III.10. DETERMINATION OF THE CURIE TEMPERATURE FOR FERRIMAGNETIC MATERIALS

1. Work purpose

The determination of the Curie temperature for ferrites.

2. Theory

The magnetism of the substances is due to the presence and orientation of the individual magnetic momenta of their constituents. For the magnetic materials, there are two types of magnetization: **permanent**, if the material is intrinsically magnetized, regardless to the presence of an external magnetic field, and **temporary**, if the magnetic properties appear only under the action of an external magnetic field.

According to the temporary magnetization law: $\vec{M} = \vec{M}\left(\vec{H}\right)$, there are two types of magnetic materials:

a) **Quasi-linear** magnetic materials, for which $\vec{M} = \chi\vec{H}$, where χ is a material constant, called *magnetic susceptivity*. Into this category enter:

- **Diamagnetic** materials, for which $-1 << \chi < 0$, χ being practically independent on temperature.

- **Paramagnetic** materials, for which $0 < \chi << 1$. These are substances whose atoms have non-zero magnetic momenta, randomly oriented due to the thermal agitation. An external magnetic field can partially order them in its direction, but the magnetization will be very weak. For high temperatures and weak fields, the magnetic susceptivity obeys Curie's law:

$$\chi = \frac{const.}{T}. \qquad (1)$$

b) **Non-linear** magnetic materials, for which the magnetic susceptivity strongly depends upon the external field. Into this category enter:

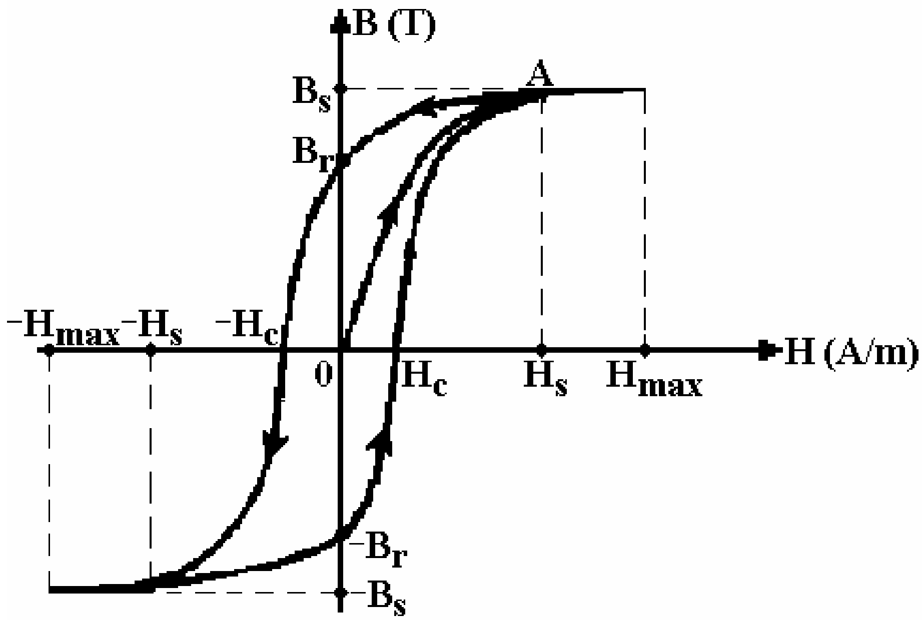

Figure 1.

- **Ferromagnetic** materials, characterized by a very large and positive magnetic susceptivity. The magnetization curve $\vec{M} = f(\vec{H})$is called, in this case, **hysterezis curve (cycle**) (see Figure 1), characterized by the following quantities: H_c – coercive magnetic field intensity, B_r – remnant magnetic field induction, B_s – saturation magnetic field induction. Weiss's theory explains ferromagnetism by the existence of quantum interactions between the atomic magnetic momenta in the crystalline lattice. Due to these interactions, there appear regions of spontaneous magnetization, called **Weiss domains**, characterized by the parallel alignment of the magnetic momenta. However, the spontaneous magnetization has a different orientation from one domain to another, such that the resulting magnetic moment is null (see Figure 2). When the magnetic material is placed into a magnetic field, the volume of the domains with unfavorably oriented magnetization diminishes, while the volume of the domains with the magnetization oriented almost parallel with the external field increases. The thermal vibrations of the atoms act against the alignment process and, above a certain temperature, specific for each substance, the domains of spontaneous magnetization disappear and the substance passes from ferromagnetic to paramagnetic state (the non-linear magnetic properties disappear). This temperature is called **the Curie point**; its value is, for instance, 770 ^{o}C for Fe, 1115 ^{o}C for Co and 358 ^{o}C for Ni. For ferromagnetic substances, the temperature dependence of the susceptivity in the paramagnetic phase is given by the Curie-Weiss law:

$$\chi = \frac{C}{T - T_C}, \tag{2}$$

where the Curie constant C and the Curie temperature T_C are material constants. $T_C = \lambda C$, where λ is the molecular field constant.

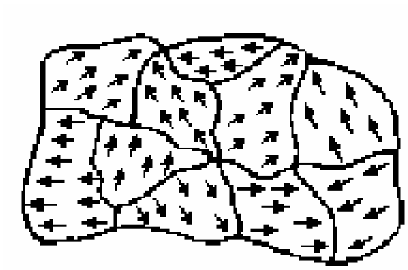

Figure 2.

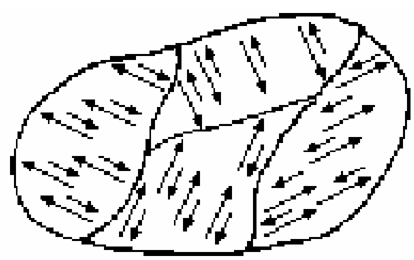

Figure 3.

- **Ferrimagnetic** materials. Ferrimagnetism looks a lot like ferromagnetism and is characteristic for **ferrites**, which are semiconductor magnetic materials, whose general chemical formula is $MeOFe_2O_3$, where Me is a bivalent ion of a transition metal in Fe period: Fe^{2+}, Co^{2+}, Ni^{2+}, Cu^{2+}, Zn^{2+} etc. One considers that the Me^{2+} and Fe^{3+} ions are distributed on two sub-lattices in the macroscopic crystal. In a spontaneous magnetization domain, the two sub-lattices have anti-parallel magnetic momenta (see Figure 3). The magnetic momenta of the two sub-lattices are not equal, so that their resultant is non-zero. Just as for ferromagnetic substances, above a certain temperature, characteristic for each ferrite, which is called **the ferrimagnetic Curie point**, the body turns from a ferrimagnet into a paramagnet. For ferrites, the Curie point is generally lower than for ferromagnetic substances (for instance: 300 °C for $MnFe_2O_4$, 520 °C for $CoFe_2O_4$, 440 °C for $MgFe_2O_4$).

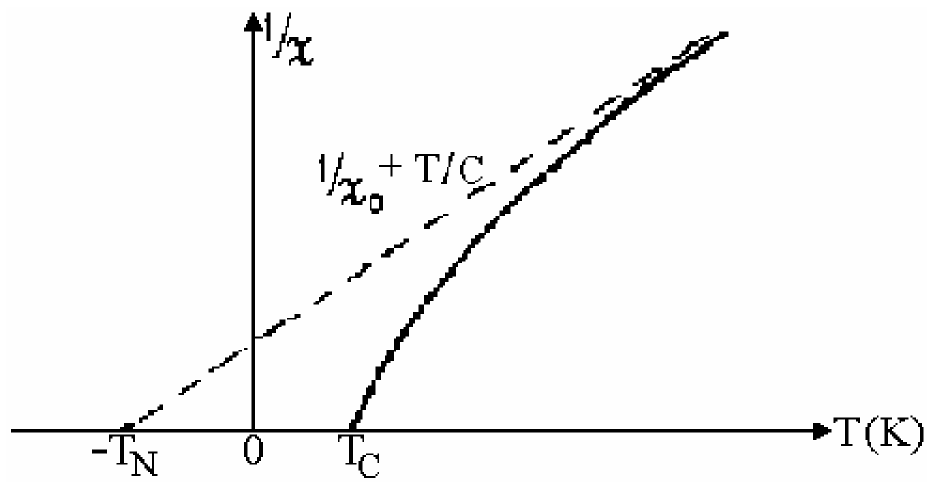

Figure 4.

Above the critical temperature, the temperature dependence of the ferrimagnetic materials susceptivity is given by:

$$\frac{1}{\chi} = \frac{1}{\chi_0} + \frac{T}{C} + \frac{\sigma}{T - T_a}, \tag{3}$$

where χ_0, C, σ, and T_a are material constants (see Figure 4). Another convenient expression for the susceptivity is:

$$\chi = \frac{T_0\,(T - \theta)}{(T + T_N)(T - T_C)}, \tag{4}$$

where $T_0 << T_N < \theta < T_C$ (see Figure 4). T_N is called Néel temperature and θ Domb-Fisher temperature.

3. Experimental set-up

In order to determine the Curie point, we use a transformer with a primary winding P and two secondary windings S_1 and S_2, concentric with the primary winding. The primary winding is supplied by the self-transformer S (it is possible to supply it directly from the plug). The secondary windings are connected in series and opposition. Between them there is a current measuring device – in this case we use a millivoltmeter V, but we could also have used a microammeter – and a germanium rectifying diode D. As the two windings S_1 and S_2 are practically identical, the voltages induced in them compensate and millivoltmeter indicates zero. However, if we place inside one of the secondary windings (e.g. in S_1) a ferrite bar F, the symmetry of the two windings is broken, as the voltage of S_1 becomes larger than the voltage of S_2; the instrument will indicate a certain voltage (or current). This depends on the size and shape of the ferrite, its magnetic susceptivity, the windings physical characteristics (length, number of turns etc.), the voltage applied to the primary winding, the functioning parameters of the measuring device and of the diode etc. The ferrite bar F is inserted into a small furnace H, supplied, also from the self-transformer S (or directly from its plug, respectively), through a switch K. The temperature is indicated by the thermometer T. By gradually increasing the temperature, the magnetic permeability of the ferrite will diminish; correspondingly, the deviation on the millivoltmeter will decrease, becoming practically zero after reaching the Curie point.

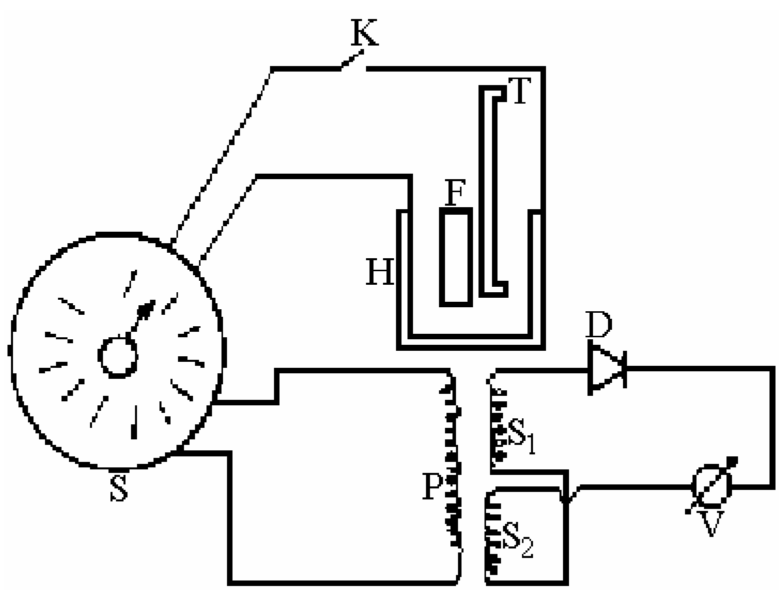

Figure 5.

4. Working procedure

After familiarizing with the set-up, one proceeds to the heating up of the furnace by switching on K. The initial deviation is written down.

The increase of the temperature in the furnace is a relatively slow process, such that each determination is made in quasistationary conditions and so there is no need for a thermostat. Simultaneous readings of the temperature *t* indicated by the thermometer and of the voltage *u* indicated by the millivoltmeter will be performed. The readings will be made every 5 ^{o}C, starting from the first mark on the thermometer above the furnace lid. We will observe that the voltage is rather constant, up to a certain temperature, then it starts decreasing. The decrease is first slow, then fast and then slow again, the voltage asymptotically approaching zero. When we have overpassed the rapid decrease region, 4 – 5 more measurements are performed (under the condition that the temperature **must not exceed 200 ^{o}C**), then the furnace is switched off. Due to the its thermal inertia, the temperature still increases with a few degrees, then starts decreasing. During the cooling, the readings for *u* will be performed again, for the same temperatures as during the heating. The data are written in Table 1:

Table 1

No.	*t* (^{o}C)	*u* (V)		
		Heating	Cooling	Mean
1.				
2.				
...				

5. Experimental data processing

Using the data from the table, plot on millimetric paper the dependence $u = u(t)$. The dependence $u(t)$ is actually given by the dependence of the spontaneous magnetization of the ferrite on the temperature; the theoretical curve $M_S = f(t)$ is shown on Figure 6.

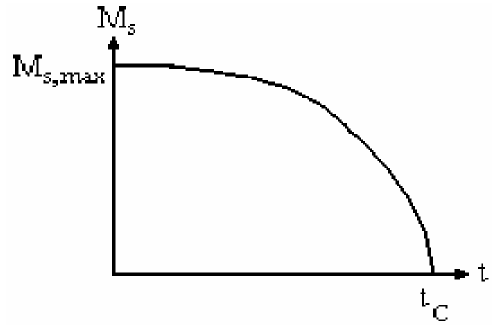

Figure 6.

The real characteristics are shown in Figure 7. Due to the different heat capacities of the ferrite and the thermometer, an apparent hysterezis cycle is produced. In fact, the thermometer heats and cools quicker than the ferrite, so that the real temperature for a given voltage is the mean one.

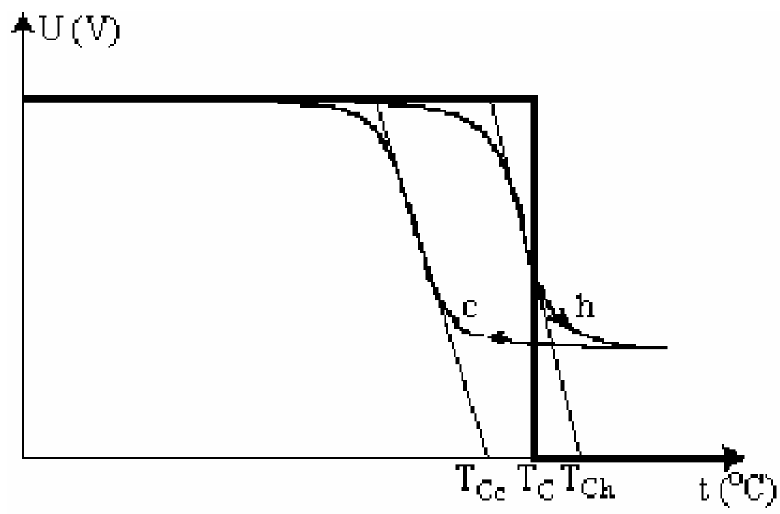

Figure 7.

Two distinctive curves, one for heating and one for cooling, respectively, will be plot. They have to have a smooth, continuous appearance. The tangents to each curve at the inflexion points will be drawn. Two values of the temperature will be obtained at their intersections with the abscise axis; their mean is the Curie temperature.