Formation of paramagnetic, polar molecules containing highly open-shell atoms

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Molecules with non-zero magnetic and electric dipole moments are extremely interesting for their novel applications in quantum information theory or experimental physics probing the fundamental theories. Obvious candidates for such molecules are the mixtures of laser-coolable closed-shell atoms (eg. Yb) with open-shell atoms (alkali-metal atoms, Cr, lanthanides). Recently [1] , a new mechanism which drives Feshbach resonances in systems like RbSr and LiYb were found. However, such Feshbach resonances are extremely narrow: their predicted widths are very small compared to resonant field values at which they occur - typical ratio $\Delta B_{res}/B_{res}$ is at best 10^{-5} which limits their application.

We discuss a mechanisms which might be much more promising for formation of paramagnetic, polar molecules. First we focus on mixture of ultracold Cr and Yb atoms which could form molecules with huge magnetic moment of μ_B and dipole moment of 0.1-0.2 D. If both atoms approach each other, anisotropic spin-spin interaction appears in interaction-distorted Cr atom. Such effect can be as large as 0.5 cm^{-1} near R_e=3.4 Å. This is enough to produce the Feshbach resonances at magnetic fields below 150 G, typically as broad as 0.1-1G for magnetically ground states of Cr atoms. In lanthanides the spin-spin interaction can be approximately order of magnitude larger because of larger spin-orbit interaction, hence the resonances can be even broader.

We examine also the YbEr system in which the spin-spin effect competes with the anisotropy of the interaction potential related to non-zero atomic angular momentum [2]. This anisotropy, is very low, of order of 10 cm^{-1} compared to the typical well depth for interaction lanthanides which is of order of 1500-2000 cm^{-1} . In this example system we also find very broad magnetic Feschbach resonances induced by those two effects. Interestingly enough, the ground state of YbEr is the state with largest possible Λ quantum number.

In conclusion - the ratio $\Delta B_{res}/B_{res}$ in the studied systems can be typically 4-5 orders of magnitude larger than in alkali-metal atom - closed-shell atom mixtures.

References:

[1] Piotr S. Żuchowski, J. Aldegunde, and Jeremy M. Hutson, Phys. Rev. Lett. 105, 153201 (2010).

[2] Alexander Petrov, Eite Tiesinga and Svetlana Kotochigova, Phys. Rev. Lett. 109, 103002 (2012).