Understanding the emission or absorption of light by atoms and molecules depends on the level of excitation in those systems, which in turn is linked to concepts of temperature. However in considering definitions of temperature, some consideration is needed for the unusual conditions found in interstellar environments relative to typical laboratory situations.

A region of gas can be considered in *Local Thermodynamic Equilibrium* (LTE) if the energy-changing processes that populate and depopulate a given energy state occur at equal rates, and the system can be characterized by a single temperature.

In LTE the relative number of atoms in different excitation states is described by the Boltzmann equation,

\[
\frac{n_j}{n_i} = \frac{g_j}{g_i} e^{-\frac{\Delta E}{kT}} ,
\]

where \( n_i \) and \( n_j \) are the number density of atoms in the \( i \) and \( j \) excitation states, \( g_i \) and \( g_j \) are the statistical weights of those states, \( \Delta E \) is the excitation energy difference between the \( j \) and \( i \) states, \( k \) is Boltzmann’s constant, and \( T \) is temperature.

In the interstellar medium, LTE usually does not hold, and the relative population of excited states in an ensemble of particles is not described by the Boltzmann equation. In discussing the relative populations of two excitation states, \( n_1 \) and \( n_2 \), it is nonetheless common to talk about the excitation temperature \( T_{ex} \) that would result by assuming equation 1 describes \( n_2/n_1 \). In this circumstance however the same \( T_{ex} \) will not necessarily describe the relative populations of two other states.

The Boltzmann equation can be generalized to derive the Saha equation, which describes the relative population of different ionization states for particles in a plasma in LTE. While the Saha equation is important for understanding ionization conditions in stars, in the interstellar medium the Saha equation generally does not apply.
Although a single temperature may be inappropriate to describe the distribution of excitation within an interstellar gas, the distribution of particle kinetic energies $E$ is often well described by a thermal distribution, given by the Maxwell-Boltzmann distribution,

$$\frac{dn(E)}{dE} = 2\sqrt{\frac{E}{\pi(kT_k)^3}} e^{-\frac{E}{kT_k}},$$

where $n(E)$ is the number density of particles with kinetic energy $E$ and $T_k$ is the kinetic temperature.

Note that in general $T_{ex} \neq T_k$, and we need to look in more detail at the processes that shift electrons between different energy states within atoms in order to understand the excitation conditions.

Finally, a perfect emitter of light produces a spectrum that can be described with a blackbody temperature $T_b$ as a single parameter, using the Planck function, which gives the intensity per unit wavelength interval as

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1},$$

and per unit frequency interval as

$$B_\nu(T) = \frac{2h\nu^3/c^2}{e^{h\nu/kT} - 1}.$$

The Cosmic Microwave Background is well described by a Planck function with $T_b = 2.7$ K, and stars can be treated approximately as blackbodies, but in general we cannot assume that the spectrum of photons interacting with an interstellar cloud is characterized by a single $T_b$. 
