

ATOM CORRAL

This sculpture is an artistic representation of the electron probability cloud for a giant two-atom rubidium molecule whose existence is predicted by scientists. Such molecules have been called 'trilobite' states because of their uncanny resemblance to a trilobite, an ancient hard-shelled creature that lived in the Earth's seas over 300 million years ago. These molecules would be huge on an atomic scale: 500 to 50,000 times larger than a typical atom – and also extremely fragile because of the very weak attraction between the rubidium atoms. Scientists are now looking for such molecules in Bose-Einstein condensates of rubidium atoms, confined to atom traps cooled to within a few millionth of a degree above absolute zero. First, using laser pulses or electromagnetic fields, an electron in one atom (represented as the metal sphere) must be coaxed into a very high orbit; then the molecule could form as this outermost electron attracts another atom (located directly underneath the double peak). The trilobite-shaped electron cloud means the molecule would have a very large permanent electric dipole moment, as much as 1000 times larger than that of any other polar diatomic molecule.

"The magnificent and elegant form of the trilobite state intrigued me particularly because it existed in image form only to our eyes. I wanted to experience it 3 dimensionally and make it available for the viewer as an 3 dimensional experience. The form, along with chronicling the fleeting state of the two-atom rubidium molecule cloud, is an entry into a space unavailable to daily physical experience. As a sculptor I was immediately drawn to that other space because of the possibilities it offered. It opened a world of new forms to me and I am determined to continue investigating the possibilities. I am also exploring the potential for realizing this form at a scale where the viewer can actually walk through the atom corral. The viewer becoming the molecule...Imagine the bronze atom corral at Fronczak as a model for the 50 ft. version...and you the viewer walking through the ripples which would be at chest height...All I need now is the budget and a site to install it. Anyone have any ideas?"

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Resources:

"The New Quantum Universe" by Tony Hey and Patrick Walters, Cambridge University Press

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Members of the low- l class of molecular Rydberg states, such as the $30d$, states in Fig. 1(a), exhibit shallow potential minima. The outermost potential well is approximately 120 MHz deep, and it supports approximately ten vibrational bound levels, three of which are indicated on the figure along with their radial wave functions. Attached to each nd dissociation threshold are additional potential curves that are not shown. Because these electronic states are dominated by Π or Δ character and vanish on the internuclear axis, they remain unshifted from their atomic energies in this Fermi n -wave approximation.

While this molecular state has no net electric dipole moment, it has a huge polarizability of order n^7 a.u. Modest laser power should produce these molecules in ample numbers. Also, in a typical condensate, the rate of inelastic transitions in the excited Rydberg level should be slow compared to the vibrational frequency.

The $n = 30$ potential curve of the perturbed hydrogenic class is shown in Fig. 1(b), and its associated electronic wave function is presented in Fig. 2. Its striking nodal pattern is reminiscent of a trilobite. Interactions with the perturbing atom split away just one such state from the quasidegenerate manifold of high- l states [7–10], which for Rb includes $l \geq l_{\text{max}} = 3$. Neglecting the small quantum defects of all $l \geq 2$ states, the lone perturbed adiabatic potential curve is given in terms of radial hydrogenic wave functions $R_{nl}(R)$ evaluated at the location of the Rb($5s$) perturber:

$$U_d(R) = -\frac{1}{2n^2} + 2\pi A_Z [k(R)] \sum_{l=0}^{l_{\text{max}}} \frac{2l+1}{4\pi} R_{nl}(R)^2. \quad (2)$$

This can be approximated [8] as $U_d(R) \approx -1/(2n^2) + A_Z [k(R)] [2/R - 1/n^2 - (A_{\text{max}} + \frac{1}{2})^2/R^2]^{1/2}/\pi n^2$.

The perturbed hydrogenic potential curves are approximately 2 orders of magnitude deeper than their low- l counterparts at $n = 30$. The low levels have roughly tenfold higher vibrational frequencies. The $n = 30$ potential curve in Fig. 1(b) supports approximately 70 vibrational levels. The potential curve depths decrease with n as $n \approx 3.5 \times 10^5 \text{ GHz}/n^2$. Moreover, in contrast to the low- l class, the sum over degenerate states now includes functions with opposite electronic parities, which is why the electronic wave function now peaks close to the perturbing atom. This class of states has a large electric dipole moment, $D \approx R - \frac{1}{2}n^2$ a.u. as mentioned earlier; the equilibrium value of R increases from 1232 a.u. at $n = 30$ to about 3000 a.u. at $n = 70$, roughly linearly with n . This translates into $D \approx 0.313 \text{ kDebye}$ (782 a.u.) for the states of Figs. 1(b) and 2.

Figure 3 proposes two different experiments to access these unusual molecular Rydberg states. One-photon excitation of an np level could also be replaced by a two-photon resonant or near-resonant process, to create a molecular Rb(nd) + Rb($5s$) state of the type shown in Fig. 1(a). The electric dipole selection rule requires more photon steps to reach the degenerate hydrogenic (trilobite) states composed of high $l \geq 3$. Accordingly, the second experiment might use a microwave photon to induce a transition from a laser-excited nd state. Alternatively, application of a weak electric field might circumvent the dipole selection rule. Pulsed field ionization could be used to detect the excited Rydberg states.

One important question is whether the Fermi model can predict these Born-Oppenheimer potential curves to adequate accuracy. Previous calculations suggest that this is a reasonable assumption for the purposes of




FIG. 2. A cylindrical coordinate surface plot of the electronic probability density, $2\pi\rho|\psi(\rho, z, 0)|^2$ and $2\pi\rho|\psi(\rho, z, \pi)|^2$, is displayed for the lowest Born-Oppenheimer state shown in Fig. 1(b). This "trilobite-resembling" density corresponds to the equilibrium internuclear distance $R = 1232$ a.u. for this $n = 30$ $^2\Sigma$ perturbed hydrogenic state. The position of the Rb($5s$) atom is directly underneath the "twin towers" centered at $R = 1232$ toward the right side of the figure, while the Rb⁺ ion is represented (with exaggerated size) as a small white sphere on the left. The region with appreciable density includes $z \in [-700, 700]$ and $\rho \in [1200, 1200]$.

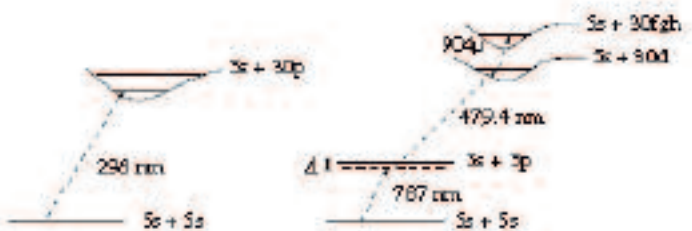


FIG. 3. Two experiments that could observe these different classes of molecular Rydberg states. The left one depicts a direct one-photon excitation of an np molecular state. The scheme on the right uses two photons to reach a high nd Rydberg state, followed by an additional microwave step to reach a perturbed hydrogenic state.

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The creation of the "Atom Corral": the corral in the form of clay



The creation of the "Atom Corral": the rubber mold and plaster mother mold in the background

From "C. Greene, A. S. Dickinson, H. R. Sadeghpour, Physical Review Letters 85, page 2458 (2000)"