Physics Factsheet
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Physics of Vision

In this Factsheet, there will be a small amount of lens theory, but primarily we will be looking at how images are focused in the eye, and how we can correct difficulties with our vision.

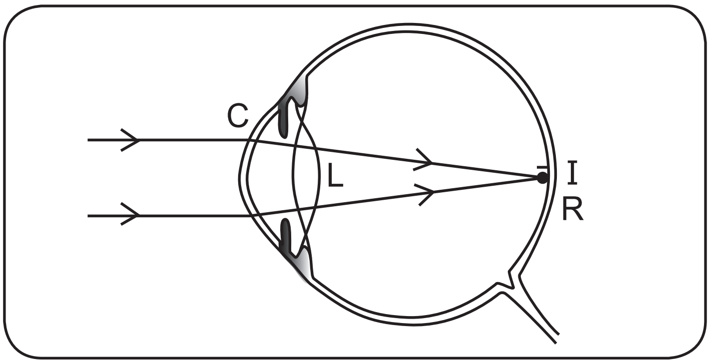
How the eye works

In the eye, light is focused onto the retina at the back of the eye by means of the cornea and lens. The cornea does most of the refracting of the light rays, but is fixed in shape. The lens contributes less refraction, but can change its shape to focus light from distant and nearby objects. The **power** of the lens changes.

In our diagrams, C will show the position of the cornea, L the lens, and R the retina. The aim is always to focus the image onto the retina. And we will use O and I for the object and the image, as we normally do.

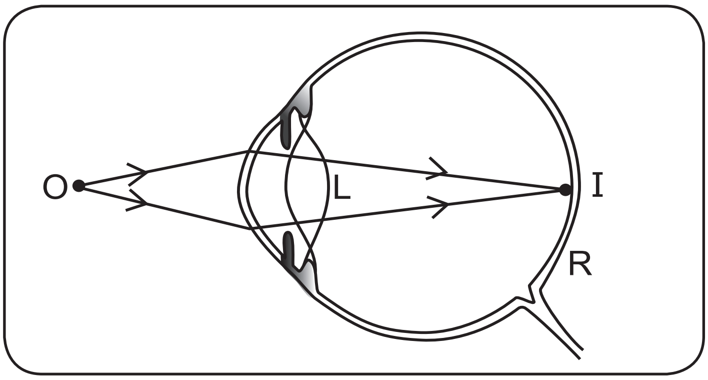
For a distant object, the light rays enter the eye almost parallel to one another, and the lens is in a relaxed state. The rays are refracted at the cornea and the lens, and form an image on the retina:

Figure 1



For a nearby object, the lens changes shape to increase its power. The image is again focused on the retina (this adjustment in shape of the lens is called **accommodation**).

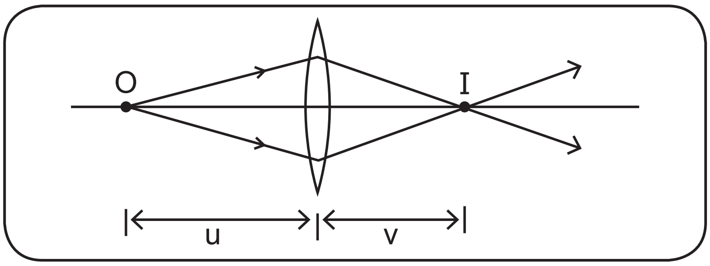
Figure 2



The power of a lens

We don't usually talk about the power of the lens in our eye. But if we require correcting lenses (glasses or contact lenses), then we must be able to specify their strength. If we look at a convex (positive) lens refracting light rays to form an image, we can use "u" and "v" for the object and image distance.

Figure 3



We define the power, P, of this lens to be:

$P = 1/u + 1/v$

The unit is dioptres (d), when the distances are in metres.

> ***Example:*** *If the object distance, u, is 80cm and the image distance, v, is 45cm, then find the power of the lens.*
> ***Answer****: P = 1/0.80 + 1/0.45 = 3.5 dioptres*

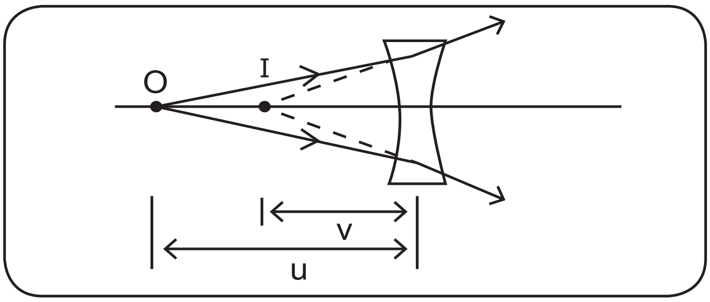
If this lens stays the same shape, then its power stays the same.

> ***Example:*** *For the same lens, if the object is brought closer to the lens, so that u = 50cm, then find the image distance.*
> ***Answer:*** *P = 3.5 = 1/0.50 + 1/v*
> *v = 67cm*

The image moves further away from the lens as the object approaches the lens.

For a concave (negative) lens, the image formed is a virtual one. However, object and image distance are used in the same way as for convex lenses. However, this time the image distance is considered as negative, leading to a negative power for the lens.

Figure 4



Example: *For a concave lens, the object distance is 80cm and the image distance is 25cm (on the same side of the lens, of course). Find the power of this lens.*
Answer: *P = 1/0.80 – 1/0.25 = -2.8 dioptres*

Both positive and negative lenses are used to correct defects of vision.

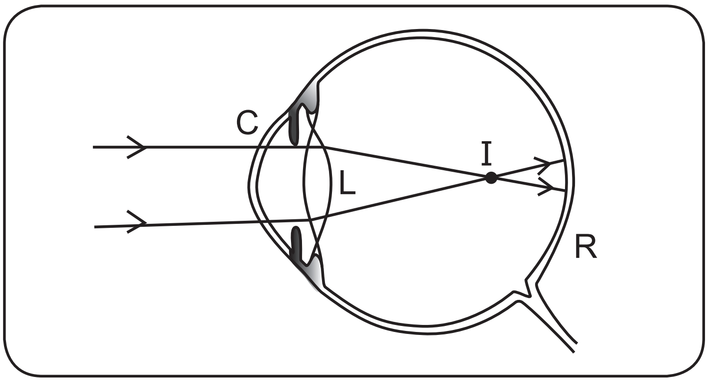
Defects of Vision

There are many ways in which your vision can be less than perfect. We will consider a few of the common ones, and look at techniques for correcting them:

a) Myopia (near-sightedness)

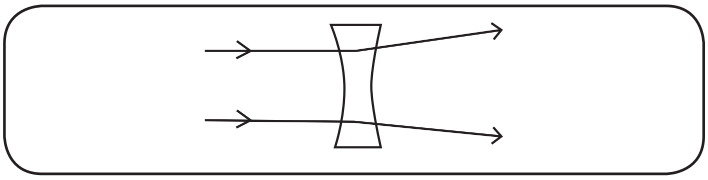
When the lens in the eye is too fat (to use the technical term), it is easy to focus light from a nearby image. However light rays from a distant image are focused in front of the retina, as the lens is too powerful. The image on the retina is blurred. This defect can also be caused by an eyeball that is slightly too long.

Figure 5



To correct this, a concave (negative) lens must be used. The lens spreads the light rays slightly outwards, as if they are coming from a closer object.

Figure 6



As we have seen with lenses in general, light from a closer object requires a greater image distance, so the rays are now focused on the retina, rather than in front of it.

This correcting lens can be a glasses lens, a contact lens, or an intraocular lens (more about this later).

b) Hypermetropia (long-sightedness)

You will also see this called **hyperopia**. In this defect, the lens in the eye is too thin. Distant objects can be focused successfully on the retina. However, the power of the lens is too small to focus light from a nearby object onto the retina. The focal point is behind the retina. Again, the image on the retina is blurred. This defect can also be caused by an eyeball that is slightly too short.

Figure 7

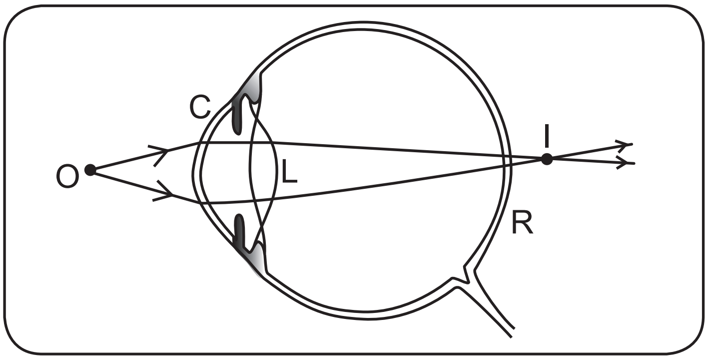
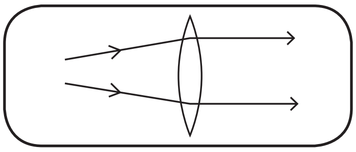


Figure 8



The correcting lens this time is convex (positive). The lens bends the light rays inward, helping the cornea and eye lens to focus the rays onto the retina.

Again, this correcting lens can be a glasses lens, a contact lens, or an intraocular lens.

c) Astigmatism

This defect can be caused by a non-spherical shape of the eye lens, but is usually caused by a non-spherical shape of the cornea. The cornea should be round when viewed from the front. But sometimes it is slightly extended along one axis. It is often explained by saying it is more like a rugby ball than a football.

Light rays reaching the cornea will be refracted more along one axis than along the axis at 90 degrees to this. This means that image formed at the retina will always be blurred, for both nearby and more distant objects.

Figure 9

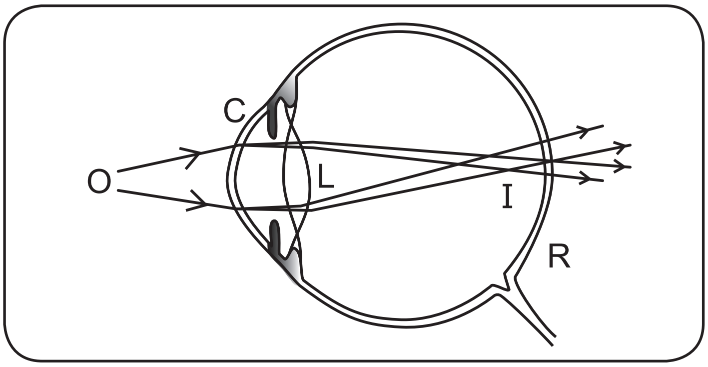
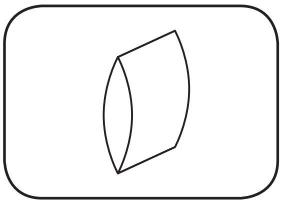


Figure 10



To correct this defect, a cylindrical lens is used rather than a spherical one.

This provides additional refraction along one axis to counteract the astigmatism effect. Once again, the lenses can be in your glasses, or contact lenses, or intraocular lenses. The prescription for astigmatism must give both the power of the cylindrical lens, and the axis of the astigmatism.

Example: *The prescription for correcting astigmatism in the left eye might read +1.50 at 85 degrees. This implies that a cylindrical lens of power +1.50 dioptres must by placed with the appropriate axis of the lens at 85 degrees to the horizontal. Placing the axis of the lens at the incorrect orientation would cause increased problems.*

d) Cataracts

This usually, but not always, occurs as people get older. It is becoming very common in our ageing population. The lens in our eyes starts to become cloudy. This tends to occur very slowly over several years, and you often don't notice it until it becomes quite extreme. Night vision becomes very poor, and even in good light conditions, it becomes more difficult to see things clearly.

Lens replacement is the only solution.

The use of intraocular lenses

These are plastic lenses that are put into the eye to replace the natural ones. For cataracts, this is the accepted method of curing the defect. The replacement lens will also automatically eliminate any myopia or hypermetropia which was present in the natural lens, and can be shaped to counteract the effects of astigmatism from the cornea. Often people don't need glasses for distance vision after cataract surgery. However, these plastic lenses can't change shape, so reading glasses will usually be needed to focus nearby objects (as in reading). However, by inserting lenses with slightly different powers in each eye, it is possible to have perfect vision for viewing both close and distant objects.

These intraocular lenses are also becoming very popular for people who don't have cataracts. As they can solve other eye defects, people are opting to undergo this surgery so that they don't need to wear glasses. This can be for cosmetic reasons, or because of the job that they do.

This used to be somewhat serious surgery, as the incision in the eye had to be large enough to remove the original lens in one piece, and insert the new lens in its place. However, nowadays the incision is only millimetres in length. An ultrasonic probe is used to break up the original lens, a tiny vacuum cleaner sucks out the bits, and the new plastic lens is inserted rolled up as a cylinder, and unrolls itself after insertion into the eye.

Figure 11

The surgery is done using eye drops which anaesthetise the eye, and last about 15 minutes. Vision is often quite good within one or two days. It is usually very safe. However, all surgery has its risks (e.g. infection), and it is a personal decision whether the risk is worthwhile, if you are having this done for cosmetic purposes.

Laser surgery

Lasers can be used to make the incision for lens replacement, but we usually refer to laser eye surgery as a procedure for reshaping the cornea. Eye defects can be minimised by shaping the cornea to counteract the problem. This is a very common procedure these days, and is often for cosmetic purposes.

A shallow incision is made in the surface of the cornea, so that a flap is formed. The flap is folded open and a laser is used to reshape the cornea as required. Then the flap is put back in place and allowed to heal.

Questions

Q1) What would be the effect of putting a positive lens into the glasses of a person suffering from myopia? Or a negative lens into the glasses of a person suffering from hypermetropia?

Q2) Can a person suffer from more than one of the defects mentioned in the Factsheet?

Q3) Name one advantage and one disadvantage of choosing laser surgery to reduce vision defects, rather than having a lens replacement.

Q4) Is using an intraocular lens to correct astigmatism as straightforward as using one to correct myopia or hypermetropia?

Q5) A positive lens has a power of 3.5 dioptres.

a) If parallel light rays were incident on the lens, where would the image be formed?

b) If the object was placed 65cm from the lens, where would the image be formed?

c) Where would the object have to be placed to form an image 1.2m behind the lens?

Answers

A1) The defect would be increased, causing an even more blurred image to form on the retina.

A2) Yes. It is not uncommon for a person who has myopia or hypermetropia to also have astigmatism, and then develop cataracts.

A3) An advantage of laser surgery is that the eye lens can still change shape (accommodation) for close-up work, so that reading glasses will not be required. A disadvantage is that the defects in the eye lens can become worse over time, so that further laser correction may be necessary (or alternatively, glasses can be worn). There is also a limit to how much the curvature can be changed meaning that it is not usually suitable for people with severe myopia or hypermetropia.

A4) There is an additional problem here. Sometimes the intraocular lens can rotate slightly in the eye. This would not be a problem with a spherical lens, but if there is a cylindrical component to the lens, then the rotation would change the axis of the cylinder

A5) a) For parallel light rays, the object distance, u = infinity.

$1/\text{infinity} + 1/v = 3.5$, so $0 + 1/v = 3.5$, then v = 29cm behind the lens.

b) $1/0.65 + 1/v = 3.5$, then v = 51cm behind the lens.

c) $1/u + 1/1.2 = 3.5$, then u = 38cm in front of the lens.

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