Spin evolution of two valence electrons in two separated ions

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Synopsis The spin evolution of two spin-1/2 valence electrons, located at two separated ions, is investigated with the help of Breit equation. This evolution that arise solely depends on their dipole-dipole magnetic interaction. Special attention is paid to the effects beyond the leading order of the dipole-dipole magnetic interaction. In contrast to just including the leading order, it is found that the spin-spin interactions flips the spin of both electrons together, while the spin-orbit interactions typically changes the spin of just single electron. As a consequence, different behaviour is observed in the time evolution of two different entangled Bell states.

Understanding the spin evolution of two or more qubits is a key task in physics and quantum engineering. In particular, the transport and relaxation of spin waves in metals and semiconductor are of fundamental interest not only in basic research, but also in the field of spintronics [1], in which the spin of electrons is utilized *instead of* or *in addition* to the charge degrees of freedom. In spin-field effect transistors, for example, the spin-orbit interaction is known to control the motion of electrons inside the semiconductor channel.

The evolution of two coupled spins have been measured recently by Kotler *et al* [2] for two separated ions. In their simplified model, however, these authors describe the associated spin-magnetic moment of the electrons as point-like dipole, an approximation that breaks down at small distances. More generally, therefore, all the spatial and spin degrees of freedom have to be accounted for the two valence electrons. In present work, we aim to work out a theory which goes beyond the leading order in dealing with the spin-dependent interactions of electrons.

In more detail, we have explored probable spin-flip transitions of the two electrons. Since the spin-flip of different spin states can be represented by a parity sign, we have studied the difference in parity for the different spin states. We especially considered the initial spin state of two electrons at $|\uparrow\downarrow\rangle$ and calculated the time evolution of this state as a function of interaction time (t) at different inter-ionic distances (d) and for a typical strength of the external magnetic field ($\vec{B}$).

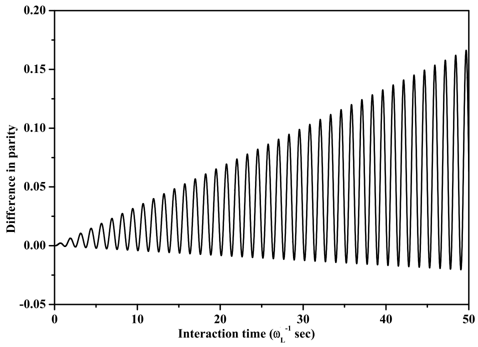

Figure 1. The difference of parity at $d = 10^3 a_0$ and $\omega_L = 1.4$ MHz (where, a_0 is Bohr radius and ω_L is spin Larmor frequency) with $\vec{B} = 0.1$ mT.

Fig. 1 displays how the parity changes exponentially with t, if terms beyond the leading order interactions are taken into account in the electron-electron interaction operator. Our results show that the spin-spin interaction always changes the spin of two electrons together, while the additional terms in the Hamiltonian may flip also the spin of just a single electron, and which results in a different behaviour of the entangled Bell states. Moreover, it is found that the parity difference (of Fig. 1), is highly sensitive to the inter-ionic distances as well as to the strength of the external magnetic field.

References

[1] S.A. Wolf *et al* 2001 *Science* **294** 1488

[2] S. Kotler *et al* 2014 *Nature* **510** 376

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