Refraction and total internal reflection

When light is passing from one transparent medium to another, it *bends*, or, as you may also say, it *changes direction*. This is called **refraction**.

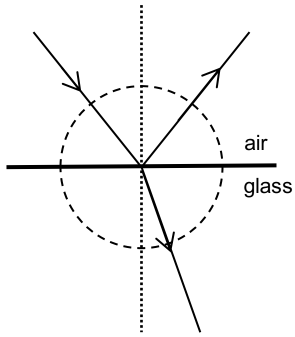
a) Label the following concepts in the picture to the right:

Normal: Line perpendicular to the mirror

Angle of incidence Θ_{air-i} ("Theta-air-i"): Angle between incident ray and normal

Angle of reflection $\Theta_{air-refl}$ ("Theta-air-refl"): Angle between reflected ray and normal

Angle of refraction $\Theta_{glass-refr}$ ("Theta-glass-refr"): Angle between refracted ray and normal

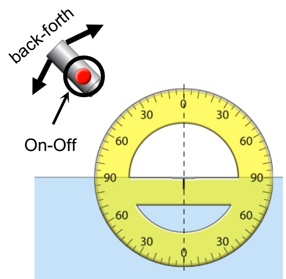


b) Go to

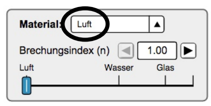
https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

and choose «Intro». A new window opens.

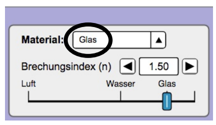
Grab the protractor from the lower left hand corner and place it onto the boundary (see picture).
Switch the light on by pressing the red button.
By moving the lamp back and forth and you can change the angle of incidence.



Make sure that you've chosen «air» for the upper material and «glass» for the lower material.



Pay attention to the fact that at the boundary the incident light ray is split into a refracted and a reflected light ray.



c) «Measurements»

1. Determine for each angle Θ_{air} the corresponding angle Θ_{glass}. Note your results into the table at the back side of this paper.
   Hint: We always measure the angle between the normal and the light ray.

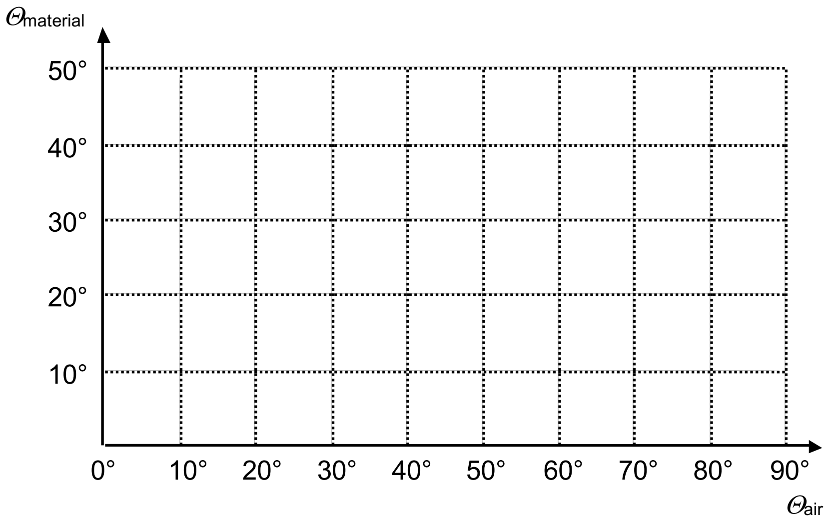
2. Instead of «glass» choose «water» for the material in the lower part. Again, determine for each angle Θ_{air} the corresponding angel Θ_{water}. Note your results into the table at the back side of this paper.

3. Transfer your values into the diagramm. Choose different colours for «water» and «glass».

Table

Θ_{air}	Θ_{glass}	Θ_{water}
0°		
10°		
20°		
30°		
40°		
50°		
60°		
70°		
80°		

Diagram



4. Which one of the angles is larger: Θ_{air} or $\Theta_{material}$?

5. When does the light bend more: If Θ_{air} is great or if it's small?

6. When does the light bend more: If it travels from air into water or from air into glass?

7. Now choose for the upper material "glass" and for the lower material "air". Start at an angle of Θ_{glass} =0 in the glass and increase it slowly. Closely watch the light ray in the air. At a certain angle something happens.
   Information: This angle is called the critical angle.

   What happens? ....

   Note the corresponding the angles: Θ_{glass} = Θ_{air} =

8. Now choose for the upper material "water" and for the lower material "air". Start at an angle of Θ_{water} =0 in the glass and increase it slowly. Closely watch the light ray in the air. At a certain angle something happens.
   Information: This angle is called the critical angle.

   What happens? ....

   Note the corresponding the angles: Θ_{water} = Θ_{air} =

9. Transfer the values from 7. and 8. into the diagram.

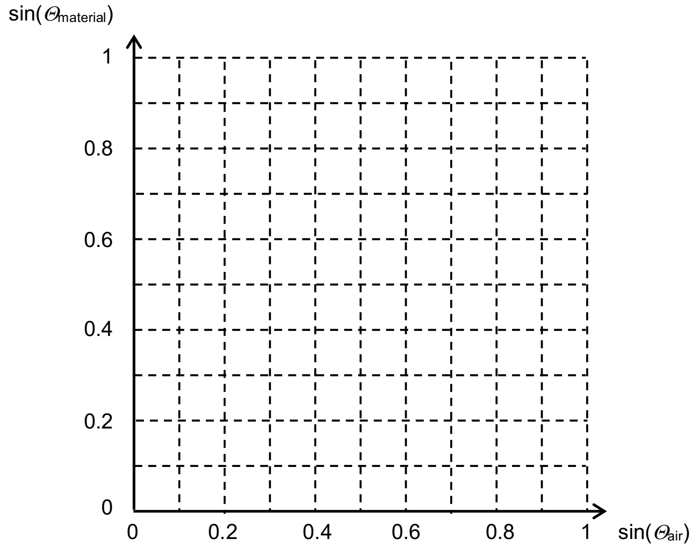
d) Results

Work with the values from the table on page 2. Calulate the sine for every angle and write it into the table. Then, tranfer your values into the diagram.

Table

$\sin(\Theta_{Luft})$	$\sin(\Theta_{glass})$	$\sin(\Theta_{water})$
0		
0.17		
0.98		

Diagram



The graph in the diagram ought to be a straight line. Thus, $\sin(\Theta_{Material})$ und $\sin(\Theta_{air})$ are proportional.

e) Theory

Index of refraction

$$n_{medium} = \frac{c_{vacuum}}{c_{medium}}$$

A medium where light travels fast has a small index of refraction and vice versa.

Law of refraction (also Snell's law)

$$n_1 \cdot \sin(\Theta_1) = n_2 \cdot \sin(\Theta_2)$$

$$c_2 \cdot \sin(\Theta_1) = c_1 \cdot \sin(\Theta_2)$$

where: Θ_1: angle in material 1
Θ_2: angle in material 2
n_1: refractive index of material 1
n_2: refractive index of material 2
c_1: speed of light in material 1
c_2: speed of light in material 2

Total internal reflection

If a light ray coming from a medium of a higher index of refraction (where light travels slower) strikes the boundary to a medium of a lower index of refraction (where light travels faster) the light ray is totally reflected into the material with the higher index of refraction, if the angle of incidence is large enough.
The *critical angle* is the smallest angle of incidence (in the medium where light travels slower) for total internal reflection to occur:

$$\Theta_{critical} = \arcsin\left(\frac{c_1}{c_2}\right) = \arcsin\left(\frac{n_2}{n_1}\right)$$