



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 6, June 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118



9940 572 462



6381 907 438



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Experimental Study of AC Conductivity of Potassium Chloride Sintered with Alundum

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ABSTRACT: Ionic crystals with high purity show a frequency independent slow temperature variation of dielectric constant up to a certain temperature and a frequency dependent larger variation at higher temperatures. In this paper, dielectric constant, the dielectric loss and A.C. conductivity have been measured on potassium chloride mixed with alundum from low frequency upto 20MHz and also its temperature variations are studied. The conductivity (σ) is given by

$$\sigma = ne\mu,$$

where n is the concentration of defects, e the charge and μ the mobility of the defect. Substitution for n from the theory of ionic conductivity, the observed conductivity has been given as

$$\sigma = A_1 \exp\left(-\frac{E_M}{k_B T}\right) + A_2 \exp\left(-\frac{E_M + E_f/2}{k_B T}\right)$$

where, A_1 and A_2 are constants for a given crystal and k_B the Boltzmann constant. Measurement of dielectric constant and loss as a function of frequency and temperature helps in understanding the polarization mechanism, process of conduction, influence of impurities and phase transition. AC conductivity obtained from the dielectric properties combined with the data on DC conductivity yields useful information on defect formation and nature of conduction.

Keywords: A.C. Conductivity, Electrical Conductivity, Dielectric Constant, Polarization Mechanism and Phase Transition .

I. INTRODUCTION

The electrical conductivities of materials range from those of superconductors through those of metals and semiconductors to those of highly resistive insulators. Electrical conductivity can be classified into three categories:

Intrinsic conductivity: Charge carriers are generated in the material based on its chemical structure only¹.

Extrinsic conductivity: Charge carriers are generated by impurities in the material, which may be introduced into it by fabrication processes or deliberately doped into it for a specific purpose.

Injection-controlled conductivity: Charge carriers are injected into the material mainly from metallic electrodes through a metal-material interface. As far as insulators are concerned, the origin of the charge carriers for intrinsic or extrinsic conductivity is by no means clear. In the topic, we shall cover only electrical conduction in dielectric solids, just a fraction of the large volume of work on electrical conduction and discuss generally applicable principles in hopes of providing a framework for an understanding of this diverse behavior. At low fields this means at average applied fields F (i.e., the applied voltage V divided by the specimen thickness d) lower than the threshold

(or critical) field F_{th} for switching on significant injection of carriers from the carrier injecting contacts electrical conductivity follows the empirical equation given by

$$\sigma = \sigma_0 \exp(-E_\sigma/kT)$$

where σ_0 is the preexponential factor and E_σ is the activation energy. Neither the interpretation of σ_0 nor E_σ is straightforward, it is rather ambiguous because electrical conduction involves various transport processes. The basic equation for total conductivity can be written as²

$$\begin{aligned} \sigma_T &= q(\mu_n n + \mu_p p) + q(\mu_- n_- + \mu_+ n_+) \\ &= \sigma + \sigma_{ion} \end{aligned}$$

where n and p are, respectively, the concentrations of electrons and holes, μ_n and μ_p are, respectively, the average mobilities of electrons and holes, n_- and n_+ are, respectively, the concentrations of negative and positive ions, μ_- and μ_+ are, respectively, the average mobilities of negative and positive ions and σ and σ_{ion} are, respectively, the electronic and ionic conductivities. Under certain conditions, electrical conduction may involve both electronic and ionic conduction. For ionic crystals, ionic conduction is mainly intrinsic because the crystals have thermally created vacant sites in the lattice through which host ions can move. The simplest types of thermally created vacant sites³ (lattice defects) are the well known Frenkel and Schottky defects. A Frenkel defect is formed when an ion originally at a lattice site moves to an interstitial position, which implies that this process generates two imperfections: a vacancy in the lattice and an interstitial ion. A Schottky defect is formed when an ion originally at a lattice site diffuses to a surface position, creating one imperfection: a vacancy in the lattice. Since the volume and the surface of a crystal must be electrically neutral, Schottky defects must be created in pairs: one vacancy created by displacing an anion and the other by displacing cation. It has been found that in most alkali halide ionic crystals, probability for the formation of Schottky defects is much higher than for Frenkel defects. It can be imagined that for large ions, vacant lattice sites must be present for the ionic movement, whereas small ions can move through the interstitial space. For nonionic solids, some structures may provide channels,⁴ allowing ions space to move. Ionic conduction is due simply to the transport of negative and positive ions. If the material contains several different species of ions, the ionic conductivity may be written as

$$\sigma_{ion} = q \sum_j \mu_j n_j$$

where μ_j and n_j are, respectively, the mobility and the concentration of ions⁵.

II. EXPERIMENTAL

The compound has been procured from Sigma-Aldrich (India), Bangalore. The chemical was grinded into the fine powder in an agate mortar, avoiding direct sunlight and preferably the most of the sample preparation was done at night. The pellets were prepared with compression machine (Flextural Testing Machine CAT No. AIM-313, S.No. 91070 AIMIL Associated, India), having pressure range 0-15 tonne wt/cm². A suitable die was used having rectangular Cross-Sectional area of the piston = 2.5 cm². The polishing of the pellets has been done to obtain smooth parallel surface to be used for electrode formation polishing of the crystal introduces electrical charges inside the material. These charges and strains are to be removed, which we did by the process of annealing of the sample. In this process the pellets were kept in a suitable furnace at nearly 2/3 of their melting points for sufficient times (generally 8-10 hours). The most of the irreproducibility was removed by annealing and therefore this process was necessarily done. The electrodes were formed using colloidal silver paints. The sample holder loaded with pellet is kept into the furnace such that it lies very near to the middle part of the furnace. A good quality thermometer, precisely calibrated is used to record the temperature. This thermometer is adjusted with the help of stand in such a way that it touches the metallic part of sample holder to record the exact temperature of sample. The usual substitution method i.e. with and without the specimen in suitable sample holder is used^{6,7}. The sample holder was

directly fastened to the capacity measuring unit (ZENITH-FM89A) and Q meter. The dielectric constant is calculated using the formula

$$\epsilon = 1 + \frac{\Delta C}{C_g}$$

where ΔC is the difference of the capacitance with the sample (C_s) and the capacitance without the sample (C_0). C_g is the geometrical capacitance of the sample. The geometrical capacitance is $\epsilon_0(A/t)$, ϵ_0 is the vacuum dielectric constant, A the area and t the thickness of the sample. For some measurement techniques, these parameters have to be measured in the presence and absence of the test sample, for other techniques only once in the presence of the test sample⁸.

III. RESULTS AND DISCUSSION

In ionic crystals, conduction is mainly due to the motion of defects. Depending on the nature of the crystal, the defects may be Schottky pairs (+ve and -ve ion vacancies) or Frenkel pairs (vacancies and ions in interstitial positions). Energy (E_f) is required to form a defect and, once a defect is created, energy E_M is required for its migration. The conductivity (σ) is given by

$$\sigma = ne\mu,$$

where n is the concentration of defects, e the charge and μ the mobility of the defect. Substitution for n from the theory of ionic conductivity, the observed conductivity has been given as⁹

$$\sigma = A_1 \exp\left(-\frac{E_M}{k_B T}\right) + A_2 \exp\left(-\frac{E_M + E_f/2}{k_B T}\right)$$

where, A_1 and A_2 are constants for a given crystal and k_B the Boltzmann constant. At low and moderate temperatures, only the first term is operative whereas at high temperatures the second term dominates. Measurement of dielectric constant and loss as a function of frequency and temperature helps in understanding the polarization mechanism, process of conduction, influence of impurities and phase transition as shown in Fig 1 and 2. AC conductivity obtained from the dielectric properties combined with the data on DC conductivity yields useful information on defect formation and nature of conduction^{10,11}.

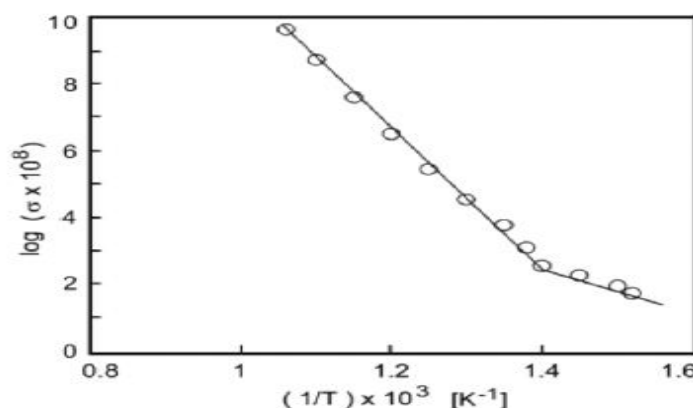


Fig.1: Plot of $\log \sigma$ vs. $(1/T)$ for KCl (DC measurement)

Crystal	Method	E_M [eV]	E_f [eV]	Ref.
KCl	DC	0.51	2.04	[5.107]
CaCO_3 a -axis	AC	0.11	1.88	[5.108]

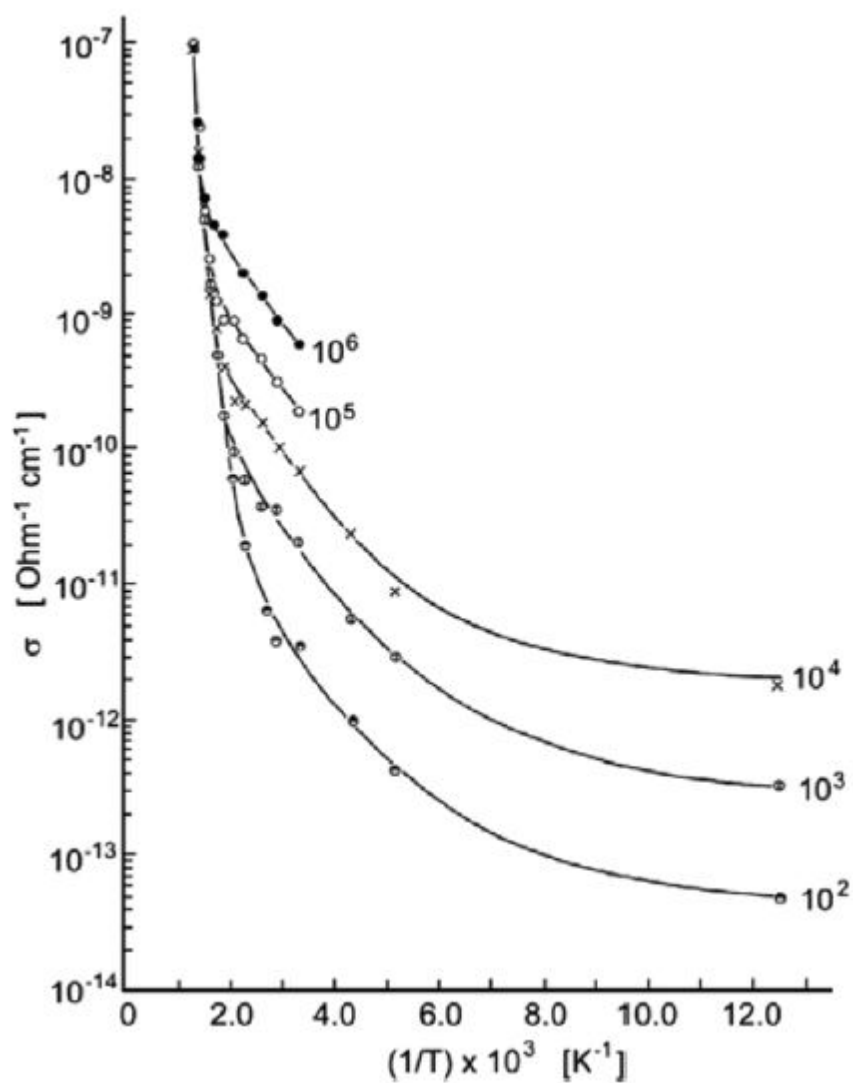


Fig.2 Plot of $\log \sigma$ vs. $(1/T)$ for calcite (a -axis) at different frequencies (Hz)



IV. CONCLUSION

A complex $\log \sigma$ vs. $(1/T)$ plot obtained from DC measurement of σ is shown in Fig.1. As expected, it consists of two linear regions, also σ can be obtained from measurement of dielectric loss. A typical plot of $\log \sigma$ vs. $(1/T)$ from AC measurements is shown in Fig.2. Here it is seen that the plot corresponding to the extrinsic region is frequency dependent. However, the slopes at different frequencies are nearly the same¹³.

ACKNOWLEDGEMENT

The authors are thankful to Head, Department of Physics, HNB GARHWAL University, Srinagar, Garhwal and The Principal, MGPG College Gorakhpur for providing experimental facilities and their encouragement.

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