Realizing that light may be considered to have both wave-like and particle-like characteristics, it is useful to consider that a given frequency or wavelength of light is associated with a "light quanta" of energy we now call a **photon**. As noted in the following equations, frequency and energy change proportionally, but wavelength has an inverse relationship to these quantities.

\[ \nu = \frac{c}{\lambda} \]

and

\[ \Delta E = h \nu \]

with

- \( \nu \) is the frequency of light
- \( \lambda \) is the wavelength of light
- \( c \) is the speed of light (\( 3 \times 10^8 \text{ m/sec} \))
- \( \Delta E \) is the transition energy (difference of energies between the initial and final states)
- \( h \) is Planck's constant (\( h = 6.626069 \times 10^{-34} \text{ J s} \))

To "see" a molecule, we must use light having a wavelength smaller than the molecule itself (roughly 1 to 15 angstroms). Such radiation is found in the X-ray region of the spectrum, and the field of **X-ray crystallography** yields remarkably detailed pictures of molecular structures amenable to examination. The chief limiting factor here is the need for high quality crystals of the compound being studied. The methods of X-ray crystallography are too complex to be described here; nevertheless, as automatic instrumentation and data handling techniques improve, it will undoubtedly prove to be the procedure of choice for structure determination. The spectroscopic techniques described below do not provide a three-dimensional picture of a molecule, but instead yield information about certain characteristic features. A brief summary of this information follows:

- **Ultraviolet-Visible Spectroscopy**: Absorption of this relatively high-energy light causes electronic excitation. The easily accessible part of this region (wavelengths of 200 to 800 nm) shows absorption only if conjugated \( \pi \) electron systems are present.

- **Infrared Spectroscopy**: Absorption of this lower energy radiation causes vibrational and rotational excitation of groups of atoms within the molecule. Because of their characteristic absorptions, identification of functional groups is easily accomplished.

- **Nuclear Magnetic Resonance (NMR) Spectroscopy**: Absorption in the low-energy radio-frequency part of the spectrum causes excitation of nuclear spin states. NMR spectrometers are tuned to certain nuclei (e.g. \( ^1\text{H} \), \( ^{13}\text{C} \), \( ^{19}\text{F} \) & \( ^{31}\text{P} \)). For a given type of nucleus, high-resolution spectroscopy distinguishes and counts atoms in different locations in the molecule.

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