Where *Zitterbewegungen* may lead

There is a valuable place for journals a little to the side of orthodoxy that allow people to explore unfashionable themes. Even classical explanations of quantum mechanics have great interest.

IN the 1940s and for some years afterwards, *Il Nuovo Cimento* was among the hottest of physics journals, if only because page charges (and currency exchange controls) prevented Europeans from using *Physical Review* except in the most exceptional circumstances. In those times, the Japanese had *International Journal of Theoretical Physics*, in which Tomanaga provided his distinctive counterpoint of the work of Schwinger, Feynman and Dyson on quantum electrodynamics.

Much of that changed with the founding of *Physical Review Letters* (by the American Physical Society and the late Samuel Goudsmit). *Il Nuovo Cimento*, now part of the European Physical Society's loose aggregation of journals, is now perhaps best known as one of the places in which Enrico Fermi used to publish. But it has also become a unique and valuable outlet for ideas on the edge of orthodox physics, and for that reason deserves more attention than it usually receives.

One recent issue, for example, contains no fewer than two articles taking as their starting-point the phenomenon of the "*Zitterbewegungen*", most tangibly that by means of which Pauli sought to provide a classical view of the origin of electron spin, but also a means by which people such as Schrödinger in the 1920s hoped to reconcile classical and quantum mechanics. *Zitterbewegungen* means 'shaking' or 'flickering' motion, and refers to the phenomenon by which particles subject to the uncertainty principle may be supposed to be constantly in motion on an unobservably microscopic scale. Several attempts to effect the reconciliation failed, yet by the early 1930s it was clear that the Schrödinger version of Dirac's relativistic equation for the motion of an electron implied that the instantaneous velocity of an electron could have only the velocity of light and its numerical opposite.

G. Cavallieri from the University of Brescia has for some time been carrying a torch for this approach to quantum mechanics; in 1985, he published such a derivation of Schrödinger's equation for a single particle. Now, with G. Spavieri of the Venezuelan University of the Andes, he has done the same for the many-body problem (*Il Nuovo Cimento* **95B**, 194; 1986) in a way that makes it possible to understand why previous attempts failed.

The starting point is the view that electron spin, and the magnetic moment that goes with it, is the electromagnetic consequence of the random motions; unpolarized electrons move randomly in all directions, but the axes of the instantaneous circular motions of partly polarized electrons are restricted. Cavallieri likens *Zitterbewegungen* to the case of a rocket equipped with an infinitely large number of motors pointing in different directions which, by being fired at random, change the instantaneous direction of the velocity of the vehicle. It is essential to his case that this strictly inertial process is distinct from that, say, in Brownian motion, where changes of direction are brought about by interaction with the environment (an unsuccessful way of seeking a classical explanation for quantum mechanics).

The manipulation of these assumptions is uncomplicated. The trick is to calculate the probability density of an electron diffusing by these principles in some external field of force. The eventual result is Schrödinger's equation, but with the reservation that there is no way, at least for the time being, of calculating the numerical constants that arise, in particular quantities such as $h/2m$ where h is Planck's constant and m the mass of the electron. The latest development, with Spavieri, is the extension of this calculation to a system of several identifiable particles.

Naturally, none of this amounts to a classical derivation of Schrödinger's equation. Even Cavallieri would not claim that, for the starting assumption of *zitterbewegungen* has no place in classical mechanics. In a sense, what this calculation has done is to lend a degree of tangibility to Pauli's old notion that would not otherwise have been just. Devotees of *Il Nuovo Cimento* will recognize this to be their journal at its most sober.

B. L. Cragin from the Center for Space Sciences at the University of Texas at Dallas goes to the other extreme (*ibid.* **95B**, 109; 1986). He starts with the observation by Dirac (*Nature* **139**, 323; 1937) that there are more "fundamental" constants than required to specify physical dimensions, with the consequence that it is possible to construct a set of dimensionless numbers from their ratios, but whose physical significance is unknown. The best known ratio is the fine-structure constant α (equal to $2\pi e^2/hc$, where e is electron charge, h Planck's constant and c the velocity of light) which is, numerically, approximately 1/137.

Cragin sets out to calculate what these numbers are from the assumption that the microscopic *Zitterbewegungen* are also related to what are called the fluctuations of the vacuum in quantum electrodynamics. To put it crudely, the starting-point is the expectation that empty space is a kind of plasma consisting of the pairs of electrons and positrons that will be created whenever and wherever the fluctuations of the energy density of the field are sufficient to cause them to appear. For consistency, the microscopic motions with velocities $\pm\, c$ of each particle in the vacuum must both drive the plasma and be driven by it. There follows a classical calculation of the conditions that must be satisfied.

Sceptical readers will by this stage be asking "to what end?". Patience. The nub of the result is an equation roughly relating α^{-1} with $-(2/\pi)\log(2\alpha^2\alpha_g^2)$ where α_g is the other dimensionless ratio $2\pi Gm/hc$, numerically equal to 1.751×10^{-2}. And the outcome is a value for the inverse of the fine structure constant that is correct to five significant figures.

Perhaps one should not be too much awed by the accuracy with which the fine-structure constant emerges from these calculations, in the course of which Glazer has explicitly decided to neglect several factors such as the 4/3 that normally precedes the usual expression for the volume of a sphere. He says himself that the agreement may be fortuitous. The crux of his argument is merely to be able to show some kind of a connection between the fluttering motion of an electron (and its partner positron) and the fluctuations of the vacuum even when there is no added energy (the zero-point fluctuations as they are called). Glazer is also anxious to make the point that his calculation of two non-dimensional ratios, one of which involves electric charge and the other the gravitational constant, is a sign that the same phenomena may link gravity with electromagnetism, a now-fashionable aim.

There are two views of these kinds of arguments, one of which is that, being founded on a bastard mixture of classical and quantum physics, they are merely means of exploring for consistency the dimensionality of the quantities involved. It is better than numerology, but, the purists would say, not much. But that may be too narrow. The arguments are entertaining, and they may have what is called heuristic value as well. Anyway, Cragin promises more, no doubt also in *Il Nuovo Cimento*. **John Maddox**