MEASUREMENTS OF THERMAL CONDUCTIVITY AND MAGNETIC SUSCEPTIBILITY OF (BI$_{1.6}$ PB$_{0.4}$)SR$_2$CA$_2$CU$_3$O$_X$ SUPERCONDUCTOR AT ROOM TEMPERATURE.

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1. INTRODUCTION:

Certain substances, when cooled below a very low temperature, completely loose all trace of electrical resistance in static electric field. This effect is known as superconductivity and such materials are called superconductors. The fascinating properties of superconductivity are the infinite current flow, zero electrical resistance, and perfect diamagnetism. In 1908 the scientist Kamerlingh Onnes at the University of Leiden in Netherland discovered the very first superconductor mercury. Superconductivity has a certain reaction to an external magnetic field. When a superconductor is cooled below its transition temperature in presence of external magnetic field, it expels all magnetic flux from its interior, acting like a perfect diamagnetic material. This observation is mostly used to identify the superconducting state of a superconductor.

Because of high cryogenic cost for application, the quest for finding higher transition temperature superconductor was accelerated worldwide. In 1986, with the discovery of Superconductivity in a compound La-Ba-Cu-O with transition temperature $T_c > 30$ K by Bednorz and Muller, the widespread interest in high temperature superconductivity began in the CuO$_2$ plane. Subsequently, a great effort was made on a worldwide scale to investigate other components containing Cu-O planes. This effort was quickly rewarded with the discovery in 1987 of superconductivity of over 90 K in the compound YBa$_2$Cu$_3$O$_{6+x}$. The same year, another superconductivity compound Bi-Sr-Ca-Cu-O was discovered. Two superconducting phases were characterized as Bi$_2$Sr$_2$CaCu$_2$O$_{8+y}$ (Bi-2212) and Bi$_2$Sr$_2$Ca$_2$Cu$_3$O$_{10+y}$ (Bi-2223) with the critical temperature about 80 K and 110 K respectively. A little later, in 1988, another increase was found in a compound with the same critical structure, Tl$_2$Ba$_2$Ca$_2$Cu$_3$O$_{10}$ (Ti-2223) with the critical temperature T_c =125 K. In 1993, a similar compound, HgBa$_2$Ca$_2$Cu$_3$O$_{8+y}$, was found to have a yet high T_c of 133 K. Application of high temperature superconductors gives low cryogenic cost because of cheap liquid N$_2$ (77 K).

2. EXPERIMENTAL TECHNIQUES:

2.1 CONSTRUCTION OF THERMAL CONDUCTIVITY APPARATUS

As the sample is in ceramic texture, an apparatus was devised based on divided bar technique, known as Forbes method. A heat source and a heat sink are the main parts of Forbes apparatus which is based on axial heat flow through the divided bar. The below figure 1 shows the schematic divided bar arrangements of the sample.

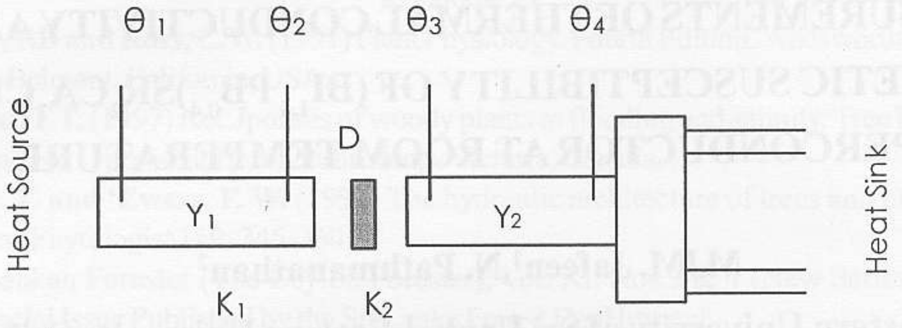

Figure 1. Divided bar apparatus. Y_1, Y_2 –length of brass rod; K_1-thermal conductivity of brass; $\theta_1, \theta_2, \theta_3, \theta_4$- equilibrium temperatures; D-thickness of specimen; K_2-thermal conductivity of specimen to be determined.

One end of the first rod is heated to a constant temperature θ_1 while θ_4 is the temperature of the cooled end of the second rod. In the steady state, θ_2 and θ_3 shows the temperature of two faces of the specimen disc. The heat flow through a specimen per unit area and per unit time is given by

$$H = K\frac{d\theta}{dx}$$

Where H is the heat flow per unit area and per unit time, K is the thermal conductivity of specimen and $\frac{d\theta}{dx}$ is the instantaneous temperature gradient of the specimen.

From figure 1, the equilibrium heat flow is given by

$$H = \left(\frac{K_1}{Y_1}\right)(\theta_1 - \theta_2) = \left(\frac{K_1}{Y_2}\right)(\theta_3 - \theta_4) = \left(\frac{K_2}{D}\right)(\theta_2 - \theta_3).$$

Also $(\theta_1 - \theta_4) = (\theta_1 - \theta_2) + (\theta_2 - \theta_3) + (\theta_3 - \theta_4).$

$$(\theta_1 - \theta_4) = \left(\frac{Y_1}{K_1} + \frac{Y_2}{K_1} + \frac{D}{K_2}\right) = K_1\frac{d\theta}{dx}(B_1 + \frac{D}{K_2}),$$

and solving for $K_2 = \frac{D}{\frac{C_1}{d\theta/dx} - B_1}$.Where $B_1 = \frac{Y_1 + Y_2}{K_1}, C_1 = \frac{\theta_1 - \theta_4}{K_1}$

Figure 2. shows the constructed thermal conductivity apparatus. As in Figure 2, two brass rods of 24 mm diameter and 10 cm length were placed coaxially, inside two separate cylindrical aluminum boxes of 10 cm diameter and 15 cm length each. With the proper support to the base unit, the whole apparatus was arranged vertically with the specimen disc. The upper end was provided heat by electrical arrangement and lower end of the second rod was provided with cooling arrangement. Thermometers attained the steady state temperatures between 40 to 60 minutes. At steady state temperature measurements were recorded. These measurements were made for the samples glass and rubber of known thermal conductivity. Then the similar measurements were made on **$(Bi_{1.6}, Pb_{0.4})Sr_2Ca_2Cu_3O_X$** superconductor.

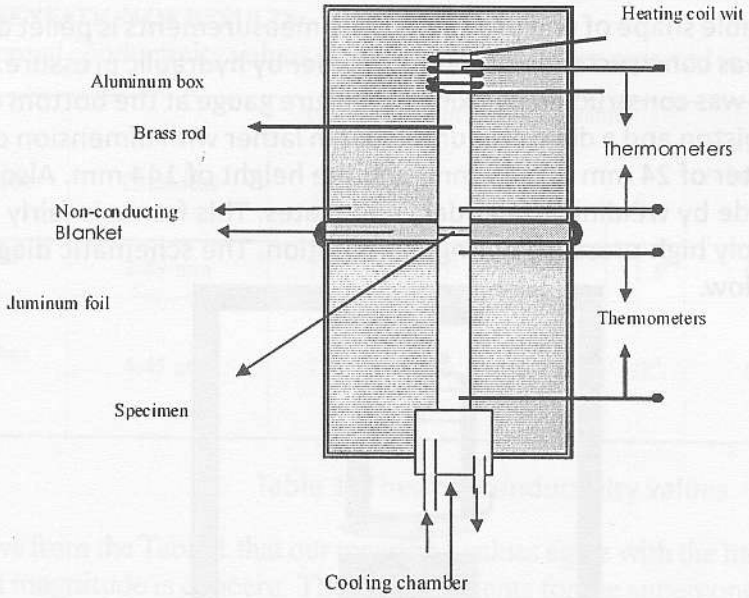

Figure 2. Apparatus devised for measurement of thermal conductivity.

2.2 MAGNETIC SUSCEPTIBILITY APPARATUS

For the measurement of magnetic susceptibility of the sample at room temperature, a locally made apparatus was used based on Guoy's observation of force that exerted on the sample is suspended half way into an external magnetic field. As in the Figure 3., the weight difference of the sample with respect to magnetic filed difference is given as in terms of magnetic susceptibility of the medium (air)(χ_1) and the sample (χ_2), permeability of vacuum($\mu_{0)}$ and cross sectional area of the sample(a),

$$(m_2 - m_1)g = \frac{\mu_0(\chi_2 - \chi_1)a(H^2 - H_0^2)}{2}.$$

The clawed cylindrical rod of 24 mm length and 27.5 mm^2 cross section was vertically suspended as in the Figure 3. By adjusting input D.C. current of the coil, the effect of mass difference due to magnetic force on the sample and respective flux density were measured by electronic balance and Tesla meter respectively. For the observation of force, a telescope was focused at the lower end of the sample.

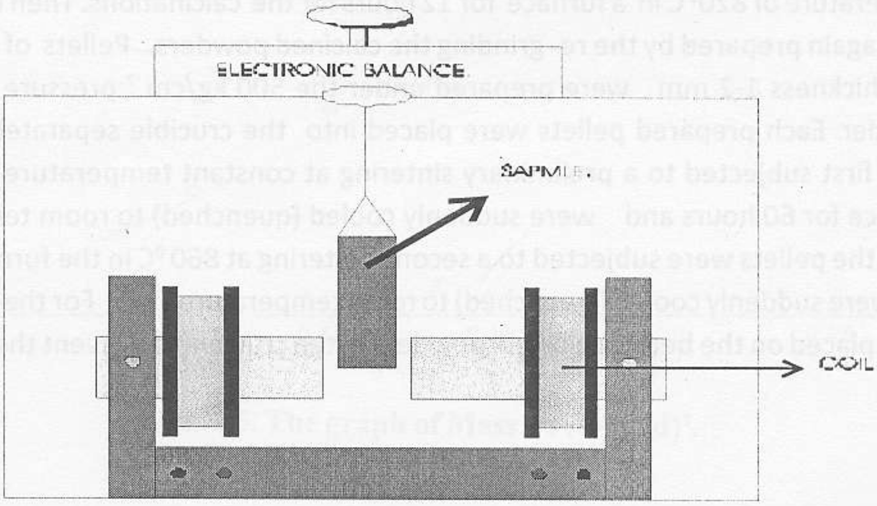

Figure 3. Apparatus designed for measurement of magnetic susceptibility.

2.3 CONSTRUCTION OF PELLETIZER

As the preferable shape of end product for the measurements is pellet of diameter 24 mm, a pelletizer was constructed to press the powder by hydraulic pressure. For this, a pressure gauged jack was constructed by fixing a pressure gauge at the bottom of a 10-Ton hydraulic jack and a piston and a die were turned out in lather with dimension of the inner and the outer diameter of 24 mm and 63 mm, and the height of 144 mm. Also, a metallic frame was firmly made by welding iron girders and plates. This frame is fairly height and strong enough to apply high pressure during pelletization. The schematic diagram of the pelletizer is given below.

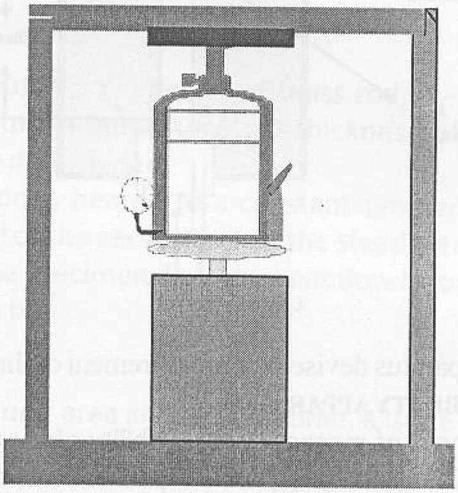

Figure 4. Apparatus designed for palletization of sample

2.4 PREPARATION OF $(Bi_{1.6}Pb_{0.4})Sr_2Ca_2Cu_3O_Y$ SUPERCONDUCTOR

The $(Bi_{1.6}Pb_{0.4})Sr_2Ca_2Cu_3O_Y$ Superconductor is a Poly–crystalline cuprate high temperature superconductor is prepared by Solid State Reaction Techniques. Bi_2O_3,PbO,$SrCO_3$,$CaCO_3$ and CuO powders of 99% Purity were used as starting raw materials. The starting raw materials with nominal cation ratio Bi:Pb:Sr:Ca:Cu=0.8:0.2:1.0:1.0:1.5 of 1/20 Mole were weighted to an accuracy of 0.1 mg. After thorough mixing of these chemicals, mixture was grinded to fine powders in dried form with the help of motor and pestle. Then the grinded powders were fired at constant temperature of 820^0 C in a furnace for 12 hours for the calcinations. Then the fine powders were again prepared by the re- grinding the calcined powders. Pellets of diameter 24mm and thickness 1-2 mm were prepared under the 500 kg/cm ^{2} pressure by constructed Pelletier. Each prepared pellets were placed into the crucible separately. Then, pellets were first subjected to a preliminary sintering at constant temperature of 830 ^{0}C in the furnace for 60 hours and were suddenly cooled (quenched) to room temperature in air. Then the pellets were subjected to a second sintering at 860 ^{0}C in the furnace for 60 hours and were suddenly cooled (quenched) to room temperature in air. For the sintering, Pellets were placed on the bed of calcined powders in the crucible to prevent the contamination.

3. PRESENTATION OF RESULTS:

The thermal conductivity values at room temperature are reported in Table 1.

Sample	Thickness	Average equilibrium Temperature / ^0c				Measured value $Wm^{-1}\,{}^0c^{-1}$	Literature Value $Wm^{-1}\,{}^0c$
		θ_1	θ_2	θ_3	θ_4		
Glass	2.89 mm	75^0	70.5^0	35^0	31.5^0	0.3669	0.8
Rubber	4.45 mm	77^0	75^0	33.5^0	32^0	0.1730	0.2070

Table 1. Thermal conductivity values

It follows from the Table 1 that our measured values agree with the literature values so far as the order of magnitude is concern. The measurements for the superconducting sample values are reported in Table 2.

Sample	Thickness	Average equilibrium temperature / ^0c				Measured value $W\,m^{-1}\,{}^0c^{-1}$
		θ_1	θ_2	θ_3	θ_4	
Bi(Pb)SrCaCuO	2.55 mm	78.917	75.083	34.083	32	0.1573±0.0007

Table 2. Thermal conductivity value of Bi- based superconductor

In order to find the magnetic susceptibility value of the sample at room temperature, a linear relation between the mass measurements of the electronic balance and (B- Field)^2 is plotted in Figure 5.

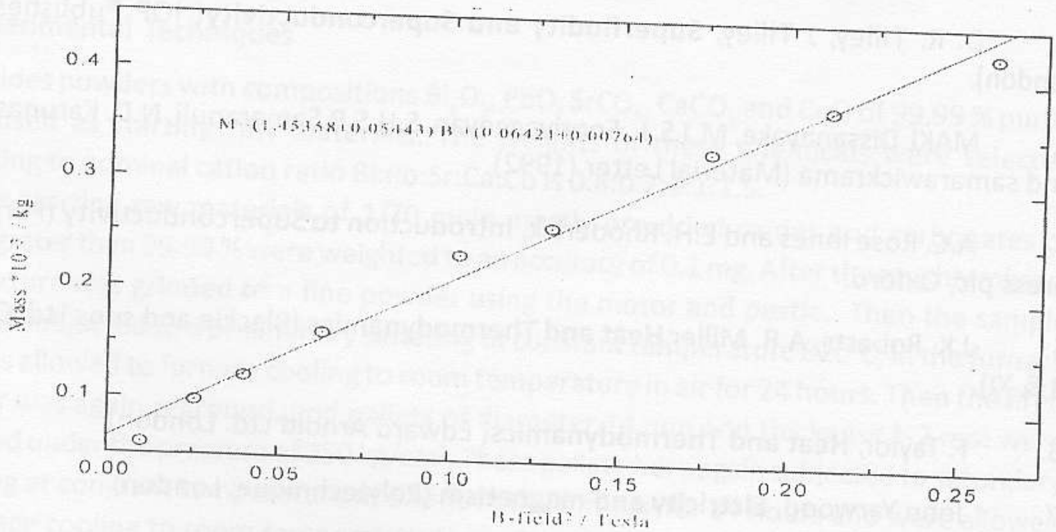

Figure 5. The graph of Mass Vs (B-field)^2.

The Magnetic susceptibility value of the sample is reported in Table 3.

Material	Measured vale
Bi(Pb)SrCaCuO	$(1.3473 \pm 0.0497)\times 10^{-3}$

Table 3. Magnetic susceptibility value of Bi- based superconductor.

4. Conclusions:

An apparatus based on Forbes method was constructed to measure the thermal conductivity of high T_c superconductor

1. In order to find the accuracy of the apparatus, the measurements of thermal conductivity of glass and rubber of known thermal conductivity were measured and found to be 0.8 $Wm^{-1}\,{}^0C^{-1}$ and 0.207 $Wm^{-1}\,{}^0C^{-1}$ respectively. Thermal conductivity of rubber is in good agreement with the literature value.

2. Using this apparatus the thermal conductivity of the $(Bi_{1.6},Pb_{0.4})Sr_2Ca_2Cu_3O_x$ superconductor was determined at room temperature and found to be 0.1573 $Wm^{-1}\,{}^0C^{-1}$.

3. The magnetic susceptibility of the $(Bi_{1.6},Pb_{0.4})Sr_2Ca_2Cu_3O_x$ superconductor was also measured at room temperature and found to be 1.3473×10^{-3} and confirmed that this sample is paramagnetic at room temperature.

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