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Udai Pratap (Autonomous) College, Varanasi

E-learning Material

Module/ Lecture	**08**
Topic	**Magneto-Caloric Effect**
Developed by	*Dr. Devendra Kumar Singh* *Assistant Professor,* *Physics Department,* *Udai Pratap (Autonomous) College, Varanasi*

Magneto-Caloric Effect

Paramagnetic salts have small but positive value of magnetic susceptibility. When the magnetization of such a substance is changed adiabatically, its temperature changes and when the magnetization is changed isothermally, heat exchanges with surroundings; such a combined effect of magnetic and thermal properties is called magneto-caloric effect.

When a paramagnetic salt is placed in a magnetic field H, the intensity of the magnetization changes by an amount, say dM. Thus the work done by the magnetic field on the substance is HdM (Magnetic field does a work on the system so that magnetic dipoles are aligned in the direction of field against a nonalignment tendency due to their thermal motion). So that from 1st and 2nd laws of thermodynamics

$\delta Q = \delta W + dU$ with $\delta Q = TdS$ and $\delta W = -HdM$ we get

$$TdS = dU - HdM$$

i.e. $$dU = TdS + HdM \tag{1}$$

The Eqn. (1) is similar to equation $dU = TdS - pdV$ except that p is replaced by –H and V is replaced by M. Hence Maxwell's Equations can be used.

Now if S=S (T, H)

$$dS = \left(\frac{\partial S}{\partial T}\right)_H dT + \left(\frac{\partial S}{\partial H}\right)_T dH$$

$$TdS = T\left(\frac{\partial S}{\partial T}\right)_H dT + T\left(\frac{\partial S}{\partial H}\right)_T dH \tag{2}$$

Now

$$T\left(\frac{\partial S}{\partial T}\right)_H = \left(\frac{T\partial S}{\partial T}\right)_H = \left(\frac{\delta Q}{\partial T}\right)_H = C_H \qquad (3)$$

Where C_H is molar specific heat of salt at constant H.

Using Maxwell's Equation $\left(\frac{\partial S}{\partial p}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_p$ we have similar relation

$$\left(\frac{\partial S}{\partial H}\right)_T = \left(\frac{\partial M}{\partial T}\right)_H \qquad (4)$$

Using Eqs. (3 & 4) we get from Eqn. (2)

$$TdS = C_H dT + T\left(\frac{\partial M}{\partial T}\right)_H dH \qquad (5)$$

This is the basic equation for magneto-caloric effect.

Case-I: for the salt isothermal process, dT=0, we get from Eqn. (5)

$$TdS = T\left(\frac{\partial M}{\partial T}\right)_H dH \qquad (6)$$

The derivative $\left(\frac{\partial M}{\partial T}\right)_H$ is a measure of the change in alignment of a system of magnets due to a change in temperature (disordering effect) when the external magnetic field (ordering effect) is kept constant. Thus this derivative will be negative.

Since $\left(\frac{\partial M}{\partial T}\right)_H = -ve$, thus . $\delta Q = TdS$ =-ve, hence heat goes out during the isothermal magnetization.

Also we can prove that heat is required for isothermal demagnetization.

Case-I: for the adiabatic process, i.e. $\delta Q = TdS = 0$, we get from Eqn. (5)

$$0 = C_H dT + T\left(\frac{\partial M}{\partial T}\right)_H dH$$

Thus $$dT = -\frac{T}{C_H}\left(\frac{\partial M}{\partial T}\right)_H dH \qquad (7)$$

Thus if H is reduced (demagnetization) i.e. if dH=-ve and since $\left(\frac{\partial M}{\partial T}\right)_H = -ve$ always , it follows from Eqn. (7),

$$dT = -ve$$

Thus adiabatic demagnetization will always result in cooling. Similarly we can show that adiabatic magnetization will result in heating.

Equations (6) and (7) show combined effect of magnetic and thermal properties which is known as magneto-caloric effect.