Richard Phillips Feynman (1918–1988)

RICHARD FEYNMAN, who died on 15 February, was one of the greatest physicists since the Second World War and, I believe, the most original. He won the Nobel prize for physics in 1965 for his work on quantum electrodynamics (QED). In 1948, simultaneously with Schwinger and Tomonaga (with whom he shared the prize), he showed that QED can be renormalized, removing infinities, so that it gives finite results for all observable quantities. Schwinger and Tomonaga did this by building on existing theories in an ingenious way. Feynman invented a completely new method of treating the Schrödinger (or Dirac) equation. This was typical of Feynman's physics: he always had his own way of looking at and solving a problem.

Both methods were essential: Schwinger's immediately convinced quantum theorists, because it connected with previous knowledge. Feynman's seemed abstruse at first and Niels Bohr, for instance, found it hard to accept, but it soon became clear that it enormously simplified concepts and calculations. Only by these methods was it possible to extend theory to increasingly complicated problems and quantum electrodynamics to fabulous accuracy: the magnetic moment of the electron has now been calculated to an accuracy of 1 part in 10^8, and measured to a similar accuracy.

Feynman also developed, in 1953, a fundamental theory of liquid helium, justifying the earlier theories of Landau and Tisza. Because ^{4}He atoms are Bose particles, having spin zero, the ground-state wavefunction of a mass of liquid helium is symmetrical in all the particles and everywhere positive. There is only one such wavefunction, and the entire mass of helium behaves as one unit. This is why helium near 0 K is superfluid, showing no viscosity. At low temperature, pressure waves are the only possible motions in the liquid. At a higher temperature, about 0.5 K, it becomes possible for a small ring of atoms to circulate without other atoms being much disturbed; these are the 'rotons' of Landau theory. Feynman showed why the energy of a roton is minimum at a certain wavelength and that this wavelength is closely related to the average distance of helium atoms from each other.

To make a roton takes energy, therefore their number increases with temperature. They also interact with each other and thus show viscosity. An assembly of rotons therefore behaves much like a normal liquid, and moves independently of the superfluid. Helium may be regarded as a mixture of superfluid and normal liquid. When the concentration of normal liquid becomes too big, there is a phase transition in which the whole liquid turns 'normal'.

Feynman's work on the nuclear weak interaction is also of fundamental importance. In 1956, Lee and Yang concluded that parity symmetry is not conserved in weak interactions, and this was soon confirmed experimentally by Wu and others. On the basis of experiments, physicists concluded that the violation of parity is the maximum possible. This stimulated Feynman and Gell-Mann to postulate that only the left-handed part of the wavefunction of a particle is involved in weak interactions. They postulated, in fact, that this was true not only for the neutrino, but for any particle, electron, muon and even composite particles like protons and neutrons. They also proposed that the weak interaction is universal: all particles interact and with the same strength. This theory permitted many conclusions, nearly all of them agreeing with experiments. One experiment at first seemed to disagree, but when repeated more carefully, agreed with the Feynman–Gell-Mann theory. The concept of chirality, left- or right-handed spin, turns out to be extremely fruitful in particle theory.

Experiments in the late 1960s on the scattering of high-energy electrons by protons at the Stanford Linear Accelerator showed very large inelastic scattering. Feynman soon concluded that smaller units were contained in the protons which he called partons, and that these collided elastically with electrons. The partons were soon identified with the quarks deduced from general theory, and one of the important tasks of particle physics has been the determination of the distribution of quarks in proton and neutron. Feynman's attempts to understand quantum chromodynamics, the theory of parton interactions, were characteristically individual, especially his treatment of the confinement of quarks in hadrons. But his long struggle with abdominal cancer cut this work short.

Feynman enjoyed all life, and he lived in physics. He was able to transmit his enthusiasm to others, his colleagues and his students. He was beloved by my children, then 2–6 years old, for whom he babysat many times while he was at Cornell. It helped that he was also a clown. Once, when he was explaining nuclear fission at a high school, he did it simultaneously to two classes, standing in the doorway drawing pictures on two blackboards simultaneously with his right and left hands.

Feynman's approach was always direct, to life as to science. He disliked pompous people and made fun of them, but usually gently so as not to hurt them. His uncanny ability to get immediately to the core of a problem became well known when he sat on the commission to investigate the Challenger disaster and demonstrated the central problem simply by dropping a rubber O-ring into a glass of ice water.

In physics he always stayed close to experiment, and had no interest in esoteric theories. The three volumes, *The Feynman Lectures on Physics*, which tie the elementary problems of physics with the most advanced ideas, exemplify this. More than other scientists, he was loved by his colleagues and his students.

H.A. Bethe

H.A. Bethe is at the Newman Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14853, USA.

Molecular evolution

How old is a polymorphism?

Jonathan C. Howard

PERHAPS because the mathematics of classical population genetics entail the assumption of continuous interbreeding populations, polymorphism is often considered to be a within-species affair. If this were so, mutations which generate the allelic forms of polymorphic genes must have occurred within the lifetime of a single species, and variant forms of genes pre-existing in the ancestral population must not survive the speciation event. There is not a shred of evidence in favour of this position, and it is difficult to find a rational argument to support it with either. As all studies of wild populations show extensive heterozygosity at multiple loci, it is inconceivable that a founder population, no matter how small, will not transmit old alleles to new species. Speciation events may well involve striking changes in allelic frequencies because of founder effects and new patterns of selective pressure, but that new species enter the world already polymorphic can hardly be disputed. This conclusion is not, of course, the same as saying that all polymorphism is ancient, only that some of it must be, and that arguments that depend on transmission of allelic forms through speciation events are not necessarily wrong.

On page 651 of this issue[1], McConnell *et al.* present direct evidence for trans-species polymorphism in the major histocompatibility complex (MHC) of the mouse. Even if the sound *a priori* argument above were not enough, several features of MHC polymorphism make trans-species transmission incomparably