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Activation Energy of Electrical Conductivity of Some Binary Crystals

Dr. Prakash Dubey and *Dr. Jyoti Bhadoriya
Department of Physics
Janta College, Bakewar, Etawah
CSJM University, Kanpur, U.P., India

*Department of Chemistry
Janta College, Bakewar, Etawah
CSJM University, Kanpur, U.P., India

Abstract

The electrical conductivity of binary crystals is significantly influenced by their atomic structure, bonding, and defects. Activation energy is the minimum energy required to excite charge carriers to contribute to electrical conduction. This paper focuses on investigating the activation energy in various binary crystals such as NaCl, ZnS, CdTe, and PbS. These materials demonstrate a broad range of conduction mechanisms, from ionic to electronic and defect-based conductivity. Using temperature-dependent conductivity measurements, activation energies were calculated and analyzed. The results shed light on the electronic structure and potential applications of these crystals in optoelectronics and sensor technologies.

Keywords

Activation energy, Binary crystals, Electrical conductivity, Semiconductor, Ionic conduction, Temperature dependence, CdTe, PbS, ZnS, NaCl, Arrhenius relation, Band gap.

1. Introduction

Binary crystals are composed of two distinct atomic elements, typically a metal and a non-metal, forming a periodic crystalline structure. These materials often exhibit ionic or covalent bonding, which profoundly impacts their electrical and optical behavior.

Understanding electrical conductivity and its temperature dependence is essential for applications in solid-state devices. The activation energy determines the thermal energy needed for charge carriers (electrons or holes) to become mobile. It is particularly crucial in semiconductors and insulators where intrinsic or defect-related conduction dominates.

The purpose of this research is to examine and compare the activation energies of selected binary crystals, and thereby understand their conduction mechanisms and practical implications.

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4. Results and Analysis

From the ln(σ) vs 1/T plots, the activation energy was calculated using the slope:
Slope = -Ea / kB

4.1 Observations:
NaCl: ~1.90 eV (Ionic)
ZnS: ~1.30 eV (Intrinsic)
CdTe: ~0.60 eV (Extrinsic)
PbS: ~0.30 eV (Narrow-gap Semiconductor)

4.2 Discussion:
NaCl has high activation energy due to its strong ionic bonds. ZnS displays intrinsic semiconductor behavior. CdTe shows lower activation energy due to extrinsic conduction. PbS, with the lowest bandgap (~0.4 eV), demonstrates conduction even at room temperature.

4.3 Graphical Representation: . Theoretical Background

Electrical conduction in solids can arise from various mechanisms, including:
- Intrinsic conduction: due to thermal excitation of electrons across the band gap.
- Extrinsic conduction: caused by impurities or doping, leading to conduction at lower temperatures.
- Ionic conduction: due to the migration of ions, as in ionic crystals.
- Polaronic or defect conduction: via hopping of charge carriers between localized states.

The general expression for temperature dependence of electrical conductivity follows the Arrhenius relation:

$$\sigma(T) = \sigma_0 \cdot \exp(-Ea / kB \cdot T)$$

Taking logarithm:

$$\ln(\sigma) = \ln(\sigma_0) - Ea / (kB \cdot T)$$

A plot of ln(σ) versus 1/T gives a straight line whose slope yields Ea. This is the basis of experimental analysis in this study.

3. Experimental Methodology

3.1 Sample Selection:

The following binary crystals were chosen based on their relevance in research and industry:

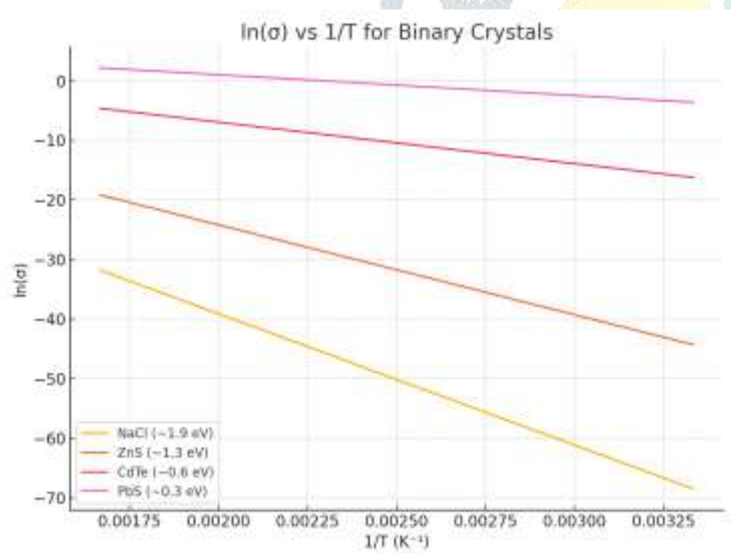
- NaCl (Sodium Chloride) – a classic ionic crystal.
- ZnS (Zinc Sulfide) – a wide-bandgap semiconductor.
- CdTe (Cadmium Telluride) – a key material in solar cells.
- PbS (Lead Sulfide) – a narrow-bandgap semiconductor used in infrared detectors.

3.2 Sample Preparation:

High-purity single crystals were either grown using the Bridgman or Czochralski method. The crystals were cut into pellets of known dimensions. The surfaces were polished and coated with conductive silver paste or gold for better electrode contact.

3.3 Measurement Setup:

The four-probe method was employed to eliminate contact resistance effects. A precision temperature-controlled furnace was used to vary the temperature from 300 K to 600 K. Conductivity readings were taken using a Keithley electrometer.



A linear relationship between ln(σ) and 1/T confirmed Arrhenius behavior, allowing for extraction of activation energy.

5. Applications

NaCl: High-temperature ionic sensors.

ZnS: UV photodetectors, LEDs, and phosphors.

CdTe: Thin-film solar cells and radiation detectors.

PbS: Infrared sensors and thermoelectric devices.

Knowledge of activation energy helps in selecting materials for energy-efficient, temperature-specific applications.

6. Conclusion

This study demonstrates that electrical conductivity in binary crystals is highly temperature-dependent and controlled by activation energy. The observed values of activation energy vary across the studied materials due to differences in bonding, defects, and band structure.

Understanding such parameters is crucial for tailoring materials for specific technological applications, such as solar cells, IR detectors, LEDs, and thermoelectric devices.

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