Stern-Gerlach Experiment

In 1921stern and Gerlach performed and experiment to study the behaviour of atoms in non homogenous magnetic field to verify the space quantization of spinning electron and quantized magnetic moments

Experiment Arrangement and working

- The experimental setup was used by stern and Gerlach is shown in figure. It consist of a highly evacuated metallic box B.The silver atoms beam is produced by heating silver in an electric oven O.This beam of silver atom is made to pass through to narrow slit S1 and S2 then the beam of silver atom is passed between the specially shaped pole pieces of the strong magnet .The magnetic field is intense and non homogenous. The magnetic line of force are perpendicular to the direction of Beam.finally ,the beam is made to strike the photographic plateP normal to the initial direction of the beam.

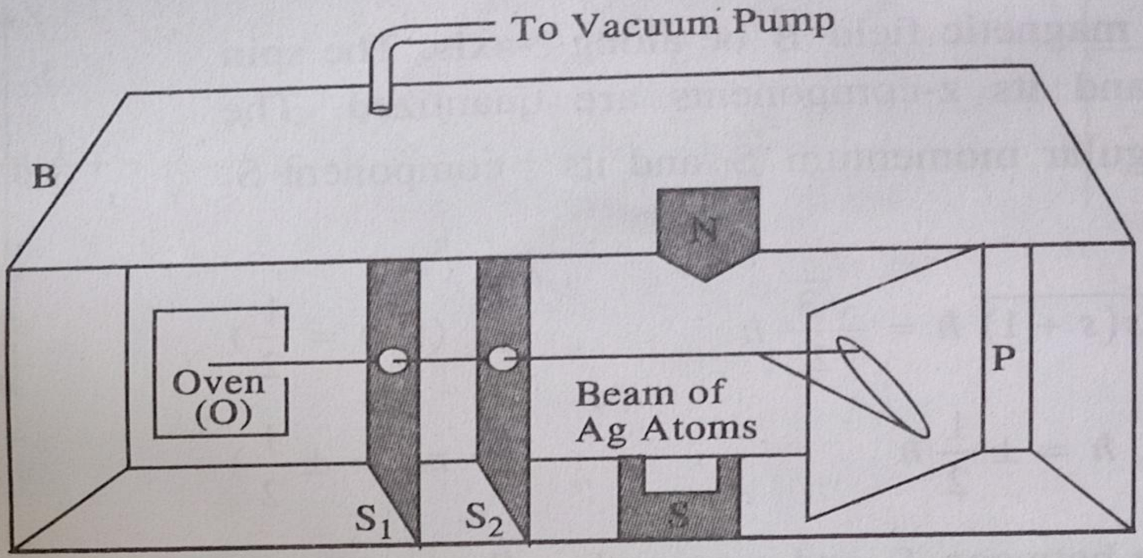
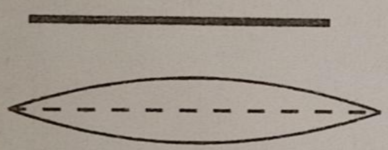


Fig. 1.14

When there is no magnetic field, a fine line is obtained on the photographic plate P due to the deposition of silver atoms. When a non-uniform magnetic field is applied, the beam splits up into two components, one on either side of the original line (Fig. 1.15).



(*a*) No magnetic field

(*b*) With non-homogeneous magnetic field

Fig. 1.15

Theory

Consider the silver atom as a short bar magnet (*i.e.* an atomic magnet) of magnetic moment $\vec{\mu}$. When this atom is placed in the magnetic field $\vec{B}$ at a certain angle to the field, it experiences a torque given by

$$\vec{\tau} = \vec{\mu} \times \vec{B}.$$

This torque tends to align the silver atom parallel to the field $\vec{B}$.

Let the atomic magnet (*i.e.*, silver atom) turns through an angle θ from the field direction, then it possesses additional energy given by

$$U = -\vec{\mu} \cdot \vec{B} = -\mu B \cos\theta$$

Let the magnetic field $\vec{B}$ varies along Z-axis and suppose the silver atom enters this magnetic field with a speed υ along X-axis. Then the force acting on the atomic magnet (*i.e.*, silver atom) along Z axis is

$$F_z = -\frac{\partial U}{\partial Z} = \frac{\partial}{\partial Z}(\vec{\mu} \cdot \vec{B}) = \mu \cos\theta \frac{\partial B}{\partial Z}$$

If M be the mass of the silver atom, then acceleration produced in it is given by

$$a = \frac{F_z}{M} = \frac{\mu \cos\theta}{M} \frac{\partial B}{\partial Z}$$

If l be the length of the path of the beam through the magnetic field, then time taken by the beam to travel through the field, $t = l/\upsilon$. Therefore, the displacement of the silver atom along Z-axis on coming out of the field is given by

$$z = \frac{1}{2} a t^2 = \frac{1}{2} \frac{\mu \cos\theta}{M} \frac{\partial B}{\partial Z} \frac{l^2}{\upsilon^2} \qquad \left(\text{Using } S = u + \frac{1}{2} at^2\right)$$

$$z = \frac{\mu l^2 \cos\theta}{2M\upsilon^2} \frac{\partial B}{\partial Z}$$

According to Maxwell's law of distribution of velocities,

$$\upsilon = \left(\frac{3kT}{M}\right)^{\frac{1}{2}}$$

where $k = 1{\cdot}38 \times 10^{-23}$ J K^{-1} is the Boltzmann constant and T is the temperature of the oven.

$$\therefore \qquad z = \frac{\mu l^2 \cos\theta}{2M \times 3kT / M} \frac{\partial B}{\partial Z} = \frac{\mu l^2 \cos\theta}{6kT} \frac{\partial B}{\partial Z}$$

This equation gives the maximum displacement of the silver atom at the centre of the trace [Fig. 1.15(*b*)].

Special Cases

1. If there is no magnetic field or there is uniform field i.e., $\frac{\partial B}{\partial Z} = 0$, then $z = 0$.

Hence, there will be no displacement of the atomic magnets (*i.e.*, silver atoms) along Z-axis. Therefore, they will produce a fine straight line on the photographic plate (P) as shown in Fig 1. 15(*a*).

2. If there is non-uniform magnetic field, the atomic magnets will be displaced from their path in + Z-axis direction depending upon their orientations (*i.e.*, value of θ) and hence produce a trace on the plate (P) as shown in Fig. 1.15 (*b*).

Explanation

In the normal state, the whole magnetic moment of silver atom is due to the spin of one its

- Electron. In a uniform magnetic field such an atomic dipole or atomic magnet with experience a torque tending to align it in the direction of magnetic field. in non homogenous magnetic field each pole of the dipole is subject to a force of different magnitude. As a result of this,there will be a resultant force on the dipole that varies with its orientation with respect to the magnetic field. according to classical Idea, the atomic diaper can have any includation to the magnetic field so the silver atom will be deposit on the plate p at the place bounded by the trace corresponding to the volume -1 and +1of cos theta.However, Stern and Gerlach observed that the initial beam of the silver atoms splits up into two distinct part, corresponding to the two opposite spin orientation in the magnetic field that are allowed by space quantization.

Thank you