

the reacting molecules, which are incredibly fast — typical vibration periods are 10–100 femtoseconds. (One femtosecond is  $10^{-15}$  seconds, which is to a second what a second is to 32 million years.) It was not possible to observe such reactions in real time until the development of femtosecond laser pulses. In one type of experiment, two laser pulses are used to monitor the molecular motions. The first 'pump' pulse excites the molecule to a higher energy state with a particular type of motion, and the subsequent 'probe' pulse examines what is happening.

In Frohnmeyer *et al.*'s experiment<sup>14</sup>, the probe pulse is also used to ionize the excited molecule, producing an electron. The amount of energy carried away by this electron depends on the separation of the atoms in the molecule. By varying the delay between the two pulses, Frohnmeyer *et al.* are able to record the motion of the sodium atoms in the excited molecule. Moreover, by increasing the intensity of the probe pulse they observe systematic changes in the bonding between the sodium atoms, which is one way of using femtosecond pulses to control chemical reactions.

One of the most interesting and rapidly advancing uses of active control of molecular dynamics is for product selection in a branching chemical reaction (Fig. 1). Most chemical reactions produce more than one product, and the art of synthetic chemistry is devoted to improving the yield of the desired product. Some desired products can only be produced with difficulty and with poor yield using conventional methods. If the reaction could always be channelled towards that product, the efficiency of synthesis would be greatly enhanced. Advances in femtosecond lasers in the past five years, especially in the technology for shaping laser pulses with respect to spectral content, phase distribution and temporal shape, have made such control possible for simple reactions.

So far, control of product selection using timed pulses has already been demonstrated for branching between photo-fragmentation and photo-ionization of the sodium dimer<sup>11</sup>. A different control method has been used to select between the competing processes of photo-fragmentation and photo-ionization of hydrogen iodide<sup>12</sup>. In this case, interference between optical fields used to excite two independent transitions between the same initial and final states was exploited to control product selection. In another experiment, different excited states generated by the photo-fragmentation of the sodium dimer were selected by generating coherent (in-phase) oscillations of population between a small set of molecular levels<sup>15</sup>. Finally, control of bond breaking in a polyatomic molecule using an optimally phase-controlled pulse has been demonstrated for the competing formation of  $\text{FeCl}^+$  and  $\text{CpFeCOCl}^+$  from the photo-

fragmentation of  $\text{CpFe}(\text{CO})_2\text{Cl}$  (Fig. 1)<sup>13</sup>.

Although our understanding of the requirements for active control of molecular dynamics is well founded, there remain many fundamental questions that must be addressed. For example, is there a fundamental limit to the control of many-body quantum dynamical processes? How does the efficiency of a control method depend on the number of possible motions of the controlled molecule? And how sensitive is the control field to source fluctuations, other experimental imperfections and uncertainties in the molecular potential energy? To what extent is control of molecular dynamics possible when dissipation of energy must be accounted for, as when the reaction is carried out in solution? Moreover, is it possible to control collision processes, so as to affect the choice of products in a bimolecular reaction<sup>16</sup>?

The existing theories and experiments only hint at what will be possible in the future. For some time to come, applications using control of molecular dynamics are likely to be most important as tools for learning more about molecular dynamics and for testing and developing better theories. But as laser technology improves, and our understanding of complex molecules advances, practical applications will be developed. In the short term, the most likely applications will be in optoelectronics — we have already seen optical control of the microscopic state of a quantum dot<sup>17</sup> and of a fast semiconductor switch based on interference between optical excitation pathways<sup>18,19</sup>. What next for control of molecular dynamics? ■

Stuart A. Rice is at the James Franck Institute, University of Chicago, 5640 South Ellis Avenue, Chicago, Illinois 60637, USA.

e-mail: sarice@rainbow.uchicago.edu

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## Daedalus

### Perfect dryness

Daedalus once devised a mist-proof plastic for lenses, windows, and so on. He charred its surface with a laser and treated it with fluorine, converting it to graphite fluoride, the most water-repellent substance known. Water drops simply could not adhere. He now plans to extend the idea to wood, leather and similar organics.

Such materials are porous. Water does not merely condense on them; it penetrates, and acts as a medium for biological decay. But how to char their vast internal porosity with a few monolayers of graphite?

Strong sulphuric acid is notorious for charring organic materials. It abstracts the elements of water from their molecules, leaving carbon. Sulphur trioxide, says Daedalus, is in effect dehydrated sulphuric acid. It should extract hydrogen and oxygen from organics even more avidly. Being easily volatile, it could permeate into the most porous material. Dilution with inert gas could limit its charring action to a few monolayers of surface. Diluted fluorine would then convert the graphite to its fluoride. All internal porosities, however complex, would be perfectly waterproofed.

DREADCO chemists are now trying it. They are exposing oars, pairs of boots, plywood shingles, woollen socks, carpets and similar objects to sequences of vapours in a large pressure-vessel. When the process has been perfected, these products will emerge utterly waterproof. Even under high pressure, water will not wet them, let alone enter their pores. But like lesser 'breathable' waterproof fabrics (some of which are also based on fluorocarbon polymers), they will still be freely permeable to air and water vapour.

This elegant process will transform many technologies. The British building industry is dominated by fear of wood-rot. The first waterproofed, unpainted wooden buildings, flaunting their appealing natural grain against the now impotent weather, will arouse amazement and disbelief. So will truly waterproof boots, fabrics that need no washing (and indeed cannot be washed — water, like dirt, simply falls off them), and wooden boats that slip unwetted through the water. Daedalus even hopes to waterproof human skin. A waterproof swimmer would break all Olympic records. The slow renewal of the skin would gradually remove the coating.

David Jones

*The Further Inventions of Daedalus* (Oxford University Press), 148 past Daedalus columns expanded and illustrated, is now on sale. Special *Nature* offer: m.curtis@nature.com