Optics II
Wave model of light

Eugenia Etkina and Gorazd Planinsic

Link to all documents for the workshop

[December 2024 Optics II (Wave optics)]

[OALG Chapter 24 Final.docx]

[ALG Chapter 24 Final.docx]

[Etkina 2e IG Chapter 24Final.docx]

And please rename yourself:

First name, where you teach- High school or college and the country

Eugenia University USA

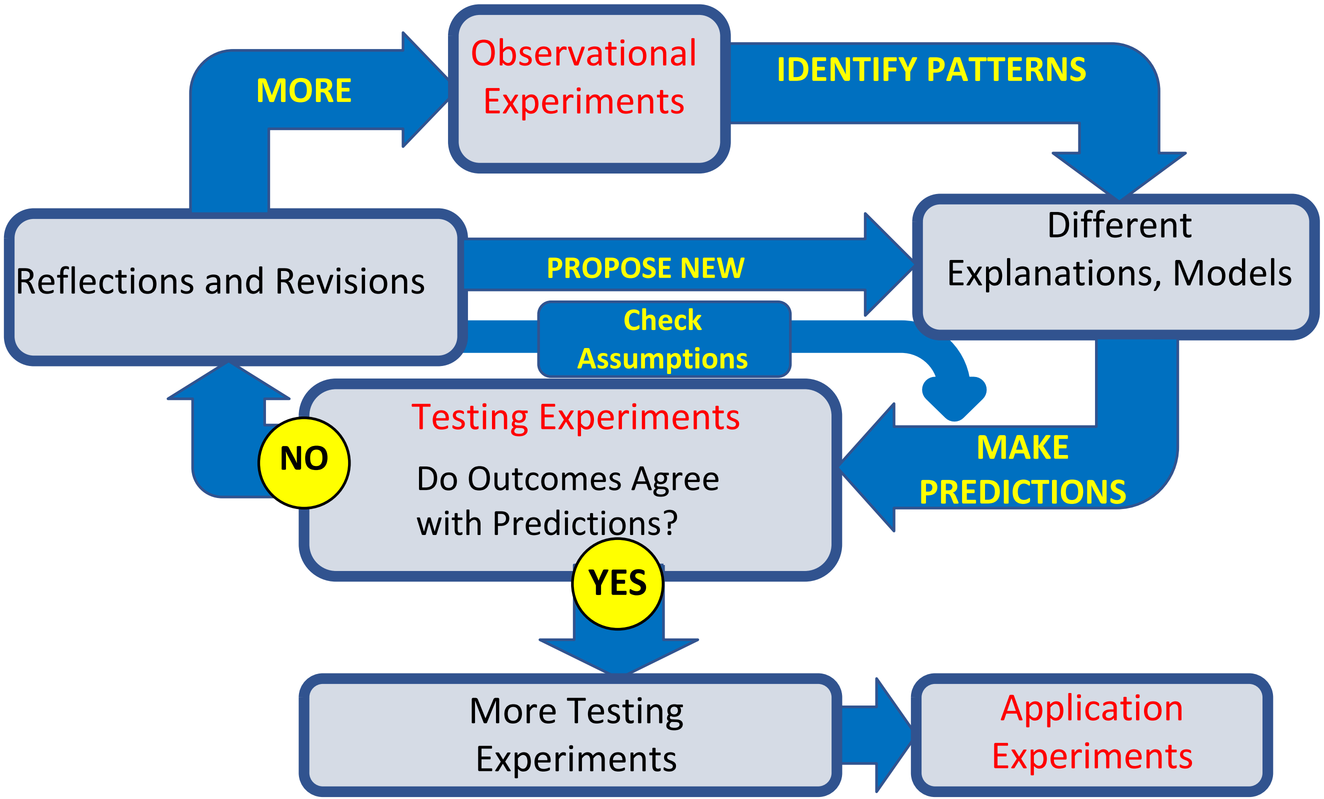
What should students have done before

Chapter 11 - waves

Chapter 22 - geometrical optics + a little bit of models of light,

Last workshop we learned that a particle-bullet model of light explains shadows and reflection but cannot explain refraction and account for the change of speed in a different medium. What model can?

The Investigative Science Learning Environment (ISLE) approach



Etkina and Van Heuvelen, 2001, 2007; Etkina, 2015

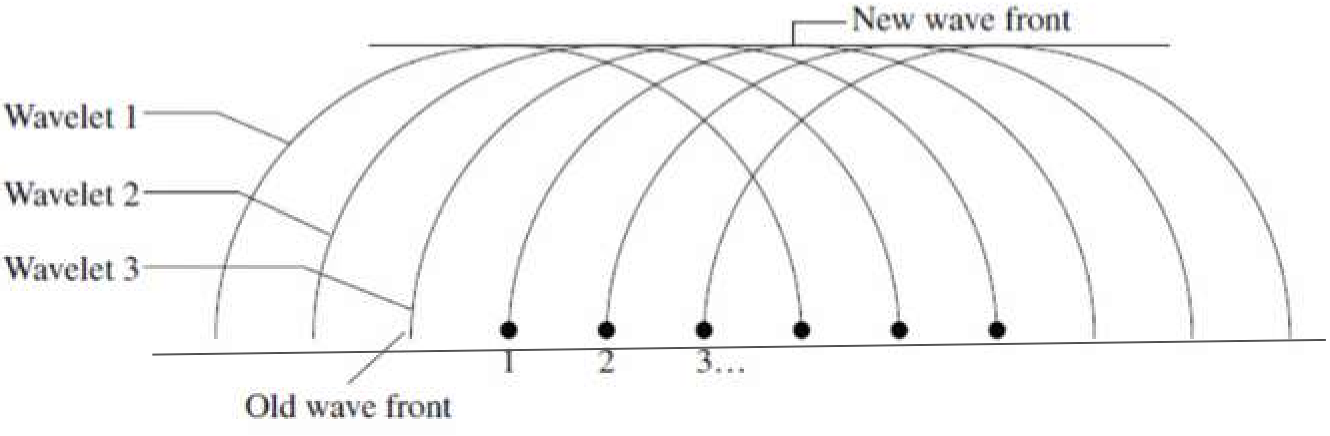
Need to know

In the previous workshop we rejected the particle bullet model of light that predicted that the speed of light in water should be higher than in the air. What model would explain reflection and refraction with the speeds matching our observations?

Christiaan Huygens, Lord of Zeelhem, also spelled Huyghens; Latin: Hugenius; (14 April 1629 – 8 July 1695) was a Dutch mathematician, physicist, engineer, astronomer, and inventor who is regarded as a key figure in the Scientific Revolution.

Wave model of light

Huygens principle: each point on a wavefront is a source of secondary wavelets and the new wave front is tangent to all secondary wavelets.



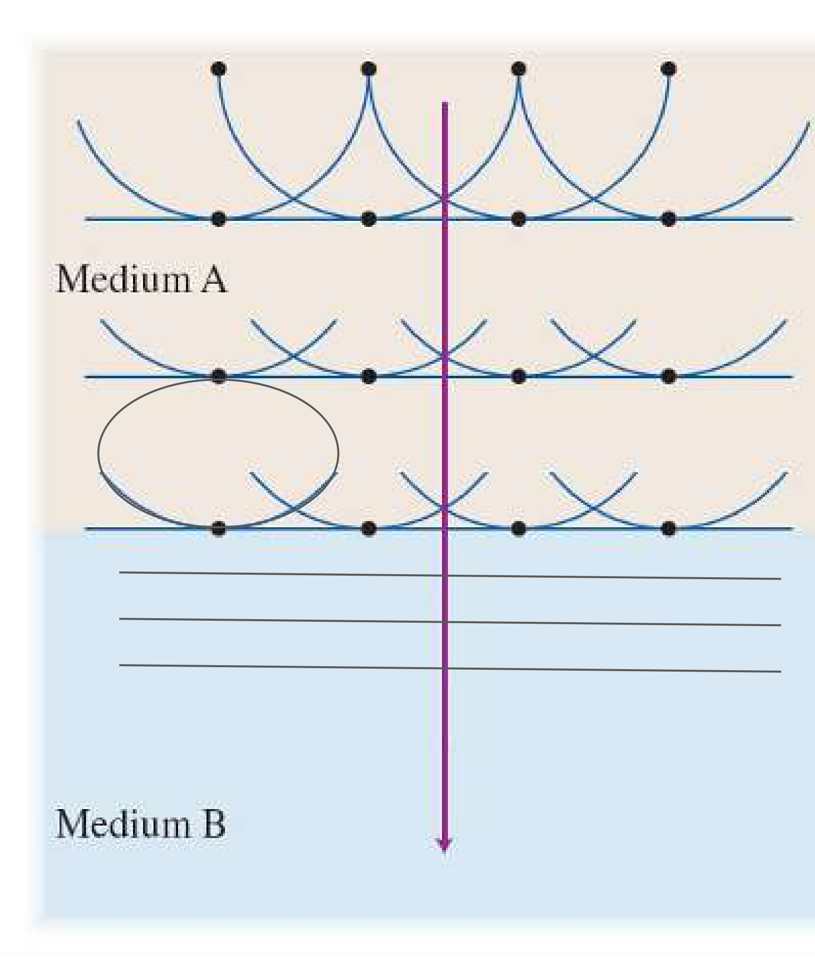
How does Huygens principle account for the change of speed of light traveling in a different medium?

Team 1

In the previous activity, semicircular wavelets all traveling at the same speed make up a new wave front. Waves often travel at different speeds in different places. For example, water waves travel more slowly in shallow water than in deeper water. Sound travels more slowly in cold air than in warm air. The difference in speed in different regions causes the wave to bend—to change direction. Huygens' principle can be used to understand this better. In the sketch below, three wave crests (wave fronts) of waves moving vertically down with a speed are constructed using Huygens ' principle. The distance between the two successive wave fronts is the wavelength in medium A. The speed of waves in medium A is three times the speed of waves in medium B.

a. On the sketch, draw a continuation of the waves in medium B. Draw at least four new wave fronts.

b. Determine the ratio between the wavelengths and between the frequencies of the waves in the two media. Explain your answer.



Team 2

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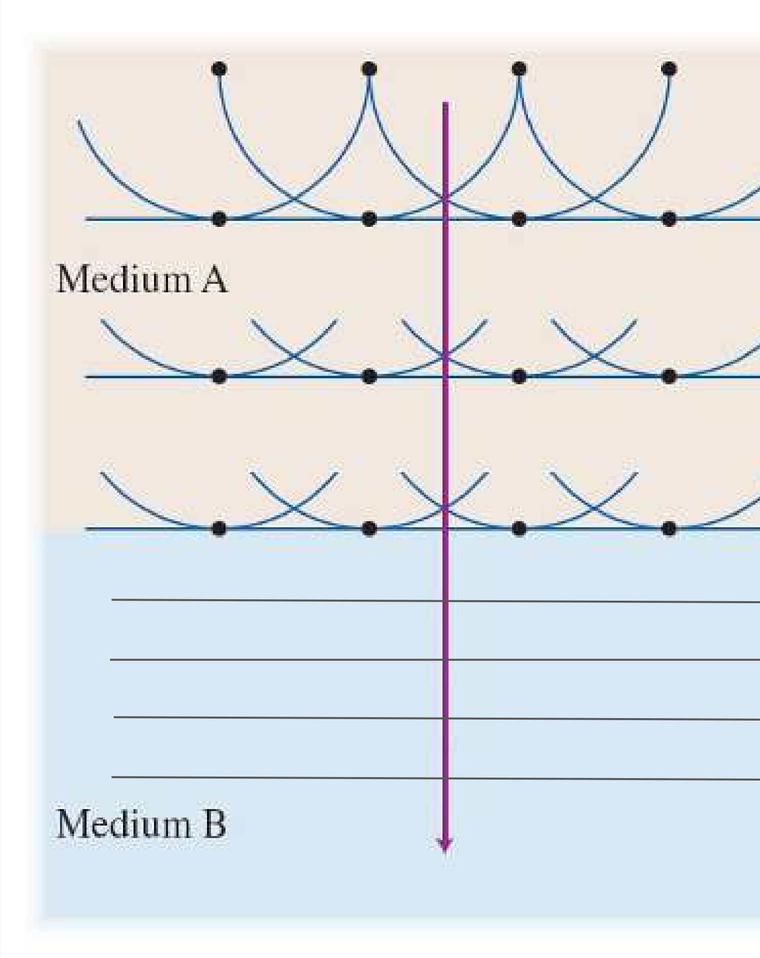

Team 3

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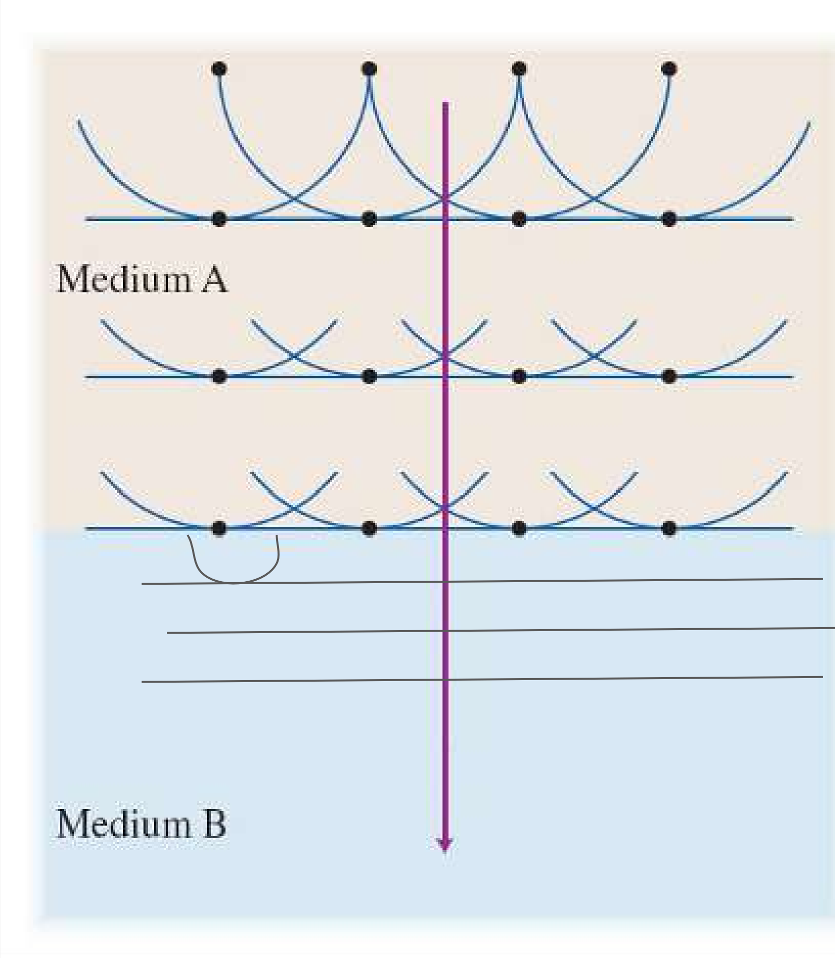
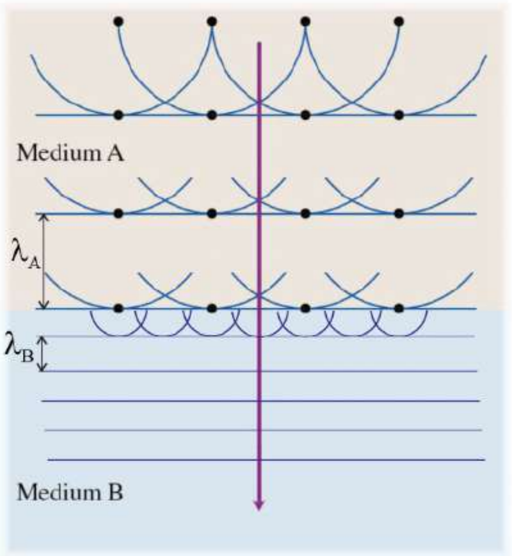




a. On the sketch, draw a continuation of the waves in medium B. Draw at least four new wave fronts.

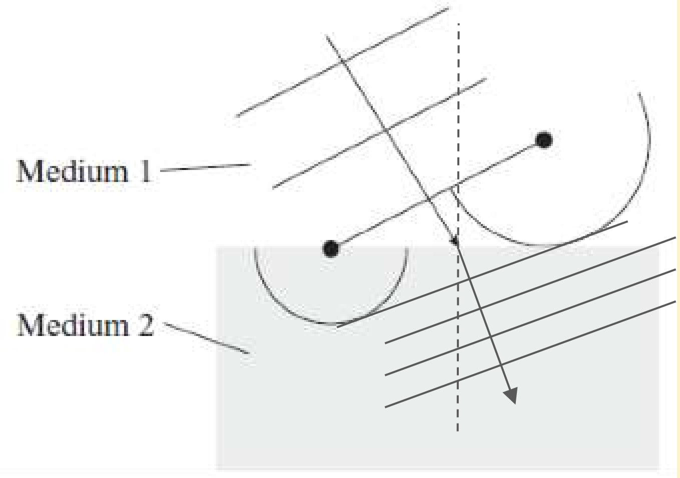
See sketch above

b. Determine the ratio between the wavelengths λ_A/λ_B and between the frequencies f_A/f_B of the waves in the two media. Explain your answer.

Frequencies should be equal, because the frequency is determined with the source of waves, so $f_A/f_B = 1$. *Knowing this and the ratio between speeds, the ratio between the wavelengths is determined by* $\lambda_A/\lambda_B = \frac{f_B v_A}{\ldots} = 3$.

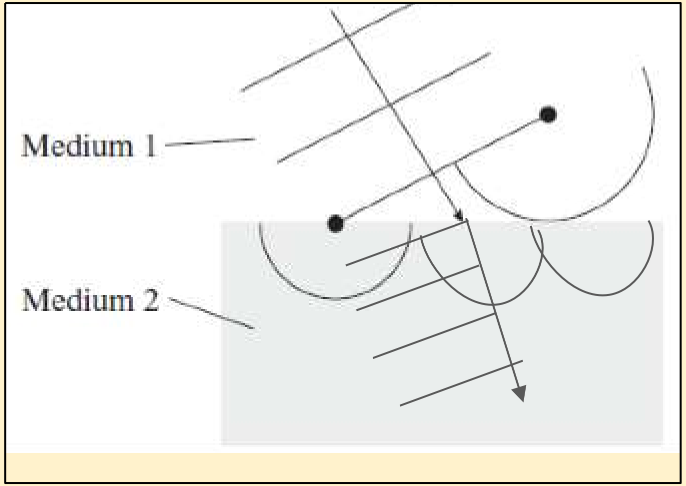
Team 1

What happens when the waves are not traveling perpendicular to the border of two media? Use Huygens principle to show how the wave will travel after going to medium 2 where the speed is slower than in 1.



Team 2

What happens when the waves are not traveling perpendicular to the border of two media? Use Huygens principle to show how the wave will travel after going to medium 2 where the speed is slower than in 1.



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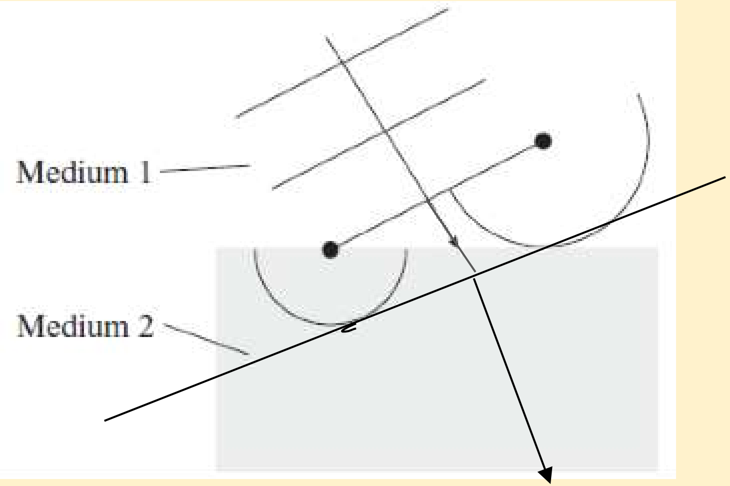
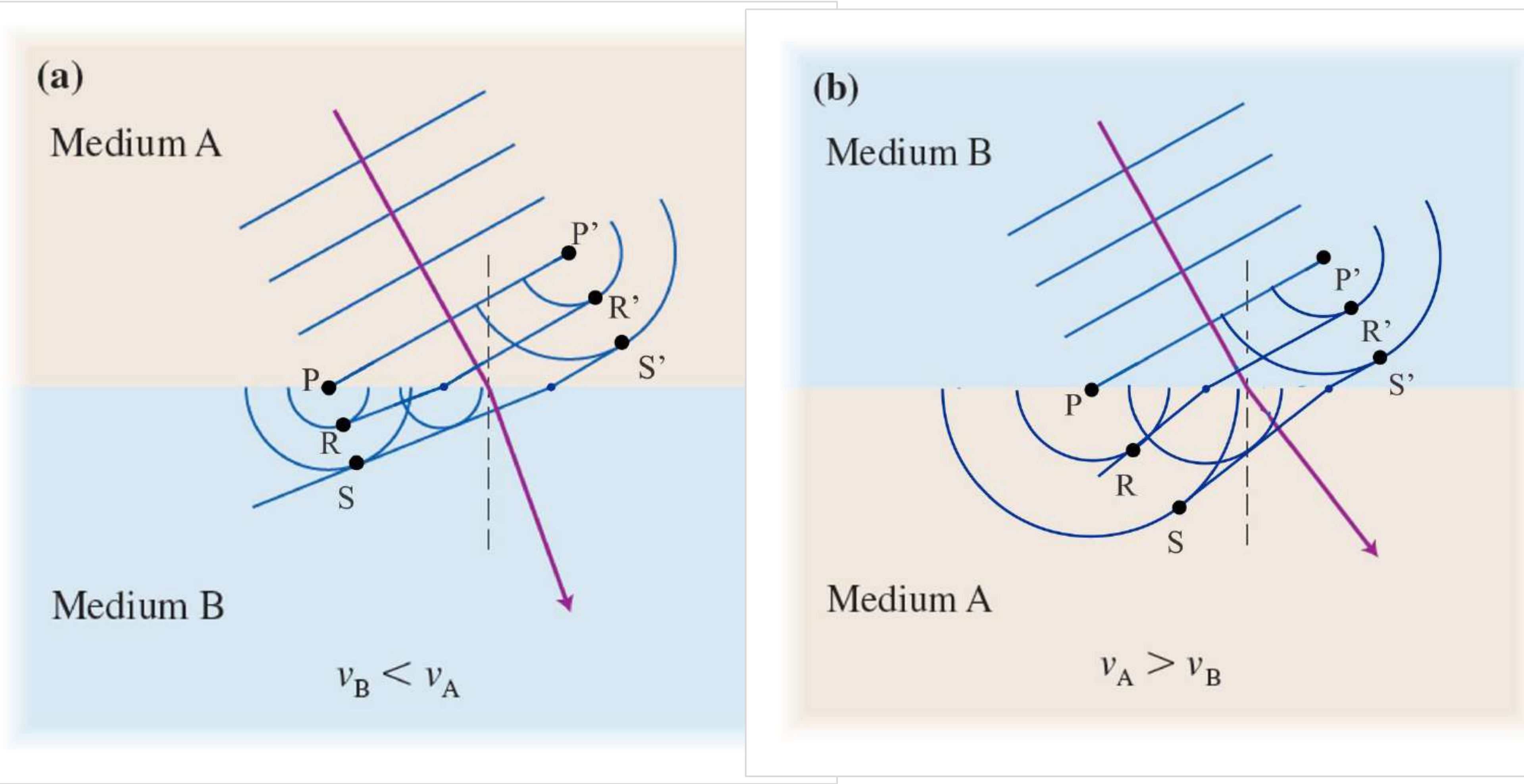



(a)
Medium A
P'
R'
S'
P
R
S
Medium B
$v_B < v_A$
(b)
Medium B
P'
R'
S'
P
R
S
Medium A
$v_A > v_B$

Team 1

How do we use Huygens principle to explain specular reflection of light?

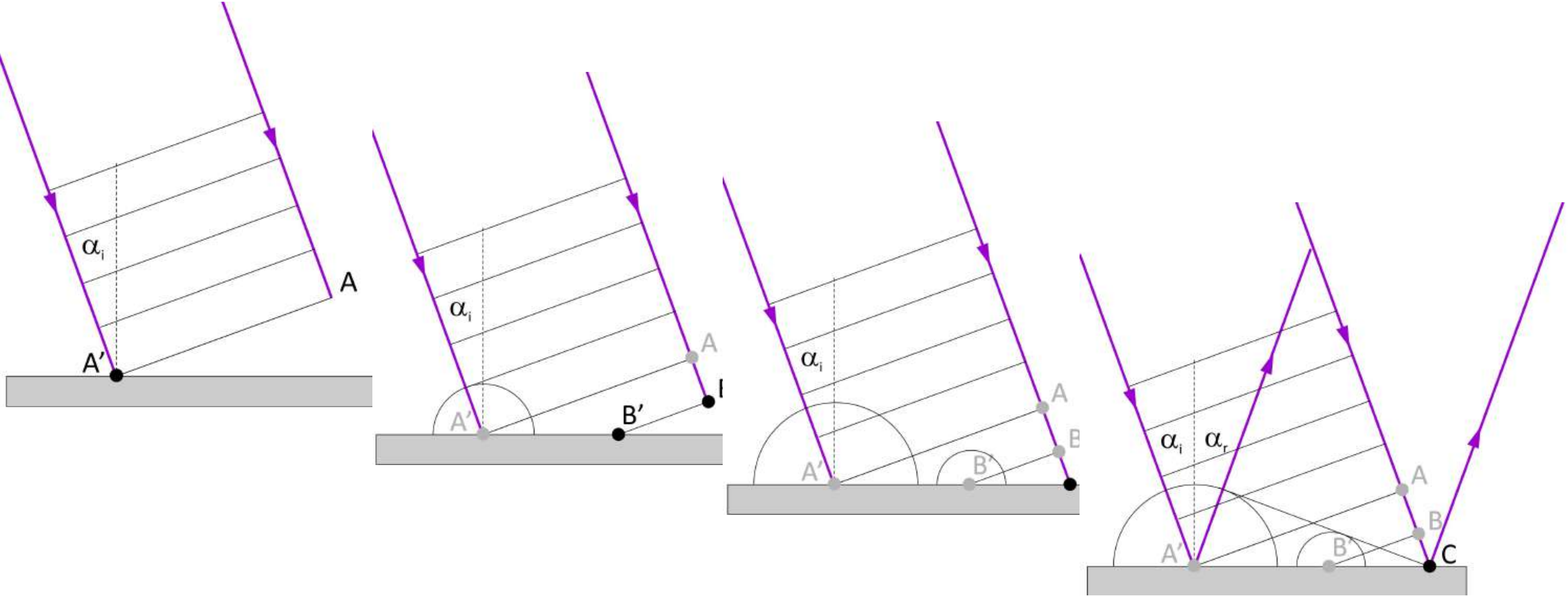
Team 2

How do we use Huygens principle to explain specular reflection of light?

Team 3

How do we use Huygens principle to explain specular reflection of light?

Using Huygens principle to explain reflection of light



We know that the particle-bullet model of light does not explain refraction correctly. But does it mean that we should throw it out completely or just use it when it works?

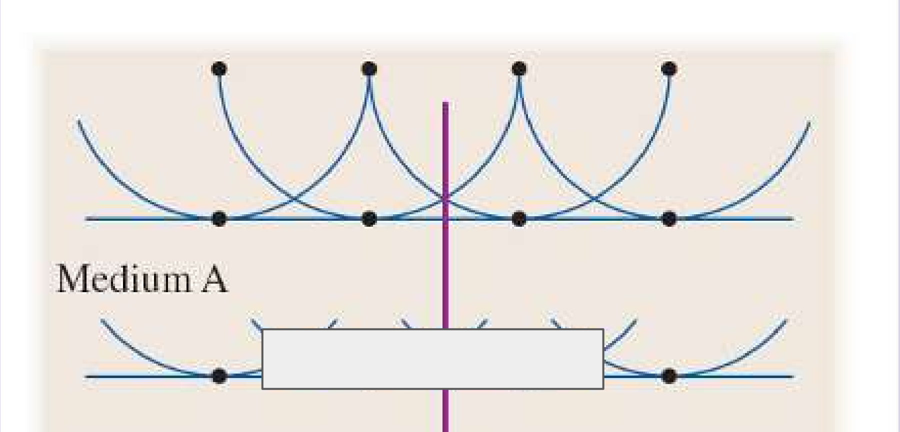
This is a very important thing about models - when we find their limits, we do not discard them completely, we continue to use them in the situations when they give predictions that match outcomes of the experiments.

Team 1: Watch the video and explain the outcomes of two experiments using both models of light

https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-24-1-1

Exp1: further apart slit - analogy wave going around a big rock

Exp2: closer slit - analogy wave going around a small rock



Team 2: Watch the video and explain the outcomes of two experiments using both models of light

https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-24-1-1

In the first experiment the distance between the slits is bigger than the with of the slits. The

Team 3: Watch the video and explain the outcomes of two experiments using both models of light

https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-24-1-1

Experiment 1: The outcome can be explained by both the models, light is blocked by the two larger slits

Experiment 2: With two smaller slits we watch on the screen a pattern of light and dark bands that can not be explained by bullet model of light.

What did we learn from the experiment?

What didn’t we learn?

All together OALG 24.1.2 and 24.1.3

OALG Chapter 24 Final.docx

Then 24.1.4 - the outcome, we will not do the derivation

d sin theta = n lambda

Team 1

OALG 24.1.5 Test your ideas

a. Use the expressions that you devised in Activity 24.1.4, parts **d** and **e,** to predict what will happen to the bright spots on the screen when in the experiment described there the distance between the slits decreases. Will the bright bands be wider or narrower? Will the distance between the brightest parts of the bands increase, decrease or stay the same? Explain how you made your predictions

b. After you make your prediction, compare it to the outcome of the experiment in the following video: https://mediaplayer.pearsoncmg.com/assets/_frames.true/secs-experiment-video-55

c. Discuss whether the outcomes of the experiments support the expressions you devised in Activity 24.1.4 parts **d**. and **e**.

Team 2

OALG 24.1.5 Test your ideas

a. Use the expressions that you devised in Activity 24.1.4, parts **d** and **e,** to predict what will happen to the bright spots on the screen when in the experiment described there the distance between the slits decreases. Will the bright bands be wider or narrower? Will the distance between the brightest parts of the bands increase, decrease or stay the same? Explain how you made your predictions.

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OALG 24.1.5 Test your ideas

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c. Discuss whether the outcomes of the experiments support the expressions you devised in Activity 24.1.4 parts **d**. and **e**.

a) If d decreases , the whole pattern will became bigger (this from the equation)

Why do we need narrow closely positioned slits?

Team 1 OALG 24.3.1 Observe describe the patterns

24.3 Gratings: An application of interference

OALG 24.3.1 Observe and describe the patterns

The figure below shows the patterns on the screen when green laser light passes through several different assortments of slits and finally through a grating – a plate of glass with a total of about 30 slits (as many as fit inside a laser beam which is about 3 mm wide). Observe the differences in the patterns on the screen as the number of slits increases and as the distance between the slits increases.

a. Describe what happens to the width of the bright bands with the increasing number of slits for the same slit separation.

The width decreases from a bar of light (two slits) to a more round dot of light (5 slits)

b. Describe what happens when we both decrease the slit separation and increase the number of slits (such as in a grating).

The bright areas are farther apart and they are dots, the smallest bright area

Team 2 OALG 24.3.1 Observe describe the patterns

a) The width becomes smaller with the increasing number of slits (for same slit separation).
b) The width should be the same, if we increase the

Team 3 OALG 24.3.1 Observe describe the patterns

With the increasing of the slits’ number each band becomes smaller (minor edge effect).

When the distance between the slits reduces the bright spots increase their distance

All together: observe and find the patterns

Most important observations:

Explanations:

Suppose we derived the expression for the maxima using a diffraction grating

$$d\sin\theta = n\lambda$$

Imagine you a shining a laser pointer at a diffraction grating and notice where the central and first maxima are. Where will those first maxima be (closer or farther away from the central) if the hole set up is submerged in water?

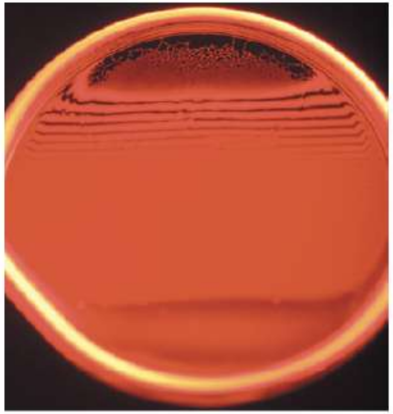
https://www.youtube.com/watch?v=HGwc2sgWMYc

Colors of soap bubbles

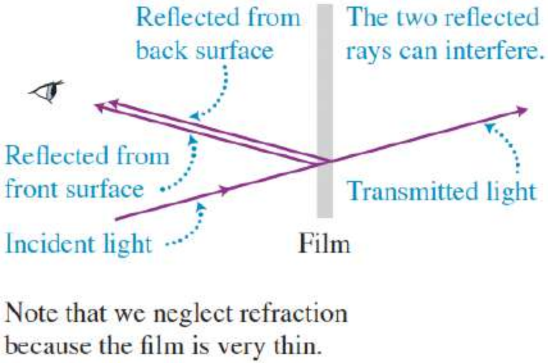
FIGURE 24.16 Soap bubble patterns caused by (a) white light and (b) red light. (c) Rays that interfere to cause the colors and fringes.

(a) Pattern caused by white light

(b) Pattern caused by red light



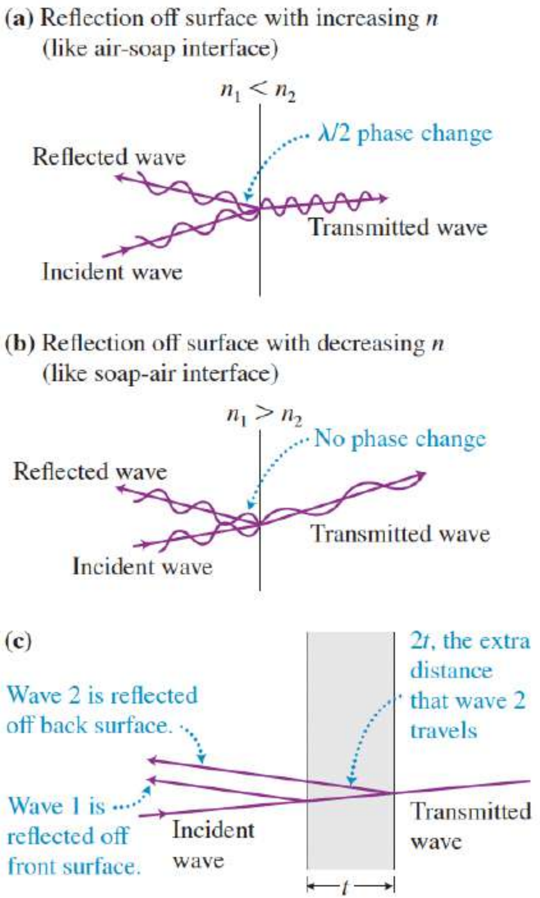
(c)



It is important to remember what we learned studying waves

ALG 11.5.1

FIGURE 24.17 Light incident on a film at almost zero angle with the normal. (a) and (b) Phase changes due to reflection. (c) Phase difference due to path length difference.



What are the predictions of this explanation for an infinitely thin film?

Why do you need a “thin film” to observe this effect?

https://www.youtube.com/watch?v=gMAsgUWrhmc

https://www.youtube.com/watch?v=yITTc6UWLE8

Team 1

OALG 24.5.1 Observe and explain

In previous activities involving two or more slits, we used very narrow slits and considered them to be point-like wave sources. In the following video one of the two slits in a double slit experiment is slowly covered https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-OALG-24-5-1. Observe the changes in the patterns on the screen and suggest an explanation. *Hint:* what would a pattern look like if each slit were infinitely thin as we assumed in all previous experiments?

Team 2

OALG 24.5.1 Observe and explain

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Team 3

OALG 24.5.1 Observe and explain

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Team 4

OALG 24.5.1 Observe and explain

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All together

The derivation comes in the next activity

OALG 24.5.2 Derive OALG Chapter 24 Final.docx

What comes next?

Chapter 25 - Polarization ; WHAT???

Electromagnetic waves - Maxwell's equations and Hertz's work

We finally know what is waving in a light wave.

Is light a wave?

What did you learn today and how did your learn it?

The formation of the black zone on the top of a soap bubble before breaking, understanding the importance that plays the width of the layer in the destructive interference (the opposition of the phase) Loved the air to water interference pattern and laser pointer applications in classroom

I wanted to know whether ISLE was a structure that could be used in the K-12 classroom, especially K-8, to have younger students understanding the process of science and habits of mind earlier than is currently available to most elementary and middle school teachers.

The introduction to ISLE was insightful. Having the opportunity to apply it as a student (in student mode).

Acceptability of using one model vs.another vs.the latest depending on context.

The beginning graphical exercises with Huygens principle are very effective. The experiment of light interference with different part of a slit is very interesting.

The first lesson geometrically describes refraction. I can see how those models will help students to relate the mathematical relationships to the visual models

The logical process that helps students discover the nature of light, their models, limitations. applications and their history