The field dependence of the magnetic moment in doublet states

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Like for a classical magnetic dipole, the energy of an atomic magnetic moment in an external magnetic field shows an orientational dependence, though discrete as expressed by the quantum mechanical M_J values. Also analogous to the classical case, the energy eigenvalues, usually obtained from the Breit-Rabi formula [1], vary linearly in weak fields as shown in the left part of Fig. 1 for a ^2P state. In this Zeeman regime, their slopes are proportional to the respective g_J factor. This factor is a measure of the intrinsic magnetic moment without a field. As the Breit-Rabi formula does not give any clue as to what is going on dynamically, simply the analogy with the behavior of a classical dipole seems to have led to the generally accepted conclusion that weak fields affect the intrinsic magnetic moment only negligibly. With this in mind and aiming at hints to possible relativistic and/or binding corrections to the magnetic moment, quite some

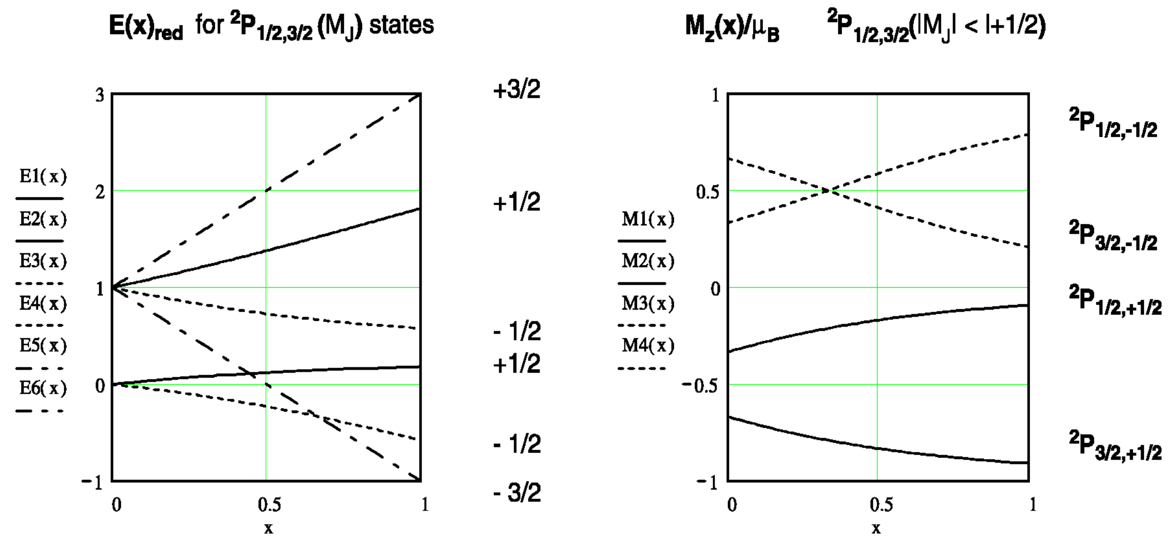

Figure 1: left: reduced energy eigenvalues for stationary M_J levels of a ^2P state; right: its eigenvalues of the magnetic moment for levels with $M_J = \pm 1/2$; both properties are displayed as a function of the reduced magnetic energy $x = \mu_B B/(fs\,splitting)$. For clarity, the constant moments at ∓ 2 for the *stretched states* with $M_J = \pm 3/2 = \pm J_+$ have been omitted.

endeavors have been undertaken in the past in order to measure field-induced level splittings, and thereby the g_J values, as precisely as possible. In this contribution we will show that the rigorous solution to the time-dependent Schrödinger equation describes the full coupling dynamics in a longitudinal field: in the nonstationary case usually dominated by nutation, it allows, other than the Breit-Rabi result, to always discern the individual contributions from the spin-orbit interaction and the magnetic dipole energy. The latter reveals that while g_J remains constant for any field strength only for the *stretched* orientations $|M_J| = J_+ = l + 1/2$, the magnetic moment varies dramatically especially in weak fields for orientations with $|M_J| < J_+$, as displayed on the right part of Fig. 1. Thus, for these levels the g_J values hold true only for $B = 0$. The reason for the strong change of the magnetic moment in the field is the field imposed change of the coupling angle between the angular momenta of orbit and spin. This is also obvious from the change of the spin-orbit energy in the field as displayed on the left part of Fig. 2. On the other hand, the magnetic dipole energy on the right hand side of this figure makes clear that the strong field dependence of the magnetic moment (right part of Fig. 1) is

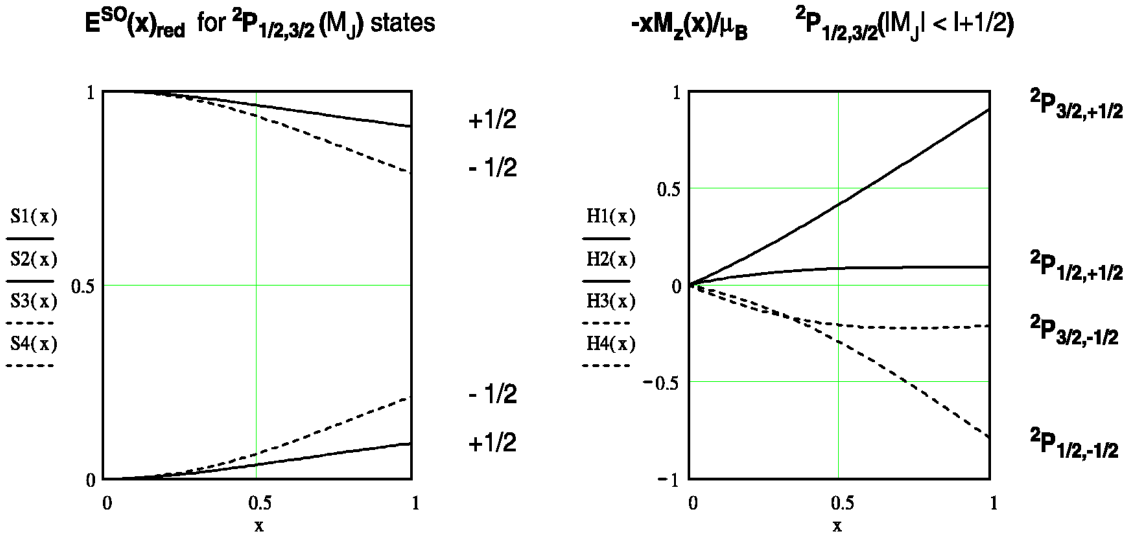

Figure 2: left: reduced eigenvalues of the spin-orbit energy of the stationary levels with $M_J = \pm 1/2$ in a ^2P state; right: the eigenvalues of the magnetic dipole energy for the same levels; both properties are displayed as a function of the reduced magnetic energy $x = \mu_B B/(fs\,splitting)$. For clarity, the constant reduced spin-orbit energy at $+1$ and the always linear magnetic dipole energies with slopes ± 2 for the *stretched states* with $M_J = \pm 3/2 = \pm J_+$ have been omitted.

transformed for weak fields into a dominating linear and a weak quadratic dependence due to the multiplication with the reduced magnetic energy x. This quadratic dependence, however, is almost fully compensated in this regime by the equally quadratic but oppositely acting change of the spin-orbit interaction. Thus, the suggestion of constant g_J values in the seemingly extended linear Zeeman regime is only brought about by the interplay between counteracting quadratic field dependences of the spin-orbit and the magnetic dipole energy.

[1] G. Breit and I. I. Rabi, *Phys. Rev.* **38** 2082 (1931).