2017

AP CollegeBoard

AP Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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- ☑ Scoring Guideline
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AP® PHYSICS
2017 SCORING GUIDELINES

General Notes About 2017 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. The requirements that have been established for the paragraph length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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 awarded. 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.

4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based and AP Physics 2: Algebra-Based Course and Exam Description*.

5. 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 of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

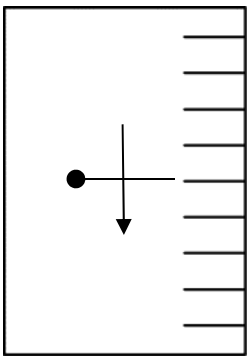
6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive 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 2
2017 SCORING GUIDELINES

Question 3

12 points total **Distribution of points**

(a) 2 points



For the arrow drawn upside down relative to the object 1 point
For bar/circle drawn left-to-right reversed relative to the object or consistent with an (incorrect) upright arrow 1 point

(b)

i. 1 point

For correctly showing a calculation of the focal length and a correct answer with units 1 point

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{20\text{ cm}} + \frac{1}{30\text{ cm}}$$

$$f = 12\text{ cm}$$

ii. 1 point

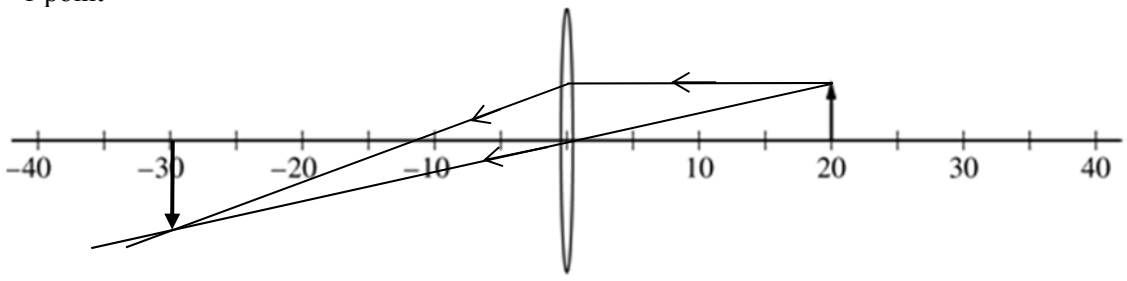
For correctly showing a calculation of the magnitude of the magnification (with or without sign) and a correct answer 1 point

$$M = d_i/d_o = 30\text{ cm}/20\text{ cm}$$

$$M = 1.5$$

(c)

i. 1 point



For two reasonably correctly drawn rays consistent with the calculated focal length, and inclusion of an inverted image 1 point

Question 3 (continued)

Distribution of points

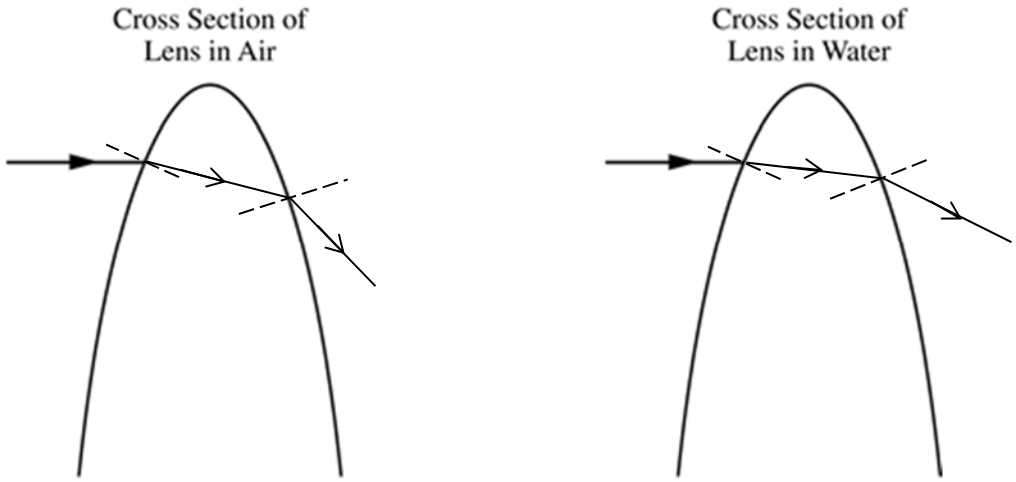
(c) (continued)

ii. 2 points

For a correct explanation of how the rays drawn relate to the focal length — 1 point
For a correct explanation of how the image relates to the magnification — 1 point
Example: The horizontal ray from the object bends to cross the axis at 12 cm from the middle of the lens, which is the focal length. The image arrow is about 1.5 times the height of the object, which is the magnification.

(d)

i. 2 points

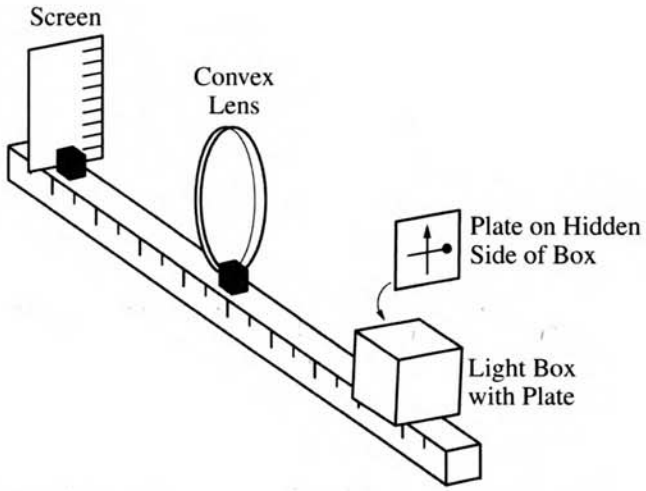


For showing the downward refraction of the rays at each surface of the lens in air (i.e., toward the normal entering the lens and away from the normal leaving the lens) — 1 point
For the rays refracted by the lens in water at greater angles to the normal than the corresponding angles for the lens in air — i.e., less bending (can be earned even if first point was not, scoring is relative to whatever is drawn for the lens in air) — 1 point

ii. 3 points

For describing a greater focal length when the lens is in water or a comparison consistent with part (d)(i) — 1 point
For describing a larger image distance and image size or a comparison consistent with part (d)(i) — 1 point
For describing how the rays drawn in (d)(i) support the descriptions — 1 point
Example: The rays do not bend as much as they pass from water to glass as when they pass from air to glass (and vice versa). This means parallel rays coming into the lens will converge at a farther distance, so the focal length is longer. Rays from an object also will converge farther from the lens, so the new image is farther and larger.

P2 Q3 A1

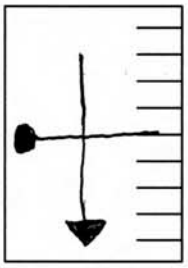


3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.



(b)

i. Calculate the focal length of the lens.

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$ $\frac{1}{30\,cm} + \frac{1}{20\,cm} = \frac{1}{f}$ $f = 12\,cm$

ii. Calculate the magnitude of the magnification of the image.

$M = \frac{s_i}{s_o} = \frac{30\,cm}{20\,cm}$

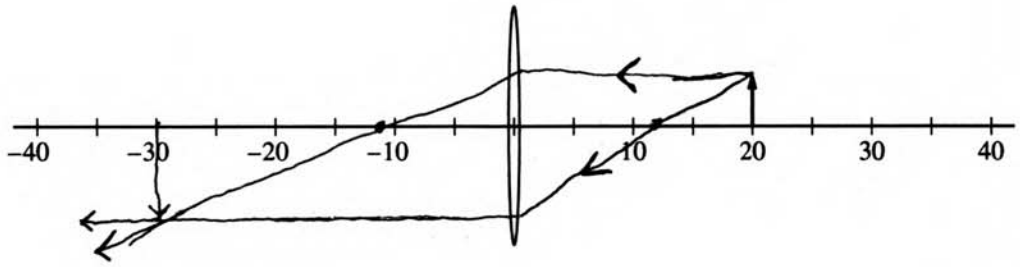
$M = \frac{3}{2}$

GO ON TO THE NEXT PAGE.

P2 Q3 A2

(c)

i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



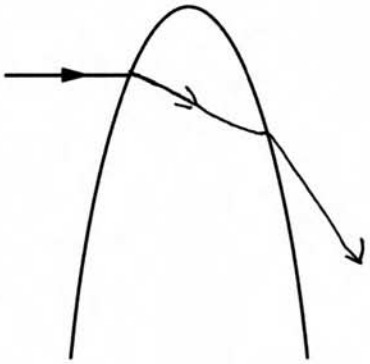
ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

By placing the focal points a distance that is 12cm from the lense, the rays create an image that is $\frac{3}{2}$ times the size of the object.

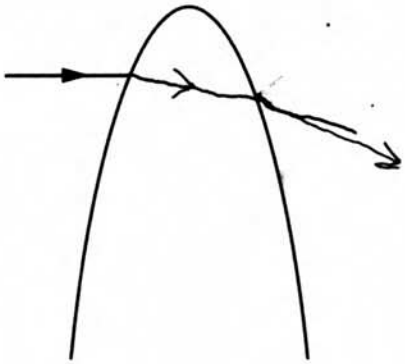
(d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.

Cross Section of Lens in Air



Cross Section of Lens in Water

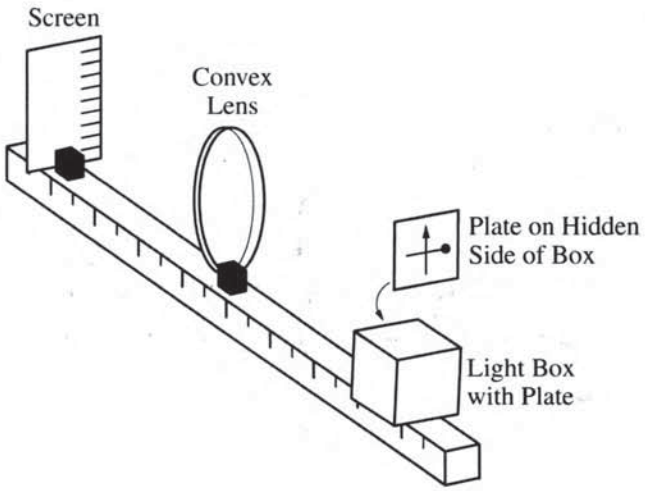


Question 3 continues on the next page.

ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

The focal length is longer when the apparatus is submerged. The image is also formed further away from the lense, and its magnification is greater. The rays from (d)(i) support this because the ray of the submerged apparatus bends less after entering the lens as opposed to the apparatus in the air. As a result, it will take a longer distance to intercept its focal point, meaning that the focal length is longer. If the focal points are further away, then that means that the ray from the object that intercepts the focal point, then enters the lens will have travelled further downwards before it reaches the lens. As a result, the magnified image will be larger.

P2 Q3 B1



3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.

(b)

i. Calculate the focal length of the lens.

$\frac{1}{d_i} + \frac{1}{d_o} = \frac{1}{F}$

$\frac{1}{.3} + \frac{1}{-.2} = \frac{25}{3} = .12$ $\quad F = .12\ m$

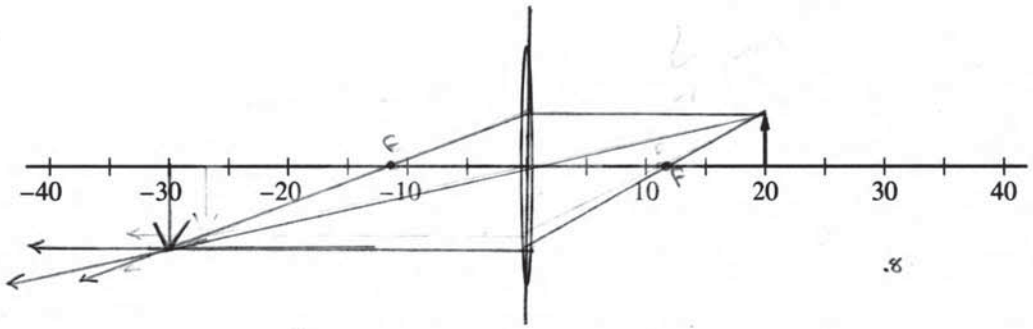
ii. Calculate the magnitude of the magnification of the image.

$M = \frac{d_i}{d_o}$

$= \frac{.3}{.2} = 1.5$ $\quad M = 1.5$

(c)

i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



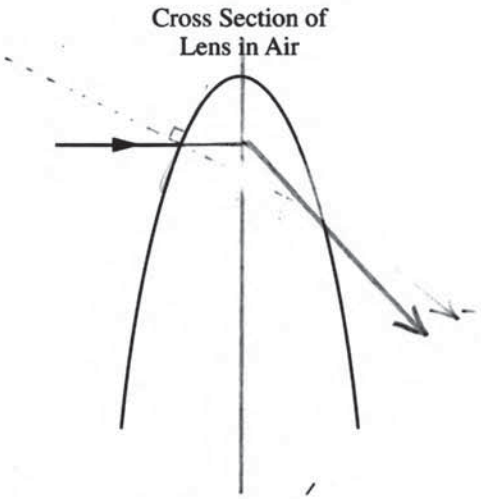
ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

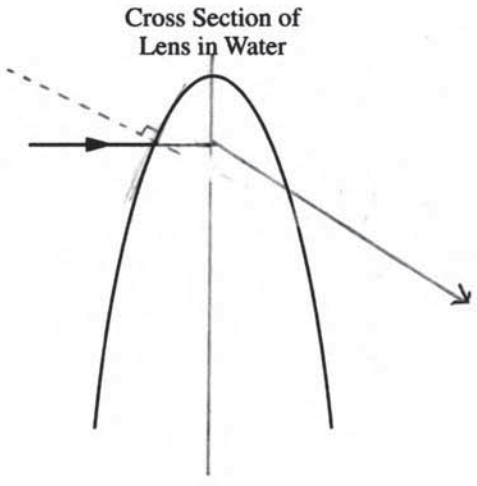
the focal length is consistant because the 2 rays that cross the x axis not at the center cross at the focus (.12m) on either side of the lense which matches my calculation of R = .12m

the magnification is consistant because the inverted imager is slightly larger than the object, about 1.5 times larger, which is consistant with my calculation that the imager would be 1.5 times bigger than the object

(d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.





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water farther refraction

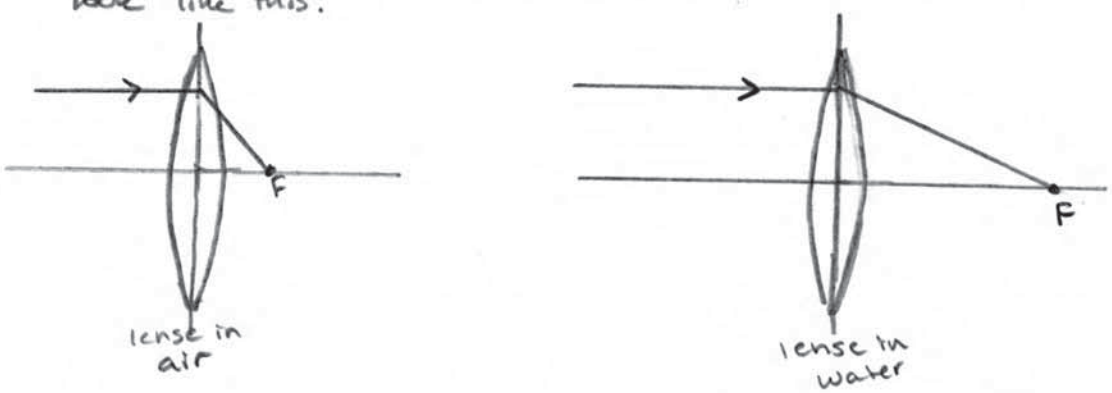
P2 Q3 B3

ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

the focus on the lense in air would be smaller than the focus in water. The water is more dense than the air so the ray coming out of the lense would bend less towards the normal than it would in air. Because this is a ray that enters the lense parallel it must leave through the focus and it is at a more extreme angle with the lense in air, it would hit closer to the lense than the ray in water

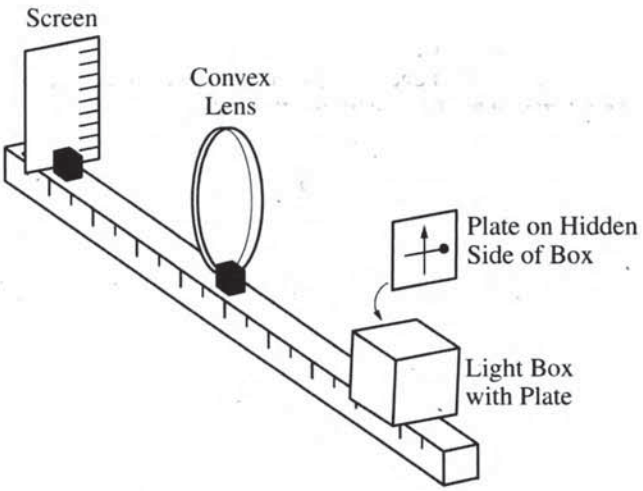
The rays drawn in di support my answer because the ray drawn in air bends much more towards the normal than the ray through water

if they were extended to meet the x axis they would look like this:



as you can see, the lense in air results in a shorter focal length than the lense in water

P2 Q3 C1

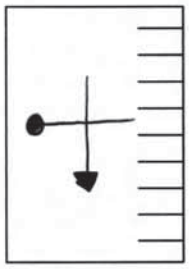


3. (12 points, suggested time 25 minutes)

Some students are asked to determine the focal length of a convex lens. They have the equipment shown above, which includes a waterproof light box with a plate on one side, a lens, and a screen. The box has a bright light inside, and the plate on the side has shapes cut out of it through which the light shines to create a bright object. This particular plate has a cutout that is a vertical arrow and a horizontal bar with a circle at one end. In the view shown above, the circle is near the right edge of the plate.

With the screen and light box on opposite sides of the lens, the box is aligned so that the plate is 20 cm from the center of the lens, and an image of the arrow and bar is formed on the screen. The students find that the image is clear on the screen when the screen is 30 cm from the center of the lens.

(a) On the figure below, sketch how the image on the screen appears to the students.



(b)

i. Calculate the focal length of the lens.

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{F}$ $\frac{1}{20} + \frac{1}{30} = \frac{1}{f}$ $f = 12\,cm$

ii. Calculate the magnitude of the magnification of the image.

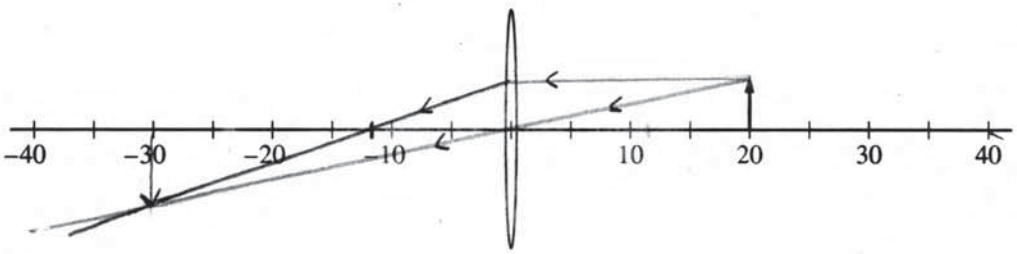
$|M| = \left|\frac{s_i}{s_o}\right| = \left|\frac{20}{30}\right|$

$|M| = 0.667$

P2 Q3 C2

(c)

i. In the side view below, the arrow represents the bright object created by the plate. Draw a ray diagram on the figure below that is consistent with your calculations in parts (b)(i) and (ii). Show at least two rays, as well as the location and orientation of the image.



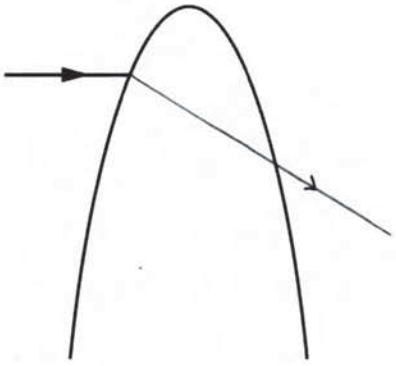
ii. Explain how your diagram is consistent with your calculated focal length and magnification in parts (b)(i) and (ii).

The ray which passes directly through the lense goes through the focal length when it refracts. The object is larger than it originally appeared

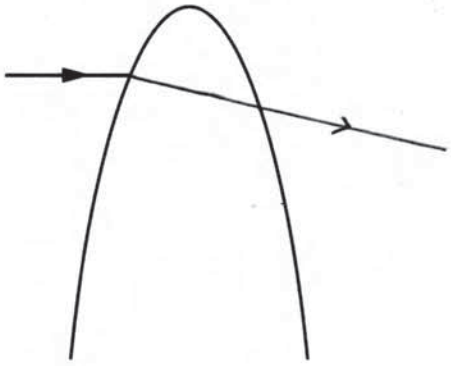
(d) The entire apparatus is now submerged in water, whose index of refraction is greater than that of air but less than that of the lens.

i. The figures below show cross sections of the top portion of the convex lens in air and the convex lens in water. An incident ray is shown in both cases. On each figure, draw the ray as it passes through the lens and back into the air or water.

Cross Section of Lens in Air



Cross Section of Lens in Water



Question 3 continues on the next page.

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P2 Q3 C3

ii. Describe how the focal length of the lens and the position and size of the image formed by the lens when it is in the water compare to when the lens is in air. Explain how the rays drawn in the figures in part (d)(i) support your answer.

The object is less magnified when it passes back into the water.

AP® PHYSICS 2
2017 SCORING COMMENTARY

Question 3

Overview

This question assessed learning objectives 6.E.3.1, 6.E.3.3, and 6.E.5.1.
The responses to this question were expected to demonstrate the following:

- Students were expected to understand how images are formed by a convex lens. This included how the image "flipped" both vertically and horizontally.
- The ability to utilize basic optics equations to determine the focal length and magnification from given image distance and object distance.
- Students were asked to construct a ray diagram to verify the given image distance and the image size.
- This Qualitative Quantitative Translation question required the students to show how their calculated focal length and image size were represented in the ray diagram they drew.
- Students were tested on their understanding of the refraction that occurred at multiple interfaces, both going into the lens and exiting the lens. They were asked to compare how the degree of refraction when the glass lens was in air compared to when it was submerged in water. This included an explanation of how the submersion of the lens affected the focal length and image characteristics.

Sample: P2 Q3 A
Score: 12

This response earned full credit for all parts. In parts (c)(ii) and (d)(ii) the paper contains explicit references to the rays in the previous diagrams.

Sample: P2 Q3 B
Score: 9

In part (a) the image is shown flipped vertically but not horizontally, so 1 point was earned. The calculations in (b) are correct and earned 2 points. Part (c) shows three correct rays and a correct image, and the explanation appropriately refers to the diagram, so 3 points were earned. In part (d)(i) the left diagram does not show refractions at the surface of the lens, but the right diagram is consistent with the left and shows less bending of the ray, so 1 point is earned. Part (d)(ii) contains a correct explanation for a shorter focal length in air and refers to the diagram, but it does not discuss the magnification, so 2 points were earned.

Sample: P2 Q3 C
Score: 6

Part (a) earned 2 points, full credit. In part (b) the focal length is correct, but the substitutions in the magnification are backward, so 1 point was earned. In part (c) the ray diagram is correct, but in the explanation, it is not clear which ray is the "ray which passes directly through the lens," so 2 points were earned. Part (d)(i) has refraction at only one surface, so the right diagram earned 1 point for being consistent and showing less bending. Part (d)(ii) has no correct information.