Lesson 28: Total Internal Reflection & Prisms

There are two topics that we should look at that are consequences of refraction:

- Total Internal Reflection
- Prisms

Total Internal Reflection

I know that it might seem like a typo, but **total internal *reflection*** is happening because of *refraction*.

- If a beam of light is traveling from an optically dense medium into a less dense medium, the light can refract so much that it actually gets trapped in the original medium (like it was reflected).

Let's look at what happens to the refracted angle as we increase the incident angle slowly for a ray leaving a more optically dense medium into a less optically dense medium.

- In these examples we will refer to the light rays by colors. This has nothing to do with the color of light being used. It's just to keep straight which diagram is referring to which situation.

Red Ray

Notice that the **red beam** in *Illustration 1* does exactly what we would expect it to do. It leaves the water and bends away from the normal.

- If we wanted to calculate anything for this situation, we would do a normal calculation using Snell's Law.
- There is nothing at all special about this first ray.

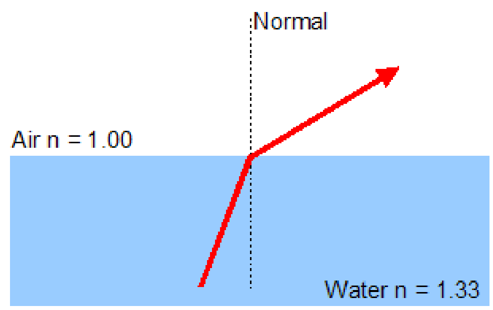

Illustration 1: This red ray has a small incident angle.

Blue Ray

We've increased the angle that the **blue beam** is traveling through the water in *Illustration 2*.

- This means that the beam leaves the water and travels into the air refracted at a bigger angle away from the normal.
- Notice that the beam traveling in the air is getting closer to the surface of the water.
- This is still solved as basic Snell's Law question.

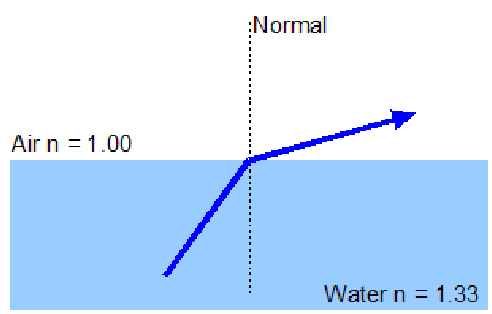

Illustration 2: The incident angle is getting bigger.

Green Ray

This **green beam** is traveling through the water at a pretty big angle from the normal.

- In fact, it is traveling at such a big angle from the normal that when the beam tries to leave into the air, it is refracted at 90°!!!
    - This means that the beam never really leaves the water, but instead skims along the surface of the water.
- For this reason we call the angle that the beam is traveling in the water its **critical angle** with air.
- We can calculate this angle in the water using the following method…

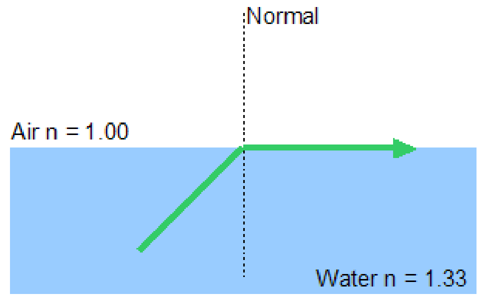

Illustration 3: The incident angle is so big that the refracted ray never truly leaves the water.

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

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

$$\sin\theta_1=\frac{\sin 90^o(1.00)}{1.33}$$

$$\theta_1=49^o$$

> When calculating the critical angle, the angle in the other medium must be, by definition, 90 degrees.

This is the critical angle for water to air.

- For any other combination of media you would have to calculate its unique critical angle.
- Notice also that critical angles can only happen if something is going from higher to lower density substances.
    - Going from lower to higher indices gives an unsolvable formula

Purple Ray

For any angle *bigger* than the critical angle you just calculated, the beam can't even leave the water.

- It will be refracted so much that it actually just starts to reflect.
- This is the total internal reflection that we were talking about in the title for this section.
- Just use the regular rule for reflection… whatever the incident angle is, the reflected angle will be the same.

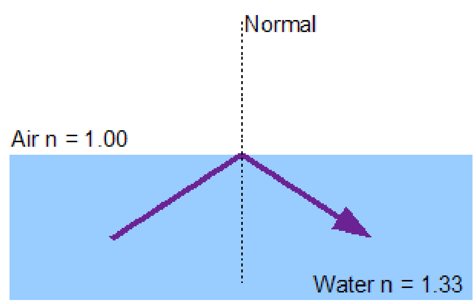

Illustration 4: The angle of incidence is so big that the ray reflects.

This is the principle used in fiber optic cables.

- The fiber optic cable itself is made of a material like Plexiglas, part plastic and part glass. It is slightly flexible, although if you bend it too sharply it will snap.
  - If you use optical cable to connect parts of your home theatre system, you basically are using fiber optic cable.
- A light beam shining in one end of the fiber will bounce off of the inside surface because of total internal reflection with very little loss.
  - The beam of light can't escape because it is trying to move from a more dense (the cable) to a less dense (the air) medium.
- The beam coming out the other end is very strong, even if the cable is hundred of kilometres long.
- A typical single strand of fibre optic cable can carry many times the information that an old fashioned thick copper cable could do.

Illustration 5: Fiber optic cable is protected on the outside by several layers of material.

Prisms

Remember in the last lesson we saw that Snell's Law shows that different wavelengths of EMR will refract at different angles.

- If the EMR is visible light then the different colors will refract at different angles and split up.
  - **Shorter wavelengths** (like **violet**) refract the **most**.
  - **Longer wavelengths** (like **red**) refract the **least**.

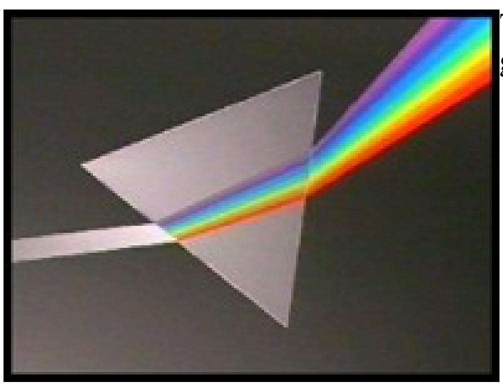

Illustration 6: A prism splits white light into all the colors.

This is what you see happening when light passes through a glass prism and forms a rainbow.

- Sir Isaac Newton noticed this effect while playing around with prisms.
- He reasoned that since shining white light into a prism resulted in all the colors of the rainbow coming out, visible white light must be made up of all the colors of visible light.
- He also found that if you used a second prism, you could make the individual colors blend back together to form white light.

Technically speaking...

- breaking white light into its colors is called **dispersion**.
- recombining colors into white light is called **recomposition**.

This also partly explains what happens when light refracts through a rain droplet and forms a true rainbow.

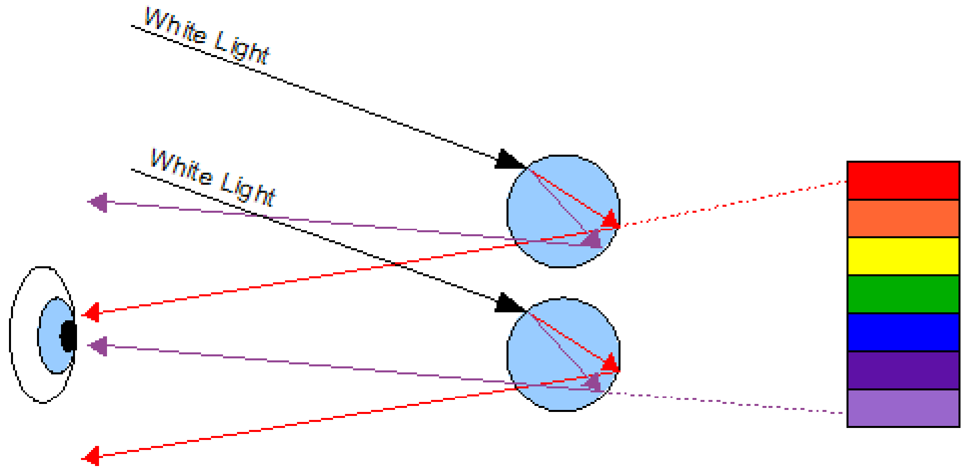

Illustration 7: Visible light entering a raindrop results in a rainbow.

- When the light enters the rain drop, it refracts.
- The light that hits the back of the rain drop has total internal reflection and reflects back into the drop.
- The light refracts one last time as it exits the rain drop.
- All these refracted light rays take different paths to your eye, so you see separated colors.

