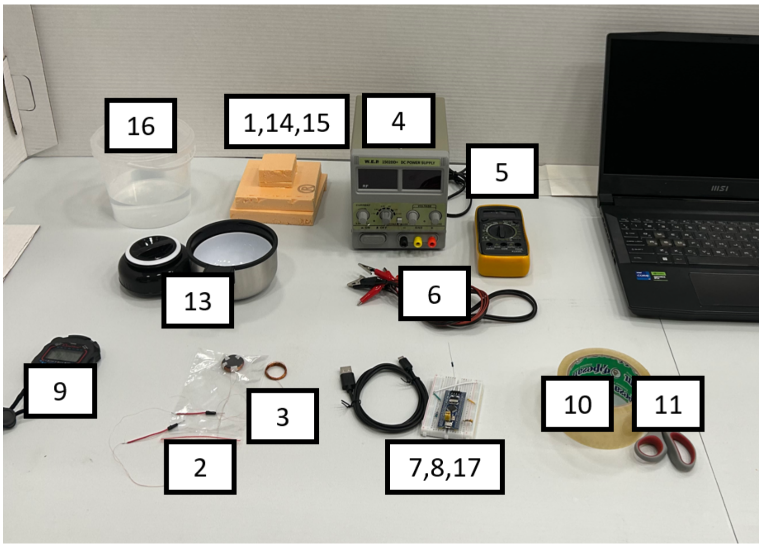
MS3 HTS

Equipment

1. Box
2. Supercondunctor with a copper coil
3. Copper coil
4. DS voltage source 15 V
5. Mutlimeter
6. Two paired «Banana-Alligator» wires
7. Resitor R_0
8. Breadborad with STM32 and USB cabel
9. Stopwatch
10. Tape
11. Scissors
12. Liquid nitrogen
13. Vacuum flask
14. Stand for flask
15. Thermal insulator head
16. Bucket with water
17. Resitor 1K. Stand in breadborad.

DO NOT CONNECT THE VOLTAGE SOURCE TO THE BREADBOARD.



The phenomenon of superconductivity was discovered at the beginning of the 20th century with the development of technologies for cooling materials to ultra-low temperatures. Over time, it became widely known, as it essentially represents the manifestation of quantum mechanical laws at the macroscopic level. The effects observed in this case contradict everyday understanding of the world, which is why superconductivity is used not only in science, medicine, and engineering but also in related entertainment industries. Nevertheless, despite the popularity of the phenomenon, there is still no complete and satisfactory theoretical description of superconductivity. Today, scientific research continues, new superconducting materials (especially high-temperature superconductors, hereafter referred to as HTS) are being sought, and new theoretical concepts are being developed to encompass the entire set of experimental facts. In this work, you will study the temperature characteristics of HTS using a sample of YBCO , observe the transition to the superconducting state, and investigate the frequency dependencies of the critical field, which is closely related to the theory of superconductivity.

Boiling temperatiure of liquid nitrogen	$T_{\mathrm{LN}_2} = 77.4\ \mathrm{K}$

With a spechial card you can orginizers ask to pour liquid nitrogen into the vacuum flask lid. Handle the provided liquid nitrogen with care and use it wisely! After completing the measurements with nitrogen, using the card call orginizersin the room: they will drain the remaining nitrogen into a separate container.

Solid state model

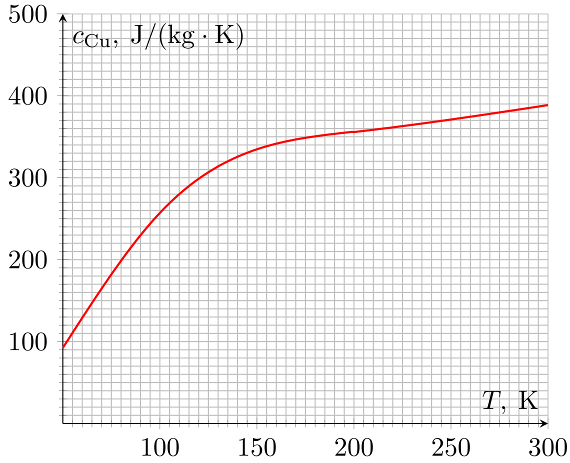
The model of a solid body in the molecular kinetic theory assumes that a solid body is a state of matter characterized by a constant shape. Using methods of statistical physics, it is possible to quantitatively describe the heat capacity of an ideal crystal. From the perspective of microscopic theory, any objects possessing their own energy contribute to the heat capacity of a body. In solids with free electrons, there are two such objects: electrons and phonons. Phonons are quasiparticles introduced to describe the vibrations of the crystal lattice. The propagation of a phonon in a crystal is the propagation of a vibrational wave.

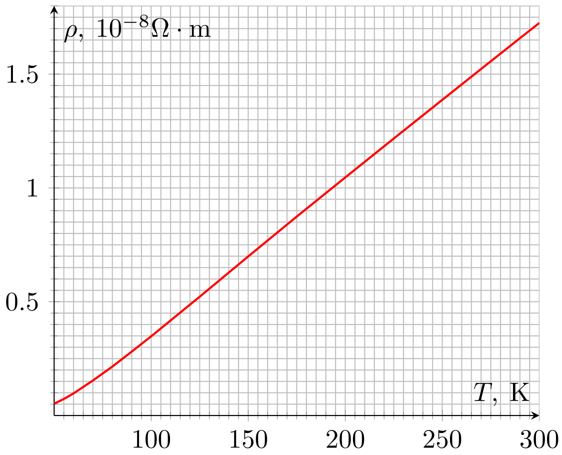
Peter Debye developed a theory that allows describing the contribution of crystal lattice vibrations to the heat capacity of solids. The corresponding expression is:

$$C \propto \left(\frac{T}{\Theta}\right)^3 \int\limits_0^{\Theta/T} \frac{x^4 e^x}{(e^x-1)^2}dx, \tag{1}$$

where Θ is a parameter called the Debye temperature. This temperature is unique to a given substance. All other contributions to the heat capacity of this sample in the studied temperature range can be neglected, so we will describe the total heat capacity of the sample exclusively by expression (1).

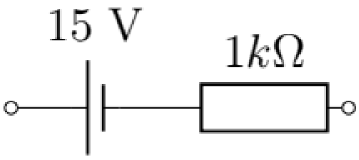
In this part, you need to measure the dependence of the temperature of the sample placed in a polystyrene box on time t during cooling and heating processes. For calibration of the setup, we will use copper, and we will consider the dependence of the specific heat capacity $c_{\mathrm{Cu}}$and specific resistance ρ_{Cu} on temprerature T as known. The dependence of the specific heat capacity of copper c_{Cu} on temperatute T is recorded in the file «*Specific heat capacity.xlsx*» The dependence of the specific resistance of copper ρ_{Cu} on temperature T is recorded in the file «*Specific resistance.xlsx*»





As a source of constant and small current, use a series connection of a DC voltage source and a resistor with a large resistance.

Since copper and YBCO have good thermal conductivity, the temperature inside the box (but not in its walls!) can be considered constant throughout the volume. The power of heat loss P from the box with temperature T_{in} to the external environment with constant temperature T_{out} is determined by the equation:



$$P = \alpha(T_{\mathrm{in}}) \cdot (T_{\mathrm{in}} - T_{\mathrm{out}})$$

Let's determine the dependence of α on T_{in}. Consider the mass of the copper coil to be $M = 0.79$ g. Note that a small piece of copper wire at room temperature has a resistance comparable to that of the entire coil cooled to T_{LN_2}.

Try to avoid accidental disconnections of the alligator clips from the coil wires. Repeated connections wear out the material and can cause the wire to break.

A1 Fix the box with copper coild inside in the cap of the vacuum flask. Note, that box floats in water. Obtain the dependence of T_{in} on time t during the cooling of box in the liquid nitrogen. The duration of series should me 20 min. Fill the spreadsheet «*A1.xlsx*» and send it as the answer. **2.0**

A2 Numericaly determine the dependence of $\alpha(T_{\text{in}})$ in the case of $T_{\text{out}} = T_{\text{LN}_2}$ using the date obtained in the previous question. Plot the graph of this dependence. Fill the spreadsheet «*A2.xlsx*» and send it as the answer. **0.5**

A3 Take cooled to the liquid nitrogen temperature box and pour water over. The temperature of water is a room temperature $T_0 = 25°\text{C}$. Note, that at the moment of adding the water there **must be no** any liquid nitrogen in the cap. Obtain the dependence of T_{in} on time t during the heating of the box in the water. The duration of series should me 20 min. Due to low heat capacitance of the system and week heet flux, the altering of water temperature could be neglected. Fill the spreadsheet «*A3.xlsx*» and send it as the answer. **2.0**

A4 Numericaly determine the dependence of $\alpha(T_{\text{in}})$ in the case of T_{out} using the date obtained in the previous question. Plot the graph of this dependence. Fill the spreadsheet «*A4.xlsx*» and send it as the answer. **0.5**

Now we can investigate the temperature dependence of the superconducting sample. Take the copper coling out of the box and put the sample there. Close the box tightly.

A5 Obtain the dependence T_{in} on time t during the cooling of the box in the liquid nitrogen.
The duration of series should me 20 min Fill the spreadsheet «*A5.xlsx*» and send it as the answer. **2.0**

A6 Obtain the dependence T_{in} on time t during the heatiging of the box in the water. The duration of series should me 20 min Fill the spreadsheet «*A6.xlsx*» and send it as the answer. **2.0**

A7 Based on results obtained in two previous questions, determine the dependence of the heat capacitance C on the temperature T. Plot two graphs of this dependence: one for the date obtained for the heating, one for the dated obtained for the cooling. Fill the spreadsheet «*A7.xlsx*» and send it as the answer. **2.0**

A8 Numericaly determine the Debay temperature Θ of YBCO. Write the soultion on the answer sheet «*A8*». Descrive used numerical methods. In the «moodle» type «*rdy*» as the answer. **1.8**

Transition normal state - superconductor

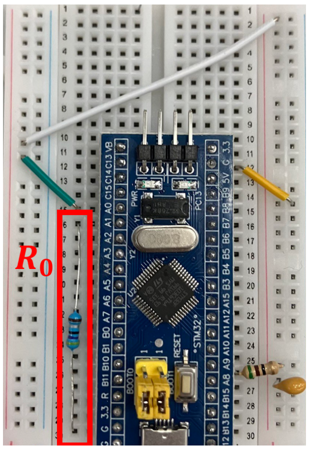
The discovery of high-temperature superconductors (HTS) in the late 1980s expanded the possibilities for practical applications of superconductivity, as it became possible to observe the phenomenon at the boiling temperature of liquid nitrogen (LN_2). The prospects of discovering materials exhibiting superconducting properties at room temperature are truly enormous and cover a significant number of scientific and technical fields. For example, the use of such superconductors in computing and space technology will provide a multiple increase in performance, and their application in the construction of power lines will significantly reduce energy losses during transmission. Moreover, materials with the above properties will greatly simplify the design of sensors used for precision measurements. In this part, the sample with a copper winding will be used as a coil with an HTS core. The inductance L of such a coil strongly depends on the magnetic permeability of its core. When transitioning to the superconducting state, the magnetic permeability becomes zero. Therefore, the transition between the normal and superconducting states of the sample can be detected by a significant change in the coil's inductance over a small temperature interval.

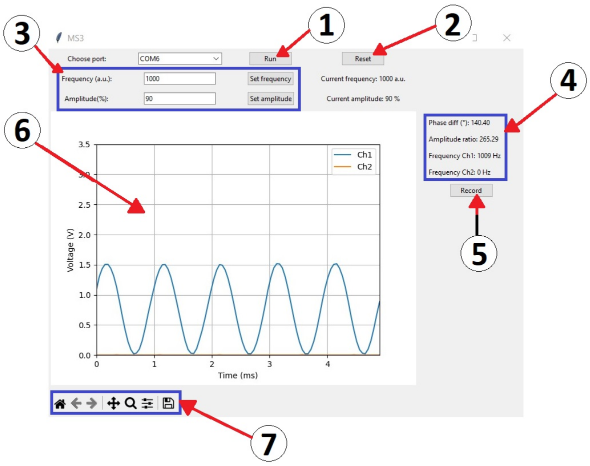
B1 Determine the resistance of the provided resistor R_0 .
Record the answer in ohms. **0.2**

Connect the coil in series with the resistor R_0. The coil, cooled to the boiling temperature of liquid nitrogen T_{LN_2} , is placed in the box. Due to slow heat exchange, it heats up, making it possible to calculate the dependence of its inductance on temperature $L(T)$ based on the measured quantities.

The figure shows the interface of the program used to plot oscillograms in the circuit of the series connection of the coil and resistor. The first channel corresponds to the voltage across the entire connection, and the second channel corresponds to the voltage across the resistor. Before starting measurements, ensure that the correct COM port is selected.

Main elements of the program:





Choose port: COM6

Frequency (a.u.): 1000

Amplitude(%): 90

Current frequency: 1000 a.u.

Current amplitude: 90 %

Phase diff (°): 140.40

Amplitude ratio: 265.29

Frequency Ch1: 1009 Hz

Frequency Ch2: 0 Hz

1. Button Run/Stop — starts/stops the program.
2. Button Reset — осуществляет сброс программы
3. Fields for entering the frequency and amplitude of the applied signal.
4. Current values of signal frequencies, as well as the amplitude ratio and phase shift of the two channels.
5. Button Record/Stop — activates/terminates the recording of the amplitude ratio and phase shift into the file « *record.xlsx* » as functions of time.
6. Scalable field with oscillograms.
7. Control panel for the field.

Note: If the program does not work correctly (e.g., no oscillograms appear when the Run button is pressed), perform a reset by pressing the Reset button in the program window. If this action does not help, press the Reset button on the board itself.

Attention: When re-recording into the file «*record.xlsx*» using the Record/Stop button, the old data will be deleted. To save them, rename the recording file.

Frequency range: 110 – 2000.

Amplitude range: 0 – 100.

B2 Obtain the desired dependence $L(T)$. You can use all the functionality of the program. Fill the spreadsheet «*B2.xlsx*» and submit it as your answer. **3.0**

B3 Repeat the above steps, replacing heating with cooling. Fill the spreadsheet «*B3.xlsx*» and submit it as your answer. **3.0**

B4 Plot the graphs of the dependencies from the two previous points and determine the phase transition temperature from the normal state to the superconducting state for YBCO. **1.0**
Fill the spreadsheet «*B4.xlsx*» and submit it as your answer.