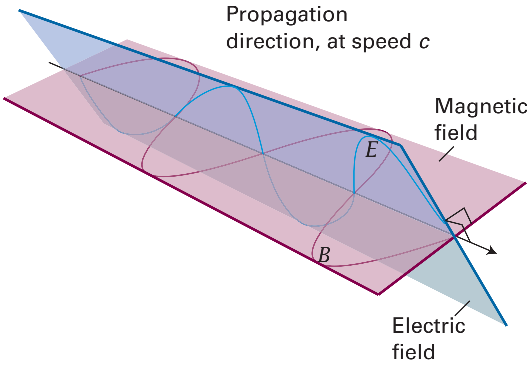
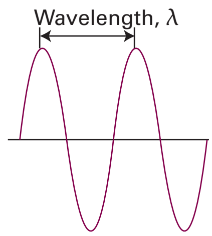
THE CHEMIST'S TOOLKIT 13 Electromagnetic radiation

Electromagnetic radiation consists of oscillating electric and magnetic disturbances that propagate as waves. The two components of an electromagnetic wave are mutually perpendicular and are also perpendicular to the direction of propagation (Sketch 13.1). Electromagnetic waves travel through a vacuum at a constant speed called the **speed of light**, c, which has the defined value of exactly $2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$.



Sketch 13.1

A wave is characterized by its **wavelength**, λ (lambda), the distance between consecutive peaks of the wave (Sketch 13.2). The classification of electromagnetic radiation according to its wavelength is shown in Sketch 13.3. Light, which is electromagnetic radiation that is visible to the human eye, has a wavelength in the range 420 nm (violet light) to 700 nm (red light). The properties of a wave may also be expressed in terms of its **frequency**, ν (nu), the number of oscillations in a time interval divided by the duration of the interval. Frequency is reported in hertz, Hz, with $1\,\mathrm{Hz} = 1\,\mathrm{s^{-1}}$ (i.e. 1 cycle per second). Light spans the frequency range from 710 THz (violet light) to 430 THz (red light).



Sketch 13.2

The wavelength and frequency of an electromagnetic wave are related by:

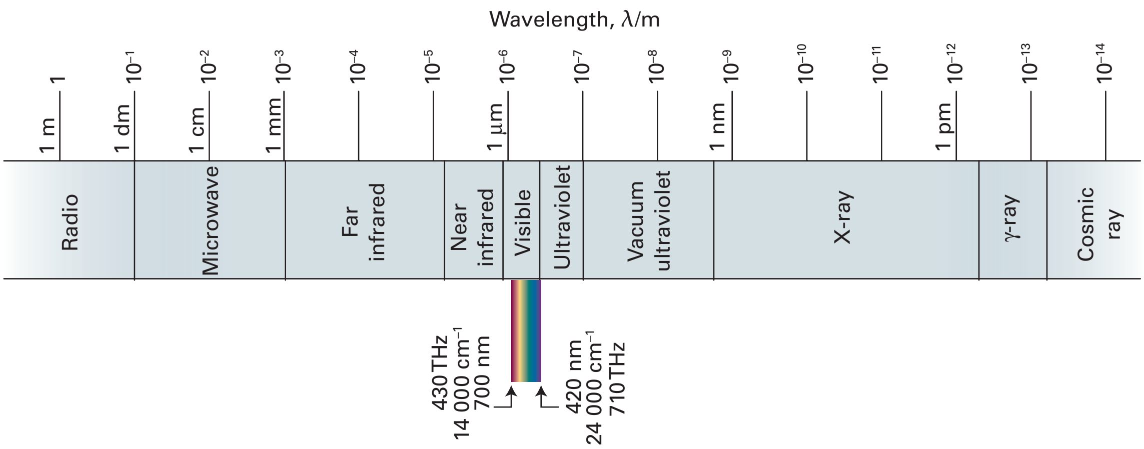
$$c = \lambda\nu \qquad \text{The relation between wavelength and frequency in a vacuum} \qquad (13.1)$$

It is also common to describe a wave in terms of its **wavenumber**, $\tilde{\nu}$ (nu tilde), which is defined as

$$\tilde{\nu} = \frac{1}{\lambda} \text{ or equivalently } \tilde{\nu} = \frac{\nu}{c} \qquad \text{Wavenumber [definition]} \qquad (13.2)$$

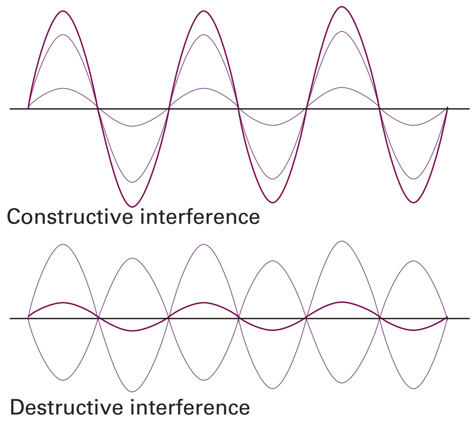
Thus, wavenumber is the reciprocal of the wavelength and can be interpreted as the number of wavelengths in a given distance. In spectroscopy, for historical reasons, wavenumber is usually reported in units of reciprocal centimetres ($\mathrm{cm^{-1}}$). Visible light therefore corresponds to electromagnetic radiation with a wavenumber of $14\,000\,\mathrm{cm^{-1}}$ (red light) to $24\,000\,\mathrm{cm^{-1}}$ (violet light).

Electromagnetic radiation that consists of a single frequency (and therefore a single wavelength) is **monochromatic**, because it corresponds to a single colour. *White light* consists of electromagnetic waves with a continuous, but not uniform, spread of frequencies throughout the visible region of the spectrum.



Sketch 13.3

A characteristic property of waves is that they interfere with one another, which means that they result in a greater amplitude where their displacements add and a smaller amplitude where their displacements subtract (Sketch 13.4). The former is called 'constructive interference' and the latter 'destructive interference'. The regions of constructive and destructive interference show up as regions of enhanced and diminished intensity. The phenomenon of **diffraction** is the interference caused by an object in the path of waves and occurs when the dimensions of the object are comparable to the wavelength of the radiation. Light waves, with wavelengths of the order of 500 nm, are diffracted by narrow slits.



Sketch 13.4