Research Opportunities — Hall Labs

What happens when one neutral atom encounters another? The atoms might stick together, briefly or permanently, as a diatomic molecule; or they might scatter off one another and go their respective ways. Determining what happens in a general atomic encounter is a complicated task, particularly when that prediction is made in a quantum-mechanical context. Remarkably, at extremely low temperatures the quantum formalism becomes extremely simple: a single parameter, the scattering length a, suffices to describe most of the interactions between the atoms. You get your scattering length when you choose the atom with which you work, and each atom has a different value of a. If a is large, the atoms interact at long-range, and if a is small the atoms hardly interact at all. The sign of a is also important: $a < 0$ implies an attractive interaction between the atoms, and $a > 0$ a repulsive one.

Under certain, quite special conditions we can adjust the scattering length to any value we want. For instance, we can turn the interactions off by making $a = 0$; or we can make a large attractive interaction to assist in diatomic molecule production. We can then control what happens when two atoms encounter one another, and for this reason this new branch of study is called "tunable quantum chemistry." The name notwithstanding, this exciting new branch of fundamental physics studies how we can tailor the interatomic interactions to make molecules in specific quantum states. At the moment, very few setups are capable of generating the requisite experimental conditions.

There is an additional delightful complication that occurs when we work with atomic collisions at extremely low temperatures: essentially *all* of the atoms in the sample are forced into the *same* quantum state; this is the Bose-Einstein condensate, or BEC, for which discovery in the dilute alkali gases the Nobel Prize was awarded this past year. In a BEC, the constituent atoms lose their identities and become a single "superatom," which amplifies the quantum-mechanical behavior of the individual atoms to a macroscopic scale. Indeed, a typical dilute-gas BEC is large enough to see with the naked eye, but its collective properties are almost entirely quantum-mechanical and counterintuitive to our everyday sensibilities.

Perhaps unsurprisingly, the properties of a BEC too depend crucially on the scattering length a. Although dilute-gas BEC properties have been well-characterized in the years since its first observation in 1995, it is only in the past year that techniques have become available to *change* the scattering length in a condensate, thereby dramatically influencing its quantum properties as well as those of the atoms within it.

Our Laboratory continues its experimental progress towards producing and studying interactions in a BEC. At the moment, we are implementing our final cooling stage and the detection system, and it is possible that we will be making BECs by midsummer. We have two positions available, both of which could turn into thesis projects for the 2002–2003 academic year. Interested students should contact Prof. David Hall (Tel. 542–2072; Email `dshall@unix.amherst.edu`) as soon as possible.