Georgia Performance Standard(GPS) Focus - Standards - SP4

Time Frame: 3 days (90 minutes each)

GPS - Focus Standard:
SP4. Student will analyze the properties and applications of waves.
   a. Explain the processes that results in the production and energy transfer of electromagnetic waves.
   b. Experimentally determine the behavior of waves in various media in terms of reflection, refraction, and diffraction of waves.
   d. Demonstrate the transfer of energy through different mediums by mechanical waves.
   e. Determine the location and nature of images formed by the reflection or refraction of light

Supporting content Standards
SP3. Students will evaluate the forms and transformations of energy.
SP5. Students will evaluate relationships between electrical and magnetic forces.
SP6. The student will describe the corrections to Newtonian physics given by quantum mechanics and relativity when matter is very small, moving fast compared to the speed of light, or very large.
   a. Explain matter as a particle and as a wave.
   b. Describe the Uncertainty Principle.

Characteristics of Science Standards - Georgia Performance Standards
• SCSh1, SCSh2, SCSh3, SCSh4, SCSh5, SCSh6, SCSh7, SCSh8 - (Evidence especially while performing the lab activity)
• SCSh1: Students will evaluate the importance of curiosity, honesty, openness, and skepticism in science
• SCSh2: Students will use standard safety practices for all classroom laboratory and field investigations
• SCSh3: Students will identify and investigate problems scientifically
• SCSh4: Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials
• **SCSh5**: Students will demonstrate the computation and estimation skills necessary for analyzing data and developing reasonable scientific explanations
• **SCSh6**: Students will communicate scientific investigations and information clearly
• **SCSh7**: Students will analyze how scientific knowledge is developed
• **SCSh8**: Students will understand important features of the process of scientific inquiry

**Previous Knowledge:**
- Understand that all waves transfer energy.
- Describe the properties of waves.
- Associate frequency and wavelength with the energy transferred by electromagnetic and mechanical waves.
- Distinguish between transverse and longitudinal wave forms and give an example of each.
- Define frequency, period, wavelength, amplitude and speed of a wave.
- Know the appropriate symbols for frequency, period, speed and wavelength.
- State the speed of light in a vacuum.
- Define translucent, transparent, and opaque objects.
- Define optical density.
- Study properties of different kinds of electromagnetic radiation, e.g., radio waves, infrared, visible, ultraviolet, X-rays.

**Learning Outcomes**
**Students will be able to with 95% accuracy**
- Understand the concepts and can identify examples of reflection, refraction, interference, and diffraction.
- Analyze the effects of different mediums on the speed of light.
- Distinguish between reflection and refraction of waves.
- Extend applications of diffraction and interference of waves to modern physics.
- Explain the dual nature of light.
- State the speed of light in a vacuum.
- Define and apply the concept of the index of refraction and discuss its effect on the velocity and wavelength of light.
Apply Snell’s law to the solution of problems involving the refraction of light.
Determine the changes in velocity and/or wavelength of light after refraction.
Define and apply the concepts of total internal reflection and the critical angle of incidence.
Have opportunity to work collaboratively, across disciplines, and in a more challenging and engaging laboratory activity which would help them better understand the world around them.
Appreciate the simplicity and beauty of physics; describe nature in terms of mathematical models. The mathematical models help them reach far-reaching conclusions, which they derive from the lab

Enduring Understanding
1. Electromagnetic waves are produced by changing the motion of charges or by changing magnetic fields.
2. The energy of electromagnetic waves is transferred to matter in quantized quantities.
3. The energy content of electromagnetic waves is directly proportional to the frequency of electromagnetic waves.
4. Light waves are transverse.
5. Light slows down, bends toward the normal and has a shorter wavelength when it enters a medium with a higher index of refraction than the medium in which it was previously traveling.
6. The energy of a wave falls off as the wave moves away from its source.
7. At the interface of a medium, light can be reflected or refracted.
8. Transverse waves cause particles to vibrate back and forth, perpendicular to the wave direction.
9. Lenses and mirrors form images. Different combinations of lenses and mirrors may form real or virtual images.
10. A photon is a unit of light.
11. Large objects have very short wavelengths when moving and thus cannot be observed behaving as a wave (DeBroglie Principle).
12. Increasing light intensity on a material increases the number of emitted electrons but not the kinetic energy of the electrons.
**ESSENTIAL QUESTIONS - (that will anchor students to learning)**

1. Why do we see different colors?
2. Why, when looking at objects through a glass, do they look like they are bent?
3. How does energy move through space?
4. Why are the colors in a rainbow (primary) always in the same order?
5. How do lenses work?
6. Why do mirrors on the passenger side of the car say “Objects may be closer than they appear?”
7. What is refraction of light? Draw a labeled diagram to explain refraction of light.
8. Which are the optical instruments that use refraction of light?

**Focused GPS- standards - SP4a, SP4b, SP4c, SP4d , SP4e**

**Related Concepts**

Electromagnetic waves, particle-wave duality, energy transfer, reflection, refraction, diffraction, interference, principle of superposition, mechanical waves, longitudinal waves, transverse waves, light, energy, uncertainty principle, virtual image, real image.

**Related Vocabulary**

Energy, waves, electromagnetic wave, electromagnetic spectrum, X-ray, Gamma ray, radio waves, infrared, visible, ultraviolet, reflection, refraction, diffraction, constructive interference, destructive interference, transverse waves, longitudinal waves, image, focus, object, image distance, object distance, magnification, inverted image, real image, virtual image, Doppler effect, pitch, intensity, amplitude, frequency, sound waves, prism, color, superposition principle, crest, trough, significant figures, calculate, experiment, precision, measure, accuracy, SI units, describe, scientific notation, conclusion, hypothesis, data, contrast, compare, variable, infer, analyze, predict, interpret, percent difference.

**Skills and Practices needed to achieve desired results**

- The instructor will utilize cognitive terminology so that students can master in taking Cornell notes / can classify notes, homework, lab reports and quizzes into viable study guide.
- Utilize teacher made instructional & interactive power points
- Complete practice test questions from [www.usatestprep.com](http://www.usatestprep.com)
- Complete teacher made GOAS questions from [www.georgiaoas.org](http://www.georgiaoas.org)
- Text Book Referred are : Physics-Principles & Problems - Glencoe
- Related websites : [www.physicsclassroom.com](http://www.physicsclassroom.com)
- Perform Lab Activity on refraction of light
Students will learn to work in peer group modeling situations

**Adaptations (Differentiated instruction)**
For on-level (conceptual) courses, the slope equation may be given to students; because that is a connection they often struggle with. It might also be useful to adapt the quantitative portion of the activity into a demonstration if students are particularly challenged by the mathematics.

**Common Misconception:**
The most common misconception about light is that light illuminates objects which then allow us to see them or that eyes actually grab images. Another misconception that is also stated by Arons is that people do not often view light as traveling in all directions and not just following the straight line between object and eye. This particular view leads to unacceptable explanations of optic instruments.

**Acceptable evidence to show desired results**
By the conclusion of this unit, students will be able to demonstrate the following skills and competencies:
- Verify the Laws of Refraction and Reflection
- Measure the wavelength of light, using the data from the lab/problem solving method
- Verify Snell’s Law

At the end of this unit the student will demonstrate the ability to:

- Given a transverse wave diagram and the time required for the completion of one cycle; determine frequency, period, wavelength, speed, and label amplitude and wavelength.
- Use the formula \( v = \lambda \) \( \times f \) in problem solving situations.
- Sketch and label light waves undergoing reflection and refraction
- Compute the angle of reflection when given the angle of incidence
- Define index of refraction of light.
- Relate speed of light in air, speed of light in the medium and the refractive index of the given medium and solve problems on it.
Work simple Snell’s Law problems.

After completing this unit, the students will meet the following scientific dispositions:

- Identify questions and concepts that guide scientific investigations.
- Design and conduct scientific investigations.
- Use technology to improve investigations and communications.
- Formulate and revise scientific explanations and models using logic and evidence.
- Recognize and analyze alternative explanations and models.
- Communicate and defend a scientific argument.
- Identify a problem or design an opportunity.
- Propose designs and chooses between alternate solutions.
- Implement a proposed solution.
- Evaluate the solution and its consequences.
- Communicate the problem, process, and solution.
- Understand conceptual schemes of science.
- Understand the relationship among the parts of a science discipline and the conceptual structure of the discipline.
- Understand organizing principles and processes of science.
- Understands the unique qualities of science.
- Differentiates science from other disciplines.
- Knows the history and nature of science discipline.
- Understands science in a social concept.
- Submit lab report on optics related experiment- reflection & refraction
- Each group will be able to conduct a round table discussion about their topic in front of the class - performance assessment
- Take related quizzes/ tests (formative assessment)
- Take 5 week exam (summative assessment)
Observe and analyze the mini demonstrations on your table on - (half filled beaker, in which is immersed a slanted ruler)

1. Write 5 facts about it
2. Identify- name the properties of light taking place here
3. Explain the property of light in this mini demonstration
4. Draw and label the mini demonstration explaining all the rays and normal, with the different medium through which light passes.
5. Comment on the optical density of different materials shown here.
6. When you look through the water, why does the numbers on the ruler look enlarged. Explain it, what type of lens does the curved surface of the beaker behave here as?

Reference: http://library.thinkquest.org/27066/lightrays/nlrefraction.html

INSTRUCTIONAL ACTIVITIES:

1. Review Snell’s Law with students using instructional interactive power point

2. Show equipment that students will use and how to use it.

3. Explain to students that they are to work cooperatively to find the index of refraction of glass square and develop a plan to reduce error in measurements.

4. Allow students to work on project, paying close attention to how students work together and complete different objectives of the lab activity.

5. Have one student give me the index of refraction that they found.
6. Have a student from each group explain what measures were taken to reduce error to reach a more accurate answer.

7. Discuss with students how they believe they worked together during the project (Assign role to each student in the group)

8. Follow the rubric given for the lab activity

9. Finally give the formal lab report to the teacher.

10. Students are required to complete an formative assessment at the end.

**LABORATORY ACTIVITY on Index of Refraction**

**Objective:**
- To trace the path of a ray of light passing through a rectangular glass slab and measure the angle of incidence and the angle of emergence.
- Given the index of refraction and incident angle of light, be able to find the angle of refraction using Snell’s Law.
- From incident and refraction angles, determine the index of refraction (‘n’) of material study the laws of refraction.
- To find velocity of light when it passes through the medium, using the value of ‘n’ above.
- Be able to find wavelength or frequency when given the other.

**Materials Required:** Cardboard, pins, protractor, ruler, glass slab and paper

**Theory:**
- The change the direction of the path of light, when it passes from one medium to another is called diffraction.
- When the radiation is made to fall from rarer to denser medium, it bends towards the normal. On the other hand when a radiation is made is made to fall from a denser to a rarer medium; it bends away from the normal.
- Refraction of light follows the laws listed below:
- The incident ray, the refracted ray, and the normal to the surface separating the media, lie in the same plane .i.e they are co-planes.
- The ratio of the sine of the angle incidence to the sine of the angle of refraction is a constant, for a given pair of media.
- i.e. $\sin i/ \sin r = $ constant (‘n’-refractive index)
• For a glass slab $<i=\angle e$, i.e. when a ray of light is incident on one side of the glass slab, it emerges from the other parallel surface in the same direction. It only suffers some lateral displacement. ($<i =$angle of incidence & $<e =$ angle of refraction)

• Lateral displacement directly proportional to the thickness of refracting material.

Procedure:
1. Place the glass slab in the center of a sheet of paper and trace an outline of the glass.
2. Remove the glass and draw a normal line (perpendicular) to the surface, using the protractor.
3. Using the protractor draw a line 30° from the normal line. This will be the angle of incidence. Place two pins in this line.
4. Replace the glass slab. With your eye level with the slab, look through the glass at the two pins. Shift until the pins line up. Now place two more pins in this side of the glass that are in line with the original pins. (One should be right up against the glass)
5. Remove the glass and draw a normal line to the surface where the new pin is placed.
6. Draw a line connecting the two new pins.
7. Remove the glass slab and connect the ray $AB$ and $CD$ to make a line $BC$. Measure the angle between the normal and the line $BC$. This is the angle of refraction.
8. Repeat for angle of 45° and 60°.
Data:

<table>
<thead>
<tr>
<th>Degree</th>
<th>Angle of incidence</th>
<th>Angle of refraction</th>
<th>Index of refraction ('n')</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

Average index of refraction

Show calculation here:

Conclusions:

1. How does the angle of incidence compare to the angle the light leave the block? Explain. Name them and compare the measurements.
2. What are some possible errors in the design of the experiment? What would you do better next time?

3. Attach your drawings to this sheet. Label your diagram with explanation.

4. Given the index of refraction ‘n’ = 1.5, incident angle of light = 60 degrees, find the angle of refraction using Snell’s Law. (Note-Use different “n” and angles of incidence - for different groups).

5. Calculate the velocity of light through the glass slab, using refractive index from your data collected in the lab. Compare the speed of light when it passes through the glass slab to speed of light when it is in air/vacuum.

6. Having found the speed of light in glass, can you determine the wavelength of light in glass, if the value of frequency of light used is given? If so, calculate it using problem solving method.

Differentiation in assessment - Challenging students

- Plot a graph using different sin $\theta_1$ (angle of incidence) and their respective sin$\theta_2$ (angle of refraction).
- Find the slope and measure the value.
- Is the slope a straight line and find value of your slope?
- Does the value of your slope have a unit? Give reason for your answer.
- What does the slope indicate?
Laboratory Activity can be further extended to the following:

**Magic Coin**

1. Refraction, index of refraction

2. Place a coin at bottom of opaque container and position container so that the coin is just out of view. Now, slowly add water and the coin will magically appear. Measure height of water when coin appears to make calculations of index of refraction. The process can be repeated for other liquids such as cooking oil and rubbing alcohol.

**Magnification**

1. Magnification, refraction

2. Fill a large beaker with water. Put in beaker a large rectangular object of wood, cardboard or something similar. Measure diameter of rectangle before placed in water. Now move rectangle back and forth and determine when the image is as it most. The magnification ratio is found by dividing image diameter with actual diameter.
Lab Activity - on Reflection of Light

Group Student Names Period ____________ Date: ___________ 2011
__________________________________________

Lab Number
Reflection of Light
Objective:
1. The purpose of this lab is to verify and prove the laws of reflection with the aid of a plane mirror

1. Lab Materials:
1. Rectangular stand up mirror
2. Drawing utensils
3. White paper
4. Drawing Board
5. Al Pins
6. Meter Scale

2. Theory:
   - The phenomenon of returning back of the light in the same medium when light is in incidence on a surface is known as reflection.
   - The light that falls on the surface of the mirror is known as an incidence ray and the radiation that returns back in the same medium after reflection is known as the reflected ray.
   - The angle between the incident ray formed with the normal, is the angle of incidence, and the angle between the reflected ray and normal is known as angle of reflection.
   - Normal is the perpendicular line it makes to the surface of the mirror

Reflection of Light follows the laws listed below:
1. The angle of incidence is equal to the angle of reflection.
2. The incident ray, reflected ray, and the normal ray to the reflecting surface at the point of incidence, all lie in the same plane.

Figure below illustrates the law of reflection.
Background knowledge & Connecting with Math (Interdisciplinary)
Normal, Angle measurements, Perpendicular lines.

Procedure:
1. Attach a white sheet of paper to the cardboard drawing board with a four drawing pins on four corners.
2. Place a mirror strip vertical by a mirror stand and mark a straight line on the paper.
3. Now, remove the mirror and draw a line NN’ at point O, perpendicular to the line MM’ (the line of the mirror). Also draw a line AO to making an angle “i” with the normal.
4. Fix pins at point P1 and Q1 and 5-10 cm distance from each other on the line AO (which is the incident ray).
5. Replace the glass mirror on its boundary MM and observe the image of the two pins P1 and Q1.
6. Fix another two pins P2 and Q2 by removing parallax with the pins P1 and Q1.
7. Remove the mirror and pins. Put the small circles around the positions of the pins P1, Q1, P2 and Q2.
8. Join the position of pins to meet them at O.
9. Measure the angle of incidence (i) - the angle between P1O and N.
10. Measure the angle of reflection \( \theta \) - angle between P2O and N.
11. Repeat the experiment within your group with different values of “i” - (angle of incidence).

Precautions:
1. Be careful to make measurements on an even surface.
2. Always use a straight edge.
3. Be careful, as all pins are sharp.
4. Insure that mirror is directly on its boundary line perpendicular to the normal.
5. Be sure to measure angles of incidence and reflection, to verify that they are exactly equal.

Results/Observation Table (More than 5 observations of different angles can be taken)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Angle of Incidence (i)</th>
<th>Angle of Reflection (( \theta ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
Analysis & Conclusion

SAFETY CONSIDERATION

A. Within the school different people have different responsibilities. The administrator of a high school has several responsibilities. It is the administrator's (academy leader's) job to ensure that the lighting and heating of the classroom is adequate. Also, the academy leader must make sure that there are two exits into open areas. Lab tables must be fire proof and shut offs must be available within the classroom. Fire extinguishers must be in the classroom with first aid kits. (NSTA Subcommittee on Safety to be followed)

B. Finn Scientific Safety Rules to be followed. Each student in the class is given 2 copies of it. They read it with their parents and submit to the teacher a copy of their signed contract.

C. The science department chairperson must discuss and identify hazards that are in the classrooms and inform the academy leader in writing.

D. The science teacher is responsible for the safety of the class. The teacher must instruct students of the hazards in the classroom. The teacher should also demonstrate all labs to students (if required) before they do the lab themselves.

E. If students are required to design the lab then a clear instruction with rubric has to be given by the teacher. Teacher's role is that of a facilitator.

F. Teacher should also list all rules for the students that apply to all labs and demonstrations.

G. There are not that many safety issues when dealing with optics and light. But one is to be careful with lasers if they are being used. Although most lasers in high school classes are not powerful enough to hurt the skin, if directly looked at, it can cause eye damage. Also, working with lenses may involve extent contact with glass, which can be dangerous if it breaks.
# RUBRIC FOR LABORATORY ACTIVITY & LAB REPORT

<table>
<thead>
<tr>
<th>Lab Format</th>
<th>Data Collection</th>
<th>Calculations</th>
<th>Conclusions</th>
<th>Writing</th>
</tr>
</thead>
</table>
| 5          | - Format is correct, all lab sections are present and complete.  
- Lab is neatly done, printed in ink or typed in smooth, final draft.  
- Lab presents a unified, whole appearance.  
- No scrap paper is included.  

- Data collection scheme is well planned.  
- Data is clearly displayed.  
- Proper units and significant figures are present.  
- All information important to the lab has been collected and displayed.  
- No calculations are included.  

- Example calculations use proper format.  
- Calculation results clearly displayed.  
- Calculated values have proper number of significant figures and units.  
- All calculations are correct.  
- Graphs, if present, are properly labeled, scale is appropriate, and correctly drawn.  

- Lab results clearly described.  
- The basic physics of the experiment is properly explained.  
- Problems with data collection are discussed.  
- Discrepancy results are noted and logically explained.  
- Success with meeting the objective of the lab is intelligently discussed.  
- Discussion of what was learned in lab is present.  

- Ideas are clear and focused.  
- Sentences are complete and flow naturally.  
- No spelling errors are present.  
- No errors in grammar are present.  
- Words are well chosen and appropriate.  
- The lab write-up is well organized. |
| 3          | - Format is substantially correct, but some minor errors have been made. Lab report has insignificant typos or is somewhat sloppy, but lab is completed in ink or typed and is basically readable.  

- Data collection scheme is generally appropriate.  
- Most required data has been obtained.  
- Some data is confusing.  
- Some data is not properly displayed.  
- Only a few minor errors in units or significant figures are present.  

- Not all steps shown in calculations.  
- Calculation results have minor display errors.  
- Minor calculation errors present.  
- Calculations are displayed in a logical way but are a little confusing.  

- Not all results reported.  
- Some relevant results ignored.  
- Minor result discrepancies are not noted.  
- Minor mistakes in explaining the physics of the lab are made.  
- Explanation of what was learned is somewhat confusing.  

- Ideas are reasonably clear, but lack focus.  
- Some minor errors in spelling or grammar exist.  
- Some sentences are poorly constructed. |
| 1          | - Format is improperly followed.  
- Sections are missing. Lab is messy.  
- Lab is difficult to read. Lab is completed in pencil.  
- Different colors of ink are used.  
- Scratch paper used.  

- Data collection not well planned.  
- Important data elements missing.  
- Data incomplete.  
- Major errors in data.  
- Data lacks proper units.  
- Proper significant figures not displayed.  

- Many calculation errors.  
- Problem solving format not followed.  
- Calculations are displayed in confusing manner.  
- Calculations are missing.  
- Calculations are incorrect.  
- Calculated values lack units or do not have proper number of significant figures.  

- Results are not reported.  
- Analysis does not agree with results.  
- Discrepancies are ignored.  
- Relevant results are not noted.  
- Little thought is evident in analysis.  
- No attempt is made to describe what was learned.  

- Ideas are poorly expressed.  
- Sentences are poorly constructed.  
- Many grammar errors exist.  
- Many spelling errors exist.  
- Paper is difficult to read.  
- Improper vocabulary. |

(Source-AP Workshop-Reference: Author-Physics Kahuna & Title-Lab Format)
LABORATORY RUBRIC (if the lab is designed by the students)
Criteria: Designs Experiment  Student demonstrates knowledge and skills necessary to perform scientific inquiry. Standards and Benchmarks: SC11.3.1; SC11.3.2; SC11.8.4; and SC11.1.X and
Communicates Results  Student communicates and applies scientific principles

<table>
<thead>
<tr>
<th>Level 4</th>
<th>Level 3</th>
<th>Level 2</th>
<th>Level 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>The experimental design meets all requirements of a Level 3, AND Considers current research and understanding of the question being addressed. Explanations are strengthened by the use of such things as:  • Graphic organizers  • Diagrams  • A keying system  • Cross-referencing Additional Tables, Models, Graphs</td>
<td>The experimental design includes:  • An hypothesis with cause/effect relationship which addresses the question being studied:  • Choice of controls  • Observations and/or measurements that are sufficient to address the question being asked and are reproducible  • A description of the procedures and materials to be used. Scientific terms are accurately and appropriately applied in report. All aspects of the experimental design are logically related to each other, to provide a defensible experiment.</td>
<td>The experimental design is incomplete, but the design is sufficient for providing information on the question being asked. (Check all elements missing or incomplete.)  • An hypothesis with cause/effect relationship which addresses the question being studied  • Choice of controls  • Consideration of sample size  • Observations and/or measurements that are sufficient to address the question being asked and are reproducible  • A description of the procedures and materials to be used. Inconsistent use of accurate and appropriate scientific terms throughout the report.</td>
<td>The experiment is completed without an explanation of the design; OR Design is inadequate for answering any aspects of the question; Scientific vocabulary used, but inaccurate throughout the report or not used when the opportunity exists;</td>
</tr>
</tbody>
</table>

Credit: AP B-- Physics Kahuna

QUIZ- Sample of Formative Assessment

Complete the following assessment given below. Explanation of each question, using problem solving method has to be shown in an additional sheet.

1. When a wave passes from a less dense medium to a denser medium, the ____ may change.  
   Speed  
   Frequency  
   Wavelength  
   Speed, frequency, and wavelength

2. Waves in which the particles of the medium move only in the same direction as the motion of the wave are ____ waves  
   are compressional waves
are transverse waves
must have a medium
are generated by static electricity

3. A ray of light strikes a thick sheet of glass \( n = 1.5 \) at an angle of 25° with the normal. Find the angle of the ray reflected off the glass surface with respect to the normal
56°
46°
39°
25°
31°

4. If light waves change speed when they pass from one medium into another, the light will be _____.
Diffused
Reflected
Refracted
Separated

5. Monochromatic light hits a piece of glass. What happens to the wavelength in the glass as the index of refraction increases?
Decreases
Increases
remains constant
approaches \( 3 \times 10^8 \) m
approaches 0 m

6. The speed of electromagnetic waves is _____.
greater in water than in air
different for each frequency in a vacuum
300,000 km/s in a vacuum
less for light than for X rays

7. A ray of light strikes a thick sheet of glass \( n = 1.5 \) at an angle of 25° with the normal. Find the angle of the refracted ray within the glass with respect to the normal.
56°
46°
25°
8. Light from a 560-nm monochromatic source is incident upon the surface of fused quartz (n = 1.56) at an angle of 60°. What is the angle of reflection from the surface?

15°
34°
60°
75°
81°

PREVIEW

Light can be refracted, or bent, through a transparent medium such as a lens. The relationship between the speed of light in two different media and the angle of the light rays can be found using Snell’s law of refraction. As light rays are refracted, they may form an image, which can be real or virtual, depending on the distance from the lens to the object which is the source of the light rays.

QUICK REFERENCE

Important Terms

angle of incidence
the angle between the normal line to a surface and the incident ray or wave

angle of refraction
the angle between the normal line to a surface and the refracted ray or wave at the boundary between two media.

critical angle
the minimum angle entering a different medium at which total internal reflection will occur

index of refraction
the ratio of the speed of light in a vacuum to the speed of light in another medium

lens
a piece of transparent material that can bend light rays to converge or diverge

magnifying glass
optical instrument which results from an object being placed within the focal length of a convex lens, producing an enlarged virtual image.

**refraction**
the change in speed, wavelength, and direction of a light ray due to a change in medium.

**Snell's law of refraction**
when light passes from one material with an index of refraction $n_1$ into a material
of a different index of refraction $n_2$, the angle of incidence $\theta_1$ is related to the angle of refraction $\theta_2$ by the equation $n_1 \sin \theta_1 = n_2 \sin \theta_2$.

**Equations and Symbols**

\[
c = f \lambda
\]

\[
n = \frac{c}{v}
\]

\[
n_1 \sin \theta_1 = n_2 \sin \theta_2
\]

\[
\sin \theta_c = \frac{n_2}{n_1}
\]

where

$c = $ speed of light $= 3 \times 10^8$ m/s
$f = $ frequency of light
$\lambda = $ wavelength of light
$n = $ index of refraction
$\theta_1 = $ angle of incidence
$\theta_2 = $ angle of refraction
$\theta_c = $ critical angle

**DISCUSSION OF SELECTED SECTIONS**

The Index of Refraction, and Snell's Law and the Refraction of Light

If you put a pencil in a clear glass of water, the image of the pencil in the water appears to be bent and distorted. The light passing from the air into the water is *refracted*, bending due to the fact that it's passing from one medium to another. If we consider a single beam of laser light, we can observe it as it passes from air into a piece of glass.
The angle \( \theta_i \) from the normal line at which the beam approaches the glass from the air is called the *angle of incidence*. The angle \( \theta_r \) from the normal line in the glass is the *angle of refraction*. As the light passes from the air, a less dense medium, into the glass, a denser medium, the beam bends toward the normal line. When the beam of light exits the glass and passes back into the air, it bends away from the normal at the same angle it entered the glass from the air.

The light bends toward the normal in the glass because the beam slows down as it enters the glass. Light travels more slowly in a denser medium. Recall that sound travels faster in a denser medium, but sound is a mechanical wave, while light is an electromagnetic wave. The ratio of the speed of light in air (approximately a vacuum) to the speed of light in the glass (or any other medium) is called the *index of refraction* \( n \):

\[
n = \frac{c}{v_{\text{glass}}}
\]

The index of refraction for a vacuum or air is 1, since \( v = c \). The index of refraction for crown glass is about 1.6, which means that light travels 1.6 times faster in a vacuum than in crown glass.

We can relate the index of refraction to the angles of incidence and refraction by using *Snell's law of refraction*:

\[
n_1 \sin \theta_i = n_2 \sin \theta_r
\]
where \( n_1 \) and \( n_2 \) are the indices of refraction of the first and second media, and \( \theta_1 \) and \( \theta_2 \) are the angles of incidence and refraction, respectively.

**Example 1**

A beam of light enters the flat surface of a diamond at an angle of 30° from the normal. The angle of refraction in the diamond is measured to be 12° from the normal. Determine the speed of light in the diamond.

**Solution 1**

The angle of incidence \( \Theta_1 = 30^\circ \) and the angle of refraction \( \Theta_2 = 12^\circ \). The index of refraction can be found by Snell's law:

\[
n_1 \sin \Theta_1 = n_2 \sin \Theta_2
\]

\[
0.5 \sin 30 = n_2 \sin 12
\]

\( n_2 = 2.5 \)

The speed of light in diamond can be found by

\[
n_2 = \frac{c}{V_{\text{diamond}}}
\]

\[
V_{\text{diamond}} = \frac{c}{n_2} = \frac{3 \times 10^8 \text{ m/s}}{2.5} = 1.2 \times 10^8 \text{ m/s}
\]

**Total Internal Reflection**

Consider a water-proof laser which you can put under the water and shine a beam of light up out of the water into the air. If you shine the light at a small angle relative to the normal, the light will emerge from the water and bend away from the normal as it enters the air.
As you increase the angle at which the laser is pointed at the surface of the water, the refracted angle also increases, eventually causing the refracted ray to bend parallel to the surface of the water:

The angle $\theta_c$ is called the critical angle. If the laser is pointed at an angle greater than the critical angle, the beam will not emerge from the water, but will reflect back into the water.

This phenomenon is called total internal reflection. The inside surfaces of a glass prism in a pair of binoculars can become like mirrors, reflecting light inside the prism if the light is pointed at the surface at an angle greater than the critical angle. Total internal reflection is also the principle behind the transmitting of light waves through transparent fiber optic cable for communication purposes.

**Example 2**

The speed of light in a particular piece of glass is $2.0 \times 10^8$ m/s, and the speed of light in water is $2.3 \times 10^8$ m/s.

(a) Find the index of refraction for
   i. the glass
   ii. water

**Solution 2**

(a) i. $n_g = \frac{c}{v_g} = \frac{3.0 \times 10^8 \text{ m/s}}{2.0 \times 10^8 \text{ m/s}} = 1.5$

ii. $n_w = \frac{c}{v_w} = \frac{3.0 \times 10^8 \text{ m/s}}{2.3 \times 10^8 \text{ m/s}} = 1.3$

(b) A sheet of this glass is placed over a tank full of water. Laser light is incident on the glass from the air above the glass at an angle of $40^\circ$. Determine whether or not the light passes into the water, and, if it does, find the angle of refraction of the light in the water.
(b) First, let’s find the critical angle for the light traveling from the glass to the water.

\[ \theta_c = \sin \left( \frac{n_w}{n_g} \right) = \sin \left( \frac{1.3}{1.5} \right) = 60^\circ \]

If the light passes from the glass toward the water at an angle greater than 60°, it will totally internally reflect inside the glass. The angle of refraction inside the glass can be found by

\[ n_{air} \sin \theta_{air} = n_g \sin \theta_g \]

\[ \theta_g = \frac{\sin \theta_{air}}{n_g} = \sin^{-1} \left[ \frac{\sin 40^\circ}{1.5} \right] = 25.4^\circ \]

Since the angle of the light in the glass less than 60°, the light will refract in the water. The angle of refraction in the water can be found by

\[ n_g \sin \theta_g = n_w \sin \theta_w \]

\[ \theta_w = \sin^{-1} \left[ \frac{n_g \sin \theta_g}{n_w} \right] = \sin^{-1} \left[ \frac{1.5 \sin 25.4^\circ}{1.3} \right] = 29.7^\circ \]

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**Example 3**

The glass plate shown above has an index of refraction that depends on the wavelength of the light that enters it. The index of refraction is 1.54 for yellow light of wavelength 5.80 x 10^{-9} m in the air and 1.62 for violet light of wavelength 4.20 x 10^{-9} m in the air. Both the yellow and violet beams of light enter the glass
from the left at the same angle of 30° above the normal, are refracted inside the glass, and exit the glass on the right.

![Diagram](image)

a) Determine the following for each color for the time the light is inside the glass. the speed of each color in the glass.

**Solution 3**

(a)

\[ v_y = \frac{c}{n_y} = \frac{3.00 \times 10^8 \text{ m/s}}{1.54} = 1.95 \times 10^8 \text{ m/s} \]

\[ v_v = \frac{c}{n_v} = \frac{3.00 \times 10^8 \text{ m/s}}{1.62} = 1.85 \times 10^8 \text{ m/s} \]

(b) On the figure above, sketch the approximate paths of both the yellow and the violet rays as they pass through the glass and then exit into the air.

**Solution b)**

Violet light slows down more than yellow light, and bends its path more than yellow light. Both beams bend toward the normal line inside the glass, and away from the normal line (at 30°) when they exit the glass into the air again.

![Diagram](image)
References:
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