CHAPTER 20

Optical Instruments

INTRODUCTION 20.1

The application of artificial lenses and mirrors is widespread; however, one of the most important natural optical instruments is the human eye. But it, too, like the human body itself, has its defects and limitations. The eye not only can have inherent defects, but its performance can change with age. It is also unable to see fine detail or make observations of distant events. For these reasons scientists have developed many complex instruments that assist the eye in overcoming these limitations.

Other animals also have inherent eye defects. For example:

- chickens' eyes contain only cones thus making them unable to adapt to the dark
- owls' eyes contain only rods, which enables them to see well at night but they blink all day long. Can owls recognise colours?

NOVEL CHALLENGE

The word **pupil** comes from the Latin *pupilla* = 'a doll'. When you look at a reflection of yourself in someone's eye you see a small doll-like image of yourself. Now someone was really creative with language. *Quick now, is the image upright or inverted?*

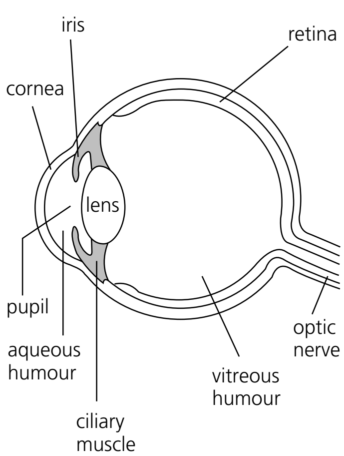
THE HUMAN EYE 20.2

It was not until the Middle Ages that the human eye was studied in any scientific sense. Around the year 1000, an Arabian scholar, Abu Alhazen, investigated the complementary colour of after-images. (Stare at an object then close your eyes to see an image of the complementary colour.) In the early 1600s Johannes Kepler described the eye in terms of a pinhole camera but this left the world puzzled about how we saw things the right way up. Rene Descartes in 1640 proved that the eye produces inverted images (which the brain re-inverts), by experimenting with the eyes of dead oxen. From then on, theories of human vision developed rapidly.

The main function of the human eye is to form images on the **retina**. Light enters the eye through the transparent **cornea** and passes through the **lens system** to be focused onto the light-sensitive retina, which responds by sending signals to the brain via the **optic nerve**.

The amount of light entering the eye through the pupil is controlled by a diaphragm, the **iris**, which reacts to the amount of light available. In very bright daylight the iris allows little light though the pupil, which may be as small as 2.0 mm. At night the iris opens up, enlarging the pupil, which may become as big as 6.0 mm. The iris gives a person's characteristic eye colour.

Figure 20.1
A schematic diagram of the eye.



EI Activity 20.1 PUPILS LOOK INSIDE THE EYE

The best way to study the optics of an eye is to cut it open. For this activity you'll need a bull's eye, scalpel, forceps, gloves and scissors.

1. Examine the eye (Photo 20.1**(a)**) and look for the optic nerve tube among the white fat and tissue at the back. Remove as much of this white stuff as you can.
2. Use a scalpel to puncture the eyeball and watch the vitreous humour ooze out.

3 Cut the eye open completely and note the bright blue iridiscent retina. Locate the optic nerve spot. (Photo 20.1**(b)**.)

4 Cut out the lens and cornea (Photo 20.1**(c)**) and place it over some newspaper to reveal the magnification. Estimate the magnification.

5 Remove the lens and note how hard it is. Can you cut it?

(a) (b) (c)

Photo 20.1
(a) A bull's eye — as supplied by the abattoir.
(b) The retina turned inside out. The optic nerve is visible as a dark spot in the middle.
(c) A bull's eye lens and cornea with the black rim of the iris visible. The letters are magnified about 1.7 times.

The lens system

Light from objects is focused onto the retina by refraction, which takes place at the cornea, the lens, and to a lesser extent in the liquid between the pupil and the cornea — the **aqueous humour** — and the liquid between the lens and the retina — **the vitreous humour**. In fact, the curved cornea, which has an optical power of 40 D, does most of the refracting. However, it is the lens, with a power of 20 D, that allows us to focus on distant objects as well as near objects. The shape and focal length of the lens is controlled by the **ciliary muscles**. When an object is at a large distance the muscles contract, making the lens long and thin and of long focal length, which brings the object into focus on the retina. The furthest distance that objects can be seen in focus is the **far point**. This point varies from person to person and changes with age. It can be from several metres to hundreds of metres. As an object moves closer the muscles relax making the lens shorter and thicker and decreasing the focal length. The closest point at which a sharp image is formed on the retina is the **near point**. If the object is brought closer than this a blurred image is seen. For most people the near point lies between 10 cm and 25 cm. This ability of the lens to adjust, thus enabling humans to see far and near, is called **accommodation**.

EI Activity 20.2 THE NEAR POINT

1 Hold this book at arm's length.

2 With one eye closed, focus on one word and slowly bring the book towards you stopping when the word starts to become blurred. This is your near point.

3 Have a partner measure this distance.

4 Repeat this with your other eye. Which eye is better?

5 What did you find about the near point for students in your class?

Light rays focus on the retina, which contains light-sensitive cells called rods and cones. The **rods** react to the level of brightness whereas the **cones** react to colour as well as brightness. The cone cells are concentrated near the centre of the retina and are thought to contain three separate receptors, one each for red, green, and blue light. The rods are more concentrated on the outside of the retina, which makes colour identification in peripheral vision poor.

Cones are more active in daylight and cannot identify colour in dim light. Rods are more active in dim light. In dim light the rods secrete a light-sensitive chemical, **visual purple**, which surrounds the tips of the rods and makes them extremely sensitive to dim light. However, it is destroyed by all but red light and therefore can only accumulate in the dark. This allows people over a period of half-an-hour or so to adapt to poor light conditions.

NOVEL CHALLENGE

Two eyes are better than one for depth perception. *Would three be better? Why or why not?*

NOVEL CHALLENGE

You blink on average once every 5 seconds while you are awake. *How many megablinks per annum is this? When you go into a shopping centre your blink rate falls to one every 12 seconds. Propose a reason for this.*

NOVEL CHALLENGE

There are three forms of colour blindness: *protanopia, deuteranopia* and *total*. Find out what they mean then propose a reason for the names based on the meaning of the prefixes: pro = one, deut = 2.

Activity 20.3 RODS AND CONES

1 Research:
   (a) whether other animals' eyes contain rods and/or cones
   (b) whether it is true that dogs are colour-blind. Do their eyes contain rods only?

2 Check yourself. A colour blindness test card is reproduced on the inside back cover. Cards such as these are used by optometrists to assess colour blindness.

The optic nerve carries signals from the retinal cells to the brain, which has to interpret these signals as the image formed on the retina is inverted and turned from left to right. However, there are no cells at the point where the optic nerve leaves the eyeball, which results in a blind spot.

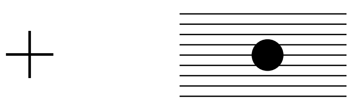
Activity 20.4 THE BLIND SPOT

Figure 20.2
Find the blind spot of the eye.

1 Close your left eye, keeping your right eye open.
2 Look at the '+' in Figure 20.2 with your right eye while holding the book at arm's length.
3 Gradually bring the book toward you while you keep looking at the '+' .
4 You will arrive at a distance at which the '•' disappears out of the corner of your eye because light rays from this point hit the retina at the blind spot — the point where the optic nerve leaves the retina.
5 Try this again looking at the '+' in Figure 20.3 this time.
6 What do you notice about the '•' and the lines when the dot is focused on your blind spot?

Activity 20.5 FLOATERS

Figure 20.3
Demonstrating how the brain tries to overcome the blind spot.



Floaters are bits of debris that come away from the inside surface of your eye.

1 Stare at something light coloured and notice the circular blobs that drift around. They tend to move upward. Why is this?
2 Stare at the ceiling and you may notice the floaters congregating at the centre. This happens as they drift into your fovea. New floaters can indicate a retinal tear.

Eye defects

Long-sightedness (Hypermetropia)

Long-sightedness is being able to see distant objects but unable to focus on near objects. It comes from Greek *hyper* = 'beyond', *metros* = 'to measure'. It is due either to the eyeball being too short, or to the inability of the lens to relax enough, so the focal length is too long and the image is formed behind the retina. (See Figure 20.4.)

This can be corrected by using a converging lens, which brings the rays closer together before passing through the eye's lens.

INVESTIGATING

Close your eyes and press an eyelid at the edge close to your nose.
How do you explain the big black circle with a yellow outline on the other corner of your eye? Hmmm!

Short-sightedness (Myopia)

This occurs when people can focus on close objects but distant objects are blurred. This is due either to the eyeball being too long, or to the inability of the muscles to contract sufficiently, making the focal length too short. The image is formed in front of the retina. (See Figure 20.5.)

It can be corrected using a diverging lens, which spreads the light rays out.