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.

AP® PHYSICS B
2011 SCORING GUIDELINES (Form B)

Question 3

15 points total **Distribution of points**

(a) 2 points

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

$\upsilon = f\lambda$

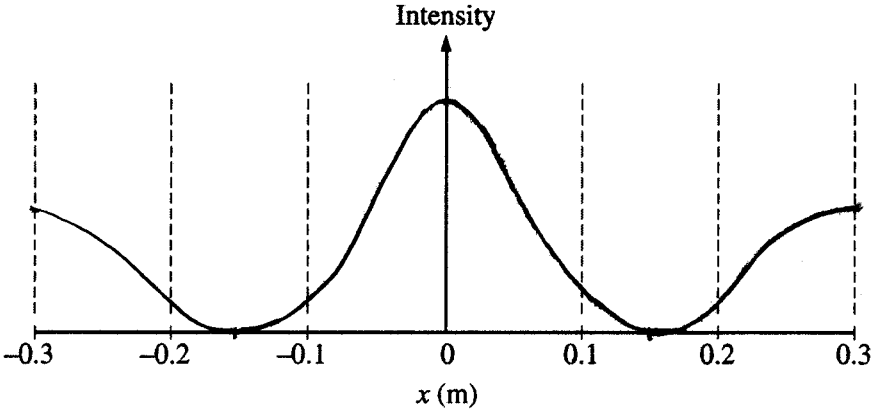
$f = \upsilon/\lambda$, where $\upsilon = c$

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

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 $x = \pm 0.3$ 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)

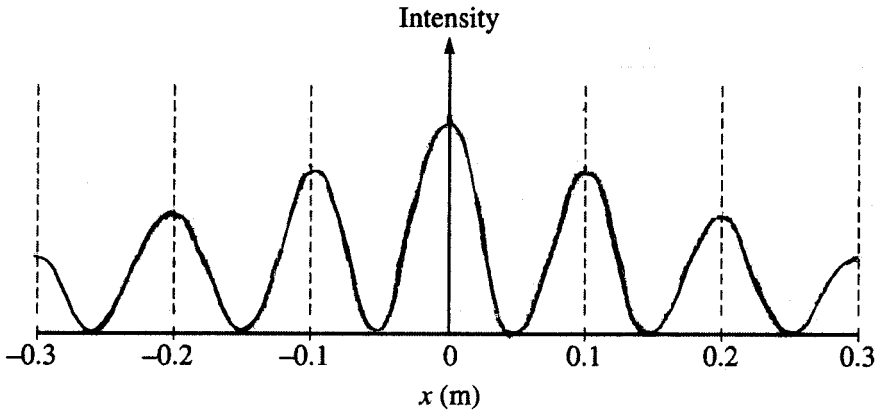
Distribution of points

(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

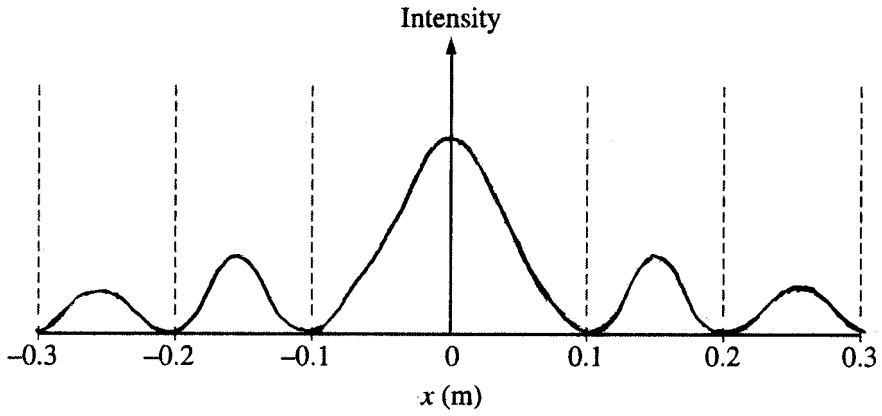


In the equation $x_m \approx \frac{m\lambda L}{d}$ for the positions of the maxima, $x_m \propto \lambda$, so when the wavelength is reduced to $\lambda/3$, the distance of each maxima from the center is $1/3$ the previous value.
For $m = 1$, $x_{m=1} = (0.30 \text{ m})/3 = 0.10$ m
For drawing more maxima 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 $x_{\text{min}} \approx \frac{m\lambda L}{d}$, 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.

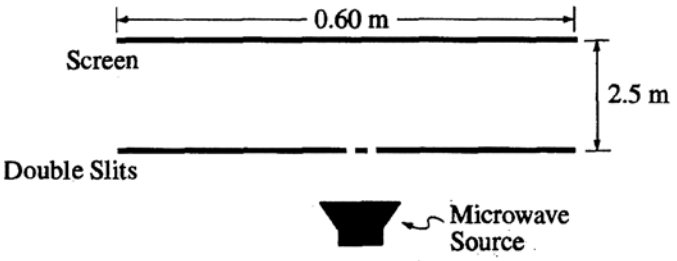
The distance between successive minima is given by

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

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



Note: Figure not drawn to scale.

3. (15 points)

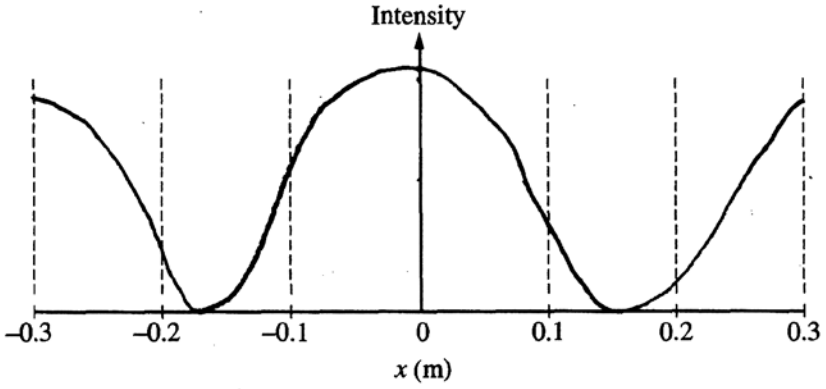
A microwave source is placed behind two identical slits, as represented in the diagram above. The slit centers are separated by a distance of 0.20 m, and the slit widths are small compared to the slit separation but not negligible. The microwave wavelength is 2.4×10^{-2} m. The resulting interference pattern is centered on a screen 0.60 m wide, located 2.5 m from the slits.

(a) Calculate the frequency of the microwave radiation.

$c = f\lambda \Rightarrow f = \frac{c}{\lambda}$

$= \frac{3\times10^{8}\,m/s}{2.4\times10^{-2}\,m} = 1.25\times10^{10}\,Hz$ //

(b) On the graph below, where the x-axis represents the distance along the screen and $x = 0$ represents the center of the pattern, sketch the intensity of the interference pattern expected for that arrangement.



$d\sin\theta = m\lambda$

When $m=1$,

$\sin\theta = \frac{\lambda}{d} = 0.12$

$x = (2.5\,m)\tan\theta$

$\Rightarrow 0.302184\,m$

(c) Consider points on the screen located at $x = 0.00$ m, $x = 0.15$ m, and $x = 0.30$ m. Rank the intensity at those points from highest to lowest, with number 1 corresponding to the highest intensity. If two points have equal intensity, give them the same ranking.

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

Justify your ranking.

Maximum brightness occurs at the centre of the pattern since it has constructive interference. From calculations in (b), next bright fringe is at $x = 0.302184\,m$, which is very close to the end of the screen, but not yet reaching maximum, thus has a bit less intensity. At $x = 0.15m$ there is destructive interference, and intensity is much, much lower.

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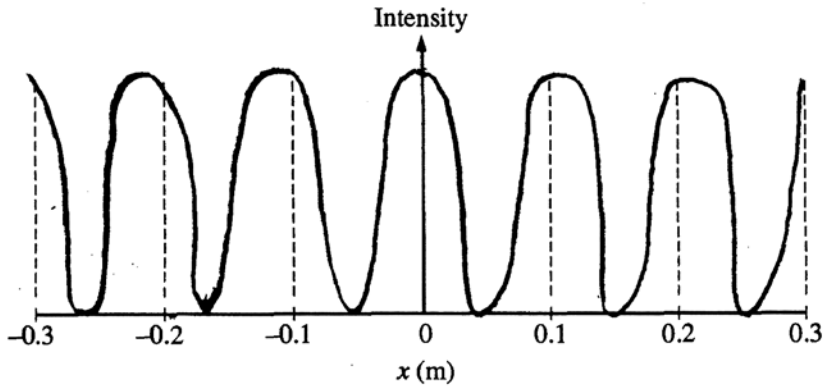
(d) Suppose the microwave wavelength is decreased by a factor of three, to 0.80×10^{-2} m. Sketch the resulting interference pattern below.



$d\sin\theta = m\lambda$

when $m=1$,

$\sin\theta = \frac{\lambda}{d}$

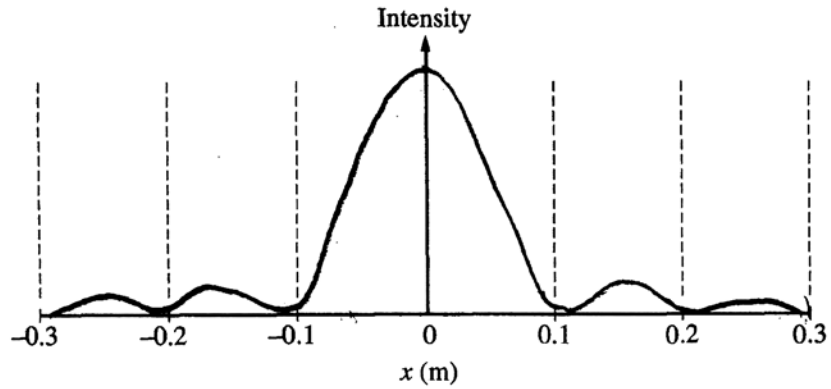
$= 0.04$

$\therefore \theta = \sin^{-1}(0.04m)$, $m = \pm 0, \pm 1, \pm 2, \ldots$

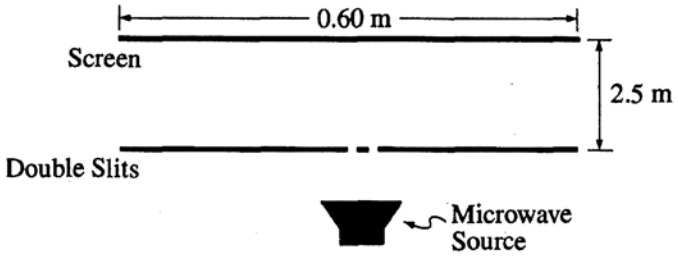
$x = (2.5m)\tan(\theta)$

$= 0, \pm 0.1m, \pm 0.2m, \ldots$

(e) Suppose the material separating the two slits is removed so that there is now one slit approximately 0.20 m in width. The wavelength is held at 0.80×10^{-2} m. Sketch the resulting diffraction pattern below.



Apart from central bright fringe, all constructive interference in (d) is now destructive. Diffraction also greatly lowers intensity as distance increases from central fringe.



Note: Figure not drawn to scale.

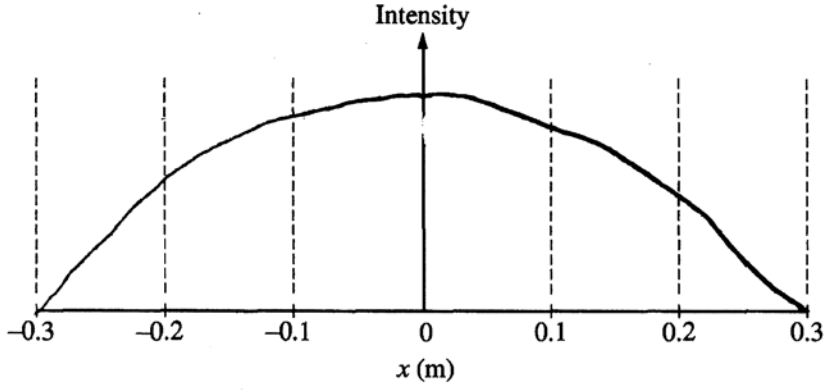
3. (15 points)

A microwave source is placed behind two identical slits, as represented in the diagram above. The slit centers are separated by a distance of 0.20 m, and the slit widths are small compared to the slit separation but not negligible. The microwave wavelength is 2.4×10^{-2} m. The resulting interference pattern is centered on a screen 0.60 m wide, located 2.5 m from the slits.

(a) Calculate the frequency of the microwave radiation.

frequency = $\frac{3.00 \times 10^{8}}{2.4 \times 10^{-2}} \approx 1.25 \times 10^{10}$ Hz

(b) On the graph below, where the x-axis represents the distance along the screen and $x = 0$ represents the center of the pattern, sketch the intensity of the interference pattern expected for that arrangement.



(c) Consider points on the screen located at $x = 0.00$ m, $x = 0.15$ m, and $x = 0.30$ m. Rank the intensity at those points from highest to lowest, with number 1 corresponding to the highest intensity. If two points have equal intensity, give them the same ranking.

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

Justify your ranking.

Bright spot at #1 0.00 m
Dark spot at #3 0.3 m
Intermediate Intensity at 0.15 m

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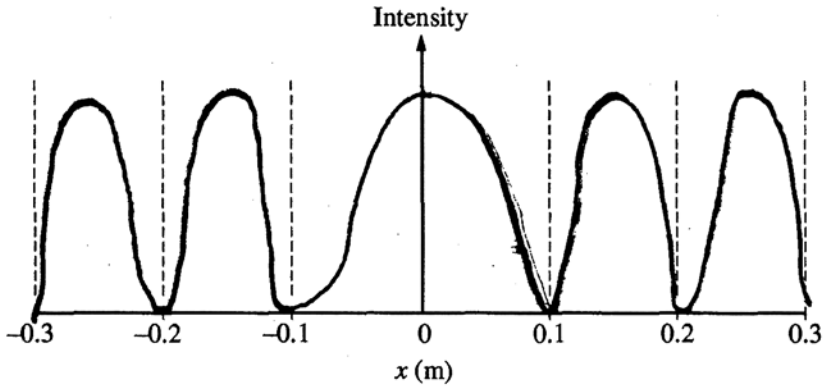
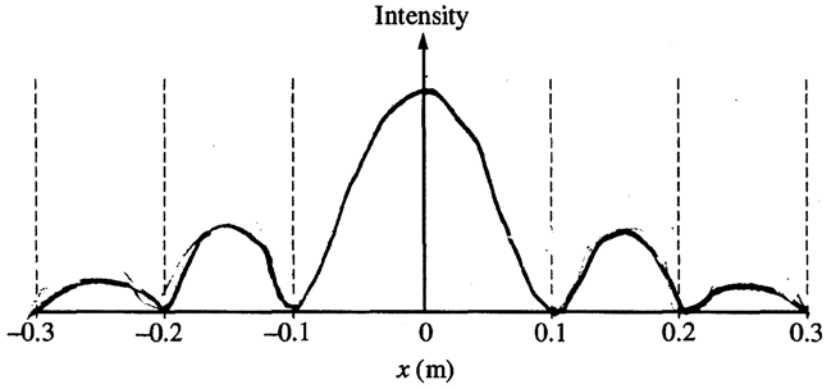
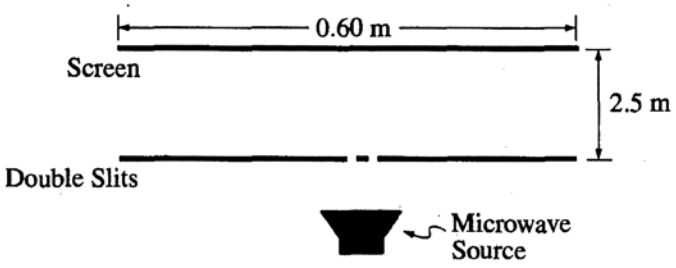
(d) Suppose the microwave wavelength is decreased by a factor of three, to 0.80×10^{-2} m. Sketch the resulting interference pattern below.



(e) Suppose the material separating the two slits is removed so that there is now one slit approximately 0.20 m in width. The wavelength is held at 0.80×10^{-2} m. Sketch the resulting diffraction pattern below.





Note: Figure not drawn to scale.

3. (15 points)

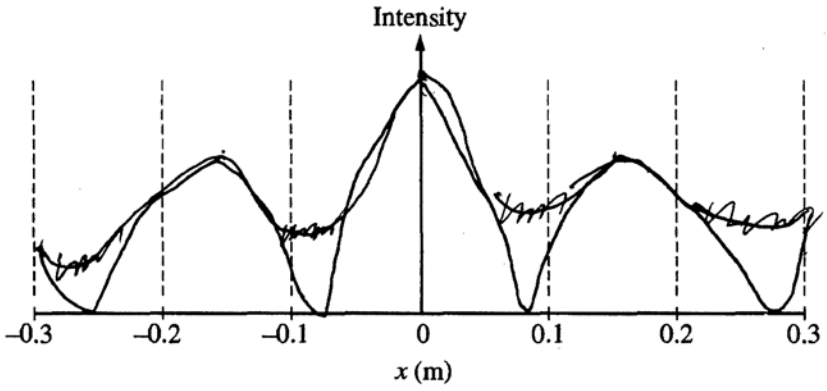
A microwave source is placed behind two identical slits, as represented in the diagram above. The slit centers are separated by a distance of 0.20 m, and the slit widths are small compared to the slit separation but not negligible. The microwave wavelength is 2.4×10^{-2} m. The resulting interference pattern is centered on a screen 0.60 m wide, located 2.5 m from the slits.

(a) Calculate the frequency of the microwave radiation.

$V = f\lambda$ $1.0 \times 10^8 = f(2.4 \times 10^{-2})$

$f = 4.167 \times 10^9$ Hz

(b) On the graph below, where the x-axis represents the distance along the screen and $x = 0$ represents the center of the pattern, sketch the intensity of the interference pattern expected for that arrangement.



disregard black lines I accidentally left in

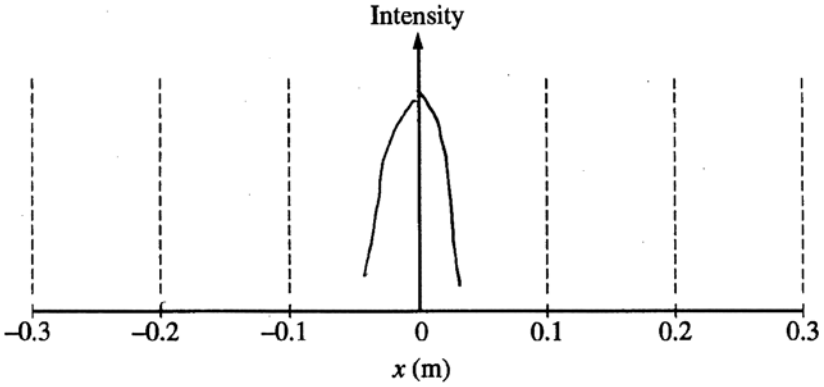
(c) Consider points on the screen located at $x = 0.00$ m, $x = 0.15$ m, and $x = 0.30$ m. Rank the intensity at those points from highest to lowest, with number 1 corresponding to the highest intensity. If two points have equal intensity, give them the same ranking.

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

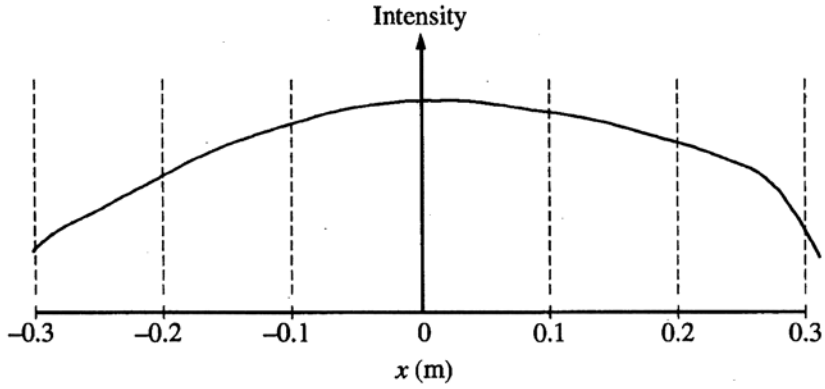
Justify your ranking.

Farther away decreases the intensity by the destructive interferences in between

(d) Suppose the microwave wavelength is decreased by a factor of three, to 0.80×10^{-2} m . Sketch the resulting interference pattern below.



(e) Suppose the material separating the two slits is removed so that there is now one slit approximately 0.20 m in width. The wavelength is held at 0.80×10^{-2} m . Sketch the resulting diffraction pattern below.



AP® PHYSICS B
2011 SCORING COMMENTARY (Form B)

Question 3

Sample: B3A
Score: 14

This solution includes all the required components and demonstrates a strong understanding of diffraction. The justification in part (c) is correct given the student's position for the first fringes. Part (d) did not earn 1 point because it does not indicate that the amplitudes of the peaks decrease as the distance from the center of the pattern increases.

Sample: B3B
Score: 8

Part (a) earned full credit. Part (b) and part (c) earned 1 point for a central peak. No other points were earned even though the ranking agrees with the graph because no justification for the shape of the graph was given. Part (d) earned 1 point for indicating that there would be more peaks. Part (e) earned full credit.

Sample: B3C
Score: 5

Part (a) earned 1 point for the correct equation, but the answer is incorrect. Part (b) earned 3 points but does not have the second peaks at ± 0.3 m. Part (c) earned 1 point for recognizing the greatest intensity at $x = 0$. No other points were earned, even though the ranking agrees with the graph, because the justification does not explain the decreasing height of the peaks. Parts (d) and (e) earned no credit.