• Roughly a sphere of ~12 mm radius  
• Typical extreme range of vision is 380 nm to 740 nm  
• The rods are sensitive to weak light, inoperative in strong light, and have maximum sensitivity at about 507 nm. Rods cover the retina.  
• The cones are sensitive to strong light, insensitive to weak light, and have a maximum sensitivity at 555 nm. Cones occupy only the fovea.  
• Cones and rods on retina are waveguides. Cats back these with a reflective tapetum to get double pass, but eyes become cat’s eye retroreflectors.  
• Pupil diameter changes from 4 to 8 mm, many times less that ~10⁶ dynamic range of eye. Reason is not light reduction but aberration reduction by “stopping down the system”. At any one time, dynamic range of eye is ~10³.  
• Spacing of rods on fovea is about equal to diffraction-limited spot size of the pupil at the minimum diameter.  
• Most refraction occurs at the cornea (large index contrast) while the lens adjusts via change of shape to change total power.  
• Typical visual resolution is about 6 minutes of arc. 20/20 vision = ability to resolve 5 arc minute features at 20 feet.

http://www.du.edu/~jcalvert/optics/colour.htm#Eyes
20/20

- A measure of Visual Acuity.
- 20 / XX implies that a subject can identify a letter at 20’ what a standard observer can at XX feet.
  - 20 / 10 GOOD
  - 20 / 40 BAD
- The retina can support better than 20 / 10

At 20/20:
The eye

A simple optical model for \( \infty \) focus

\[
z = \frac{x^2 + y^2 + pz^2}{2r}
\]

\[
f = \frac{1}{60 \text{ Diopters}} = 16.67 \text{ mm}
\]

\[
\frac{n_{\text{VH}}}{t'} = -\frac{1}{\infty} + \frac{1}{f}
\]

\[
t' = n_{\text{VH}}f = 22.22 \text{ mm}
\]

### Design of ideal imaging systems with geometrical optics

#### The eye

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emmetropic wavelength of the model, ( \lambda_D )</td>
<td>5.80 mm</td>
</tr>
<tr>
<td>Refractive index for emmetropic wavelength, ( n_D )</td>
<td>1.333</td>
</tr>
</tbody>
</table>
| Refractive index for wavelength \( \lambda \) in microns, \( n(\lambda) = a + b/\lambda - c \) | \[
a = 1.320535 \\
b = 0.004685 \\
c = 0.21402
\] |
| Constringence of ocular medium, \( F_p = (n_p - 1)/(n_p - n) \) | 50.25 |
| Apex radius of curvature, \( r \) | 5.55 mm |
| Shape parameter, \( p \) | 0.6 |
| Elliptical eccentricity \( e = \sqrt{1 - p^2} \) | 0.6325 |
| Axial position of the physical pupil from the apex, \( z \) | 2.55 mm |
| Axial position of the entrance pupil from the apex | 2.16 mm |
| Focal power for emmetropic wavelength, \( f_0 = (n_0 - 1)/r \), 60 diopters | |
| Anterior focal length for emmetropic wavelength, \( f'_0 = (1/f_0) \) | 16.67 mm |
| Posterior focal length for emmetropic wavelength, \( f''_0 = (n_0/f_0) \) | 22.22 mm |
Most important quantity
Retinal magnification factor

aka focal length!

\[ s = f\theta = 16.6\theta \]

\( f, s \) in mm, \( \theta \) in radians
Accommodation

- Power of accommodation = 4 diopters in young, decreases with age.
- Near point $D_{np}$ is 25 cm in young and increases with age as power of accommodation decreases.

<table>
<thead>
<tr>
<th>Object Distance [m]</th>
<th>Focal Length [mm]</th>
<th>Power [diopters=1/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>15.9</td>
<td>62.8</td>
</tr>
<tr>
<td>1</td>
<td>16.7</td>
<td>59.9</td>
</tr>
<tr>
<td>3</td>
<td>16.9</td>
<td>59.2</td>
</tr>
<tr>
<td>100</td>
<td>17.0</td>
<td>58.8</td>
</tr>
<tr>
<td>Infinity</td>
<td>17.0</td>
<td>58.8</td>
</tr>
</tbody>
</table>

http://www.physicsclassroom.com/Class/refrn/U14L6c.html
Ray tracing the eye

+Simple instrument: single lens magnifier

Near point, \( D_{np} = 25 \text{ cm} \)

\[
\frac{1}{D_{np}} + \frac{n_e}{t_e} = \frac{1}{f_e}
\]

\[
h_e = \left( \frac{t_e}{-n_eD_{np}} \right) h
\]

Gaussian lens & mag eqs.

Define visual magnification, \( M_v \), as increase in image size caused by new lens

\[
-\frac{1}{t_M} + \frac{n_e}{t_e} = \left( \frac{1}{f_e} + \frac{1}{f_M} \right) \quad M_v h_e = \left( \frac{t_e}{n_e t_M} \right) h
\]

Subtract

\[
\frac{1}{t_M} = \frac{1}{D_{np}} + \frac{1}{f_M}
\]

Divide

\[
M_v = \frac{D_{np}}{-t_M} + \frac{D_{np}}{f_M} = 1 + \frac{D_{np}}{f_M}
\]

Visual magnification of single lens at near point of eye
The magnifier (again)
via angles – useful for infinite conjugates

For a equal focal lengths, \( f_e \), visual magnification should be proportional to ratio of angles via similar triangles

\[
M_v = \frac{\beta}{\alpha} = \frac{D_{np}}{-t_M} = 1 + \frac{D_{np}}{f_M}
\]

For an object at infinity, this becomes \( M_v = \frac{D_{np}}{f_M} \)