AP® PHYSICS B
2006 SCORING GUIDELINES

General Notes About 2006 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 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.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 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 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 AP Physics exam equation sheet. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

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 of course 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 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.

Question 4

15 points total **Distribution of points**

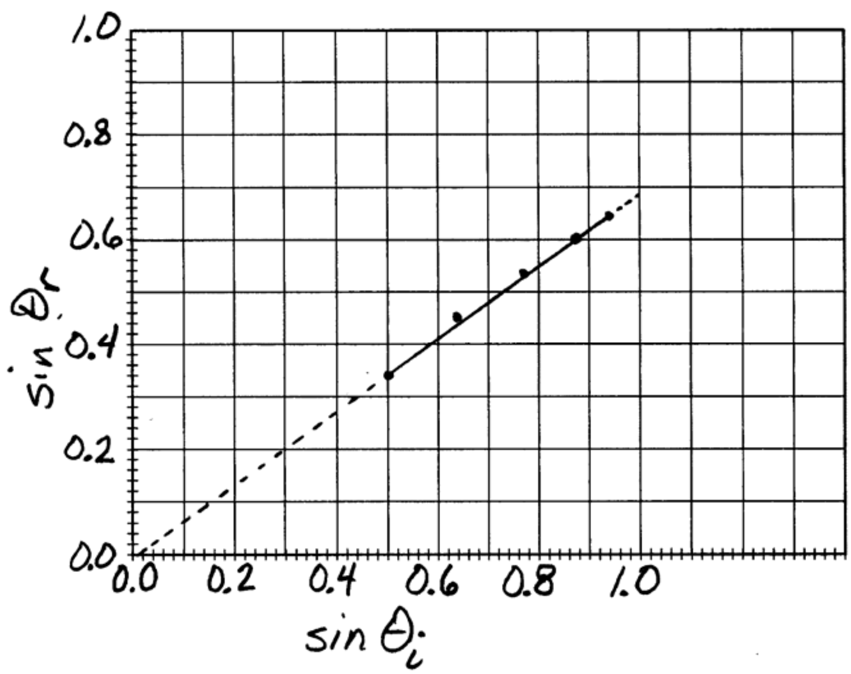
(a) 2 points

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	0.50	0.34
2	40°	27°	0.64	0.45
3	50°	32°	0.77	0.53
4	60°	37°	0.87	0.60
5	70°	40°	0.94	0.64

For identifying that both quantities to be graphed are the sines of the angles — 1 point
For correctly calculating the sines using degrees — 1 point

(b) 4 points

Example:



For correctly labeling both axes with the sines of the angles — 1 point
For correctly labeling both axes with appropriate numerical scales — 1 point
For plotting the five points — 1 point
For correctly drawing a best fit line that includes the entire range of data points and may extend beyond them — 1 point

Question 4 (continued)

Distribution of points

(c) 4 points

For a statement or implicit use of Snell's Law — 1 point

$n_1 \sin\theta_i = n_2 \sin\theta_r$ (or $\sin\theta_i = n_2 \sin\theta_r$ since $n_1 = n_{air} = 1$)

For indicating that the index of refraction n can be obtained from the slope or inverse of the slope depending on choice of variable plotted on each axis — 1 point

Example using graph above

$$n = \frac{\sin\theta_i}{\sin\theta_r} = \frac{1}{\text{slope}}$$

For using two sets of points directly from the line to find the slope — 1 point

$$\text{slope} = \frac{0.53 - 0.41}{0.78 - 0.60} = 0.67$$

For a correct calculation of the index of refraction consistent with the slope of the graph — 1 point

$n = 1/0.67 = 1.5$

(d) 1 point

For checking "The air-oil interface only" — 1 point

(e) 4 points

For indicating that the optical path difference between the waves reflecting off the air-oil interface and the oil-water interface is one-half wavelength — 1 point

$\Delta\ell = \lambda/2$

For indicating that the wave reflecting off the oil-water interface travels a distance equal to twice the thickness of the oil — 1 point

$\Delta\ell = 2t$

For indicating that the wavelength of the light in the oil film is different from the wavelength of the light in air — 1 point

$\lambda_{film} = \lambda_{air}/n_{film}$

The three equations above are combined to relate the film thickness to the wavelength.

$2t = \lambda_{film}/2 = \lambda_{air}/2n_{film}$

$t = \lambda_{air}/4n_{film}$

$t = 6.0 \times 10^{-7}\,\text{m}/4(1.43)$

For the correct answer with appropriate units — 1 point

$t = 1.05 \times 10^{-7}\,\text{m} = 105\text{ nm}$

<u>*Notes*</u>:

A student who checked "The oil-water interface only" *in part (d) and then correctly calculated a wavelength of 105 nm for the thickness of the oil was awarded full credit.*

A student who checked "Both interfaces" *or* "Neither interface" *in part (d) and then correctly calculated a wavelength of 210 nm for the thickness of the oil was awarded full credit.*

4. (15 points)

A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.

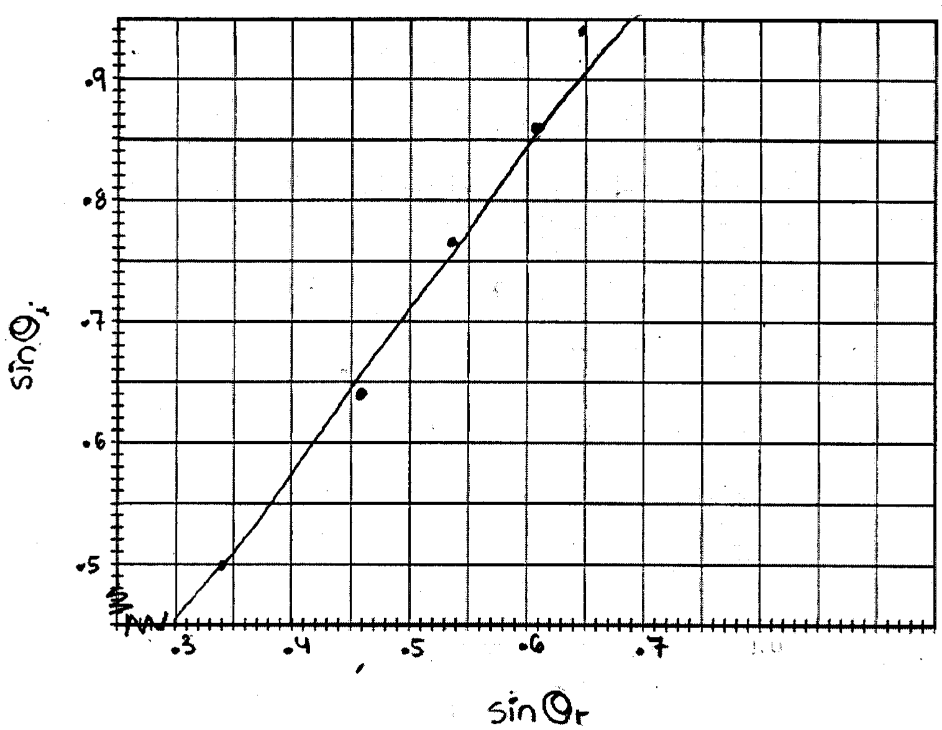
Trial	θ_i	θ_r	sin θ_i	sin θ_r
1	30°	20°	.500	.342
2	40°	27°	.643	.454
3	50°	32°	.766	.530
4	60°	37°	.866	.602
5	70°	40°	.940	.643

$n_1 = 1$

Y X

(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

(b) On the grid below, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.

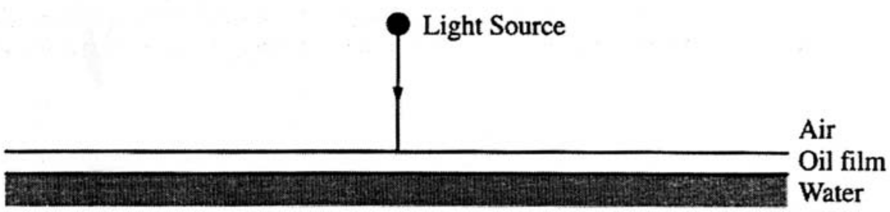


(c) Using the graph, calculate the index of refraction of the glass slab.

$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$ where $n_1 = 1$ so n_2 is slope of graph

$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{.866 - .500}{.602 - .342} = 1.4$



The student is also asked to determine the thickness of a film of oil ($n = 1.43$) on the surface of water ($n = 1.33$). Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

(d) At which of the two interfaces does the light undergo a 180° phase change on reflection?

✓ The air-oil interface only ___The oil-water interface only

___Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

Out of phase due to phase change, so must be put back in phase for constructive interference (maximum):

$2L = (m + 1/2)\lambda_n$, where $\lambda_n = \frac{\lambda}{n}$, and $m = 0$ for min. thickness

$L = \frac{\lambda}{4n} = \frac{600 \times 10^{-9} m}{4(1.43)} = 1.05 \times 10^{-7} m$ or $\approx 105 nm$

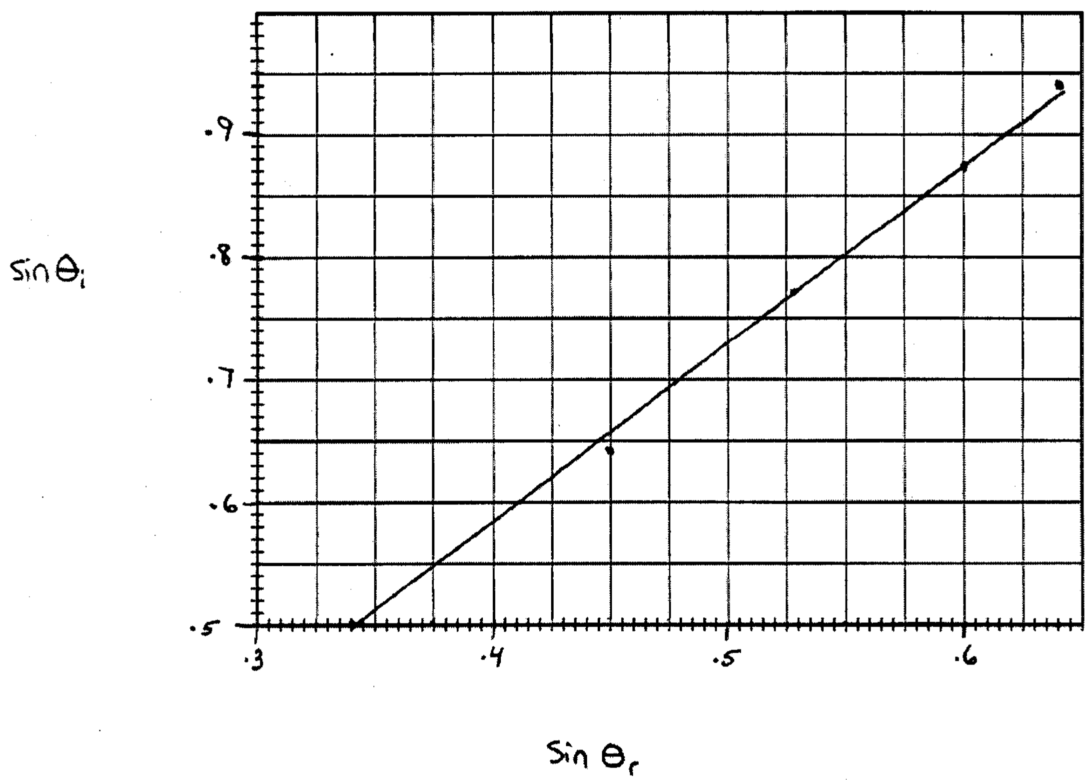
4. (15 points)

A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	.5	.34
2	40°	27°	.64	.45
3	50°	32°	.77	.53
4	60°	37°	.87	.60
5	70°	40°	.94	.64

(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

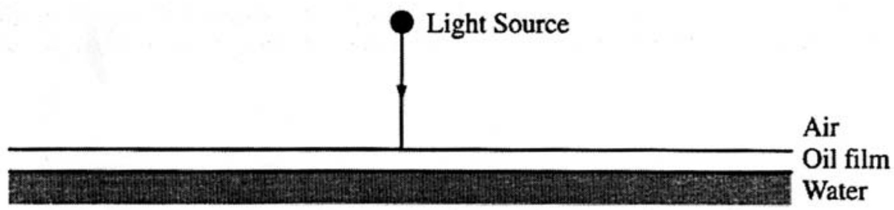
(b) On the grid below, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.



(c) Using the graph, calculate the index of refraction of the glass slab.

$n_i \sin\theta_i = n_r \sin\theta_r$

$\frac{(1.00)\sin\theta_i}{\sin\theta_r} = \frac{\Delta y}{\Delta x} = \frac{.8 - .55}{.55 - .375} = \frac{.25}{.175} = \boxed{1.43}$



The student is also asked to determine the thickness of a film of oil ($n = 1.43$) on the surface of water ($n = 1.33$). Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

(d) At which of the two interfaces does the light undergo a 180° phase change on reflection?

___The air-oil interface only ___The oil-water interface only

_X_Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

$d\sin\theta = m\lambda$

$d = ?$

$\sin\theta = \sin 90° = 1$

$m = 1$ (minimum)

$\lambda = 600\text{nm}$

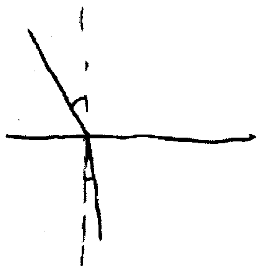
$d = \frac{m\lambda}{\sin\theta}$

$= \frac{(1)(600\text{nm})}{\sin 90°}$

$\boxed{d = 600\text{nm}}$

4. (15 points)

A student performs an experiment to determine the index of refraction n of a rectangular glass slab in air. She is asked to use a laser beam to measure angles of incidence θ_i in air and corresponding angles of refraction θ_r in glass. The measurements of the angles for five trials are given in the table below.



Trial	θ_i	θ_r	n_1	n_2
1	30°	20°	1.00	1.46
2	40°	27°	1.00	1.41
3	50°	32°	1.00	1.45
4	60°	37°	1.00	1.44
5	70°	40°	1.00	1.46

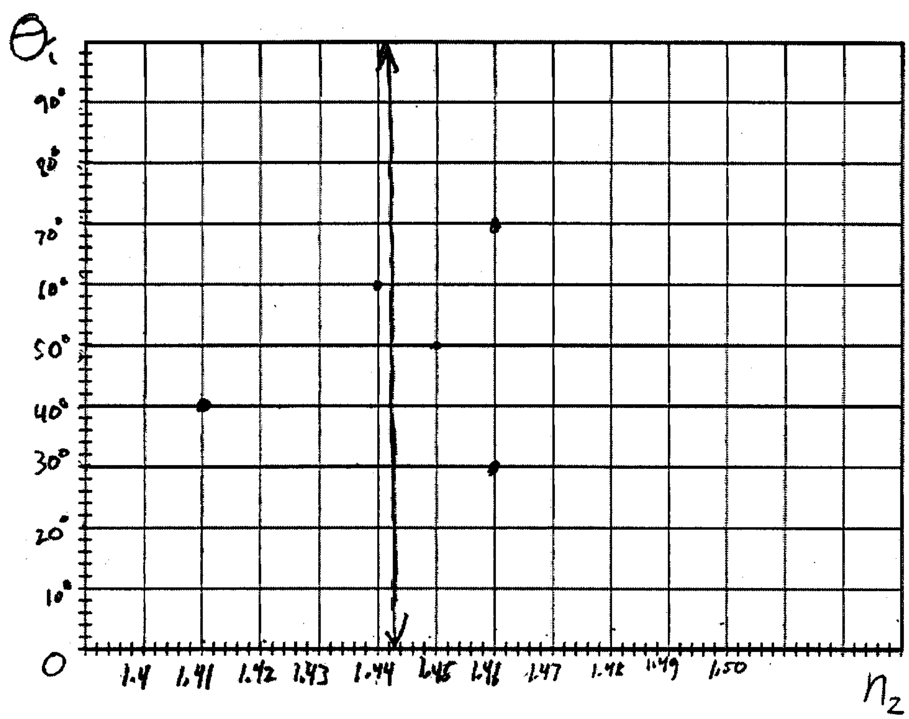
$n_1 \sin\theta_1 = n_2 \sin\theta_2$

$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2}$

$n_2 = \frac{1(\sin(30°))}{\sin 20°}$

(a) Complete the last two columns in the table by calculating the quantities that need to be graphed to provide a linear relationship from which the index of refraction can be determined. Label the top of each column.

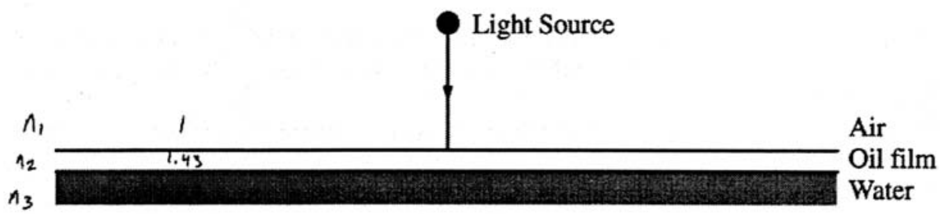
(b) On the grid below, plot the quantities calculated in (a) and draw an appropriate graph from which the index of refraction can be determined. Label the axes.



(c) Using the graph, calculate the index of refraction of the glass slab.

$$n_{avg} = \frac{2(1.46) + 1.45 + 1.44 + 1.41}{5} = 1.44$$

$$\boxed{n_{glass} = 1.44}$$



The student is also asked to determine the thickness of a film of oil (n = 1.43) on the surface of water (n = 1.33). Light from a variable wavelength source is incident vertically onto the oil film as shown above. The student measures a maximum in the intensity of the reflected light when the incident light has a wavelength of 600 nm.

(d) At which of the two interfaces does the light undergo a 180° phase change on reflection?

X The air-oil interface only ___The oil-water interface only

___Both interfaces ___Neither interface

(e) Calculate the minimum possible thickness of the oil film.

$$2t = \frac{1}{2}\lambda_f$$

$$n = \frac{c}{v} \quad c = nv \text{(air)} \quad n_1 v_1 = n_f v_f$$

$$c = n_f v_f \text{ (oil)}$$

$v = f\lambda$ f remains constant

$$n(f\lambda) = n_f(f\lambda_f)$$

$$n\lambda = n_f\lambda_f \qquad \lambda_f = \frac{n\lambda}{n_f}$$

$$2t = \frac{1}{2}\left(\frac{n\lambda}{n_f}\right)$$

$$t = \frac{\frac{1}{2}\left(\frac{n\lambda}{n_f}\right)}{2} \qquad t = \frac{\frac{1}{2}\left(\frac{1 \cdot 600\,\text{nm}}{1.43}\right)}{2}$$

$$\boxed{t = 105\,\text{nm}}$$

AP® PHYSICS B
2006 SCORING COMMENTARY

Question 4

Overview

This was a 15-point question designed to test student understanding of two different topics in optics. The first portion of the question—parts (a) through (c)—referred to an experiment designed to obtain the index of refraction of a piece of glass. Students were given a set of data consisting of the angles of incidence and refraction, and they were asked to construct a graph from which the index of refraction could be obtained. The remainder of the question dealt with thin-film interference. Students were asked to identify at which (if any) of the interfaces there is a 180˚ phase change upon reflection and to calculate the minimum possible thickness of the film.

Sample: B4A
Score: 15

This response includes clear work in part (e) to determine the minimum thickness of the oil film.

Sample: B4B
Score: 10

Full credit was earned for the first three parts. The wrong choice is indicated in part (d) and the calculation is incorrect for that choice, so no further credit was earned.

Sample: B4C
Score: 6

This student calculates a value of the index of refraction from each data point and plots that on the graph, which does not yield a graph from which the index can be determined, so no credit was earned for the first two parts. Part (c) earned 1 point for using Snell's law to obtain the five values that were averaged. Parts (d) and (e) are correct and earned full credit.