Ministry of Education and Science of Ukraine
Ternopil Ivan Puluj National Technical University

Faculty of Electrical Engineering
Department of Light and Electrical Engineering

LECTURES

on the subject of

«LIGHTING DEVICES»

Field of study 6.050701 Electrical Engineering and Electric Technologies

Ternopil
2016

Lectures on the subject of «Lighting Devices» for students of field of study 6.050701 Electrical Engineering and Electric Technologies / Author Lyubov Kostyk, DPh, TNTU, 2016.

Lecture 1

GENERAL INFORMATION ABOUT LIGHTING DEVICES

<u>Objectives of lighting devices (LD):</u>

- conversion of radiant flux of the source (spatial, spectral redistribution, polarization light source);
- commutation and stabilization of electric current;
- protection of the light source and the optical device from dirt and mechanical damage;
- isolation of the light source explosion, fire and wet environment;
- protection against electric shock.

Lighting devices – device which consisting of one or more light sources and device that converts radiant flux for lighting (irradiation), signaling and projection.
Optical device - a device which redistributes flux of sources in order to create a real or imaginary optical image of the body of radiation.

Classification of lights devices by the degree of luminous flux concentration

I. SPOTLIGHT

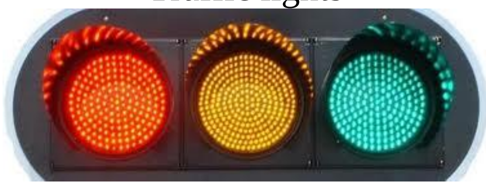
Spotlight – it's lighting devices, that using an optical device takes in luminous flux in a large solid angle and concentrates it in a small solid angle (flat angle of 1-2 degrees).

Spotlight (Paraboloid of rotation spotlights)

Floodlight (Cylindrical paraboloid spotlights)

Headlights

Traffic lights

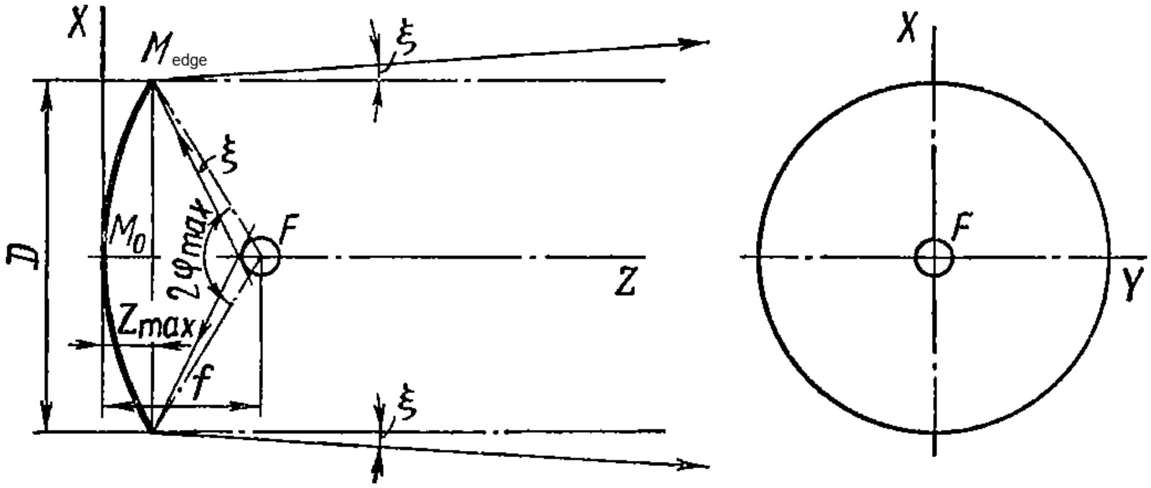


Signal searchlights (Light beacons)

Spotlight has a maximum concentration of luminous flux, which means that all or a more part of the optical device active surface should be light in the direction of the axis of the beam from infinity. The brightness of the surface the same as brightness of the light source ($\rho = 1,\ \tau = 1$).

Light hole – it's a projection of surface active optical device on a plane perpendicular to the optical axis.

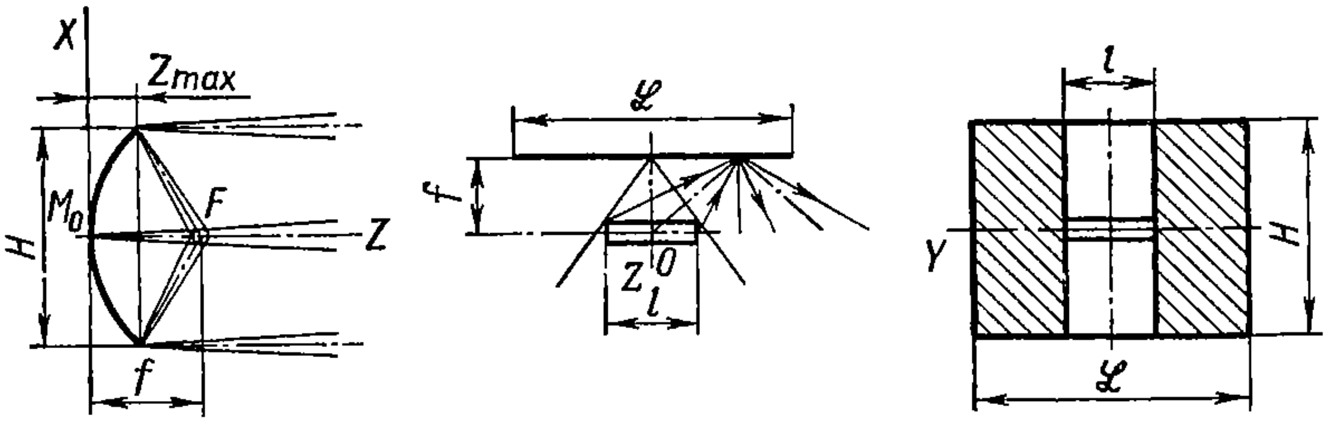
Paraboloid mirror reflector



Meridional sectional Light hole

The degree of concentration of luminous flux paraboloid mirror: $\frac{I_{axis}}{I_{LS}} = \frac{D^2}{d_{LS}^2}$

Cylindrical paraboloid mirror reflector



Meridional sectional Equatorial sectional Light hole

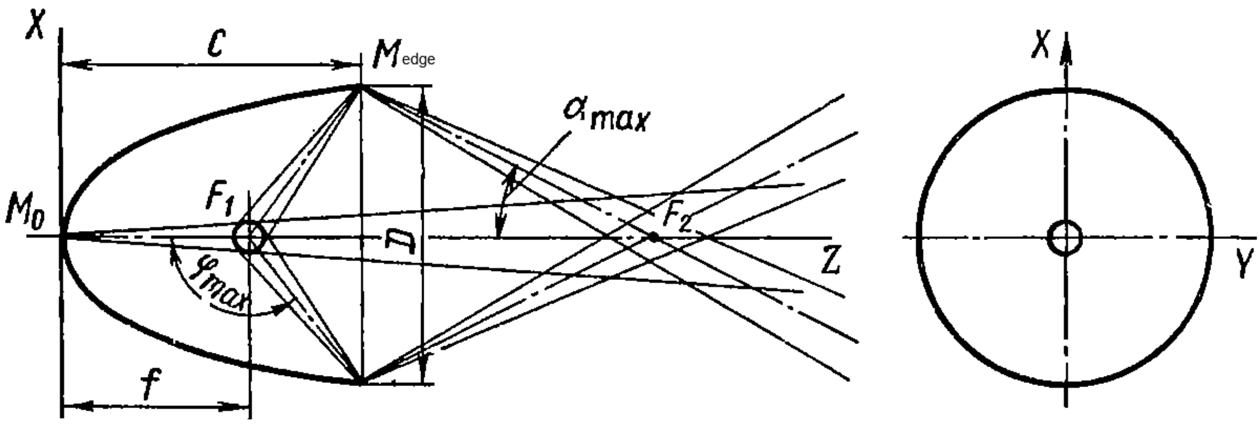
The degree of concentration of luminous flux cylindrical paraboloid mirror: $\frac{I_{axis}}{I_{LS}} = \frac{H}{d}$

By spotlight class devices include lights, focal rays which, after reflection by all points at least one meridional sectional optical device (non-aberrational) directed parallel to the optical axis.

II. PROJECTOR

Projector – a lighting devices, that using an optical device takes in luminous flux in a large solid angle and concentrates it in a small volume or on the surface of a small area (the size of the lighting area much smaller than optical device).

Ellipsoidal mirror reflector



Meridional sectional Light hole, visible from point F_2

In point F_2 formed a larger image of the light source and all luminous flux is concentrated in a volume that holds this image.

Measure concentration projector – illuminance area, which is placed inside the image of light source perpendicular to the optical axis: $E = L_{BL}\rho \sin^2 \alpha_{\max}$

Light hole completely lit only some areas of the optical axis, the amount of which is determined by the size of the actual image.

By projector class devices include lights, focal rays which, after reflection by all points at least one meridional sectional optical device (non-aberrational) directed at one point on the optical axis.

III. LUMINAIRE

Luminaire – light device that using an optical device takes in luminous flux in a large solid angle and redistributes it also in a large solid angle (up to 4π).

Light part of the optical device, usually can not fill all the light hole and have a size equal to the size of this one hole.

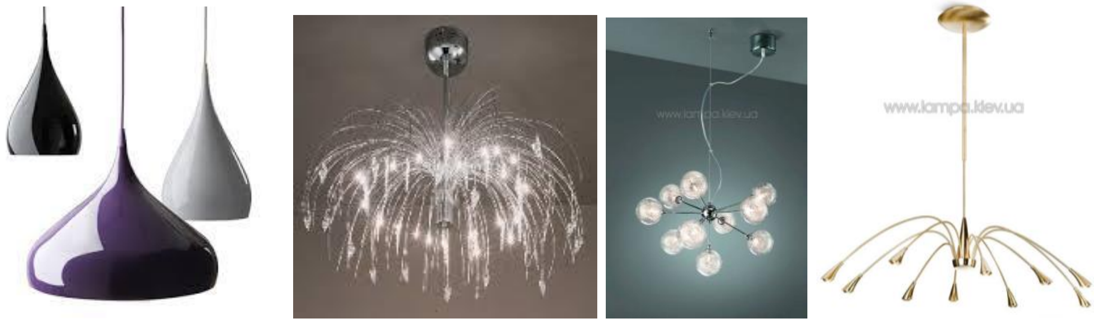
Industrial luminaires

Luminaires for administrative offices

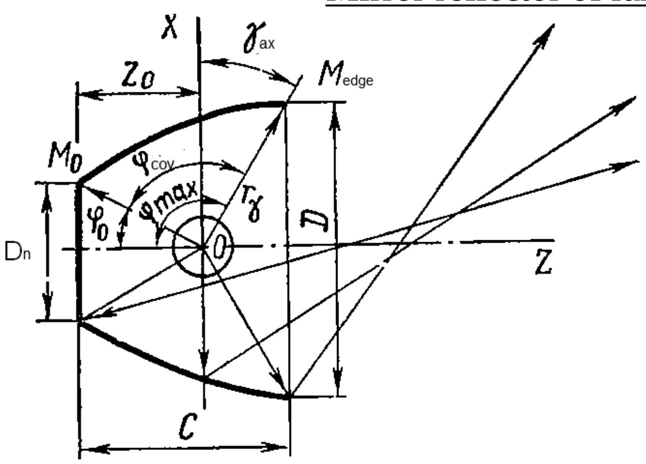
Luminaires for local illumination

Outdoor luminaires

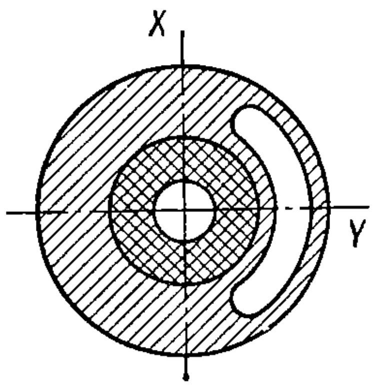
Household luminaires



Mirror reflector of luminaires



Meridional sectional



Light hole, visible in direct α

Luminaires that have a light scattering elements do not create real or virtual image of the light source, i.e., do not create a significant concentration of luminous flux in a given direction of space. Active surface brightness of such elements is much less than the brightness of the light source, and it can be considered glowing.

Classification lights devices purpose

Lighting (some headlights) devices - are used in lighting installations, where the receiver is the human eye. Their spectral region is limited by radiation visible part of the optical spectrum.

Irradiation devices - designed for operation in the UV, visible and IR region or across the optical radiation. Receivers are bacteria, people, farm animals, plants, paint and polymer coating, heating and drying facilities.

Headlights - uses radiation to transmit information in the form of signals encoded by changing the spectral composition of radiation sources, changing the frequency and duration of radiation flux pulses.

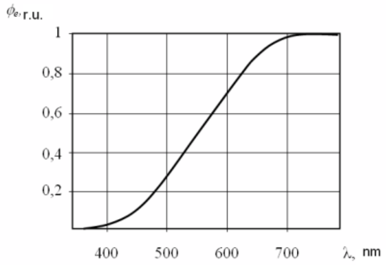
Lecture 2

MAIN ELEMENTS OF LIGHTING DEVICES

I. Light sources

1. Thermal sources of light

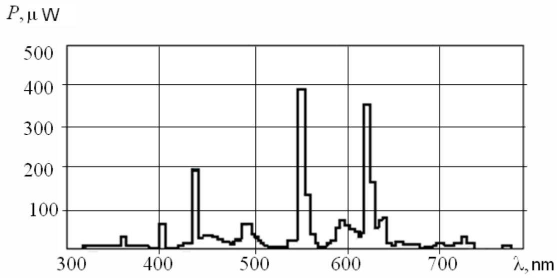
incandescent lamp halogen incandescent lamp



2. Gas discharge lamp

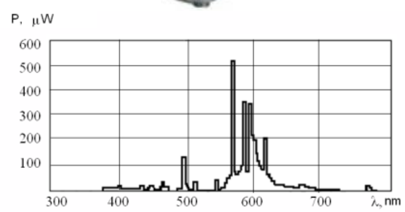
2.1. Gas discharge lamp of low pressure (P=0,1…10^4 Pa)

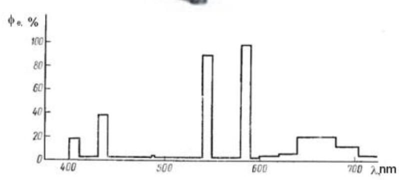
(fluorescent lamp, sodium lamp, glow discharge)

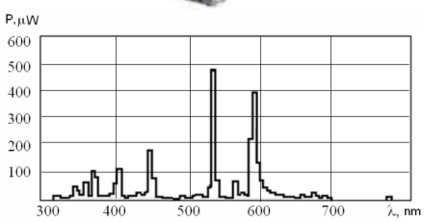


2.2. Gas discharge lamp of high pressure (P=3×10^4…10^6 Pa)

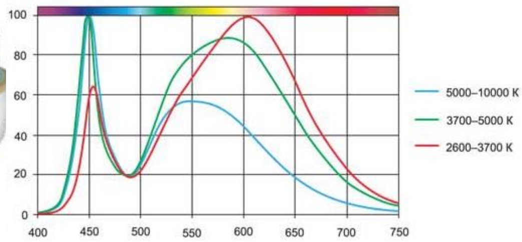
Sodium lamp Mercury lamp Metal halide lamp

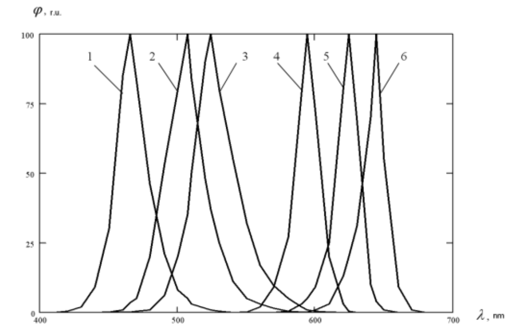






3. Light emitting diodes





1 - blue, 2 - blue and green, 3 – green,
4 – yellow, 5 - amber, 6 - red glow

II. Lighting materials

Lighting devices contain follow elements:

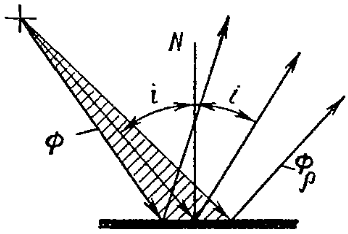
Lighting - light transformative device that redistributes light flux in the space, reduce the brightness of the light source, change the spectral composition of radiation and its polarization;

Electrical - devices for commutation and stabilizing current light source power;

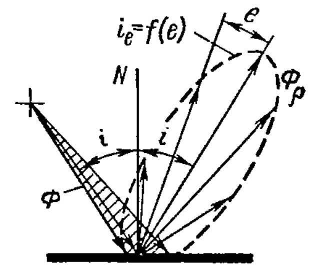
Constructional – lighting device details for light source mount, install and focusing LD, light source and optical components protection from mechanical damage of the environment.

Lighting element may be made from materials with different optical properties.

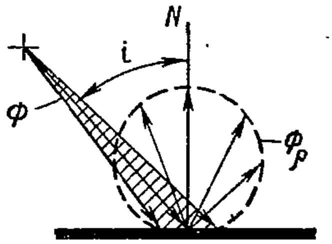
Light reflective materials



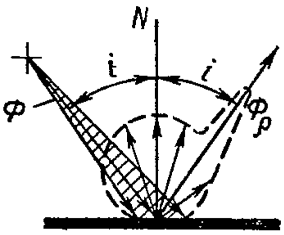
Directed reflection



Directed-diffuse reflection

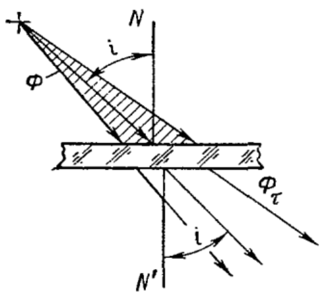


Diffuse reflection

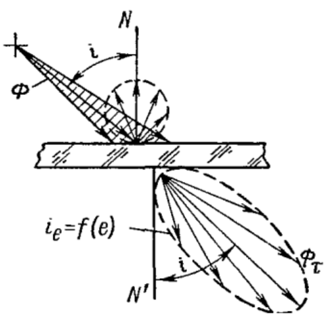


Mixed reflection

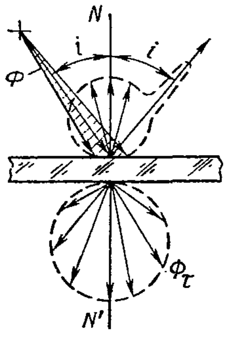
Light transmitting materials



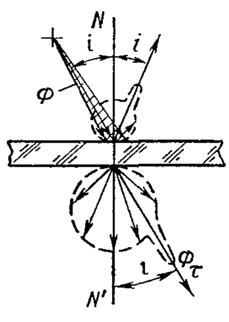
Directed transmittance



Directed-diffuse transmittance



Diffuse transmittance



Mixed transmittance

1. Material with directional reflection (transmittance) light is a material that reflects (transmitted) luminous flux so that the solid angle of the incident and reflected (transmitted) light is same.

Materials:

polished metals, sometimes with a protective coating of glass and films;
metallic coating on glass surfaces

flat silicate and organic glass;
plastic transparent

Products:

reflectors

lenses;
refractive elements;
dispersive elements

Reflectivity mirror materials:

Silver	0,90…0,92
Glass silvered mirror	0,85…0,86
Aluminium	0,85…0,90
Alzak aluminum	0,80…0,84
Rhodium	0,72…0,74
Cadmium	0,62…0,64
Chromium	0,61…0,62
Nickel	0,55…0,60

2. Material with directional-diffuse reflection (transmittance) light is a material having solid angle of reflected (transmitted) light more than falling, and the direction of the axis of the solid angle of the incident and reflected (transmitted) light is the same.

Materials:

oxidized aluminum;
etched aluminum;
galvanic nickel;
coatings obtained by spraying metal

silicate glass and organic chemical (acid etching) or mechanical (sand blasting) matting

When $i = 0...60^\circ$ for reflectors form of the photometric body scattering – ellipsoid, whose major axis is oriented directly of mirror reflection. When $i > 60^\circ$ photometric body becomes non-symmetrical.

When $i > 60^\circ$ for scatterers form of the photometric body scattering is ellipsoid.

$\tau = \tau_{dir} + \tau_{diff}$,

τ_{dir} – coefficient of directed transmittance;

τ_{diff} – coefficient of diffuse transmittance.

For $i = 0...30^\circ$ $\tau_{ä}$=0,1…0,2.

For $i > 30^\circ$ τ_{dir} decreases and τ_{diff} increases.

3. Material with diffuse reflection (transmittance) light is a material that reflects (transmittance) luminous flux within the solid angle 2π. The direction of maximum luminous intensity coincides with the normal axis and is the axis of solid angle.

Materials:

- barium sulfate;
- white enamel (based on zinc aluminate);
- chalk;
- gypsum;
- porcelain enamel;
- glue paint;
- nitrovarnish white
- opacified glass;
- milk glass (including 1 micron 100000 in 1 mm^3);
- detachable milk glass

4. Material with mix reflection (transmittance) light is a material characterized by diffuse scattering and directional reflection (transmittance) light.

Materials:

- ceramic enamel coating
- opal glass (including 100-200 nm, 100000 in 1 mm^3)

$$\rho = \rho_{dir} + \rho_{diff} ,$$

For $i = 0...45^\circ$ ρ_{diff} =0,50…0,65.

For $i > 45^\circ$ ρ_{dir} increases, a ρ_{diff} decreases.

Lecture 3

TYPES OF LIGHT REDISTRIBUTION DEVICES

1. Optical devices are redistribution of luminous flux carried formation increased or decreased imaginary or real image of the luminous body source.

$L = L_{lb}\ (\rho, \tau = 1).$

Reflecting devices:	*Refractive devices:*	*Reflective-refractive devices:*
reflector: - paraboloid (spotlight); - ellipsoid (projector); - any form (luminaire)	Frenel lens (spotlight); aspherical and condenser lens (projector)	lens diffusers (luminaire); prismatic device (luminaire)

2. Diffuse devices are redistribute radiation glow across the surface of the brightness, approximately the same in all directions and an order of magnitude smaller compared to the brightness of the luminous body source.

$L \ll L_{lb}\ (\rho, \tau = 1).$

Reflecting devices:	*Refractive devices:*
diffuse reflector (luminaire)	diffuse diffusers (luminaire)

3. Matted devices - the entire surface forming a vague image of a luminous body, which compared to the luminosity of the entire surface is stain high brightness.

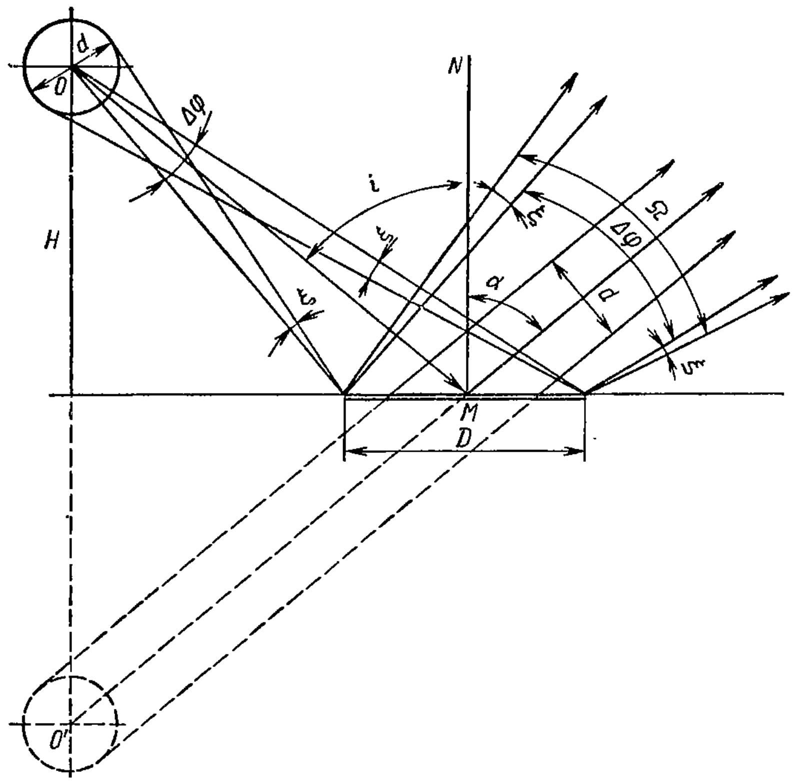
$L < L_{lb}\ (\rho, \tau = 1).$

Reflecting devices:	*Refractive devices:*
matted reflector (luminaire)	matted diffusers (luminaire)

GLOW CHARACTER OF MIRROR AND DIFFUSE-REFLECTIVE ELEMENTS

Light source is equal brightness bullet luminous body with $I_{LS\alpha} = const$.
Detector is a flat disk form element with mirror or diffuse reflection.

1. Mirror element



$\Delta\varphi$ is the angular size of the mirror element; 2ξ is the angular size of the light source; $i = \alpha$ are angles of incidence and reflection beam OM; Ω is flat angle of solid angle ω, inside which the disc reflects incident light flux $\Omega = \Delta\varphi + 2\xi$.

Brightness of mirror element: $L_{mirror} = \rho L_{LB}$.
Luminous intensity towards α: $I_\alpha = \rho L_{LB} A_\alpha$.

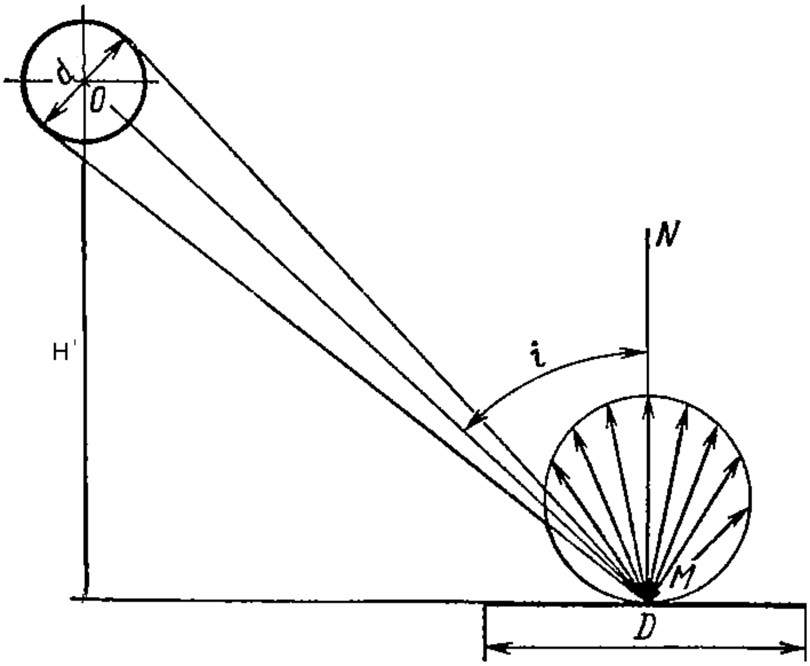
For $D < d_L$ image of the light source overlaps the disk.
Than $I_\alpha = \rho L_{lb} A_1 \cos\alpha$, A_1 is area of disk.

For $D > d_L$ image of the light source overlaps the disk is not full.
Than $I_\alpha = \rho L_{lb} A_2 \cos\alpha$, A_2 is light area of the disk.

For $i = \alpha$ $\quad A_2 \cos\alpha = \dfrac{\pi d_L^2}{4}$ and $\quad I_\alpha = \rho I_L$.

For directions α, where the image source is incomplete, $A_2 \cos\alpha < \dfrac{\pi d_L^2}{4}$ and $I_\alpha < \rho I_L$.

2. Diffuse element



Brightness of diffuse element:

$$L_{diff} = \frac{M}{\pi} = \rho \frac{E}{\pi},$$

where M is the disk luminosity, lm/м^2.

For real (non-equal brightness) diffuse element brightness defines by lighting element and the brightness ratio of the element material.

$$\rho = \frac{1}{2\pi} \int r_{\alpha\beta} d\omega,$$

where $r_{\alpha\beta}$ is brightness ratio of the material in the direction (α, β).

$$L_{\alpha\beta} = \frac{M_{\alpha\beta}}{\pi} = r_{\alpha\beta} \frac{E}{\pi}$$

For diffuse materials $r_{\alpha\beta} > 1$, for directed-diffuse reflection materials $r_{\alpha\beta} > 20$.

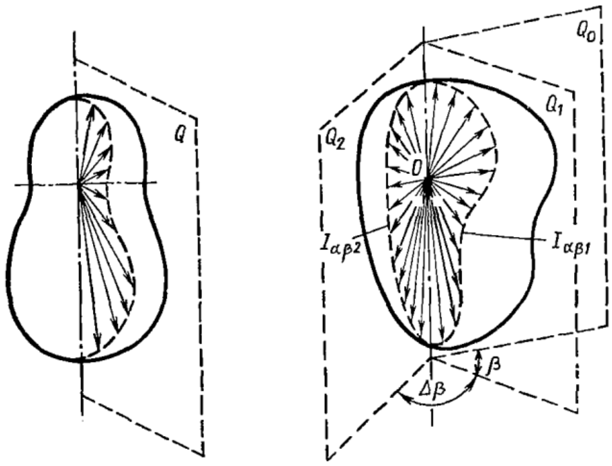
Mirror element	Diffuse element
Creates a virtual image, which determines the light area and it brightness $L_{mirr} = \rho L_{LB}$	Does not create a virtual image, the whole surface glows with brightness $L_{diff} = \frac{\rho Å}{\pi}$
Visible light within the limits of solid angle $\Delta\omega$ that is determined by size reflective element and source	Visible light within the limits of solid angle 2π not dependent on the size of the element and the source
If the distance between the source and the element changes than $L_{mirr} = const$, $\Delta\omega = \text{var}$, $\hat{O} = \text{var}$	If the distance between the source and the element changes than $L_{diff} = \text{var}$, $\Delta\omega = 2\pi$, $\hat{O} = \text{var}$

Lecture 4
MAIN CHARACTERISTICS OF LIGHTING DEVICES

1) luminous intensity and its spatial distribution;
2) Illumination and its distribution over the surface of the illuminated object;
3) brightness of luminous surface and its distribution over the surface of the light distributing device and in different directions of space;
4) efficiency;
5) amplification factor;
6) spectral composition of radiation;
7) polarization.

1. Luminous intensity and its spatial distribution

$$I_{\alpha,\beta} = \frac{d\hat{O}}{d\omega}, \text{ cd}$$

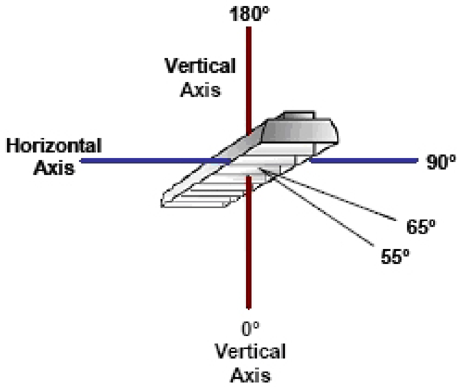


Photometric body is the locus of the radius vector ends which coming from the light center of the device, the length of which is proportional to the luminous intensity in that direction.

Luminous Intensity Distribution Curve (IDC) is the dependence of luminous intensity of lighting device at meridian and equatorial angles obtained photometric body section lighting device meridional or equatorial plane.

Luminous intensity distribution curves are typically represented in polar plots because this format allows us to visualize both the orientation and the light distribution of the luminaire.

Luminous intensity distribution curves of a luminaire upon reflector design, shielding type, and lamp-ballast selection. It is assumed that the luminaire position is at the crossing of two axes (horizontal and vertical), and that 0° (nadir) is beneath the luminaire. Other angles, which represent the various placements of a photocell as it moves in a circular pattern around the luminaire, are marked on the graph as well.



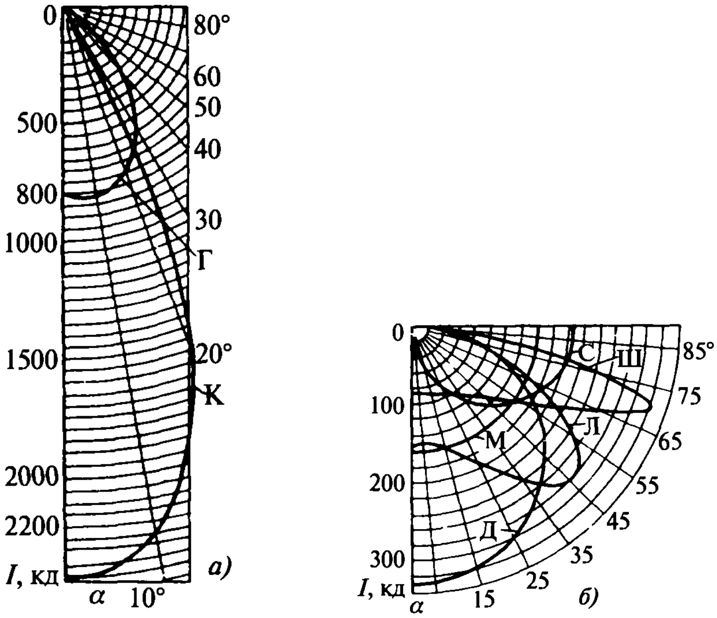
If the distribution of light is not symmetrical in all directions around the vertical axis luminaire, luminous intensity values may be taken in a number of vertical planes through the luminaire. The planes shown in photometric reports are 0°, 22.5°, 45°, 67.5°, and 90°. The planes most commonly used in lighting practice are 0° or parallel to the lamp axes, 90° or perpendicular to the lamp axes, and at an angle 45° to the lamp axes.

Types IDC of luminaire

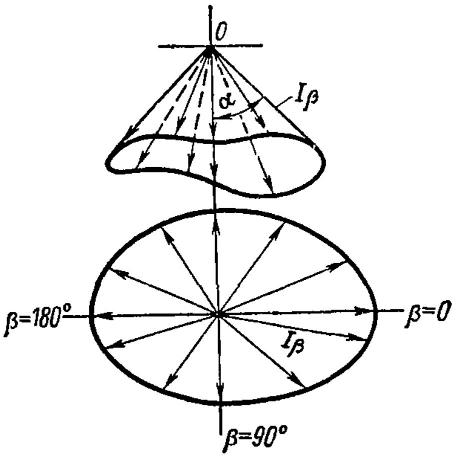
Type IDC	Name the type of IDC in the upper and lower hemispheres	Zone of possible directions of maximum luminous intensity, degree	The value of form coefficient IDC
К	Concentrated	0-15	$K_f \geq 3$
Г	Deep	0-30; 180-150	$2 \leq K_f < 3$
Д	Cosine	0-35; 180-145	$1{,}3 \leq K_f < 2$
Л	Half a wide	35-55; 145-125	$1{,}3 \leq K_f$
Ш	Wide	55-85; 125-95	$1{,}3 \leq K_f$
М	Uniform	0-90; 180-90	$K_f \leq 1{,}3$ for $I_{\min} > 0{,}7 I_{\max}$
С	Sinus	70-90; 110-90	$K_f < 1{,}3$ for $I_0 < 0{,}7 I_{\max}$

Form coefficient IDC K_f is the ratio of the maximum luminous intensity in the meridional plane to the mean value luminous intensity for the same plane:

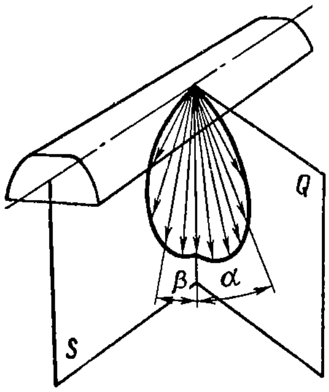
$$K_f = \frac{I_{\max}}{I_{mean}},$$



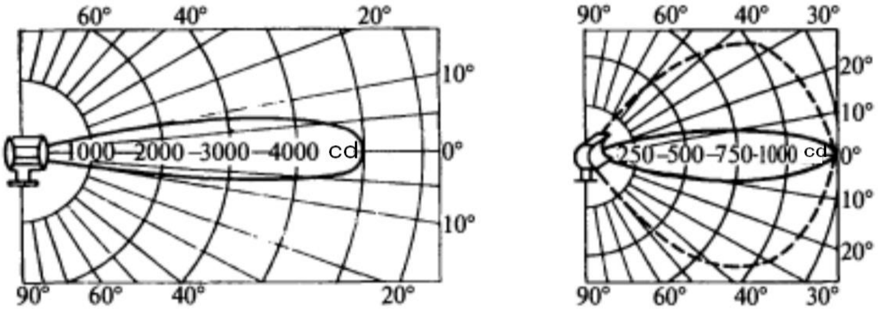
Types IDC of luminaire $I(\alpha)$



Types IDC of luminaire $I(\beta)$
for $\alpha = const$

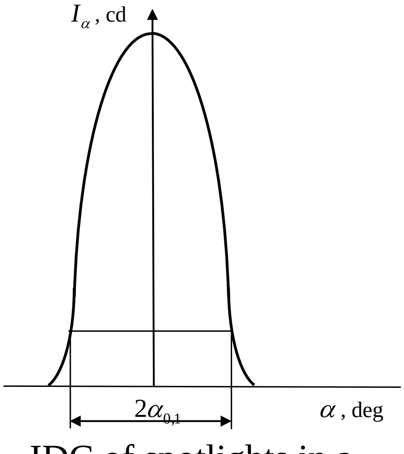


Equatorial *S* and meridional *Q* planes
for fluorescent lighting devices



a) b)

IDC of axisymmetric spotlights: a) with one axis of symmetry; b) with two axes of symmetry



IDC of spotlights in a rectangular coordinate system

2. Illumination and its distribution over the surface of the illuminated object

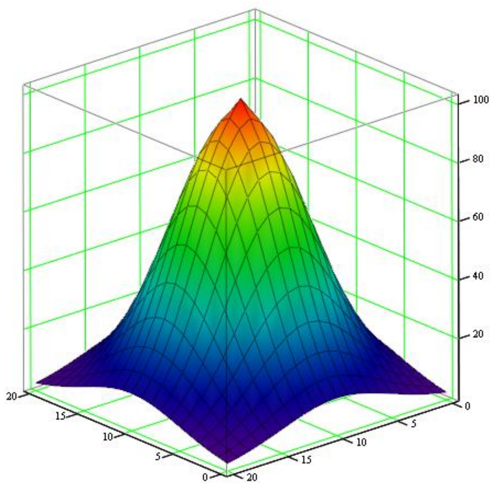
$$E = \frac{d\hat{O}}{dA}, \text{ lx}$$

Type of illumination:

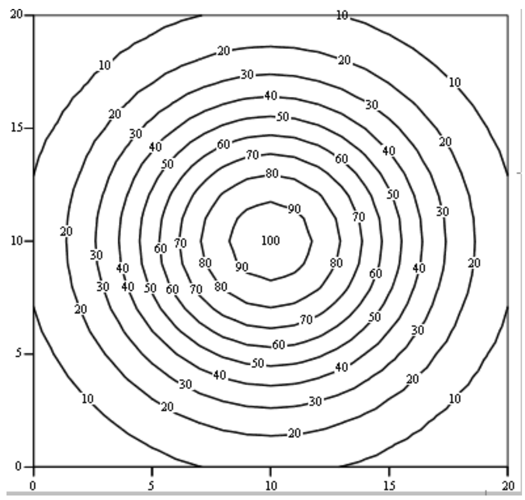
1) Illumination section plane E_P;
2) spatial illumination E_0 is the amount of normal illumination at a given point of the field;
3) the average spherical illumination $E_{4\pi}$ is average illumination surface areas vanishingly small radius;
4) the average hemispherical illumination $E_{2\pi}$ is average spherical surface illumination hemisphere vanishingly small radius;
5) the average cylindrical illuminance E_C is average illuminance lateral surface of the cylinder with vanishingly small size of its height and diameter of the base.

The body of equal values of illumination is body surface which is the locus equal its values.

Intersection bodies of equal values by equatorial plane gives light traces in the form of spatial curve equal illuminations (izolux) of points, which correspond to the value of variable height suspension of lighting device above the plane of intersection and distance from the projection of a point light source at plane and a constant angle of inclination of the optical axis of the lighting device to the illumination plane.



The bodies of equal values of illumination of elementary areas from one point source of light



Curve equal illuminations from one point source of light

3. Brightness of luminous surface and its distribution over the surface of the light distributing device and in different directions of space

Brightness at the point of source surface is the ratio of the luminous intensity, irradiated by an element in this direction, to the product of the area and the cosine of the angle of radiation distribution:

$$L = \frac{dI}{dA \cdot \cos\theta}, \text{ cd/м}^2$$

Brightness at the point of the surface of the light receiver - the ratio of illumination that is created at this point the receiver in a plane, which is perpendicular to the direction of radiation distribution to the elementary solid angle, which contains the flux that creates this illumination:

$$L = \frac{dE}{d\omega}, \text{ cd/м}^2$$

Brightness at the point on the way distribution of elementary beam - the ratio of luminous flux, which is transferred by beam of radiation to the product of area sectional of the beam, solid angle, which is filled with luminous beam, the angle between the normal to the area of source and direction of radiation distribution:

$$L = \frac{d^2\hat{O}}{dA \cdot \cos\theta \cdot d\omega}, \text{ cd/м}^2$$

4. Efficiency

Coefficient of performance (efficiency) of lighting device is the ratio of its useful flux to the luminous flux of all light source of this lighting device:

$$\eta = \frac{\hat{O}_{usefull}}{\sum_{i=1}^{n} \hat{O}_{lamp}},$$

where n – number of lamps in the luminaire.

Useful flux of lighting device depends on the shape of the curve of light distribution of lighting device and characteristics of lighting objects.

For lighting devices, the all luminous flux which can be useful used, the efficiency is characterized by the ratio of total flux of lighting device to lamps flux:

$$\eta = \frac{\hat{O}_{LD}}{\sum_{i=1}^{n} \hat{O}_{lamp}}.$$

For floodlights taken useful flux that distribution within the scattering angle.

5. Amplification factor

Amplification factor (coefficient) is the value that characterizes amplification of lamp light in this direction by lighting devices.

Amplification factor of lighting device with axe-symmetric light source (incandescent lamp, mercury, metal halide, sodium lamps) is the ratio of the maximum luminous intensity of the device to the average spherical luminous intensity:

$$K_a = \frac{I_{max}}{I_{sph}}, \qquad I_{sph} = \frac{\hat{O}_{lamp}}{4\pi}.$$

Amplification factor of lighting device with linear light source (fluorescent lamp, tube discharge lamp) is the ratio of the maximum luminous intensity of the device to the maximum luminous intensity of the lamp:

$$K_a = \frac{I_{max}}{I_{lamp\,max}}, \qquad I_{max} = \frac{\hat{O}_{lamp}}{m_{lamp}},$$

m_{lamp} is a coefficient, which depending on the type of lamp:

m_{lamp} =9,25 – for fluorescent lamp,

$m_{lamp} = \pi^2$ – for sodium lamp,

m_{lamp} =11,0 – for metal halide lamp,

m_{lamp} =12,3 – for xenon lamp.

6. Spectral composition of radiation

The spectral distribution is determined by the light source and the design of the device.

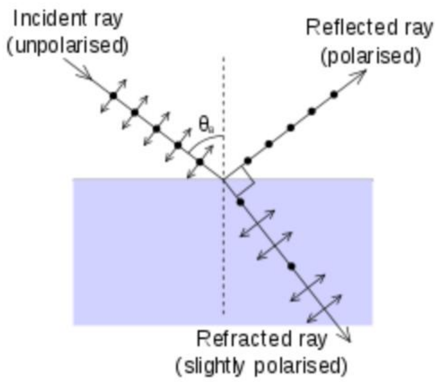
For the spectral composition lighting devices are divided:

1. Lighting devices with monochromatic (quasi-monochromatic, homogeneous) radiation:
- color LED;
- laser.

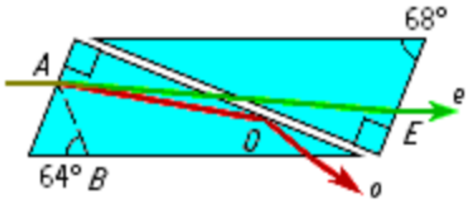
2. Lighting devices with multy-line distribution:
- fluorescent lamp;
- sodium lamp;
- metal halide lamp.

3. Lighting devices with continuous (continuous) distribution:
- thermal sources of light;
- white LED

7. Polarization of radiation



Mirror Brewster



Prism Nicolas

Having missed beam unpolarized light through a prism polarization receive two light beams, fluxes each of which make up half of luminous flux unpolarized radiation minus the transmittance of the prism. Luminous flux after passing through the second prism could decompose into fluxes $\hat{O}_1$ and $\hat{O}_2$:

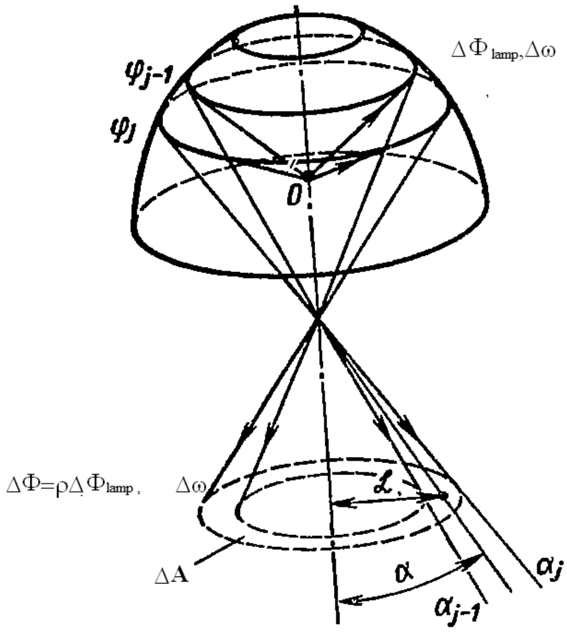
$$\hat{O} = \hat{O}_1 + \hat{O}_2 = \hat{O}\cos\Theta + \hat{O}\sin\Theta,$$

where Θ is the angle between the planes of the two main optical polarizing prisms.

Lecture 5

LIGHTING ENGINEERING CALCULATION METHODS OF LIGHTING

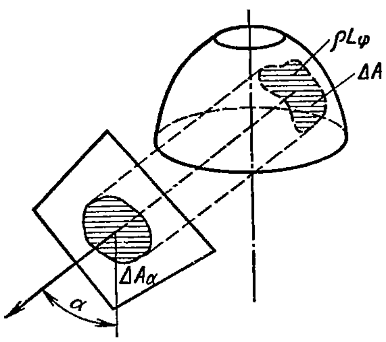
1. The method is based on the calculation of the luminous flux emitted by the light device in different areas of space or on different parts of the surface

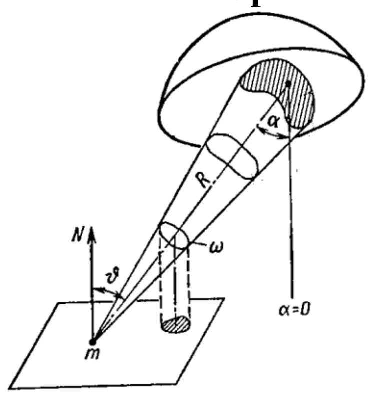


The method used for:

- point luminous body;
- uniform distribution of light flux in a certain area of space;
- for diffuse scattering optical devices;
- for lighting devices with a low luminous flux concentration and small and simple form of luminous bodies.

2. The methods are based on the calculation of the area and brightness of the lighting devices that visible light from some direction or supervision points





$$I_\alpha = \rho L A_\alpha$$

$$E = \rho L \Delta \bar{\omega}_{pr}$$

2.1. The method of optical imaging

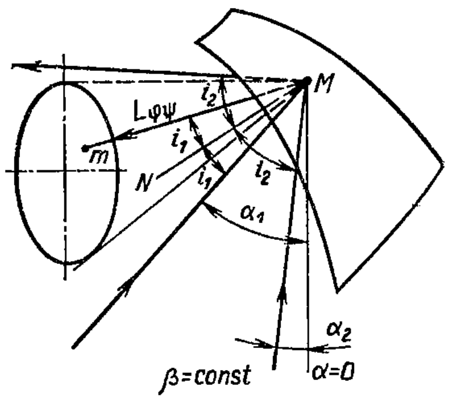
Consider each ray emanating from the luminous body source, and trace of its passing in the optical system. Basis of an analysis of the optical image source.

The peculiarity of the method: a clear image of the whole body and luminous glow all surface for points of lighting surface inside the image, and its complete extinction for points that are outside the image.

Disadvantages: The error due to the uneven surface of the reflector glow, bulkiness of theories and calculations.

2.2. Method of reverse move of the rays

It consists in calculating the brightness and light areas of the lighting devices, watching the move of the aggregate conditioned rays, which fall on the surface of the optical system from outside field of the chosen direction, using the rule of mirror reflection or refraction.



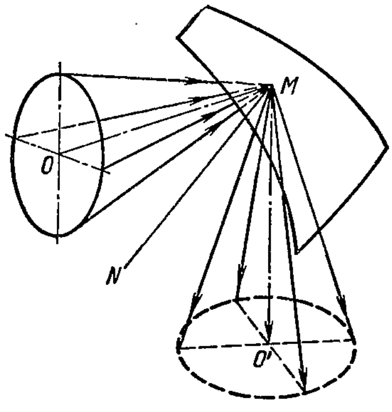
Advantages: high accuracy incorporation of shape, size and brightness of the luminous body, the ability to automate calculations.

Disadvantages: analysis of two sets - the points of luminous body and the reflector).

2.3. The method of elementary reflections

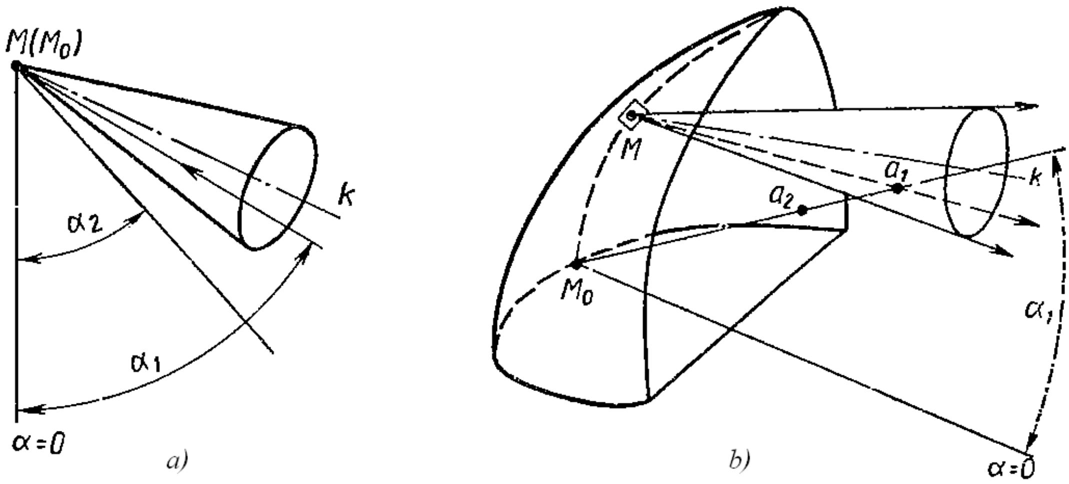
Sets ray of the source and the optical system are combined into a subset that gives a summary of all the points of the optical system and the properties of the luminous body source.

In the simplest conical grouping of beams believe that all the space is saturated with light rays that make up the conical beams with tops at the points of radiate or irradiate surfaces.



Elementary reflection (ER) is a conical beam falling from the luminous body to the point of the surface of the optical device and sent to him in the surrounding space.

The size form, position in space of beam of optical device determined by the size and form of the conical beam luminous body and the properties of the optical system.



Glow point M for: *a*) infinite distance, *b*) for a finite distance

Advantages of the method: allows for full and partial glow for different directions and distances, taking into account real placement of light rays in space, simplicity.

Disadvantages: the calculation of form and size ER require certain assumptions, analysis of ER placement by using the image plane, causing the error.

Lecture 6

THE FORM AND SIZE OF ELEMENTARY REFLECTIONS

<u>The extreme elementary reflection (ER) rays</u> are rays that are on the surface of the cone.

<u>The angular size of the ER</u> is the angle between the extreme beams in the plane that intersects the ER on its axis.

ξ is the angular size of ER in the meridional plane.

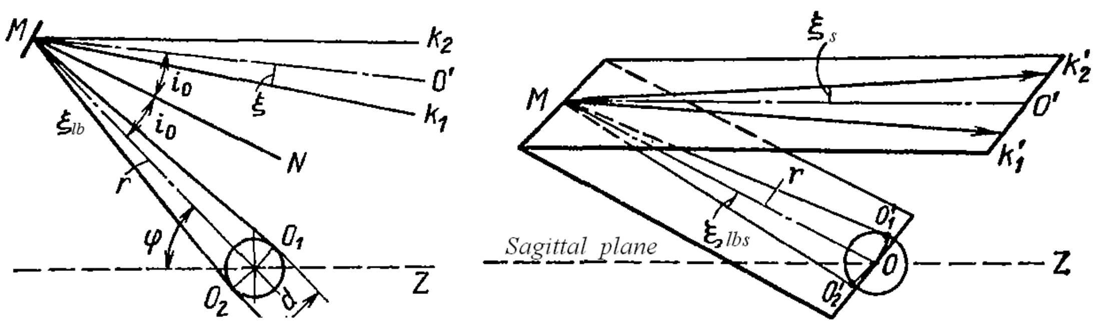
ξ_s is the angular size of ER in the sagittal plane.

ξ_{lb} is the angular size of the luminous body in the meridional plane.

ξ_{lbs} is the angular size of the luminous body in the sagittal plane.

In the incident radiation form and size of ER depend only on the form and sizes of visible luminous body.

1. Mirror element



For spherical luminous body: $2\xi_{lb} = 2\xi_{lbs} = 2\arcsin\dfrac{d}{2r}$,

where d is a diameter of the luminous body.

For $r \gg d$ $\quad \xi_{lb} \approx \dfrac{d}{2r}$

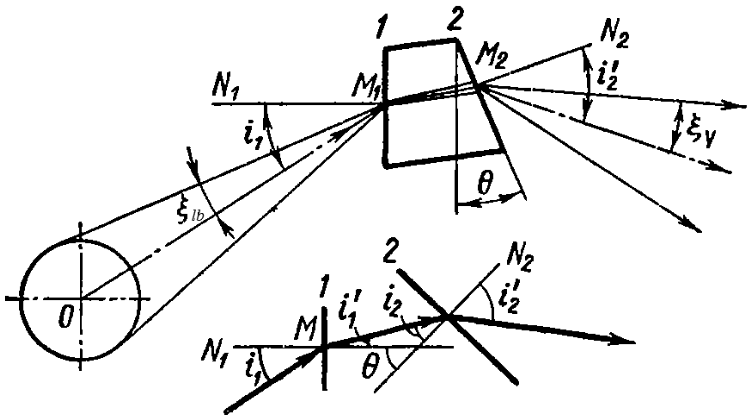
ER orientation in space is determined by direction of its axial beam MO', which is fixed coordinates (α,β). Point M fixed coordinates (φ,ψ). That is, for any optical device can be set depending on $\alpha(\varphi)$ and $\beta(\psi)$.

<u>Trace of elementary reflection</u> is the bright spot formed on the screen in the way of the rays of ER.

<u>Contour line of the trace of ER</u> is the locus of extreme traces rays of ER centered at p.O'.

2. Refractive element

Monochromatic luminous body



$$2\xi_V \neq 2\xi_{lb}$$

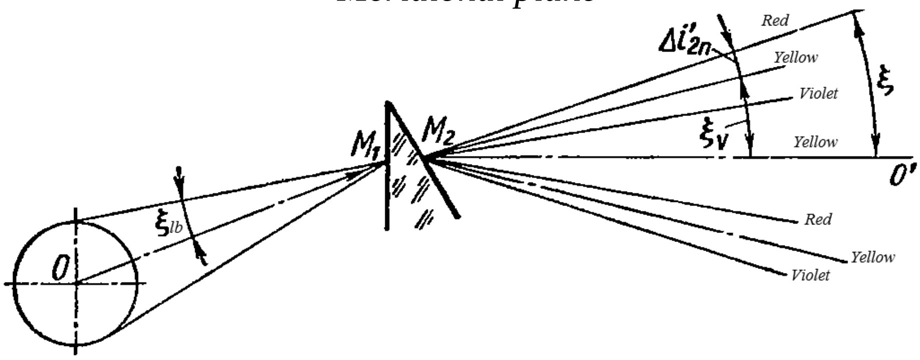
The refractive index $$V = \frac{\cos i_1 \sqrt{n^2 - \sin^2 i'_2}}{\cos i'_2 \sqrt{n^2 - \sin^2 i_1}}.$$

Depending on the relationship i_1 and i'_2 possibly $V > 1$ and $V < 1$

$$V = \frac{\xi_V}{\xi_{lb}}, \qquad \xi_V = V\xi_{lb}$$

Not monochromatic luminous body

Meridional plane



$$\xi = \xi_V + \Delta i'_{2n}, \qquad \xi = \xi_V + U\xi_{lb} = \xi_{lb}\left(V + U\right),$$

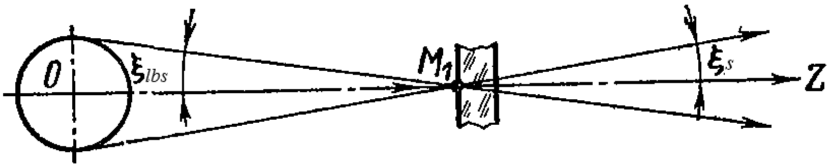
$\Delta i'_{2n} = \dfrac{\Delta n \sin\theta}{\cos i'_1 \cos i'_2}$ is the angle formed extreme violet and red rays with an angle which have $\lambda = 589$ nm;

Δn is a half of full dispersion equal to the increase in the index of refraction for violet and red radiation;

$U = \dfrac{i'_2}{\xi_{lb}}$ is an index of dispersion effects.

$$\left(V + U\right) > 1, \qquad \text{than} \quad \xi > \xi_{lb}$$

Sagittal plane



In the sagittal plane refractional consider planar element, i.e., refractive and dispersion effects are not taken into account, i.e.: $\xi_s = \xi_{lbs}$, $V = 1$, $U = 0$.

In sections, intermediate between the meridional and sagittal, the discrepancy between the size ξ and ξ_{lb} characterized by coefficients that lie within $(V+U)$...1.

For spherical luminous body ER has the form of elliptical cone with the major axis in the meridian and low axis in the sagittal plane.

3. Direct scattering element

If photometric scattering body is an ellipsoid of rotation $\left(\frac{v}{q} \le 0\right)$, each beam after reflection matted-mirror element is divided into many beams within the photometric body equally in all areas.

$$\xi = \xi_{lb}(1+W), \qquad \xi_s = \xi_{lbs}(1+W_s),$$

where $W = \frac{e_{sc}}{\xi_{lb}}$, $W_s = \frac{e_{sc}}{\xi_{lbs}}$ are the indicators of dispersion in the meridional and sagittal plane; e_{sc} is a half the scattering angle.

For refractive scattering element size ER also changing equally in all directions at an angle $2e_{sc}$. Besides take into account the refractive and dispersion effects.

4. Diffuse element

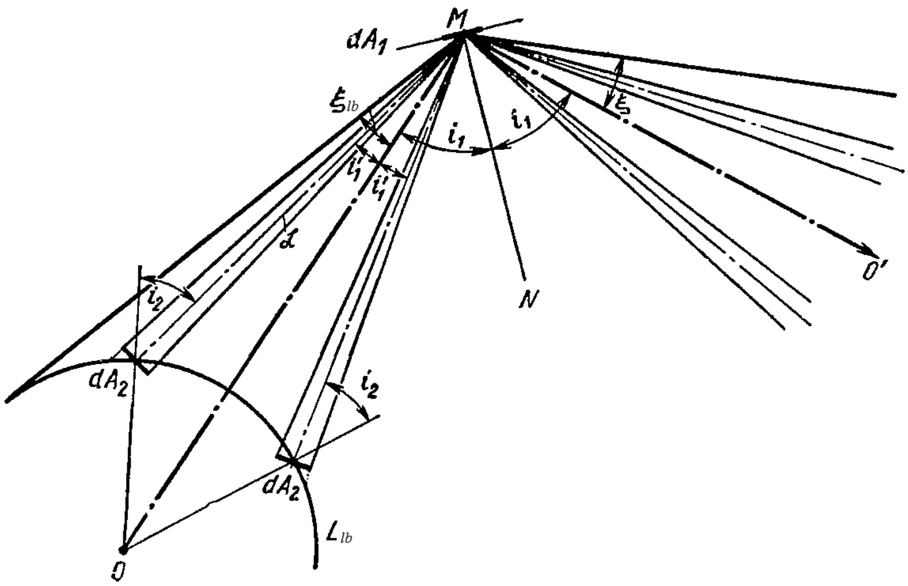
Form and size of ER does not depend on form and sizes of the incident ER. Opening angle of ER is 90°.

Angular size of elementary reflections

Type of optical element		Angular size of elementary reflections	
		Meridional plane	Saggital plane
Mirror		$\xi = \xi_{lb}$	$\xi_s = \xi_{lbs}$
Refractional		$\xi = \xi_{lb}(V+U)$	$\xi_{lb} = \xi_{lbs}$
Direct scattering	Reflectional	$\xi = \xi_{lb}(1+W)$	$\xi_s = \xi_{lbs}(1+W_s)$
	Refractional	$\xi = \xi_{lb}(1+W)(V+U)$	$\xi_s = \xi_{lbs}(1+W_s)$
Diffuse scattering		$\xi = 90^\circ$	$\xi_s = 90^\circ$

Lecture 7

LUMINOUS FLUX RAYS OF ELEMENTARY REFLECTIONS



Illumination of element dA_1 from some parts of the surface dA_2 of spherical luminous body with brightness $L_{lb} = const$:

$$dE = \frac{L_{lb} dA_2 \cos i_2}{2\mathcal{L}^2}\left[\cos\left(i_1 + i_1'\right) + \cos\left(i_1 - i_1'\right)\right]$$

Luminous flux falling from the part of source dA_2 to the part of the reflector dA_1:

$$d^2\hat{O} = dE dA_1 = L_{lb} dA_2 \cos i_2 \cos i_1 \cos i_1' \frac{dA_1}{\mathcal{L}^2}$$

$$d^2\hat{O} = L_c d^2 N = L_{lb} dN_1 dN_2,$$

where d^2N is measure of geometric rays:

$dN_1 = dA_1 \cos i_1$ is number of conical beams falling from the part of source dA_2 to the part of the reflector dA_1

$$N_1 = \int_{A_1} dA_1 \cos i_1;$$

$dN_2 = \dfrac{dA_2 \cos i_2 \cos i_1'}{\mathcal{L}^2}$ is number of rays in the beam,

$$N_2 = \int_{A_2} \frac{dA_2 \cos i_2 \cos i_1'}{\mathcal{L}^2} = \int_{\omega_{pr}} d\bar{\omega}_{pr} = \bar{\omega}_{prlb}$$

$\hat{O} = L_{lb} \int_{A_1} \int_{\omega_{pr}} dA_1 \cos_1 d\omega_{pr} = L_{lb} N_1 N_2$ is equation of light beams of elementary reflection.

BRIGHTNESS OF RAYS OF ELEMENTARY REFLECTIONS

I. Mirror and refractional elements

Luminous flux falling on an element of the ideal mirror surface:

$$d\hat{O}_{fall} = L_{lb}\pi \sin^2 \xi_{lb} dA_1 \cos i_1$$

After the reflection:

$$N_1 = dA_1 \cos i_1, \qquad N_2 = \pi \sin^2 \xi_{lb}.$$

Since $d\hat{O} = \rho d\hat{O}_n$, then $L = \rho L_{lb}$.

For equally bright luminous body brightness of rays of elementary reflection of mirror reflection is constant.

For unequally bright - like the distribution of the brightness of rays falling of elementary reflection.

For refractive element made of ideal transparent optical glass and *monochromatic* radiation:

$$L = \tau L_{lb}$$

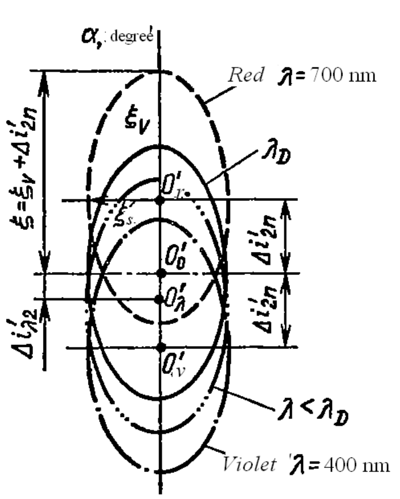
For non-monochromatic radiation the elementary reflection consists of a set of monochromatic ER shifted in the meridional plane at some angles.

The brightness of the beam in a certain direction is the sum of monochromatic brightness ER in the same direction.

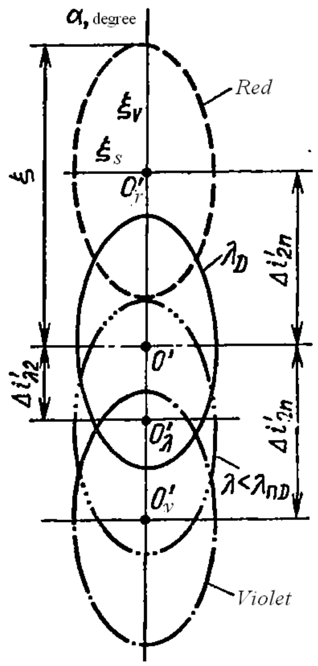
Traces of elementary reflection for refractive element

$$\xi = \xi_V + \Delta i'_{2n}$$

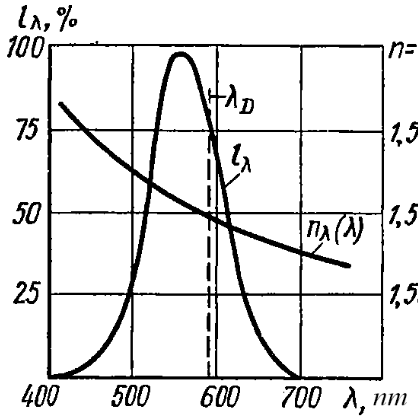
$\xi_V > \Delta i'_{2n}$



$\xi_V < \Delta i'_{2n}$



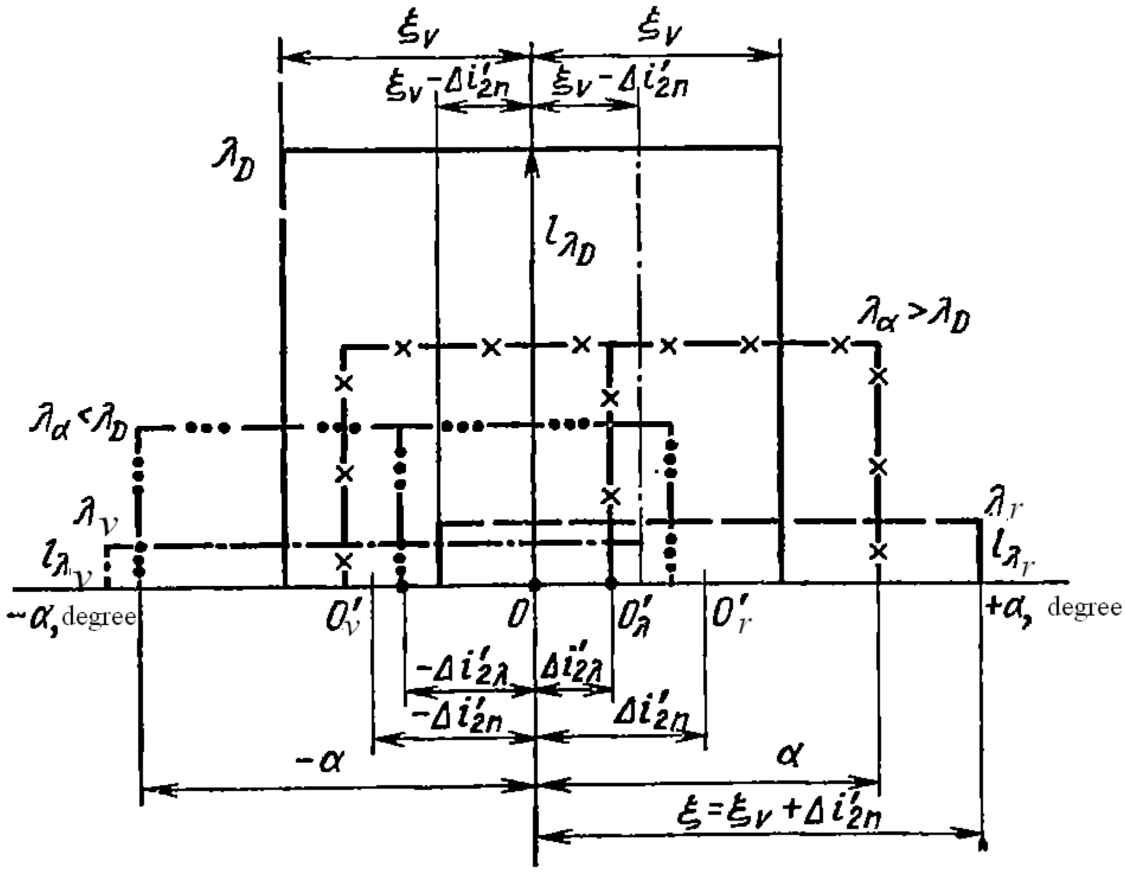
$\lambda_D = 589{,}3$ nm – average wavelength (Fraunhopher lines)



Spectral density curves of brightness $l_\lambda(\lambda)$ and dispersion $n_\lambda(\lambda)$

Each ER represent as rectangle with a height l_λ and length $2\xi_V$. The value α is determined by the dispersion shift $\Delta i'_{2\lambda}$. $\alpha = 0$ for the rectangle with λ_D.

Calculation of brightness of rays at $\xi_V > \Delta i'_{2n}$

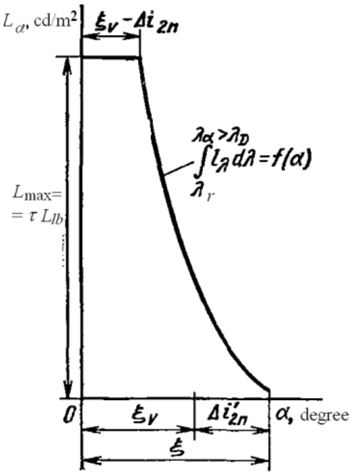


In all angles $0 \le \alpha < (\xi_V - \Delta i'_{2n})$ all ER of λ_{red} to λ_{violet} covers these directions and the total brightness of rays ER equal brightness luminous body (at $\tau = 1$).

For angles $(\xi_V - \Delta i'_{2n}) < \alpha \le (\xi_V + \Delta i'_{2n})$ number of monochromatic ER is different, but for all directions is the component λ_{red} that is the lower limit of integration $l_\lambda(\lambda)$ is λ_{red}.

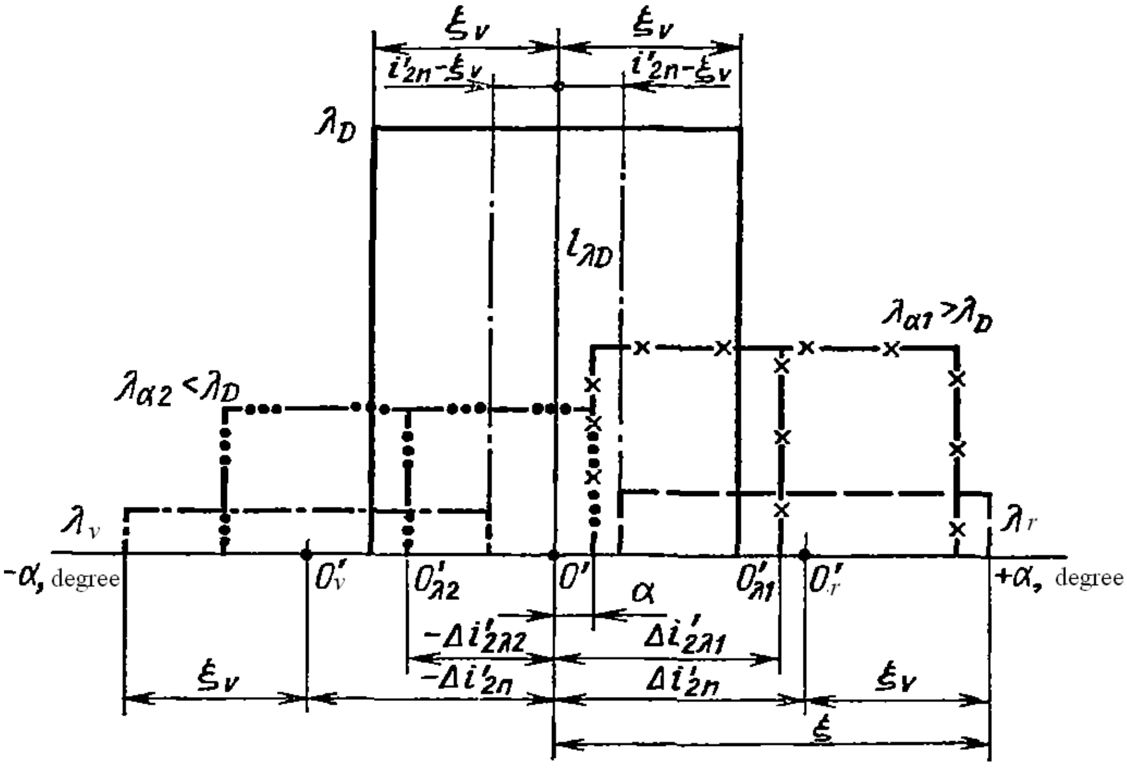
To find the upper limit of integration find the ER with wavelength λ_α, boundary beam which coincides with the selected direction. To do this:

- find the angle of displacement ER in a given direction: $\Delta i'_{2\lambda} = \alpha - \xi_V$;
- find the value of dispersion: $\Delta n_\lambda = \dfrac{\Delta i'_{2\lambda} \cos i'_1 \cos i'_2}{\sin\theta}$;
- find λ_α at dispersion curve and Δn_λ.



$L_\alpha = \int_{\lambda_÷}^{\lambda_\alpha} l_\lambda d\lambda$ is the law reducing the brightness rays of ER in the profile plane of refractive element

Calculation of brightness of rays at $\xi_V < \Delta i'_{2n}$



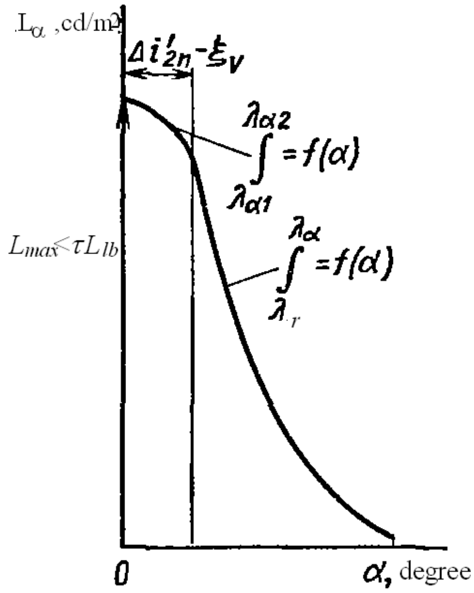
Inside ER no directions, overlapping all monochromatic ER. Therefore, the maximum brightness can not be equal to the brightness of the luminous body.

Direction α do not overlap either red or violet rectangles that is why boundaries of integration will be $\lambda_{\alpha 1}$ and $\lambda_{\alpha 2}$. They are follows as:

- find the angles of displacement ER in given direction on the right and left:

$\Delta i'_{2\lambda 1} = \alpha + \xi_V$; $\Delta i'_{2\lambda 2} = \alpha - \xi_V$;

- find the value of dispersion: $\Delta n_{\lambda 1}$ and $\Delta n_{\lambda 2}$;
- find $\lambda_{\alpha 1}$ and $\lambda_{\alpha 2}$ at dispersion curve and Δn_{λ}.

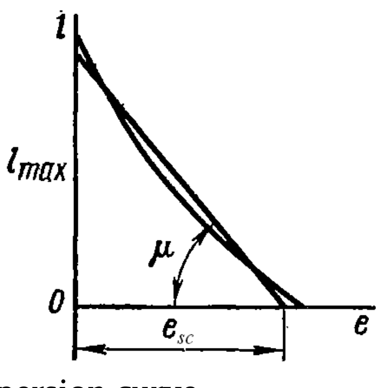


For direction $0 \le \alpha < \left(\Delta i'_{2n} - \xi_V\right)$ $\quad L_\alpha = \int\limits_{\lambda_{\alpha 1}}^{\lambda_{\alpha 2}} l_\lambda d\lambda$

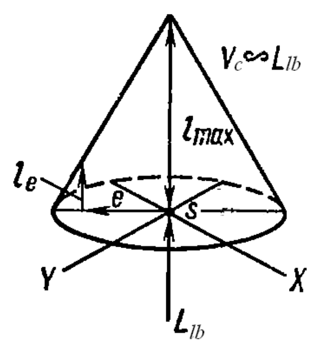
For direction $\alpha > \left(\Delta i'_{2n} - \xi_V\right)$ $\quad L_\alpha = \int\limits_{\lambda_r}^{\lambda_\alpha} l_\lambda d\lambda$

Traces of ER for directed-scattering element

Let the surface – mirror matted, body of scattering – ellipsoid with $\frac{v}{q} \le 0{,}05$. Distribution of brightness of rays of scattering $l(e)$ – linear and circular symmetrical.



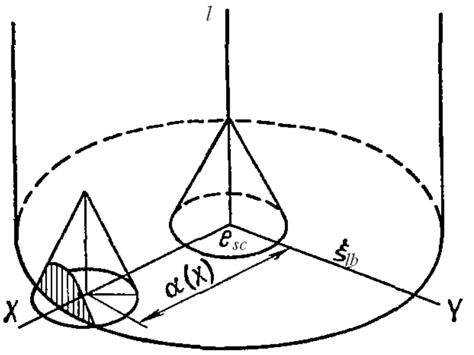
Dispersion curve



Cone of scattering

Amount brightness of rays of is proportional to the volume of a cone of scattering and brightness of the incident beam of source.

$e_{sc} < \xi_{lb}$



To find the brightness in the direction α find the set of rays that coincide with this direction. Measure of rays – the area of the figure placed inside the curve described by the center of the circle of scattering related to point *a.*

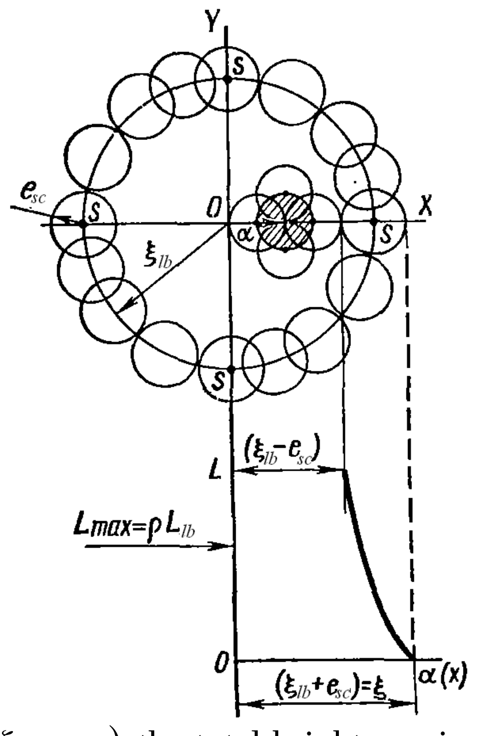
The brightness of the ray of ER reflected in the direction α equal to the sum of brightness rays that are based on the point of indicated figure. The total brightness:

$$L = C\int_X \int_Y \int_l l_e dxdydl = C\iiint_V l_e dxdydl ,$$

where C is a coefficient of proportionality,

X, Y are the axis of angular distances α,

l_e is a relative brightness value.

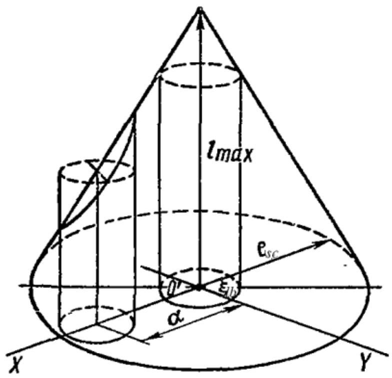


For angles $0 \le \alpha < \left(\xi_{lb} - e_{sc}\right)$ the total brightness is proportional to the volume of a cone of scattering V_{cone}, i.e. for these angles $L_\alpha = \rho L_{lb} = const$.

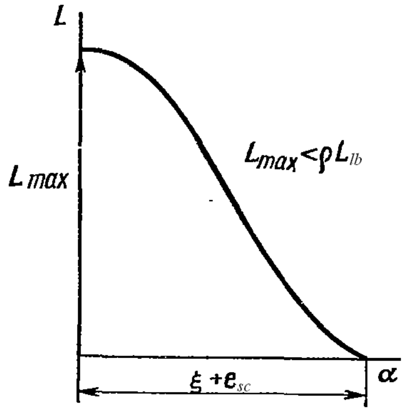
For angles $\left(\xi_{lb} - e_{sc}\right) < \alpha < \left(\xi_{lb} + e_{sc}\right)$ brightness is $L_\alpha = L_{lb}\dfrac{V'_\alpha}{V_{cone}}$,

where V'_α is a volume part of cone inside the cylinder with base equal to the diameter of a luminous body, whose center is at coordinate origin $\left(X, Y, l_e\right)$.

$$e_{sc} > \xi_{lb}$$

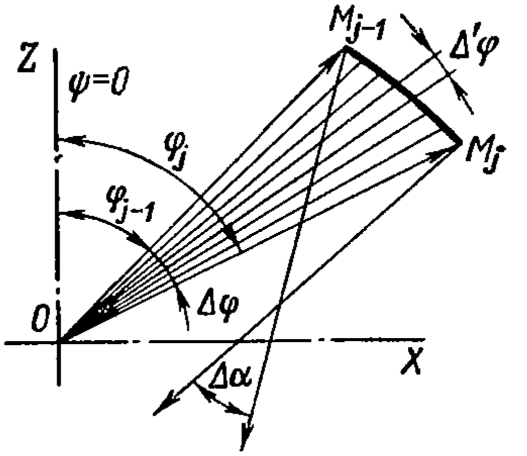


Law reducing the brightness rays of reflected ER described by law of reducing the volume of the body, cut the cylinder of the cone.

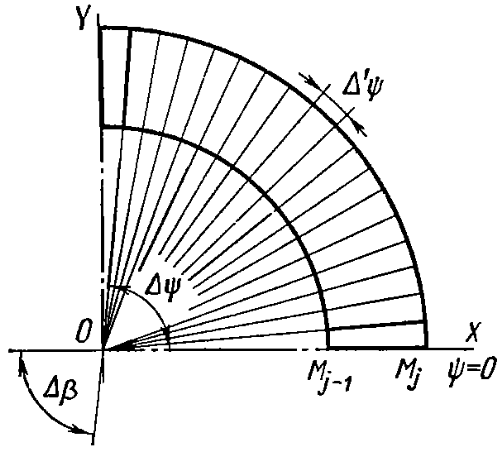


$$L_{\max} = \frac{3\rho L_{lb}\xi_{lb}^{2}\left[\left(e_{sc} - \xi_{lb}\right) + \frac{\xi_{lb}}{3}\right]}{e_{sc}^{3}} < \rho L_{lb}$$

Lecture 8
FILL FACTOR OF THE SURFACE OF OPTICAL DEVICES BY LIGHT PART



The division of zone $\Delta\varphi$ into a number of sections $\Delta'\varphi$



The division of zone into a number of elements $\Delta'\varphi\Delta'\psi$

Number of sections is

$$N = \frac{\Delta\varphi\Delta\psi}{\Delta'\varphi\Delta'\psi},$$

where $\Delta\psi$ is the girth angle of zone in the transverse plane (for circular symmetric zone $\Delta\psi$ =360°)

Area of element zone of mirror reflector:

$$\Delta A_{\varphi\psi} = \frac{\Delta'\varphi\Delta'\psi\sin\varphi_{av}}{\cos i'_{av}\cos i''_{av}} r_{av}^2,$$

where i'_{av}, i''_{av} are projections of angles of beam incidence on the midpoint of the element on the meridian and equatorial plane.

For $\Delta\varphi < 10^\circ$ $\Delta A_{\varphi\psi} = const$ for all zone:

$$A_{\varphi\psi} = \sum_{k=1}^{N} \Delta A_{\varphi\psi k} \approx N\Delta A_{\varphi\psi k}$$

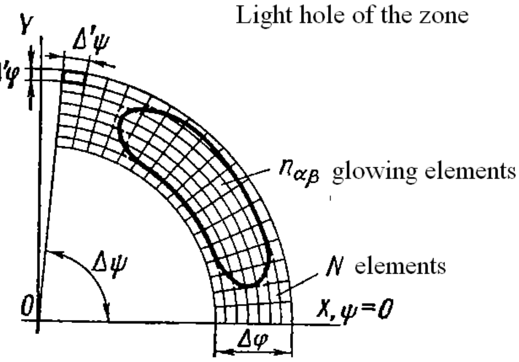
In the separation zone in the N elements its light part is divided into $n_{\alpha\beta}$ elements.

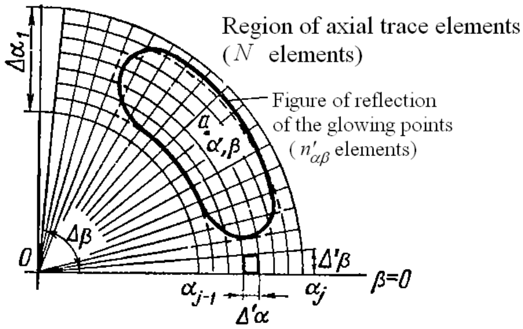
Area of the light part of zone

$$A_{\alpha\beta} = n_{\alpha\beta}\Delta A_{\varphi\psi}$$

Fill factor of the surface of optical devices by light part:

$$K_{\alpha\beta} = \frac{A_{\alpha\beta}}{A_{\varphi\psi}} = \frac{n_{\alpha\beta}}{N}$$





The light hole of zone The figure of light points reflected

Sizes sections determined as follows:

$$\frac{\Delta\varphi}{\Delta'\varphi} = \frac{\Delta\alpha}{\Delta'\alpha}, \quad \Delta'\alpha = \frac{\Delta'\varphi}{\Delta\varphi}\Delta\alpha,$$

$$\frac{\Delta\psi}{\Delta'\psi} = \frac{\Delta\beta}{\Delta'\beta}, \quad \Delta'\beta = \frac{\Delta'\psi}{\Delta\psi}\Delta\beta,$$

than $N = \dfrac{\Delta\alpha\Delta\beta}{\Delta'\alpha\Delta'\beta}$.

Area of luminous part of the surface area for direction α is follow:

$$A_\alpha = K_{\alpha\beta} A_\varphi,$$

where A_φ is an area of zone surface.

Lecture 9

SPOTLIGHTS WITH MIRROR REFLECTOR

Types of spotlights:

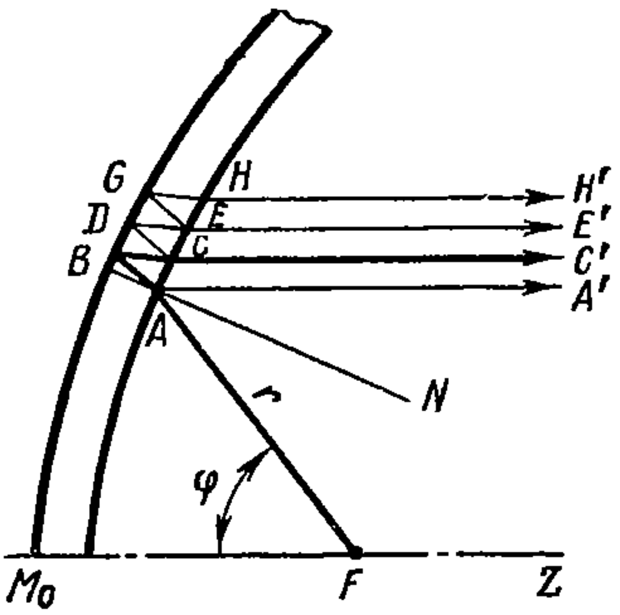
1. **Spotlights of long-range:** light beam is conical, axial luminous intensity I_0 is large, angle of radiation $2\varphi_{max}$ is small.
2. **Floodlight:** the light beam is fan-shaped, axial luminous intensity I_0 is small, the angle of radiation $2\varphi_{max}$ is small, the angle of radiation $2\psi_{max}$ is great.
3. **Headlights:** light beam is specifically, the axial intensity I_0 is small, radiation angles are great.
4. **Signal searchlights** ((a) light beacons, (b) light signaling devices (c) traffic lights), the light beam is conical, axial luminous intensity I_0 is large, angle of radiation $2\varphi_{max}$ is small.

Co-paraboloid

Co-paraboloid is light device with glass reflector, the back side of which is covered by reflecting coating.

The first and the second reflector facets have not the same form. The curvature of the facets is calculated so that all the focal rays after refraction, passing through the glass and reflection from the reflective layer go parallel to the optical axis of devices.

For co-paraboloid geometric thickness of the reflector is different, and the optical – constant.



The first component – rays AA', $\rho_1 = 4,4\%$ (at $n = 1,53$)

The second component – rays CC', $\rho_2 = 72,9\%$ (at $\tau = 0,97$, $\rho_{\grave{\imath}} = 0,92$)

The third component – rays EE', HH' … $\rho_3 = 3,1\%$.

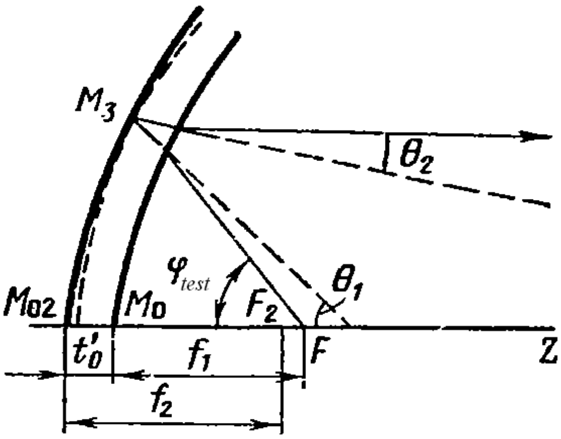
Total reflection coefficient is $\rho_\Sigma = 86,7\%$/

Double paraboloid

The first and the second reflector facets have the same form.

The curvature and thickness of the double paraboloid is calculated so that there is at least one point of contact between the reflective faces and co-paraboloid calculated for internal face.

For double paraboloid optical thickness of the reflector is different, and the geometric – constant.



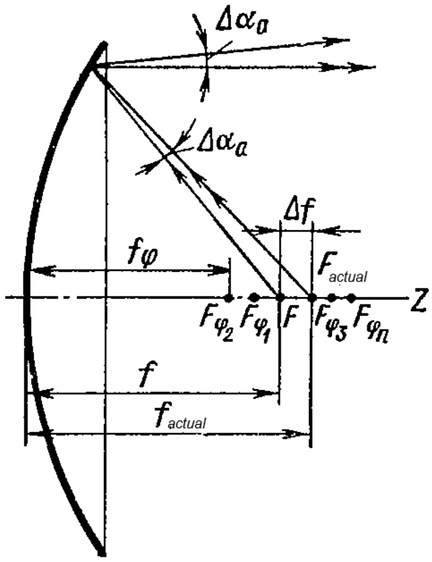
f_1 – the focal length of the front surface

f_2 – the focal length of the back surface, $f_2 = \dfrac{X_3}{2tg\dfrac{\theta_1 + \theta_2}{2}}$

$$t_0' = \frac{X_3^2}{4f_2} - Z_3$$

Lecture 10

ABERRATION OF A PARABOLOID REFLECTOR

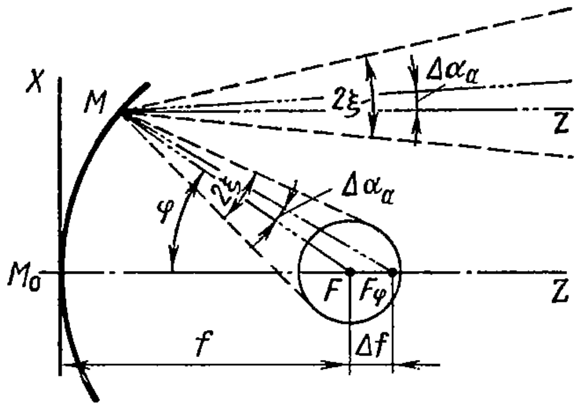


Aberration – it's not-coincidence of the focuses of individual sections of the reflector.

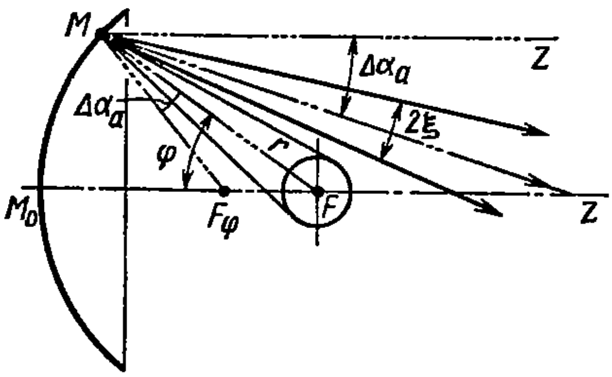
The angular aberration for spherical luminous body is follow:

$$\alpha_a = \Delta f \frac{\sin(\varphi \pm \Delta\alpha_a)}{r} \simeq \Delta f \sin\frac{\varphi}{2} = \frac{\Delta f}{f}\cos^2\frac{\varphi}{2}\sin\varphi$$

Influence of longitudinal aberration on a basic reflection



Positive aberration ($+\alpha_a$)

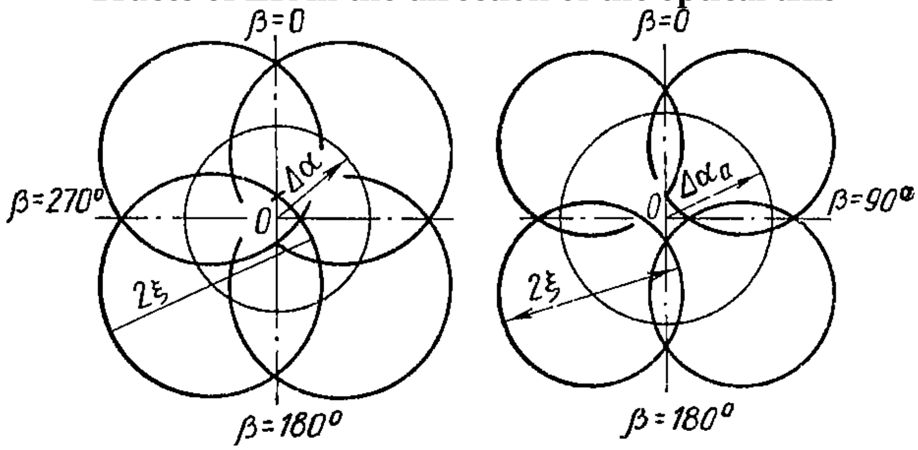


Negative aberration ($-\alpha_a$)

Sign of the angular aberration is important for the close range and when $\Delta\alpha_a > \xi$. When aberration is negative, the point M is lighting on the areas of the optical axis on which ER crossed it. When aberration is positive, the point M does not lighting at moving along the optical axis for any distance from the lighting device.

Since $\Delta f \ll r$ then $MF \simeq MF_\varphi$, that the size and form of ER are independent of aberration.

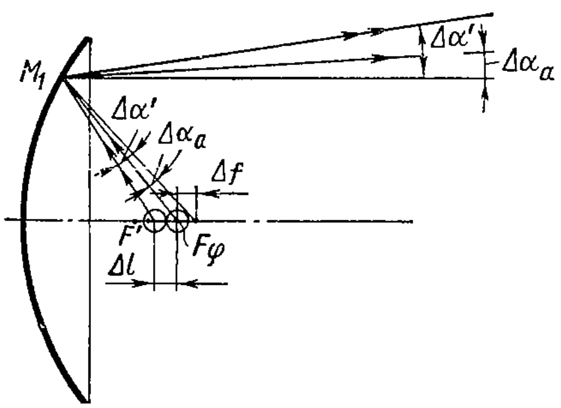
Traces of ER in the direction of the optical axis

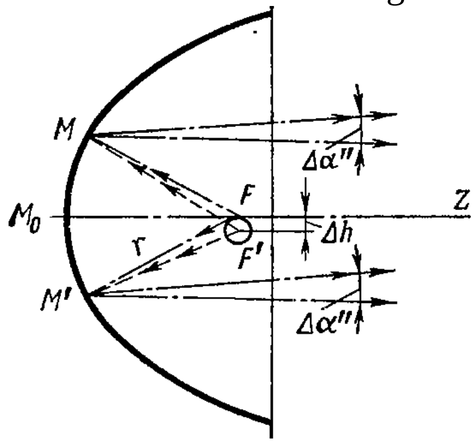


$\Delta\alpha_a < \xi$ $\Delta\alpha_a > \xi$

Defocusing of paraboloid reflector

Longitudinal defocusing Δl Transverse defocusing Δh





Conventional angular aberration is $\Delta\alpha_a' = \dfrac{\Delta f'}{r'}\sin\varphi$,

$\Delta f' = \Delta f \pm \Delta l$, $r' = \sqrt{r^2 - 2r\cos\varphi + (\Delta f')^2}$.

Angular transverse defocusing is $\Delta\alpha_a'' = \dfrac{\Delta h}{r}\cos\varphi$

The actual focus of the paraboloid reflector F_{actual}

The coefficient of the light values zones is $G_\varphi = \dfrac{I_\varphi}{I_0} = \dfrac{\rho L_\varphi A_{\varphi lh}}{\rho\sum L_\varphi A_{\varphi lh}}$.

For equally bright luminous body $G_\varphi = \dfrac{A_{\varphi lh}}{A_{lh}}$.

Aberration coefficient is $G_\alpha = \dfrac{\Delta\alpha_a}{\xi}$.

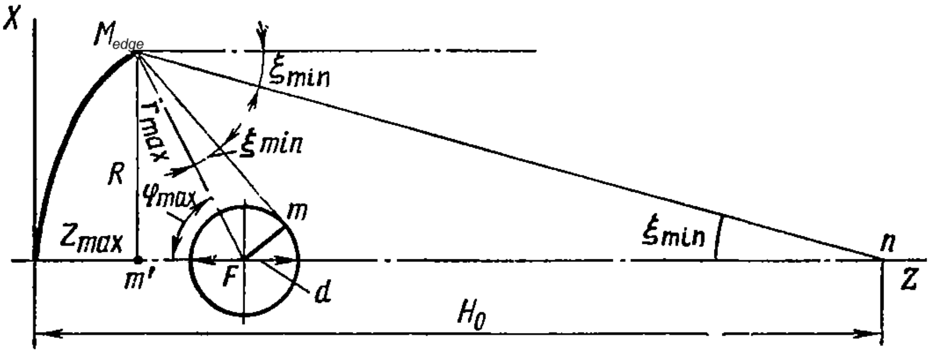
The actual focal distance is $f_{actual} = \dfrac{\sum G_\alpha G_\varphi f_\varphi}{\sum G_\alpha G_\varphi}$.

Lecture 11

FORMATION OF PARABOLOID REFLECTOR LIGHT BEAM

1. Distance of full glow

Globular equally bright luminous body



For p. M_{edge} the distance of full glow is $$H_0 = R ctg\xi_{\min} + Z_{\max}$$

From the triangle $M_{edge}Fm$: $$ctg\xi_{\min} = \frac{\overline{M_{edge}m}}{\overline{Fm}} = 2\frac{\sqrt{r_{\max}^2 - \frac{d^2}{4}}}{d}.$$

Since $r_{\max} = f + Z_{\max}$, $Z_{\max} = \dfrac{R^2}{4f}$

$$H_0 = \frac{D\sqrt{\left(f + \frac{D^2}{16f}\right)^2 - \frac{d^2}{4}}}{d} + \frac{D^2}{16f}.$$

If $d << r$, than $\overline{M_{edge}m} = r$

$$H_0 = \frac{D\left(f + \frac{D^2}{16f}\right)}{d} + \frac{D^2}{16f}.$$

Since $r_{\max} = \dfrac{D}{2\sin\varphi_{\max}}$, than $H_0 = \dfrac{D^2}{2d\sin\varphi_{\max}}$.

Globular not-equally bright luminous body

If the brightness decreases from the center of the luminous body to the edge, then:

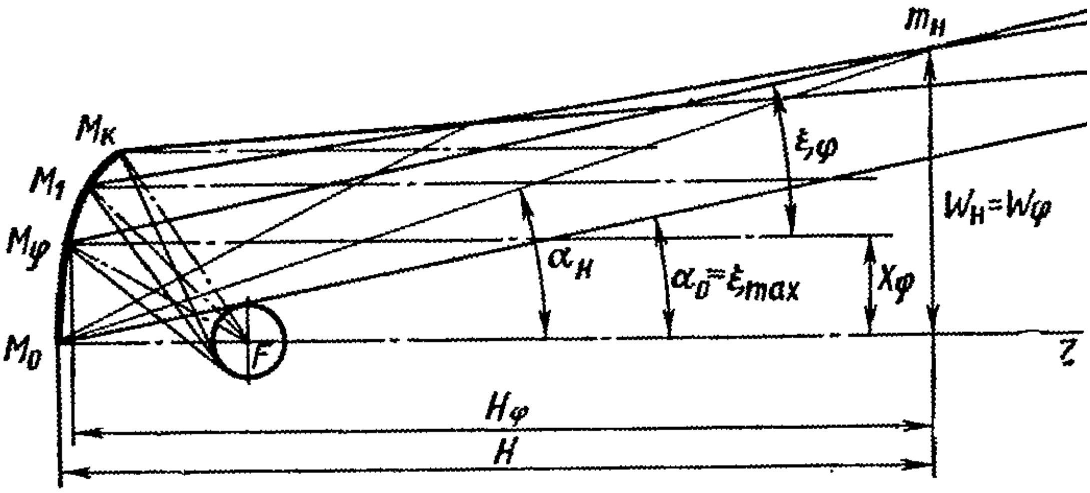
axial beam brightness is $L_{\max}$

edge beams brightness is $L_{\min}$

H_0 determined by the point at which the edge rays of ER of p. M_{edge} cross the optical axis.

For $H > H_0$ $L \uparrow$ and $H_0 \Rightarrow \infty$

2. **The width of the light beam**



$2W_H$ is linear width of the light beam

$2\alpha_H$ is angular width of the light beam

$2\alpha_0 = 2\xi_{\max}$ is true angular width of the light beam

$$tg\alpha_H = \frac{X_\varphi + H_\varphi tg\xi_\varphi}{H_\varphi} = \frac{X_\varphi}{H_\varphi} + tg\xi_\varphi,$$

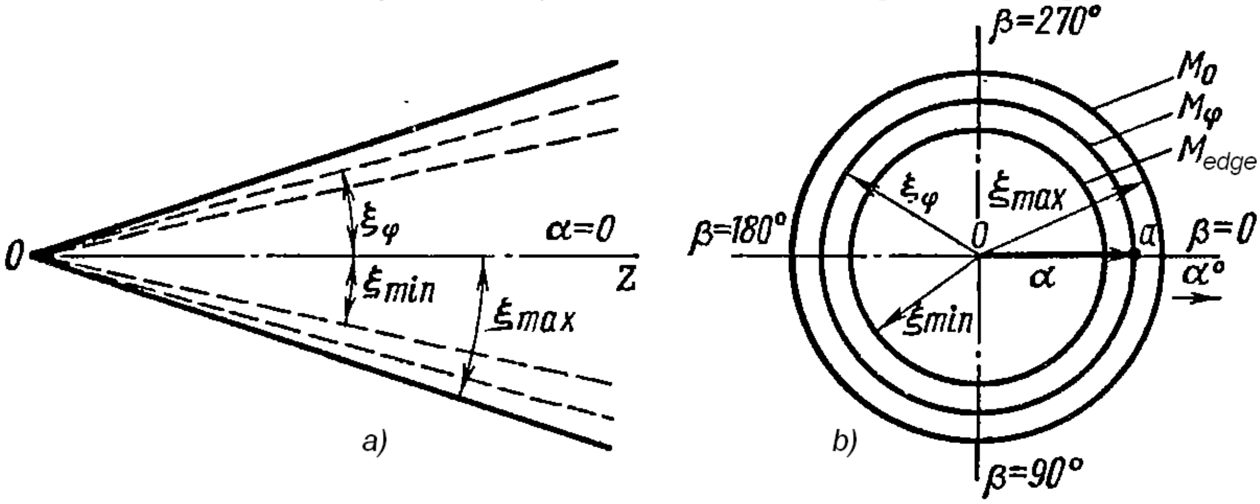
X_φ – coordinate of a point reflector edge beam ER which comes on the edge of the light beam at a distance H_φ.

Calculation of IDC (Luminous intensity distribution curve) of the paraboloid mirror reflector

Law by Manzhen (for axial luminous intensity)**:** $I_0 = kL_{lb}A_{lh}$

1. Analytical calculation of IDC

Sectional of the light beam by meridional (a) and equatorial (b) planes



For p.M_0 $\xi_{\max} = \dfrac{d}{2f}$, for p.$M_к$ $\xi_{\min} = \dfrac{d\cos^2\dfrac{\varphi_{\max}}{2}}{2f}$

For $0 \le \alpha < \xi_{\min}$ the whole active surface of the reflector glows, $I_0 = I_{\max} = const$,

For $\alpha > \xi_{\min}$ only part of the reflector glows from top to p. M_φ with $\xi_\varphi = \alpha$,

for $\alpha = \xi_{\max}$ surface of the reflector is not glows.

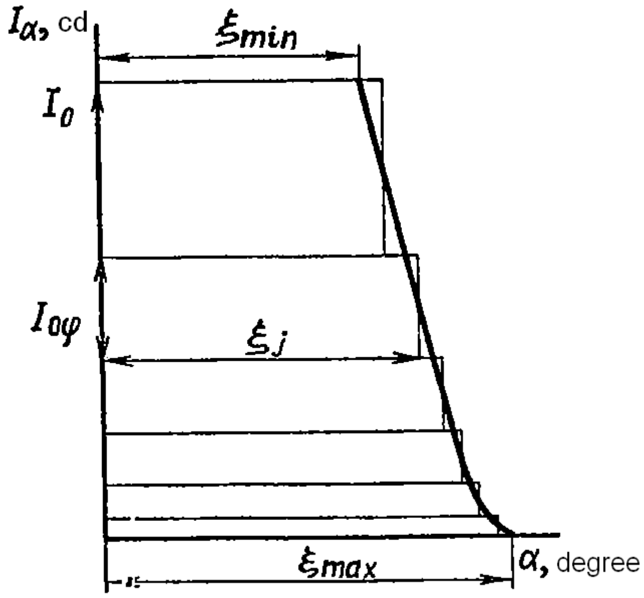
Taking a $\alpha = \dfrac{d}{2f}\cos^2\dfrac{\varphi_\alpha}{2} = \xi_{\max}\cos^2\dfrac{\varphi_\alpha}{2}$, $\dfrac{\varphi_\alpha}{2} = \arccos\sqrt{\dfrac{\alpha}{\xi_{\max}}}$

Luminous intensity in the direction α is $I_\alpha = \rho L_{lb} \cdot 4\pi f^2 tg^2 \dfrac{\varphi_\alpha}{2}$.

2. Zonal method for calculating luminous intensity distribution curve

The order of calculation:

1. The surface of reflector is divided into zones $\Delta\varphi_j = (\varphi_j - \varphi_{j-1})$
2. Calculate the area of zone light hole $A_{lh\varphi} = 4\pi f^2 \left(tg^2 \frac{\varphi_j}{2} - tg^2 \frac{\varphi_{j-1}}{2} \right)$
3. Calculate the axial luminous intensity of zone: $I_{0\varphi} = \rho L_\varphi A_{lh} = \rho L_\varphi \cdot 4\pi f^2 \left(tg^2 \frac{\varphi_j}{2} - tg^2 \frac{\varphi_{j-1}}{2} \right)$
4. Calculate the size of elementary reflections: $\xi_j = \frac{d}{2f} \cos^2 \frac{\varphi_{av}}{2}$ (globular luminous body)
5. Determine the fill factor K_α
6. Build a zonal IDC. For globular luminous body zonal IDC is a rectangle with height $I_{0\varphi}$ and foundation ξ_j.
7. The amount zonal IDC.

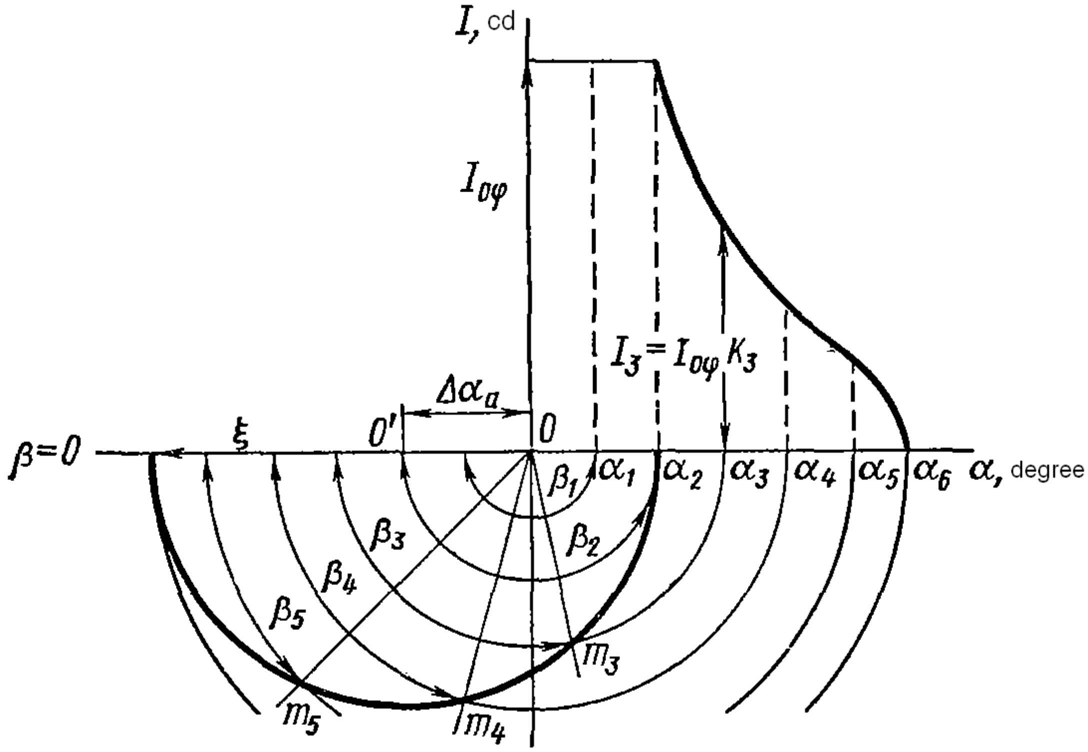


Total IDC of the reflector with equally bright globular body

Calculation of IDC of aberrational reflector

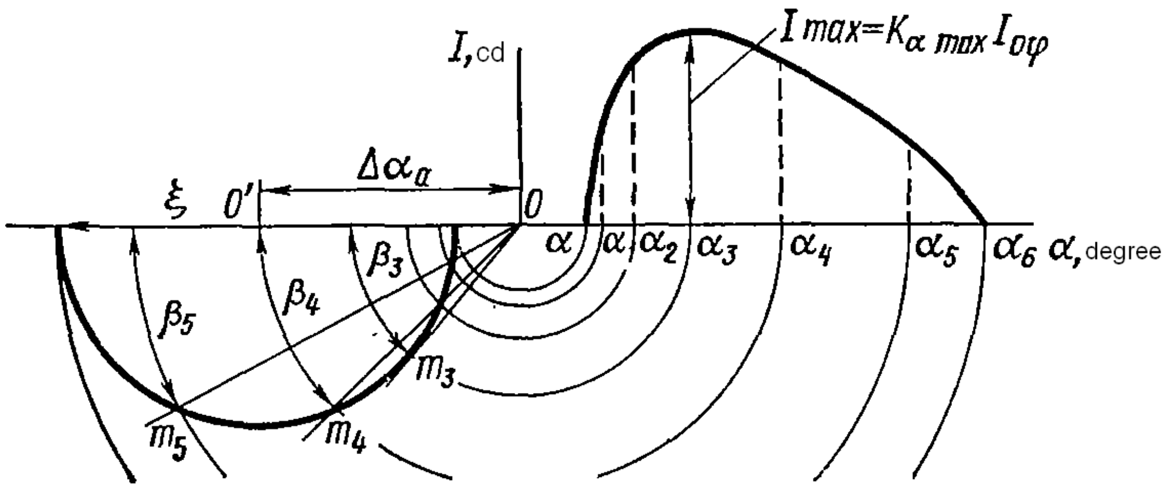
Globular luminous body

$\Delta\alpha_a < \xi$

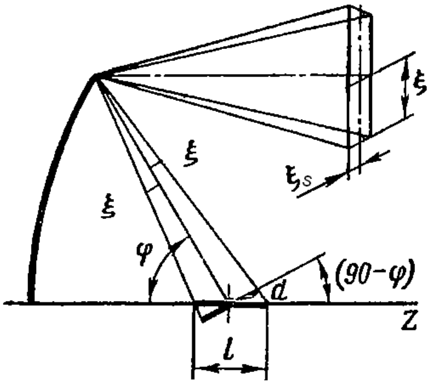


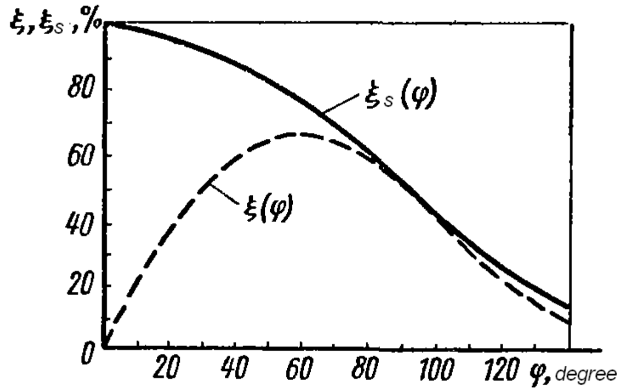
$$K_{\alpha i} = \frac{\beta_i}{180}, \quad I_{\varphi i} = K_{\alpha i} I_{0\varphi}$$

$\Delta\alpha_a > \xi$



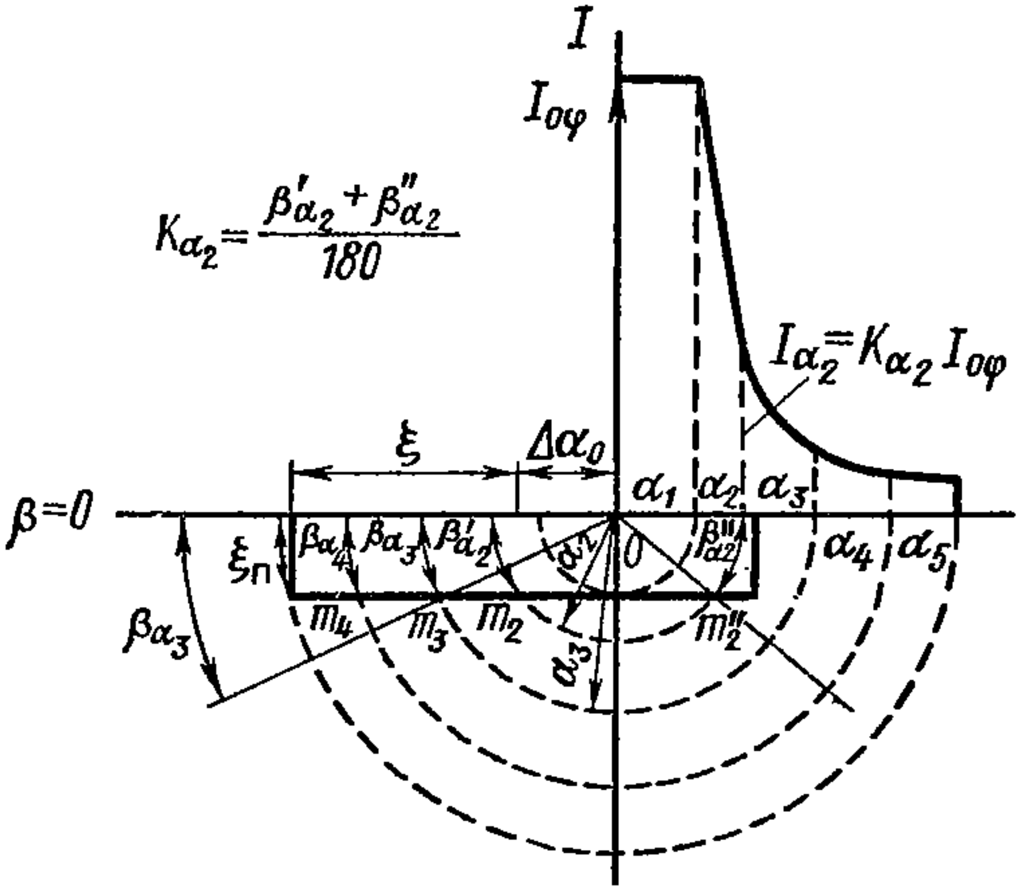
Cylindrical luminous body



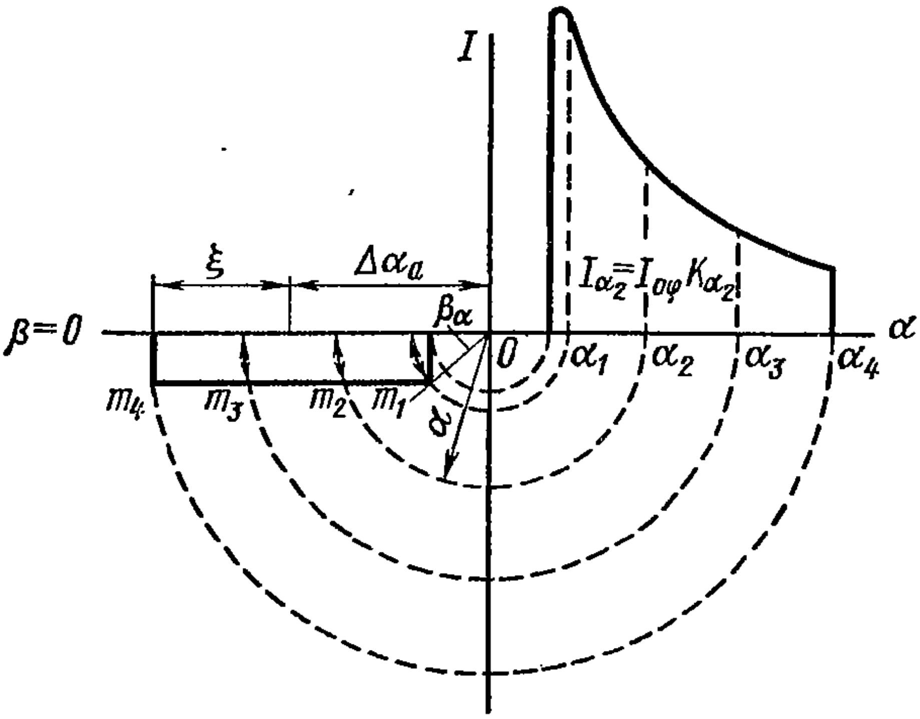


$$\xi = \frac{l}{2f}\sin\varphi\cos^2\frac{\varphi}{2}, \qquad \xi_s = \frac{d}{2f}\cos^2\frac{\varphi}{2}$$

$$\Delta\alpha_a < \xi$$



$$\Delta\alpha_a > \xi$$

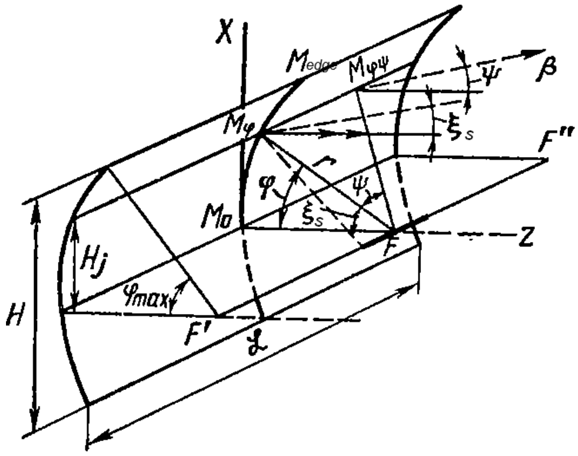


Luminous intensity zone: for $\alpha > \xi_s$ decrease sharply for $\alpha > \dfrac{\xi}{2}$ decreasing smoothly, for $\alpha \in \left(\xi; \sqrt{\xi^2 + \xi_s^2}\right)$ sharply reduced to zero.

Lecture 12

SPOTLIGHT PARABOLO-CYLINDRICAL (SPOTLIGHT FLOODING LIGHT)

Spotlight with continuous reflector

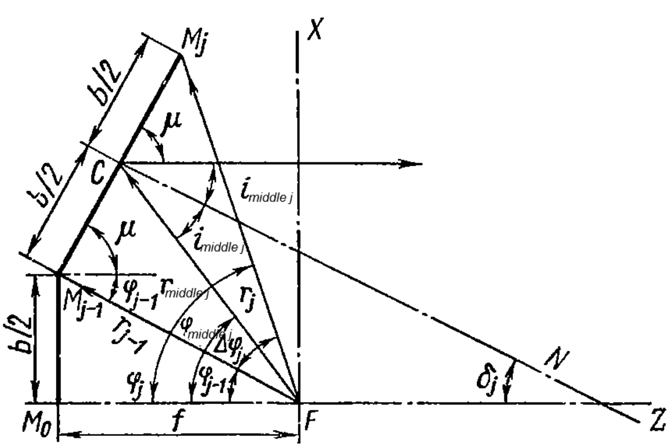


<u>Parameters of reflector:</u>

1. Meridional (profile) planes
2. The focal line (longitudinal axis)
3. Equatorial (focal) plane
4. Longitudinal planes
5. The length and the height of the reflector
6. The radius vector of the point of the reflector

$$r_{\varphi\psi} = \frac{r_\varphi}{\cos\psi} = \frac{f}{\cos^2\frac{\varphi}{2}\cos\psi}, \ \varphi = arctg\,\frac{H_j}{f-z}; \quad \psi = arctg\,\frac{\mathscr{L}_j}{f+z}$$

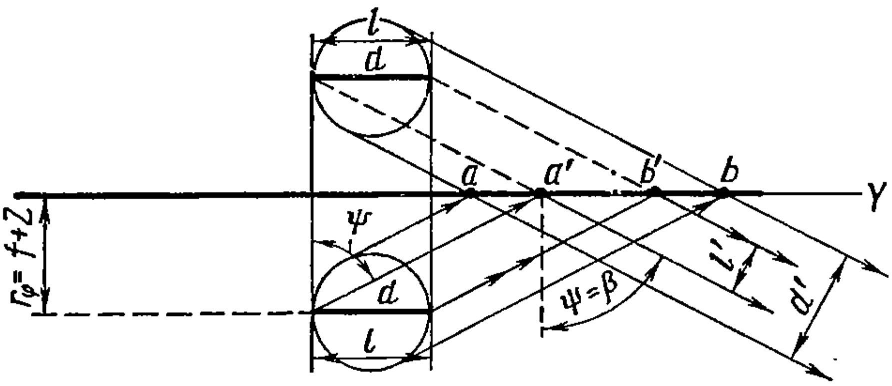
Lamellar (Plates) parabolo-cylindrical reflector



$\underline{b \neq const, \quad 2\alpha_{irr} = const}$	$\underline{b = const, \quad 2\alpha_{irr} \neq const}$
$\Delta\varphi_j = 2\alpha_{irr} - \arcsin\dfrac{d}{2r_{middle}}$ For extreme point $r_j = \dfrac{r_{j-1}\cos\left(\varphi_{j-1} - \dfrac{\varphi_{middle}}{2}\right)}{\cos\left(\varphi_j - \dfrac{\varphi_{middle}}{2}\right)}$. Since $z_j = r_j\cos\varphi_j, \quad x_j = r_j\sin\varphi_j$, width of the plates $b = \sqrt{\Delta Z^2 + \Delta X^2}$.	Number of the plates is $N = \dfrac{K_n - 1}{\rho} + 1$, $\Delta\varphi \approx \dfrac{2\varphi_{\max}}{N}$ $\Delta\varphi_j = \arcsin\left(\dfrac{b\cdot\sin\left(\mu + \varphi_{j-1}\right)}{r_j}\right)$

Light part of the parabolo-cylindrical reflector and its axial luminous intensity

Continuous reflector



Calculation of the visible size of the luminous body in the equatorial plane

Globular luminous body:

in meridional sectional light interval ab, $d' = d$

Cylindrical luminous body:

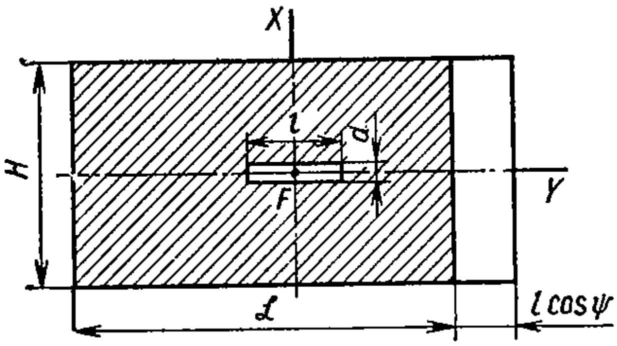
in meridional sectional light interval $a'b'$, $l' = l\cos\varphi$.

The axial luminous intensity in the direction of the optical axis at $L_{lb} = const$:

Globular luminous body: $I_0 = \rho L_{lb} H d$

Cylindrical luminous body: $I_0 = \rho L_{lb} H l$.

For unequally a bright luminous body $L_{lb} = L_{\max}$.



Light part a continuous of the reflector towards the beginning of the marginal effect (luminous body is cylindrical)

<u>Continuous edge reflector without end face</u>

Meridional plane: $2\alpha_{irr} = 2\xi_{\max} \approx \frac{d}{f}$,

Equatorial plane:

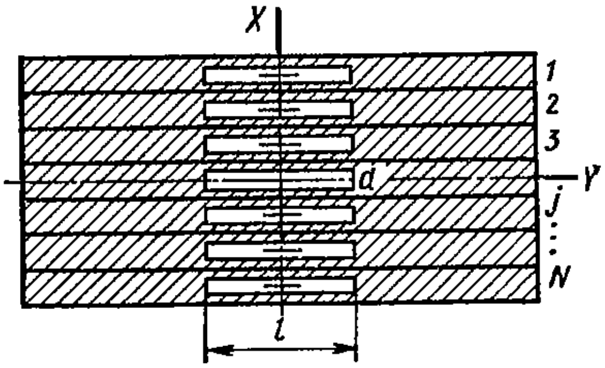
Globular luminous body: $$2\beta_{irr} = 2\left(\beta_{\max} + \frac{d\cos^2\frac{\varphi}{2}\cos\psi_{\max}}{2f}\right),$$

Cylindrical luminous body: $$2\beta_{irr} = 2\left(\beta_{\max} + \frac{l\cos^2\frac{\varphi}{2}\cos\psi_{\max}}{2f}\right).$$

Lamellar (plates) reflector

Meridional plane: $2\alpha_{irr} = \Delta\varphi + 2\arcsin\frac{d}{2f}$,

Equatorial plane: same for continuous.



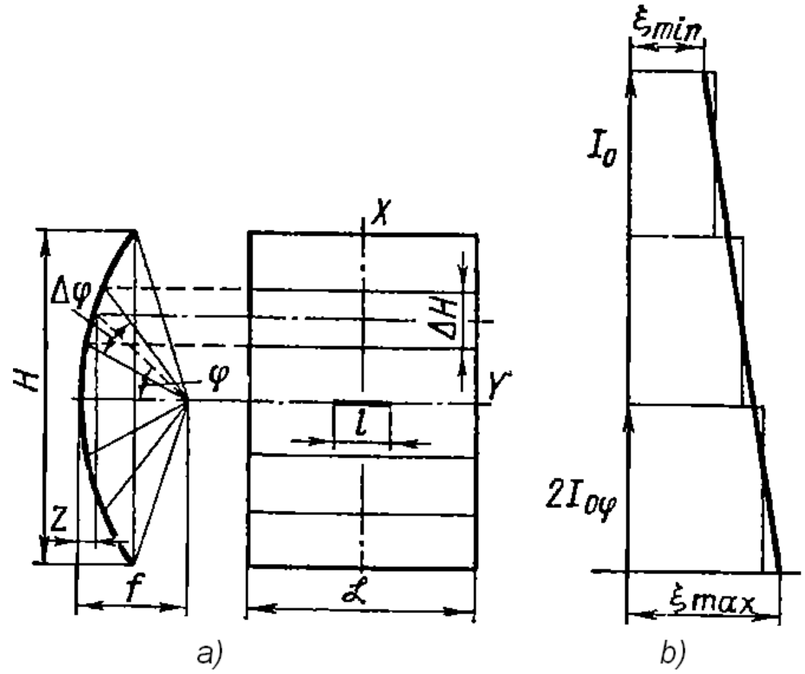
Light part in the direction of optical axis.

Luminous intensity is $I_0 = I_{LS}\left(\rho\left(N-1\right)+1\right)$

Calculation of the luminous intensity curve of a parabolo-cylindrical reflector by zonal method

Meridional plane

1. No aberrational reflector

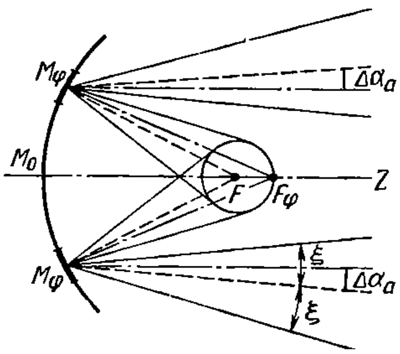


a) the separation into zones, b) IDC of the reflector in the meridional plane

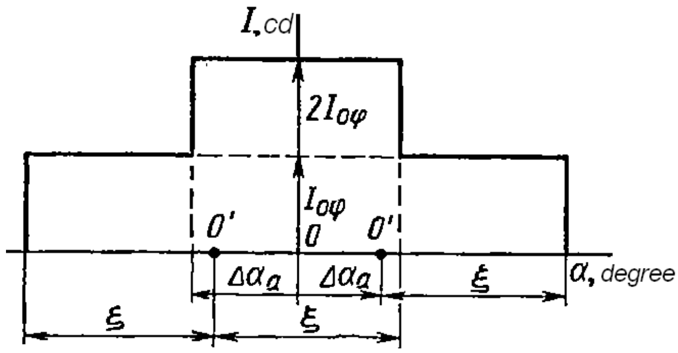
Globular luminous body: $I_{0\varphi} = 2\rho L_{lb}\Delta H d$,

Cylindrical luminous body: $I_{0\varphi} = 2\rho L_{lb}\Delta H l$

2. Aberrational reflector



Meridional plane



Zonal IDC

Equatorial plane

Continuous edge reflector without end face

Globular luminous body: $I(\beta) = \rho L_{lb} \Delta H d$,

Cylindrical luminous body: $I(\beta) = \rho L_{lb} \Delta H l \cos\beta$.

Let β_1 is the angle at which the edge effect begins to appear, β_2 is the angle at which the luminous only boundary point of the reflector. Then for:

Globular luminous body: $tg\beta_1 = \dfrac{\mathscr{L} - d}{2(f + z_j)}$, $tg\beta_2 = \dfrac{\mathscr{L} + d}{2(f + z_j)}$,

Cylindrical luminous body: $tg\beta_1 = \dfrac{\mathscr{L} - l}{2(f + z_j)}$, $tg\beta_2 = \dfrac{\mathscr{L} + l}{2(f + z_j)}$.

The visible size of the light part in the area of the edge effect is follow:

$l'_{light} = \left[0{,}5(\mathscr{L} + l) - (f + z_j) tg\beta\right]\cos\beta$.

Luminous intensity in the zone of edge effect is:

Globular luminous body: $I'_\beta = \rho L \Delta H \left[0.5(\mathscr{L} + d) - ((f + z_j) tg\beta\right]\cos\beta$,

Cylindrical luminous body: $I'_\beta = \rho L \Delta H \left[0.5(\mathscr{L} + l) - ((f + z_j) tg\beta\right]\cos\beta$

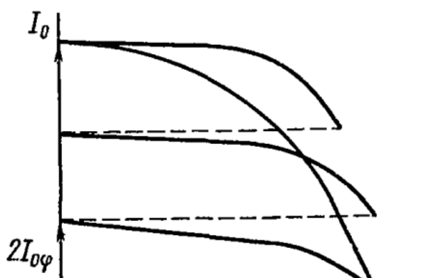
Continuous edge reflector with end face

If the edges of the ends coincide with the boundary points of the profile of the parabola then

$$tg\beta_1 = arctg\frac{\mathscr{L} - l}{2(f + Z_{\max})}, \quad tg\beta_2 = arctg\frac{\mathscr{L} + l}{2(f + Z_{\max})}$$

The visible size of the light part for the direction β that is not shaded by end face:

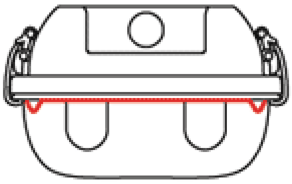
$$l_{light\beta} = \frac{\mathscr{L} + l}{2} - (f + Z_{\max}) tg\beta.$$



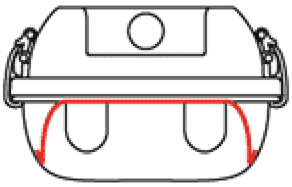
Total IDC in the equatorial plane

Lecture 13

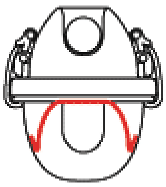
LUMINAIRES WITH MIRROR REFLECTOR



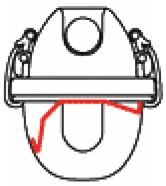
The flat reflector



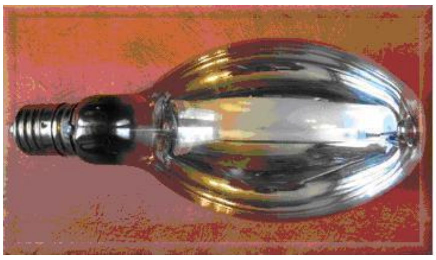
Symmetrical reflector



Symmetrical reflector



Asymmetric reflector



Sodium mirror lamp

Metal halide mirror lamp

Incandescent lamp

Standart

Neodymium

lamp with reflector

lamp of black glass

Classification of luminaries:

<u>1. By appointment:</u>

- luminaries of general lighting (industrial, administrative, social, outdoor)
- local lighting luminaries (industrial, domestic, focusing)

<u>2. By the luminous distribution:</u>

- deeply radiators

(with K_a=10…20 is deeply radiators with concentrated IDC,
with K_a= 4…10 is deeply radiators with deep IDC)

- widely radiators (K_a=2…4)

(with I_{max} within the angles 35-55° is widely radiators with a half wide IDC,
with I_{max} within the angles 55-85° is wide radiators with wide IDC)

The efficiency of luminaries with different types of optical elements

Type of luminaries	**Efficiency, %**
With light scattering glass	60-85
With a diffuse reflector	65-80
With a metallic mirror reflector	70-85
With mirrored glass reflector	75-90
Prismatic	75-85

Calculation of efficiency

$$\eta = \frac{\hat{O}_{lum}}{\hat{O}_{lamp}},$$

where $\hat{O}_{lum}$ is luminous flux of the luminaire,
$\hat{O}_{lamp}$ is luminous flux of lamps placed in the luminaire.

1. Calculation of efficiency by the luminous distribution

$$\hat{O}_{lum} = \sum I_{\alpha} \Delta\Omega = 2\pi \sum I_{\alpha} \left(\cos\alpha_{i-1} - \cos\alpha_i\right)$$

2. Calculation of efficiency by the luminous flux

$$\hat{O}_{lum} = \rho m \hat{O}_{lamp} + m_1 \hat{O}_{lamp} + m_0 \hat{O}_{lamp},$$

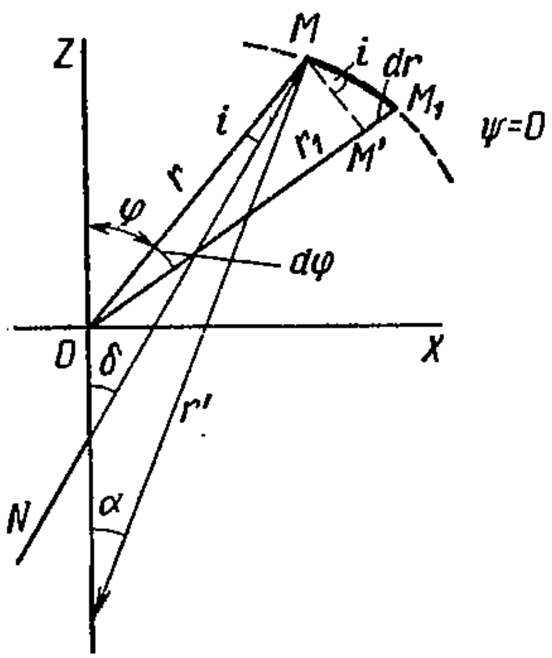
where $m\hat{O}_{lamp}$ is flux which fell on the reflector,
$m_1\hat{O}_{lamp}$ is flux which fell directly at the light of the luminaire hole,
$m_0\hat{O}_{lamp}$ is flux which fell on the neck of the reflector, take $m_0\hat{O}_{lamp}$=0.

$$\hat{O}_{lum} = \rho m \hat{O}_{lamp} + m_1 \hat{O}_{lamp}$$

$$\eta = \frac{\hat{O}_{lum}}{\hat{O}_{lamp}} = \frac{\rho m \hat{O}_{lamp} + m_1 \hat{O}_{lamp}}{\hat{O}_{lamp}} = \rho m + m_1.$$

1. Equation of round mirror symmetric zone of the luminaire

1. The differential equation



$OM = OM'$, we believe that $\Delta MM'M_1$ is right-angled triangle.

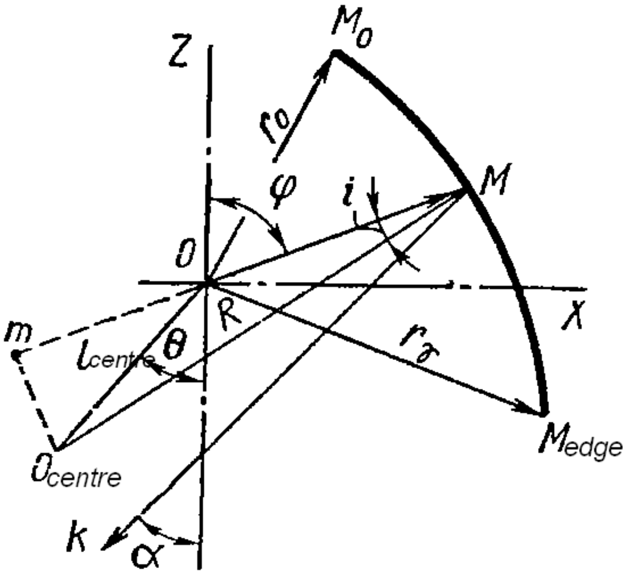
So, $dr = rd\varphi \text{tg} i$, $M'M_1 = MM'\text{tg} i$,

where $\frac{dr}{r} = \text{tg} i d\varphi$, $i = \frac{\varphi - \alpha}{2}$.

$$\ln r_j - \ln r_{j-1} = \text{tg} i_{cp} \Delta\varphi$$

2. Equations of profile curves of mirror reflector

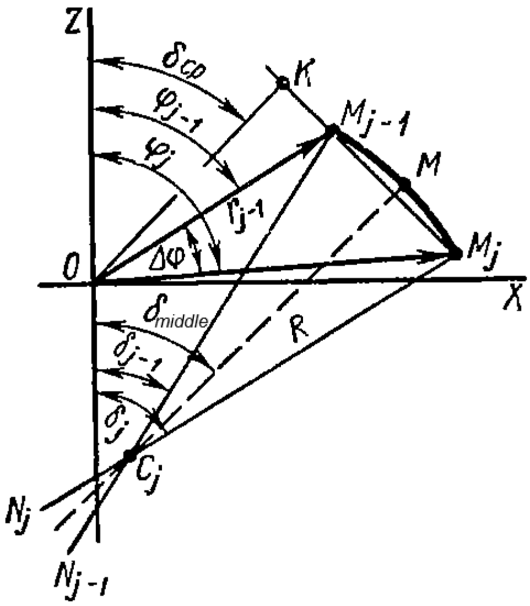
Toroidal mirror surface



$$r = \sqrt{R^2 - l_{centre}^2 \sin^2(\varphi - \theta)} - l_{centre} \cos(\varphi - \alpha),$$

$$\alpha = \pm \arcsin\left[\frac{l_{centre}}{R} \sin(\varphi - \theta)\right]$$

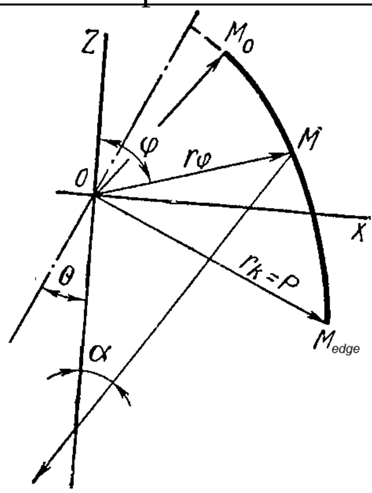
Reflector consisting of a toroidal mirror tangents zones



$$r_j = \frac{\cos(\varphi_{j-1} - \delta_{middle})}{\cos(\varphi_j - \delta_{middle})} r_{j-1}, \qquad R = \frac{r_{j-1}\cos\varphi_{j-1} - r_j \cos\varphi_j}{\cos\delta_{j-1} - \cos\delta_j},$$

$$\alpha = \pm \arcsin\left[\frac{l_{centre}}{R} \sin(\varphi - \theta)\right].$$

Mirror reflector with profile curves conic section

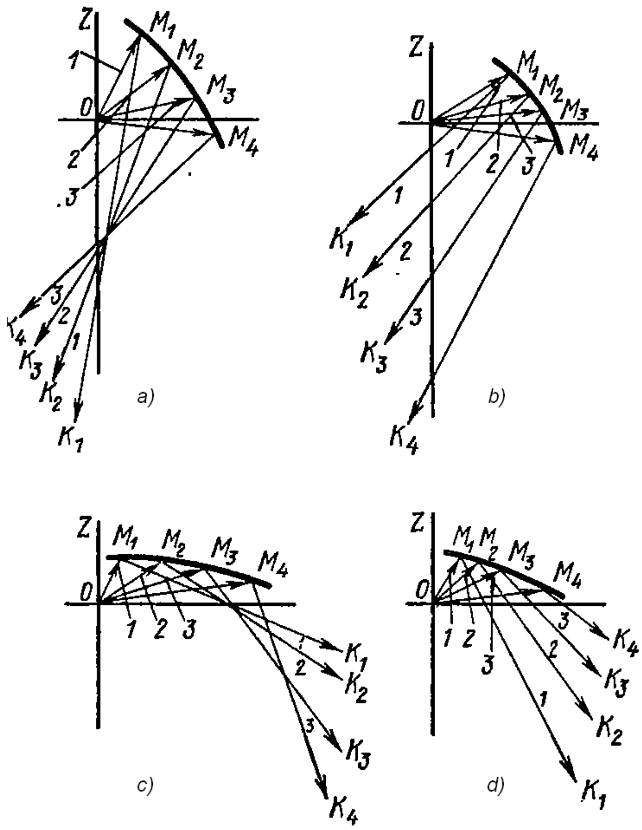


$$r_\varphi = \frac{P}{1+e\cos(\varphi-\theta)},$$

where P is focal parameter curve, e is eccentricity
At $e<1$ the form of the profile curve is ellipse
At $e=1$ the form of the profile curve is parabola,
At $e>1$ the form of the profile curve is hyperbole.

$$\alpha = \varphi - 2\operatorname{arctg}\frac{e-\sin(\varphi-\theta)}{1+e\cos(\varphi-\theta)}$$

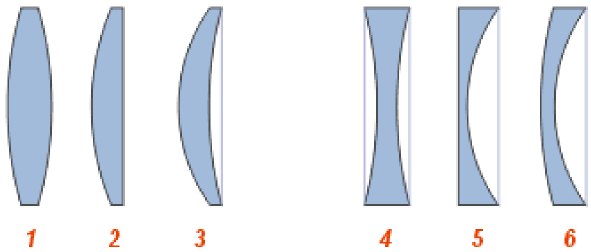
Schemes of move the falling and reflected rays



Lecture 14

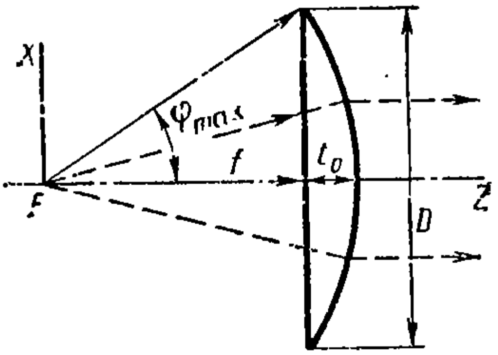
LENSES LIGHTING DEVICES

Types of lenses and their parameters



Collecting: 1 - double arched, 2 – plano-curved , 3 - concave-curved.
Scattering 4 - double concave 5 – plano-concave, 6 - curved-concave.

Plano curved lens is a lens formed by rotation around the axis *OZ* segment with a radius of curvature *R*.



Light the hole of the lens is the projection of the outer surface of the lens in a plane perpendicular to its optical axis.

R is a radius of curvature of the lens;

$f = 0{,}5R$ is a focal distance;

t_0 is the thickness on the optical axis;

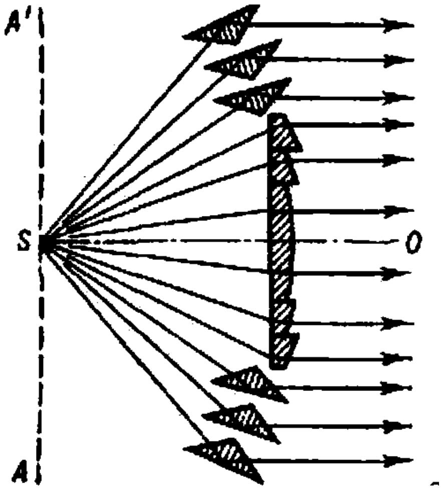
D is diameter;

$2\varphi_{\max}$ is a flat angle of girth.

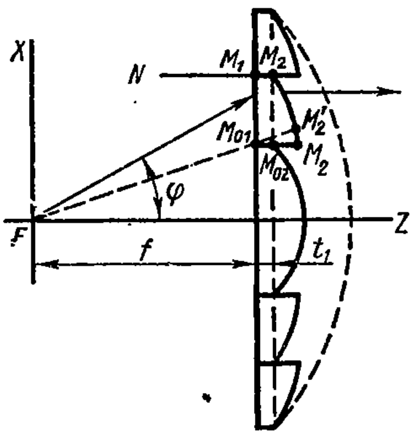
Spherical lens is the lens whose surface is formed by the surface of the sphere.

Aspherical lens is the lens, external refractive facet formed by a profile curve composed of two arcs of circles of different radiuses and centers of curvature, and that is part of an ellipse with some eccentricity.

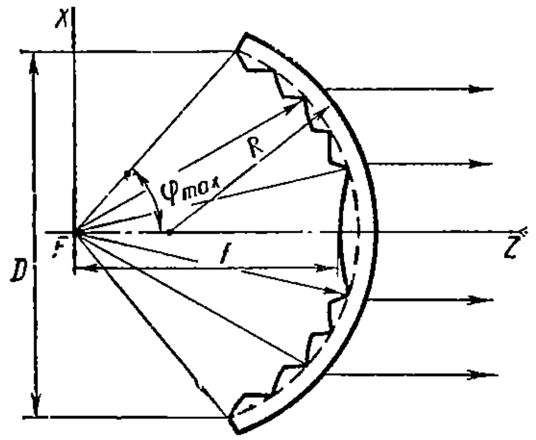
Fresnel lens is the lens composed of a central plano-curved element and a certain number of ring elements.



Fresnel lens



Carrier layer is direct, inside

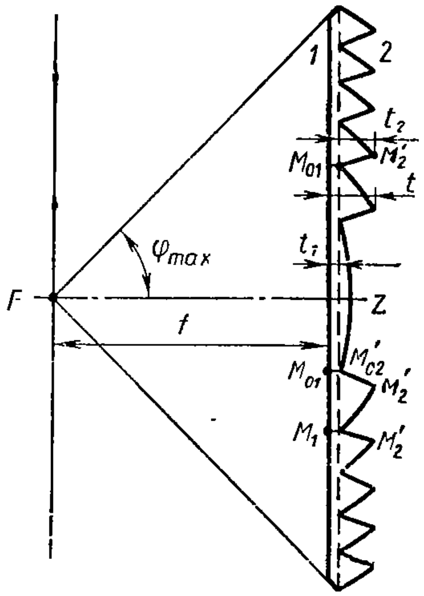


Carrier layer is curved, outside

Parameters of lens:

- Element carrier layer is the layer of the lens element between surfaces M_1M_{01} and M_2M_{02}
- Carrier layer of the lens is a layer common to all elements of the of the lens
- The thickness of the carrier layer t_1 is the projection of the facet $M_{01}M_{02}$ on the normal N_1
- The total thickness of the element t is the projection of the facet $M_{01}M_2$ on the normal N_1
- Protrusion of element over the carrier layer $t_2 = t - t_1$
- Element height is the distance between the extreme points of the connecting facets on the inside surface of the refractive

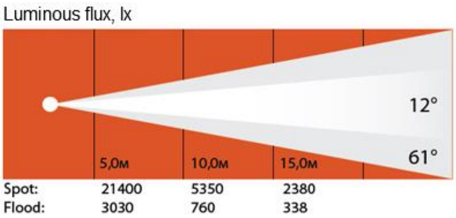
Allar Profile of Fresnel lens



Weight increases by 7%, loss of luminous flux increases by 3%.

Application of lens lighting devices

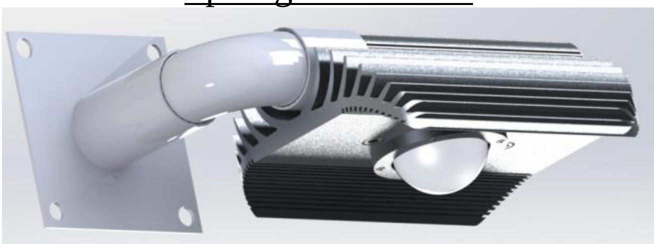
Theater spotlight with Fresnel lens



Industrial LED lens luminaries

Outdoor LED lens luminaries

Spotlight LED lens



Light beacons

OPTICAL CALCULATION OF FRESNEL LENS

For lens with direct inside carrier layer the objective of the calculation is to find the forms of external refractive surface of each element (i.e., the center and radius of curvature of the second refracting edge, the coordinates of the nodal points of the profile element).

The calculation of the whole lens begins from the central element, then calculate all other elements.

Calculation of idc of devices with a disk fresnel lens

To equally bright not monochromatic luminous body $L \neq const$

$$\xi_V \leq \xi_e < \xi,$$

where ξ_V is an ER size of missed light for monochromatic light,

ξ_e is the size of equivalent ER,

ξ is an ER size of missed light for not monochromatic light.

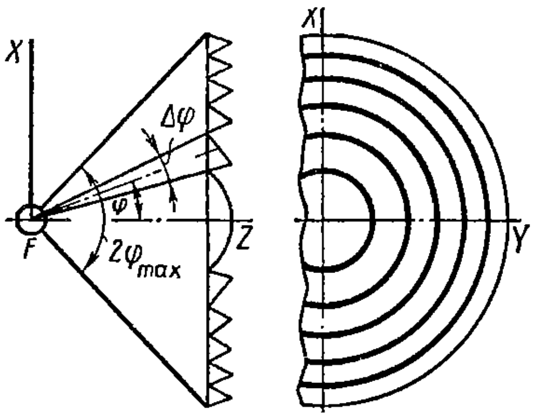
The angular size of ER in the meridional plane is follow:

$$\xi_e = \xi_V + \Delta i'_{2e} = \xi_c \left(V + U_e\right),$$

where V is the refractive index, U_e is the index of dispersion effects.

Axial luminous intensity of disk lens

For the direction $\alpha = 0$ light part of the light hole is the projection of surfaces of external refractive lens elements in a plane perpendicular to the optical axis.



The bright ring centered on the optical axis and a width equal to the height of the external refractive the facet in the meridional plane.

Dark rings are the projection of bases prismatic elements.

Axial luminous intensity of disk lens is:

$$I_0 = \sum_{j=0}^{n} I_{0\varphi_j}, \qquad I_{0\varphi_j} = \tau_j L_{\varphi_j} \pi \frac{\left(X_2\right)_j^2 - \left(X'_2\right)_j^2}{\left(1 + \frac{U_e}{V}\right)_j}.$$

Zonal IDC

For any point of inside surface of the lens radius vector is $r = \dfrac{f}{\cos\varphi}$

The sizes of equivalent ER for the element of lens is follow:

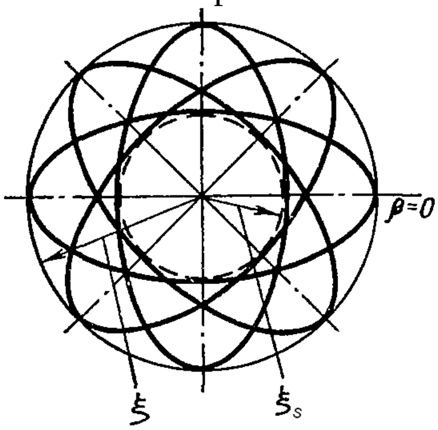
$$\xi_e = \frac{d}{2r}\left(V + U_e\right) = d\cos\varphi_{middle}\left(V + U_e\right), \quad \xi_s = \frac{d}{2f}\cos\varphi_{middle}.$$

At $V + U_e = 1$ ER has the form of a circular cone;

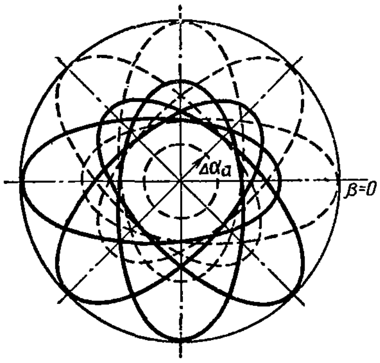
at $V + U_e > 1$ ER is elliptical cone with the major axis $2\xi_e$ in the meridional plane;

at $V + U_e < 1$ ER is elliptical cone with a small axis $2\xi_e$ in the meridional plane.

Trace of ER of point on the surface lens is an ellipse with semiaxes ξ_e and ξ_s, trace of zonal reflection is a set of such ellipses.



For aberrational refractive element $\Delta\alpha_a = \dfrac{\Delta f}{f}V\sin\varphi\cos\varphi = \dfrac{\Delta f}{2f}V\sin 2\varphi$



Trace of zonal reflection for $\Delta\alpha_a < \xi$

Changing light part of the light hole lens element at $V + U_e > 1$

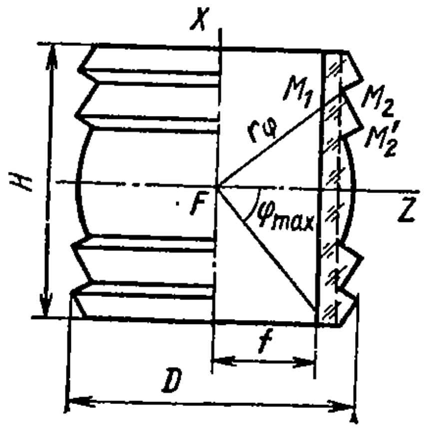
For $0 \le \alpha \le \xi_s$ – all light hole is light;

For $\alpha > \xi_s$ – only part of the light hole is light (light points are turns off in the meridional plane perpendicular to the plane of observation);

For $\alpha \gg \xi_s$ – turns off all light hole.

Lecture 15

CYLINDRICAL FRESNEL LENS



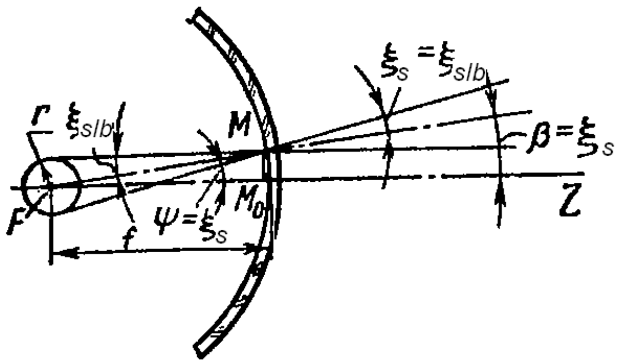
Cylindrical lens is a lens, the rotating of lens with Allar profile around the axis *FX*, which passes through its focus.

A cylindrical lens focuses the flux in a circular fan-shaped body and redistributes it into space.

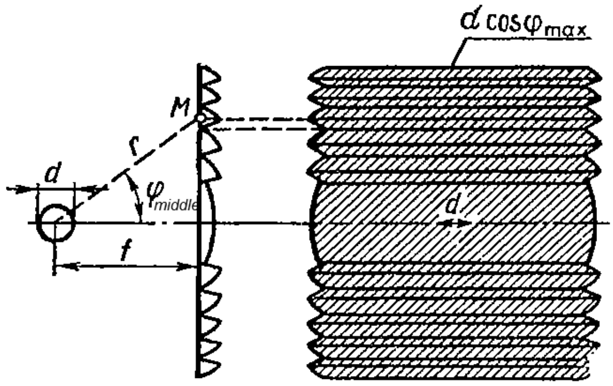
Profile planes is the planes that passes through the axis *FX*.

Equatorial planes is the planes perpendicular to the axis of *FX*.

Let the luminous body is a globular with equal brightness.



Light part of the equatorial sectional of the central element of the lens



Light part of the light hole of the cylindrical lens

Since distance H_0 light part of the zone will have a size equal to the height of the second refracting edge $\left(X_2 - X_2'\right)$.

$\xi_{slb} = \xi_s$ and $\psi = \beta$. So last points of light will p.*M* of equatorial sectional.

$\overline{MM_0} = f\sin\xi_s = f\dfrac{d}{2f} = \dfrac{d}{2} = r$. Accordingly, light points of the main equatorial sectional placed on segment $2\overline{MM_0} = d$.

Light part of the central element is rectangular with a width d and a height $2X_{02}$, that height projections external refracting facets on a plane perpendicular to the axis *FZ*.

In equatorial sections, passing through the point M_{middle} of any element of lens, width of the lighting segment is follow:

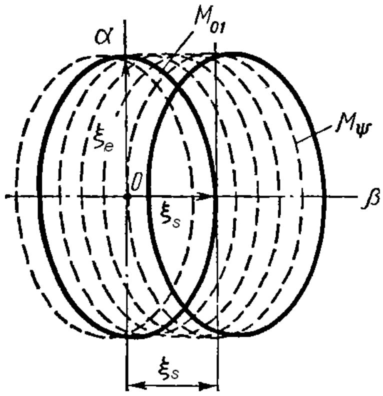
$$\overline{MM}_{\varphi middle} = f \sin \xi_{smiddle} = d \cos \frac{\varphi_{middle}}{2}.$$

The light part of the cylindrical lens with globular luminous body is stripe, the width of which varies according to the law $d\cos\varphi$, and height equal to the height of the lens from its external side of the refractive surface.

Axial luminous intensity of zone is:

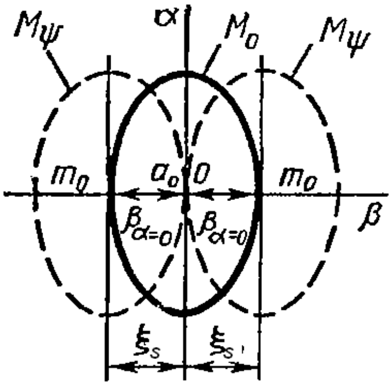
$$I_{0\varphi} = \tau L_{\varphi j} \cos\varphi_{cp} V d \frac{X_2 - X_2'}{V + U_e}.$$

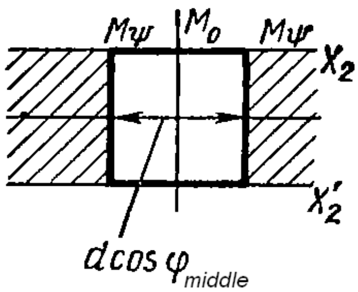
The trace of the reflection of the zone is characterized by $\Delta\alpha = 0$, then reflection its external refractive facet in the graph (α, β) in a rectangular coordinate system is straight (α, β). Traces of ER are the ellipses with the major axis ξ_e and short axis ξ_s (at $(V + U_e) > 1$). The trace of zonal reflection is a set of ellipses whose centers are on the line $\beta(\alpha = 0)$.



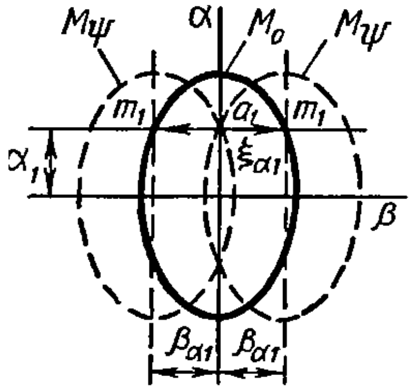
Zonal reflection of the cylindrical lens with globular luminous body

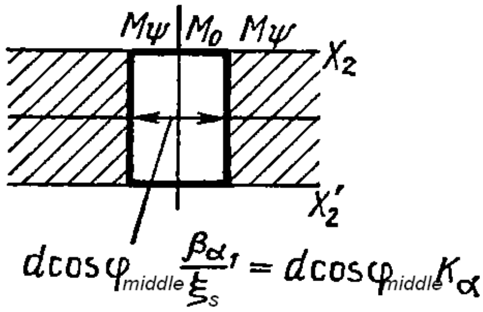
The measure of the set of ER, which cover any direction $\beta, \alpha = 0$ is the size $2\xi_s$, which defines the linear width $d\cos\varphi_{middle}$ of the light part of element for the axial direction.



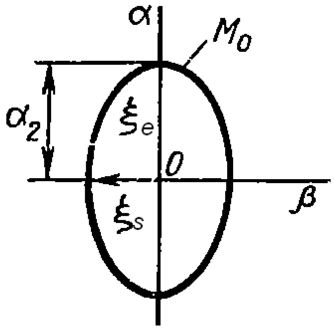


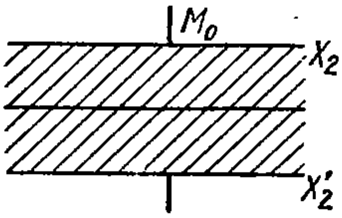
$\alpha_0 = 0$





$0 < \alpha_1 < \xi_e$





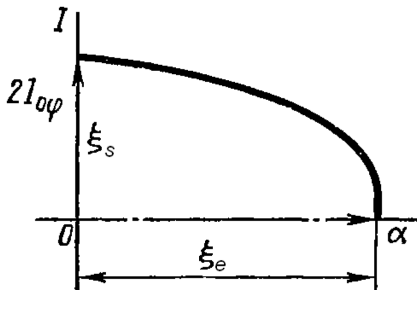
$\alpha_2 = \xi_e$

Light part of the of the lens zone by changing the angle α:

$$K_\alpha = \frac{2\beta_\alpha}{180} = \frac{\beta_\alpha}{90} \quad \text{or} \quad K_\alpha = \frac{\beta_\alpha}{\xi_s}.$$

Luminous intensity is: $I_{\varphi\alpha} = I_{0\varphi} \dfrac{\beta_\alpha}{\xi_s}$.

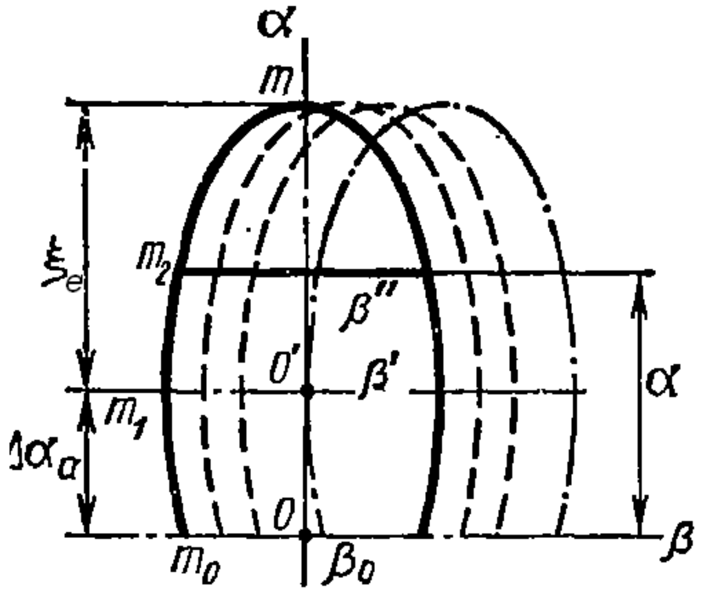
Zonal IDC of the cylindrical lens with globular luminous body is described by elliptical law. It can be constructed in a coordinate system (α, I). The scale of the curve is determined by the axial luminous flux.



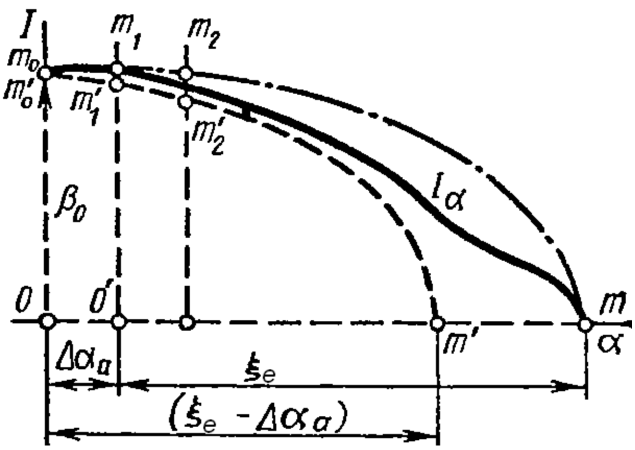
A cylindrical lens with longitudinal aberration

Effects of longitudinal aberrations is rotate the axes of all ER in the meridional plane relatively the main equatorial plane.

The angular aberration is $\Delta\alpha_a = \Delta f \dfrac{V}{f} \sin\varphi\cos\varphi = \Delta f \dfrac{V}{2f} \sin 2\varphi$.



Zonal reflection of aberrational element of lens.



Construction of zonal IDC of aberrational of the cylindrical lens

Upper curve is the part of the ellipse with the size along the axis α $(\xi_e + \Delta\alpha_a)$.

Lower curve is the part of the ellipse with the size along the axis α $(\xi_e - \Delta\alpha_a)$.

Axial luminous intensity is:

$$I_{0\varphi} = 2I'_{0\varphi} \frac{\beta_0}{\xi_s},$$

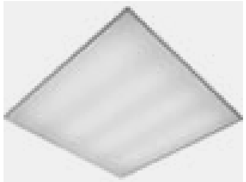
where $I'_{0\varphi}$ is an axial luminous intensity of one element of not aberrational lens,

β_0 is angle that determines the size of light part of aberrational element in the direction $\alpha = 0$.

Lecture 16

LUMINAIRE WITH PRISMATIC REFRACTING OPTICAL ELEMENTS

1. Luminaires for administrative offices

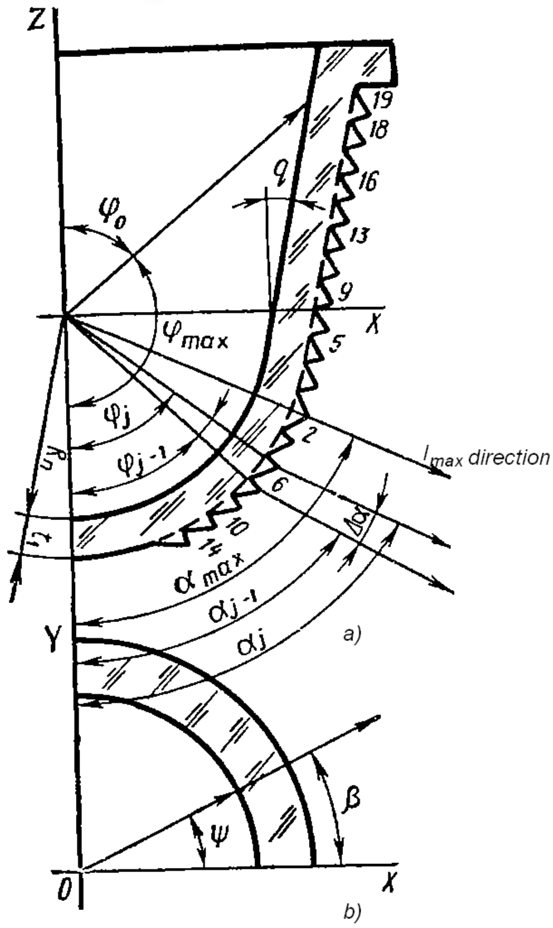
2. Outdoor luminaries


3. Industrial luminaries


Symmetric prismatic device is a device with a glass horizontally placed circular prisms, which redistributes the light flux in meridional plane.

The image size of the luminous body in the meridional plane is not equal to the height of the hood, depending on the given intensity.

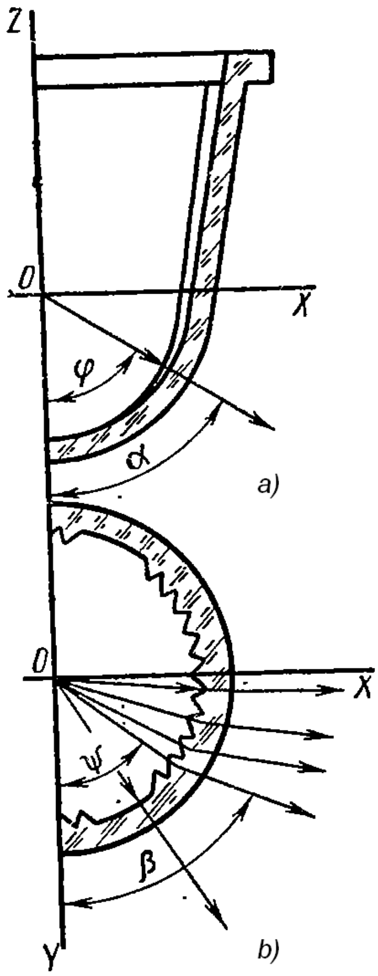
The image size of the luminous body in the equatorial plane is equal to the size of the luminous body.



Un-symmetric prismatic device is a device with a glass vertically placed circular prisms, which redistributes the light flux in equatorial plane.

The image size of the luminous body in the meridional plane is equal to the size of the luminous body.

The image size of the luminous body in the equatorial plane is not equal to the size of the luminous body.



Advantages of prismatic luminaries:

- create a significant concentration of luminous flux at large angles $\alpha = 80 - 85^{\circ}$ at the corners of a given β;
- provide the necessary asymmetrical IDC;
- high efficiency (up to 86%);
- large amplification factor;
- stability to influence of environmental.

Disadvantages of prismatic luminaries:

- large blinding effect;
- difficult surface cleaning;
- industrial error at making of devices.

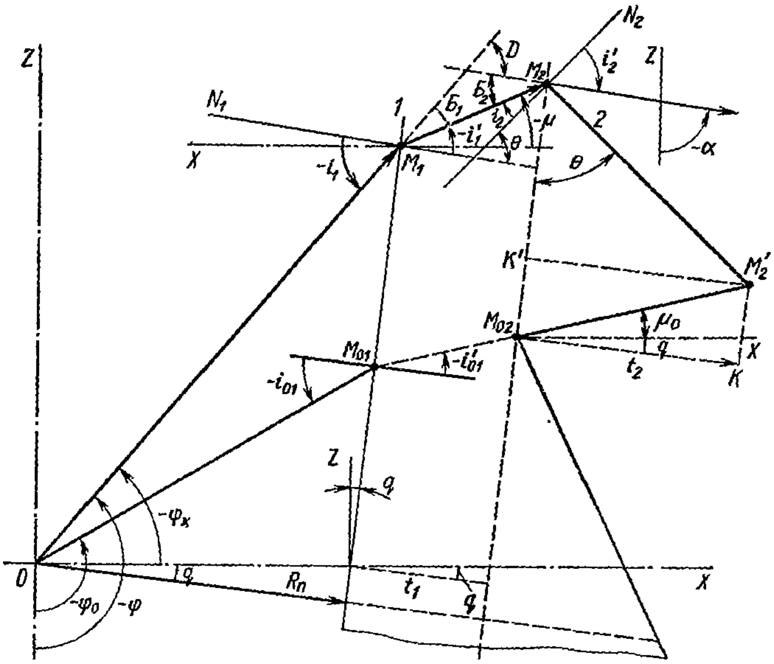
Optical calculation of prismatic elements

For refractor with an *internal carrier layer* of the first refractive facet set when choosing the form of a carrier layer, a second facet is oriented by angle of refraction. The base of element must coincide with the beam, refracted by first facet at the base of the element.

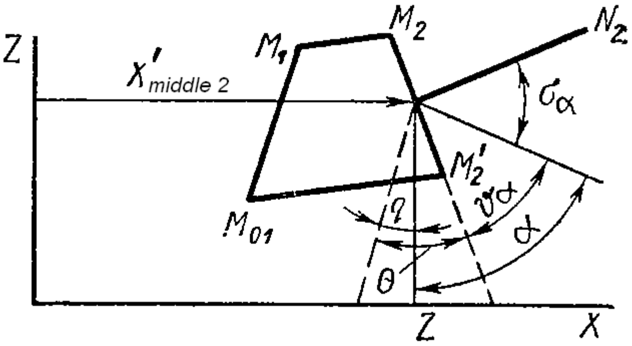
For refractor with an *external carrier layer* of the second facet is set when choosing the form of a carrier layer, the first facet is determined by angle θ.

The order of calculating (for optical device with an internal carrier layer)

1. Select the size of the first refracting prism facets and placing it on the hood.
2. Calculation of the peaks of the prism M_1 on the edge 1 and M_2 on the facet 2.
3. Calculate the angle of refraction. θ.
4. Calculation of the coordinate p. M_2'.
5. Construction of profile prism by coordinates of points and angle of refraction.



Luminous intensity prismatic zone in the direction α is $I_\alpha = L_e A_\alpha \cos\sigma_\alpha$.



$$I_\alpha = \tau L_\varphi A_\alpha' \sin\left(\alpha + q - \theta\right)\frac{V}{V + U_e}.$$

At $0 \le \Delta\alpha \le 2\xi$ IDC has pointed character.

By increasing $\Delta\alpha$ IDC becomes smoother.

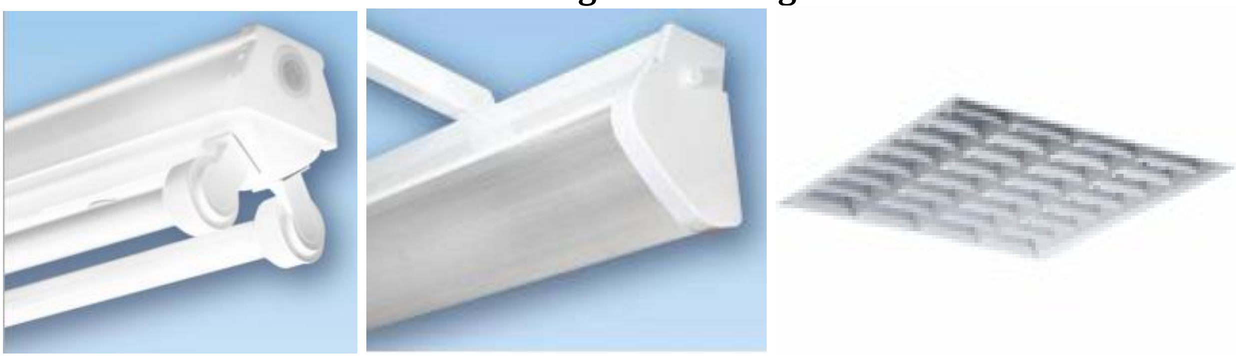
The order of calculating of zonal IDC of circular prismatic element:

1. Construction of rectangular coordinate system α, β.
2. Calculation of the angular size of the luminous body to the middle point of the first refracting prism facet.
3. Calculation V and U_e.
4. Calculation of the angular size of equivalent ER and sweep angle of axial rays $\Delta\alpha$.
5. Calculation of the part area of the second refracting surface of zone A_φ'.
6. Construction of the trace of equivalent ER.
7. Calculation of fill factor K_α for selected directs α.
8. Calculation of bright of light parts L_e.
9. Calculation I_α and construction $I(\alpha)$.

Lecture 17

LUMINAIRES FITTED WITH LIGHT SCATTERING MATERIALS

Luminaires with light scattering reflectors



Luminaires with light scattering diffuser

Luminaires with light scattering reflectors and diffuser

Advantages of luminaires with light scattering reflectors:

- simple design;
- ease of fabrication;
- low cost;
- the coating is also the lighting, protective and anti-corrosion.

Disadvantages:

- low efficiency (0.6…0.8).

Advantages of luminaires with light scattering diffuser:

- variability design;
- the ability to control the redistribution of flux;
- low cost;
- absence of blinding action.

Disadvantages:

low efficiency (0.75 for the lighting devices with diffuses 0.85 – with directed-scattering elements).

I. Calculation of luminaires with diffuse reflectors

1. Calculation of efficiency

The coefficient of multiple reflections χ is the ratio of total luminous flux incident on the surface of the reflector to luminous flux, which initially fell from the lamp:

$$\chi = \frac{\hat{O}'_{\varphi}}{\hat{O}_{\varphi}} = \frac{1}{1-\rho(1-u)},$$

where $\hat{O}'_{\varphi}$ is the total flux incident on the reflector surface as a result of multiple reflections,

$\hat{O}_{\varphi}$ is the flux incident on the reflector from the lamp,

ρ is the reflection coefficient,

u is an exploitation coefficient of surface reflector relative to the light hole (percentage of reflected flux that falls on the light hole).

$\chi = 1$ for flat and convex surfaces,

$\chi > 1$ for concave surfaces.

If the light hole is a disk with the brightness of the reflector, then:

$$\pi L_r A_r u = \pi L A_{lh},$$

where L_r is reflector's brightness,

A_r is reflector's area,

A_{lh} is area of the light hole.

$$u = \frac{A_{lh}}{A_r},$$

$u < 1$ for convex reflectors, $u = 1$ for flat reflectors.

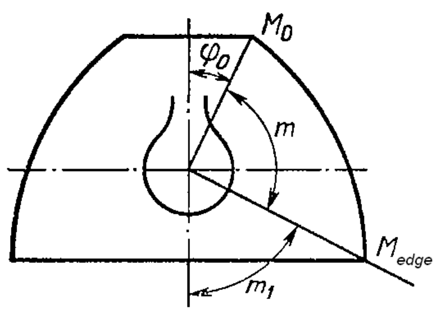
$$\hat{O}_{LD} = m_1 \hat{O}_{lamp} + \rho u \hat{O}'_{\varphi},$$

where $m_1 \hat{O}_{lamp}$ is the flux directly from the lamp went out in light hole,

$\rho u \hat{O}'_{\varphi}$ is the flux that went through the light hole as a result of multiple reflections.

$\hat{O}_{\varphi} = m \hat{O}_{lamp}$, that $\hat{O}_{LD} = m_1 \hat{O}_{lamp} + m \hat{O}_{lamp} \rho u \chi$, and

$$\eta = \frac{\hat{O}_{LD}}{\hat{O}_{lamp}} = m_1 + \rho m u \chi$$



2. Calculation of luminous intensity distribution curve (IDC)

2.1. Smooth axially symmetric reflector

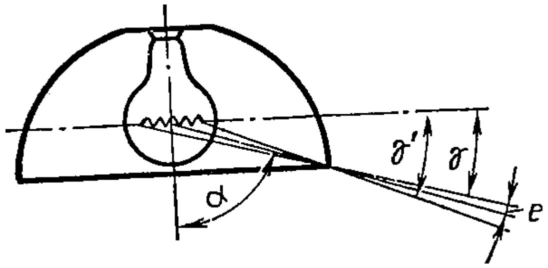
The brightness of the reflector's surface is:

$$L_r = \frac{\rho \hat{O}_\varphi \chi}{\pi A_r}.$$

The luminous intensive in the direction α is:

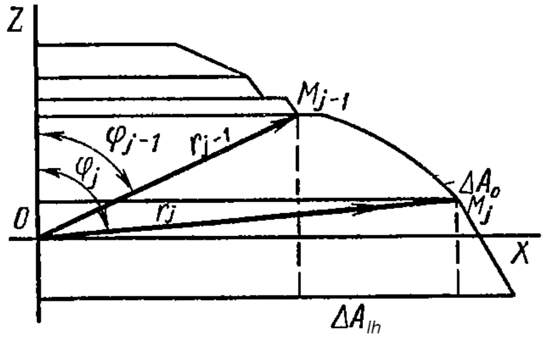
$$I_{LD\alpha} = I_{lamp\,\alpha} k_\alpha + L_r A_{lh} \cos\alpha,$$

where k_α is a coefficient of screening of the luminous body by reflector edge, $k_\alpha = \frac{e}{\gamma' - \gamma}$



By increasing the protective angle:
– the flux captured by reflector is increases,
– reflector's brightness is increases,
– reflector's luminous intensive is increases,
– the axial luminous intensive is increases,
– IDC becomes more narrow,
– efficiency is decreases.

2.2. Stairs-like reflector



- luminous flux and brightness change sharply from zone to zone,
- light hole is not exactly bright disk,
- in direct α concentric rings of different brightness are visible,
- at $\alpha > 0$ zones overlap and close by edge of outlet hole,
- not uniform brightness creates a luminous flux that fell from the lamp on the reflector,
- uniform additional brightness creates by multiple reflections of light flux.

Luminous intensity in direction α is:

$$I_\alpha = I'_\alpha + I''_\alpha,$$

where I'_α is the luminous intensity, formed at the first reflection,
I''_α is the luminous intensity, formed at the first and next reflections.

$$I'_\alpha = \frac{\rho\cos\alpha}{\pi}\sum_{j=1}^{n} c_{\alpha j} u_j \Delta\hat{O}_j ,$$

where $c_{\alpha j} = \frac{\Delta A_{lh}}{\Delta A_r}$.

$$I''_\alpha = \frac{\rho\hat{O}_\varphi(\chi-1)u\cos\alpha}{\pi}$$

$$I_{LD\,\alpha} = k_\alpha I_{lamp\,\alpha}\left[\sum_{j=1}^{n} c_{\alpha j} u_j \Delta\hat{O}_j + \hat{O}_\varphi(\chi-1)u\right]\frac{\rho\cos\alpha}{\pi}$$

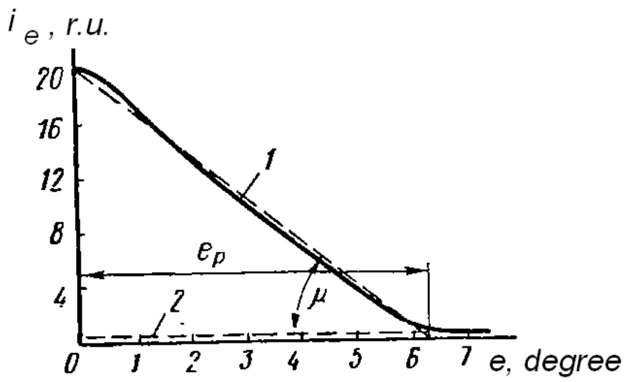
Order of calculating:

1. Select on the reflector's surface circular zones.
2. Calculate the zonal luminous fluxes $\Delta\hat{O}_j$ and luminous flux captured by reflector $\hat{O}_\varphi$.
3. Calculate u_j for even zone.
4. Calculate graphically the coefficient $c_{\alpha j}$.
5. Calculate the coefficient χ and equation $\left[\hat{O}_\varphi(\chi-1)u\right] = const$.
6. Calculate the multiplier $\frac{\rho\cos\alpha}{\pi}$.
7. Calculate luminous intensity $I_{LD\,\alpha}$.
8. Built IDC.

II. Calculation of reflectors with matted reflectors

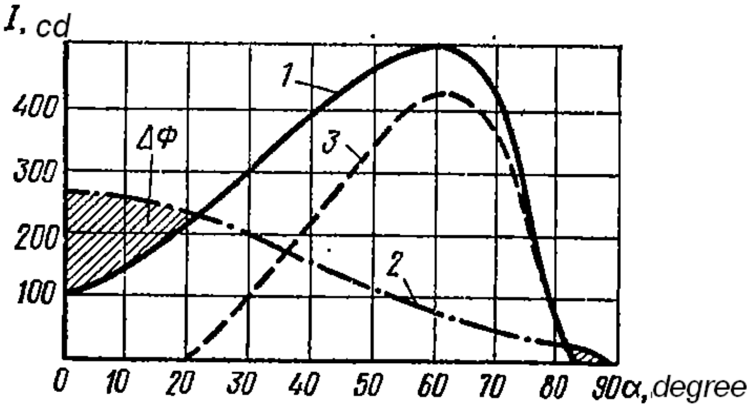
Order of calculating:

1. The choice of reflectors initial parameters $\varphi_0, r_0, \gamma_{ax}$.
2. Calculation of diffuse ρ_{diff} and directional ρ_d reflectance on the curve of scattering of matted material $i_e(e)$.



Curve 1 – scattering curve of directional reflectance,
Curve 2 – scattering curve of diffuse reflectance.

3. Calculation of IDC of conditional diffuse luminaired.
4. Calculation scale factor for the transition from standard units to candelas.
5. Calculating the needed IDC which corresponding directional reflectance.



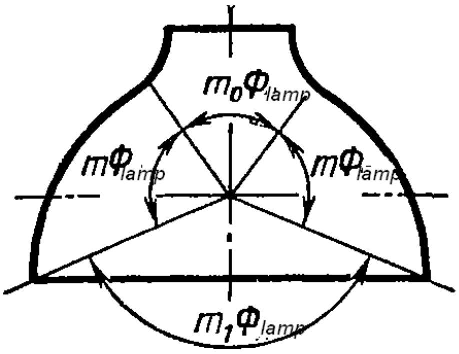
Curve 1 is needed IDC,
Curve 2 is IDC of diffuse luminaire,
Curve 3 is IDS of mirror luminaire.

6. Calculate the angular size of the luminous body for the first zone of the reflector.
7. Calculation of brightness distribution for the first zone and allocation of equally bright areas.
8. Choice of scattering angle for the first zone $\Delta\alpha_1$.
9. Calculate the first zone of the curve $I_\alpha = \dfrac{A_\varphi \cos\sigma_\alpha^* \sum_{i=1}^{m} L_i n_{\alpha i}}{N}$, $n_{\alpha i}$ is number of sections grid α, β, covered by figure of luminous reflections points, m is number of equally bright areas.
10. Calculation of the second limiting radius vector of the first zone r_1 of the equation mirror.
11. Calculation all zones by method of filling needed zonal IDC by zonal IDC.

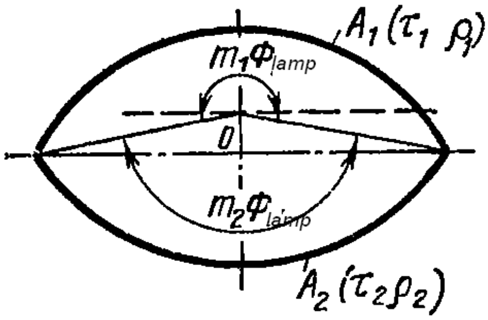
III. Calculating of luminaires with diffuse scatteres

1. Calculation of efficiency

Nonclosed scatter



Closed scatter



Luminous flux nonclosed scatter consists of the following components:

$m_1\hat{O}_{lamp}$ is the flux that goes through the light hole,

$\hat{O}_{lh} = \rho m\hat{O}_{lamp} u\chi$ is the flux that went through the light hole as a result of multiple reflections from the inner surface of scatter,

$\tau m\hat{O}_{lamp} + \tau \dfrac{\rho m\hat{O}_{lamp}(1-u)}{1-\rho(1-u)} = \tau m\hat{O}_{lamp}\chi$ is the flux that went through the light hole as a result of multiple reflections.

Efficiency of nonclosed scatter is:

$$\eta = m_1 + m(\rho u + \tau)\chi$$

Efficiency of closed scatter ($u = 0, m_1 = 0, m = 1$) is:

$$\eta = \frac{\tau}{1-\rho}.$$

For a luminaire with a large seating lamp holder:

$$\eta = \frac{m\tau}{1-\rho(1-u)},$$

where $u = \dfrac{A_{ò sc}}{À_{sc}}$, $A_{ò sc}$ is an area of holder zones, A_{sc} is an area of scatter.

2. Calculate of efficiency

Reduced to calculating of brightness of internal and external scatter's sides projection surface area and its light hole in planes perpendicular directions α.

Luminous intensity in the direction α:

$$I_{LD\,\alpha} = I_{lamp\,\alpha} k_\alpha + I'_\alpha + I''_\alpha,$$

where I'_α is the luminous intensity created by the outside surface of the scatter in the direction α,

I''_α is the luminous intensity created by inside surface of the scatter, which is visible through a light hole in the direction α,

k_α is the coefficient of screening of luminous body lamp of a scatter's edge.

The brightness of scatter's is:

$$L'_{sc} = \frac{\tau \hat{O}_\varphi \chi}{A_{sc}\pi}, \qquad L''_{sc} = \frac{\rho \hat{O}_\varphi \chi}{A_{sc}\pi}$$

Luminous intensity of luminaire in the direction α is:

$$I_{LD\,\alpha} = I_{lamp\,\alpha} k_\alpha + L'_{sc} A_{sc\,\alpha} + L''_{sc} A_{sc\,\alpha}$$

$$I_{LD\,\alpha} = I_{lamp\,\alpha} k_\alpha + \frac{\hat{O}_\varphi \chi}{\pi A_{sc}} \left(\tau A_{sc\,\alpha} + \rho A_{sc\,\alpha} \right)$$

<u>IV. Calculate of luminaires with matted scatters</u>

For $\frac{v}{q} < 0{,}1$ (little matting) using notion of elementary reflection.

The calculation is to determine the efficiency and IDC at known form of scatter, characteristic of scattering $i_e(e)$, distribution of source brightness $L_\varphi(\varphi)$.

The calculation of light distribution reduces to the calculation of luminous intensity of conditional luminaire with diffuse scatter and of a scatter with directional transmission of light.

<u>Order of calculating:</u>

1. Calculation of coefficients transmission τ_d and τ_{diff} on the scattering curve $i_e(e)$.
2. Calculation IDC of conditional luminaire with diffuse scatter.
3. Divide the scatter's surface into a number circular zones with size $\Delta\varphi$ ($\Delta\alpha = \Delta\varphi, \varphi = \alpha, \psi = \beta$).
4. Calculate the angular size of luminous body relative to the midpoint of each zone.
5. Calculation of the brightness distribution of ER rays of each zone
6. Calculation of zonal IDC.
7. Summation of zonal IDC and definition of IDC received directional light transmission.
8. Calculation of total luminaire's IDC.

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