Problem № 14: Einstein–de Haas Experiment

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The problem

When you apply a vertical magnetic field to a metallic cylinder suspended by a string, it begins to rotate. Study this phenomenon.

Theoretical part

The experiment, done by Einstein and de Haas is connected with determination of the ratio between the magnetic moment of the electron and its angular momentum during its motion around the nucleus.

According to the known by that time the theory, the magnetization of a given magnetic material is a result of the orientation of the electrons' orbit and the summarizing of all atomic magnetic moments in the external magnetic field.

Fig.1 presents the classical understanding for the motion of the electrons around the nucleus in circular orbit.

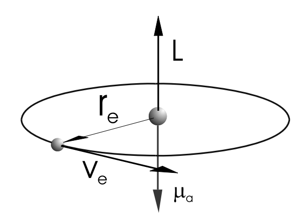

Fig. 1

For the ratio

$$\gamma_c = \frac{\mu_a}{L},$$

where μ_e is the magnetic moment of electrons and L is the angular momentum we can obtained:

$$\mu_a = \frac{e.\omega.S}{2\pi} \quad and\, L = m_e v_e r_e$$

$$\gamma_c = \frac{1}{2}\frac{e}{m_e}.$$

Einstein and de Haas realize experiment in which ferromagnetic cylinder is suspended to an elastic thread into homogeneous magnetic field in parallel to its magnetic field lines.

When the magnetic field is applied, the atoms would be orientated in the field and according to the low of the conservation of the angular momentum, the cylinder to rotate, twisting the thread.

Magnetization of the cylinder

$$J_m = \frac{P_m}{\Delta V} = \frac{N\mu_a}{\Delta V} = \chi H$$

where χ_m is the magnetic susceptibility of the cylinder, ΔV - the value of the cylinder, and H – the intensity of the magnetic field in which it is put.

The angular momentum is determined by the torsion moment of the thread D, the inertial moment of the cylinder J and the angle H, to which the thread is twisted after the applying of the field

$$L = \varphi\sqrt{J.D}\ .$$

Because of the small angle of twisting of the thread in the experiment of Einstein and de Haas, the mechanical resonance has been used and the obtained result has been two times more than expected one. Consequently the magnetization is due not only to the orientation of the electrons orbits but also and to the own magnetic moments of the electrons.

$$\gamma_q = \frac{e}{m_e}$$

The ratio: $$g = \frac{\gamma_q}{\gamma_c} = 2$$

is called gyro-magnetic ratio and in ideal case is equal to 2.

Experiment

In order to obtain the value 2 for the gyro-magnetic ratio it is needed all atoms of the ferromagnetic cylinder to be orientated into the magnetic field. Even to the intensities of the saturation of the materials, by which the cylinder is made only a part of the atoms would be orientated (interaction between domains, heat fluctuations, etc.)

Fig.2

In our experiment we have used the steel with low content of carbon, which have relative magnetic permeability

$$\mu = 0.988.10^4 \text{ T. m/A.}$$

In order we to be in the area of the saturation of the ferromagnetic material we have used solenoid, creating along its axis the intensity of the magnetic field:

$$H = 3880\frac{A}{m}$$

In order to be realized the condition for the homogeneity of the field, in which the cylinder is hung, the length of the solenoid is *l = 510 mm* and its diameter is *D = 65 mm* (Fig.2).

The experiment is divided in two parts:

The first part – qualitative part of the experiment. Establishment of the rotation of the cylinder in the homogeneous magnetic field and observing the effect of Einstein-de Haas.

The second part – quantitative measurement of the gyro-magnetic ratio.

Carrying out of the first part of the experiment

For the implementation of this part of the experiment we have used a cylinder, made from the same ferromagnetic material, with a diameter D *=14mm* and a height *h = 9mm,* fixed on the bottom of hollow semi-sphere, leaved freely to float in a little vessel filled with water- a float (Fig. 3 and Fig. 3a).

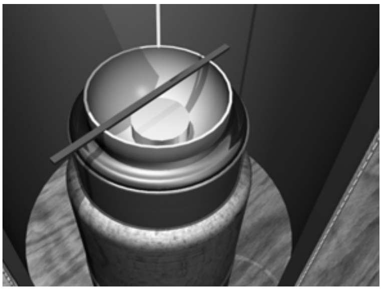

Fig. 3

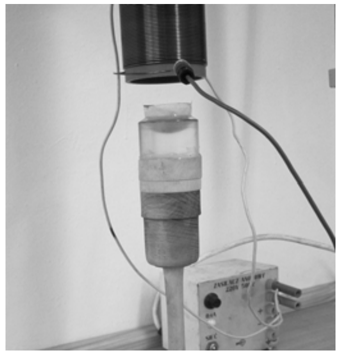

Fig. 3a

Wetting surface of the semi-sphere and not wetting material of the vessel gives a possibility of the obtaining of stable equilibrium of the semi-sphere in the middle of the vessel with the water. Because of the extremely little resistance of the liquid, the appearance of the moment of the force even with very little value would rotate the float.

When the magnetic field is applied, when the vessel with the float is inside of the solenoid, the orientation of the magnetic moments starts. In consequence of the low of the conservation of the angular momentum the ferromagnetic cylinder together with the semisphere rotate.

After the ending of the process of the orientation of the atomic moments the force of internal friction stop rotation of the cylinder. The existence of the section of the free stopping of the rotation is a proof of that the effect of Einstain-de Haas is observed. If such section missed it would mean that the rotation is provoked by magnetic forces, creating by the non-homogeneity of the field.

In order to specify the existence of such section two dependences are compared:

$\omega_L = f(t)$ - for the free stopping float and

$\omega_E = g(t)$ - for the float in magnetic field.

With a digital camera the float have been photographed when it stops freely and in the magnetic field of the solenoid (Fig. 4).

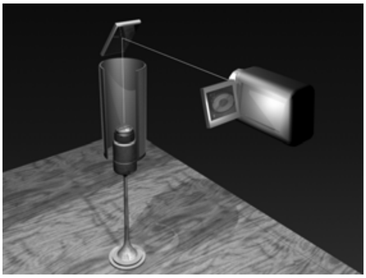

Fig.4

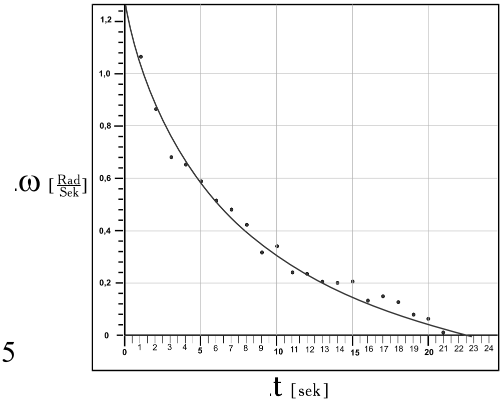

Fig.5

By the analysis of the slides the angle velocities have been determined at different time moments. The data are graphically presented on Fig. 5 for the freely stopped float.

On Fig.6 are presented the data for the float in the magnetic field.

On the right part above is shown a slide of the photographed float inside the solenoid. Along the diameter of the float is put amarker for the determination of the angle of rotation.

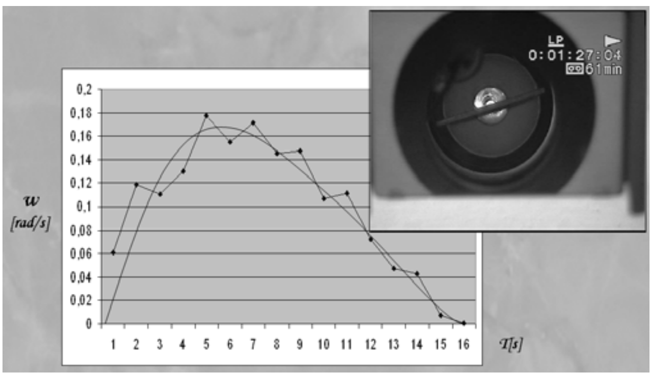

Fig6

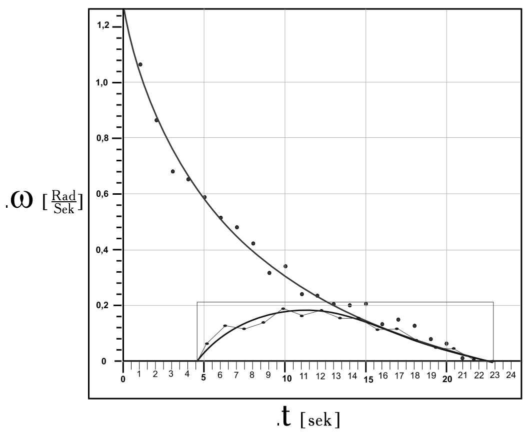

Fig. 7

On Fig7.the two graphs are united in order to be seen the coincidence of the two curves in the passive section (15s-22s) of the stopping of the float. It proves the effect of Einstein- de Haas.

Realization of the second part of the experiment

For the quantitative determination of the gyro- magnetic ratio we have carried out the experiment of Einstein- de Haas. By this reason we have used the sample of ferromagnetic material with fixed to it a mirror (Fig. 8).

1- a sample of ferromagnetic material.

2- holder of the mirror by diamagnetic.

3- mirror.

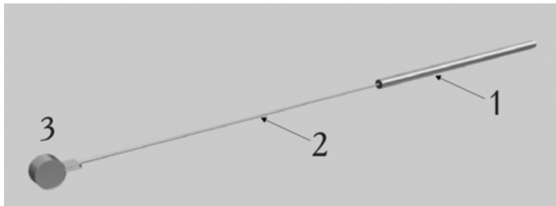

Fig.8

The sample is hung into the solenoid (3), in such way that the mirror (2) is outside it – Fig.9. The beam of the laser (1), reflected by the mirror (2) is directed to the screen (6).

The angle of rotation can be determined by direct measurement, but not by the resonance. It decreases the mistake of the final result.

The sample is hung to the thin bronze thread. In order to decrease the horizontal vibrations is used a thread (4), in the lower part of the sample, which is constantly strained (5).

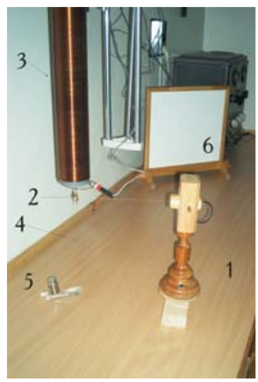

Fig. 9

Data from the experiment

1. Parameters of the setting and the sample

Sample- iron $d = 5\ mm,\quad L = 113\ mm$

Holder of the mirror –copper $d = 1.2\ mm,\ L = 220\ mm$

Mirror- glass $d = 10\ mm,\ L = 6\ mm$

Current through the solenoid – *5A*

Intensity along the axis of the solenoid – $H = 3880\ \frac{A}{m}$

Magnetic permeability of the sample – $\mu = 0.998\ 10^4$

2. Data from measurement of the angle of deviation

The distance between the screen and the mirror- $l = 547\ cm$

Measurement	1	2	3	4	5	6
Deviation of the light mark [cm]	39.5	37	38	38	37.5	38.5
Angle of displacement of the light beam φ_L $[rad]$	0,0722	0,0676	0,0694	0.0694	0,0685	0,0703

Average value of the displacement of the light beam- $\varphi_L = 69.6\ 10^{-3}\ \ [rad]$

Angle of rotation of the sample- $\varphi = \frac{\varphi_L}{2} = 34.78\ 10^{-3}\ \ [rad]$

Result

Angular momentum of the sample - $L = 2.3\ 10^{-9}\ \frac{kg.m^2}{s}$

Magnetic moment of the sample – $P_m = 85.8\ A.m^2$

$$g = \frac{e/m}{P_m/L} = 4{,}7$$

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