

Quadrant II – Notes

Programme : Bachelor of Science (Third Year)
Subject : Physics
Paper Code : PYC 105
Paper Title : DSC: Classical Mechanics and Thermal Physics – Section II
Unit 2 : Production of Low Temperature
Module Name : Cooling by adiabatic demagnetization of paramagnetic substances
Module No : 11
Name of the Presenter: Dr. Mathias Bosco Lawrence

- In this module, we will study the attainment of very low temperatures through the process of adiabatic demagnetization of paramagnetic substances. We will describe the apparatus used and the procedure involved. Finally, the process will be briefly explained using the T-S indicator diagram.
- The experimental set-up consists of a vessel A that contains the paramagnetic salt. The vessel is surrounded by a Dewar flask D₁ containing liquid Helium. The liquid Helium is boiled under reduced pressure. D₁ is surrounded by Dewar flask D₂ containing liquid Hydrogen. The entire apparatus is surrounded by pole pieces of a powerful magnet.

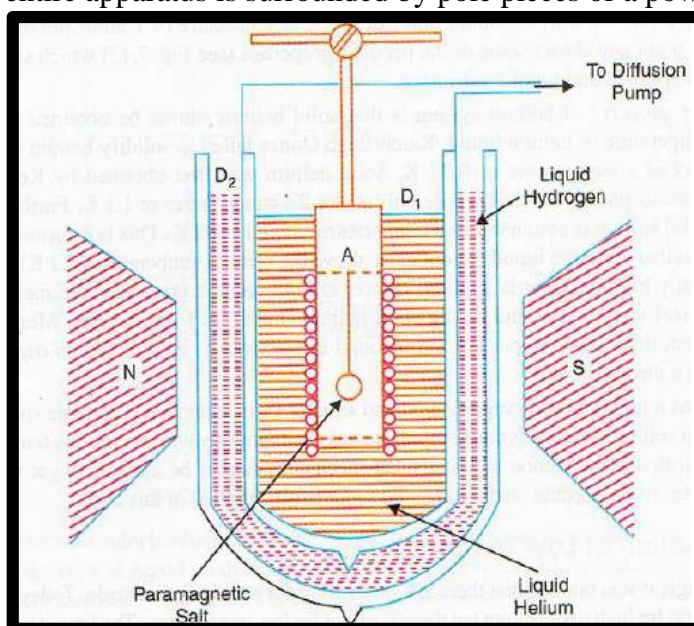


Fig.: Arrangement for cooling by adiabatic demagnetization of a paramagnetic salt
< Lal, B., Subrahmanyam, N., Hemne, P.S. (2012). *Heat, Thermodynamics and Statistical Physics*, S. Chand Publishing >

- A magnetic field of 30000 Gauss is applied leading to the magnetization of the paramagnetic salt. The magnetization causes generation of heat which is removed through the introduction of Hydrogen gas into A. Later, the Hydrogen gas is pumped out. The salt attains the temperature of liquid Helium. After some time, the magnetic field is switched off. This leads to adiabatic demagnetization which decreases the temperature of the salt.
- The fall in temperature is given by the equation:

$$\Delta T = \frac{CV}{2C_B T} [H_2^1 - H_1^2]$$

In the above equation, C = Curie constant.

V = molar volume of the salt.

C_B = specific heat of the substance at constant magnetic field H.

T = Temperature of the paramagnetic salt.

H₁ = Initial magnetizing field.

H₂ = Final magnetizing field.

- When the magnetic field is switched off, its value drops from H₁ to 0. This causes temperature change to be given by the equation:

$$\Delta T = \frac{CV}{2C_B T} [-H_1^2]$$

- The negative sign points to the reduction of temperature when the magnetic field is switched off. From the equation, it is observed that the fall in temperature is directly proportional to the initial field and inversely proportional to initial temperature.
- Using this method, a temperature of 0.002°K was attained with the double sulphate of potassium and aluminium. Similarly, powdered mixed crystals of chromium alum and aluminium alum allowed attainment of 0.0014°K.

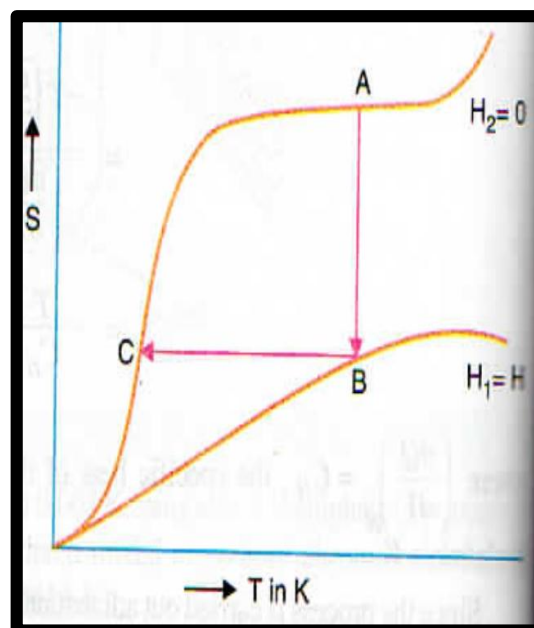


Fig.: T-S diagram of adiabatic demagnetization process for a paramagnetic salt
 < Lal, B., Subrahmanyam, N., Hemne, P.S. (2012). *Heat, Thermodynamics and Statistical Physics*, S. Chand Publishing >

- The temperature-entropy diagram can be used to explain the process of cooling by adiabatic demagnetization of a paramagnetic salt. In the diagram, the entropy is shown for two different magnetizing fields ($H_2 = 0$ and $H_1 = H$). The arrow AB shows the change in entropy during isothermal demagnetization at constant temperature. AB represents decrease in entropy during magnetization. When the magnetic field is switched off, the paramagnetic salt demagnetizes adiabatically. The fall in temperature occurs at constant entropy (arrow BC).
- The reference book for this module is “Heat, Thermodynamics and Statistical Physics” by Brij Lal, Subrahmanyam and Hemne.