Imaging

Waves

The speed, frequency and wavelength of a wave are related by the formula:

$$v = f\lambda$$

Where v is the speed (ms^{-1}), f is the frequency (Hz) and λ is the wavelength (m) of the wave.

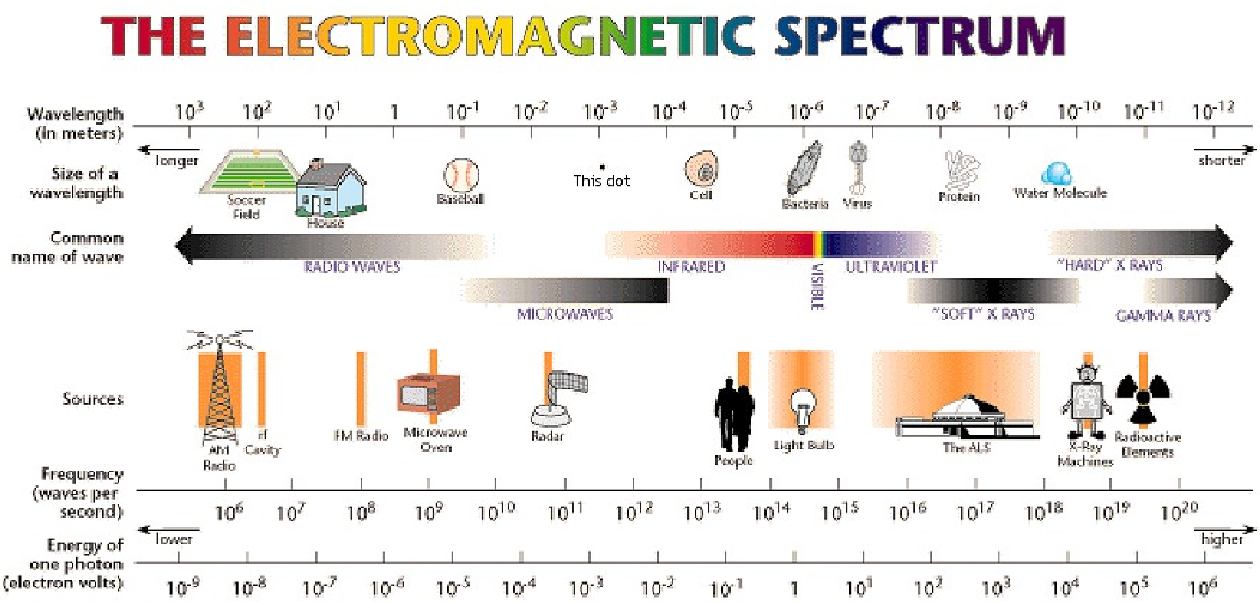
The time period of a wave is the amount of time it takes for one vibration to occur, and is given by:

$$T = 1/f$$

Where f is the frequency of the wave.

The Electromagnetic Spectrum

All EM waves are transverse (as oppose to sound waves, which are longitudinal) and travel at the speed of light, $3 \times 10^8\ ms^{-1}$, (sound waves travel at 340 ms^{-1}). The EM spectrum is as follows:



Name	Typical Wavelength (m)	How Produced	Use
Gamma	1×10^{-12}	Excited nucleus releases energy in radioactive decay	Tracing the flow of fluids and treating cancer
X-rays	1×10^{-10}	High-speed electrons being stopped by a target	Seeing inside the body
UV	1×10^{-8}	Very hot objects and passing electricity through glass	Suntan and security marketing

Light	1×10^{-6}	Hot objects and passing electricity through gasses	Vision and photography
IR	1×10^{-5}	Warm and hot objects	Heating and cooking
Microwave	1×10^{-1}	Microwave diode or oscillating electrons in an aerial	Communications and cooking
Radio	1×10^{2}	Oscillating electrons in an aerial	Communications

Resolution

The resolution of an image is the smallest thing which can be distinguished. Resolution is a fundamental characteristic of all measuring systems. **The resolution of any instrument is the smallest difference which is detectable.** You cannot resolve images smaller than one wavelength. The ability of a lens to resolve detail is improved by using a wide objective lens.

To calculate the resolution of an image, divide the length of the image by the number of pixels across.

Pixels

A pixel (picture element) is the smallest addressable unit on a display screen. The higher the pixel resolution (the more rows and columns of pixels), the more information can be displayed. In storage, pixels are made up of one or more **bits**. The greater this **bit depth**, the more shades or colours can be represented.

The bit depth, also called **colour depth** and **pixel depth**, is the number of bits used to hold a pixel, and it determines the maximum number of colours that can be displayed at one time.

The most economical system is monochrome, which uses one bit per pixel (0 or 1). On screen, pixels are made up of one or more dots of colour. Monochrome and grey scales use **one dot per pixel**. For monochrome, the dark pixel is energised light. For grey-scale, the pixel is energised with different intensities, creating a range from dark to light. Colour systems use r**ed, green** and **blue dots per pixel**, each of which is energised to **different intensities**, creating a range of colours. The more bits in a pixel, the more alternatives there are, and therefore the image has a better resolution.

- 1 bit = 2 alternatives
- 2 bits = 4
- 3 bits = 8
- 4 bits = 16 etc.
- 8 bits (1 byte) = 256 alternatives

The number of alternatives = 2^n, where n is the number of bits.

If each pixel in an image is 8 bits, then for a black and white pixel there are 256 shades of grey between black and white. 24 bits are required for photo-realistic images and video. This is called True Colour (16 million alternatives).

The amount of information in an image = no. pixels × no. bits.

Logarithms

A logarithm is a power (index) which another number can be raised to. It is a convenient way of representing very large, very small, or a large range of numbers on a simple scale. Hence many graphs will use a logarithmic scale.
e.g. $10^1 = 10$, $10^2 = 100$, $10^3 = 1000$ etc.

Image Processing

To remove noise or smooth edges, we can take the **median** of the 9 pixels (the one with noise, and the 8 which surround it), and replace each of those pixels with their median value. Another way is to work out the **mean** of the 9 pixels and replace them with their mean. Using mean rounds off sharp corners and blurs edges, which may be the cause of detail loss in the image.

Lenses

A lens is a device for either concentrating or diverging light. In its usual form, a lens consists of glass or other optically transparent material (such as perspex) with two shaped surfaces of a particular **curvature**. It is the **refractive index** of the lens material and the curvature of the two surfaces that give a particular lens its particular properties. A lens works by **refracting** the light that passes through it. When light leaves a light source it spreads out or diverges, reducing in intensity with increasing distance from the source.

- A **concave** or **diverging lens** exaggerates this effect, making the light more divergent.
- Light from a source converges after passing through a concave lens if the source is at a greater distance from the lens than the focal length.
- A **convex** or **converging lens** acts against this effect, so that the light either converges or becomes less divergent.

(see diagrams)

The diagrams also show some important features of the lenses:
- The **optical centre** is at the centre of the lens.
- The **principal axis** is a line drawn through the optical centre, perpendicular to the plane of the lens.
- The **principal focus** is the image position for light that is parallel to the principal axis.
- The **focal length** is the distance between the optical centre and the principal focus.

The shorter the focal length of a lens, the greater the effect on converging or diverging light that passes through it. This effect is measured by the power, in **dioptres (D)** of the lens, given by the formula:

$$\textbf{Lens Power} = 1/f$$

Where f is the focal length, measured in metres.

Concave lenses form **virtual images**. Convex lenses can form either **real** or virtual images, depending on the distance of the object from the optical centre of the lens compared to its focal length. In each case, the position, nature, and size of the image can be determined by a ray diagram or using the **lens formula**:

$$1/v = 1/u + 1/f$$

Where v is the distance between the image and the lens, u is the distance between the object and the lens (always negative due to Cartesian convention and, in effect, it has a negative effect on the curvature of the waves), and f is the focal length of the lens.

If an object is very far away, then you can assume *u* to be infinite, and so 1/u to be 0.

When the curvature of the waves is zero, the light is said to be **collimated** (the rays are parallel). A light can be collimated by a number of processes, the easiest being to shine it on a concave mirror with the source at the focus. Collimated light is sometimes said to be focused at **infinity** which, for experimental purposes is approximately 2m.

For a positive (converging) lens, the focal length is **positive**, and is the distance from the lens at which a collimated beam of light will be **focused** to a single spot. For a negative (diverging) lens, the focal length is **negative,** and is the distance in front of the lens to the point at which a collimated beam appears to be **emerging** from after passing through the lens.

- **The nearer the object is to the lens, the further away the image is,** provided the object is no nearer than the focal point.

- If the object is placed **between** the focal point and the lens, the refracted rays **cannot be brought into a focus**. But an observer looking into the lens from the other side to the object can see an image formed where the rays appear to come from. The image is a **virtual image**, and it is **magnified** compared with the object. A convex lens can hence be used as a magnifying glass.

- The image formed using a convex lens is **up-side down**.

- The virtual image formed using a concave lens is **upright**, but has **diminished in size**.

The **magnification**, i.e. the size of the image compared to the object can be expressed as:

$$m = v/u$$

Where *v* is the image distance, *u* is the object distance, and *m* is the magnification.