INFLUENCE OF THE SCREENING EFFECT ON ATOMIC TRANSITION PROBABILITIES IN DENSE PLASMAS

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In his well known work "Strahlungs-Emission und-Absorption nach der Quantentheorie" Albert Einstein[1] for the first time introduced radiation coefficinets A_{mn}, B_{mn} and B_{nm} (in the literature usually known as Einstein coefficients) which afterwards appeared to be very useful in different fields of physics, in particular in the field of laser and plasma physics.

In his approach to the problem of matter and radiation interaction Einstein, following Planck, considered an idealized system - matter + radiation in which the matter consists of identical "molecules", each of them independently interacting with the radiation field. However, different from Planck's the "molecules" are not treated as the harmonic oscillators, so that their energetic spectrum (which, in the sense of N.Bohr's idea, is supposed to be discrete) could not be equidistant.

Denoting the state of "molecule" by Z_m and corresponding energy of the state by E_m then, following Einstein, for every molecular transition from state Z_m to Z_n with simultaneous absorption (or emission) of photon of frequency $\omega_{mn} = \frac{E_m - E_n}{h}$ and, with regard to the kind of transition, one can define corresponding coefficients:

A_{mn} - for the spotaneous transition $Z_m \rightarrow Z_n$ (emission of photon);

B_{nm} - for the transition $Z_n \rightarrow Z_m$ (absorption of photon),

and

B_{mn} - for the transition $Z_m' \rightarrow Z_n$ induced by the interaction of "molecule" with radiation field (emission of photon).

If by N_m we denote number density of "molecules" in state Z_m and by $\varepsilon(\omega_{mn})$ the density of radiation field then, under the conditions of thermodinamic equilibrium, the following equality holds:

$$N_m A_{mn} + N_m \varepsilon(\omega_{mn}) B_{mn} = N_n \varepsilon(\omega_{mn}) B_{nm} \quad (1)$$

Each of the terms in the above equation represents the number of photons emitted (or absorbed) oer unit volume and unit time.

It is worth to note that Einsten's approach to this problem is very fruitful, since the atoms and molecules of real matter, interacting with radiation, could play a role of "molecules" appearing in his model (in a broad range of parameters). For the isolated atoms (molecules) corresponding coefficients could be determined by using the methods of Quantum mechanics or, more strictly, the methods of Quantum Electrodinamics.

However, in plasmas with high electron concentrations (>10^{17} cm^{-3}, often called dense plasmas), contrary to the case of rarified plasmas, the situation radically changes. Under such extreme conditions, the atoms could not be any longer regarded as isolated. Thus, under dense plasma conditions, it is not possible to describe the relative movement of electron-ion pair in the frame work of binary interaction model (with Coulombic asymptotic), so that it is necessary to introduce a pseudo-potential, which takes into account the interactions in plasma.

However, even under such conditions Einstein's approach to the problem still remains correct, with such a difference that, as "molecules", one would not consider the atoms (molecules), but certain quasi-particles (described by the Hamiltionian which includes the electron-ion-plasma interaction operator). The simplest way to take into account the effect of electrostatic screening is to replace the Coulomb potential with a certain potential of finite range (such as Debye potential, or screened Coulomb potential).

The calculation we performed in the approximation of Coulomb potential with cut-off radius[2], vields the following equation:

$$\frac{A_{nm}}{A_{nm}^{(o)}} = 1 - C(\gamma_n) r_x^{2/\gamma_n - 1} e^{-2\gamma_n r_x} \qquad (2)$$

where $A_{nm}^{(o)}$ is Einstein coefficient for isolated atoms, $C(\gamma_n)$ is a constant characterizing the atoms, r_x is cut-off radius and, $\gamma_n = \sqrt{2I_n}$, I_n being ionization potential of the upper state.

By comparing our results with the experiment (so far performed only in krypton plasma[3,4]) we find mutual qualitative agreement, as can be seen from Fig. 1. However, in order to confirm the dependence of atomic transition probabilities on plasma parameters, it is necessary to perform more sophisticated calculations as well as to find out further experimental evidence.

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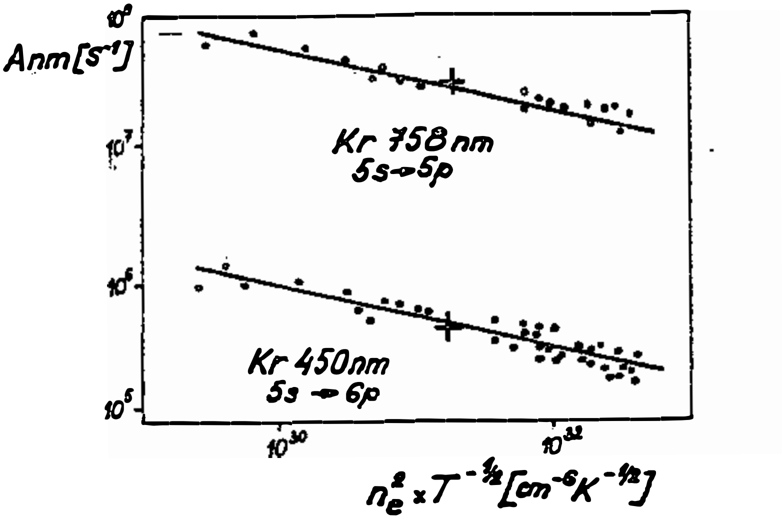

Fig. 1. Dependence of atomic transition probabilities of KrI lines λ = 758 nm and λ = 450 nm, on electron concentration and temperature; (...) experimental results[3,4], (+) our results.