TOPIC 8.A. Geometric Optics

Optics is the branch of physics that studies optical radiation, its propagation processes and phenomena that are observed in the interaction of light with matter.

Exercise 8.1a. Supplement the definitions.

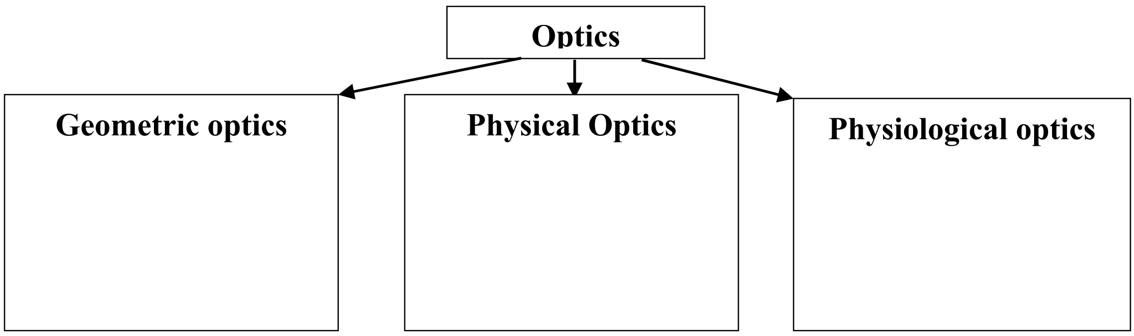
Optical radiation is ____

____

Optical radiation includes the following types of radiation:

____

Exercise 8.2a. Fill out the scheme:



Light ray is ____

____

An optically homogeneous medium is ________________________________

____

Fermat's principle. A ray of light always spreads in the space between two points along the path, for which it needs the shortest time, in comparison with another path between the same points.

Absolute refractive index*:*

$$n = \frac{c}{v}, \tag{8.1a}$$

where c is the light speed in vacuum, v is the light speed in medium.

The time t_0 of the light path l in the medium with the absolute refractive index n is equal to:

$$t_0 = \frac{s}{c} = \frac{nl}{c} = \frac{cl}{\upsilon c} = \frac{l}{\upsilon} \tag{8.2a}$$

Basic Laws of Geometric Optics

1. In a homogeneous medium, the light propagates rectilinearly.
2. The angle of incidence i is equal to the angle of reflection i'. The incident and reflected rays lie in one plane (*the law of reflection*).
3. The ray refracted always lies in one plane with the incident and reflected.

The Snell`s law of refraction:

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1} = n_{21}, \tag{8.3a}$$

where n_{21} – the relative refractive index of the second medium with respect to the first one.
If $n_1 < n_2$ and $i = \pi/2$ the beam is refracted at an angle $r_{cr} < \pi/2$ – *critical angle of refraction*:

$$\sin r_{cr} = \frac{n_1}{n_2}. \tag{8.4a}$$

If $n_1 > n_2$, then for some $i = i_{cr}$ and $r = \pi/2$ light passes into the second medium, this phenomenon is called *total internal reflection:*

$$\sin i_{cr} = \frac{n_2}{n_1}, \tag{8.5a}$$

where i_{cr} is the limiting angle of incidence or the maximum *angle of total internal reflection*.

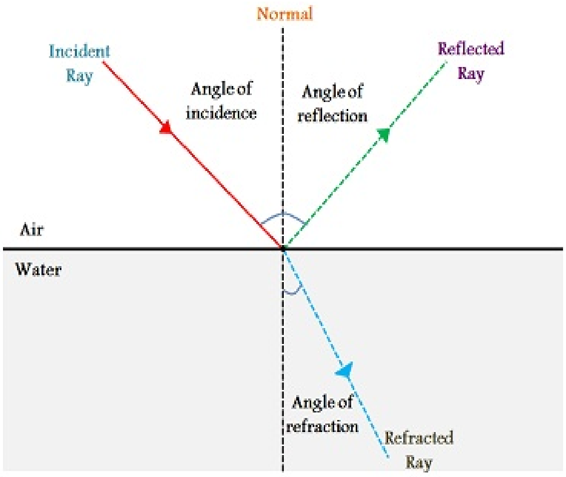


Fig. 8.1a. Difference between reflection and refraction

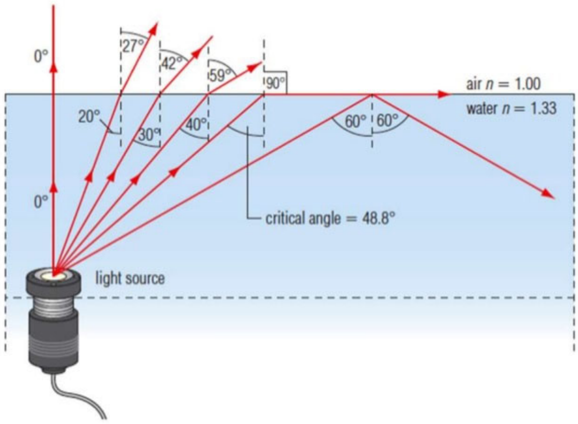


Fig. 8.2a. Total internal reflection

Thin Lenses

Exercise 8.3a. Supplement the definitions.
Lens is ____

____

The lens main optical axis is ____

____

The optical lens center is ____

____

The convergent (convex) lens is ____

____

The divergent (concave) lens is ____

____

The principal lens focus is ____

____

The focal length is ____

____

The lens power is ____

____

The *thin lens formula*:

$$D = \frac{1}{a_1} + \frac{1}{a_2} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{1}{f}, \tag{8.6a}$$

where D is ____

a_1 is ____

a_2 is ____

n is ____

R_1 is ____

R_2 is ____

f is ____

Real image is ____

____

Virtual image is ____

____

Linear magnification is ____

____

Linear magnification of the lens is:

(8.7a)

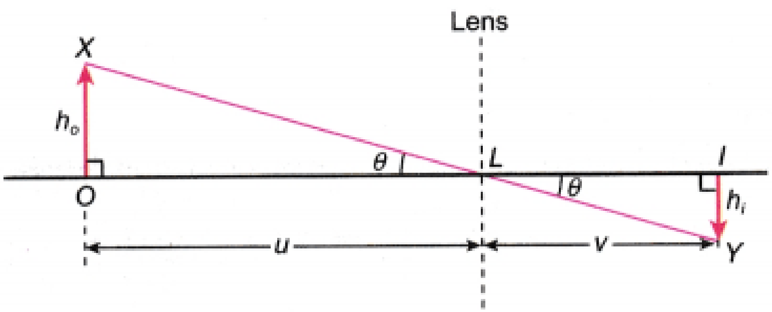


Fig. 8.3a. Linear magnification of the lens

Loupe is ____

The microscope linear magnification is:

$$G_M = \frac{\Delta d_0}{f_1 f_2}, \tag{8.8a}$$

where Δ is ____

d_0 is ____

f_1 is ____

f_2 is ____

The threshold of the microscope magnification:

(8.9a)

λ is ____

n is ____

u is ____

The microscope resolution ability:

(8.10a)

Example of problem solution

The collecting lens gives on the screen a clear image of the object, which is 2 times larger than this object. The distance from the object to the lens at l = 6 cm exceeds its focal length. Find the distance f from the lens to the screen.

Data:

G=2

$d=F+l$

---

f-?

Solution:

Let`s use the well-known formula: $\frac{1}{F}=\frac{1}{f}+\frac{1}{d}$, so as magnification of the image $G=\frac{f}{d}$ Let substitute the conditions of the problem. So $d=\frac{f}{G}$, a $F=d-l=\frac{f}{G}-l=\frac{f-Gl}{G}$.

Thus, the lens formula will have the form:

$$\frac{G}{f-Gl}=\frac{G}{f}+\frac{1}{f}=\frac{G+1}{f}\Rightarrow Gf=Gf-G^2l+f-Gl\Rightarrow$$

$$f=G(Gl+l)=Gl(G+1)\Rightarrow$$

$$f=2\times 6(2+1)=36\,cm.$$

Answer: The distance from the lens of the dozen screen is 36 cm.

Problem 8.4a. Determine the refractive index and the speed of light in the media, if it is known that at the incident angle is 45 ° and refraction angle is 30 °.

Data:

Solution:

Answer: ____

Problem 8.5a. A ray of light comes out of the ethyl alcohol into the air. Ultimate angle of ray incidence $i_{lim}=47.24°$. Calculate the speed of light in alcohol.

Data:

Solution:

Answer: ____

Problem 8.6a. The focal length of microscope objective is 0.1 cm, focal length of microscope eyepiece is 3 cm. The distance between the objective and eyepiece (tube length) is 20 cm. Determine the magnification.

Data:	***Solution:***

Answer: ____

Control questions

1. The light propagation speed in the matter.
2. What lenses are called thin?
3. Convex and concave lenses.
4. Dependence of the image magnitude on the distance to the object.
5. Propagation of the light in the optical fibers.

Individual assignments

1. Determine the camphor refraction limiting angle, if the beam incident at an angle of 40° is refracted in it at an angle of 24°.
2. The microscope with a sevenfold eyepiece has a total magnification of 140. Find a total magnification if the tenfold lens will be applied?
3. Calculate the objective focal length of microscope with total magnification of 500, if the eyepiece focal length is 4 cm, and the tube length is 20 cm.
4. Calculate the angle that the ray deviates from the original direction, if the one falls from the air at an angle of 45° to the surface of the water (n = 1.33)? On the glass surface (n = 1.51)? On the surface of a diamond (n = 2.4)?
5. The magnifier being a biconvex lens with the same radii of the surface curvature R = 25 mm is made from glass with the refractive index n = 1.5. Find the linear magnification G of the magnifier a) for a normal eye with the distance of the best vision d_0 = 25 cm; b) for a short-sighted eye with d_0 = 10 cm; c) for a far-sighted eye with d_0 = 10 cm.

TOPIC 8.B. The Main Phenomena of Wave Optics

The Light Dispersion

Exercise 8.1b. Define the following terms:

Wave optics is ____

____

Dispersion is ____

____

$$D = \frac{dn}{d\lambda} \tag{8.1b}$$

Coherent waves are ____

____

Resonance is ____

____

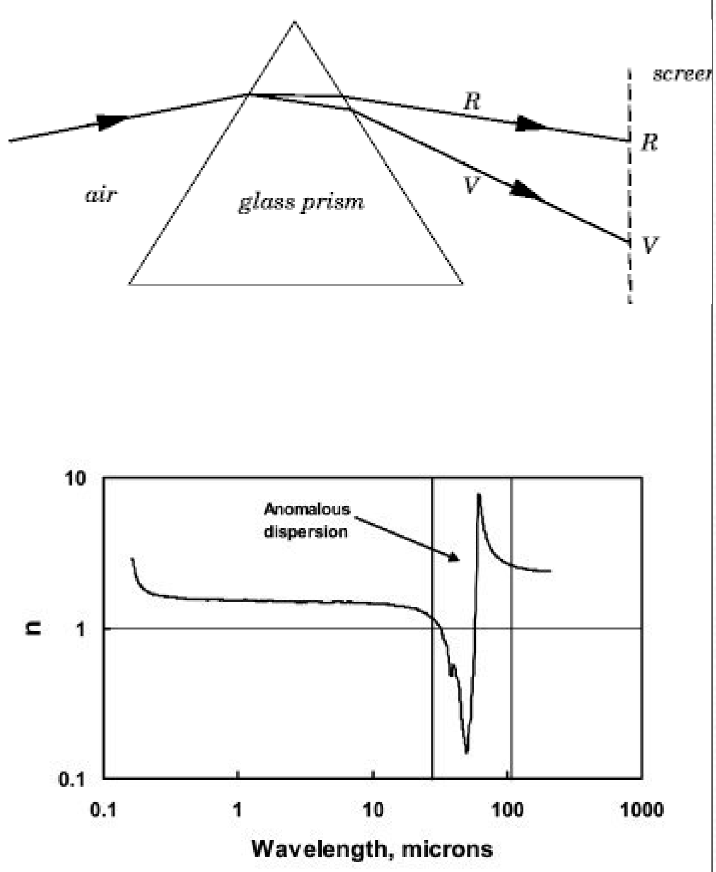


Fig. 8.1b. Normal and anomalous dispersion

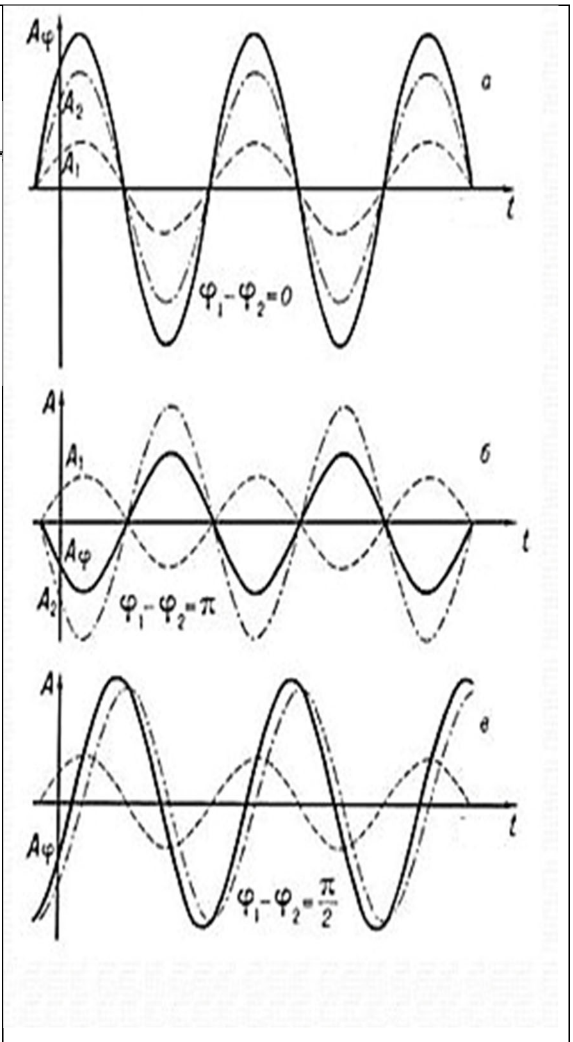


Fig. 8.2b. Coherent waves and resonance

Problem 8.2b. Sodium yellow line matches the wavelength 589 nm in the air. Determine the wavelength of this light in cedar oil, which refractive index is 1.52.

Data:	***Solution:***

Answer: ____

The Light Interference and Diffraction

Exercise 8.3b. Define the following terms:

Interference is ____

____

____

____

____

During propagation waves in media with different refractive indices n_1 and n_2:

$$\Delta\varphi = \varphi_2 - \varphi_1 = (\omega t - \frac{\omega x_1}{\upsilon_1}) - (\omega t - \frac{\omega x_2}{\upsilon_2}) = \frac{2\pi}{\lambda_0}(x_1 n_1 - x_2 n_2) = \frac{2\pi}{\lambda}\Delta r. \qquad (8.2b)$$

where λ_0 is ____

x_1 is ____

x_2 is____

t is____

Δr is ____

During considering interference in ***reflected*** light in a medium with a refractive index n, the optical path difference will be:

$$\Delta r = 2d\sqrt{n^2 - \sin^2 i} - \frac{\lambda}{2}. \qquad (8.3b)$$

Condition for interference max: $2d\sqrt{n^2 - \sin^2 i} = (2m+1)\frac{\lambda}{2}$.

Condition for interference min: $2d\sqrt{n^2 - \sin^2 i} = 2m\frac{\lambda}{2}$.

In case of ***transmitted*** light the optical path difference: $\Delta r = 2d\sqrt{n^2 - \sin^2 i}$. (8.4b)

Condition for interference max: $2d\sqrt{n^2 - \sin^2 i} = 2m\frac{\lambda}{2}$.

Condition for interference min: $2d\sqrt{n^2 - \sin^2 i} = (2m+1)\frac{\lambda}{2}$.

Diffraction is ____

____

The diffraction grating constant: $c = a+b$, *min*: $a\sin\alpha$ = ________________________________

max: $a\sin\alpha$ = ________________________________

a is ____

b is ____,

c is ____.

α is ____

The eye resolution is equal to z_0 = 70 µm (at the distance d_0 = 25 cm).

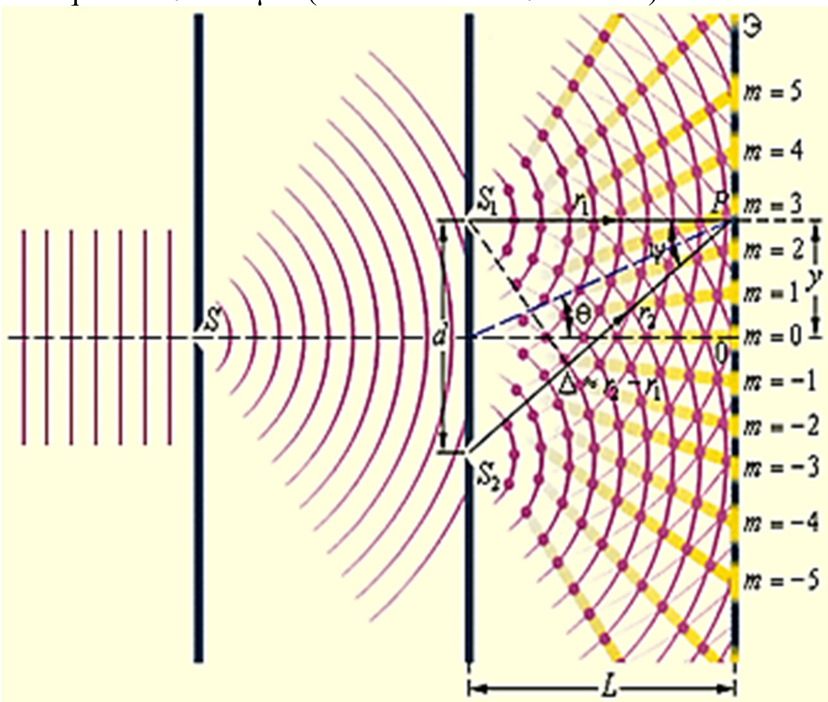


Fig. 8.3b. Maximum and Minimum Conditions

Problem 8.4b. Determine the threshold of resolution of dry and immersion microscope objective (n = 1.55) lens with an aperture angle u = 70 °. Accept that the wavelength is λ = 555 µm.

Data:

Solution:

Answer: ____

The Light Polarization

Polarimetry is optical method for the study of optically active substances, which is based on measurement of the angle of rotation of polarization plane of the plane-polarized light that passed through the investigated substance. The method is widely used to determine the concentration of optically active substances in the solution, and to assessment of their purity. Specific rotation angle of the polarization plane is a constant that characterized the substance and it can be used for identification of the substance, including to determine the drugs.

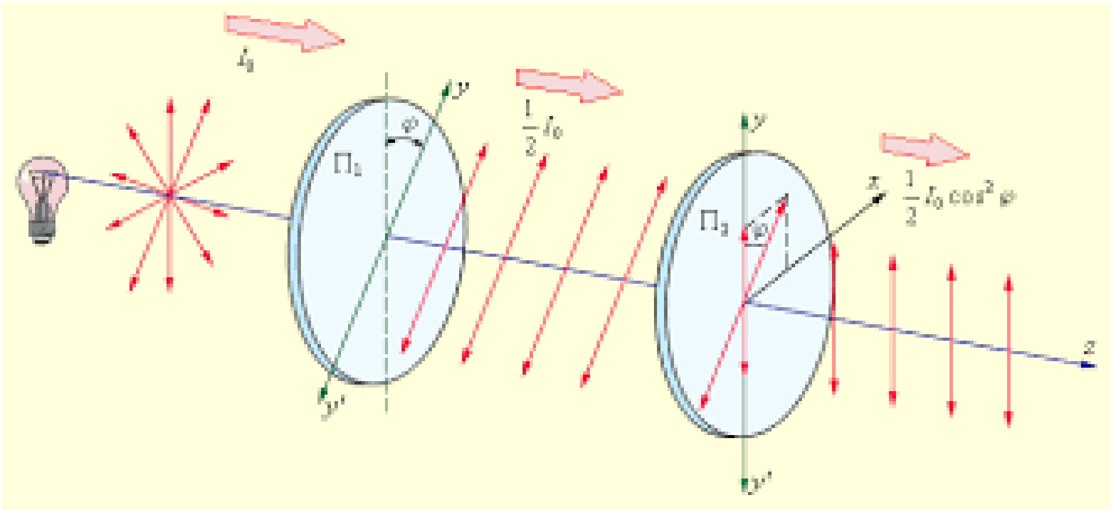


Fig. 8.4b. The light polarization

Exercise 8.5b. Define the following terms and write down the answer:

The light polarization is ____

____

Optically active substances are ____

____

The Malus`s law is described by formula: $I_2 = I_1 \cos^2 \alpha = \frac{1}{2} I_{nat} \cos^2 \alpha$, (8.5b)

α is ____

I_{nat} is ____

I_2 is ____

I_1 is ____

The angle of optical rotation and its relationship with the concentration of optically active substance in the solution:

α = (8.6b)

α is____

[α_0] is____

C is ____

l is ____

Partially polarized light can be obtained from natural one using______________________

____

____

Problem 8.6b. Find the angle of rotation, the polarization plane of the diabetic patient urine if the concentration of sugar in it $C = 0.05$ g·cm^{-3}. The length of the tube $l = 20$ cm, specific rotation angle of sugar at the given wavelength [α_0] = 6.67 deg·cm^2·g^{-1}.

Data:	***Solution:***

Answer: ____

Control questions

1. Write down the resultant wave amplitude of two coherent plane waves.
2. What is the difference in maximum and minimum condition for incident and reflected light?
3. What is the resolving power?
4. List the sources of polarized light.
5. Formulate the Malus`s law.
6. Application of the polarimetry method in pharmacy.

Individual assignments

1. The optical path difference Δr of two interfering waves is equal to **(a)** 0; **(b)** 0.25 λ; **(c)** 0.5 λ; **(d)** 0.75 λ; **(e)** λ. Find the corresponding difference phase $\Delta\varphi$.
2. The optical path difference of two interfering waves is $\Delta r = 2$ μm. Find all wavelengths of the visible range (from 760 nm to 380 nm), for which maximum **(a)** and minimum **(b)** of interference are observed.
3. The white light falls on a soap film ($n = 1.33$) of the thickness $d = 0.1$ μm at the angle of $i = 30°$. What colour does the film seem to be coloured at observation in the incident light?
4. The period of a diffraction grating is $c = 10$ μm. What is the least width l of the grating where the doublet of the yellow line of mercury ($\lambda_1 = 576.96$ nm and $\lambda_2 = 579.06$ nm) can be seen separately in the spectrum of the first order?
5. A saccharimeter is used for determination of the sugar concentration in urine of a diabetic patient. According to readings the angle α of the optical rotation is $\alpha = 7°$. Find the sugar concentration c if it is known that the length of a tube with the urine is $l = 20$ cm; the rotational constant of sugar at the given wavelength and temperature is $[\alpha_0] = 6.67$ deg cm^2 g^{-1}.
6. A sugar solution ($c_1 = 10\%$) rotates the plane of polarization through the angle of $\alpha_1 = 30°$. Find the concentration c_2 of sugar in other solution, if under the same conditions the plane of polarization is rotated through the angle of $\alpha_1 = 20°$.
7. A quartz plate of thickness $l_1 = 0.3$ mm cut out perpendicularly to its optic axis rotates the plane of polarization of the light through the angle $\alpha_1 = 7°57'$. Find the angle α_2 of rotation the polarization plane of a quartz plate of the thickness $l_2 = 2.5$ mm.