TOPIC 9.A. The Optical Mechanism of Vision

Optical System of the Human Eye

The human eye is an optical device. The basic principles of the functioning of its light-conducting system are described by the geometrical optics laws. The mechanism of visual perception generation is a photobiological process.

Problem 9.1a. Indicate the main elements of the eye optical system.

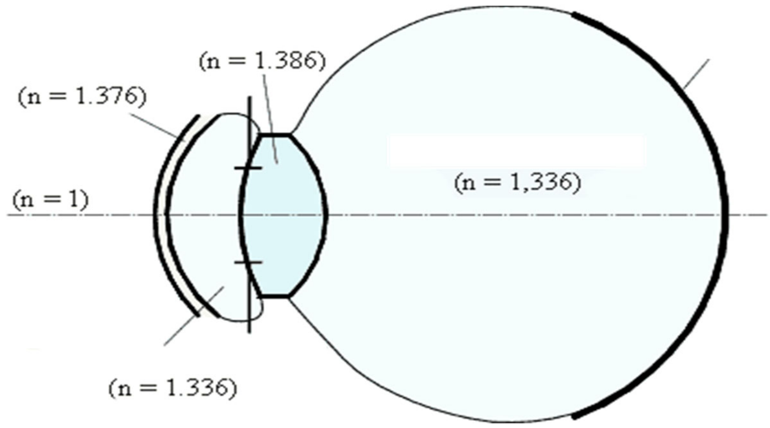

Fig. 9.1a. The individual eye structures refractive indices

For a spherical surface, the *focal lengths* are calculated from the formula:

$$f = \frac{n_2 R}{n_2 - n_1}, \quad (9.1a)$$

and *the optical power* of a spherical surface is:

$$D = \frac{1}{f} = \frac{n_2 - n_1}{n_2 R}, \quad (9.2a)$$

where n_1 is ____

n_2 is ____

R is ____

The optical power of a lens with two refractive surfaces is*:*

$$D = D_1 + D_2 - \frac{d}{n} D_1 D_2, \quad (9.3a)$$

where D_1 is ____

D_2 is ____

d is ____

n is ____

The linear magnification of the eye optical system:

$$G = \frac{a_2}{a_1} = +1, \quad (9.4a)$$

where a_1 is ____

a_2 is ____

The image size on the retina is calculated by the formula: $h = \frac{lH}{L}$, (9.5a)

H is ____

l is ____

L is ____

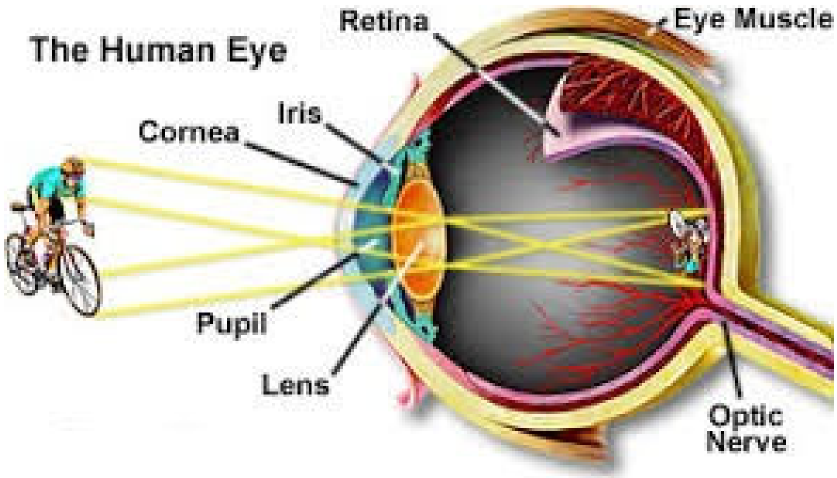

Fig. 9.2a. The principle of object image constructing on the eye retina

Exercise 9.2a. Supplement the definitions**.**

Angular resolving power is ____

____

Linear resolving power is ____

____

Accommodation is____

____

The best vision distance is ____

____

Astigmatism is ____

____

Spherical aberration is ____

____

Chromatic aberration is ____

____

Myopia is ____

____

Hyperopia is ____

____

Nodal points are ____

____

Exercise 9.3a. Determine on the Fig. 9.3a., which of the pictures corresponds to certain eye clinical refraction types.

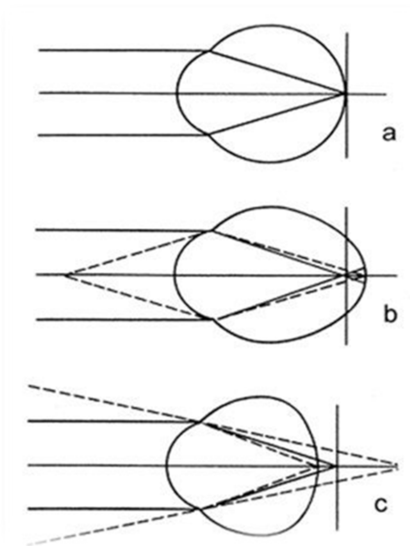

Fig. 9.3a. The rays path in the case of different clinical refraction types: emmetropia (normal vision), hyperopia, myopia

Problem 9.4a. The short-sighted person eyes without glasses are accommodated in the range from a_1=16 to a_2=44 cm. Define the eye optical power change with accommodation. At what minimum distance will a person able to read in glasses selected correctly, if eyes and glasses are lenses placed closely?

Data: *Solution:*

***Answer*:**

Problem 9.5a. Calculate the resolution ability of the human eye at the distance L=15 m from the object. The average distance between the cones is h_{min}=5 µm, the distance between the coincident nodal point and the retina is equal to l=15 mm.

Data: *Solution:*

***Answer*:**

Molecular Mechanism of Vision

Exercise 9.6a. Supplement the definitions.

Scotopic vision is ____

____

____

Photopia is ____

____

____

Visual pigments are ____

____

____

Absolute sensitivity threshold is ____

____

____

Differential threshold is ____

____

____

The relationship between the sensation intensity ψ and the light intensity is described with the *Weber-Fechner law*:

$$\psi = k \ln \frac{I}{I_0}, \quad (9.6a)$$

where ψ is ____

k is ____

I is ____

I_0 is ____

Rhodopsin is ____

____

Iodopsin is ____

____

Early receptor potential is ____

____

Late receptor potential is ____

____

Color blindness is ____

____

Exercise 9.7a. Choose and underline the correct answer.

1. **The reason of the spherical aberration existence is:**

   a) dispersion,

   b) cataract,

c) retinal detachment,

d) difference in the focal length of the cornea central part and lens compared with the focal length of their peripheral part.

2. **Under the condition of astigmatism:**

a) the distance of the best vision is 25 cm,

b) the cornea curvature radii are different in two mutually perpendicular directions,

c) the distance of the best vision is greater than 25 cm,

d) the distance of the best vision is less than 25 cm.

Control questions

1. The human eye optic system.
2. Give examples of diseases associated with a) human eye optic system; b) molecular mechanism of vision.
3. .What kind of image we have on the retina?
4. What is the best vision distance?
5. What is the accommodation?
6. Genetic and non-genetic eye optic system pathologies.

Individual assignments

1. How many times is the object image on the retina smaller than the object`s one, located on 30 m from the observer? The focal length of the eye optical system is taken to be 1.5 cm.
2. At what distance is the short-sighted person able to read a small print without glasses, if he uses glasses with optical power 4 D?
3. Sarah is short-sighted. Without glasses, her far point is 50 cm. If the distance between her eye lens and her retina is 20 mm, find the power of the lens needed to correct her vision.
4. James is long-sighted. Without glasses, his near point is 50 cm. If the distance between his eye lens and his retina is 20 mm, find the power of the lens needed to bring his near point to 25 cm.
5. How does a person estimate the size H of an object being at the distance of $L = 3$ m from his eye if the size of the image of this object on the retina is $h = 400$ μm. The distance between the coincident nodal point and the retina is $l = 17.5$ mm.
6. The absolute threshold of sensitivity of the eye at a wavelength of $\lambda = 500$ nm is approximately $E = 2.5\times10^{-17}$ J on the cornea surface. Calculate the number of the light quanta corresponding to this energy.
7. The minimal light intensity perceived by the eye at the pupil radius of $r = 1$ mm is equal to $I_{\min} = 10^{-11}$ W m^{-2} at the wavelength of $\lambda = 500$ nm. In this case $N = 40$ light quanta per second strike the retina. Neglecting the light reflection, calculate the total absorption factor k of the optical media of the eye.

TOPIC 9.B. Light and Substance Interaction. Thermal Radiation

Light Attenuation

A light wave passing through a substance causes electrons and ions oscillations. As a result, a number of processes are observed. The most important of ones are dispersion, absorption and light scattering.

Exercise 9.1b. Supplement the definitions.

Light absorption is ____

____

The Bouguer-Lambert-Beer law: $I = I_0 \cdot \exp(-\varepsilon c l) = I_0 \cdot \exp(-n\sigma_{\Pi} l)$. (9.1b)

Transmittance: $T = \dfrac{I}{I_0}$. (9.2b)

The optical density of solution: $D = \lg\dfrac{1}{T} = \lg\dfrac{I_0}{I} = \varepsilon' c l$, (9.3b)

c is ____

l is ____

I is ____

I_0 is ____

T is ____

ε is ____

The light scattering is ____

____

$$I = I_0 \cdot \exp(-kl) \quad \text{or} \quad I = I_0 \cdot 10^{-k`l} \qquad (9.4b)$$

k is ____

l is ____

I is ____

I_0 is ____

$k`$ is ____

Example of problem solution

The beam of monochromatic light passes through a glass plate with thickness l = 1 cm. In this conclusion, 0.1 of incident light is absorbed. Determine the glass natural monochromatic absorption index for this wavelength.

Data:

l = 1 cm

α_λ -?

Solution:

So as it was absorbed 0,1 of incident light, then $I = 0.9I_0$.

$$\ln(\frac{I_0}{I}) = \alpha_\lambda l; \ln(\frac{I_0}{0.9I_0}) = \alpha_\lambda l;$$

$$\ln(1.11) = \alpha_\lambda l$$

$$\alpha_\lambda = \frac{\ln(1.11)}{l} = \frac{0.104}{1} = 0.104 cm^{-1}$$

Answer: the glass natural monochromatic absorption index for this wavelength is equal to 0.104 cm^{-1}.

Problem 9.2b. The tyrosine natural molar absorption coefficient on certain wavelength is equal to $\varepsilon = 1.34 \times 10^3\ L \cdot mol^{-1} \cdot cm^{-1}$. Calculate the tyrosine solution transmittance with concentration $c = 10^{-4}\ mol \cdot L^{-1}$, if experiment is carried out in cuvettes with length $l = 1\ cm$.

Data:	***Solution:***

Answer: ____

Problem 9.3b. A beam of monochromatic light passes through the glass plate with thickness $l = 1$ cm. It absorbs 0.1 of incident light intensity. Determine the monochromatic natural absorption coefficient of glass at this wavelength.

Data:	***Solution:***

Answer: ____

Exercise 9.4b. Specify arrows the accordance between the physical quantity and the formula for its calculation:

1. Optical density	a. $D = \lg\frac{I_0}{I} = \varepsilon` c\ell = \lg(\frac{1}{\tau}) = -\lg\tau$
2. Molar absorption coefficient	b. $\tilde{\nu} = \frac{2\pi}{\lambda}$
3. Transmittance	c. $\tau = \frac{I}{I_0}$
4. Wave number	d. $\varepsilon` = \frac{1}{c\ell}\lg\frac{I_0}{I}$

Thermal Radiation

Each body, with a temperature different from zero by the Kelvin scale, emits the radiation. Such radiation is called the *thermal radiation*.

Exercise 9.5b. Define the following terms and write down the units of their measurement in the SI system:

Radiant exitance (M_e) is____

____

Spectral density of radiant exitance ($M_{e,\lambda}$) is ____________________________

____

Black body is____

____

Blackbody spectrum is ____

____

Gray body is ____

____

The dependence between radiation and absorption of bodies is described by the *law of Kirchhoff*:

$$\frac{M`(\lambda,T)}{\alpha(\lambda,T)} = M(\lambda,T). \qquad (9.5b)$$

Exercise 9.6b. Write the definition of the parameters and their units of measurement.

λ is ____

T is ____

$M(\lambda, T)$ is ____

$\alpha(\lambda, T)$ is ____

$M`(\lambda, T)$ is ____

The Stefan-Boltzmann law for a black body: $$M_e = \sigma T^4. \qquad (9.6b)$$

The Stefan-Boltzmann law for a gray (emitting) body: $$M_e = \varepsilon\sigma T^4. \qquad (9.7b)$$

Exercise 9.7b. Write the parameters of the laws submitted and their units of measurement.

M_e is ____

T is ____

σ is ____

ε is ____

If the emitting and absorbing surfaces have the same area, then the Stefan-Boltzmann`s law has the following form:

$$M_e = \varepsilon\sigma\left(T_1^4 - T_2^4\right), \qquad (9.8b)$$

where: T_1 is the temperature of emitting body; T_2 is the ambient temperature.

Problem 9.8b. Glowing metal ball with radius R = 5 mm in time t = 1 s emites energy E = 1.4 J. Calculate the ball temperature, considering it, as the gray body with the emissivity ε = 0.6.

Data:	***Solution:***

Answer: ____

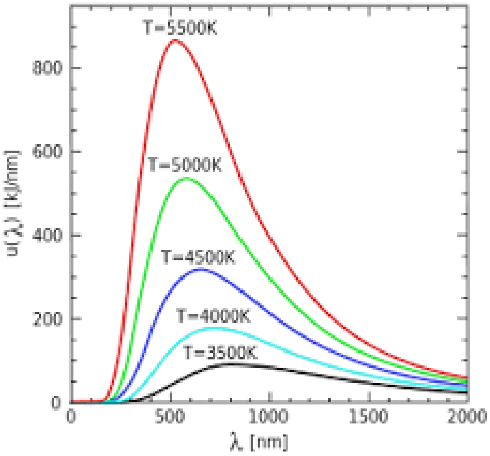

Fig. 9.1b. Wien`s law

The Wien`s displacement law:

$$\lambda_{max} T = c_1 . \qquad (9.9b)$$

The Wien`s second law:

$$M_{e,\lambda\max}(T) = c_2 T^5 . \qquad (9.10b)$$

Exercise 9.9b. Write down the parameters of each law and their units of measurement. Specify the value of the constants.

λ_{max} is ____

____

c_1 is ____

T is ____

$M_{e,\lambda max}$ is ____

c_2 is ____

Problem 9.10b. Calculate what wavelength λ_{max} is corresponded to the maximum spectral density of the radiant exitance of:

a) body with room temperature t_1 = 20 °C;

b) spirals of electric lamp (T_2 = 2500 K);

c) Sun surface (T_3 = 5800 K);

d) nuclear blowout ($T_4 = 10^7$ K).

Data:	***Solution:***

Answer:____

Control questions

1. List quantitative characteristics of thermal radiation and give their physical definition.
2. What can explain the human body thermostability?
3. What factors determine the temperature distribution on the body surface?
4. Which condition corresponds to black body?
5. Which condition corresponds to grey body?
6. Under what conditions is the Bouguer-Lambert-Beer law applicable?

Individual assignments

1. Cholesterol solution in ether with concentration 0.06 $g \cdot cm^{-3}$ rotates the polarization plane of the yellow sodium line light on 18° in a tube with a length 0.95 dm. Determine the cholesterol specific rotation.
2. When light passes through a layer of solution, 1/3 of the initial light energy is absorbed. Determine the transmittance and optical density of the solution.
3. A solution absorbs 25 % of the incident radiation. Find the transmittance T and the optical density D of the solution.
4. The temperature of a black body is T = 1000 K. By how many percent its radiant exitance changes with increasing temperature on $\Delta T = 1K$?
5. The spectral density of the black body radiant exitance at a certain wavelength range is 3×10^4 W / (m^2 · nm). Determine the corresponding spectral density of the gray body radiant exitance having the same temperature and absorption coefficient.
6. At what temperature is the gray body radiant exitance equal to M_e = 500 $W \cdot m^{-2}$? Emissivity is 0.5.
7. In medicine, a method called thermography was used to diagnose a number of diseases. It is based on recording the difference in thermal radiation of healthy and sick organs, due to a slight difference in their temperatures. Calculate in how many times are the thermodynamic temperatures and radiant exitance of the human body surface areas different, if the temperatures of the last are 30.5 and 30.0 °C.