Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

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Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	2. Bases of medical physics
Theme of lecture:	**Interaction of light with substance (dispersion, absorption, scattering, photoeffect). Photometry.**
Year	1
Faculty	Medical
Speciality	Medicine

Poltava - 2020

The topic significance:

At a light absorption atoms and the molecules of substance gain padding energy and transfer in an excited state. On occasion it can cause rising of their chemical reactivity and, in particular, ability to enter in chemical changes, which do not descend at their usual state. Such atoms and molecules are named activated. The activation of molecules is featured by the equation $\boldsymbol{A + h\nu = A^*}$, where $\boldsymbol{A}$ is molecule in a ground state, $\boldsymbol{h\nu}$ – photon absorbed by a molecule $\boldsymbol{A}$, and $\boldsymbol{A^*}$ – activated molecule. The basic law of photochemical reaction:

The quantity of the reacted substance is directly proportional to quantity of an absorbed energy of radiation.

At interaction of light with substance, at enough major energy of a photon exceeding a work function of an electron descends either electron emission, or change of conductivity of substance. Thus there is a dismissal of electrons from atoms of substance or translates electrons in a state of conduction, i.e. in a state of a photoeffect.

Specific targets:

To carry out examination of dependence of illuminating intensity from distance of a photoelectric cell from a light source.

To construct the diagram of this dependence.

To acquire concepts: photoeffect, photoemission, photoelectric work function of an electron, photoelectric cells, photochemical reaction, photobiological reaction.

To know Einstein's equation, equation of brightness calculation by the parameters light source intensity, distance to the surface, incident angle .

To seize technique of experiment on determination of the brightness (luxmetry methods) .

To be able to determine brightness with the help of a luxmeter .
To seize habits of work with optical bench.
To determine illuminating intensity on working place.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	**Obtainable skills**
Previous (providing disciplines): physics, chemistry, biology	To know basic concepts of optics and physical chemistry: light, wave, light absorption, electron–light interaction, molecule excitation
The subsequent disciplines: Biochemistry; Pharmacology; Normal physiology	To give definitions of concepts: photoeffect, photoemission, photoelectric work function of an electron, photoelectric cells, photochemical reaction, photobiological reaction. To give definitions of energy of radiation, radiant flux, emittance, exitance, light intensity, light flux, illuminating intensity, luminosity, brightness. To know : Diurnal rhythms. Light-linked season rythms. Concept of molecule excitation as physical and chemical reactions beginning. To formulate laws: Einstein's equation, equation of brightness calculation. To explain photoelectic cell principle of operation.

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
Photoeffect	Group of phenomena appearing as a result of interaction of light with substance, at which there is or emission of electrons, either change of conductivity of substance or originating of an electromotive force
Extrinsic photoeffect	Emission of electrons owing to interaction of light with substance
Intrinsic photoemissive effect	Increase of conductivity of substance or originating of an electromotive force owing to interaction of light with substance
Photoelectric work function of an electron	The quantity of augmentation of an electron kinetic energy due to photon absorption
Photoelectric cell	Element using the extrinsic photoemissive effect observed in metals for for photometric needs
Photochemical reaction	The elementary photochemical reaction can be connected or to losses of an electron by a molecule, or with its acquisition, or with destruction of molecules due to light quantum absorption (Photoionization, Photoreduction and photooxidation, Photodissociation, Photoisomerization, Photodimerization).
Photobiological reaction	The processes descending in biological systems at absorption of a radiant energy: 1) photosynthesis**,** 2) regulation processes: phototaxis, phototropism and photoperiodism of plants and 3) infringement and destruction processes
Radiant flux	It is energy W irradiated during the time t
Light flux	Φ: It is product of light intensity of light source ***I*** on space angle **ω**
Exitance (luminosity)	R: It is ratio of luminous flux ***Φ*** emitted by luminescent surface to area S of it surface
Emittance	Surface density of luminous flux φ is ratio of luminous flux Φ to area of cross-section S through that this flux pass is used for

	measuring of characteristic of emitting surfaces
Brightness	Surface density of luminous flux φ is ratio of luminous flux Φ to area of cross-section S through that this flux pass is used for measuring of characteristic of illuminated surfaces
Diurnal rhythm	Changes of biological organisms activity during day and night (photosynthesis, hormon levels, another biochemical reactions and total activity changes in microorganisms, plants, and animals).

Theoretical questions to class:

1. What is light [luminous] flux?
2. What is one steradian angle?
3. What units are used for luminous flux measurement?
4. What is named as light intensity?
5. What units are used for light intensity measurement?
6. What light intensity is 1 cd?
7. What is named as illuminance [illumination intensity]?
8. On what illumination intensity depends?
9. On what formula illumination intensity is measured?
10. How illumination intensity depends on distance from a light source?
11. How illumination intensity depends on angle of incidence of a light?
12. In what unities illumination intensity is measured?
13. What is lux?
14. What is termed as luminosity?
15. What is difference between illuminance and luminosity?
16. What is termed as brightness unit stilb?
17. What is termed as brightness unit nit?
18. In what the appearance inner and extrinsic photoemissive effect consists?
19. Formulate the laws of a photoeffect.
20. Note the Einstein's equation for a photoeffect.
21. Formulate definitions and specify units of the basic photometric quantities: a luminous flux, force of light, illuminating intensity.
22. Tell about use of photoelectric cells in scientific and medical examinations and about their practical application.
23. How the photoresistance varies depending on a luminous flux?
24. What is a photoelectric work function of an electron and from what it depends?
25. What is thermal electron emission?
26. What is light diffraction?
27. What phenomenon is termed as photoeffect?
28. What kinds of a photoeffect exist??
29. What is difference between inner and extrinsic photoeffect?
30. How action of light on the chemical substances speaks?
31. How biological action of light on an organism speaks?
32. What is purpose of photoelement using in medicine?
33. Why it is necessary to measure illumination intensity in medical practice?

Practice work executed at class.

Professional algorithms (instructions, reference cards) concerning mastering habits and skills:

Devices: a luxmeter, optical bench, ruler.

№	Task	Sequence of performance	Remarks, warnings concerning self-checking
1	Determine	Carry out in such sequence:	Remember about

	illuminating intensity on a working table with the help of a luxmeter.	1. Establish the device. 2. To measure with the help of a luxmeter illuminating intensity on various distances from a light source (window-sill, blackboard, different points of a working room). 3. Light up a room maximally with the lamps.	correct position of the device sensitive element in relation to direction of light incidence.
2	Measure with the help of a luxmeter illuminating intensity on various distances from a light source	Familiarize with optical bench and luxmeter. Allocate sensitive photoelectric cell on 10 cm distance from the lamp on the one level with lamp (on the axis of the box output opening). Choose 300 lux sensitive range. Readout data. Put into the table observed data and results of evaluations. Move photoelectric cell on the next position. Repeat measurement.	To give attention on accuracy work with optic bench. When output data will be in the short range (30 lux), change luxmeter sensitive range.

Data chart

r, cm	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
E, lux															

4) Construct the diagram of dependence of illuminating intensity from distance between a photoelectric cell and light source ***E = f (r).***

5) On the basis of these measurement to make a deduction.

The content of the topic:

Thermal electron emission [thermionic emission, Edison effect, Richardson effect, filament emission, термоэлектронная эмиссия] is emission of the electrons by heated metals. Electron can leave metal if its full energy W is more then work function A. This appearance becomes intensive at metal temperatures near hundreds Kelvin degrees. It’s used in work of electronic vacuum tubes. Illumination influences on electron energy too.

Photoeffect is term of group of appearances appearing as a result of interaction of light with substance, at which there is or emission of electrons (extrinsic photoemissive effect), either change of conductivity of substance or originating of an electromotive force (inner [or intrinsic] photoemissive effect).

The extrinsic photoemissive effect can be observed in metals. In these problems the Russian scientist O. G. Stoletov was engaged which has paid attention to practical use of photoelectric cells for photometric needs. The extrinsic photoemissive effect arises at irradiating metal, when the photon is absorbed with a conduction electron; that gives augmentation of a kinetic energy of an electron. If the quantity of this energy exceeds a photoelectric work function of an electron, the electron leaves from metal. This process energy is featured by the Einstein's equation:

$hv = A + mv^2/2,$

Where hv – energy of a photon, A – photoelectric work function of an electron, $mv^2/2$ – kinetic energy of the emitting electron.

The analysis of this equation testifies that electrons move independently from each other in metal, and consequently the change of one electron energy at uptake of a photon does not give change of energy of other electrons, i.e. the photon interacts only with one electron.

On the basis of experimental data three laws of a photoeffect were ascertained:

1) The number of photoelectrons which are pulled out from a surface of metal for a time unit is proportional to a luminous flux incident on metal, at an invariable spectral distribution.

2) The maximal initial kinetic energy of photoelectrons is determined by frequency of an incident light and does not depend on its intensity.

3) For each metal there is a red photoelectric threshold, i.e. maximal wavelength λ_0, at which the photoeffect is even possible.

The magnitude of a photoeffect depends on a chemical nature of metal and state of its surface. From the Einstein's equation it follows, that the electron can exceed the bounds of metal, if the energy, imparted to it, is not less a photoelectric work function, i.e. $hv_0 \geq A$. As frequency $v_0 = c/\lambda_0$, that $\lambda_0 = hc/A$.

The appearance of a photoeffect has gained wide use in various branches of a science and technique for account of its basic property to transmute light energy into electrical. The devices, which transmute light energy into electrical, are termed as photoelectric cells.

The photoelectric cells are widely utilized in devices for measuring and recording of luminous fluxes (various relays, signal system, accounting automatic devices, systems of protection near machine tools, television, sound cinema, phototelegraph, electrophotocolorimeters, luxmeters etc.)

Illuminating intensity is measured by a luxmeter, which represents a photometer used for determining of a degree both artificial and natural illuminating intensity. Or else, the receiver of light energy in luxmeters is served by photoelectric cells presenting photoelectric sensor. The division of optics occupied with problems of an emission, diffusion and absorption of light, and as irradiating of various items, is termed as a photometry.

Light spreading in space has certain energy. If on the given surface the luminous flux falls, it means, that the given surface every second gains some of a radiant energy.

Energy of radiation W is measured in J (joule, watt-second) as some other energy.

Volume density of irradiation energy is ratio of energy of radiation W to volume V in which this energy contains, and unit is J/m^3.

Radiant flux is energy W irradiated during the time t, and unit is J/s. $\Phi = W/t;$ 1 J/s = 1 W (watt). It is equivalent to mechanical power.

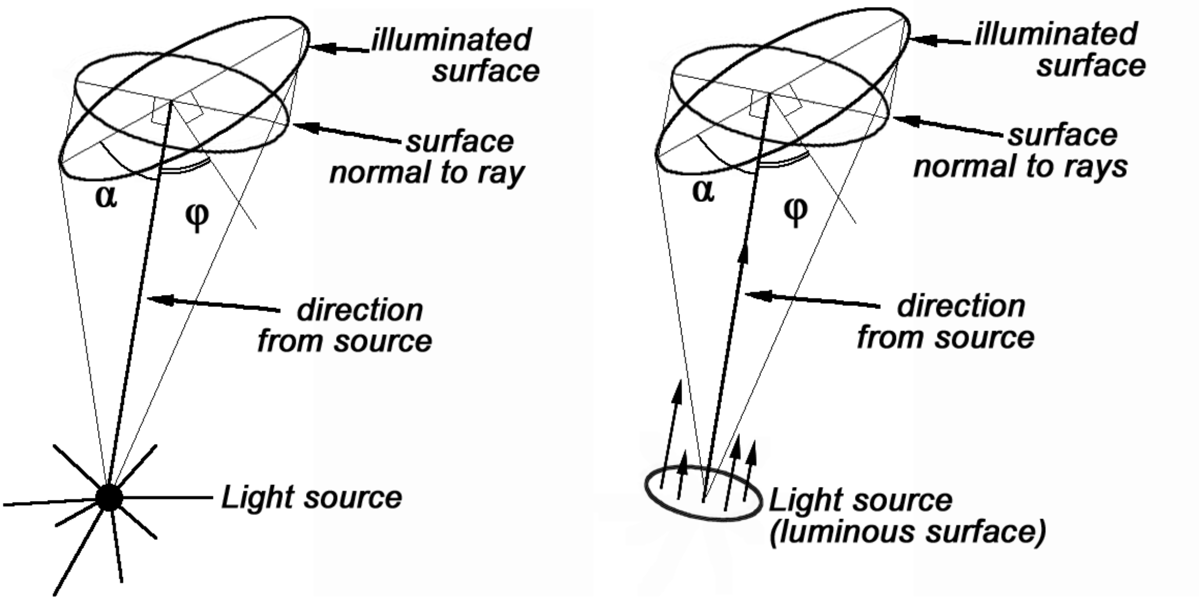
Surface density of luminous flux φ is ratio of luminous flux Φ to area of cross-section S through that this flux pass. $\varphi = \Phi/S.$ Unit is W/m^2.

This unit is used for measuring of ***emittance*** [***radiant exitance, radiancy***] and ***energetic brightness*** [***energetic illuminance***, energetic illumination].

Emittance is used as characteristic of emitting surfaces, their emissivity [emittance, transmissibility], brightness – characteristic of illuminated surfaces.

Light intensity [luminous intensity, intensity, illumination power, light power, luminous power]. It is one of basic ideas and mark as ***I***. Unit of light intensity is one of 7 main units of SI – International Unit System**. Candela (cd)** is equal to light intensity irradiated from surface 1/600 000 m^2 of complete radiator at platinum solidification temperature of radiator at pressure 101 325 Pa and perpendicular direction. (Complete radiator is meant as an absolute black body).

Measuring of light values is based on physiological action of light and therefore in considerable part it has subjective character. Radiation with λ=556 nm makes most action on eye. Thus during measuring of light *average sensitivity* of many healthy people is used.



A B

Fig.1. Illumination of surface from the luminous point (A); Illumination of surface from the of luminous surface and brightness of light source (B).

Light flux [***luminous flux***] **Φ** is product of light intensity of light source ***I*** on space angle **ω** [solid angle, spatial angle]: $\boldsymbol{\Phi = I\omega}$. Unit is **lumen** (**lm**); 1 lm = 1cd·sr, where **sr** is *steradian* – unit of space angle.

The ***complete luminous flux*** of a light source names a luminous flux radiated by this light source on all directions.

The ***illuminating intensity*** [brightness, illuminance, illumination] (***E***) is determined by a luminous flux come on unit of a surface. As unit of illuminating intensity 1 **lux** is accepted illuminating intensity framed by an evenly distributed luminous flux 1 lumen on the surface 1m^2, normally posed to a luminous flux:

$\boldsymbol{E=\Phi/S}$.

Unit is **lux** (**lx**); 1 lx = 1 lm/m^2.

Except for unit of illuminating intensity a lux, one more unit – **phot** (**ph**) is accepted. 1 Phot is illuminating intensity created by an evenly distributed luminous flux 1 lm on a surface 1 sm^2, normally posed to a luminous flux: 1phot = 10^{-4} lux.

Exitance [***luminous exitance, luminosity***] **R** – is ratio of luminous flux ***Φ*** emitted by luminescent surface to area S of it surface: $\boldsymbol{R = \Phi/S}$.

Unit of exitance is lux (as unit of illuminating intensity).

Concept of exitance. It can be distinguished luminosity or brightness of active radiator and brightness of surface with reflectance. The surface brightness terms value gauged by force of light irradiated from a unit area of this surface in normal to the surface a direction; i.e. the luminosity is quantity, characterised not only radiating light surfaces, but also surfaces reflecting it (for example, illuminated by a light source).

$\boldsymbol{B = I/S}$.

If the light power is equal to 1 candela (cd), and the area of radiating surface 1 m^2, its luminosity is equal to unit named **nit**: B = 1cd/m^2. In Russia this name don't used today.

Other unit of luminosity – 1 **stilb**. 1 stilb = 1 cd/cm^2 = 10^4 cd/m^2 = 10^4 nit.

Brightness [***brilliance, luminance***, intensity, luminosity, luma] ***Bφ*** of luminescent surface into certain direction ***φ*** is ratio of light intensity ***I*** in this direction to area ***S*** of luminescent surface projection on the plane which is perpendicular to given direction**:**
$B\varphi = I/(S\cos\varphi)$.

Unit is candela per square meter – 1 cd/m^2.

Other determination is following. Thus, the illuminating intensity [brightness, illuminance, illumination] is directly proportional to force of light source and cosine of an angle of incidence of rays and is inversely proportional to a square of distance from a light source up to a surface element lighted by it.

The illuminating intensity from a point source of light can be determined by the formula: $E = I \cdot \cos\alpha/r^2$ (see fig.1,A).

Where ***I*** – force of light of a point source of light in the given direction in unit of a space angle; ***r*** – distance from a light source to the illuminating area; ***cos α*** – cosine angle, under which the light rays fall. Unit is candela per square meter too.

Self-control material:

Test tasks to be done :

1. Under what formula illumination intensity calculates?
   A) $E=I\bullet r^2/\cos\alpha$
   B) $E=I\bullet\cos\alpha / r^2$
   C) $E=I\bullet\sin\alpha / r^2$
   D) $E=I\bullet r^2 \bullet \cos\alpha$

2) Under what formula brightness calculates?
   A) B=IS
   B) $B=S/I\bullet\sin\varphi$
   C) $B=I\bullet\cos\varphi/S$
   D) $B=I/S\bullet\cos\varphi$
   E) $B=I/S\bullet\sin\varphi$

   3) Under what formula photon energy calculates (*hv* – energy of a photon, *A* – photoelectric work function of an electron, *m* – emitting electron mass, *v* – emitting electron velocity)?
   A) $hv = A\bullet mv^2/2$
   B) $hv = A + mv^2/2$
   C) $hv = A + 2m/v^2$
   D) $hv = A + 2v^2/m$
   E) $hv = A - 2v^2/m$

Tasks for self-checking:

A brightness of working surface must be 350 lux. How many lamps with luminous flux 1000 lm must be allocated at the 3 m distance from the working surface to average brightness correspondence to requirements?

Task 2. Calculate parameters of dependence $E = I \cdot \cos\alpha/r^2$ in conditions of our experiment.

Literature recommended

Main sources.

- Chaliy A.V. at all., Biological and medical physics. – A.V. Chaliy et all.– Ed.A.V. Chaliy. – Vinnitsia, Nova Knyha, 2013. – 480 pp.
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