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Methodological Notes

FREE SUSPENSION OF DIAMAGNETIC BODIES IN A CONSTANT MAGNETIC FIELD

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IN the study of diamagnetism one demonstrates most frequently experiments on the expulsion of diamagnetic bodies from a constant magnetic field. For example, the Faraday method consists of placing a rod of diamagnetic material (bismuth or graphite), suspended horizontally on a thin filament, in the space between the pole pieces of an electromagnet, perpendicular to the direction of the magnetic field[1]. Another demonstration of diamagnetism is the expulsion of a bismuth or graphite sphere, suspended on one arm of a balanced scale, from the space between the poles of an electromagnet[1].

The setup proposed below makes it possible to demonstrate free suspension of diamagnetic bodies in a constant magnetic field. The possibility of such a suspension was demonstrated in 1939 by Braunbeck[4], who effected free suspension of pieces of graphite in the form of small rods weighing up to 75 mg in the field of an electromagnet with special pole pieces[3].

The force F acting in a magnetic field with induction B on a diamagnetic body of unit volume with relative magnetic permeability μ_r is given by

$$F=\frac{1-\mu_r}{2\mu_0}\frac{\partial B^2}{\partial z}.$$

The body can hang freely in the gravitational field if

$$F > \rho g \quad \text{for} \quad \frac{\partial B^2}{\partial z} > \frac{2g\mu_0\rho}{1-\mu_r},$$

where $\partial B^2/\partial z$ is the gradient of the square of the induction in the vertical direction, g is the acceleration to the gravity, μ_0 is the magnetic permeability of vacuum, and ρ is the density of the body.

Of all the solid diamagnetic materials, the smallest value of $\rho/(1 - \mu_r)$ is possessed by graphite (2.3×10^7 kg/m^3), and this determines its choice as the suspended body. For graphite it is necessary to have $\partial B^2/\partial z \geq 5.7 \times 10^2$ Tl^2/m. In strong magnetic fields (with $B \approx 2$–3 Tl), the inhomogeneities of this order can be realized only at small distances, thus limiting the linear dimensions of the suspended bodies to values on the order of several centimeters[4]. The suspension will be stable in the vertical and horizontal directions if the configuration of the limiting induction of the field has the form of a tumbler, and the diamagnetic body has the form of a sphere or cylinder. Such a field was realized with the aid of an electromagnet with pole pieces of rather simple form.

The construction of the electromagnet is shown schematically in Fig. 1. The armature of the electromagnet 1 and its central core 2 of 40 mm diameter are made of low-carbon steel. The magnetizing winding 3 is wound on a duraluminum frame and contains 1200 turns of wire with rectangular cross section (2.5×1.5 mm) in glass insulation. The dc resistance of the winding is

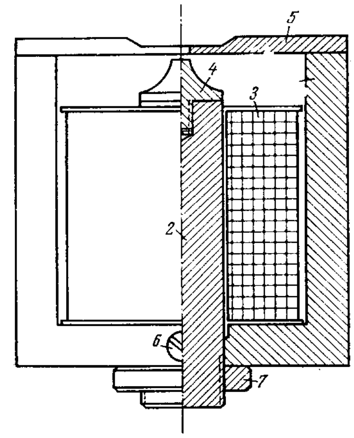

FIG. 1

FIG. 2

1.67 ohm. The winding is calculated for a current of 8 A, and can withstand up to 24 A for a short time. To the upper end of the central core 2 is attached a pole piece 4 with gradually decreasing cross section of "Armco" iron. On the lower end of the core 2 is a thread for a nut 7, with the aid of which it is possible to vary the vertical position of the core. Screw 6 fixes the position. The upper pole piece 5 is a plate with a cylindrical opening in the middle.

The described electromagnet makes it possible to suspend freely spherical and cylindrical rotors of electron-erosion graphite weighing up to 0.98 and 3.8 g, respectively, which is much higher than the weights suspended by Braunbeck. To demonstrate the free suspension, it is best to use a spherical rotor weighing 0.48 g (8.3 mm diameter), which stays freely in the interpole space of the electromagnet consuming a magnetic power 140 W. In this experiment the hole in the upper pole piece is 9.8 mm, the smallest diameter of the lower pole piece is 7.0 mm, the vertical distance between the pole pieces is 2.5 mm. The induction at the surface of the lower pole piece reaches 1.42 Tl.

At this power consumption it is possible to suspend freely a cylindrical rotor of 17.4 mm diameter and 6.7 mm height, weighing 2.55 g. In this case the hole in the upper pole piece is 18.3 mm, the smallest diameter of the lowest pole piece is 13.3 mm, and the vertical distance between the pole pieces is 1.2 mm.

Figure 2 shows a photograph of the pole pieces of the electromagnet with a spherical rotor freely suspended in the magnetic field. The figure shows the opening in the upper pole piece, in which a rotor of 8.3 mm diameter is freely suspended (without touching the walls) over the lower pole piece. When the current through the winding of the electromagnet changes from 0 to 24 A, it is possible to vary the height of the rotor suspension over the lower pole piece from 0 to 1.5 mm. The suspended rotor can be rotated by an external rotating magnetic field with frequency of several revolutions per second. After the rotating field is turned off, the rotor keeps on rotating for a long time by inertia. The same can be effected also when a cylindrical rotor is suspended.

The free suspension of graphite rotors can be demonstrated either directly or by shadow projection on a screen.

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[3] W. Braunbeck, Zs. Phys. 112, 764 (1939).

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Translated by J. G. Adashko