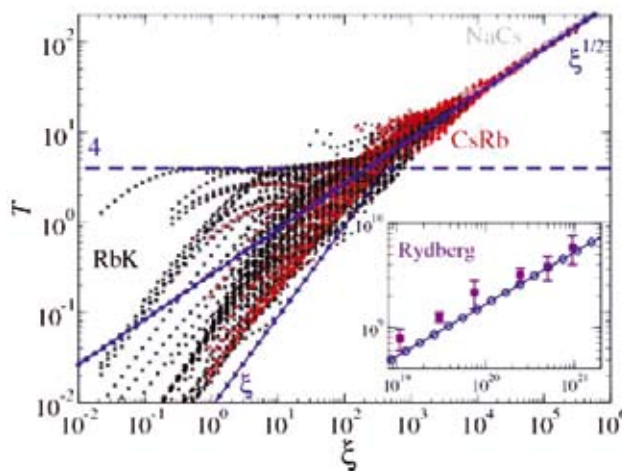# Universal dipolar scattering

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When polarised by an external electric field the scattering of polar molecules is dictated by their dipole-dipole interaction. The characteristic length and energy of a dipolar system are defined in terms of mass m and the induced dipole moment d, and they are $D = md^2/\hbar^2$ and $E_D = d^2/D^3 = \hbar^6/m^3d^4$, respectively. With the scattering energy, we form a dimensionless quantity $\xi = E/E_D = m^3d^4E/\hbar^6$ which parametrizes the scattering. If one rescales the multi-channel radial Schrödinger equation using the length scale D, one finds the only free parameter is ξ. This suggests universal scaling of dipolar scattering. To illustrate this behaviour we have compiled scattering data from many different molecular systems for a variety of conditions. In the figure we have plotted $\mathcal{T}$, ($\sigma = \frac{2\pi}{k^2}\mathcal{T}$), as a function of ξ for many different polar molecules. The figure shows the transition in the scattering from highly variable at low ξ, where the scattering depends on short range, to uniform at large ξ. This transition of $\mathcal{T}$ signifies the onset of universal dipolar behaviour. This will occur when the dipolar interaction is dominant and the scattering will be insensitive to the short range interaction. For this reason different molecules, even bosons and fermions, have the same scattering behaviour. The details are in Ref. [1, 2].

For large ξ, dipolar systems obey a universal scaling, where all scattering dipoles will behave similarly irrespective of the details of the short range. A striking example of this theory being applied is an experimental measurement of the cross section for resonant collisions of Rydberg atoms [3]. In this experiment two identical Rydberg atoms in the ns state, where n (s) is the principal quantum number (orbital angular momentum), are resonantly scattered into a degenerate threshold to which it is coupled via the dipole-dipole interaction. This system has huge dipole moments, $d \propto n^2$, e.g., consider $n = 22$, the dipole moment is about 100 D! Typical molecular dipole moments are $1D$.

Numerically converging this calculation would be impossible with the present computational techniques, but using the scaling presented here we can obtain an accurate estimate of the total cross section, see the figure inset.

With the growing importance of cold polar molecules, with possibilities such as quantum computing, tests of the standard model, and novel many body physics, accurate and yet simple theories to understand their collisions will be important. We have studied the scattering and find an accurate scaling of quantum mechanical dipolar scattering. The universal scattering regime will be readily achieved in polar molecule experiments. Consider collisions of RbCs and NaCs at a temperature of $500nK$ with a modest field of $5kV/cm$; ξ is 230 and 14570, respectively. Both are in the universal dipolar regime.

The transition of dipolar scattering to a universal behavior is shown by plotting $\mathcal{T}$ vs ξ for many polar molecules. The molecules are ^{87}Rb^{41}K (black x), fermionic ^{87}Rb^{40}K (black +), NaCs (brown square), and RbCs (red ◇) with many different scattering conditions. The inset is the experimental cross section for scattering Rydberg atoms from Ref. [3] with the scaling.

References

[1] C. Ticknor, arXiv:0711.4846.

[2] C. Ticknor, Phys. Rev. A **76**, 052703 (2007).

[3] T.F. Gallagher *et al.*, Phys Rev. A **25**, 1905 (1982).

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