Introduction and background - The Light

Is that part of the electro-magnetic spectrum to which the human eye is sensitive i.e. the visible part of the electro-magnetic spectrum.

It’s wavelength range is 400-760 nm.

light travels through space in straight lines.

If a ray of light meets a body in its passage through space, one of three things may happen to it:

1. Absorption: opaque materials for example black bodies, absorb the light which falls on them;
2. Reflection; materials such as mirror surfaces, reflect the light backwards;
3. Transmission: transparent materials such as glass, transmit the light; a considerable proportion of it, allowing to pass through them but it’s direction will be changed (Refraction).

Many substances combine these effects to some degree.

In space, light maintains a constant speed of about 186 000 miles per second, but as it travels through the substance of such a transparent body, it will encounter more resistance, this retards its progress.

When a beam of light strikes a glass plate with parallel sides, it is retarded while traversing the plate, and then travels on unaffected.

Refraction

Refraction at a curved surface (Refraction by lenses)

When parallel rays of light strike a spherical surface, each individual ray will be bent to a different degree and the rays may then all meet at a focus. The distance of this focus from the surface depends on

1- curvature of the surface
2- optical density of the two media concerned
3- wavelength of the light

Lenses are of many varieties, and the ones most commonly used in ophthalmic practice are spherical and cylindrical with either convex or concave surfaces or combinations of these.

Types of spherical lenses:
Images formed by convex lenses

If the incident rays are parallel (that is, come from infinity), they will be converged upon a single point on the other side of the lens; at this point the image will be formed. This point is known as the principal focus, and its distance from the lens is called the focal length.

![Image of convex lens with incident rays converging to a single point](image1)

**Fig.** The incident rays are parallel, coming from infinity; the focus (F) is called the principal focus.

In practice, an object which is 6 meters or more away, is considered to be at infinity, and the rays of light issuing from it are parallel.

Images formed by concave lenses

The construction of images formed by concave lenses. These lenses diverge the rays of light so that they never form a real image but always a virtual one. When the object is in any position, it will be found that the image is virtual, erect, and smaller than the object.

![Image of concave lens forming a virtual image](image2)

**Fig.** The image formed by a concave lens. If AB is the object, the image ab is diminished and erect and, being formed on the same side of the lens as that from which the incident light comes, is virtual.

The notation of lenses

The more a lens is able to refract light the more powerful we consider it to be, the power of thin glass lenses is related to the surface curvature. The focal length of a lens, is the distance from it of the focus which to measure the refractive power. A focal distance of 1 meter is taken as the unit, and a lens with a focal distance 1 meter away is spoken of as having a refractive power of 1 dioptre (1 D). Since a stronger lens has a greater refractive power, the focal distance will be shorter. Lenses having a power (P) or strength, with the unit being in diopters (d). The power of a lens is the inverse of the focal length. \[ P = \frac{1}{f} \] Where \( P \) is in diopters and \( f \) is in metres.

![Diagram of concave and convex lenses showing focal length and power](image3)
Refraction by astigmatic lenses

*Spherical* lens where all meridians have the same curvature the rays coming from a point can be focused as a point; *cylindrical* lens where one meridian is curved and the one at right angles has no curvature at all, the image formed of a point object is a straight line. This therefore is the simplest form of an astigmatic lens.

It can therefore be appreciated that an astigmatic lens, because of the different curvature of its meridian, can never produce a point focus of a point object. Where the two meridians in question are at right angles to each other, the condition is termed regular astigmatism.

Refraction by prisms

When light passes through a medium with parallel sides the incident rays and the emergent rays are parallel; but if the sides of the medium are not parallel the direction of the rays must also change. Such a medium is typified in the prism.

The entire deviation is towards the base. The total amount of the deviation between the incident ray and the emergent ray is called the angle of deviation.

Thus while the light is deviated towards the base, the image is displaced towards the apex of the prism.

Refraction by the eye

To generate accurate vision by the eye, light must be correctly focused on the retina. This focus is done by refraction of the light. The eye is a compound optical system:

The *cornea*, or actually the air/tear interface is responsible for two-thirds of refractive power of the eye, because of the large difference in index of refraction of both media.

The *crystalline* lens is responsible for one-third of the focusing (refracting) power of the eye.

*The eye.*

C: the cornea.

L: the lens.

M: the macula.

O: the optic nerve.

FA: the optic axis, meeting the retina at A.

N: the nodal point.
Optical system of the eye

- **a**: anterior surface of cornea;
- **b**: posterior surface of cornea;
- **c**: anterior cortex;
- **d**: anterior core,
- **e**: posterior cortex;
- **f**: posterior core;
- **v** and **g**, anterior and posterior poles of the eye through which the optical axis passes; line **j** **h**, visual axis.

Visual Acuity

Normal VA is 6/6 or 20/20

The Snellen test is a test of minimum separable acuity, it is the clinically preferred acuity test.

Emmetropia & Ametropia

*Emmetropia (normal refractive state): optically normal eye*

Parallel rays of light from a distant object (at infinity) are brought to a focus on the retina when the eye is at rest (not accommodating).

*Ametropia (abnormal refractive state)=Refraction errors.*

Parallel rays of light are not brought to a focus on the retina in an eye at rest. A change in refraction is required to achieve sharp vision.

Refractive errors

Defective vision is most commonly caused by ammetropia (errors of refraction) that is why, when a patient complaints of a visual problem, it is extremely important to ask the question:

*Is it caused by a refractive error?*

The use of a simple “pinhole” made in a piece of card will help to determine whether or not there is a refractive error. The vision will improve unless the refractive error is extremely large.

*Refraction status development.*

Most infants are hyperopic, probably because the axial length of their eyeballs is too short.

Consequently, hyperopia decreases with growth.

It occurs when the length of the eyeball, the curvature of the cornea, and the power of the unaccommodated lens all are appropriate for focusing collimated light on the retina.

*Ametropia*

All three types of ametropia can be corrected by wearing spectacle lenses

In hypermetropia, accommodative effort will bring distant objects into focus by increasing the power of the lens so he uses his accommodation that reserved for near objects, if the degree of hypermetropia is more than his accommodation, he cannot see far objects also.
Myopia

(short sightedness); the optical refractive power of the eye is too high so the parallel rays of light are brought to a focus in front of the retina, (when the eye is at rest).

**Causes:**

1- ↑ ant-post diameter of the globe = axial myopia
2- ↑ curvature of the cornea = curvature myopia
3- ↑ refractive index of the lens = index myopia

Spectacle correction of myopia

a. Rays from the far point are focused on the retina.

b. A negative lens whose second focal point coincides with the far point forms a virtual image of rays from infinity at the far point.

c. Rays from the infinity strike the eye with a vergence as if from the far point and are focused on the retina.

Hypermetropia

(long sightedness); the optical power is too low so parallel rays of light converge towards a point behind the retina, (when the eye is at rest).

**Causes:**

1- ↓ A-P diameter of the globe = axial hypermetropia.
2- ↓ curvature of the cornea = curvature hypermetropia.
3- ↓ refractive index of the lens = index hypermetropia.

Spectacle correction of hyperopia by plus spherical lens.

a. The far point lies behind the eye. Rays converging to the far point lies behind the eye. Rays from the far point are focused on the retina.

b. A plus lens focuses rays from infinity at its second focal point, which is coincident with the far point.

c. Convergent rays strike the eye and are focused on the retina.

Astigmatism

The optical power of the cornea in different planes is not equal.

Parallel rays of light passing through these different planes are brought to different points of focus.

Corneal topography demonstrates with-the-rule astigmatism. The purple lines drawn suggest the pattern for Limbal relaxing incisions.

**Types of regular astigmatism**

1- Simple hyperopic astigmatism.
2- Simple myopic astigmatism
3- Compound myopic astigmatism
4- Compound hypermetropic astigmatism
5- Mixed astigmatism
Astigmatism & correction by cylindrical lenses

Cylinders, have a maximum curvature along their circumferential direction and zero curvature along their length, that is, parallel to the cylinder axis.

The zero curvature is 90 degrees to the maximum curvature.

A cylindrical refracting surface will form a line image of a point parallel to the cylinder axis.

Irregular Astigmatism

In reality, the axes may be at any meridian. If the maximum and minimum curvatures are 90 degrees apart, the astigmatism is regular, for example, 45 degrees and 135 degrees, or 65 degrees and 155 degrees.

If, however, the two principal meridians of curvature are not 90 degrees apart or the corneal curvature is not axially symmetric, the condition is irregular astigmatism.

This may be due to injury, corneal diseases that leave scars, Keratoconus, or congenital abnormalities.

Anisometropia

Anisometropia is the condition in which the refractive error of one eye differs from the other.

It may be characterized by unequal amounts of myopia or hyperopia, or one eye may be myopic and the other hyperopic, to which the special term Anisometropia is applied.

After cataract extraction! Aphakia.

The lens provides one-third of the refractive power of the eye so that after cataract extraction (the removal of an opaque lens) the eye is rendered highly hypermetropic, a condition termed aphakia.

This can be corrected by:

1- The implantation of an intraocular lens (IOL) intra-operatively [pseudophakic] ;
2- Contact lenses;
3- Aphakic spectacles (eye glasses).

Contact lenses

Types: (rigid, gas permeable & soft hydrophilic CLs).

Rigid retard the diffusion of oxygen to the cornea. Rigid gas permeable lenses are relatively more permeable to oxygen.

Although soft lenses are better tolerated, gas permeable lenses have certain advantages:

- Their ↑ oxygen permeability ↓the risk of corneal damage (from hypoxia)
- Their rigidity allows easier cleaning and offers less risk of infection;
- Their rigidity allows for a more effective correction of astigmatism;
- Proteinaceous debris is less likely to adhere to the lens and cause an allergic conjunctivitis.

Plane soft contact lenses may also be used as ocular bandages, e.g. in the treatment of some corneal diseases as a persistent epithelial defect.
The optical benefits of contact lenses over spectacle correction in high myopia include:

1- **Image magnification**, (when the optical correction in myopia is brought closer to the corneal surface, image magnification decreased.)

2- The elimination of prismatic object displacement with its attendant “barrel” distortion.

3- **Elimination** of image degradation caused by the spherical aberration of spectacle lenses with off-axis viewing (coma).

**Is Presbyopia refractive error? Accommodation error!**

The rays of light from closer objects, such as printed page, are divergent, can be seen well only by the process of accommodation, at which the circular ciliary muscle contracts, allowing the naturally elastic lens to be more globular shape = greater converging power, the eyes also converge.

With age the lens gradually hardens and the lens no longer becomes globular, so the accommodation ↓, reaching a critical point after age of 40 years.

Close work becomes gradually more difficult. Objects have to be held away to reduce the need for accommodation.

Convex lenses in the form of reading glasses therefore are needed to converge the light rays from close objects.

This occurs earlier in hypermetropes than myopes.

The physical part is related to hardening or sclerosis of the crystalline lens that reduces the elasticity of the lens capsule and the plasticity of the lens core.

The physiologic part of accommodation is the innervations and contraction of the ciliary muscles. Some hold that sclerosis of the ciliary body reduces its ability to constrict, and the lens does not sufficiently obtain the conditions required for changing its shape.

**Low vision aids**

Patients with poor vision can be helped by advice on lighting conditions & low vision aids. Devices used include:

- Magnifiers for near vision;
- Telescope for distant vision
- Closed circuit TV to provide magnification & improve contrast;
- Large print books;
- Talking clocks and watches; etc

**Refractive surgery**

Although refractive errors are most commonly corrected by spectacles or contact lenses, laser surgical correction is gaining popularity.

The laser & non laser surgeries either modify the shape of the cornea or do an open eye surgery as in pseudophakia IOL, clear lens extraction, and the new phakia IOL.

The excimer laser precisely removes part of the superficial stromal tissue from the cornea to modify its shape.

Myopia is corrected by flattening the cornea and hypermetropia by steepening it.