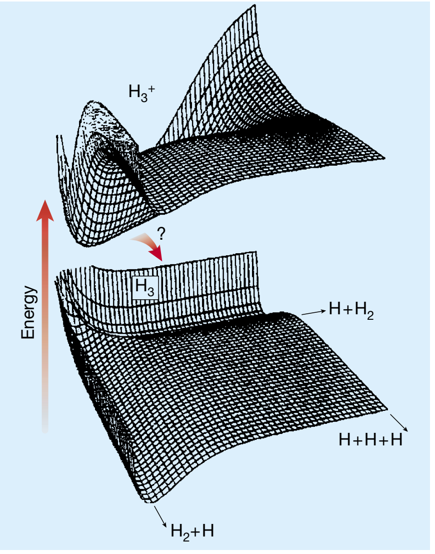

Figure 1 **Bridging the gap between theory and experiment. Values for the destruction of interstellar H_3^+ ions by low-energy electrons (dissociative recombination) differ widely between calculations and measurements. The potential energy surfaces for the ground states of H_3^+ and H_3 molecules are separated by a large energy gap, which makes the dissociative recombination of H_3^+ difficult to explain by usual mechanisms. Kokoouline *et al.*[1] include a previously ignored decay mechanism in their new calculation, which allows the efficient fragmentation of H_3 (formed from $H_3^+ + e^-$). (Figure reproduced from ref. 9.)**

experimentalists, theoreticians and astronomers to pin it down. First, the experimental value for the rate of H_3^+ destruction by low-energy electrons has ranged over several orders of magnitude, depending on the method used to measure it. The most recent measurements converge towards a relatively fast rate constant, but the ion-storage-ring value[4,5] of about 10^{-7} cm^3 s^{-1} still differs by one order of magnitude from the result[6] obtained using a flowing-afterglow Langmuir probe (10^{-8} cm^3 s^{-1}).

Second, using the higher destruction rate from the storage-ring data, astrophysical models[3] cannot explain the large abundance of H_3^+ ions observed in diffuse interstellar clouds, which have high electron density. As a result of the rapid destruction of H_3^+, the measured abundance would require stable molecular clouds to be unreasonably large. At most, present astrophysical models can accept the slower rate constant of 10^{-8} cm^3 s^{-1}.

Third, reaction (1) has long been considered theoretically impossible for the very cold electrons in the interstellar medium. In the conventional 'Born–Oppenheimer' approximation of molecular physics, which treats separately the fast electronic processes and the slow dynamics of the heavy nuclei, an efficient fragmentation of the $\{H_3^+ + e^-\}$ complex is expected to occur only if it has a similar electronic energy to a dissociative state of the neutral H_3. But the potential energy well of the H_3^+ ground state lies far above the repulsive potential surface of the neutral H_3 ground state, the only path to dissociation at very low energy (Fig. 1).

The gap between theory and experiment began to narrow when theorists realized (from studies on diatomic ions[7] such as HeH^+) that dissociative recombination can be helped by dynamical couplings between electronic and nuclear motion, beyond the Born–Oppenheimer approximation. The reaction can then proceed in steps, through a series of H_3 bound excited states, whose potential energy surfaces mimic that of the H_3^+ ground state and span the energy gap between it and the dissociative H_3. A two-dimensional calculation[8] including this mechanism led to an H_3^+ destruction rate close to 10^{-9} cm^3 s^{-1} at very low temperature. This value is acceptable for astrophysical models but is still far below the rates observed experimentally.

Kokoouline and colleagues[1] take a decisive step towards resolving this puzzle by identifying a previously neglected decay mechanism. This mechanism also involves a coupling between electronic and nuclear motion, but requires a full three-dimensional treatment of the nuclear dynamics. The Jahn–Teller effect results from the combined vibration and rotation of the three hydrogen nuclei when distorted by the incoming electron from their equilibrium positions in the ground state of H_3^+. The authors show that this symmetry-breaking effect induces a cascade of energy-reducing transitions that may raise the rate of reaction (1) up to a value of 10^{-8} cm^3 s^{-1}, compatible both with recent astrophysical models and Langmuir-probe experiments. Moreover, the effect should increase for rotationally hot H_3^+ target ions, perhaps explaining the larger value measured in storage-ring experiments. The new calculation[1] not only reproduces the tendency for interstellar H_3^+ to break up into three rather than two fragments, but also correctly predicts the vibrational energy of those fragments. A complete quantitative treatment is still required, but the main destruction mechanism for interstellar H_3^+ has now almost certainly been identified. ■

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Daedalus

A cosmic background

One of the most significant discoveries in cosmology is the cosmic microwave background, or 'relic radiation' as the Russians call it. Originally, in the early Universe, it was visible light. But the Universe has expanded so much since then that its frequency has been shifted down all the way to the microwave band, a frequency drop of perhaps 10^5 or so.

Last week Daedalus proposed a directional neutrino telescope, underground as usual to filter out competing particles, but consisting of a tube many metres long. It would be filled with a liquid such as dry-cleaning fluid or heavy water, as used in dedicated neutrino detectors. For some liquids it would be covered with photomultipliers. There would be several telescopes. Giving each some spectroscopic resolution, they could even estimate neutrino energies. Each tube would be sensitive to neutrinos mainly in its long direction, in which they would traverse it from end to end, and so had the best chance of interacting with its contents.

Seeking new uses for his device, Daedalus now reckons that the early Universe should also have created plentiful neutrinos, by the combination of protons or the commonest helium nuclei. As the Universe expanded, these 'relic neutrinos' will have lost energy. By now they should have formed a fairly uniform cosmic background. His directional neutrino telescope will therefore slowly establish that background, and distinguish it from that of the Sun.

It will take many years to sample this very weak neutrino background. But there are very few pieces of information in cosmology (the microwave background is one of them), so the slow effort seems worthwhile. It might even identify a neutrino flux from the nearer stars — Sirius is perhaps the best bet, although Alpha Centauri is nearer. But Daedalus will aim his device in the stellar gaps, especially out of the galactic plane, so as to acquire a true background. There might be surprises, of course. All previous neutrino astronomy has used detectors with no directionality, so it would be intriguing to discover that many neutrinos were coming from some concentrated source.

Indeed, Daedalus would like his telescope to found a whole new branch of astronomy. But he freely admits that the very low rate of data acquisition will greatly restrict the rate at which DREADCO can transform cosmology. David Jones