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Nobel Prize in Physics 1944

Isidor Isaac Rabi

The Nobel Prize in Physics 1944 was awarded to Isidor Isaac Rabi *"for his resonance method for recording the magnetic properties of atomic nuclei"*.

RESEARCH INFORMATION:

There is a certain relation between electric and magnetic phenomena in that the magnetic field can generally be ascribed to the presence of electric currents. It was in this way that the famous Ampère sought to trace magnetism back to rotary currents of electricity in the particles of matter, the atoms and molecules. This hypothesis has in fact been confirmed, *inter alia* by spectroscopical investigations into light sources placed in very strong magnetic fields. However, certain difficulties arose when it came to accounting in detail for the influence of the magnetic field on the movement of electrons, which here represents the electric currents in the interior of the atom. For the electrons proved disinclined to obey the electrodynamic laws which have otherwise so brilliantly demonstrated their validity in, for instance, the field of electrotechnics. *Inter alia*, it seemed as if the small, freely moving atomic magnet in the source of light was only capable of assuming certain discrete local positions in relation to the direction of the applied field. I

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shall start, then, with a reference to an experiment which for the first time revealed this remarkable so-called directional or space-quantization effect.

The experiment was carried out in Frankfurt in 1920 by Otto Stern and Walter Gerlach, and was arranged as follows: In a small electrically heated furnace, was bored a tiny hole, through which the vapour flowed into a high vacuum so as to form thereby an extremely thin beam of vapour. The molecules in this so-called atomic or molecular beam all fly forwards in the same direction without any appreciable collisions with one another, and they were registered by means of a detector, the design of which there is unfortunately no time to describe here. On its way between the furnace and the detector the beam is affected by a non-homogeneous magnetic field, so that the atoms - if they really are magnetic - become unlinked in one direction or another, according to the position which their magnetic axles may assume in relation to the field. The classical conception was that the thin and clear-cut beam would consequently expand into a diffuse beam, but in actual fact the opposite proved to be the case. The two experimenters found that the beam divided up into a number of relatively still sharply defined beams, each corresponding to one of the just mentioned discrete positional directions of the atoms in relation to the field. This confirmed the space-quantization hypothesis. Moreover, the experiment rendered it possible to estimate the magnetic factors of the electron, which proved to be in close accord with the universal magnetic unit, the so-called "Bohr's magneton".

When Stern had, so to speak, become his own master, having been appointed Head of the Physical Laboratory at Hamburg in 1923, he was able to devote all his energies to perfecting the molecular beam method. Among many other problems investigated there was a particular one which excited considerable interest.

It had already been realized when studying the fine structure of the spectral lines that the actual nucleus of the atom, like the electron, possesses a rotation of its ovn, a so-called "spin". Owing to the minute size of the nuclear magnet, estimated to be a couple of thousand times smaller than that of the electron, the spectroscopists could only determine its size by devious ways - and that too only very approximately. The immense interest

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attaching in this connection to a determination of the magnetic factors of the hydrogen nucleus, the so-called proton, was due to the fact that the proton, together with the recently discovered neutron, forms the basic constituent of all the elements of matter; and if these two kinds of particles were to be regarded, like the electron, as true elementary particles, indivisible and uncompounded, then as far as the proton is concerned, its magnetic factor would be as many times smaller than the electron's as its mass is greater than the electron's, implying that the magnetic factor of the proton must be, in round figures, 1,850 times smaller than the electron's. Naturally then, it aroused great interest when, in 1933, Stern and his colleagues made this determination according to the molecular beam method, it being found that the proton factor was about $2^1/_2$ times greater than had theoretically been anticipated.

Let us now for a moment touch upon Rabi's achievements in this field. Returning to the essential point of the problem, let us put the question: How does the atom react to the magnetic field? According to a theorem stated by the English mathematician Larmor, this influence may be ascribed to a relatively slow precession movement on the part of the electron and the atomic nucleus around the field direction - a gyromagnetic effect most closely recalling the gyroscopic movement performed by a top when it spins around the vertical line. If the strength of the magnetic field is known, the magnetic factor of the electron and of the atomic nucleus can also be estimated by this means, provided that we can observe and measure these precessional frequencies. Rabi solved the problem in a manner as simple as it was brilliant. Within the magnetic field was inserted a loop of wire, attached to an oscillating circuit the frequency of which could be varied in the same manner as we tune in our radio receiving set to a given wavelength. Now, when the atomic beam passes through the magnetic field, the atoms are only influenced on condition that they precess in time with the electric current in the oscillating circuit. This influence might perhaps be described graphically: the nucleus performs a vault (salto) - the technical term for which is a "quantum jump" - thereby landing in another positional direction to the field. But this means that the atom has lost all chance of reaching the detector and of being registered by it. The effect of these quantum jumps is observable by the fact that the detector registers a marked resonance minimum, the frequency position of the registration being determined with the extraordinary precision achievable with the radio frequency gauge. By this method Rabi has literally established radio relations with the most subtile particles of matter, with the world of the electron and of the atomic nucleus.

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