Homework 24

Snell's law

Last class we discussed refraction. Similar to the reflection, the refraction can change the direction of light propagation. As we will see later, this effect can be used to focus the light beam and, hence, it can be used for image construction.

We learned that in any material light propagates slower than in vacuum. The number which shows how many times the speed of light in a material less than in vacuum is called *index of refraction,* or *refractive index*. For example, the index of refraction of diamond is ~2.4. It means that light propagates in diamond 2.4 times slower than in vacuum.

The direction of a light beam changes as the light enters into one media from another media, say, from air to water. This phenomenon is called *refraction*.

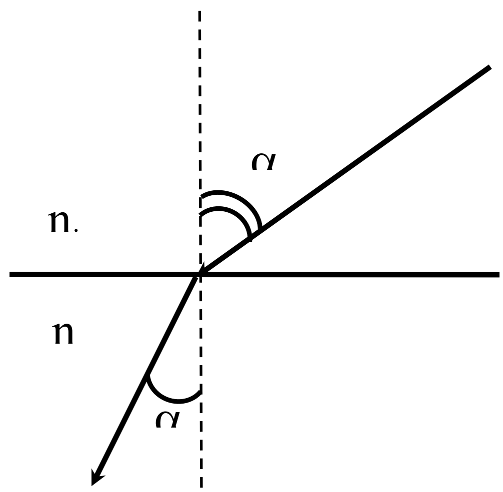


Figure 1.

Let us imagine that the light enters into the media characterized by the refractive index $\mathbf{n_r}$ from the media characterized by the refractive index $\mathbf{n_i}$ (Figure 1). The angle α_i, as we remember, is called "the angle of incidence"; α_r is the *angle of refraction*. There is an important expression which "connects" these angles. It is called "Snell's law":

$$\frac{sin\alpha_i}{sin\alpha_r} = \frac{n_r}{n_i} \qquad (1)$$

It is easy to obtain the expression for the $sin\alpha_r$:

$$sin\alpha_r = \frac{n_i}{n_r} sin\alpha_i$$

If you know the angle of incidence you can easily calculate the angle of refraction.

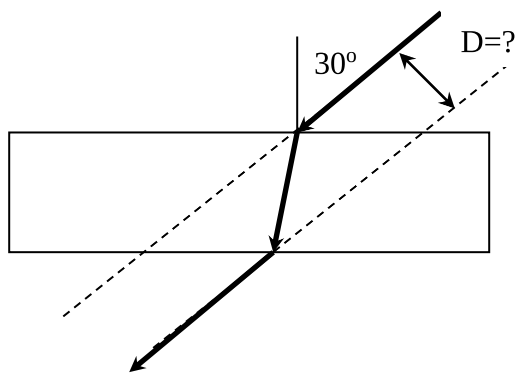
If the light moves from material with higher refractive index to material with lower refractive index then the angle of refraction is higher than the angle of incidence. In this case, at a certain angle of incidence the angle of refraction reaches 90^o.If we further increase the angle of incidence then no light will penetrate into the material with lower refractive index – all the light will be reflected from the interface. This phenomenon is called "***total internal reflection***", and the corresponding angle – "angle of total internal reflection" - $\boldsymbol{\alpha_t}$. It can be found using expression (1): we have to make α_r=90^o and replace α_i to α_t.

$$\alpha_t = arc\ sin\frac{n_r}{n_i} \qquad (2).$$

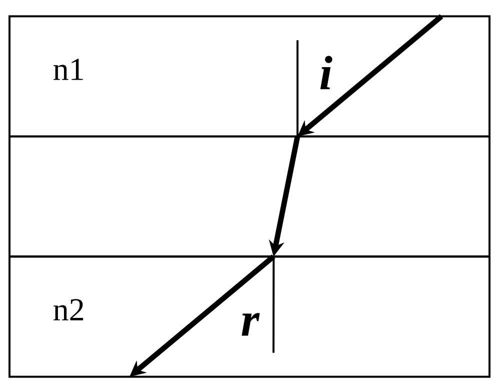
If the light moves from low refractive index media to high refractive index one, n_r/n_i>1 and no $\boldsymbol{\alpha_t}$ exists.

Problems:

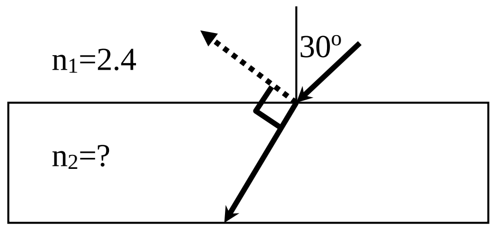
1. A beam of light comes from air (the index of refraction n=1) and passes through a glass plate (the index of refraction n=1.5). The thickness of the plate is 1cm. The angle of incidence is 30^o. Find the displacement of the beam (i.e. the distance between beam axis before and after it passes through the plate – see picture below).



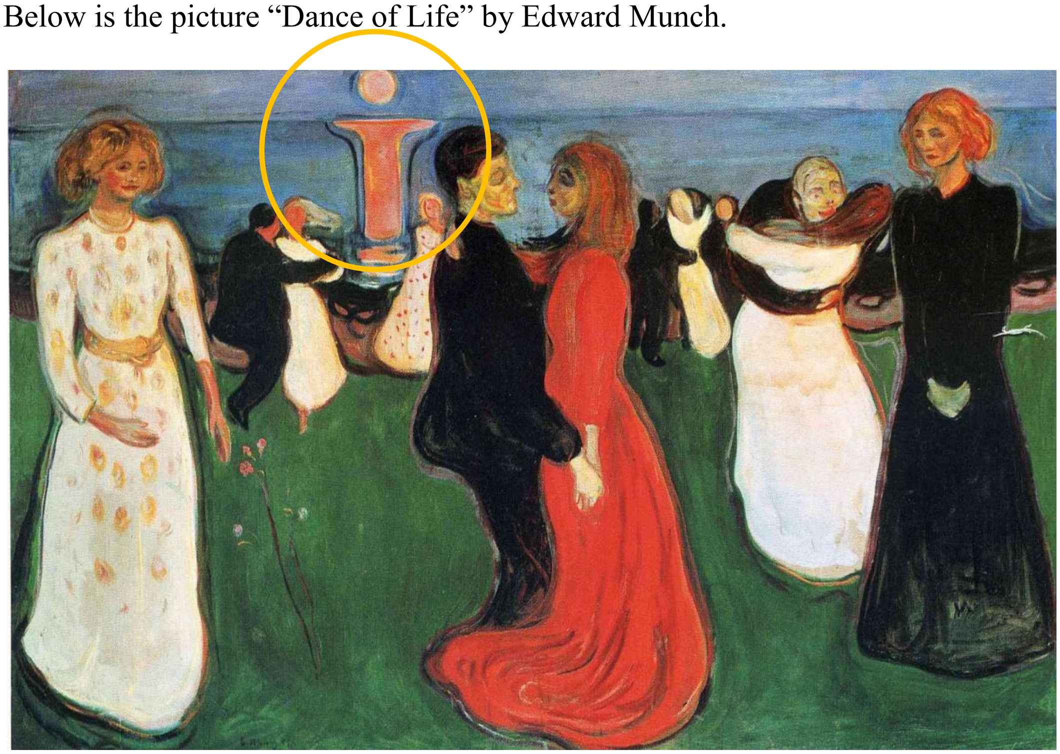
2. There are two transparent plates and liquid between them (see picture below). The indexes of refraction of the plates are $\boldsymbol{n_1}$ and $\boldsymbol{n_2}$. The beam of light propagates from the upper plate at the angle ***i*** and enters the lower plate at the angle ***r***. Prove that $\boldsymbol{sin(i)/ sin(r) = n_2/n_1}$ independently on the thickness of the layer of liquid.



3. A beam of light hits the plane separating two transparent materials at the angle of 30^o (see picture below). The index of refraction of the upper material is $\boldsymbol{n_1=2.4}$. Find the index of refraction of the lower material if the reflected beam is perpendicular to the refracted beam.



4. Below is the picture "Dance of Life" by Edward Munch.



In the upper part of the picture you can see a bright "light path" (inside the yellow circle) which "goes" on the surface of the water from the low sun. Try to explain this effect