

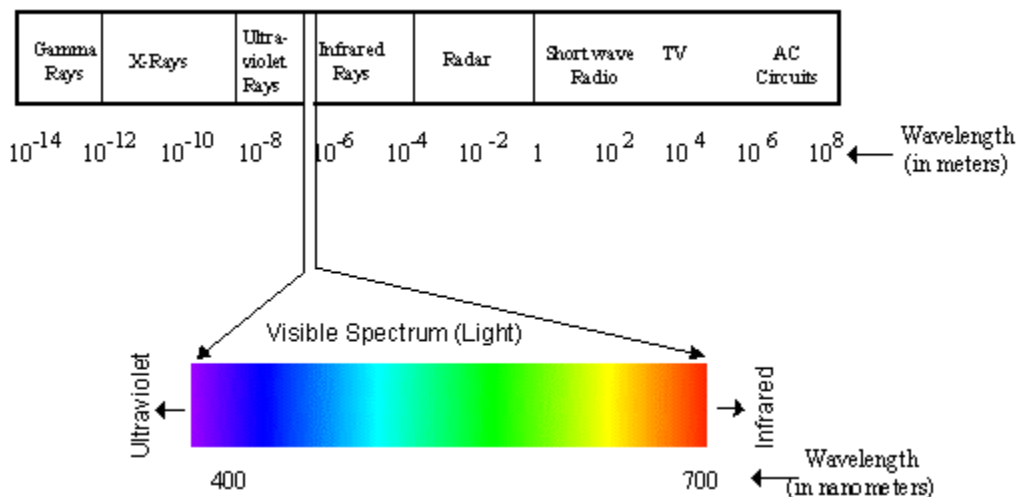
14 - Principles of Light

The Basics

- Light is energy in the form of electromagnetic radiation.
- Light is the visible portion of the electromagnetic spectrum.
- All electromagnetic radiation has the properties of both a wave and a particle. In this lecture it is most useful to consider this radiation as a wave with the following properties:
 - Velocity v
 - Wavelength λ
 - Frequency f

and the relationship between them is: $v = f\lambda$

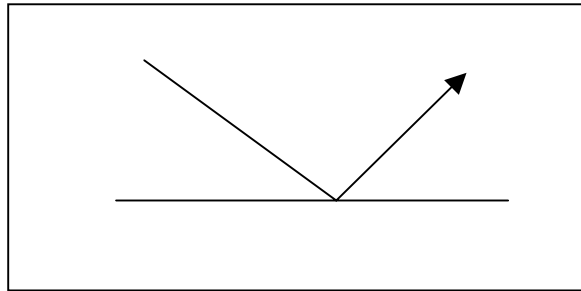
- Light occupies a small portion of the electromagnetic spectrum (400nm < λ < 700nm), with infrared radiation (λ > 700nm) and ultraviolet radiation (λ < 400nm).



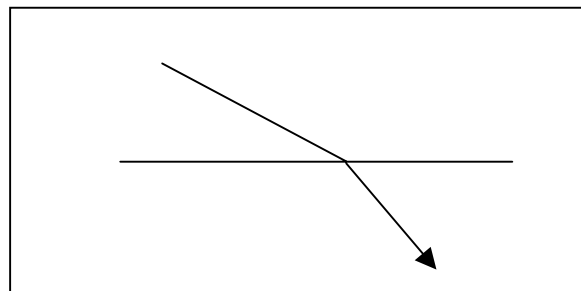
- Light waves, as with all electromagnetic waves, require no transport medium and so can travel through a vacuum.

- Electromagnetic waves have different frequencies and wavelengths but the *same* velocity: 3×10^8 m/s.
- All waves can undergo the following effects:

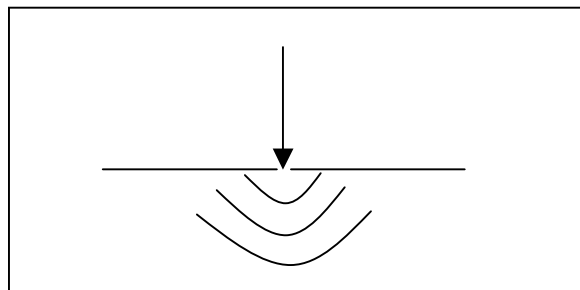
Reflection – change of direction at a surface;



Refraction– deflection at the boundary of a surface;



Diffraction – deflection at apertures or the edges of objects.

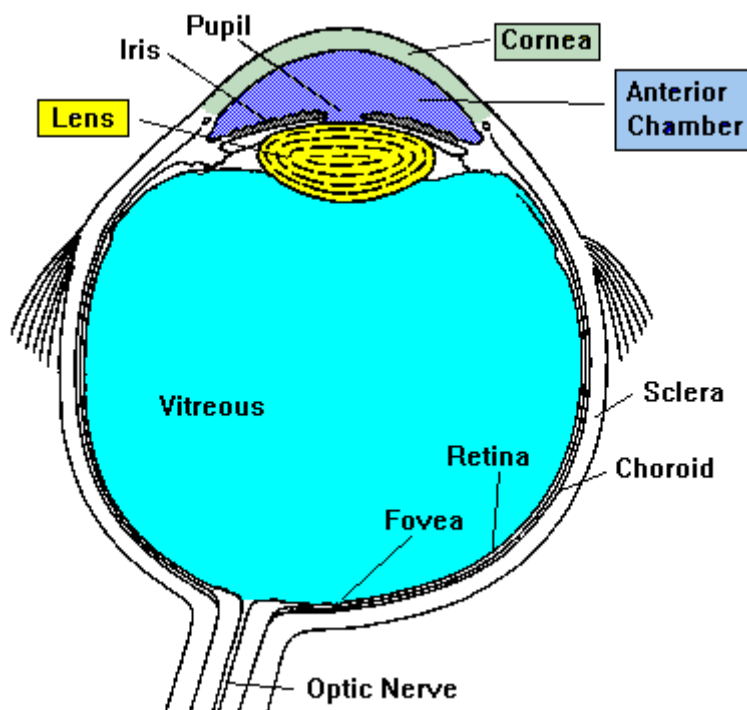


- A packet of electromagnetic radiation is called a “photon”.

Visible Electromagnetic Radiation (Light)

- Light of different wavelengths appears as a different colour to the eyes, from violet through to red.
- While light is the combination of all the visible wavelengths of light, it can be split into its constituent parts by diffraction using a prism.
- Monochromatic light is light of one particular wavelength.

Vision and the Eye

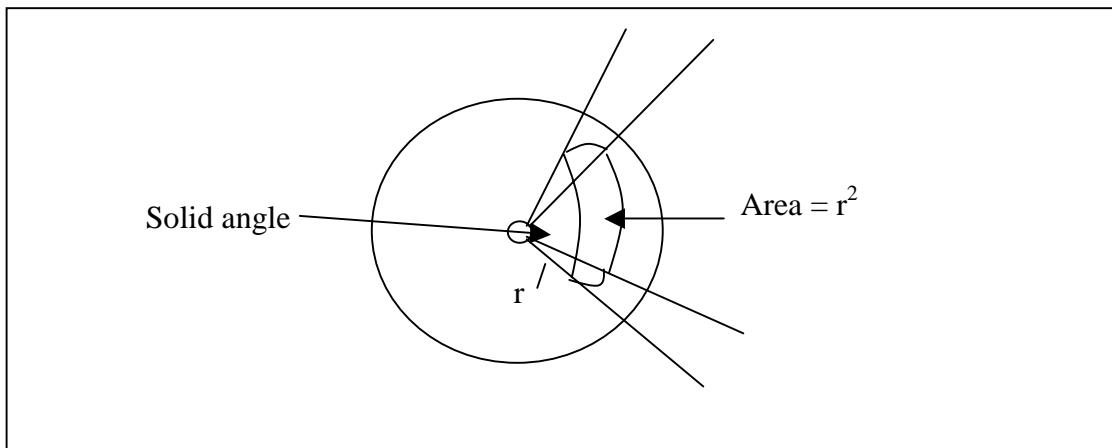


- Vision is a sensation triggered in the brain when light reaches the eye. The main features of the eye are:
- **The lens** – to concentrate the incoming light into an inverted image, the lens can be thickened or thinned to focus images at different distances.
- **The iris** – which controls the amount of light entering the eye.
- **The retina** – on which the image is focused – it contains the eyes' light sensitive receptors.

- **The receptors** – these react chemically to light, emitting electric signals. There are two types of receptor: rods and cones. Rods are sensitive to very low levels of light, and are biased to the blue end of the spectrum; cones have a more even sensitivity across the colour spectrum but are less sensitive to low levels of light.
- **The optic nerve** – transmits the signals from the receptors to the brain.

Lighting Measurement and Terminology

- The measurement of light is dependent both on the physical properties of light *and* upon the sensitivity of the eye.
- **The luminous intensity** (I) is the power of a light source to emit visible light in a particular direction. Luminous intensity is measured in candelas (cd).
- Light can radiate in 3-dimensions. Therefore the space around a light source needs to be divided into “solid angles”, the unit of which is the steradian (ω). The steradian is defined as the solid angle subtended at the centre of a sphere by an area on its surface equal to the radius squared.



- The total number of steradians on a sphere surrounding a point of light are therefore:

$$\text{Total solid angle (steradians)} = \frac{\text{Surface area of sphere}}{\text{Area given by 1 steradian}} = \frac{4\pi r^2}{r^2} = 4\pi \quad (1)$$

- **The luminous flux** (F) is the quantity of light emitted by a point source. The unit of luminous flux is the lumen (lm).
- Luminous flux and luminous intensity are related by the following equation:

$$F = I\omega \quad (2)$$

So a uniform source of luminous intensity I cd will produce 4π lumens.

- **Illuminance** (E) is the quantity of luminous flux falling on a unit area of a surface. The unit is lux (lx) where 1 lux is equal to 1 lumen per m^2 . A common minimum level for working is 200 lx , but illuminance can reach 50000 lx in bright sunlight.
- The illuminance is related to the luminous flux, for normal incidence, as follows:

$$E = \frac{F}{A} = \frac{I\omega}{A} \quad (3)$$

The Inverse Square Law of Illuminance

- The area A of a small surface element a distance D from a source of light is related to the solid angle that it subtends by:

$$\omega = \frac{A}{D^2} \quad (4)$$

- Hence the illuminance (lumens/m^2) at a surface can be expressed by:

$$E = \frac{I}{D^2} \quad (5)$$

(The relationships are therefore $E = \frac{F}{A} = \frac{I\omega}{A} = \frac{I\omega}{\omega D^2} = \frac{I}{D^2}$)

- The illuminance is therefore directly proportional to the intensity of the source in the direction of the surface, and inversely proportional to the square of the distance from the source.

Cosine Law of Illuminance

- If the surface under consideration is not normal to the direction of the light from the source, but is tilted, the illuminance on this surface will be less as the light is now spread over a larger area. If the surface normal is tilted at an angle θ to the direction of the incident light, then the illuminance on the surface will be:

$$E = \frac{I \cos \theta}{D^2} \quad (6)$$

- **Luminance** is essentially related to the density of luminous flux emitted from a light source and gives the viewer an impression of brightness. Two sources of the same luminous intensity may have totally different luminance values; this is dependent upon the area of the source “seen” by an observer. The luminance (L) is given by:

$$L = \frac{I}{A} \quad (7)$$

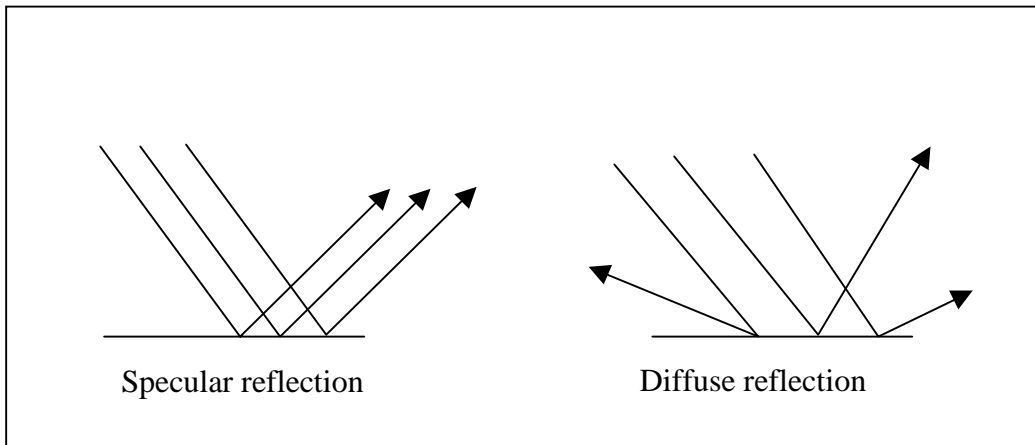
where I is the luminous intensity in the direction of the viewer, and A is the area of the source seen from that direction. The units are therefore (cd/m^2).

Glare

- Glare is discomfort or impairment of vision caused by an excessive range of brightness in the visual field.
- Glare can be caused by bright light sources (lamps, windows, etc) in a comparatively dim general background. Glare can be classified as follows:
- **Disability Glare:** where glare lessens the ability of the eye to see detail, but does not necessarily cause visual discomfort.
- **Discomfort glare:** causes visual discomfort, but does not necessarily cause impairment of the ability to see detail. The amount of discomfort depends upon the angle of view and the location.

Reflection and Absorption

- When light hits an opaque surface it either undergoes reflection or absorption. There are two distinct types of reflection:
- Specular reflection – each light beam incident on the surface is reflected in one direction only so that the angle of reflection equals the angle of incidence.
- Diffuse reflection – reflected light is scattered in all directions.



- Light absorbed at a surface cannot be reflected and is eventually converted to heat.
- The reflectance r of a surface is the ratio of the incident light flux reflected from the surface (F_r) to the light flux incident upon that surface (F_i).

$$r = \frac{F_r}{F_i} \quad (8)$$

- The luminance of a reflecting surface in cd/m^2 is given by:

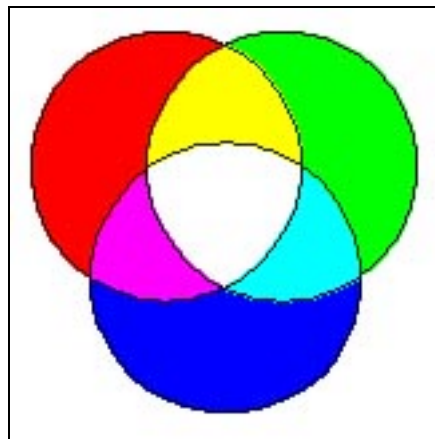
$$L = \frac{rE}{\pi} \quad \text{i.e. luminance} = \text{iluminance} \times \text{reflectance} / \pi \quad (9)$$

Colour

- Colours are essentially the brain's means of distinguishing between the light of different wavelengths received by the eye.
- Combinations of different wavelengths of light received by the brain can appear to be the same colour. This combination of wavelengths can be done through either addition or subtraction (additive or subtractive colour).

Additive Colour

- If coloured light of different wavelengths are added together then they will produce other colours.
- The additive primary colours (Red Green and Blue) can be added together in varying intensities to give any other colour.
- The addition of the three primary colours together at equal intensity will produce white light.

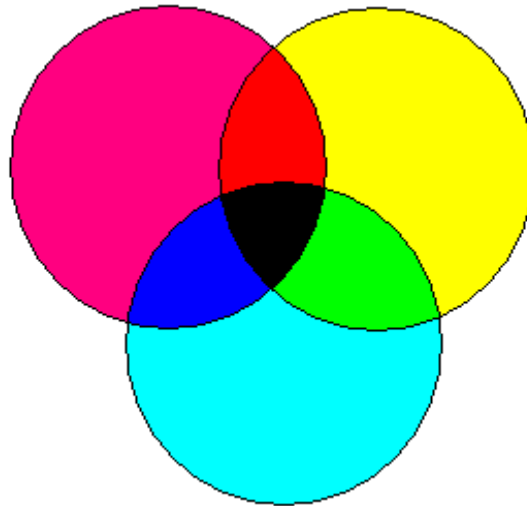


Examples of colour addition:

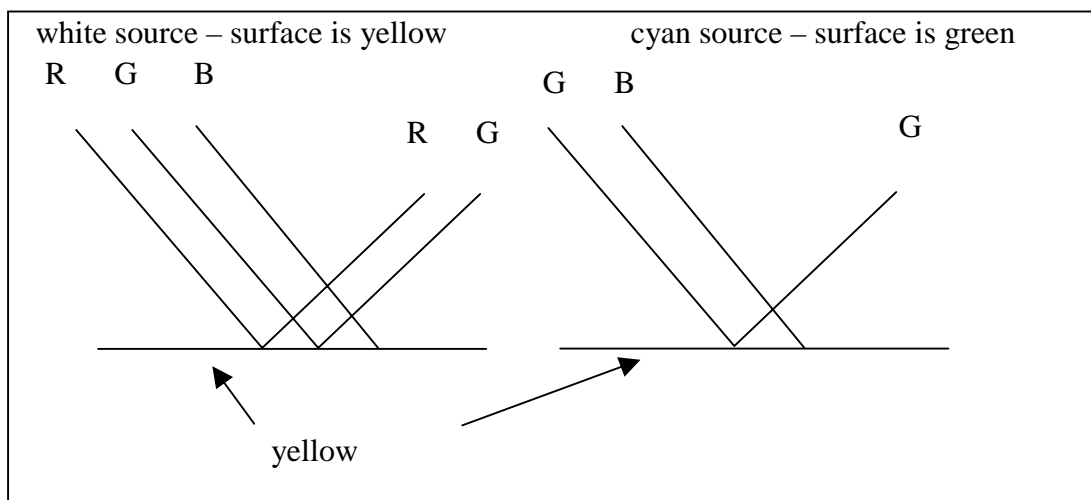
Red + Green + Blue	White
Red + Green	Yellow
Green + Blue	Cyan
Red + Blue	Magenta

Subtractive Colour

- White light can be considered as a combination of red green and blue light. If colours are subtracted from white light then other colours will be produced. Any colour can be produced by a combination of the three subtractive primary colours (Cyan, Magenta, and Yellow). Cyan subtracts red from white light, magenta subtracts green and yellow subtracts blue.



- The addition of all three subtractive colours creates black.
- A red surface subtracts (absorbs) green and blue from white light while red light is reflected. To appear red the paper must have a combination of magenta and yellow pigments.
- Note that the colour of a surface may change if viewed under a different light source:



Tutorial Questions – Principles of Light

McMullan Chapter 6

Additional questions

1. To what extent are visible light and thermal radiation identical phenomena, and in what respect do they differ?
2. In terms of the eye, what do we mean by accommodation?
3. Name the two main types of light sensitive cells in the eye, and indicate the function of each.
4. What do we mean by light-adaptation and dark-adaptation? Which of the two processes is faster?
5. Indicate which types of glare may be encountered, and indicate the differences between these different types.
6. What is meant by visual acuity?
7. Why is the ability to recognise details related to the amount of light?
8. Which two aspects of vision (or abilities of the eye) are most likely to become less as people get older?