^{-31} \text{ kg}\right)(0.64 \text{ eV})\left(1.6\times10^{-19} \text{ J/eV}\right)}$$

$$\lambda = 1.54\times10^{-9} \text{ m} = 154 \text{ nm} \quad (\text{or 151 nm using } K_{max} = 1.06\times10^{-19} \text{ J})$$

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 ($5.95\times10^{14}\text{ Hz}$) 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*.