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The translation of the article by Otto Stern and Walter Gerlach showing the splitting of an electron beam by its passage through a magnetic field of sharp inhomogeneity

Otto Stern and Walter Gerlach were carrying out experiments to demonstrate the existence of what they called *Space Quantization in a Magnetic Field*. This means that the angle between the direction of the angular momentum of an electron and the gradient of the magnetic field can take on only discrete values. Stern and Gerlach worked with a beam of silver atoms but the effects were due to the valence electrons of the silver atoms so their beam was essentially a beam of

massive electrons. Otto Stern was a seasoned experimental physicist of about 34 years of age. He had been trained as a theoretical physicist but found that experiment physics was his real strength. He had studied with Albert Einstein for a number of years. Walter Gerlach was about 22 years of age and was just completing his training as a physicist.

Their article was originally published in *Zeitschrift für Physik*, volume 9 (1922) pp. 349-352. The translation below is from Basic Books, 1966, pp. 936-939.

Although the authors focused upon the Space Quantization in a Magnetic Field the significance of the article has become that of the first evidence of the spin of electrons.

Experimental Proof of Space Quantization in a Magnetic Field

by Walter Gerlach and Otto Stern

A short time ago a possible procedure was outlined in this journal for determining whether or not space quantization in a magnetic field exists. In a second communication it was shown that the normal silver atom has a magnetic moment. By continuing these investigations, on which we shall report in what follows, we have established *space quantization in a magnetic field* as a fact.

EXPERIMENTAL SETUP

The methods and apparatus were in general the same as in our earlier experiments. In certain details, however, essential improvements were introduced which we shall describe in this completion of our previous report.

The silver atom beam emanated from an electrically heated furnace with a steel insert, in the cover of which, at the exit point of the silver atom beam, a 1-mm² circular opening was found. The separation between the oven opening and the first beam aperture was increased to 2.5 cm which prevented the clogging of the aperture by the occasional spurting of drops of silver from the oven as well as by the too rapid growth of layers of silver through precipitation of the atomic beam itself.This first aperture is approximately circular and has an area of 3 X 10-3 cm²; 3.3 behind this circular aperture the silver beam passes through a slit-shaped aperture 0.8 mm long and 0.03 to 0.04 mm wide. Both apertures are made of sheet platinum. The slit-shaped stop is situated at the front end of the magnetic field. The opening of the slit stop lies directly over the cut S [see Fig. 57-1] and is so adjusted to the circular stop and to oven opening that the silver beam runs parallel to the 3.5-cm long cut. Directly at the end of the cut the silver atomic beam strikes a glass plate onto which it is deposited.

The two stops, the two magnetic poles, and the glass plate sit in a brass housing having 1-cm thick walls, all rigidly connected so that any pressure of the magnetic pole of the electromagnet will not cause a deformation of the housing nor result in a change in the relative positions of the stops, the pole, and the glass plate.

Just as in the first experiments, the evacuation is carried out with two Volmer diffusion pumps and Gaede Hy-pumps as preliminary pumps. By means of continuous pumping and cooling with solid carbon dioxide, a vacuum of about 10^{-5} mm Hg was achieved and continuously maintained.

The "irradiation time" was stretched out to eight hours without interruption. But even after eight hours of vaporization the layer of silver deposited on the receiving plate was so thin because of the very narrow apertures and the great length of the beam that, just as previously reported, it had to be developed.

RESULTS

To begin with, [Fig. 57-2] shows a photograph after a 4½ hour irradiation time without magnetic field; the enlargement is about 20-fold. The measurement of the original with a microscope having an ocular microneter gave the following dimensions: length 1.1 mm., width at

the narrowest point 0.06 mm:, at the widest point 0.10 mm. We see that the slit is not exactly parallel. We must, however, note that the figure is a 40-fold enlargement of the slit since the "silver image" of the slit itself already had double the dimensions; it is difficult to make such a slit in a frame a few millimeters in size.

[Fig. 57-3] gives a photograph [after] eight hours irradiation with magnetic field, enlarged 20-fold (20 scale divisions of the imaged scale = 1 mm). This is the most successful photograph. Two other photographs gave pretty much the same results in all essential points but not with this complete symmetry.

We must point out here that a precise adjustment of such small stops by optical methods is very difficult; that to obtain completely symmetrical photograph as in [Fig. 57-3] is in part due to luck; an error of only a few hundredths of a millimeter in the position is sufficient to ruin a photograph completely.

The results of the other two experiments are shown schematically in [figs. 57-4a and b]. In [Fig. 57-4a] the

silver beam was arranged intentionally to move at a slightly greater distance past the cut than in the experiment of [Fig. 57-3]. In this case the split aperture was not completely filled. In the case of [Fig. 57-4b] the same glass plate was used for a deposit with and without field; the beam passed very close to the cut, but it was displaced by about 0.3 mm in a direction at right angles to the field [Fig. 57-4c]. As far as clarity of the pictures, complete splitting, and all otlher details, these pictures are in no way inferior to these given in [Fig. 57—3].

The pictures show that the silver atom beam in an inhomogenec magnetic field is split up into two beams in the direction of the inhomogeneity, one of which is attracted to the knife-edged pole and the other of which is repelled. The deposits show the following details (compare with the diagram of [Fig. 57-5]).

- **(a) The dimensions of the originals were measured in a microscope; length 1, 1.1 mm; width a, 0.11 mm; width b, 0.20 mm.**
- **(b) The splitting of the atomic beam in the magnetic field occurs in two discrete beams. No undeviated atoms are found.**

- **(c) The attraction is somewhat stronger than the repulsion. The attracted atoms come closer to the pole and hence into zones of larger inhomogeneity so that the deflection increases more and more during the flight. [Figs. 57-3 and 4b] show the quite appreciably increased deflection directly at the knife edge of the one magnetic pole. In the immediate vicinity of the edge the attraction becomes very large so that a bulge, show by the sharp point toward the edge, arises.**
- **(d) The width of the deflected strip is larger than that of the undeviated image. The latter is just the image of the slit B_2 projected onto the glass plate by the slit B_1. The deflected bands are broadened because of th velocity distribution of the silver atoms.**
- **(e) This fact sharpens the evidence against the existence of undeflecte atoms in any perceptible amounts (compare point (b)). For the evidenc based on undeflected atoms falling together on a small surface is much more sensitive than that based on a dispersed beam of undeflected atoms falling on a wide area.**

We view these results as direct experimental verifications of space quantization in a magnetic field.