Vision

The eye

Image formation

Eye defects & corrective lenses

Visual acuity

Colour vision
Vision

Perception of light --- eye-brain system

Physiology -- describes how the image is processed by eye-brain combination

Perceptual Psychology --
high level processing of information

Physics ---
image formation on the retina
Iris

- Muscular diaphragm
- Controls size of pupil
- Colour of the eye
Vision

Physics --- image formation on the retina

Cornea (refractive index = 1.376 provides main refractive power of the eye)
Aqueous humor (refractive index = 1.336)
Pupil (variable opening in iris)
Lens (refractive index = 1.437)
Vitreous humor (refractive index = 1.336)
Retina (image is formed on the retina)
Physics --- image formation on the retina

**Lens** contributes only about 20-25% of the refractive power of the eye.

**Lens-cornea** system focuses light onto the retina (rear surface of the eye). Shape of the lens is altered by the ciliary muscles.

**Iris** regulates the amount of light entering the eye by controlling the diameter of the pupil.
Vision

Retina
consists of millions of **photo-receptors**
called **rods** \((1.3 \times 10^8)\) and **cones** \((7 \times 10^6)\)

Converts light energy into electrical energy

These structures send **electrical impulses to the brain** via the optic nerve

**Rods & cones** chemically adjust their sensitivity depending on light levels
-- takes about 15 minutes

“getting used to the dark”

**Fovea** -- most sensitive part of retina
slightly **off centre**
At the **optic disk** there are no photo-receptors

**Blind spot on retina at optic disk**

Not noticeable because each eye compensates by seeing what the other doesn't.
Vision

Accommodation

\[ \frac{1}{s'} + \frac{1}{s} = \frac{1}{f} \]

Lens to retina distance (image distance \( s' \)) is fixed.

**Focal length** (and hence the power) of the lens must vary to ensure objects at various distances can be brought to a focus at the retina.

The process called **Accommodation**.

**Normal eye** is capable of focusing on objects over a range from **infinity (far point)** (Ciliary muscle relaxed) (loupe design) to the **near point of 25 cm**.

**Ciliary muscle tense**

Near point increases with age.
Example

Calculate the refractive powers of the eye required to view an object clearly
(a) at far point and (b) at near point

Strength = 1/s′ = 1/f = 1/(0.023 m) = 43.5 diopters

At the far point (≈ infinity) object distance s is very large, therefore
Strength = 43.5 diopters
Eye defects

Farsightedness (hyperopia)

Object at normal near point: Eye lens cannot be made sufficiently converging to bring object to focus on the retina: lens to weak (focal length to long)

Near point

25cm

Converging eyeglass lens required to ensure focus at retina

Near point

eyeglass
**Eye defects**

**Nearsightedness (myopia)**

Eye lens cannot relax sufficiently to focus a very distant object on the retina, **lens to strong** (focal length to short)

Diverging eyeglass lens required to ensure focus at retina
Example

A woman with an eye defect has a far point of 80 cm. Name the defect and calculate the focal length of a suitable corrective lens.
Eye defects

**Astigmatism**
Results from an asymmetry in the cornea (irregular curvatures)

Cornea: different curvature in different directions. e.g.

different foci for rays that propagate in two perpendicular planes

**Test chart**

**Astigmatism** can be corrected using cylindrical lenses, correctly orientated
Eye defects

Astigmatism

Rays in horizontal plane not in focus

Correctly orientated cylindrical lens corrects astigmatism
Eye defects

Presbyopia

**Loss of accommodation** (presbyopia)
Inability for eye to **accommodate** increases with age.

Eventually affects nearly everyone.

difficulty in seeing near and distant objects clearly

**Correction**
bifocal
or varifocal lens
Visual acuity—ability of the eye to see fine detail

Also known as **spatial resolving power**

Visual acuity is mainly limited by:
1. photoreceptor density on the retina
2. Diffraction effects,

\[
\theta = \frac{y}{d}
\]

Eye can resolve points with a minimum angular separation of \(3 \times 10^{-4}\) radians = 1.0 minute of arc

Minimum Spatial separation \(y\) at distance of 6 m??
Rows of retinal cells 2μm apart

Images of two adjacent dots must fall on two nonadjacent retinal cells

Idealy there should be a few unexcited cells separating the the ones on which the images appear---otherwise the images will not be resolved
Example

Determine the size of the image on the retina of (a) a dot 1.8 \times 10^{-2} \text{ cm} in diameter at a position 60 \text{ cm} from the eye and (b) a person of height 1.7 \text{ m} at a distance of 10 \text{ m} from the eye.
Diffraction is the spreading of light as it passes through an aperture or passes by the edge of an object. Diffraction effects are dependent on the size of the aperture or object – greatest when the dimensions approach that of the wavelength of the light.

**Visual acuity (resolution)**

- Clear circular spot the size of circular aperture produced on screen
- Clear circular spot the size of circular aperture produced on screen
- Fuzzy circular spot, much larger than aperture, produced on screen
Visual acuity (resolution)

Diffraction effects

Pupil is, on average, 3mm diameter. Hence diffraction effects are extremely small.

However, this small effect is important when considering the limits of visual acuity.

Other less important effects that limit visual acuity are:
- illumination,
- contrast,
- location of image on retina.

20/20 vision  Normal sighted person

Someone with 20/20 or 6/6 vision (visual acuity) is just able to decipher a object (letter) that subtends a angle of 1 minute of arc at the eye.

20/20 not perfect
young adults 20/16>>>20/12
Hawk 20/2
Large pupil, & small photo-receptors
Electromagnetic Waves

Visible waves
- Wavelength: \(\approx 400 \text{ nm} - 700 \text{ nm}\)
- Frequency: \(\approx 10^{15} \text{ Hz}\)

Characteristics
- The only waves the eye can see
Red light has the lowest frequency
and violet has the highest

-What colour does the eye see best?

[Graph showing sensitivity vs. wavelength with peaks at 500 nm for Green Cone, 400 nm for Blue Cone, and 600 nm for Red Cone.]
Isaac Newton (1643—1727) demonstrated that white light is composed of several colours.

White light passing through a prism is separated into its constituent colours.

Reason: refractive index of the glass in the prism varies with wavelength (colour).
This variation of refractive index with wavelength is called **Dispersion**.

Wavelength: 400 nm - 700 nm
Objects have a particular colour
- reflection/absorption characteristics.

Example; an apple appears **green** because all wavelengths except **green** are absorbed; **green** is reflected.

Red eye effect
Due to blood vessels at back of eye (retina)

**Various levels of absorption** will result in an object having more complex shades of colour.
Colour Vision

Visible spectrum

Infrared  Wavelength  Ultra violet

Colour vision is related to the wavelength of light

Rods and Cones
Light sensitive cells in the retina:

Cones:
• Less sensitive
• Colour vision
• Concentrated in fovea

Rods:
• Highly sensitive
• Low light level vision
• Peripheral vision
• Little colour information
The sensitivities of the three cones overlap and the perceived colour is due to the relative response of the three cones.

**Colour blindness** results from absence of one or more types of cones.
Dentistry: colour matching
Tooth enamel is semi-translucent, light passes through in a disuse manner.

Main colour of tooth is that of dentine colour

**Colour matching in restorative work**
Spectral distribution of illumination important;

Affects the colour appearance of the object

natural light, artificial light may be different

**Spectral distribution Sun**

Colour matching should be carried out in natural light or artificial light with spectral distribution close to that of natural light.
Dentistry: colour matching

Other factors to consider

Colour matching impaired by colour blindness

Colour fatigue
Prolonged exposure to one colour reduces the response of the eye to that colour

Perceptual Psychology:
Example: appearance of an object depends on the background colour

> dark backgrounds make materials appear brighter
Colour matching aesthetics in restorative work

What factors affect visual perception

Teeth composed of layers of different structures

How does light interact with different structures

Enamel is translucent: light is
• transmitted
• reflected
• scattered

Dentine more opaque than enamel

Colour perception of incisal edges of anterior teeth defined by enamel.