CHAPTER 3

The Electromagnetic Spectrum

In the previous chapter, we examined how electromagnetic radiation behaves on a purely physical level, without being concerned yet with its detailed interactions with matter. One important observation was that we can treat an arbitrary radiation field as a superposition of many "pure" sinusoidal oscillations. The clearest everyday example of this is the rainbow: white sunlight interacting with raindrops is decomposed into the constituent colors red through violet, each of which corresponds to a narrow range of frequencies. Radiation associated with a given frequency and trajectory in space may be analyzed completely independently of all the others.

We also saw that there is no fundamental constraint on the frequency that EM radiation can exhibit, as long as an oscillator with the right natural frequency and / or an energy source with the minimum required energy is present (recall from Section 2.6 that a single photon has a specific energy determined by its frequency and that an oscillator cannot emit less than that minimum amount).

In a vacuum, the frequency or wavelength of a photon is of little practical consequence, as it cannot be absorbed, scattered, reflected, or refracted but rather is condemned to continue propagating in a straight line forever, regardless. In the presence of matter however, the frequency becomes an all-important property and, to a very great degree, determines the photon's ultimate fate.

There are several reasons why frequency *does* matter in the atmosphere. First of all, as already mentioned several times, the energy of a photon is given by $E = h\nu$. The rate of absorption and emission of photons by the atmosphere is strongly dependent on the precise value of that energy. Among other things, a physical or chemical event requiring a minimum input of energy ΔE_{min} cannot be initiated by a photon with a frequency of less than $\nu_{\text{min}} = \Delta E / h$. Furthermore, the quantum mechanical behavior of matter at the molecular level imposes an even stronger constraint in many cases: to be absorbed, the energy of a photon must almost exactly match a certain well-defined set of values associated with allowable energy levels in that molecule. We will examine these issues in considerable detail in Chapter 9.

Another reason arises from the wave nature of radiation, which comes to the forefront when radiation is scattered or reflected by particles or surfaces. Such interactions arise primarily when the dimensions of a particle are comparable to or larger than the wavelength. Thus, radiation in the visible band is rather weakly scattered by air molecules but strongly scattered by cloud droplets. Longer wavelengths in the microwave band (e.g., radar) are negligibly scattered by cloud droplets but rather strongly by raindrops and hailstones. Longer wavelengths still (e.g., AM radio, with wavelengths of order 10^2 m) may propagate unimpeded through any kind of weather but may be diffracted around hills and reflected by deep layers of ionized gases in the extreme upper atmosphere.

3.1 Frequency, Wavelength and Wavenumber

The most fundamental characteristic of a harmonic electromagnetic field is its frequency $\nu = \omega / 2\pi$, which has units of cycles per second, or Hertz (Hz). Regardless of where you are and what other processes affect it, radiation with frequency ν will always have that frequency until such time as it is absorbed and converted into another form of energy[1].

---

[1] This assumes that you, the observer, are at a fixed distance from the source. Otherwise the frequency will be shifted by the Doppler effect.

Return to: A First Course in Atmospheric Radiation

In practice, it is usually more convenient to specify the wavelength λ rather than the frequency ν. This is because the frequencies of interest to most atmospheric scientists tend to be numerically large and unwieldy. The two parameters are related by

$$\boxed{c = \lambda\nu\ .} \tag{3.1}$$

Note that this relationship is valid for the wavelength in a vacuum. Inside a medium like air or water, the phase speed of radiation is somewhat slower than c and the actual wavelength is correspondingly shorter. The dependence of the actual wavelength on the index of refraction of the medium is important for understanding some effects such as refraction. Normally, if we refer to wavelength without further qualification, we mean wavelength in a vacuum.

For atmospheric radiation, wavelength is most commonly expressed using one of the following units, whichever is most convenient: nanometers (nm = 10^{-9} m), micrometers or *microns* (μm = 10^{-6} m), or centimeters (cm = 10^{-2} m). Other units, such as the Angstrom (10^{-10} m) are no longer widely used by meteorologists.

The description preferred by some specialists is neither wavelength nor frequency but *wavenumber* $\tilde{\nu}$, which is just the reciprocal of wavelength:

$$\boxed{\tilde{\nu} = \frac{1}{\lambda} = \frac{\nu}{c}\ .} \tag{3.2}$$

Wavenumber is usually stated in units of inverse centimeters (cm^{-1}).

3.2 Major Spectral Bands

The electromagnetic spectrum spans an enormous range of frequencies, from essentially zero to extremely high frequencies associated with energetic photons released by nuclear reactions. As a matter of convention, the spectrum has been subdivided by scientists and engineers into a few discrete spectral *bands*. The frequency and wavelength boundaries of the major spectral bands are given in Table 3.1

Return to: A First Course in Atmospheric Radiation