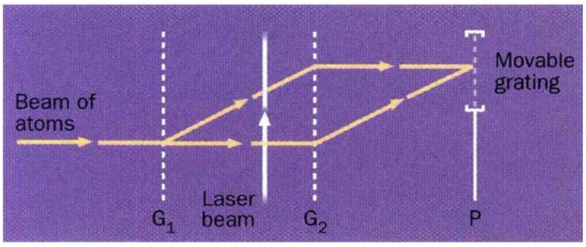

FIG. 2 The experiment uses an interferometer consisting of two parallel diffraction gratings G_1 and G_2. There are two different ways that atoms can move from the first grating to a plane P beyond the second grating. In this plane there is a pattern of interference between the two beams. As in the two-slit experiment, this interference pattern would not be possible if each atom took one definite route through the apparatus. It is possible to observe the atoms by shining a laser beam on them as they pass between the first two gratings, and focusing the scattered light to show which path the atom was on. Chapman *et al.* show that the pattern is indeed destroyed, even though in their experiment the light was not actually focused: it is enough that it could have been. (Figure adapted from ref. 2.)

The experiment of Chapman *et al.* does not have two slits, but it retains the essential feature that the beam of atoms is split into two parts that move along different paths and show an interference pattern when they are recombined, the interference being lost when the atoms are observed by means of a laser beam to see which way they went (Fig. 2). The third stage of the dialogue, the effect of reducing the frequency of the light until its wavelength is greater than the separation between the two possible paths, was realized in a different way: the frequency of the light was kept the same, but the path separation was changed by moving the laser beam. As predicted by Feynman, the interference is present when the wavelength of the light is longer than the separation between the paths, and is progressively lost as the separation increases.

But there is a surprise: the interference is restored again as the separation increases still further. This can be seen as an effect of optical diffraction. A single photon of wavelength λ can give information on which of two point objects scattered it if the separation of the objects is $\lambda/2$, but not if the separation is $3\lambda/4$, because we cannot then tell whether the photon is arriving at the screen in the centre of the image of one of the objects or in the first diffraction ring surrounding the image of the other object.

Even when the atoms are observed when the two paths are well separated, so that the scattered light potentially contains definite information about the path, it is still possible to restore the interference pattern. In order to collect the information the light must be focused, which makes it impossible to know its direction of travel. Conversely, measuring the direction of the scattered photon destroys the information about the path of the atom. Chapman's group modified their experiment so as to do something equivalent to this, and found that those atoms which scattered the photons in any particular direction fell into an interference pattern. The patterns associated with different photon directions had different phases, so that the overall appearance was of no interference.

This illustrates a general feature of quantum measurement processes. Before a measurement is made on a system, several different potential results coexist in a delicate balance; the measurement affects the system by apparently destroying this balance, or 'coherence'. In the two-slit experiment, observing the path of the particle destroys the coherence which makes the interference pattern possible. However, the coherence is not really lost: it has been extended to involve properties of the measuring apparatus — the apparatus and the system are said to be 'entangled'. If the apparatus is large and complicated, its state cannot be known in sufficient detail to reveal this coherence. In the experiment of Chapman *et al.*, however, the apparatus could be taken to be the single photon that scatters off the atom, and the coherence in the extended system consisting of the photon and the atom is revealed in the interference patterns associated with photons moving in particular directions. In general, one can always delay the loss of coherence until one has made a further observation on the measuring system. This is von Neumann's principle of the arbitrariness of the boundary between the observed system and the observing apparatus.

A slight extension of the experiment pushes one uncomfortably close to paradox. In principle one could delay the observation of the photons, and the decision whether to focus them or measure their direction, until after the atoms had formed their pattern. Then one and the same pattern could be interpreted either as the sum of two non-interference patterns formed by atoms which went along the two different paths, or as the sum of many interference patterns formed by atoms which could not be said to have gone along either of the paths. Einstein would not have been happy. ☐

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1. Feynman, R. P., Leighton, R. B. & Sands, M. L. *The Feynman Lectures on Physics* Vol. 3, 1–4 (Addison-Wesley, Reading, 1965).
2. Chapman, M. S. *et al. Phys. Rev. Lett.* **75**, 3783–3787 (1995).

DAEDALUS

Smooth reactions

Heat, the most fundamental tool of chemistry, is a very blunt instrument. It accelerates all reactions, particularly useless and destructive ones. Even with the aid of catalysis, the oxidation of ammonia to nitric oxide is always liable to go to valueless nitrogen, while that of ethylene to ethylene oxide may run away to carbon dioxide. And who knows what you might get by heating gunpowder if it didn't explode first?

Heating, of course, is simply an uncontrolled bombardment by thermal phonons of all energies. Last week Daedalus devised a novel monochromatic 'tuned heat' whose phonons all had the same energy. He generated it by hitting the sample with a uniform electron-beam of precisely defined energy. He now argues that tuned heat should be ideal for promoting specific chemical reactions. It could give the molecules the precise activation energy needed for one desired reaction, while leaving side-reactions unexcited. DREADCO's chemists are trying it. They are beaming monochromatic phonons into a wide variety of reaction mixtures. By accurate tuning, they should be able to promote just one reaction out of many. Competing reactions, including that bugbear of all chemistry, general thermal decomposition, will be left out in the cold. With their competitors frozen out, even previously impossible reactions could be tickled along nicely.

One reaction crying out for this treatment is depolymerization. Even pure polymers cannot usually be turned back to the original monomer. A mixture of plastic waste seems even more hopeless. But properly tuned heat could activate one depolymerization at a time. All the polystyrene (say) in the mixture could be converted neatly to styrene, and distilled off to be used afresh. A quick change of tuning could then unzip the PVC to vinyl chloride, then the polythene to ethylene gas, and so on in sequence. Other waste materials could be reclaimed by selectively tuned hydrolysis. Wood waste could go to glucose and lignin monomers, and motor oil to alcohol.

Tuned heat should also tame that jungle of thermal decomposition, cooking. Normal heat promotes pleasant and acrid flavours, browning and charring, tenderizing and toughening, all at once. High skill is needed to get the best from the raw material. But the DREADCO tuned oven will coax entrancing flavours, textures and shades from the cheapest and most unpromising ingredients — even vegetarian. Hopeless cooks everywhere, and the unscrupulous barons of the food processing industry, will rejoice.

David Jones