Optics 1

Optics is concerned with the genesis and propagation of light, the changes that it undergoes and produces, and other phenomena closely associated with it. To study Optics it helps to understand something of the nature of light. What is it?

Some Fundamentals

Which way does light go?

An apparently trivial question but Pythagoras thought that perception was rather like touch: a meeting of the "inner fire" (mind) emitted by the eyes with the world: the sensation of sight was obtained when these rays touch the object. Superman illuminated objects with X-Ray vision. Actually light comes from a source and is registered by a detector.

- Sources: The sun, stars, light bulb, candles, lightening, TV, bio-luminescence (cold), Lasers.

- Detectors: The eye, film, solar cells, photomultipliers, CCD's.

- Before reaching a detector light is often travels through or is bounced off an object. You can only see an object if it redirects or "scatters" some light into your eye.

- Cannot see a beam of light that is not directed at your eye.

- Light travels in straight lines in free space.

What is it that travels?

- Light is a form of energy. Energy in the form of light is always moving.
- Light also carries momentum – a powerful laser can support a small ball.
- Light can convey information from one place to another. More information reaches the human brain through the eyes than through any other sense organ.

How fast does it go?

- Speed of light 1983: $c = 2.997\,924\,58 \times 10^8$ m s^{-1}.
- A good approximation $c \approx 3.0 \times 10^8$ m s^{-1}, or $c \approx 300\,000$ km s^{-1}.

What is the medium?

Sound needs air to travel but light can travel through a vacuum. The idea of an "ether" persisted for a long time but was refuted by the Michelson and Morley experiment (1887). This showed that the speed of light is the same irrespective of the earth's motion around the sun.

A Brief History of Optics

The Ancient World

The earliest known mirrors are made of polished obsidian (volcanic glass) and date from ~7000 BCE. They were found at Catal Höyük (now in Turkey).

Ancient Egypt, China and Greece all used polished metal mirrors <1000 BCE. There are early references to burning mirrors. Early lenses made of crystal.

In this period, there were innumerable confusions and false starts toward an understanding of light. Sometimes an idea was stated, though not clearly, and then almost forgotten for centuries before it reappeared and was generally accepted.

Pythagoras (~550 BCE) suggested that vision is like touch and that light consists of rays that, acting like feelers, travel in straight lines from the eye to the object and that the sensation of sight is obtained when these rays touch the object.

The Atomists and Plato (5th century BCE) favoured the corpuscular theory of light. Light travels in straight lines and bounces off a mirror like a ball off a wall.

Greeks and Romans reported to use burning glasses 424 BCE.

Aristotle and Euclid (4th century BCE) discussed rays of light.

Euclid (~300 BCE) discussed laws of reflection. Hero of Alexandria thought that light travels by shortest path. Seneca noted that a globe filled with water magnifies.

Epicurus of Samos (~300 BCE) believed that light is emitted by a source and reflected by an object and then enters the eye to produce the sensation of sight. However, the Pythagorean hypothesis generally persisted until Alhazen.

Ptolemy (~50BCE) measured angles of incidence and of refraction. He correctly deduced that the ray is bent toward the normal on entering the denser medium.

European Dark Ages

The Arabic mathematician and physicist Alhazen (1000 CE) published a treatise on optics that was translated into Latin in 1270. In it he developed theories on refraction, reflection, binocular vision, focusing with lenses, the rainbow, parabolic and spherical mirrors, spherical aberration, atmospheric refraction, and the apparent increase in size of planetary bodies near the Earth's horizon. He was first to give an accurate account of vision, correctly stating that light comes from the object seen to the eye.

Roger Bacon (1215-1294) knew of Alhazens work. Studied rays and lenses. Made the earliest recorded comment on lenses for correcting vision (1268), but magnifying lenses inserted in frames were used for reading both in Europe and China at this time.

Early Dutch painters (1300-1400) are believed to have used the camera obsucra and focussing mirrors (according to David Hockney).

The Renaissance

Leonardo da Vinci (1452-1528) described the "camera obscura".

Della Porta (1535 - 1615) camera obscura with a *convex lens* at the aperture - likened this to the eye.

Kepler (1604) published *Dioptrice* : discussed rays, optics for thin lens systems and an approximate law of refraction. Light propagated instantaneously. Description of shadows.

Galileo Galilei (1565 - 1642) - first high quality telescope (1609).

Snell (1591 - 1626) empirically rediscovered (1621) and Descartes (1596 - 1650) formulated an exact *law of refraction.* Descartes: velocity *changed* when travelling in different media. Light viewed as a pressure transmitted in an elastic medium (1637) i.e. a longitudinal wave.

Pierre Fermat (1601 - 1665) suggested that path taken by a ray of light is “that which takes the least time”. An *almost* correct statement.

Robert Hooke (1635 - 1703) described the microscope 1665.

Ole Chistensen Römer (1644-1710) first measurement of the speed of light (1676).

Christiaan Huygens (1629 - 1695) developed the wave theory and the principle of secondary wavefronts: light moved in an "ether" *Traité de la Lumière* (1690). Studied polarization and correctly inferred that this was inconsistent with longitudinal waves.

Isaac Newton (1642 - 1726) - *dispersion* of light through prisms - white light is a mixture of colours. Invented the reflecting telescope. Published *Opticks* (1704) light was "corpuscular" and had finite velocity. Newton’s authority upheld the corpuscular theory against the wave theory long after his death.

Nineteenth Century

Thomas Young studied *interference phenomena* (1804). Proved that light was capable of bending around obstacles and was strongly criticized.

Augustin Fresnel (1788 - 1827) considered light as waves and showed that interference effects could be explained by wave theory.

Young, Fresnel, Arago, Fizeau, Lloyd and Kirchhoff all contributed to the establishment of a *transverse* wave concept for light.

James Clark Maxwell (1831-1879) mathematically unified magnetism and electricity to explain light as an electromagnetic wave.

Michelson and Morley (1887) attempted to detect the motion of the earth with respect to the hypothetical "ether". The null result discredited these theories.

Heinrick Hertz (1857-1894) generated and detected radio waves (1888).

Twentieth Century

Max Planck (1858-1947) quantized the radiation field to explain black body radiation (1900).

Albert Einstein (1879-1955) Special relativity (1905): speed of light is a universal constant independent of motion, an "ether" is superfluous.

Einstein - again - proposed particle theory of light to explain the photoelectric effect (1905). Much later he said "I spent my life to find out what a photon is and I still don't know it."

Einstein – once again – wrote down the equations (1916) that formed the theoretical foundation for the laser.

Charles Townes built the first maser (1953). The first laser was demonstrated in 1960. This decade saw the early development of fibre optics and light for communication.

Laser light bounced off a mirror left on the moon (1970).

Adaptive optics system at the European Southern Observatory produces images to rival the Hubble space telescope (2001). See: http://www.eso.org/.

Modern physics - all particles have a dual wave-particle nature. Either view is a simple explanation for something more complex. Which aspect comes to the fore depends on the experiment or phenomenon we are interested in. Particles of light, called photons, are massless and so the classical electromagnetic wave theory is frequently the best to adopt.