Vision

Structure and function of the eye.
Image formation in the eye, accommodation.
Vision defects.
Properties and function of photoreceptors.
Resolving power of the eye.
The process of color vision.

11/18/2014

Vision

The act of sensing with the eyes through the detection of visible light.
The eye is a special organ for light detection.

**Light:** electromagnetic radiation with wave and particle properties.
**Visible** light: ~350 nm (purple) – 750 nm (red)
Wave

A disturbance, oscillation, or vibration either of a medium (e.g. water) or of some quantity (e.g. electric field) with different values at different points in space as it is moving through space (e.g. water waves; electromagnetic waves).

Energy can be transferred with waves.

Classification

• based on the needs for a medium to propagate
  — mass waves (propagate through a medium e.g. seismic waves, sound)
  — electromagnetic waves (medium is not needed, travels through vacuum)

• based on the direction of its vibration (oscillation) and the direction of propagation
  — Transverse: a wave that oscillates perpendicular to the axis along which the wave travels (e.g. electromagnetic waves)
  — Longitudinal: a wave that oscillates along the axis of the wave propagation (e.g. sound waves).

Basic wave properties

Reflection: the wave is bouncing back from a second medium.

Refraction: The bending (change of direction) of a wave, such as a light or sound wave, as it passes from one medium to another medium of different density (different optical activity: different refractive power).

Absorption: energy lost in the other medium.

Diffraction: a deviation in the direction of a wave at the edge of an obstacle in its path.

Interference: the combination (superposition) of two or more waves (reinforcement and attenuation based on the phase difference between the waves).

Polarisation: vibration or oscillation in one plane (only the transverse wave can be polarised).
Wave equation

\[ c = \nu \lambda \]

- \( c \): speed of the wave (m/s)
- \( \nu \): frequency of the wave (s\(^{-1}\)) – number of waves/seconds
- \( \lambda \): wavelength (m)

**Transversal wave**

**Longitudinal wave**

Compression (high density)

Direction of travel

Expansion (low density)
Traveling vs. standing (stationary) wave

- The wave is moving in a certain direction.

Standing (stationary) vs. traveling wave

- The combination of two waves of equal frequency and intensity travelling in opposite directions.
- The wave stays in a constant position.
Basic characteristics of electromagnetic wave

Electromagnetic waves

Electromagnetic Spectrum

Wavelength, $\lambda$ (in meters)

Visible Light

Wavelength, $\lambda$ (in nanometers)
Thin convex (converging) lenses

\[
\frac{1}{f} = \frac{1}{P} + \frac{1}{O}
\]

Accommodation - focusing

The ability of the eye to change its focus from distant to near objects. The lens changing its shape.

- Distance vision:
  - contracted ciliary muscle
  - relaxed fibres

- Near vision:
  - relaxed muscle
  - tense fibres

\begin{align*}
\text{Lens is less convex} \\
\text{Lens is more convex}
\end{align*}
The refractive parts of the eye

- cornea
- aqueous humor
- the crystal lens
- vitreous humor

The total refractive power (diopter) of the human eye ~ 62 D (f~1.6 cm).
Properties of the receptor cells

<table>
<thead>
<tr>
<th>Rods (~125 million)</th>
<th>Cones (~ 6 million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very sensitive (1 photon!)</td>
<td>Less sensitive, works in wider intensity range.</td>
</tr>
<tr>
<td>Mainly at the “periphery” of the retina</td>
<td>Mainly in the fovea.</td>
</tr>
<tr>
<td>More sensitivity but low spatial resolution.</td>
<td>Better spatial resolution.</td>
</tr>
<tr>
<td>Does not sense the colour only the presence of the light (&quot;black or white&quot;)</td>
<td>Colour sensing:</td>
</tr>
<tr>
<td></td>
<td>- red (560nm)</td>
</tr>
<tr>
<td></td>
<td>- green (530nm)</td>
</tr>
<tr>
<td></td>
<td>- blue (426nm)</td>
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</table>

Molecular mechanism behind the vision

**Rhodopsin** is a transmembrane protein complex.

**RHODOPSIN**: opsin — 11-cis-retinal

**Opsin**: colorless protein that in combination with retinal forms a visual pigment (as rhodopsin). The reaction is reversed by light.

**Retinal**: a yellowish to orange aldehyde derived from vitamin-A.

**RHODOPSIN + LIGHT** $\rightarrow$ opsin + 11-trans-retinal

**Isomerization**: same molecular formula but different structures (arrangement of atoms in the molecule).
Phototransduction

In the retina photoreceptors do not exhibit action potentials.

**light activation → graded** change in membrane potential → corresponding change in the rate of transmitter release onto postsynaptic neurons.

- **In the dark:**
  - photoreceptors are **depolarized** (-40 mV)
  - the number of open voltage sensitive Ca\(^{2+}\) channels in the synaptic terminal is **high**
  - the rate of transmitter release is correspondingly **great**

- **In the light:**
  - photoreceptors are **hyperpolarized** (-65mV)
  - the number of open Ca\(^{2+}\) channels is **reduced**
  - the rate of transmitter release is also **reduced**

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**Phototransduction**

- Light stimulation of rhodopsin → **activation of a G-protein** (transducin) → **activation of a phosphodiesterase** (PDE).
- The phosphodiesterase **hydrolyzes** cGMP → cGMP cc. **decreasing** → closure of sodium channels in the outer segment membrane → **hyperpolarisation**
Trichromatic theory of colour vision

Thomas Young (1773-1829) english doctor, scientist: discovered that in the human eye there are three different color sensitive cones.

Hermann Helmholtz (1821-1894) german doctor, physicist: discovered that the cones can detect wide range of the spectra (colors).
The end!