Physics in the classroom

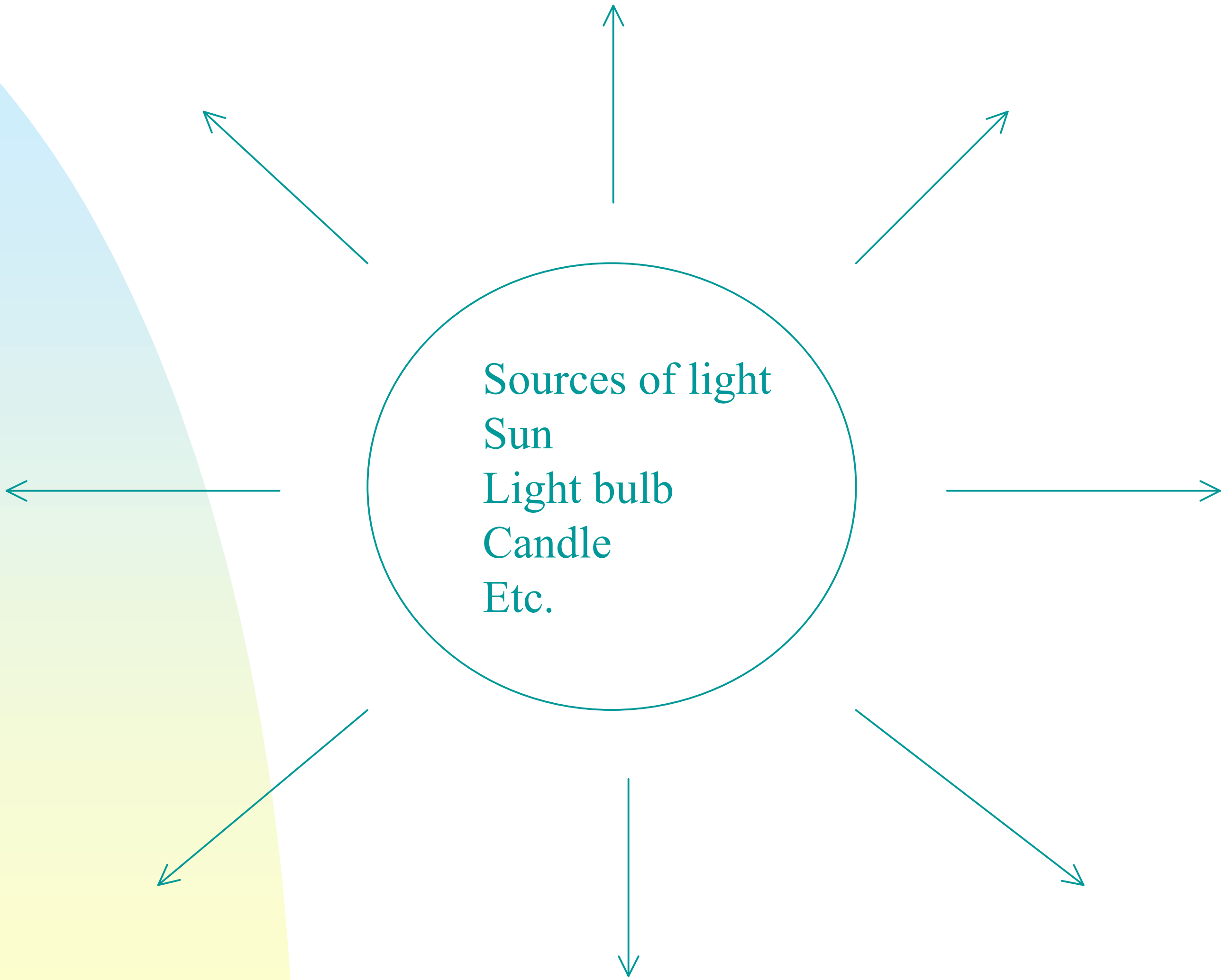
Lecture 8

Optics

Geometric optics

Applications: Eyes, eye glasses, magnifying glasses, microscopes and telescopes to name a few.

Rays of light



Parallel rays of light

If we move far enough away from the source of light, the rays of light are almost parallel.
There are also other ways of producing parallel rays of light.

The speed of light

$c = 3 \times 10^8$ m/s

Light can actually travel in a vacuum.
The speed of light in a vacuum is 3×10^8 m/s (fast!)
The speed of light in a vacuum is a constant and usually denoted by the letter c.
The speed of light depends on the material it is traveling in.
The speed of light is a measly 1.5×10^8 m/s in some types of glass

Refraction

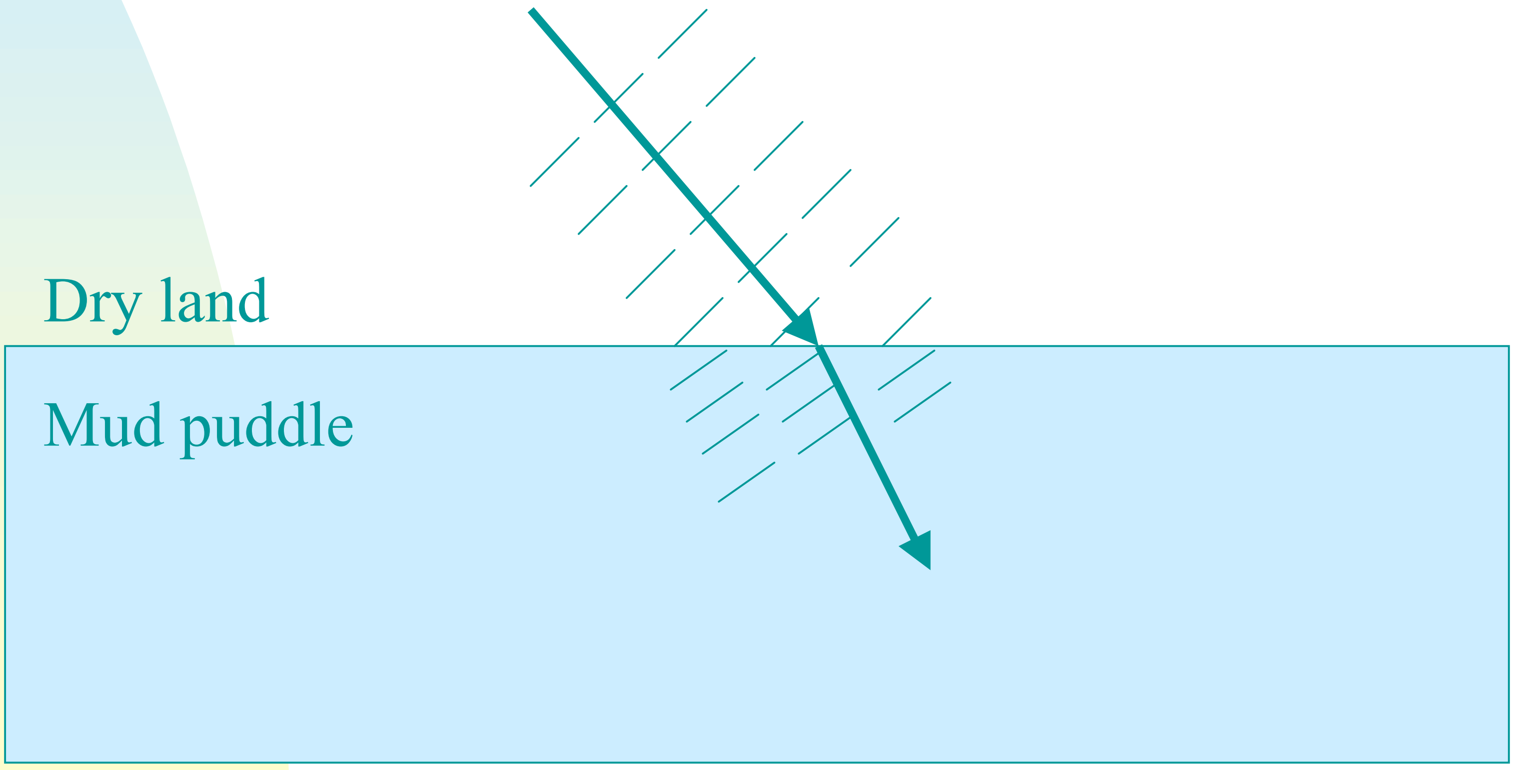
Refraction is the bending of light as it passes from one material into another

The amount of bend depends on the difference between the speeds of light in each material.

Hopefully, the following marching band analogy will clarify this point.

Marching band.

Imagine a marching band, marching on a field that has a mud puddle in it. As each member of the marching band enters the mud puddle she/he slows down. The net effect is that the band changes direction.



Index of refraction

So, refraction (the bending of light) depends on the relative speeds of light in each material.

The index of refraction for a material is a pure number (no units) which is equal to the ratio of the speeds of light in a vacuum and in the particular material.

$$\text{Index of refraction} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in material}}$$

In shorthand form: $n = \frac{c}{v}$

Example 1

If light slows from 3×10^8 m/s to 1.5×10^8 m/s when it passes from vacuum into a typical piece of glass, what is the index of refraction of the glass?

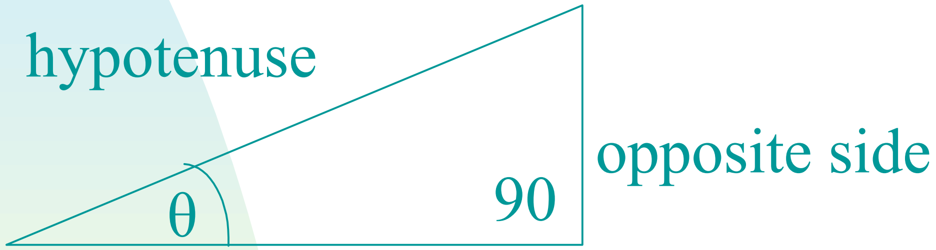
$$n = \frac{c}{v} = \frac{3 \times 10^8 \text{ m/s}}{1.5 \times 10^8 \text{ m/s}} = 2$$

Notice that the units (m/s) cancel.

Trick question: What is the index of refraction of vacuum?

A LITTLE trigonometry

Thousands of years ago the Egyptians discovered that the sides of a special triangle (called a right triangle) were related.



The sine (abbreviated sin, and pronounced sign) is equal to the opposite side divided by the hypotenuse.

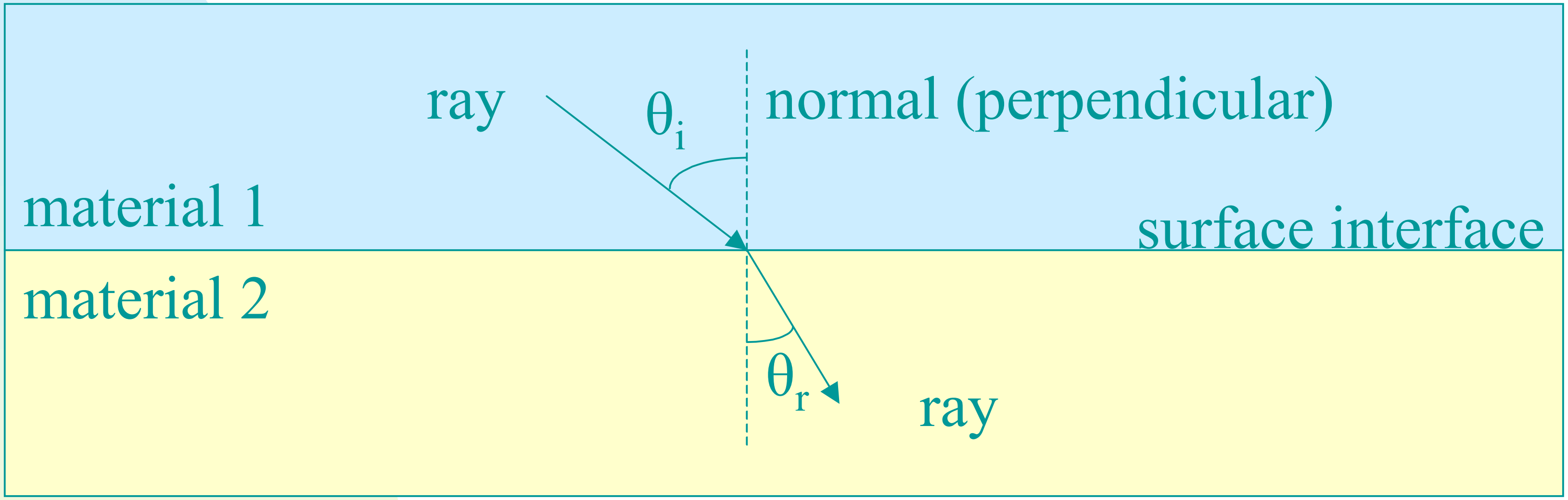
Sin on a calculator

Most modern scientific calculators include trigonometric functions like sin. Simply enter the angle and then press the sin button.

Notice that the answer is never greater than one. You should also know that the result is a pure number,unitless.

Snell's Law

The bending of light as is passes from one material, into another can be determined with a formula known as Snell's Law. But first a few definitions.



θ_i = angle between incident ray and the normal

θ_r = angle between refracted ray and the normal

n_i = index of refraction for material 1

n_r = index of refraction for material 2

Snell's Law (continued)

$$n_i \sin \theta_i = n_r \sin \theta_r$$

Example: Suppose material 1 is vacuum and material 2 is glass with an index of refraction of 2. If a ray of light strikes the surface at an angle of 45 degrees with respect to the normal, what angle will it be bent to, upon refraction in the glass?

θ_i = angle between incident ray and the normal = 45 degrees

θ_r = angle between refracted ray and the normal = ?

n_i = index of refraction for material 1 = 1

n_r = index of refraction for material 2 = 2

Example (cont.)

$$n_i \sin \theta_i = n_r \sin \theta_r$$

Algebraically solving Snell's law for what we want to know (θ_r)

$$\sin \theta_r = (n_i / n_r) \sin \theta_i$$

Plugging in some numbers …

$$\sin \theta_r = (1/ 2) \sin 45$$

Using your calculator, enter 45 then press the "sin" key, you should get 0.7071 (you can use the first few numbers). Now divide by 2 to get 0.3536 (again rounding to four significant figures).

Example (continued 2)

At this point, we have

$\sin \theta_r = 0.3536$

Now we want to find the angle who's sin is equal to 0.3536. This is done on most calculators by pressing the inverse (inv) key and then the sin key to get. 20.71 degrees for the refracted angle.

Notice that in this case, the index of refraction was greater in the second material resulting in the ray being bent towards the normal in the second material.

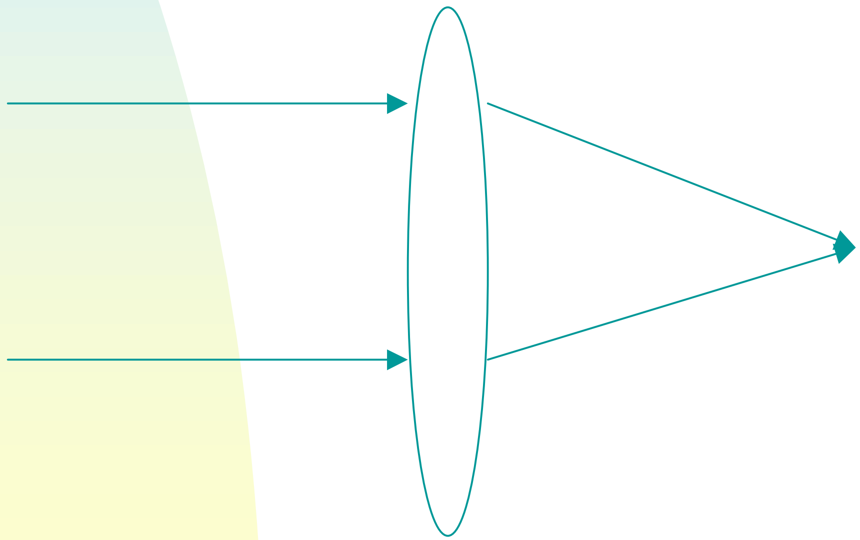
Lenses

Refraction can be used to construct lenses. The light is bent as it enters the lens and bends again as it exits the lens. The net result is a refocusing of the light.

Examples:
Magnifying gasses
Corrective eye glasses
The lenses in your eyes themselves
Camera lenses
more

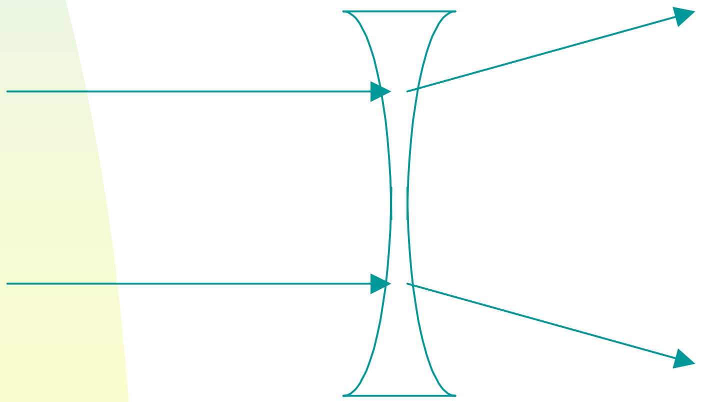
Converging lenses

Lenses which are thicker in the center than on the edges tend make parallel rays of light converge, make rays which are converging converge even more, or make diverging rays diverge less.



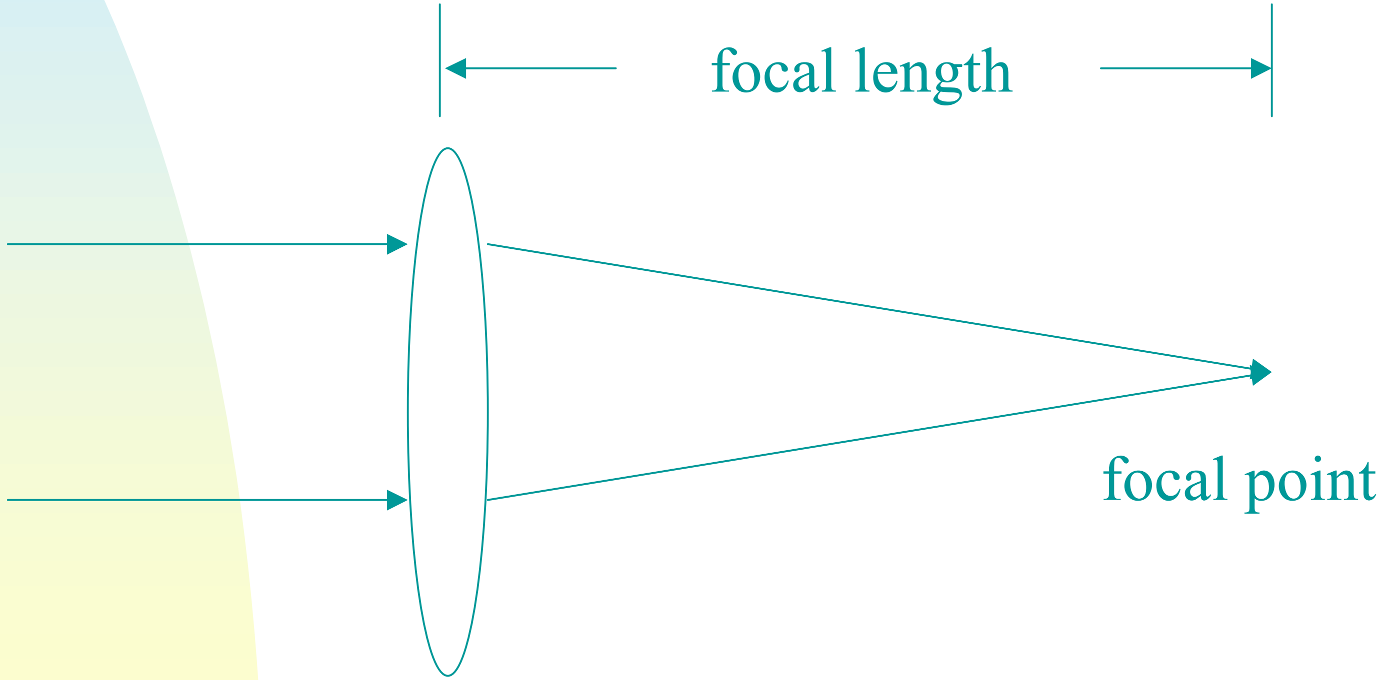
Diverging lens

Lenses which are thicker at the edges than at the center tend to make parallel rays of light diverge. These lenses are called diverging lenses. These lenses also make rays of light which are diverging already, even more divergent and rays which are converging, less converging.



Focal length

The focal length of a conversing lens is the distance from the lens to where rays cross at the focal point.



Combining lenses

Lenses can be combined to make optical instruments.

Microscope: A simple microscope can be constructed by using a short focal length lens as the objective lens (that is the lens closest to the object to be examined) and a longer focal length lens as the eyepiece (that is the lens closest to the eye).

Telescope: A simple telescope can be constructed by reversing the lenses, using the long focal length lens as the objective and the short focal length lens as the eyepiece.

Demos

Blackboard optics.