Optical Instruments & Photometry

Defects of Vision

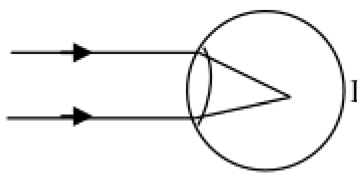
- ## Points to note:
  - The least distance upto which an object can be clearly seen by a naked eye is called the least distance of distinct vision which is 25 cm for normal eye.
  - The farthest point for the clear vision is infinity.
  - Ability of eye lens to change its focal length is called power of accommodation.
  - When eye is relaxed it has maximum focal length and minimum focal length when eye is most strained (25 cm).
  - The limit of resolution of eye is one minute.
  - The persistence of vision of human eye is $\left(\frac{1}{10}\right)$ sec

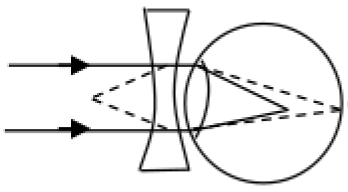
- ## Myopia (Short sightedness)

  In it distant object are not clearly visible. Image of the objects form before the retina. This defect can be removed by using spectacles having divergent lens. Suppose a person can see an object at a maximum distance 'x', then to see the distant object a divergent lens has to be introduced which makes a virtual image of the object at a distance of 'x' from the eye.

  i.e, $u = \infty$
  $v = f = -x$

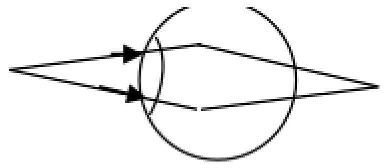
  $$\therefore \text{Power of the lens}(P) = \frac{1}{f} = -\frac{1}{x}$$

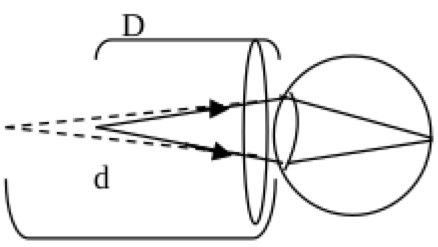
  

- ## Hypermetropia or long sightedness

  In it near objects are not clearly visible. Image of the object forms behind the retina. This detect can be removed by using spectacles having convergent lens.

$$u = D$$
$$v = -d$$
$$\text{Or, } \frac{1}{f} = \frac{1}{u} + \frac{1}{V}$$
$$\therefore \quad \frac{1}{f} = \frac{1}{D} - \frac{1}{d}$$

- **Presbyopia:**

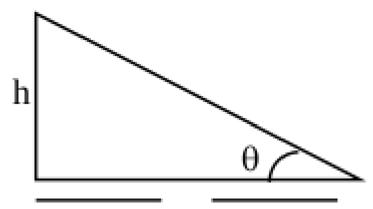
  In this defect both near and far objects are not clearly visible. This defect takes place at old age and is called old age detect. This defect is remedied by using bifocal lens. It is due to the loss in elasticity of ciliary muscles.

- **Astigmatism:**

  It is not equally clear in two mutually perpendicular directions which is due to the uneven curvature of the cornea. This detect is corrected by using a cylindrical lens.

- **Visual angle:**

  It is the angle subtended by an object at the eye. It is maximum when the object is at the least distance of distinct vision.



Visual angle, $\theta = \frac{h}{D}$

Microscope

It is an optical instrument used to increase the visual angle of near objects which are too small to be seen by naked eye. Microscopes are of two types viz, simple microscope and compound microscope.

- **Simple microscope:**

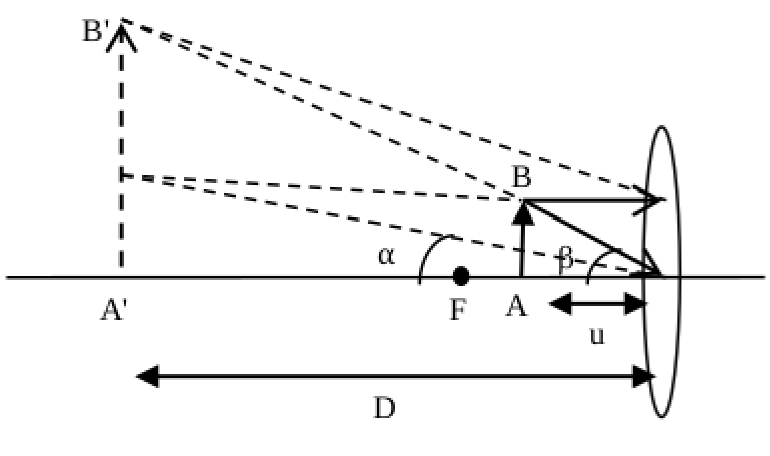
  It is also known as magnifying glass or magnifier and consist of a convex lens with object between its focus and optical centre. The image formed by it is erect, virtual, enlarged and on same side of lens.

$$\text{Magnifying power} = \frac{\beta}{\alpha} = \frac{\text{angle between by image at eye}}{\text{angle by object at least distance when seen unaided}}$$

$$\tan\beta \approx \beta = \frac{AB}{u}$$

$$\tan\alpha \approx \alpha = \frac{AB}{D}$$

$$\therefore M = \frac{\beta}{\alpha} = D/u$$



- When image is formed at D:

$$M=\frac{D}{u}=\left(1+\frac{D}{f}\right)$$

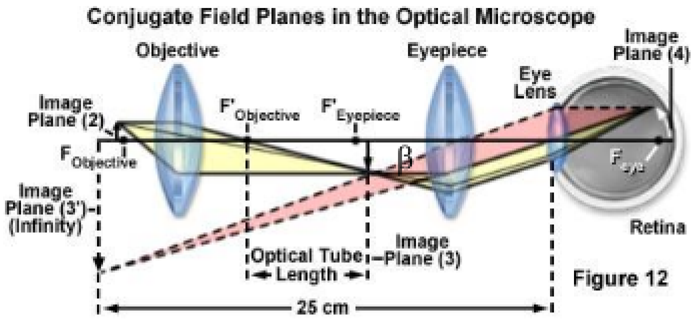
- When image is at infinity $(u=f)$:

$$M=\frac{D}{u}=\frac{D}{f}$$

- **Compound microscope:**

It consists of two convex lens of short focal length $(f_e > f_o)$ is objective lens and longer focal length is eye piece. Object is outside the focus of objective which forms real image and acts as object for the eye piece. Depending on the adjustment, the image can be formed at the least distance of distinct vision or at the infinity.

Magnifying power $(m)=\frac{\beta}{\alpha}$



$$\tan\beta \approx \beta = \frac{\mathrm{A''B''}}{\mathrm{D}}$$
$$\tan\alpha \approx \alpha = \frac{\mathrm{AB}}{\mathrm{D}}$$
$$\therefore \quad m=\frac{\beta}{\alpha}=\frac{\mathrm{A''B''}}{\mathrm{D}}\times\frac{\mathrm{D}}{\mathrm{AB}}=\frac{\mathrm{A'B''}}{\mathrm{A'B'}}\times\frac{\mathrm{A'B'}}{\mathrm{AB}}$$
$$\text{Or, } m=m_0\times m_e$$

- When image is formed at D:

$$m=m_0\times m_e$$
$$m=\frac{V_0}{u_0}\left(1+\frac{\mathrm{D}}{f_e}\right)$$

and length of microscope is:

$$L=V_0+u_e$$

- When image is at infinity :

then $m=m_o\times m_e$

$$m=\frac{v_o}{u_o}\times\frac{D}{f_e}$$

and length of microscope is:
$$L=v_o+f_e$$

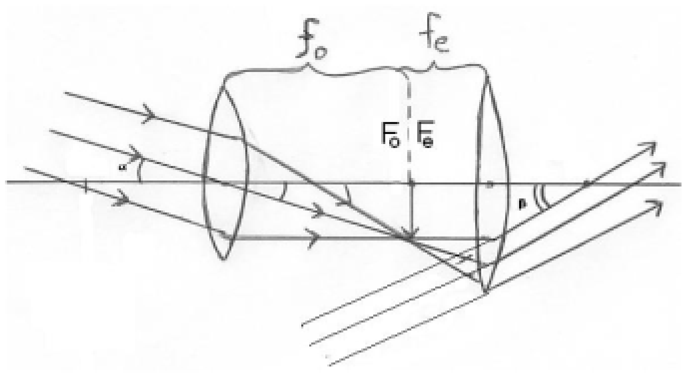
Telescope

It is an optical instrument used to increase the visual angle of distant objects.

- **Astronomical telescope:**

  It consists of two convex lens. Objective lens of large focal length and aperture and eye piece of small focal length and small aperture. Object is at the infinity, so the image is formed at the focus of the objective lens which acts as the object for eye piece.

  - **Normal adjustment:**

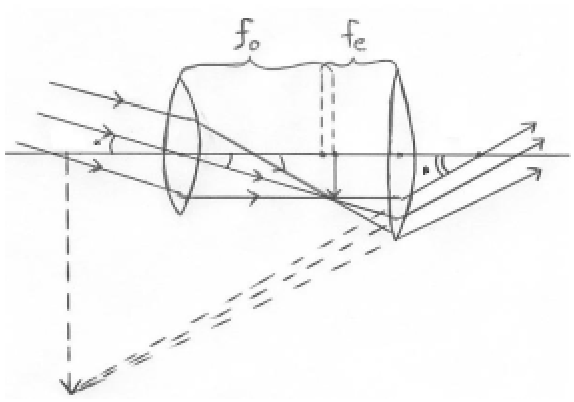
    Final image is formed at the infinity.

    So the image of objective lens is at the focus of eye piece.

    $\therefore L = f_o + f_e$

    Magnification $(m) = \dfrac{\beta}{\alpha} = \dfrac{f_o}{f_e}$

  - **Final image at least distance of distinct vision:**

    If the image has to be formed at least distance of distinct vision then the image by objective lens should be within the focus of eye piece.

    So the length of telescope is $L = f_o + u_e$ and magnification:

    $$m = \frac{\beta}{\alpha}$$
    $$m = \frac{f_o}{f_e}\left(a + \frac{f_e}{D}\right)$$

- **Terrestrial telescope:**

  It is used to see distant object on the earth. The final image is virtual, erect and magnified.

  Length of telescope, $L = f_o + 4f + f_e$

  Magnification, $m = \dfrac{f_o}{f_e}$

  - **Galilean Telescope:**

It is also a type of terrestrial telescope but of much smaller field of view. It's objective lens is a convergent lens while the eye piece lens is divergent lens. The final image is virtual, erect and magnified.

When the final image is formed at infinity then its length, $L = f_o - f_e$
and magnification $m = \frac{f_o}{f_e}$

If the final image is formed at least distance of distinct vision then its length is:
$L = f_o - f_e$
and magnification:
$m = \frac{f_o}{f_e}\left(1 - \frac{f_e}{D}\right)$

Camera

- **f number:**

  f number of camera give the size of aperture so diameter of aperture is : $d = \frac{f}{f - \text{number}}$

- **Illuminance:**

  Amount of light entering the camera is directly proportional to area of aperture.

- **Brightness:**

  Brightness of image is proportional to $\frac{d^2}{f^2}$. So, $B \propto \frac{d^2}{f^2} i.e, B \propto \frac{1}{(f - \text{number})^2}$

- **Time of exposure:**

  The time during which shutter open is called time exposure which is proportional to square of f number. $T \propto (f - \text{number})^2 \propto \frac{f^2}{d^2}$

Photometry

The branch of optics which study and measure the light emitting capacity of a source and illuminance produced by it.

- **Radiant Flux (R)**

  Total energy radiated by a source per second (unit is watt)

- **Luminous flux (Φ)**

  Light energy radiated by a source in one second (unit is lumen)

- **Luminous intensity (I)**

  Luminous flux per unit solid angle (unit is candela i.e lumen per steradian)

  $$L = \frac{\Phi}{\Omega} = \frac{\Phi}{4\pi} \quad (i.e, \text{lumen per steradian})$$

- **Illuminance (I)**

  Luminous flux per unit area falling normally.

  Its unit is lumen/m^2 or lux.

  $$\therefore I = \frac{\phi}{A} = \frac{L}{r^2} \quad \text{(for point source)}$$

  $$I = \frac{\Phi}{A} = \frac{4\pi I}{2\pi r I} = \frac{2I}{rl}$$

  $$\therefore I \propto 1/r \quad \text{(For a cylindrical source)}$$

- **Lambert Cosine Law**

  At a given point for a given source illuminance varies linearly with cosine of angle of incidence.

  $$i.e\ I \propto \cos\theta$$

- Efficiency of source

  It is the ratio of luminous flux to the powe of source. i.e, $\eta = \frac{\Phi}{P} = \frac{4\pi I}{P}$

  Its unit is lumen/watt.

- Luminance or Brightness

  It is the luminous flux reflected from a unit area of surface.
  Its unit is lambert.

- Photometer

  It is a device use to compare illuminating power of two sources Two sources placed at a distance r_1 and r_2 form a screen have same illuminance then:

$E_1 = E_2$

$\text{or, } \frac{I_1}{r_1^2} = \frac{I_2}{r_2^2}$

$\text{or, } \frac{I_1}{I_2} = \left(\frac{r_1}{R_2}\right)^2$