**Lecture four**

**Absorption**

**1- Beer-Lambert Law**

A fraction of the incident radiation is absorbed along the path of propagation in a

Medium (here refer to the atmosphere). The Beer-Lambert law (also referred to as the Beer-Lambert-Bouguer law) governs the reduction in the radiation intensity *Iλ* at wavelength *λ* (Fig. below ). If *s* stands for the medium thickness (oriented in the direction of propagation), the evolution of the radiation intensity is:

Where is the absorption coefficient at wavelength *λ* (depending on the

Medium). The unit of is, for instance, m−1 or cm−1. Assuming that the medium is homogeneous, then has a constant value and:



**Fig.** Absorption of an incident radiation traversing a medium (*gray box*)

Consider a medium composed of *p* absorbing species, with densities, expressed in molecule cm−3. The absorbing coefficient is then obtained by summing over all species. For a given species, the contribution depends on the density and on the so-called *absorption cross section* (the effective cross section resulting in absorption), , usually expressed in cm2:

A way to define the absorption cross section is to consider an incident flux of energy per surface, *F* (in Wcm−2). The resulting absorbed energy is then:

(Expressed in Watt).

Another classical concept is the so-called *optical depth* (unitless), defined for a monochromatic radiation by:

Rewriting the Beer – Lambert law yields:

**2. Kirchhoff’s Law**

For a given wavelength *λ*, the *absorptivity* is defined as the fraction of the incident radiation that is absorbed by the medium. Kirchhoff’s law (1859) connects the absorptivity and the emissivity of a medium at thermodynamic equilibrium, namely

The absorption properties of a medium are therefore directly related to its emission properties. Note that can be derived from . For a medium supposed to be homogeneous, with a thickness *z* (typically a cloud), with an absorbing coefficient, the ratio of the absorbed intensity to the incident intensity is . At thermodynamic equilibrium, when

Taking into account absorption and emission, the evolution of the intensity is then

For a body at temperature T Maximum of emitted radiance at wavelength is given by the so-called Planck distribution,

**3. Spectral Line Broadening**

For a given energy transition, Planck’s law describes only monochromatic absorption or emission, with a unique wavelength given by this defines the so-called *spectral lines*. In practice, monochromatic radiations are not observed. As shown by the absorption spectrum for a few species, there is a *broadening* of the wavelengths, mainly related to two effects:

**Doppler Broadening:** For moving molecules, the *Doppler Effect* implies that the Emission and absorption wavelengths are broadened. This is usually described by the so-called Doppler profile, centered at , given by a Gaussian distribution with respect to the frequency :

Where and stand for the half width of the line and the line strength, respectively. The half width of the line is related to the velocity of the molecule in the direction of the incident radiation, and is proportional to √*T* .

The Doppler effect states that the frequency appears shifted as seen by a stationary observer to the frequency  *.*

**Pressure Broadening (Lorentz Effect)** The collisions between the molecules

contribute to broaden the lines. The distribution function is then

where and stand for the width and the strength of the line, respectively. The width is related to the collision frequency and is proportional to the product of the molecule density, *n*, by the velocity (proportional to √*T* ). With the ideal gas law, *n* ∝ *P/T* (*P* is the pressure), and thus ∝ *P/*√*T* .

The Lorentz effect is a decreasing function of altitude. For a hydrostatic atmosphere (Chap. 1), supposed to be adiabatic (Chap. 3), the vertical profiles of pressure and of temperature are indeed *P(z)* =*P*0 exp*(*− *z/H)* and *T (z)* = *T*0 −*z*.

The typical shape of the Doppler and Lorentz profiles is shown in Fig. 2.. Up to 40 kilometers, the Lorentz effect is the dominant effect (due to high densities), then the Doppler effect and, finally, the joint impact of both effects (described by the so-called *Voigt profile*).



Figure 2: Normalized distribution functions for the Lorentz and Doppler effects