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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.

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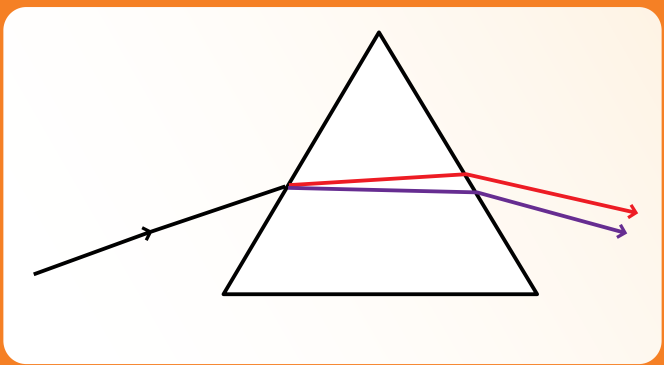
Refraction and Dispersion

Refraction is seen as the changing of the angle of light as it passes from one medium into another. The angle will be slightly different for different wavelengths of light.

When a beam of white light passes through a prism it will separate into rainbow colours showing that white light is a mixture of different wavelengths. This separation of colours (wavelengths) is known as "dispersion".



A triangular prism of glass used to "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.

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.

Diffraction

Diffraction is the bending of waves through openings and around obstacles. This is how you can hear voices around corners, even if there are no walls or other buildings to provide echoes. Light waves diffract just like sound waves diffract but on a much smaller scale due to the much shorter wavelength of light compared to sound waves. Diffraction is strongest when the wavelength is the same size as the gap it passes through. This creates circular wave-fronts emerging from the opening even though the incident wave front was linear. It is as though there is a point source radiating out circular waves from the centre of the gap.

Interference & Interference Patterns

Interference, and the patterns that result from it, occur when two or more waves pass through each other. A familiar example is two stones falling into a pond at the same time; concentric waves radiate outwards and then pass through each other creating an intersecting pattern. Interference happens with sound and light waves as well.

There are two types of interference- constructive and destructive. ***Constructive interference*** is seen when two wave crests coming from different directions meet in the same place. The two waves temporarily combine and add together, the result being a larger amplitude crest. The same thing happens with two troughs- they add together, or "superpose", creating a larger amplitude trough. Two overlapping waves will combine "constructively" where two wave troughs, or two wave crests coincide. The technical wording for this is to say they are "in phase" with each other.

Destructive interference is seen when the crest of one wave meets the trough of the other wave. The crest is cancelled out by the trough, the resultant wave amplitude is therefore zero (assuming the original waves were of the same amplitude). Another way of looking at this situation is that the two waves are "out of phase" by half a wavelength.

An ***interference pattern*** is the overall pattern produced by successive wave fronts passing through each other and interfering both constructively and destructively. With the pond example the interference pattern is seen in two dimensions on the water surface. With light the interference pattern is seen only where it hits the screen and reflects off it to our eyes. The screen displays a cross-section through the interference pattern.

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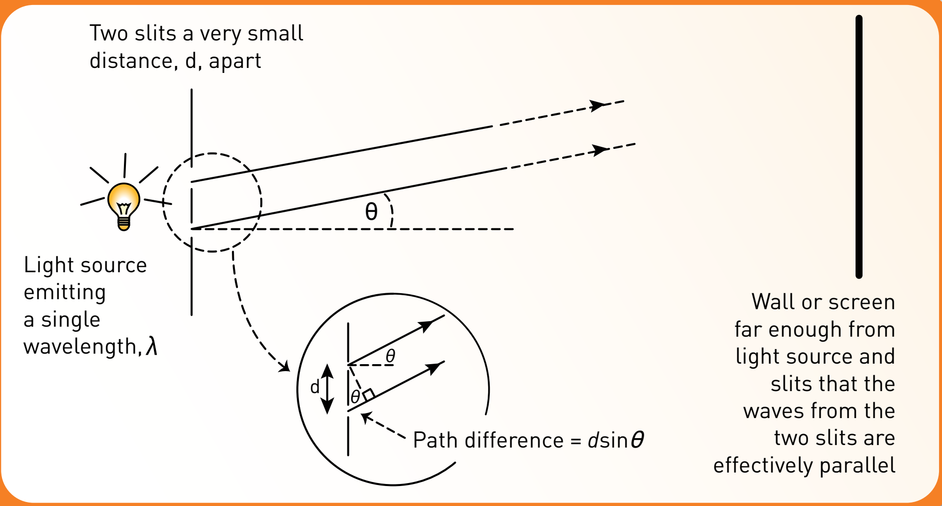
Thomas Young and the Two Slit Experiment

Young's experiment shows:

- Light from a source passing through two slits (thin gaps) will undergo ***diffraction*** as it passes through each slit.
- The resulting circular wave fronts then interact through the process of ***interference*** creating an interference pattern on a screen.

Young's experiment splits a monochromatic beam (light of a single colour or wavelength) into two parts by passing it through two very narrow slits (diffraction).



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 θ, 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 θ = nλ where n could be 0, 1, 2 or any other whole number.

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Diffraction Grating

The diffraction grating is a device consisting of multiple slits that offers an easier way to display spectra and calculate wavelengths than using a prism to refract and disperse light into its spectrum. CDs and DVDs act as reflective diffraction gratings to create a colour spectrum similar to a prism as white light is separated (dispersed) into its component colours through diffraction and interference.

The diffraction grating is composed of thousands of very narrow slits through which light diffracts and then interferes to create a pattern. 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 and more clearly defined. This is because a diffraction grating has a multitude of evenly spaced slits only a micrometre (a millionth of a metre or a thousandth or a millimetre) or so apart.

If d is the spacing of lines in a diffraction grating, then interference maxima occur at angles given by:

$d \sin \theta = n\lambda$ where n could be 0, 1, 2 , 3 …

Suppose d = 10^{-6} m (1 micrometre), and λ = 500 nm = 5 x 10^{-7} m (yellow light), then the equation above tells us that constructive interference occurs when sin θ = 0, 0.5, 1.0. Since sin θ cannot be greater than 1, bright "fringes" of light known as maxima are observed only at angles: θ= 0 ° (n=0; central maxima), 30 ° (n=1; first order maxima) and 90 ° (n=2; second order maxima).