

Light, Light Bulbs and the Electromagnetic Spectrum

● Spectrum

The different wavelengths of electromagnetic waves present in visible light correspond to what we see as different colours. Electromagnetic waves of 400 nm wavelength cause us to see violet and we see 700 nm wavelength electromagnetic waves as red. In between are wavelengths corresponding to all the colours of the rainbow or visible spectrum: indigo, blue, green, yellow and orange.

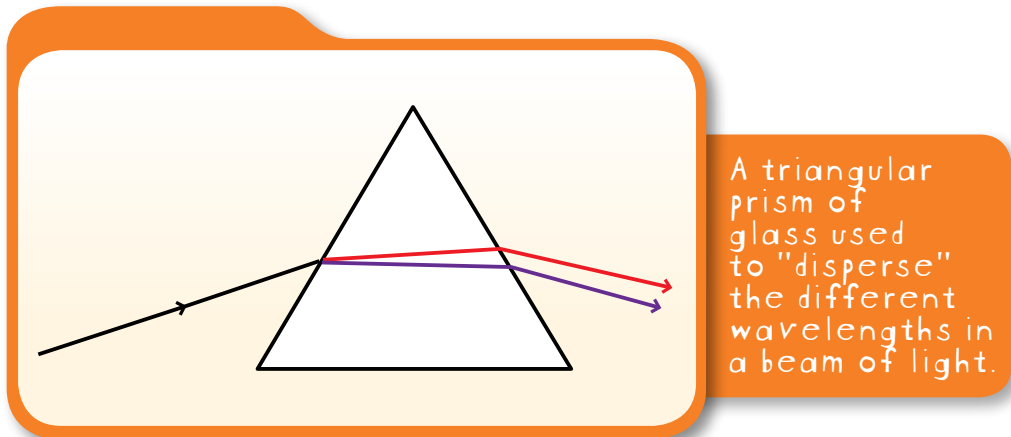
Sunlight is a continuous spectrum of all these visible wavelengths, plus some ultraviolet and a lot of infrared. It is the result of thermal radiation from the surface of the Sun, which is at a temperature of about 6000 K. When many different wavelengths enter our eyes simultaneously, as in the case of sunlight, the light itself does not appear coloured – it appears “white”. Only objects which preferentially absorb some wavelengths while reflecting others appear to be coloured.

Different light bulbs emit different mixtures of wavelengths: incandescent lamps produce a continuous spectrum, which is something like sunlight. Spectral lamps, on the other hand, emit only a few discrete wavelengths. The quality or “whiteness” of their light depends on how we perceive the particular combination of wavelengths emitted.

In order to study the spectrum produced by a lamp or light bulb, we need to separate out the different wavelengths. Nature does this dramatically in the formation of a rainbow. The water droplets in a rain shower slow down the different wavelengths to slightly different extents, causing their rays to be refracted or bent by slightly different angles on entering and leaving the raindrops. The different colours therefore appear to be reaching us from different directions in the sky. The separation of wavelengths by refraction in this way is called dispersion.

● Refraction and Dispersion

In the laboratory, a triangular prism of glass can be used to refract and separate or “disperse” the different wavelengths in a beam of light.

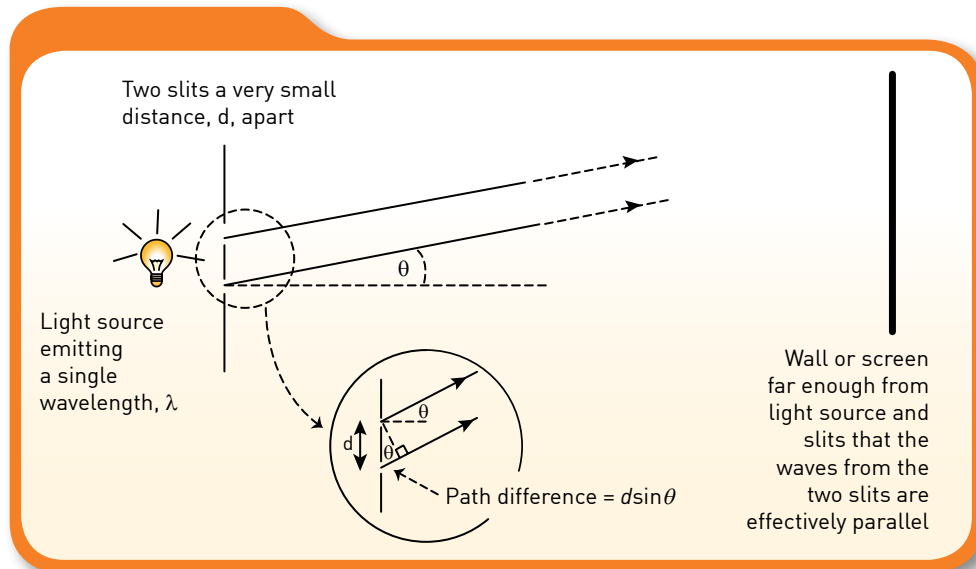


You can calculate the angles at which each colour emerges from the prism if you know the angle of incidence of the light beam, the angle of the prism, and the refractive index of the glass for each wavelength. The theory involves Snell’s Law of refraction, which is explained in the glossary on page 7.

● Interference and Diffraction

Diffraction offers an easier way to display spectra and calculate wavelengths. It occurs because of the wave properties of light, in particular the wavelength, and the fact that two overlapping waves will only combine “constructively” if their wave troughs and peaks coincide. The technical wording for this is to say they are “in phase” with each other.

Thomas Young was the first to show that light is actually a wave. He split a monochromatic beam (light of a single colour or wavelength) into two parts by passing it through two very narrow slits, then recombining the two beams and showing that there are a number of ways in which they can constructively recombine.



The light from the two slits reaches the screen in phase if the difference in their path lengths is a whole number of wavelengths. Some simple geometry shows that the path difference is approximately $d \sin \theta$, where d is the separation of the slits and θ is the angle above the straight-through direction. So, Young expected the waves to combine or “interfere” constructively at angles given by the equation:

$$d \sin \theta = n\lambda \quad \text{where } n \text{ could be } 0, 1, 2 \text{ or any whole number}$$

A diffraction grating produces exactly the same effect as Young’s two-slit experiment, but the intensity or brightness of the light in the interference maxima is much brighter. This is because a diffraction grating has many, many slits or rulings, evenly spaced only a micron (a millionth of a metre or a thousandth of a millimetre) or so apart. If d is the spacing of lines in a diffraction grating, then interference maxima occur at angles given by:

$$d \sin \theta = n\lambda ; n = 0, 1, 2, 3 \dots$$

Suppose $d = 10^{-6} \text{ m}$ (1 micron), and $\lambda = 500 \text{ nm} = 5 \times 10^{-7} \text{ m}$ (yellow light), then the equation above tells us that constructive interference occurs when $\sin \theta = 0, 0.5, 1.0$ ($\sin \theta$ cannot be greater than 1),

and so diffraction maxima (bright spots of light) are observed at angles:

$\theta = 0^\circ$ (straight through), 30° (first order maximum) and 90° (second order maximum)

Glossary

atomic emission

The electrons in the space around the nucleus of an atom occupy shells or orbitals which have distinct energy levels. When an atom absorbs energy an electron is elevated to a higher energy level. This is a temporary excited state, and the electron soon drops back to a lower energy level, emitting a photon of electromagnetic radiation. The energy of the photon is equal to the difference in the electron energy levels.

colour

The retina of the human eye contains two types of light-sensitive cells: rods and cones. Rods discriminate different brightnesses, but cones are wavelength-sensitive, and transmit signals to the brain that enable us to see different wavelengths or combinations of wavelengths as different colours. The traditional colours of the rainbow are how we see the wavelengths of visible light from 400 nm (violet) to 700 nm (red).

diffraction

Diffraction is the interference effect of waves from many sources, for example, the lines of a diffraction grating.

dispersion

Different wavelengths (colours) are refracted through different angles. This separation is called dispersion.

efficiency

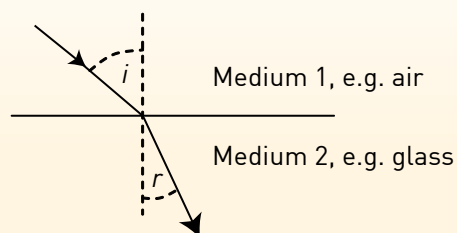
Efficiency is the ratio of the output power to the input power of a light bulb (or any other device or machine). It is easy to remember when thought of as “what you want” divided by “what you pay for”.

electromagnetic waves / electromagnetic radiation	These are waves of coordinated, transverse electric and magnetic fields that travel through space at the speed of light (about $3 \times 10^8 \text{ m.s}^{-1}$) without requiring any material medium for their propagation. Electromagnetic waves range from gamma rays and X-rays with wavelengths of nanometers, through ultraviolet, light and infra red to radio waves which have wavelengths of kilometres.
energy	Energy is the capacity to do work and is measured in joules. Energy comes in many different forms, for example, light and sound waves carry energy. Gravitational and kinetic energy are two forms of mechanical energy. Energy can be transformed between its different forms, but cannot be created or destroyed.
fluorescence	Fluorescence is the property of some materials to absorb electromagnetic radiation of one wavelength and emit radiation of another, for example, the phosphor coating inside a fluorescent light bulb, which absorbs ultraviolet radiation and visible light. A fluorescent spectrum usually differs significantly from the spectra of incandescent bulbs or natural sunlight, making some colours look different.
frequency	The frequency of a wave is the number of whole waves that pass a point in one second. It is measured in cycles per second or hertz.
halogen lamps	Halogen bulbs are essentially incandescent bulbs containing a small amount of halogen gas to improve efficiency and lifetime. They produce significant heat, so are not as efficient as compact fluorescent bulbs.

incandescence	Incandescence is the emission of light from an object at a high temperature. (See thermal radiation.)
infrared radiation (waves)	Infrared radiation is the band of the electromagnetic spectrum with wavelengths just longer than those of visible light. Certain wavelengths of infrared radiation are absorbed strongly by the molecules of some atmospheric gasses, for example, water, carbon dioxide, methane. This leads to the greenhouse effect, and enhanced global warming, if the concentration of these gasses is allowed to rise too much.
interference	The addition of two or more waves of the same frequency and wavelength depends on the relative alignment of their peaks and troughs (their phase difference). If the peaks align, the result is constructive interference and the resultant combined wave has a maximum amplitude and intensity; if the peaks of one wave align with the troughs of the other, they cancel one another, resulting in destructive interference.
LED (light-emitting diode)	A LED is a semiconductor diode that emits a narrow spectrum of light, as a result of electroluminescence. Electrons and holes recombine at the p-n junction of the diode. The electrons jump to lower energy levels in the process, releasing photon of light. Different semiconductor materials are used to make different colour LED's, e.g. the original red LED's were made from gallium arsenide, and gallium nitride is used to make green and blue LED's.
light	Light is electromagnetic waves that are visible to the human eye. Visible light has wavelengths between 400 and 700 nm (4×10^{-7} and 7×10^{-7} m).

photon	When energy is transferred from light or other forms of electromagnetic radiation to matter, it does so in fixed amounts, or quanta called photons. The energy of a photon is related to the frequency, f , of the electromagnetic radiation by Planck's Constant, h (6.63×10^{-34} J.s): $E_{\text{photon}} = hf$.
power	Power is the rate at which energy is released, transmitted or converted to another form; it is the rate of doing work. One watt (W) = 1 joule per second ($\text{J}\cdot\text{s}^{-1}$).
refraction	Refraction is the bending of the direction of light as it passes from one medium or material to another, as result of the change in its speed.
refractive index	The refractive index of a medium or material, for example, water, glass etc. is the ratio of the speed of light in a vacuum to the speed of light in the material, for example, glass (approximately 1.5), water (approximately 1.3).
Snell's Law of Refraction	When light passes from one medium (for example, air, glass, water, or even a vacuum) to another its speed changes, and this makes the direction in which it is travelling (its direction of propagation) change. The relation between the angle of incidence, i , and the angle of refraction, r , is given by Snell's Law:

$$\frac{\sin i}{\sin r} = \frac{\text{speed of light}_{\text{medium1}}}{\text{speed of light}_{\text{medium2}}} = \frac{\text{refractive index}_{\text{medium2}}}{\text{refractive index}_{\text{medium1}}}$$



Snell's Law of Refraction

thermal radiation

All objects above absolute zero emit a broad spectrum of electromagnetic waves called thermal radiation. The peak in the spectrum depends on the temperature of the object: cold bodies radiate mainly in the long wavelength infrared, hotter bodies emit short wavelength infrared and some red light (hence the term red-hot), still hotter bodies (for example the Sun and stars) radiate light of all colours and so appear yellow or white. Hotter objects also emit energy (power) at a faster rate than colder ones, so you can feel the heat radiated by a glowing coal or a bar heater, but not from everyday objects at room temperature.

ultraviolet radiation (waves)

Ultraviolet radiation is the band of the electromagnetic spectrum with wavelengths just shorter than those of visible light. Sometimes ultraviolet radiation is sub-divided into UV-A (320-400 nm), which is harmless, UV-B (280-320 nm), which can cause sunburn, eye damage and skin cancers, and UV-C (<280 nm) which may be lethal.

wavelength

The wavelength is the distance from a point on a wave to the next identical point, for example, from one peak to the next, or one trough to the next.