AP Physics Standards

Applicable to the activities in this guide

BIG IDEA 1:
Objects and systems have properties such as mass and charge. Systems may have internal structure.

Essential Knowledge 1.A.4:
Atoms have internal structures that determine their properties.

Learning Objective 1.A.4.1:
The student is able to construct representations of the energy-level structure of an electron in an atom and to relate this to the properties and scales of the systems being investigated.

BIG IDEA 5:
Changes that occur as a result of interactions are constrained by conservation laws.

Essential Knowledge 5.B.8:
Energy transfer occurs when photons are absorbed or emitted, for example, by atoms or nuclei.

Learning Objective 5.B.8.1:
The student is able to describe emission or absorption spectra associated with electronic or nuclear transitions as transitions between allowed energy states of the atom in terms of the principle of energy conservation, including characterization of the frequency of radiation emitted or absorbed.

BIG IDEA 6:
Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.

Essential Knowledge 6.E.3:
When light travels across a boundary from one transparent material to another, the speed of propagation changes. At a non-normal incident angle, the path of the light ray bends closer to the perpendicular in the optically slower substance. This is called refraction.

Learning Objective 6.E.3.1:
The student is able to describe models of light traveling across a boundary from one transparent material to another when the speed of propagation changes, causing a change in the path of the light ray at the boundary of the two media.

Learning Objective 6.E.3.2:
The student is able to plan data collection strategies as well as perform data analysis and evaluation of the evidence for finding the relationship between the angle of incidence and the angle of refraction for light crossing boundaries from one transparent material to another (Snell's law).

Learning Objective 6.E.3.3:
The student
is able to make claims and predictions about path changes for light traveling across a boundary from one transparent material to another at non-normal angles resulting from changes in the speed of propagation

TEACHERS GUIDE

GRADE LEVEL HS+

ADVANCED SPECTROMETER
ITEM # 3381-00

LIGHT AND COLOR - COLOR

For introducing students to principal type of spectra, determination of wavelength, frequency of emitted light and for quantitative spectrometric measurement of angle of prism, refractive index of the prism material etc.

Materials

- spectrometer
- prism
- sodium, mercury, hydrogen (and other spectrum tubes)
- Handbook of Chemistry and Physics
- power source for spectrum tubes

Goals & Objectives

See page 8 for AP Physics Standards applicable to the activities in this guide. For more information go to www.collegeboard.org.

History

The phenomenon of refraction has been known for hundreds of years.
It was first described by Snell in 1621, but it wasn't until 1666 when Issac Newton described how different wavelengths refracted at different angles, some bent more.
Although Newton used a slit in in later experiments, the complete prism spectroscope was designed by Fraunhofer. Fraunhofer is best known from mapping out approximately 700 of the spectra lines in the solar spectrum.

Assessment

1 Participation, Vocabulary, Tables, Drawings (Student Handout)

2 **Glossary/Vocabulary:**

spectroscopy
spectrometer
diffraction
refraction
Snell's law
Cauchy Relation
angle of incidence
angle of refraction
prism apex angle
grating law
parallax
collimator
telescope
prism table
spectrum

Discussion

Additional Discussion and Real Life Applications

1 There are many types of spectroscopy used in modern science including:

- flame spectroscopy,
- infrared spectroscopy,
- absorbance,
- emission,
- transmission,
- ion-coupling,
- x-ray florescence,
- photoelectron,
- mass spectroscopy,

This is just to name a few.

In fact, there are many types of spectroscopy used in forensics.

Have students research the different types of spectroscopy and their uses to benefit society.

ACTIVITIES

Student Activities *continued*

e Have them graph n vs 1/wavelength squared (n vs 1/λ^2). This is a linearized relationship.

They should calculate the slope and y-intercept and write an equation for this line.

3 Use another spectrum tube and determine the angle of deviation for any three bright lines in its spectrum.

Calculate the index of refraction. Use the table below.

Use the Cauchy calibration curve that you made for your prism in the previous experiment to find the wavelengths of the lines you observed.

Is there a relationship between color of the spectral line and the wavelength?

4 Measure angle of diffraction experiment with mercury tube and determine the wavelengths for the Balmer series of the hydrogen spectrum using the instructions found at

http://hendrix2.uoregon.edu/~dlivelyb/classes/390_08w/390lab5.pdf

Type of Lamp: ______________

color	intensity (dim, bright etc.)	angle of deviation β min degree	angle of deviation β decimal deg	Index n	1/ λ^2 $(\mu m)^{-2}$	wave-length λ

How it works

An electromagnetic wave needs no medium to travel through and when it is traveling through a vacuum it is moving at its maximum speed, the speed of light. When it changes medium it will slow down and refract (bend) away from the perpendicular if the new medium is optically slower.

A good analogy is a remote controlled car traveling on a wooden surface changing surfaces to a thick carpet. The car will slow down and change direction bending away from the perpendicular.

Prisms will refract light into its individual wavelengths, and longer wavelengths bend less than shorter ones. (A large remote car would change direction less than a small one would when encountering the carpet).

The spectrometer has 3 basic parts: a telescope, a prism table, and a collimator (makes parallel lines of light).

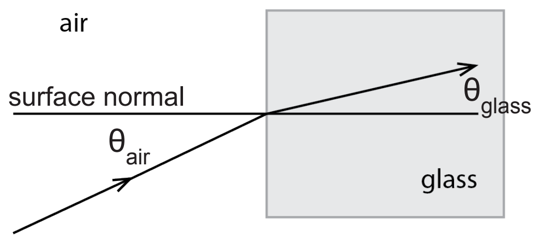
The vernier scale measures how the incident light changes angles after it refracts in radians, and minutes (we have to convert to degrees). Diffraction grating will also refract the light into individual wavelength.

The spectrum tubes work because adding electricity to the gas sealed inside the vacuum tube excites the electrons and they jump to a higher energy level (in discrete amounts) they begin emitting that energy as visible light (other wavelengths too, but we only see the visible wavelengths).

BACKGROUND

Snell's Law:

$\sin\theta_{air} = n \sin\theta_{glass}$



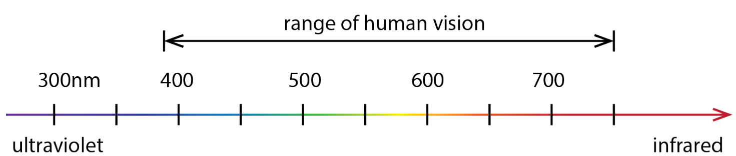
When a beam of light passes from air to glass, the light beam bends according to Snell's Law.

Angles are measured from the surface normal, which is the line perpendicular to the glass surface and n is the index of refraction of the glass.

The refraction index n is a dimension-less number used to measure the strength of the medium in terms of bending light. The larger the refraction index, the greater the bend. Air has a refraction index of 1, the index for glass depends on the type of glass and the wavelength of the light passing through it, it ranges from 1.3 to 1.8.

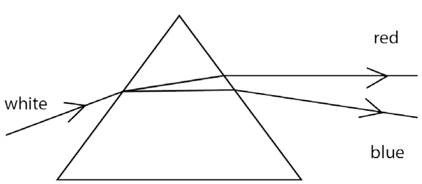
$$\mu = \frac{Sin\,(\frac{d+D}{2})}{Sin\,(\frac{A}{2})}$$

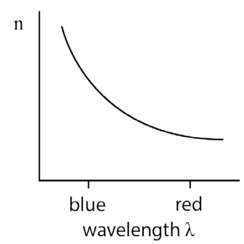
White light is made up of all colors that make up a rainbow, violet, blue, green, yellow, and red and each color corresponds with different wavelengths on the spectrum. Wavelengths are measured in nanometer (nm), the visible spectrum for humans ranges from 380 nm (violet) to 750 nm (red), where 1nm = 10^{-9}m.



Violet	380 - 420nm	Yellow	570 - 585nm
Indigo	420 - 440nm	Orange	585 - 620nm
Blue	440 - 490nm	Red	620 - 780nm
Green	490 - 570nm		

Depending on the wavelength, glass has a different index of refraction. This means that glass bends blue light differently (more) than red light. Glass (specifically if in shape of a prism) can be used to break up white light into its color components.





ACTIVITIES

1 Use the instruction included with the product to do the initial set up.

The instructions explain how to do the initial adjustments, angle of the prism, determine angle of minimum deviation, and calculate n (the refractive index of the prism for a single line in the sodium spectra.

2 Once that lab is done, or instead of using sodium, use a mercury tube.

a Have students find the angle of minimum deviation for the 7 lines in the mercury spectrum given in the table below. (There is a copy of the table on the attached Student Handout.)

b Make sure they convert the wavelength into micrometers first before they square it and take the inverse. Use the equation given to calculate the refractive index.

c Make a graph of n vs wavelength. This is called the Cauchy relationship and it is not a straight line. It is the smooth curve shown at the bottom of page 4.

d Ask your students to use the Handbook of Chemistry and Physics to determine what kind of glass material their prism is made of by finding n for the a wavelength of 589.0 nm from their graph.

zinc crown glass	1.517
higher-dispersion crown	1.520
light flint	1.575
dense flint	1.650
densest flint glass	1.890

continued on page 6

Prism apex angle α=60°

color	wavelength λ (nm)	$1/\lambda^2$ $(\mu m)^{-2}$	angle of deviation β min degree	angle of deviation β decimal deg	Index of refraction n
red	690.8				
yellow 1	579.1				
yellow 2	577.0				
green	546.1				
blue-green (dim)	491.6				
blue	435.8				
violet	404.7				

STUDENT HANDOUT

Student Name: ______________________

1 Find the angle of minimum deviation for 7 lines in the mercury spectrum

Make sure you convert the wavelength into micrometers first before you square it and take the inverse.

Use the equation given to calculate the refractive index.

$$\mu = \frac{Sin\,(\frac{d+D}{2})}{Sin\,(\frac{A}{2})}$$

color	wavelength λ (nm)	$1/\lambda^2$ $(\mu m)^{-2}$	angle of deviation β min degree	angle of deviation β decimal deg	Index of refraction n
red	690.8				
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green	546.1				
blue- green (dim)	491.6				
blue	435.8				
violet	404.7				

Prism apex angle α=60°

- Make a graph of *n vs wavelength* (Couchy calibration curve).

- Use the Handbook of Chemistry and Physics to determine what kind of glass material your prism is made of.
- To do this, find n for the a wavelength of 589.0 nm from your graph

- Graph n vs 1/wavelength squared.
- Calculate the slope and y intercept and write an equation for this line.

2 Use a different spectrum tube, record the type of lamp below and then determine the angle of any three bright lines in its spectrum and calculate the angle of refraction.

Type of Lamp: ________________________

color	intensity (dim, bright etc.)	angle of deviation β min degree	angle of deviation β decimal deg	Index n	$1/\lambda^2$ $(\mu m)^{-2}$	wavelength λ

- Use the Cauchy calibration curve that you made for your prism in the previous experiment to find the wavelengths of the lines you observed.
- Is there a relationship between the color of the spectral line and the wavelength?