

Chapter 2

Electromagnetic Radiation

Bohr demonstrated that information about the structure of hydrogen could be gained by observing the interaction between thermal energy (heat) and the atom. Many analytical techniques used today follow the same principle. Atoms or molecules can absorb energy, become excited, and then emit the excess energy in order to return to their original ground state configuration. High-energy impacts with charged particles and induced nuclear reactions are also used to excite sample atoms, but the most common approach is to employ electromagnetic radiation. The electromagnetic radiation absorbed or emitted provides information about elemental composition, molecular configuration, or other characteristics about the sample.

Wavelength, Frequency, and Energy

Electromagnetic radiation (EM) is described in terms of its wavelength, frequency, or energy. All electromagnetic energy travels at the speed of light, c , which is 2.998×10^8 m/s, so wavelength (λ) and frequency (ν) are inversely related: $c = \lambda\nu$. Long waves have a low frequency and short waves have a high frequency (Fig. 2.1). The wavelength and frequency also indicate the energy of the wave. The relationship between wavelength and energy, E , is described by the equation, $E = hc/\lambda$, where h is Planck's constant ($h = 6.625 \times 10^{-34}$ Joule-seconds or J s) and c is the speed of light. By replacing the constants h and c with their respective values, we see that $E = 1.986 \times 10^{-25}$ Joule-meters or J m/ λ . An inverse relationship exists; electromagnetic radiation with shorter wavelengths is more energetic. The relationship between energy and frequency is given by the equation, $E = h\nu$, where h is Planck's constant. A direct relationship exists; electromagnetic radiation with a higher frequency is more energetic.

The Electromagnetic Spectrum

The electromagnetic spectrum has been divided into many sections; familiar names are assigned to the different ranges (Fig. 2.2). Gamma rays and X-rays are types of

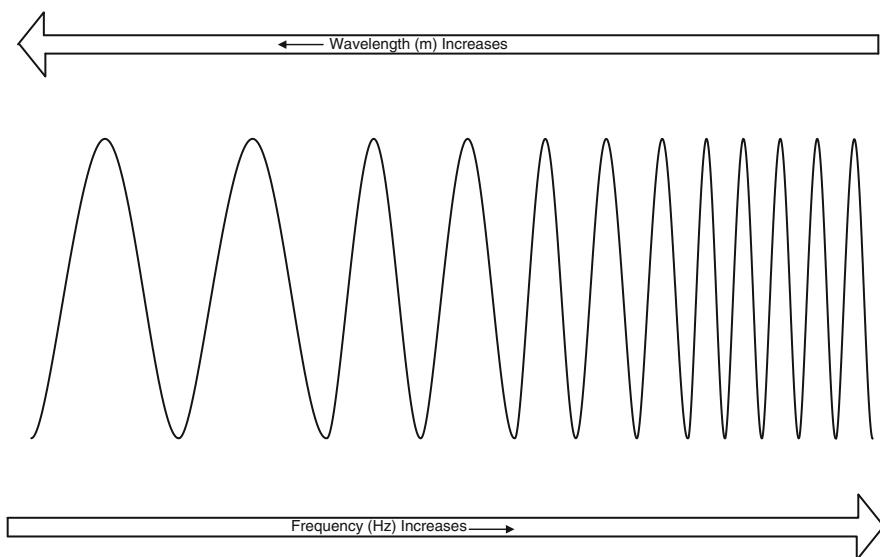


Fig. 2.1 The relationship between wavelength and frequency (Original Figure by M.E. Malainey and T. Figol)

EM radiation with the shortest wavelength, highest frequencies, and, consequently, the highest energy. At the other end of the spectrum are the low energy waves. In the order of increasing energy, these include radio waves, television waves, microwaves, and radar waves. The energy we know as light is the middle of the spectrum. The lowest energy light is infrared, followed by visible and ultraviolet. The human eye is capable of discriminating between EM waves of different energy in the visible range between about 400 and 700 nm in wavelength. The spectrum of visible light appears as the different colors: red, orange, yellow, green, blue, and violet. Within the visible range, red light has the lowest energy and violet the highest.

Energy Absorption and Emission by Atoms and Molecules

As outlined in [Chapter 1](#), electrons are found at various discrete energy levels within an atom. Electrons are very small particles and the electronic energy levels are widely spaced. Electrons occupying the energy levels closest to the nucleus have the lowest energy; as one moves to the outer energy levels, electrons have progressively higher amounts of energy. Certain types of EM radiation are absorbed by the atoms or molecules in a sample and move them to a higher energy or excited state. Atoms or molecules in an excited state emit excess energy in order to return to ground state. The excess energy can be lost by the production of heat or the emission of radiation. Spectroscopic techniques involve monitoring the energy absorbed, emitted, or the behavior of excited molecules.

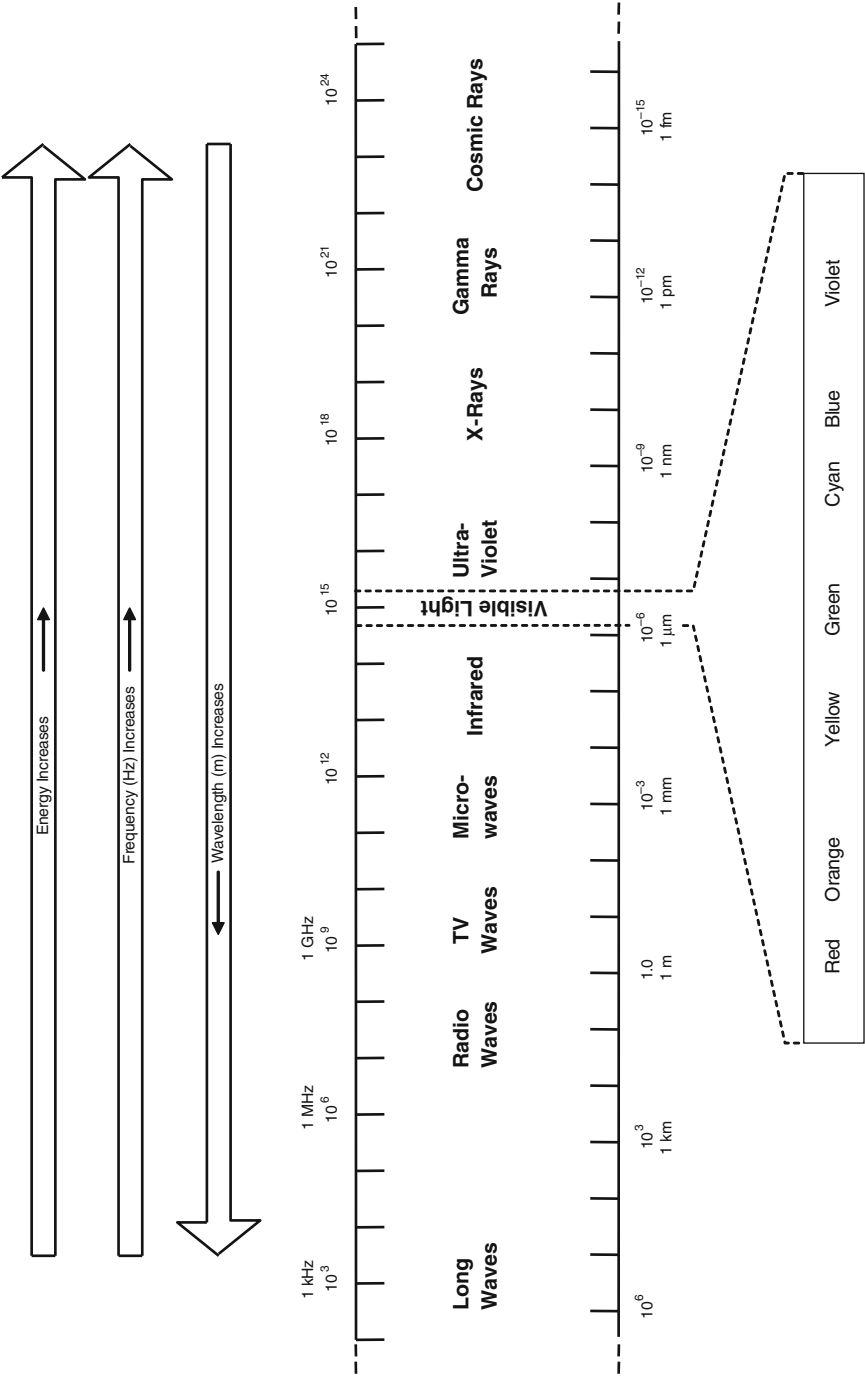


Fig. 2.2 Electromagnetic spectrum with visible region expanded (Modified from “Fundamentals of Physics”, Second Edition Extended, David Halliday and Robert Resnick, copyright 1981, Reproduced with permission of John Wiley & Sons, Inc.)

Several of the analytical techniques described in Part IV either manipulate a sample with EM energy or expose it to conditions that cause its constituent atoms to emit EM energy. With spectroscopic techniques, electromagnetic radiation, $h\nu$, is directed at atoms or molecules. Under certain conditions, some radiation is absorbed which is called the photoelectric effect. The effect of this absorption varies with the types of atoms or molecules present, the type of radiation, and the environment in which it occurs. With nuclear magnetic resonance (NMR) spectroscopy, the absorption of radio frequency energy in a strong magnetic field causes the nuclei of certain sample atoms to flip. Electron spin resonance (ESR) dating involves the application of microwave energy to a crystalline sample in a strong magnetic field, which causes trapped electrons to resonate. Several spectroscopic techniques utilize EM radiation in the infrared (IR), visible (VIS), or ultraviolet (UV) range to characterize a sample. Molecular bonds absorb light in the UV and visible range; IR radiation causes molecular bonds to vibrate.

Inductively coupled plasma-atomic emission spectroscopy (ICP-AES), optical emission spectroscopy (OES), and atomic absorption spectroscopy (AA) all involve heating the sample and monitoring characteristic light emitted or absorbed by excited atoms. Instrumental neutron activation analysis (INAA or NAA) determines the elemental composition of a sample on the basis of the characteristic gamma rays emitted by artificially created radioisotopes.

X-radiography uses the differential absorption of high-energy X-rays by elements to image the interior of an object. X-ray diffraction (XRD) uses the characteristic interference pattern of X-rays produced by its crystal structure to identify specific minerals. In X-ray fluorescence (XRF), whether it be energy-dispersive (ED) or wavelength-dispersive (WD) spectrometry, high energy X-rays excite sample electrons which then return to ground state by fluorescing X-rays characteristic of that element. Characteristic X-rays emitted by elements following high-energy impacts with electrons can be monitored with either scanning electron microscopy with ED XRF or electron microprobe analysis. High-energy impacts with protons or α -particles also cause the emission of X-rays and gamma rays characteristic of elements in a sample when using proton/particle-induced X-ray emission (PIXE) or proton/particle-induced gamma ray emission (PIGE).

A Consumer's Guide to Archaeological Science
Analytical Techniques

Malainey, M.E.

2011, XX, 603 p. 135 illus., Hardcover

ISBN: 978-1-4419-5703-0