EXAM PREPARATION: OPTICS

Theory: Know these concepts by heart

a) Vector/scalar
b) Explain the meaning of "inertia" as a property of mass.
c) Explain the meaning of "gravity" as a property of mass.
d) Definition of work
e) Light ray
f) Give examples of luminous and illuminated objects
g) How do we see an object?
h) Diffuse reflection
i) Specular reflection
j) Magnification
k) Refraction
l) Index of refraction
m) Total internal reflection
n) Critical angle for total internal reflection
o) Focal length
p) Describe the shape of a converging lens
q) Describe the shape of a diverging lens
r) How does a light ray continue when exiting a converging lens, if it
    - enters the lens parallel to its principal axis
    - passes through the center of the lens
    - passes through the focal point before entering the lens
s) How does a light ray continue when exiting a diverging lens, if it
    - enters the lens parallel to its principal axis
    - passes through the center of the lens
    - aims at the virtual focal point on the other side of the lens
t) What is a virtual image?
u) What is a real image?

Skills:

- transform equations, insert numbers with units into the equation, calculate results correctly
- round your results to the correct number of significant digits and write your answer with a power of ten in the normalized scientific format
- draw and read scientific graphs
- represent vectors graphically by drawing them as arrows and solve problems by using this method
- Draw a free-body-diagram to show all the forces acting on an object (representing the forces as arrows)
- Determine the resultant of several vectors, as well as the components of a vector, using their graphical representation as arrows
- construct image formation by plane mirrors
- construct image formation by a pinhole camera
- Know the rules for ray tracing for thin lenses
- Construct the formation of images by thin lenses using the technique of ray tracing

Formulae: A formula sheet will be handed out. Please find the formula sheet on massenpunkt.ch.

Physical quantities: Know these physical quantities by heart (symbol and unit)

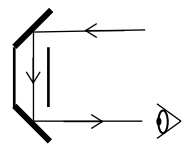
	symbol	unit		symbol	unit
time			distance, displacement		
velocity			acceleration		
mass			force		
work			energy		
power			period		
frequency			angular velocity		
image height			object height		
image distance			object distance		
magnification			focal length		
speed of light			index of refraction		

Exercises:

An algebraic solution and all values used in calculations are required to get the full mark.

All work sheets, and assignment sheets A25 – A28

Additional problems

1. 

You are watching the image of a person who is standing behind you, the light rays being reflected twice, by two mirrors (see picture).
Is the image of the person upright or upside down? Draw a sketch and give reasons for you answer.

2. A mirror shall be placed horizontally onto the table in such a way that the light from the lamp L reflecting off it fully illuminates the area A.
Determine the size and the location of the mirror by construction.

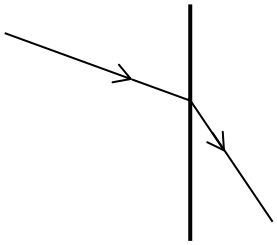
3. A tree of 0.0028600 km height is located in front of the opening of a pinhole camera of 338.0 mm length. The image at the back of the camera is 0.0569 m high. The distance between the tree and the opening of the camera (in cm) is to be calculated.

a) Place a dot above the digits which are significant. How many significant digits do the given values have? How many significant figures does your final answer require?
b) Calculate distance between the tree and the opening of the camera (in cm).
c) Write your result (in cm) in the normalized scientific notation with a power of ten and round it to the correct number of significant figures.

4. Calculate the absolute index of refraction for PMMA (plexiglass).

5. Calculate the speed of light in methanol.

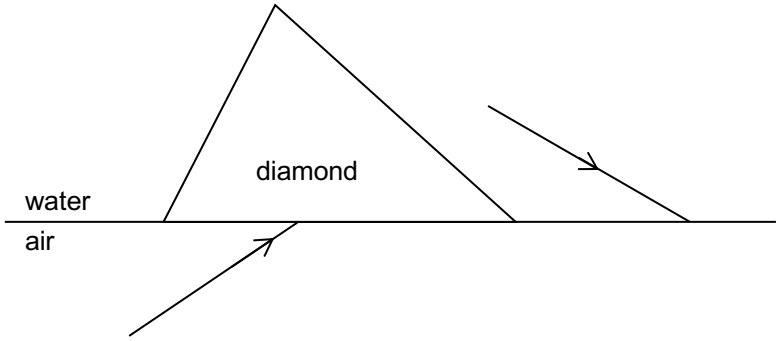
6. A light ray that is incident on the surface between air and another material is reflected and refracted.



a) Draw the reflected light ray.
b) Draw the normal, the angles of incidence, of reflection and of refraction. Measure the angles and write their values in the picture.
c) Which side of the boundary is air?
d) What is the other material?

7. A light ray strikes the boundary between ethanol and ice.
a) In which case is it possible for total internal reflection to occur? If the light ray is travelling in ethanol or in ice?
b) Calculate the critical angle.

8. The sketch shows two light rays striking two different boundaries. How do they continue? Draw the paths of the light rays as they travel on, until there is no further boundary to be met.



9. Construct to scale (no calculation!): A candle of 3.0 cm height is located at 12 cm from the center plane of a converging lens of focal length 3.0 cm.
a) At what distance from the lens (and on which side) is the image formed?
b) How tall is the image?
c) Is it a real or a virtual image?

10. Construct to scale (no calculation!): A candle of 1.0 cm height is located at 2.0 cm from the center plane of a converging lens of focal length 3.0 cm.
d) At what distance from the lens (and on which side) is the image formed?
e) How tall is the image?
f) Is it a real or a virtual image?

11. Construct to scale (no calculation!): A candle of 2.0 cm height is located at 12 cm from the center plane of a diverging lens of focal length –9.0 cm.
g) At what distance from the lens (and on which side) is the image formed?
h) How tall is the image?
i) Is it a real or a virtual image?

12. Construct to scale (no calculation!): The distance between an object (h_o = 3.0 cm) and its real image (h_i = 2.5 cm) formed by a converging lens is 8.0 cm.
a) What is the distance between the lens and the object?
b) What is the focal length of the lens?

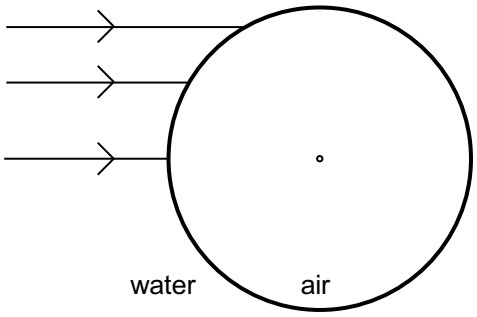
13. Of two identically shaped lenses one is made of glass and the other one of diamond.
a) Does the material of a lens have an influence on its focal length? Give reasons for your anwser.
b) If yes: Which lens has a larger focal length? Give reasons for your anwser.

14. You're taking a picture of a flower of 5.2 cm height, from a distance of 1.10 m. The clear image on the film is 2.7 mm high.
a) What is the focal length of the camera's lens?
b) From what distance would you have to take a photo for an image height of 4.0 mm?

15. A woman who is 1.66 m tall is standing at a distance of 6.47 m from the lens of a camera (f = 55 mm).
What is the image height?

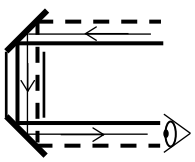
16. *difficult* The virtual image formed by a converging lens is 1.5 times larger than the object. Determine the ratios of image distance to object distance to focal length as accurately as possible (by construction and/or calculation)

17. *difficult* Three light rays travelling in water are incident on a spherical bubble of air in the water.
Draw the paths of the light rays as they travel on, until they exit the air bubble and enter the water. Write the values of the angles in the picture.

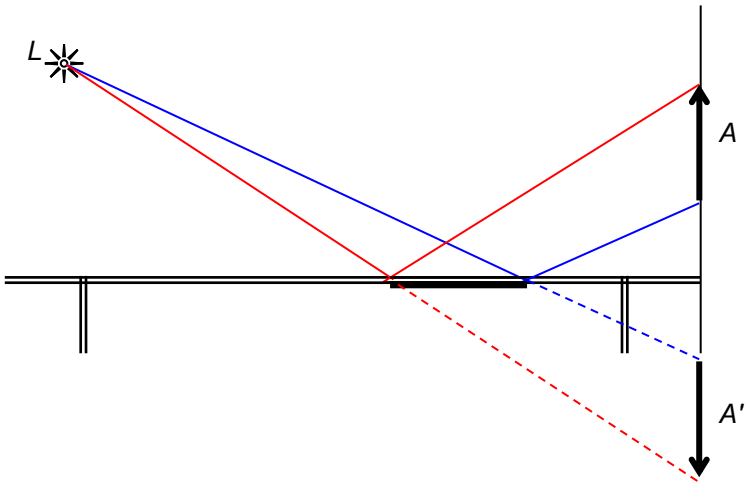


Solutions:

1. Upside down:



2. Draw the mirror image of the area A on the other side of the table. Drawing two straight lines from the lamp to the top and the bottom of the mirror image will show you the location and the size of the mirror.



3. a) h_o = 0.00$\dot{2}\dot{8}\dot{6}\dot{0}\dot{0}$ km (5 significant figures); d_i = $\dot{3}\dot{3}\dot{8}.\dot{0}$ mm (4 significant figures); h_i = 0.0$\dot{5}\dot{6}\dot{9}$ m (3 significant figures); result: 3 figures

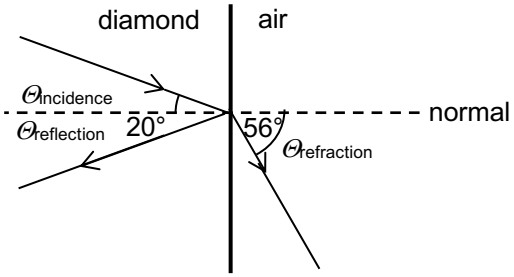
b) $d_o = \dfrac{h_o \cdot d_i}{h_i} = \dfrac{286.00\text{ cm} \cdot 33.80\text{ cm}}{5.69\text{ cm}} = 1698.9104\text{ cm}$

c) $d_o = \underline{\underline{1.70 \cdot 10^3\text{ cm}}}$

4. $n_{plexiglass} = \dfrac{c_{vacuum}}{c_{plexiglass}} = \dfrac{299'792\ \frac{km}{s}}{201'000\ \frac{km}{s}} = \underline{\underline{1.49}}$

5. $c_{methanol} = \dfrac{c_{vacuum}}{n_{methanol}} = \dfrac{299'792\ \frac{km}{s}}{1.33} = 225'408\ \frac{km}{s} = \underline{\underline{2.25 \cdot 10^8\ \frac{m}{s}}}$

6. a) and b)



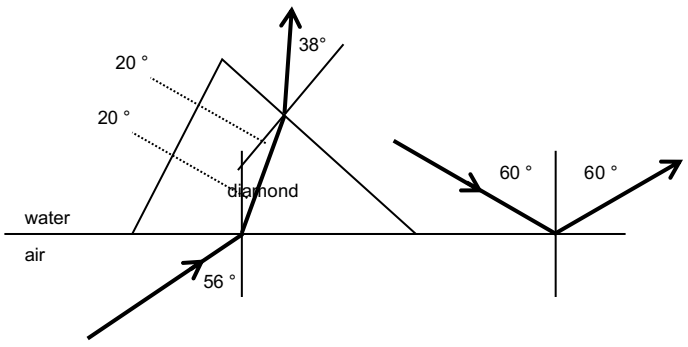
c) the angle in air is always larger than the angle in a certain material. Therefore, air is to the right and $n_{right} = n_{air} = n_{vacuum} = 1$.

d) $n_{left} = n_{right} \cdot \left(\dfrac{\sin(\Theta_{right})}{\sin(\Theta_{left})}\right) = 1 \cdot \left(\dfrac{\sin(56\ °)}{\sin(20°)}\right) = \underline{\underline{2.42}}$ Diamond

7. a) $c_{ethanol} = \dfrac{c_{vacuum}}{n_{ethanol}} = \dfrac{299'792\ \frac{km}{s}}{1.36} = 220'435\ \frac{km}{s} = 2.20 \cdot 10^8\ \frac{m}{s}$, while $c_{ice} = 1.90 \cdot 10^8\ \frac{m}{s}$
the speed of light is less in ice, therefore total internal reflection can only occur if light is travelling in ice

b) $\Theta_{critical} = \arcsin\left(\dfrac{c_{slower}}{c_{faster}}\right) = \arcsin\left(\dfrac{1.90 \cdot 10^8\ \frac{m}{s}}{2.20 \cdot 10^8\ \frac{m}{s}}\right) = \underline{\underline{59.7\ °}}$

8.



The light ray on the left passes first from air into diamond:

$\Theta_{diamond} = \arcsin\left(\dfrac{n_{air}}{n_{diamond}} \cdot \sin(\Theta_{air})\right) = \arcsin\left(\dfrac{1}{2.42} \cdot \sin(56°)\right) = \underline{\underline{20\ °}}$

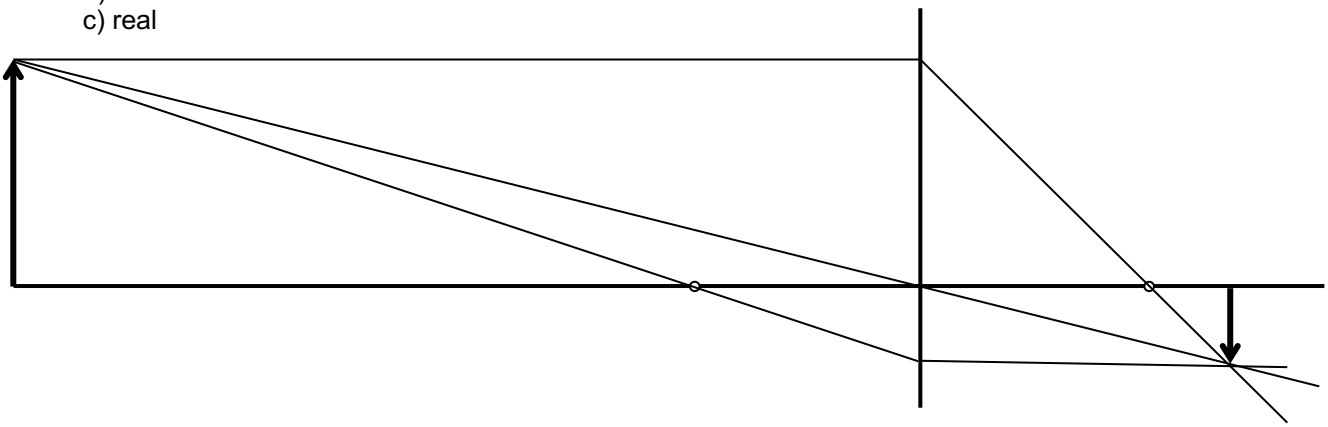
Then it passes from diamond into water:

$\Theta_{water} = \arcsin\left(\dfrac{n_{diamond}}{n_{water}} \cdot \sin(\Theta_{diamond})\right) = \arcsin\left(\dfrac{2.42}{1.33} \cdot \sin(20°)\right) = \underline{\underline{38\ °}}$

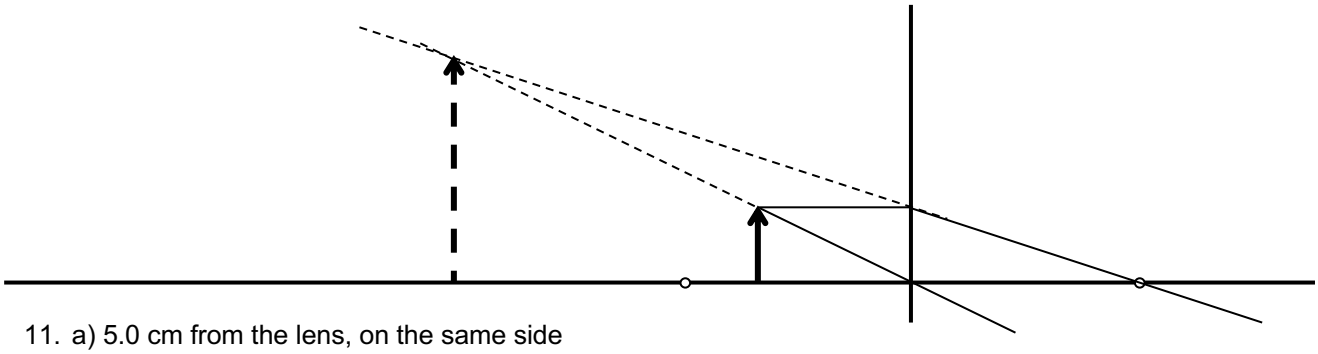
The light ray on the right is reflected totally off the surface because the angle of incidence is larger than the critical angle:

$\Theta_{critical} = \arcsin\left(\dfrac{n_{lower}}{n_{higher}}\right) = \arcsin\left(\dfrac{1}{1.33}\right) = 49°$

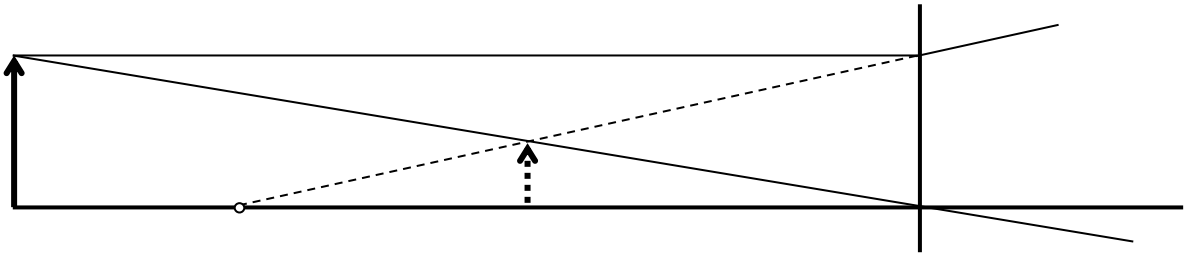
9. a) 4.0 cm from the lens, on the other side
   b) 1.0 cm
   c) real



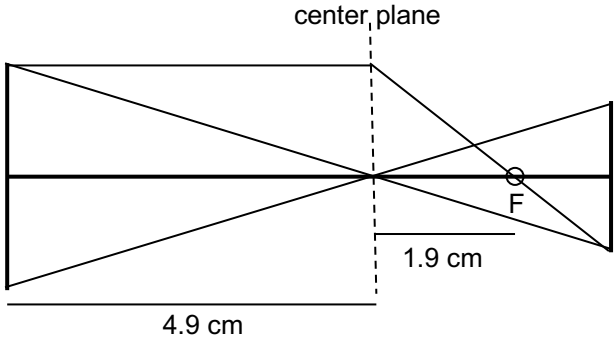
10. a) 6.0 cm from the lens, on the same side
    b) 6.0 cm
    c) virtual



11. a) 5.0 cm from the lens, on the same side
    b) 0.83 cm
    c) virtual



12.



13. a) Yes: If the light is bent more because the refractive index of a medium is larger, then the focal length will be shorter.
    b) The diamond lens: A higher index of refraction results in a shorter focal length.

14. a) $d_i = \dfrac{h_i \cdot d_o}{h_o} = \dfrac{0.27\text{ cm} \cdot 110\text{ cm}}{5.2\text{ cm}} = 5.71\text{ cm}$

$f = \dfrac{d_o \cdot d_i}{d_o + d_i} = \dfrac{110\text{ cm} \cdot 5.71\text{ cm}}{110\text{ cm} + 5.71\text{ cm}} = \underline{5.43\text{ cm}}$

b) $\dfrac{h_i}{h_o} = \dfrac{4.0\text{ mm}}{52\text{ mm}} = \dfrac{1}{13} = \dfrac{d_i}{d_o}$ $\qquad d_o = 13 \cdot d_i$

$f = \dfrac{d_o \cdot d_i}{d_o + d_i} = \dfrac{13 \cdot d_i \cdot d_i}{13 \cdot d_i + d_i} = \dfrac{13 \cdot d_i \cdot d_i}{14 \cdot d_i} = \dfrac{13 \cdot d_i}{14}$ $\qquad d_i = \dfrac{14 \cdot f}{13} = \dfrac{14 \cdot 5.43\text{ cm}}{13} = 5.85\text{ cm}$

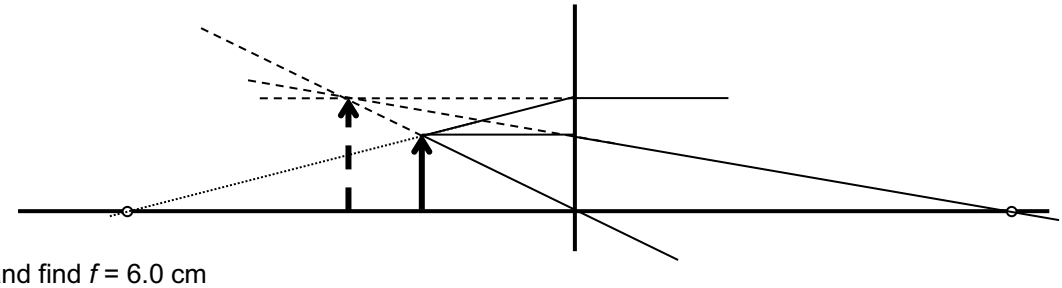
$d_o = 13 \cdot d_i = 13 \cdot 5.85\text{ cm} = \underline{76\text{ cm}}$

15. $d_i = \dfrac{d_o \cdot f}{d_o - f} = \dfrac{647\text{ cm} \cdot 5.50\text{ cm}}{647\text{ cm} - 5.50\text{ cm}} = 5.54\text{ cm}$

$h_i = \dfrac{d_i \cdot h_o}{d_o} = \dfrac{5.54\text{ cm} \cdot 166\text{ cm}}{647\text{ cm}} = \underline{1.42\text{ cm}}$

16. Construction: The magnification is 1.5, therefore $m = \dfrac{h_i}{h_o} = \dfrac{d_i}{d_o} = 1.5$ $\qquad d_i = 1.5 \cdot d_o$

We use $h_i = 1.5$ cm, $h_o = 1.0$ cm, $d_i = 3.0$ cm, $d_o = 2.0$ cm



and find $f = 6.0$ cm

hence $\underline{d_i : d_o : f = 3 : 2 : 6}$

Calculation: The magnification is 1.5, therefore $m = \dfrac{h_i}{h_o} = \dfrac{d_i}{d_o} = 1.5 = \dfrac{3}{2}$ $\qquad d_i = 1.5 \cdot d_o$

For a virtual image d_i is negative, therefore $d_i = -1.5 \cdot d_o$ or $2 \cdot d_i = -3 \cdot d_o$

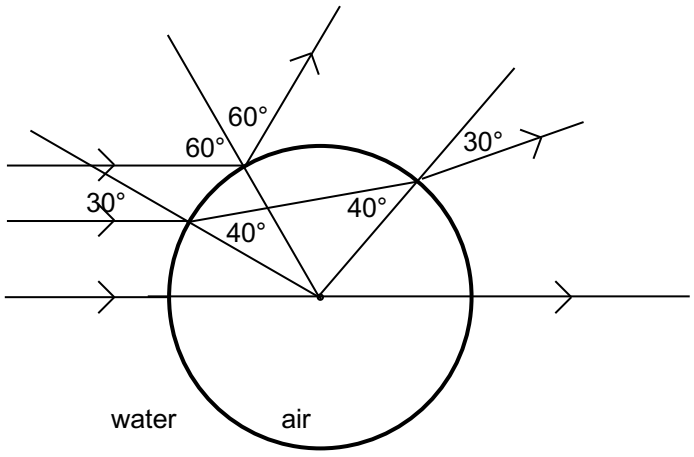
Using the thin lens equation we get

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{d_o} + \frac{1}{-1.5 \cdot d_o} = \frac{1.5}{1.5 \cdot d_o} - \frac{1}{1.5 \cdot d_o} = \frac{0.5}{1.5 \cdot d_o} = \frac{1}{3 \cdot d_o}$$

$f = 3 \cdot d_o = 2 \cdot d_i$ $\qquad$ with $\dfrac{d_i}{f} = \dfrac{1}{2} = \dfrac{3}{6}$ $\qquad$ and $\dfrac{d_o}{f} = \dfrac{1}{3} = \dfrac{2}{6}$ $\qquad$ and $\dfrac{d_i}{d_o} = \dfrac{3}{2}$

we get $\underline{d_i : d_o : f = 3 : 2 : 6}$

17.



Bottom light ray: continues in a straight line, is not refracted as the angle between the normal and the light ray is 0

Middle light ray: $\Theta_{air} = \arcsin\left(\dfrac{n_{water}}{n_{air}} \cdot \sin(\Theta_{water})\right) = \arcsin\left(\dfrac{1.33}{1} \cdot \sin(30°)\right) = \underline{40\ °}$

top light ray: The angle of incidence is greater than the critical angle -> total internal refraction