***Light – Reflection, Refraction and Polarization – OH MY!***

***Reflection:*** There are two types of reflection that light can undergo. Oh, by the way, when we are looking at the path of light, we talk about light rays. A light ray is the path that a single photon will follow – in general, a straight line. (At least on earth. Einstein found that light follows curved paths in space. This curvature is caused by the bending of spacetime by objects with a great deal of gravity.)

Here are the two types of reflection:

***Diffuse reflection*** - the rays are reflected in random directions.

***Specular reflection*** - parallel rays are reflected parallel to each other.

Objects that exhibit diffuse reflection are said to be opaque. Most things are opaque – clothing (usually), paper, wood, leaves, concrete, people, hair, dirt, rugs, etc. are all examples of opaque objects.

Specular reflection is often called ***mirror*** or ***regular reflection***. Mirrors, polished metal surfaces, the surface of calm water, and other really smooth surfaces exhibit mirror reflection.

***Specular Reflection:*** Light rays obey the law of reflection during specular reflection. In the rest of the course, when we discuss the reflection of light we will be talking about specular reflection.



The reflection of light must obey the law of reflection, this means that the angle of reflection is equal to the angle of incidence.

Angle ***i*** is the angle of incidence – this is the angle made by an incoming light ray to a normal to the surface. A normal to the surface is a line that is perpendicular to the surface. Angle ***r*** is the angle of reflection. This is the angle the reflected ray makes with a normal to the surface.

***Refraction:*** Refraction occurs when a wave travels from one medium to another. The light rays are said to be “bent”. You can see this in a glass of water. Place a pencil in the glass – the pencil looks like it is broken, shifted to the side, and larger in the water.

This occurs because light rays from the pencil are bent as they travel through the water.

 ***Refraction of light ≡ change in the path direction in a different medium.***

The refraction happens because of the velocity difference for light in the two mediums.

This brings us to a very important concept. ***The index of refraction***. This is the ratio of the speed of light in a vacuum to the speed of light in the new medium.

***The index of refraction*** ***≡ ratio of the speed of light in a vacuum to the speed of light in a different medium.***

  

***n*** is the index of refraction, ***c*** is the speed of light in a vacuum, and ***v*** is the speed of light in the medium.

You will be provided with this equation on the AP Physics Test.

|  |  |
| --- | --- |
| ***Substance*** | ***Index of Refraction*** |
| Diamond | 2.419 |
| Fused quartz | 1.458 |
| Crown glass | 1.52 |
| Flint glass | 1.66 |
| Ice | 1.309 |
| Polystyrene | 1.49 |
| Zircon |  |
| Benzene | 1.501 |
| Ethyl alcohol | 1.361 |
| Water | 1.333 |
| Air | 1.000 293 |
| Carbon dioxide | 1.000 45 |

On the right is a table of values for the index of refraction for different substances. Using this table, one can easily calculate the speed of light in any of the listed substances.

* What is the speed of light in ice?

We use the index of refraction equation to find the speed in the ice.



***Important Thingee:*** Observe the table for the index of refraction for air. It is essentially one. So on all problems, let the index of refraction be one for all calculations.

***Snell’s Law:*** The amount of refraction is of great interest to we physicists – you are interested are you not?



If the light rays travel from one medium into another, they will be bent. The bigger the difference in the light speed in the two media, the bigger the refraction. If the speed of light is the same in both media then there will be no refraction.

In the drawing to the right, the angle of incidence is ***θI***, the angle of refraction is ***θ2***. These angles are measured relative to a normal to the surface of the boundary between the two substances.

Another important point is that the ***frequency*** of light ***does not change*** as it goes from one medium to another. The wavelength can change and the speed of light can change, but the frequency does not.  must hold true.

The amount of refraction, that is, the angle of refraction, is related to the angle of incidence by Snell’s law. The drawing to the right shows a ray of light passing from one medium into another. In the first medium it has an index of refraction of ***n1***in the second medium its index of refraction is ***n2***. Here is Snell’s law:

 

***n1***isthe index of refraction in the first medium, ***n2*** is the index of refraction in the second medium, ***θ1*** is the angle of incidence, and ***θ2*** is the angle of refraction.

You will be provided with Snell’s law on the AP Physics Test.

* A beam of light that has a wavelength of 651 nm traveling in air is incident on a slab of transparent material. The angle of incidence is 35.0°. The angle of refraction is 23.4°. Find index of refraction for slab.

  

***For all practical purposes, the index of refraction in air is 1.***



***Wavelength and Frequency:*** What happens to the wavelength and frequency as light travels from one medium to another? We could, actually you could, develop any number of equations relating wavelength and frequency or index of refraction. Unfortunately, you won’t have access to any of those equations.

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Question

* A Beam of light with a wavelength of 565 nm is traveling in air and is incident on slab of transparent material. The angle of incidence is 32.0°. The refracted beam makes an angle of 20.5°. (a) Find the index of refraction for the slab and (b) find the wavelength of the light in the second medium.

(a)  



1. We know the index of refraction in the second medium. We can use this to find the speed of light in this medium:



Using this and the equation relating wavelength and velocity, we can find the wavelength in the new medium

 But what is the frequency? Well we can solve for the frequency of the light in air (recall that the frequency of the light will be the same in both mediums):



Okay, we can plug this into the velocity equation, which we solve for wavelength.





* A beam of laser light, wavelength 633.8 nm in air is incident on a block of polystyrene at an angle of 32.0°. Its wavelength in the new medium is 345 nm. Find (a) the index of refraction of the light in the polystyrene and (b) the angle of refraction in the polystyrene.
1. We can find the frequency of the light in air and that’s the same as it is in the polystyrene.



 Next we find the speed of the light in the new medium:



Now we can find the index of refraction:



1. This is simple, just use Snell’s law.

 



***Total Internal Reflection:*** When a light ray encounters a new medium, some of the wave is reflected and some of the energy is transmitted. So at a boundary when the incident wave is not perpendicular to the surface we would see both reflection and refraction.



As the angle of incidence increases, the angle of refraction also increases. Eventually the angle of refraction is big enough so that it is bent into the surface of the boundary. This means that none of the energy goes into the second medium, all of it is trapped in the first medium. We call this total internal reflection. This is really big in the field of fiber optics.

Total internal reflection will occur at the angle where the refracted ray stays in the boundary. This is called the critical angle. The critical angle is given by the formula:



The nice thing is that you will be given this equation on the AP Physics Test.



* What is the critical angle for water and air?



***Polarization:***

We have already learned that light is a transverse wave. It is created by electrons when they change energy levels in atoms. As they do this, the energy that they give up is converted into photons of light. This happens in all directions and orientations – there is no “up” or “down” to an atom, electron, or photon. So the electromagnetic waves that are formed are oriented in all possible planes.

Light can undergo processes that orient all the waves so that they are in the same plane. Such light is said to be ***polarized***.

Please note that just about all sources of light – the sun, a candle, lightbulbs, etc. produce light that is ***unpolarized***. In fact the idea of polarization was not even dreamed of until the 1940’s when a brilliant inventor, Edmund Land, discovered it. He also learned how to make a filter that would produce polarized light. These are called ***polarizing filters***. When normal light passes through a polarizing filter, only light in one plane gets through, the rest is absorbed by the filter.

What happens to the filter when it absorbs this light? (It heats up, right?)

Here is a poor drawing made to try to give you an idea of this polarizing filter thing. Does the drawing make any sense at all?

The other way that light can get polarized is during reflection off planer surfaces (i.e., flat surfaces).

This is called polarization by reflection and is quite common.

Edmund Land invented polarizing filters in the 1940's. One of their first applications - and still popular today - is in sunglasses. Most of the surfaces that cause glare (reflected sunlight) are horizontal: bumpers, car windows, water puddles, the polished hood of a car, etc. Land made sunglasses that had the filters vertically polarized. Normal light which contains light oriented in all planes can come through the lenses, but only the light that is vertically polarized gets through. So the light reaching the eyes is diminished (just what you want in sunglasses). Light reflected off horizontal surfaces is polarized horizontally. Normally this reflected light causes glare. But the vertically oriented polarized filters won’t let this light come through. So they do a bang up job of reducing glare.



Polarized light is also used in 3D movies. We see in three dimensions (3D stands for three dimensions). This is because we have two eyes that are set slightly apart. Because of this, we have ***parallax***, each eye sees a slightly different picture. The brain receives two slightly different images. Objects that are very close are situated very differently in the two images. Objects that are very far away look about the same. Hold a finger a few inches from you nose and look at it with one eye closed. Then close the other eye. The finger will look very different. Next look at something farther away in the same manner. You will see that there isn’t much of a change between what the right and left eye sees when the object is distant. Anyway, your brain puts the two images from each eye together and gives you a sense of depth. You can tell just by looking if a thing is close or distant. In a 3D movie, the film that is projected on the screen is made up of two such images. One image is polarized horizontally, the other is polarized vertically. Each member of the audience is given special glasses. One of the lenses is polarized horizontally and the other vertically. Only one of the pictures is allowed through each of the filters so the brain has two images to put together, just as in real life. So you see a 3D image.

