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ENHANCEMENT OF RADIATION DAMPING BY RESONANCE COUPLING

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In recent experiments the oscillator strength of the resonance transition $1\,^1S$-$2\,^1P$ in helium was determined as $0.37_7 \pm 0.03_5$.[1] This value has caused some discussion, since it is notably different from the theoretical value of 0.276 ± 0.001 found by Schiff and Pekeris[2] which is similar to other theoretical values.[3,4] The experimental value was determined from interferometric profile analysis of emission lines in the visible and near infrared arising from combination with the resonance level $2\,^1P$. The Lorentz component of the Voigt profile was considered to be made up of instrumental width, radiation width, and pressure broadening. Over a range of density of $(0.3\text{-}2.8)\times 10^{17}$ atom cm^{-3} the Lorentz width was found to vary linearly with density, and by extrapolation to zero density and subtraction of the accurately known instrumental width, the radiation width of the $2\,^1P$ level was determined as 13.1 ± 1.2 mK. The natural width corresponding to the theoretical oscillator strength is 9.5 mK.

Many possibilities of experimental error have been considered, and have been eliminated as the result of further extensive measurements.[5] The discrepancy of some 30-40% between the experimental extrapolated value and the theoretical values must accordingly be regarded as real.

A similar situation exists in neon. The theoretical oscillator strength of 0.12 found by Gold and Knox[6] for the resonance transition at 736 A gives a radiation width of 2.8 mK for the $2p^5(^2P_{1/2})3s[\frac{1}{2}]_1$ level with an expected accuracy of perhaps ±0.7 mK. Korolev, Odintsov and Fursova[7] find a value of 3.5 ± 0.3 mK from an atomic-beam experiment. In measurements similar to those in helium, Kuhn and Lewis,[8] by extrapolation of a closely linear plot of Lorentz width to zero denisty, have obtained a radiation width of 5.8 ± 0.6 mK. This is some 50-60% greater than the other values, though the latter cannot claim as high accuracy as in helium.

A characteristic feature of these anomalies is the fact that they are observed under conditions where the natural width and pressure broadening are similar in magnitude, while the Doppler width (of the resonance lines) is one order of magnitude greater. The magnitude of the pressure broadening and its linear relation with gas density over a wide range down to 0.3×10^{17} atom cm^{-3} is in good agreement with theories of pressure broadening.[9] However, theories of pressure broadening usually neglect effects of natural linewidth. The extrapolation of our linear plots of Lorentz width against gas density assumes the absence of additional interaction effects which predominate at still lower density. The experiments indicate that this assumption is apparently not valid, and we propose an explanation in terms of an enhancement of radiation damping due to resonance interactions.

Consider a system of two like atoms, one of which is initially excited. Quantum mechanically the state of the system can be represented by a superposition of two states, one of which is symmetric and the other antisymmetric with respect to interchange of the atoms. The antisymmetric one does not radiate, while the symmetric one radiates by transition to the symmetric ground state at twice the rate compared with a single atom. This enhancement occurs if the interatomic distance is small compared with the resonance wavelength λ, leading to halving of the lifetime and doubling of the radiation width. Classically this corresponds to the radiation of two coupled oscillators radiating in the normal mode in which both vibrate in phase. The super-radiant states discussed by Dicke[10] present a form of this enhancement effect.

The effect has been discussed for the case of two stationary atoms by Stephen[11] and by Hutchinson and Hameka.[12] The latter authors find, for the interatomic distances $R=\lambda/2\pi$ and $2\times\lambda/2\pi$, respectively, that the radiated widths are increased to approximately 1.9 and 1.65 times the natural width from an isolated atom. These distances are of the order of magnitude of the average interatomic distances in our experiments, i.e., considerably larger than the "optical collision radius" for pressure broadening. These and other estimates show that the enhancement effect should be operative in our experiments and should predominate at still lower densities.

Clearly the actual experimental situation is complicated, and a full theoretical treatment would have to consider the existence of more than two atoms at various distances and also the influence of the relative motion. It is plausible that under the conditions stated these will modify the effect but not destroy it.

On the basis of classical theory the problem has actually been treated by Weisskopf[13] where he deals with the general problem of many atoms. At low densities his theory gives an interruption width due to optical collision effects and an additional "coupling width." The latter contains the enhancement effect discussed above for the simple case of two atoms. At larger densities the coupling effect becomes unimportant by comparison with the interruption width, and this indicates that it would scarcely affect the slope of our linear plots. The effect is also reduced if the Doppler width is much greater than the natural width. The quantum mechanical treatment by Mead[14] is similar in approach to that of Weisskopf, but does not include all these effects.

We conclude that resonance broadening at low densities is due to two fairly distinct mechanisms: the interruption or impact broadening due to phase changes, and the enhancement of radiation width due to the "coupling effect." The latter predominates at lower pressures and causes the linear extrapolation in the pressure range of the present experiments to give too high a value for the natural width. Weisskopf remarks that the coupling width would be virtually unobservable experimentally. This would certainly be true of earlier experiments and is probably why the effect has been neglected in further discussions of pressure broadening.

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