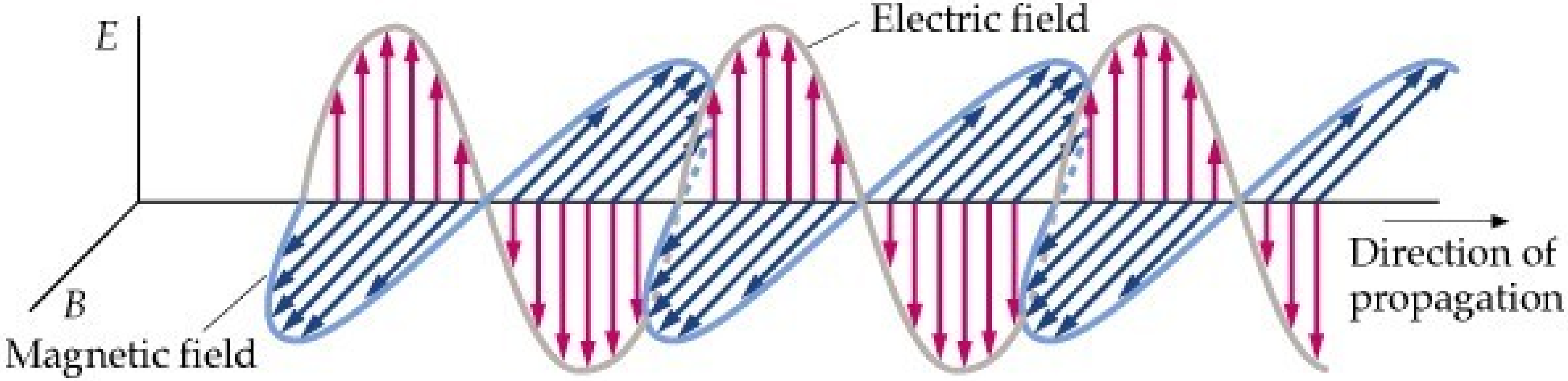
Optics a

Lectures 10-11

-Ray optics
-Huygen's principle
-Fermat's principle
-Reflection
-Refraction

Young and Freedman Chapter 33.1-
33.4, 33.7

We have developed a formalism which we can now apply to electromagnetic waves – light
Electromagnetic waves are oscillations of the electric (E) and magnetic (B) fields



Light does not need a medium, it can propagate in vacuum.
Light does not involve the oscillation of particles.
Light is a transverse wave.

Wave equation for electromagetic waves

$$\frac{\partial^2 E}{\partial x^2} = \varepsilon_o \mu_o \frac{\partial^2 E}{\partial t^2}$$

where

$$c = \sqrt{\frac{1}{\varepsilon_o \mu_o}}$$

$\varepsilon_o \mu_o$ are two constants which describe how well waves propagate through electric and magnetic media the $_o$ subscript tells about the propagation in free space – the vacuum (c=299792458 ms^{-1}).

For materials with values of relative permittivity (ε_r) and relative permeability (μ_r) the velocity of the light is

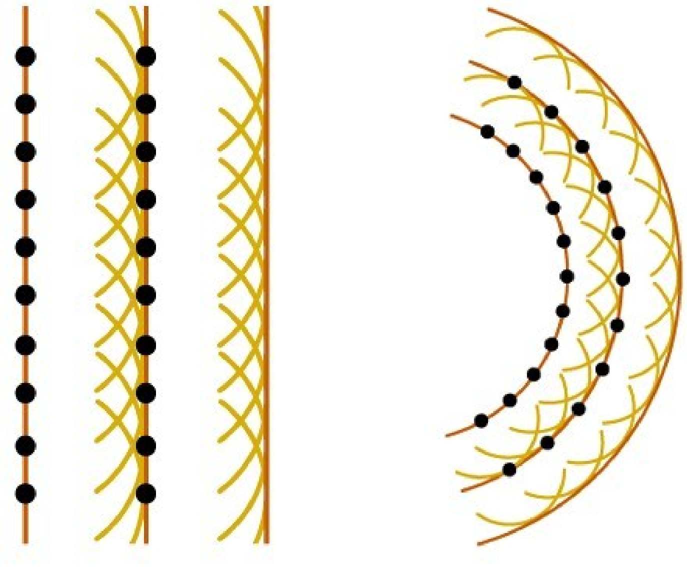
$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}} = \frac{c}{n}$$

where *n* is the refractive index n>1, light travels slower in matter.

There are two guiding principles that we shall employ extensively:

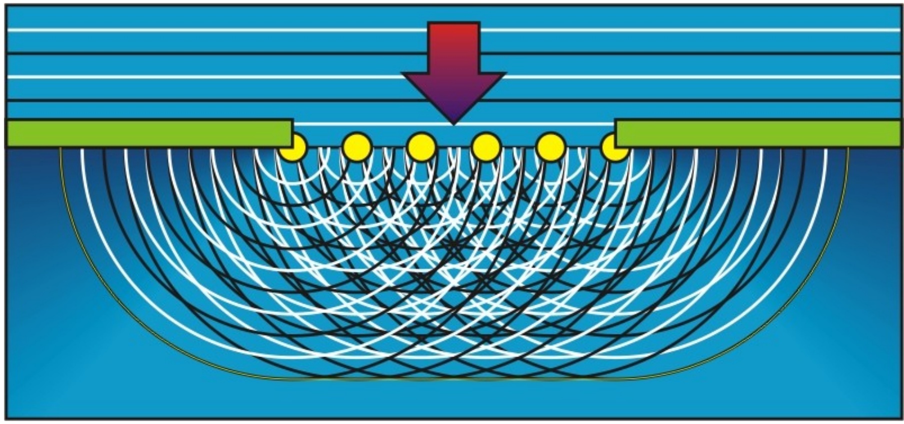
1. Huygen's principle

Each point on a wavefront serves as the source of spherical secondary wavelets that advance with a speed and frequency equal to those of the primary wave.



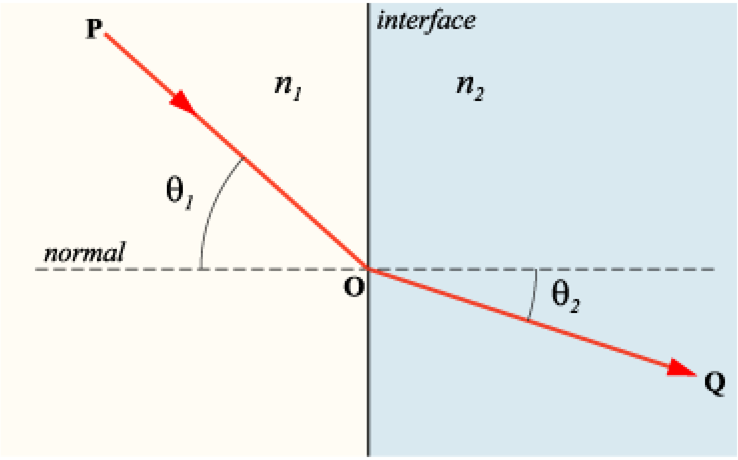
(a) (b)

Christian Huygens

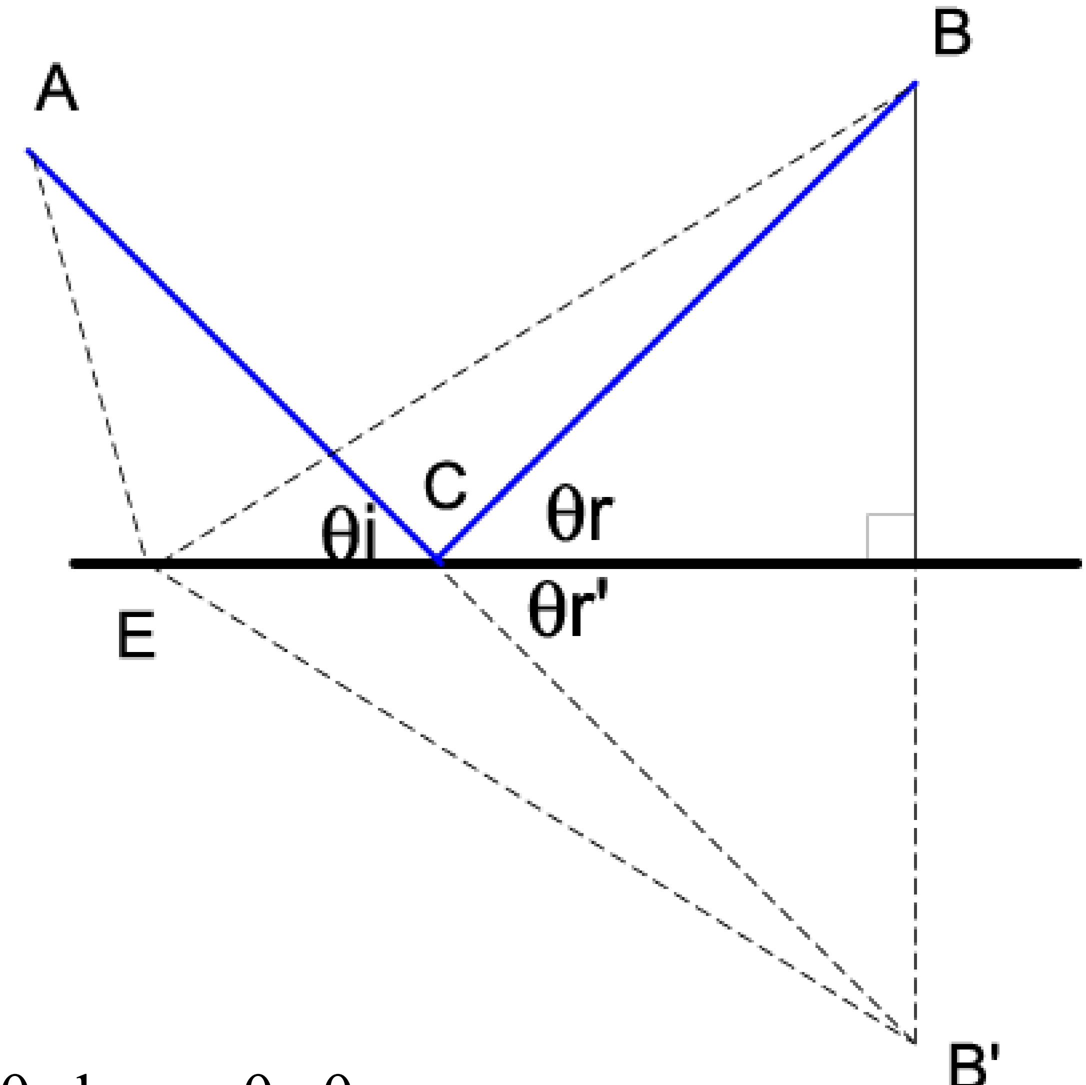


Fermat's Principle (Pierre de Fermat)

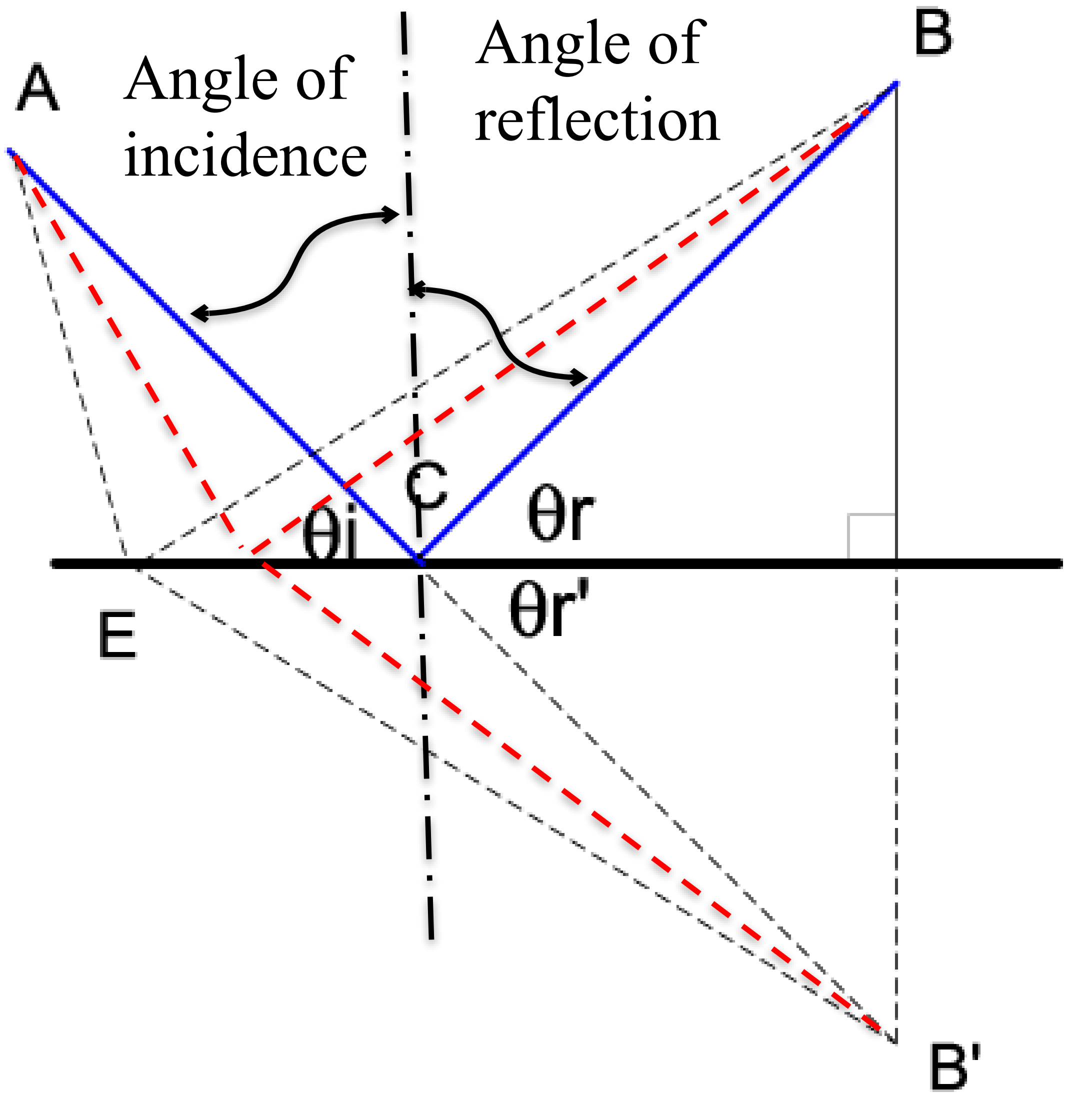
The actual path between two points taken by a beam of light is the one which is traversed in the least time (dt/dl=0).



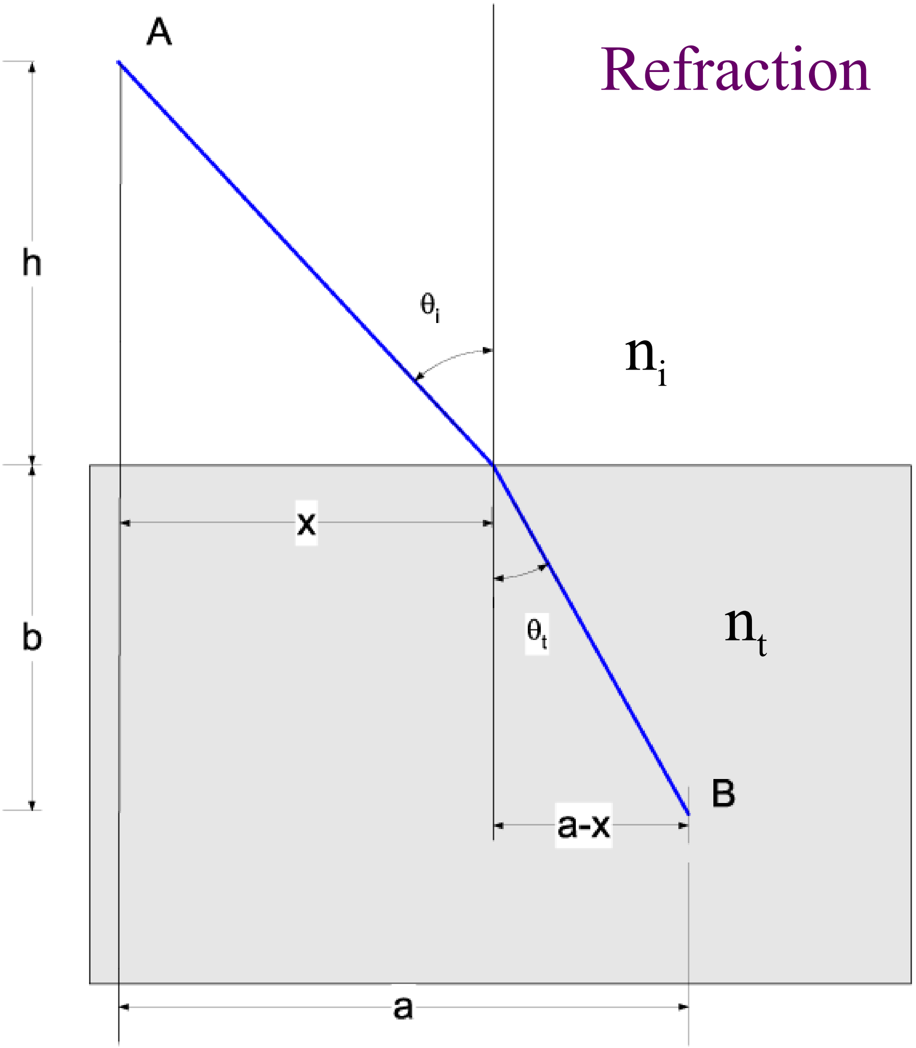
Reflection from a surface



$\theta_i = \theta_r'$, $\theta_r' = \theta_r$, hence $\theta_i = \theta_r$



A
Angle of incidence
Angle of reflection
B
C
θi
θr
θr'
E
B'



Refraction

$$t = \frac{\sqrt{h^2 + x^2}}{v_i} + \frac{\sqrt{b^2 + (a-x)^2}}{v_t}$$

To find the minimum time, we need to solve for *x* such that

$$\frac{dt}{dx} = \frac{x}{v_i\sqrt{h^2 + x^2}} + \frac{-(a-x)}{v_t\sqrt{b^2 + (a-x)^2}} = 0$$

Which is

$$\frac{\sin\theta_i}{v_i} = \frac{\sin\theta_t}{v_t}$$

$$\text{Since } \frac{c}{v_i} = n_i; \quad \frac{c}{v_t} = n_t$$

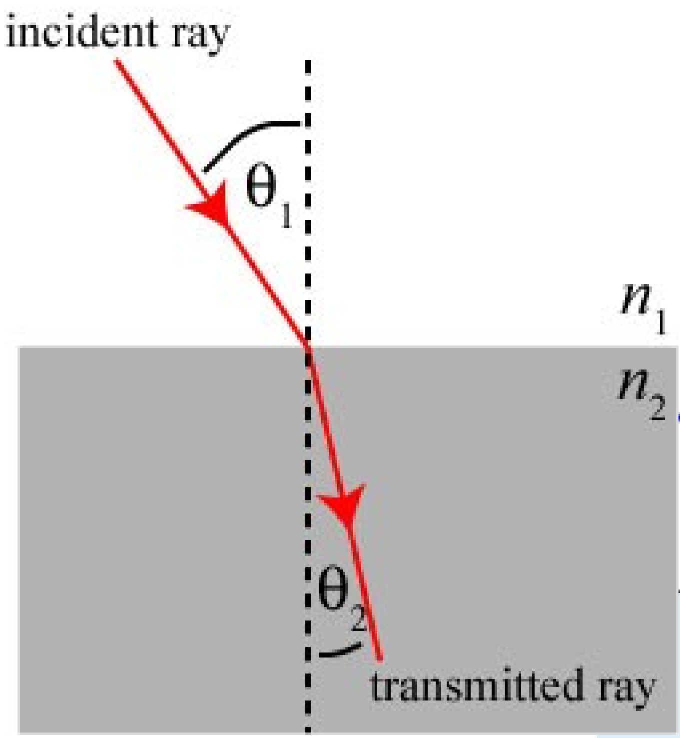
$$\text{hence}: n_i \sin\theta_i = n_t \sin\theta_t$$

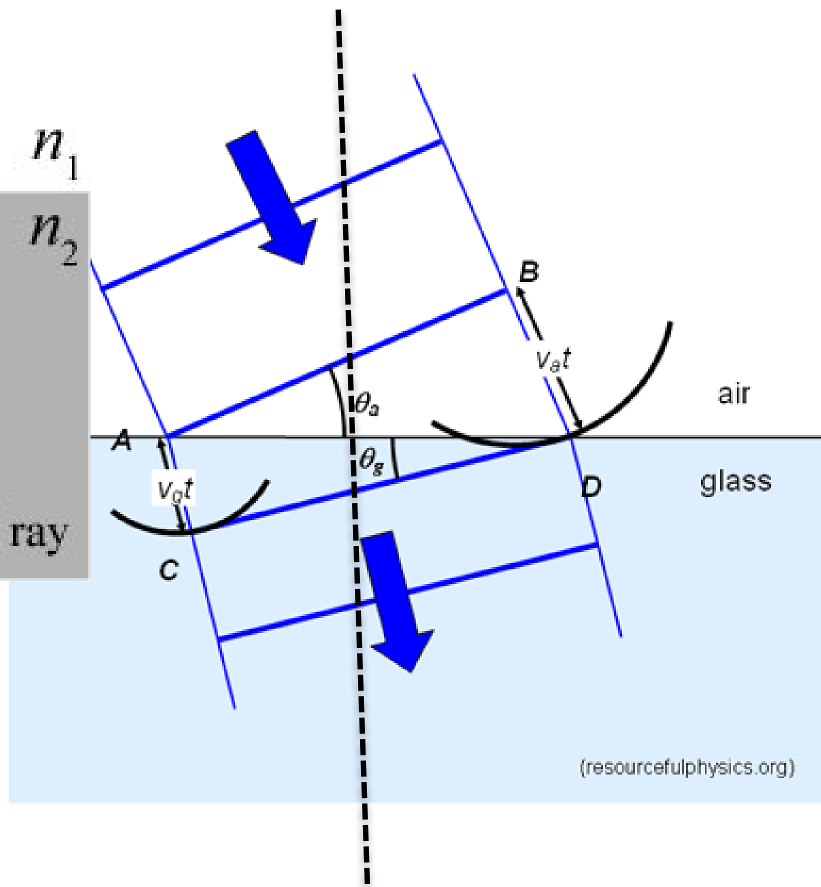
This is Snell's law

Relationship between Huygen's and Fermat's Principles

Speed of light in a medium is less than in vacuum. Speed is characterised by index of refraction (n)

n=c/v



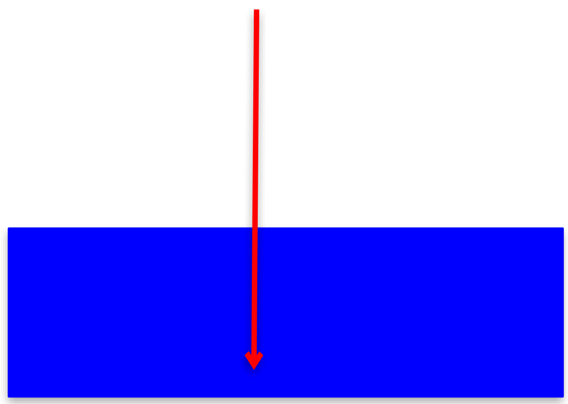


For water n=1.333
air n=1.0003

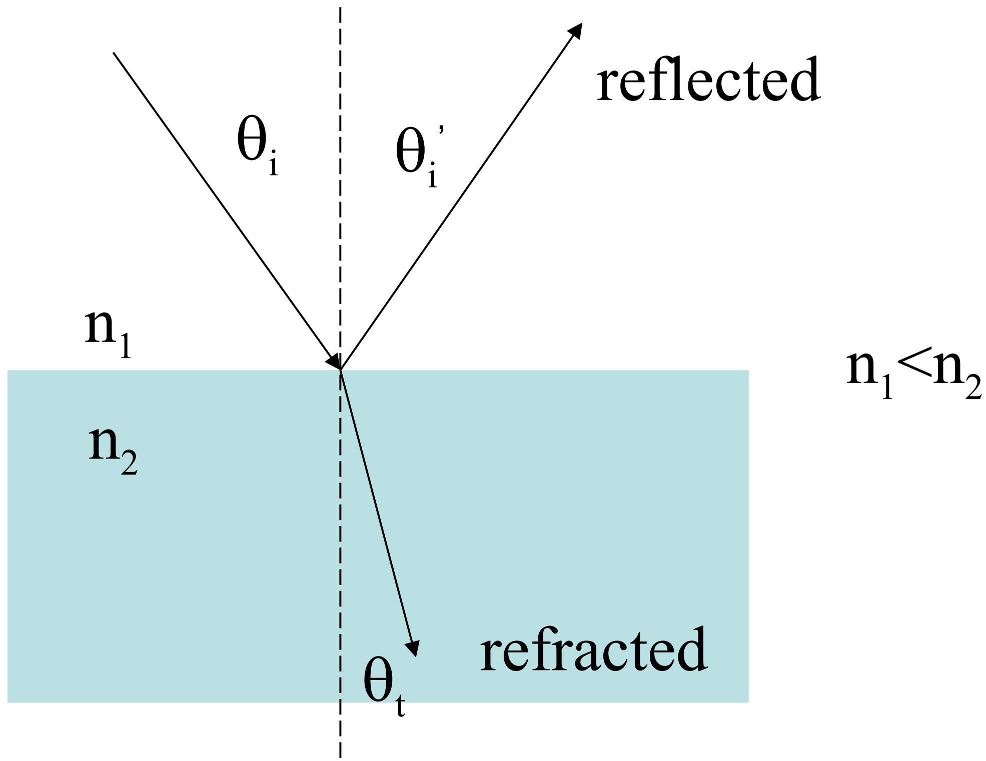
http://tap.iop.org/vibration/reflection/317/page_46713.html

If normal incidence: $\theta_i = \theta_t = 0$

Velocity change, no direction change.



When light strikes the boundary surface, there is a transmitted and reflected component (just as with waves on a string).

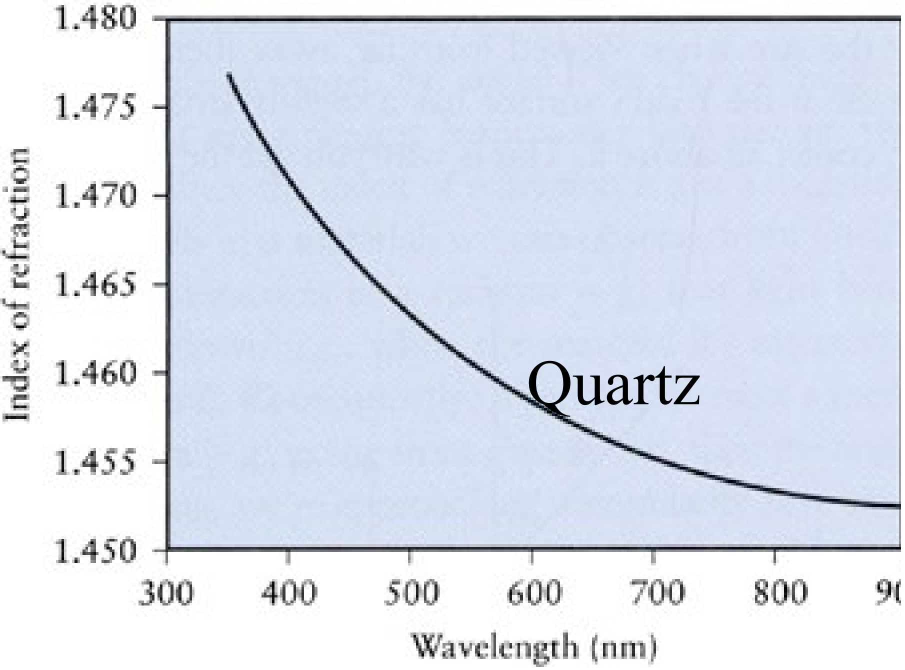


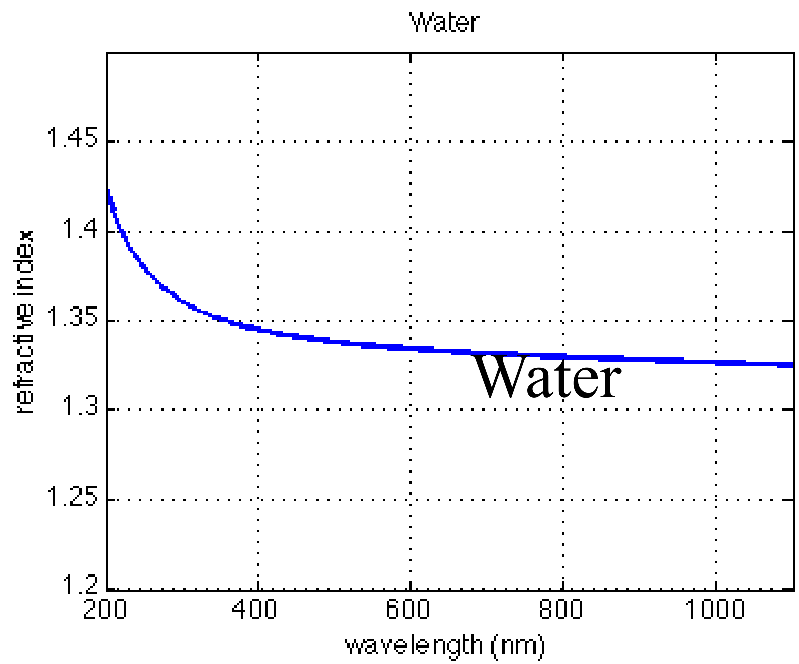
$\theta_i = \theta_i'$ (angle of incidence = angle of reflection)

$n_1 \sin(\theta_i) = n_2 \sin(\theta_t)$ (Snell's law)

Light travels at speed c in vacuum, and this is independent of wavelength.

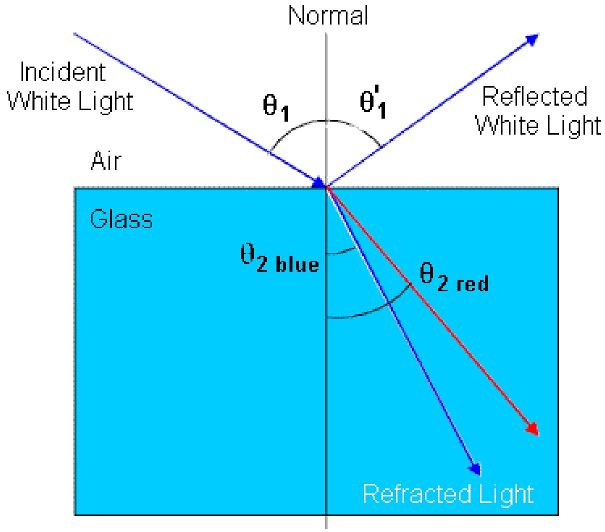
Refractive index changes with frequency of light, so light of different wavelengths travel at different speeds in a medium.



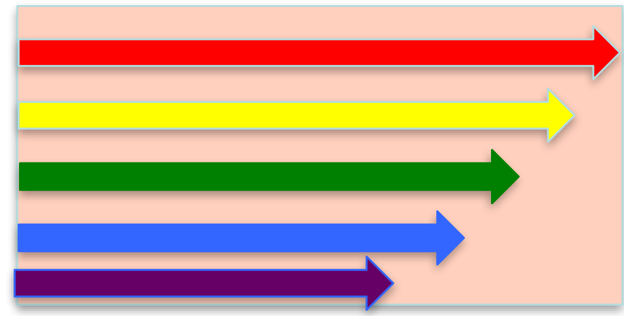


n is larger for shorter wavelengths. So higher frequency light is slower in a medium.

Higher frequency light bends more at the interface.



http://www.instant-analysis.com/Principles/spectra.htm

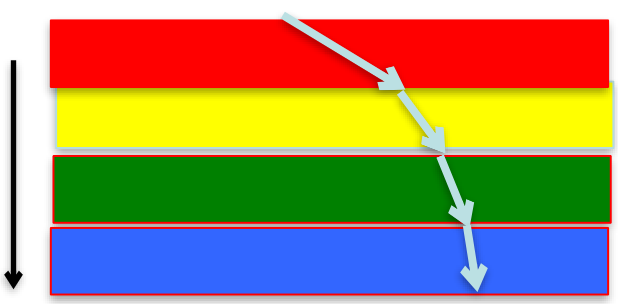


$$n_i \sin\theta_i = n_t \sin\theta_t$$

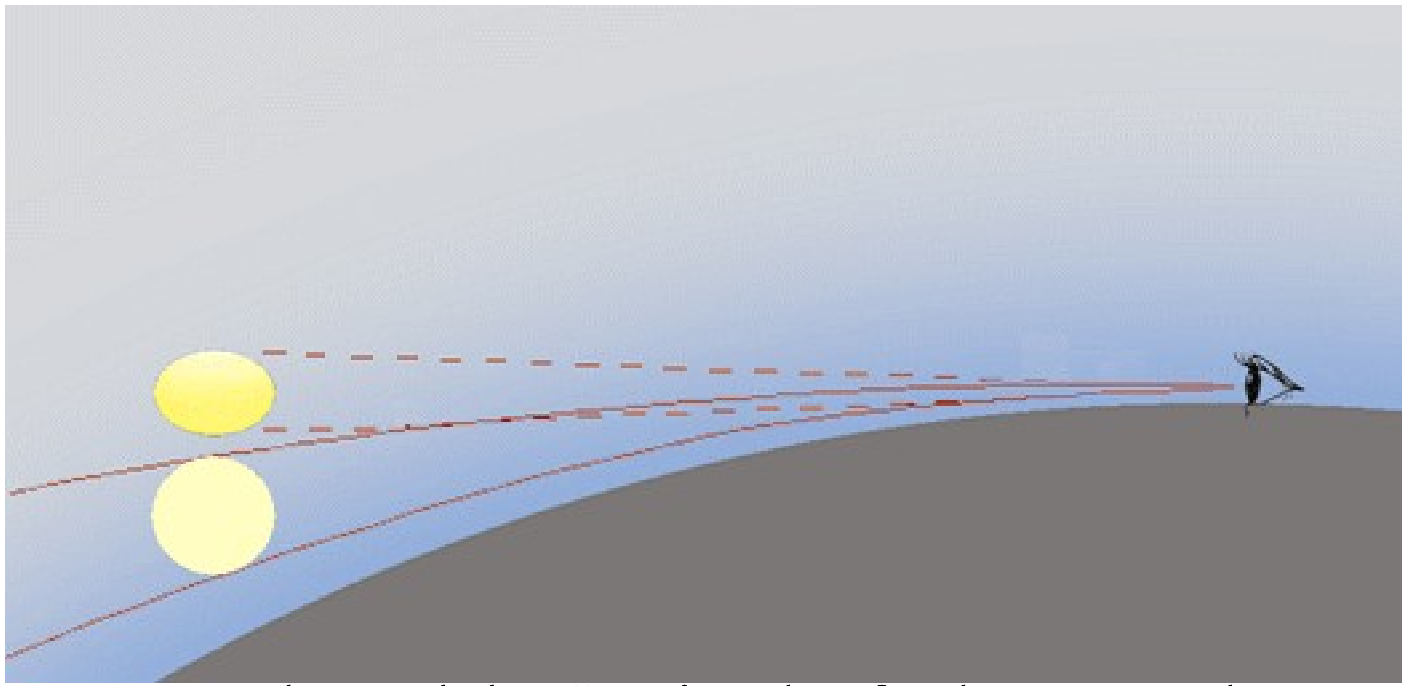
$$\frac{\sin\theta_t}{\sin\theta_i} = \frac{n_i}{n_t} = \frac{1}{n_t} \text{(if one side is air)}$$

If light travels through a medium with a non-uniform *n*, light tends to bend towards regions of high *n*.

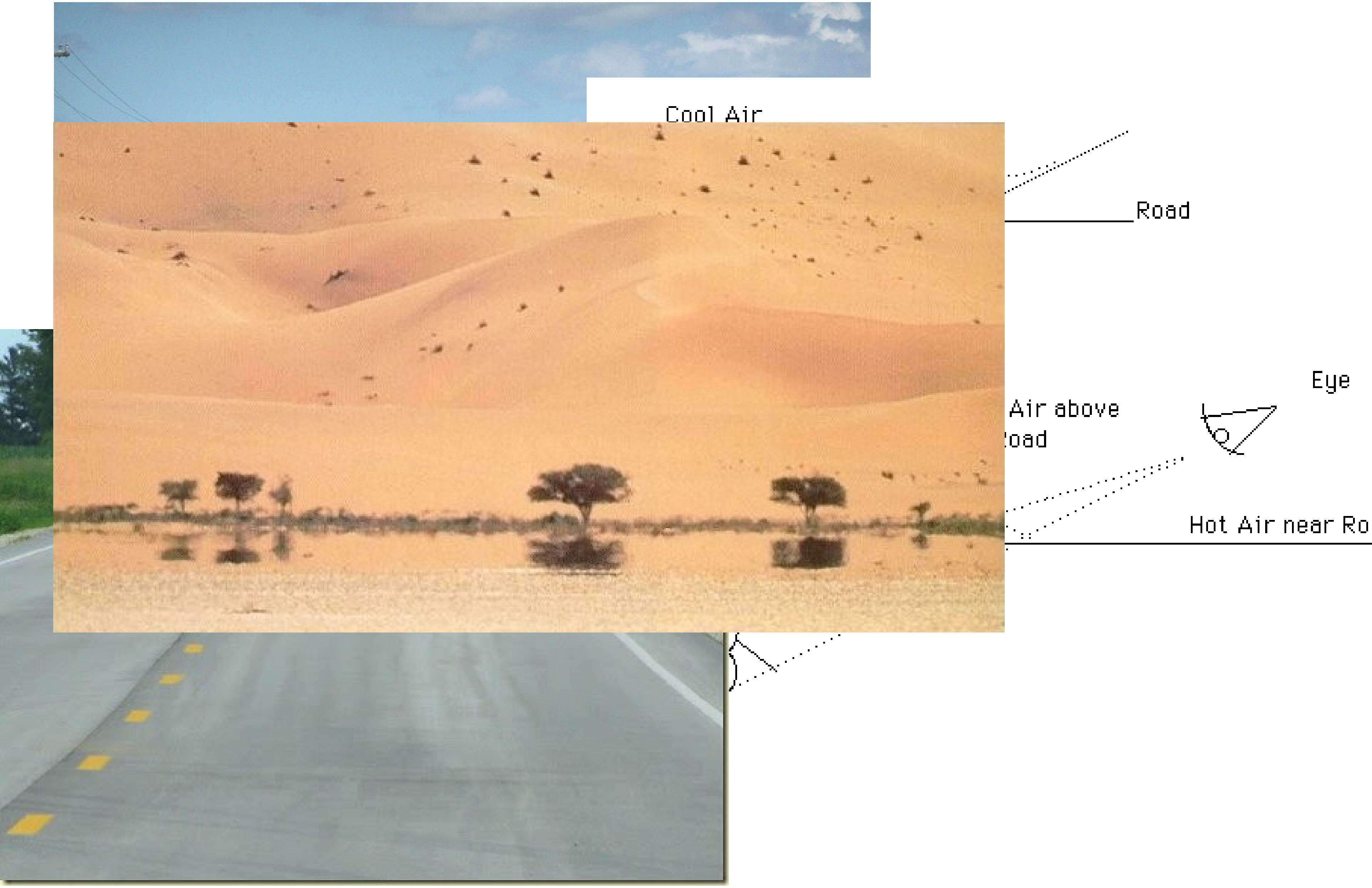
Increasing *n*

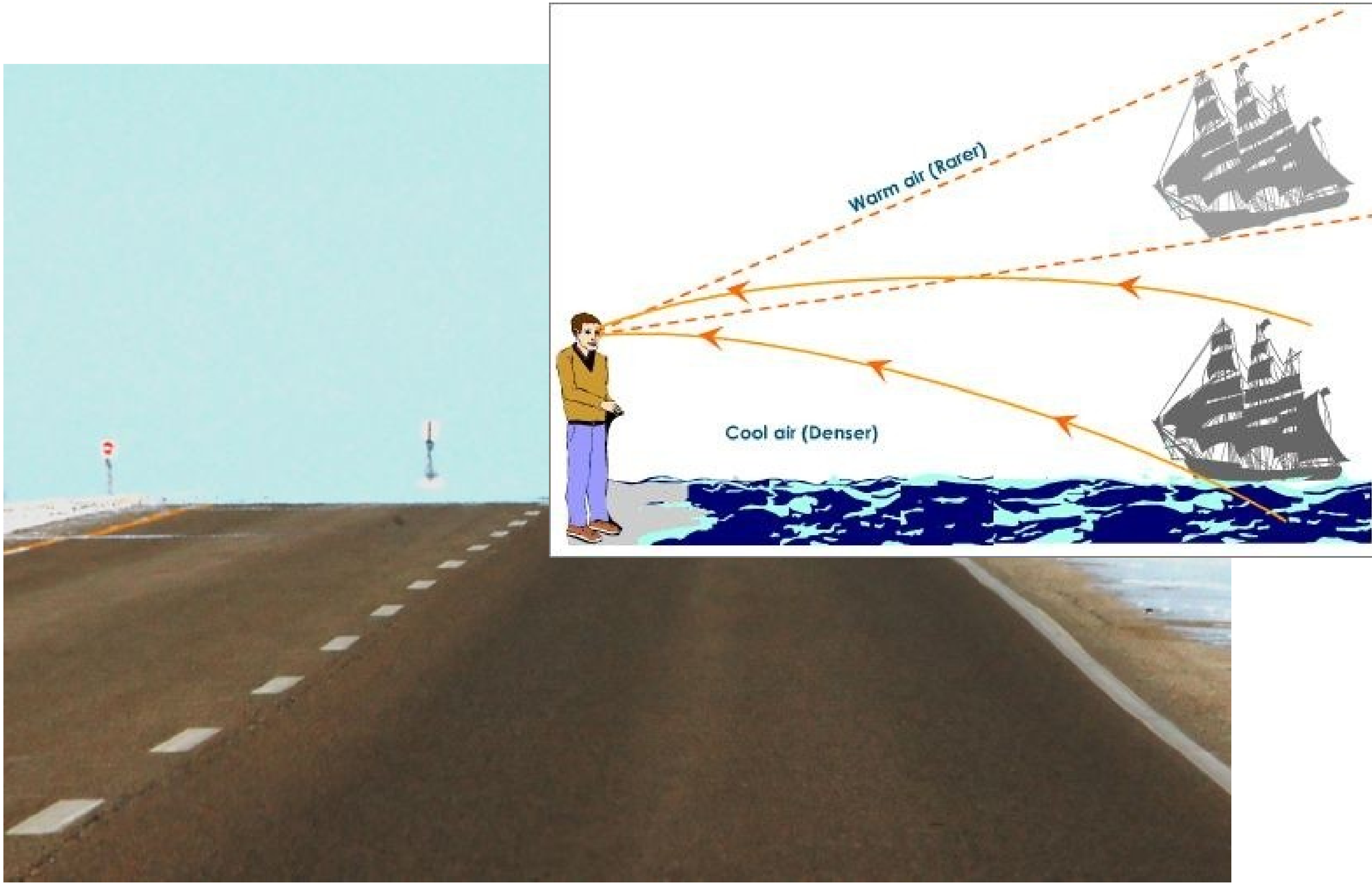


When you see the Sun just above horizon, the Sun has actually already set.

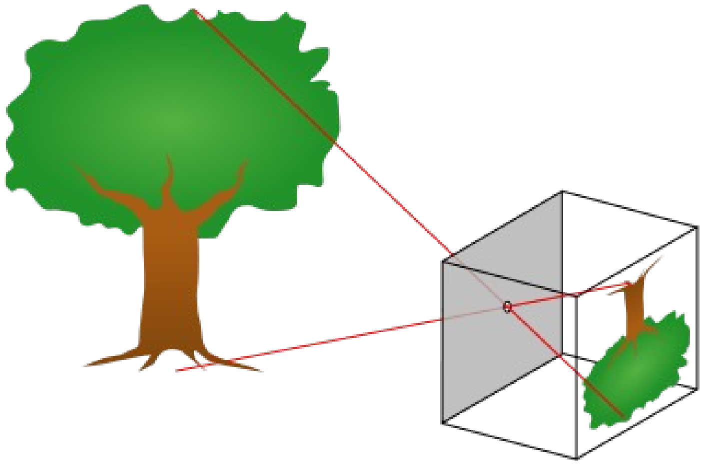


The sketch is not to scale, and the Sun is a lot further away than shown.


Cool Air
Road
Air above
Eye
Hot Air near Ro


Warm air (Rarer)
Cool air (Denser)

Pinhole camera



http://en.wikipedia.org