7 OPTICS IN BIOLOGY

Light is the electromagnetic radiation in the wavelength region between about 400 and 700 nm (1nm = 10^{-9}m). Although light is only a tiny part of the electromagnetic spectrum. The importance of light is due to its fundamental role in living systems.

7.1 STRUCTURE OF HUMAN EYE

Vision is our most important source of information about the external world. It has been estimated that about 70% of a person's sensory input is obtained through the eye.

A diagram of the human eye is given in Figure 15. The eye is roughly a sphere, approximately 2.4 cm in diameter. All vertebrate eyes are similar in structure but vary in size. Light enters the eye through the **cornea**, which is a transparent section in the outer cover of the **eyeball**. The light is focused by the lens system of the eye into an inverted image at the **photosensitive retina**, which covers the back surface of the eye. Here the light produces **nerve impulses that convey information to the brain**.

The focusing of the light into an image at the retina is produced by the curved surface of the cornea and by the **crystalline lens** inside the eye. The focusing power of the cornea is fixed. **The focus of the crystalline lens** is alterable, allowing the eye to view objects over a wide range of distances.

If light originates from two-point sources that are close together, their image diffraction disks may overlap, making it impossible to distinguish the two points. An optical system can **resolve** two points (see Figure 15) if their corresponding diffraction patterns are distinguishable. **The resolution power of a lens** can be determined by:

$$\theta = \frac{1.22\lambda}{d}$$

where λ is the wavelength of light and d is the diameter of the aperture. The angle θ is given in radians (1 rad = 57.3°). With the green light (λ = 500 nm) and an iris diameter of 0.5 cm, this angle is 1.22×10^{-4} rad.

Let us now calculate the size of the **smallest detail that the unaided eye can resolve (see** Figure 16**)**. To observe the smallest detail, the object must be brought to the closest point on which the eye can focus. If this distance is 20 cm from the eye, **the angle subtended by two points separated by a distance** x is given by:

$$\theta = \frac{x}{20}$$

Because the smallest resolvable angle is 5×10^{-4} rad, **the smallest resolvable detail** x is

$$x = 5 \times 10^{-4} \times 20 = 100\ \mu m = 0.1\ mm$$

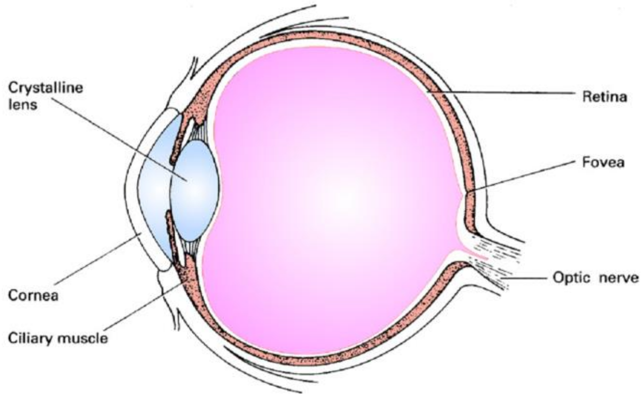

Figure 15: The human eye.

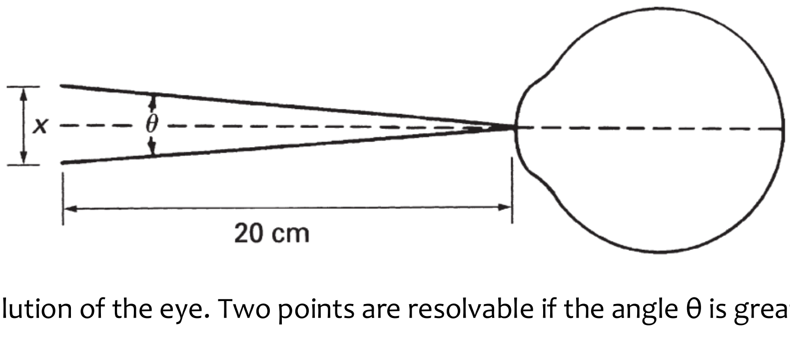

Figure 16: Resolution of the eye. Two points are resolvable if the angle θ is greater than 1.22λ/d.

7.2 MICROSCOPE

A simple microscope consists of a **single lens** that magnifies the object. Better results can be obtained, however, with a **two-lens system** compound microscope objective lens and an eyepiece.

With the **conventional microscope**, it is not possible to observe small objects embedded in translucent materials. Light is **reflected** and **scattered** not only by the cell of interest, but also by the surface of the tissue and by the cells in front and behind the cell being examined (see Figure 17).

This spurious light is also intercepted by the microscope and masks the image of the single cell layer within the tissue. **The confocal microscope** is designed to accept light only from a thin slice within the tissue and to reject light reflected and scattered from other regions. Therefore, the confocal microscope is used for observation of cells within living tissue.

This microscope requires a **parallel beam of light** for illumination of the object. As the source of parallel light, we used a **laser** with a power output that is relatively low so that it does not damage the tissue under observation. The laser beam is reflected by a half-silvered mirror into the objective lens, which focuses the beam to a point inside the tissue. Because the light is parallel, the beam is brought to a point at the principal focus of the lens. The depth of this point in the tissue can be changed by altering the distance between the lens and the tissue. Light is scattered and reflected from all points in the path of the entering light, and part of this returning light is intercepted by the objective lens.

However, **only light originating from the focal point** emerges from the lens as a parallel beam; light from all other points either converges toward or diverges from the lens axis. The returning light passes through the half-silvered mirror and is intercepted by the collecting lens. Only the parallel component of the light is focused into the small exit aperture that is placed at the principal focal point of the collecting lens. Nonparallel light is defocused at the exit aperture.

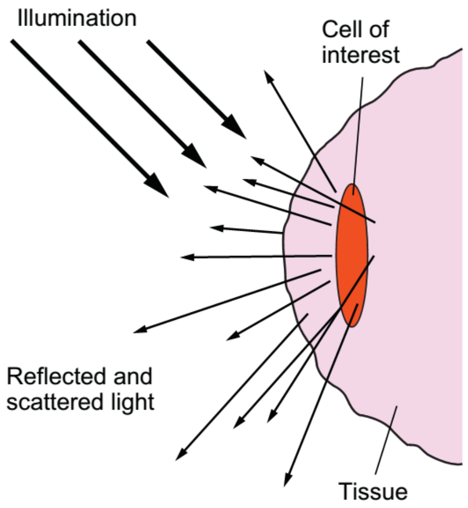

Figure 17: Light scattered and reflected from tissue.

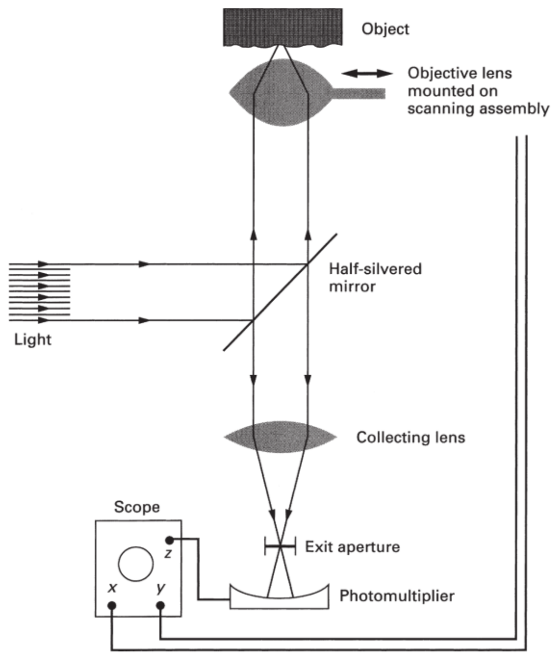

Figure 18: Confocal microscope

7.3 Fibre Optics

Fibre-optic devices are now used in a wide range of medical applications. A typical optical fibre is about 10 μm in diameter and is made of high purity silica glass. The fibre is coated with a cladding to increase light trapping. Such fibres can carry light over tortuously twisting paths for several kilometres without significant loss.

Fiberscopes or **endoscopes** are the simplest of the fibre-optic medical devices. They are used to visualize and examine internal organs such as the stomach, heart, and bowels. A fiberscope consists of two bundles of optical fibers tied into one flexible unit. Each bundle is typically a millimetre to about 1.5 cm in diameter, consisting of about 10,000 fibres. Depending on their use, the bundles vary in length from 0.3 to 1.2 m.

The two bundles as a unit are introduced into the body through orifices, veins, or arteries and are threaded toward the organ to be examined. Light from a high intensity source, such as a xenon arc lamp, is focused into one bundle which carries the light to the organ to be examined. Each of the fibers in the other bundle collects light reflected from a small region of the organ and carries it back to the observer. Most endoscopes now utilize attached miniature video cameras to form images of the internal organs for display on TV monitors.

The use of fiber-optic devices has been greatly expanded by attaching to the endoscope remotely controlled miniature instruments to perform **surgical operations** without major surgical incisions. More recent applications of fiber optics include **measurement of pressure in arteries, bladder, and uterus** using optical sensors and **laser surgery** where powerful laser light is directed through one of the bundles to the tissue which is selectively destroyed.

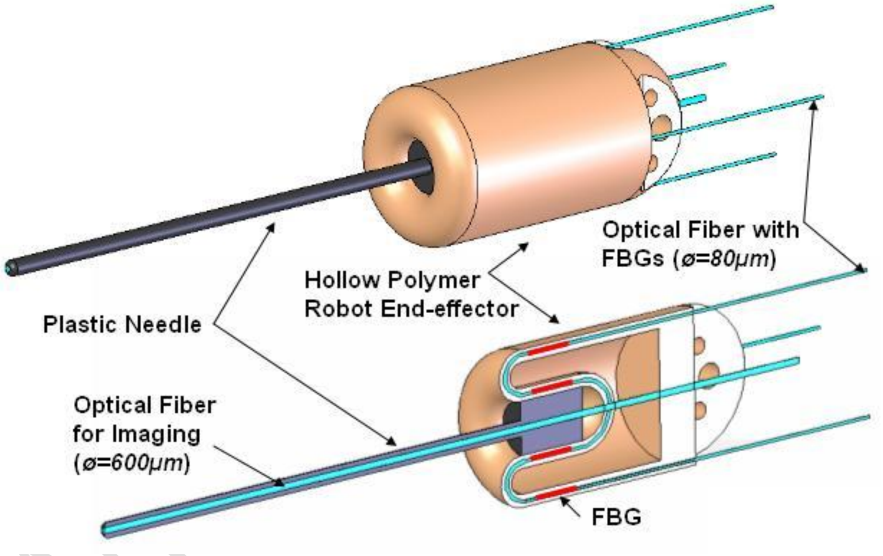

Figure 19: A schematic illustration of Fiber-optic sensor (Fiber Bragg Gratting FBG).