Thus, the study of the influence of anion defectivity on the phase transition temperature has shown that the superconducting transition temperature in the ceramic two-layer samples $Tl_2Ba_2CuO_x$ and $Tl_2Ba_2CaCu_2O_x$, regardless of the presence of a calcium layer, is determined by the value of Cu-O1 interatomic distances. The dependence obtained for the $Tl_2Ba_2CaCu_2O_x$ phase should be taken into account when choosing methods to increase the T_c of thallium-based superconductors.

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Studying the magnetic field of a multilayer solenoid in the laboratory physics workshop

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This paper presents the theory of the magnetic field of a multilayered solenoid of finite length with an arbitrary number of coils. It describes the methods of experimental and theoretical investigation of solenoid magnetic field distribution in laboratory practice for students of physics and engineering specialties.

In the conditions of implementation of the international students' training program within the framework of the joint department of BNTU and TSTU (Tashkent) on training engineers-technicians it is necessary to develop and implement into the educational process methodical and laboratory support, which would allow to combine not only educational, but also scientific and research technologies to the fullest extent. This is especially relevant when teaching students according to the modular-block system, when the course of physics is studied in a certain period of time determined by the curriculum. This development meets the above principles and allows you to acquire certain skills of scientific research in the process of performing laboratory physics practical work.

The purpose of this work is to develop a methodological and laboratory support for studying the magnetic field distribution in a multilayer solenoid of finite length using a Hall sensor.

The development was based on the principle of learning [1-5] from simple to complex: learning the basic concepts of DC magnetic field theory is based on studying the magnetic field of a rectilinear conductor with current and the magnetic field on the axis of a circular coil with current. The use of the above principle helps students to form the necessary conceptual base. Next, the distribution of the magnetic field at various points along the axis of a single-layer solenoid of finite length is examined step by step. Then the magnetic field inside the multilayer solenoid is examined.

Let the multilayer solenoid contain k layers. Let us isolate a thin solenoid of thickness dR in a multilayer solenoid with inner radius R_1 and outer radius R_2 (Fig. 1). If a current kI flows through the wire of the multilayer solenoid, then the separated thin solenoid of thickness dR will have a current

$$dI = \frac{IkdR}{R_2 - R_1}.$$

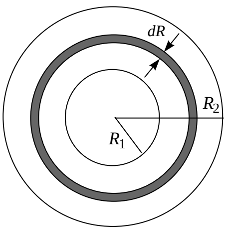

Fig. 1. Extraction of a thin solenoid of thickness dR in a multilayer solenoid with inner radius R_1 by outer radius R_2

A thin solenoid of thickness dR, through the coils of which current dI flows, creates induction

$$dB = \frac{\mu_0 n dI}{2}\left(\frac{L-x}{\sqrt{R^2+(L-x)^2}} + \frac{x}{\sqrt{R^2+x^2}}\right).$$

Given the above expression for the current element $dI = \frac{IkdR}{R_2 - R_1}$, we obtain

$$dB = \frac{\mu_0 InkdR}{2(R_2 - R_1)}\left(\frac{L-x}{\sqrt{R^2+(L-x)^2}} + \frac{x}{\sqrt{R^2+x^2}}\right)$$

.

Let's integrate this expression over the radius of the multilayer solenoid in the range from R_1 до R_2

$$B=\int_{R_1}^{R_2}\frac{\mu_0 InkdR}{2(R_2-R_1)}\left(\frac{L-x}{\sqrt{R^2+(L-x)^2}}+\frac{x}{\sqrt{R^2+x^2}}\right),$$

or

$$B=\frac{\mu_0 Ink}{2(R_2-R_1)}\int_{R_1}^{R_2}\frac{L-x}{\sqrt{R^2+(L-x)^2}}dR+\frac{\mu_0 Ink}{2(R_2-R_1)}\int_{R_1}^{R_2}\frac{x}{\sqrt{R^2+x^2}}dR.$$

Let us use the table integral of the form

$$\int\frac{dx}{\sqrt{x^2+a^2}}=\ln\left(x+\sqrt{x^2+a^2}\right),$$

where a is a constant.

After integration we obtain the expression for the modulus of the magnetic induction vector [6]

$$B=\frac{\mu_0 Ink}{2(R_2-R_1)}\left((L-x)\ln\frac{R_2+\sqrt{R_2^2+(L-x)^2}}{R_1+\sqrt{R_1^2+(L-x)^2}}+x\ln\frac{R_2+\sqrt{R_2^2+x^2}}{R_1+\sqrt{R_1^2+x^2}}\right).$$

The formula obtained makes it possible to calculate the magnitude of the magnetic field induction at any point on the axis of a multilayer solenoid of finite length. The magnitude of the magnetic field induction of a multilayer solenoid depends on its length, the number of layers, the number of turns, the current in the turns, the values of external and internal radii.

After mastering the theoretical part, students conduct an experimental study.

The main parts of the laboratory setup (Fig. 2) are: solenoid **1**, solenoid **2**, support for Hall sensor **9**, Hall sensor **4**, measuring unit **10**, which is a microprocessor system.

The solenoids have a length of 0.02 m, 35 layers and contain each 100 turns per unit length. The inner diameter of the solenoids is 0.011 m, the outer diameter is 0.056 m. The solenoid is powered by a special current source.

All parts, except the measuring unit, are mounted and can be moved on the guiding support rail **5** with a millimeter scale. The position of the sensor support is set by the arrow **3** with the help of marks on the scale with millimeter accuracy.

To experimentally measure the magnitude of magnetic field induction on the solenoid axis, the Hall sensor **4**, which is used to measure the Hall potential difference, is used in this work.

Fig. 2. View of the experimental laboratory setup

The Hall sensor is a thin semiconductor plate attached to the end of a long tube (rod) **6**. The rod automatically moves inward one or two coils.

When the sensor is in the area of space where there is a magnetic field of unknown magnitude, with a constant current through the plate, knowing its dimensions and the Hall constant, the magnitude of the magnetic field induction B is determined by the measured Hall potential difference.

On the front panel of the measuring unit **10** there is a control panel **8** and a graphic display **7**.

The experimental setup allows to carry out investigations: **in mode 1** (Mode 1) − study of dependence of B(x) magnitude of magnetic induction on the distance L along the solenoid axis; **in mode 2** (Mode 2) − study of dependence of module and direction of magnetic induction vector on the magnitude and direction of the current flowing along the solenoid, at a fixed point located on the solenoid axis.

In the first mode, the motor moves the Hall sensor on the rod inside the solenoid, and the graphical display **7** shows the dependence of $B(x)$ magnitude of magnetic induction on the distance x along the solenoid axis, and the numerical display shows the corresponding values of these values. In the second mode with fixed position of the sensor inside the solenoid the dependence of magnetic induction value on the current strength $B(I)$ is displayed on the graphical panel **7** (current of solenoid **2** varies from 0 A to 2 A).

Students solve the following problems while doing the research:

1. Study the distribution of the magnitude of the magnetic induction vector along the axis of a multilayer solenoid of finite length. Students study the distribution of the magnetic field inside the solenoid, experimentally determine the value of the maximum magnetic induction B_{max} and its corresponding values x

for a given value of the solenoid current. Theoretical calculation $B(x)$ with the same parameters is performed, the theoretical values of $B_{max}(x)$ are compared with experimental data and conclusions are drawn.

2. Study the relationship between the direction of magnetic induction vector and the direction of current flowing through the solenoid at the point located on the solenoid's axis. By comparing the graphical relationships obtained, students should conclude about the influence of the direction of the current in the solenoid on its magnetic field.

3. Investigate the distribution of the magnetic induction vector along the axis passing through the centers of two multilayered solenoids with currents flowing first in one and then in opposite directions. In the assignment, students compare the obtained graphical dependences and draw conclusions about the superposition principle for the magnetic induction vector.

This technique showed its high efficiency in terms of formation of students' conceptual base and acquisition of research skills by students in the process of laboratory physics practical work.

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