Nobel Prizes 1998

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The 1998 Nobel prize for physics was awarded to three researchers from the US: Robert Laughlin (Stanford University), Horst Störmer (Columbia University and Bell Labs) and Daniel Tsui (Princeton University). They were cited "for their discovery of a new form of quantum fluid with fractionally charged excitations" which is realized in the Fractional Quantum Hall Effect.

The ordinary Hall effect was discovered more than 100 years ago: passing a current through a piece of metal in the presence of a magnetic field produces a Hall voltage which is perpendicular to both current and field. In 1980 Klaus von Klitzing (Nobel prize 1985) studied the Hall effect in semiconductor structures which confine the electron motion to a two-dimensional layer. At high magnetic fields (above 1 Tesla) and low temperatures (below 1 K) he found a step-wise dependence of the Hall resistance on the applied magnetic field. The step height, h/e^2, contains two fundamental constants only, the electric charge e and Planck's constant h; moreover, the steps are quantized to such a high precision that metrological institutes are now using this quantum Hall effect to define the resistance standard.

Störmer (born in Germany in 1949) and Tsui (born in China in 1939) extended von Klitzing's experiment using higher fields, lower temperatures, and cleaner samples. To everyone's surprise they found additional steps in the Hall resistance. This phenomenon was termed the Fractional Quantum Hall Effect (FQHE). What seems at first sight to be a slight modification of von Klitzing's integer effect turns out to be something entirely different: whereas the integer effect is essentially due to the quantization of the electron's kinetic energy in a magnetic field, Coulomb interactions are the underlying cause of the FQHE.

Within one year of this discovery the theoretical physicist Laughlin (born in the US in 1950) managed to explain the most important features of the FQHE. He showed that the additional fractional steps were due to a new ground state of the electron system, which is a new type of "quantum liquid." We already know a number of quantum liquids in many-body physics, each characterized by its own set of fascinating and surprising properties. One example is the superconducting state which occurs at low temperatures in many metals, leading to the flow of electrical currents without resistance. In the superconducting state the electrons condense to form new "particles", the so-called Cooper pairs. In the FQHE ground state, a similar condensation occurs: the electrons combine with an odd-integer number (*eg* 3) of magnetic flux tubes, in other words quantized parts of the applied magnetic field.

The observable physical properties of a many-body system (such as the FQHE system) are determined not solely by its ground state but by its low-energy excitations (often called quasiparticles). The excitations of the FQHE turn out to have an electrical charge which is a fraction (*eg* 1/3) of the elementary charge. The fractional steps were already a good indication that fractional charges might appear in the system. A more direct experimental proof has been found in recent years by studying the current noise, *ie* small deviations from the average current through quantum-Hall samples. Current flow will be more regular if the charge of the current-carrying particles is small, in other words if the flow is less "granular". Indeed, the intensity of the shot noise in FQHE samples was found to be 1/3 of its value in ordinary samples—which indicates the existence of quasiparticles carrying 1/3 of an elementary charge.

The Nobel prize for chemistry was awarded to two US scientists: Vienna-born (1923) theoretical physicist Walter Kohn, of the University of California in Santa Barbara, and quantum chemist John Pople at Northwestern University (near Chicago), who was born in Britain in 1925. The Prize was awarded for the development of theoretical and numerical methods which can be used to predict the structure and electronic properties of molecules and solids.

Using the laws of quantum mechanics, namely the Schrödinger equation, it is "in principle" possible to calculate the conformation (geometry) and other properties of chemical compounds: the techniques used to do this go under the name of quantum chemistry. In practice, however, the resulting equations are too complicated to be solved for anything but the simplest systems, such as the hydrogen atom. During the sixties Kohn and his co-workers showed that the exact equations, taking into account all the electrons in a molecule (or solid) can be replaced by simpler equations in which only the density of electrons at each point in space enters. This "density-functional theory" (combined with an approximation scheme for the dependence of the interaction energy on the electron density) is a substantial simplification and allows the treatment of large molecules containing thousands of electrons.

Around 1970 Pople developed a computer code based on Hartree-Fock theory, which gained great popularity among chemists. After being improved and modified many times, present-day versions of Pople's program package now include methods drawn from density-functional theory. This theory, and the numerical methods which depend on it, have changed quantum chemistry profoundly. It is now possible to calculate not only the structure of chemical compounds (*eg* bond lengths or angles) but also chemical reaction paths. Quantum chemistry has acquired predictive power: it is no longer necessary to try many possibilities to synthesize a chemical compound in the laboratory. The possibility of developing, for example, new enzymes and pharmaceutical products using these computational methods is becoming increasingly important.

In a sense, the 1998 Nobel prizes for both physics and chemistry were awarded for contributions to the quantum physics of condensed-matter systems. Whereas all of these systems consist of the same elementary building blocks (electrons, protons, and neutrons) their interactions produce the complexity of our physical world, from the semiconductors used in computers, through snow flakes, to biological systems. Many of these systems show completely new and fascinating properties, like the fractionally charged excitations in the FQHE—and there is no doubt that quantum physics has other surprises in store for us.

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