1.2: Electromagnetic Spectrum

Electromagnetic fields exist at frequencies from DC (0 Hz) to at least 10^{20} Hz – that's at least 20 orders of magnitude! At DC, electromagnetics consists of two distinct disciplines: *electrostatics*, concerned with electric fields; and *magnetostatics*, concerned with magnetic fields. At higher frequencies, electric and magnetic fields interact to form propagating waves. Waves having frequencies within certain ranges are given names based on how they manifest as physical phenomena. These names are (in order of increasing frequency): radio, infrared (IR), optical (also known as "light"), ultraviolet (UV), X-rays, and gamma rays (γ-rays). See Table $1.2.1$ and Figure $1.2.1$ for frequency ranges and associated wavelengths.

Definition: Electromagnetic Spectrum

The term *electromagnetic spectrum* refers to the various forms of electromagnetic phenomena that exist over the continuum of frequencies

The speed (properly known as "phase velocity") at which electromagnetic fields propagate in free space is given the symbol c, and has the value $\cong 3.00 \times 10^8$ m/s. This value is often referred to as the "speed of light." While it is certainly the speed of light in free space, it is also the speed of *any* electromagnetic wave in free space. Given frequency f, wavelength is given by the expression

$$\underbrace{\lambda = \frac{c}{f}}_{\text{in free space}}$$

Table $1.2.1$ shows the free space wavelengths associated with each of the regions of the electromagnetic spectrum. This book presents a version of electromagnetic theory that is based on classical physics. This approach works well for most practical problems. However, at very high frequencies, wavelengths become small enough that quantum mechanical effects may be important. This is usually the case in the X-ray band and above. In some applications, these effects become important at frequencies as low as the optical, IR, or radio bands. (A prime example is the *photoelectric effect*; see "Additional References" below.) Thus, caution is required when applying the classical version of electromagnetic theory presented here, especially at these higher frequencies.

Table $1.2.1$: The electromagnetic spectrum. Note that the indicated ranges are arbitrary but consistent with common usage.

Regime	Frequency Range	Wavelength Range
γ-Ray	$> 3 \times 10^{19}$ Hz	< 0.01 nm
X-Ray	3×10^{16} Hz – 3×10^{19} Hz	10–0.01 nm
Ultraviolet (UV)	2.5×10^{15} – 3×10^{16} Hz	120–10 nm
Optical	4.3×10^{14} – 2.5×10^{15} Hz	700–120 nm
Infrared (IR)	300 GHz – 4.3×10^{14} Hz	1 mm – 700 nm
Radio	3 kHz– 300 GHz	100 km – 1 mm

The radio portion of the electromagnetic spectrum alone spans 12 orders of magnitude in frequency (and wavelength), and so, not surprisingly, exhibits a broad range of phenomena. This is shown in Figure $1.2.1$.

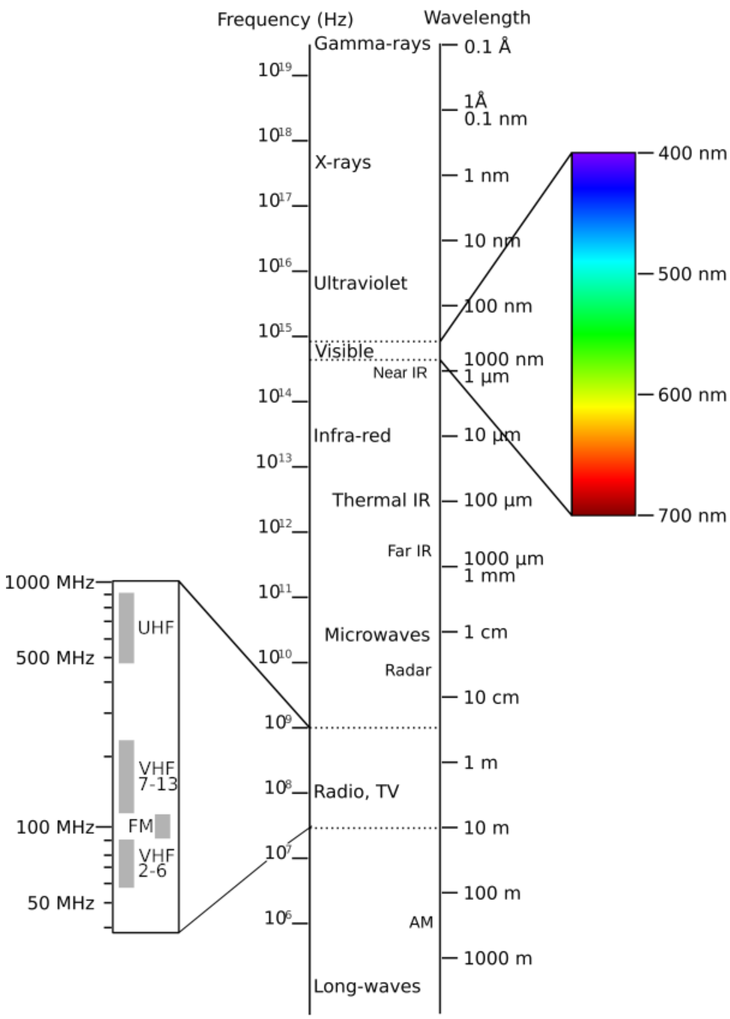

Figure 1.2.1: Electromagnetic Spectrum.

Table 1.2.2: The radio portion of the electromagnetic spectrum, according to a common scheme for naming ranges of radio frequencies. WLAN: Wireless local area network, LMR: Land mobile radio, RFID: Radio frequency identification

Band	Frequencies	Wavelengths	Typical Applications
EHF	30-300 GHz	10–1 mm	60 GHz WLAN, Point-to-point data links
SHF	3–30 GHz	10–1 cm	Terrestrial & Satellite data links, Radar
UHF	300–3000 MHz	1–0.1 m	TV broadcasting, Cellular, WLAN
VHF	30–300 MHz	10–1 m	FM & TV broadcasting, LMR
HF	3–30 MHz	100–10 m	Global terrestrial comm., CB Radio
MF	300–3000 kHz	1000–100 m	AM broadcasting
LF	30–300 kHz	10–1 km	Navigation, RFID
VLF	3–30 kHz	100–10 km	Navigation

Table 1.2.3: The optical portion of the electromagnetic spectrum.

Band	Frequencies	Wavelengths

Band	Frequencies	Wavelengths
Violet	668–789 THz	450–380 nm
Blue	606–668 THz	495–450 nm
Green	526–606 THz	570–495 nm
Yellow	508–526 THz	590–570 nm
Orange	484–508 THz	620–590 nm
Red	400–484 THz	750–620 nm