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# DIELECTRIC BEHAVIOR AND A.C. CONDUCTIVITY IN $CdO-P_2O_5$ GLASSES

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## Abstract
The present study deals with the dielectric behavior and ac conductivity of a series of binary cadmium phosphate glasses having composition x% CdO - (100 - x) % $P_2O_5$. The measurements were made, at room temperature, on three fixed frequencies 0.1, 1.0 and 10 kHz. The results show that both the dielectric constant and the conductivity increase with increasing concentration of CdO in these glasses.

**Keywords:** A.C. conductivity, binary cadmium phosphate glasses, dielectric constant, optical band gap energy.

## INTRODUCTION
Phosphate glasses have been of great interest for a variety of technological applications due to several unique properties [Pemberton *et al.*1991]. Phosphate glasses containing a significant amount of transition metal ions are regarded as semiconductor. The very first example of such glasses was reported by Denton *et al*. [1954], who showed that vanadium phosphate glasses behave as n-type semiconductor. The electrical properties of glasses containing significant quantity of transition metal oxides have been studied extensively [Hekmat Shoar *et al*. 1995]. In all semi conducting phosphate glasses, conduction arises due to the transition of unpaired d-electrons form low oxidation state to one in a higher oxidation state, as discussed by different researchers [Austin and Mott 1969, Owen 1970, Murawski *et al*. 1979].
Dielectric relaxation processes and the associated ac conductivity have been studied widely in transition metal oxide containing phosphate glasses of composition $MO-P_2O_5$ where MO is the oxide like $V_2O_5$, $WO_3$ or $Fe_2O_3$ etc. [Mansingh and Dhawan 1983]. The mechanism of conduction is associated basically with thermally activated hopping of electrons between transition metal ions [Mansingh *et al*. 1983]. The electronic states involved may be regarded as discrete at high temperature, leading to a form of dipolar response [Mansingh *et al*. 1983], or as occupying a narrow band at low temperature, giving rise to ac conductivity similar to that characteristic of electron hopping in amorphous systems [Pollak 1971, Mansingh *et al*.1983]. Most of the researchers studied

temperature and frequency dependent properties of glasses [Mansingh and Dhawan 1983], but a very little attention has been paid to study the complex conductivity or dielectric constant of glasses containing transition metal oxide with the variation of their composition. This state of affairs persuaded the present authors to study the dielectric constant and ac conductivity of binary $CdO$-$P_2O_5$ glasses at room temperature as a function of composition and frequency.

## MATERIALS AND METHODS

Cadmium-phosphate glasses were prepared by high purity (99.99%) oxides (CdO and $P_2O_5$) with different compositions as listed in Table 1. The samples were prepared by using 15g ingredients mixture of x% CdO-(100-x) $P_2O_5$ in an alumina crucible. The crucible with the required material was first placed in a furnace at 500 $^oC$ for half an hour to avoid possible fuming of phosphorous pentoxide. The crucible was then shifted to another furnace having a temperature of 1100 $^oC$ where it was kept for three hours. To achieve homogeneity, the contents were stirred occasionally. Finally, the melt was cast into discs of 12 mm diameter by using stain-less-steel die. All the samples were annealed at 300 $^oC$ for two hours to eliminate mechanical and thermal stresses produced during casting of the samples. Evaporated aluminum electrodes of 10 mm diameter were deposited on both sides of the samples by using an Edward Coating Unit. These samples were again annealed to make good ohmic contacts. In a two–probe conductivity measuring setup, the specimen was fixed in a spring-loaded sample holder to measure the capacitance and conductance. The measurements were made on a General Radio Capacitance Measuring Assembly (Model 1620). Measurements were made by using a signal of amplitude of one volt (r.m.s.) across the sample.

## RESULTS AND DISCUSSION

Dielectric behavior and ac conductivity of a series of binary cadmium-phosphate ($CdO$-$P_2O_5$) glasses have been studied at room temperature with respect to their compositions. The observations were made on three fixed frequencies 0.1, 1.0 and 10 kHz. The results are listed in Table 1 and depicted in Figs. 1 and 2. The results show that both dielectric constant and conductivity increase with increasing concentration of CdO in these glasses. It can be observed from these curves that the increase in dielectric constant is nonlinear.

**Table 1:** Variation of dielectric constant, ac conductivity, and slope ‘s’ of the conductivity curves with frequency and composition of binary cadmium-phosphate glasses.

| $CdO$- $P_2O_5$ mol % | Dielectric constant . $\varepsilon_r$ | | | Conductivity x$10^{-9}$ $(ohm\text{-}m)^{-1}$ | | | Slope s $(ohm\text{-}m)^{-1}$ $Hz^{-1}$ |
|---|---|---|---|---|---|---|---|
| | 0.1 kHz | 1.0 kHz | 10 kHz | 0.1 kHz | 1.0 kHz | 10 kHz | |
| 35% - 65% | 10.15 | 09.87 | 09.79 | 1.11 | 5.17 | 09.79 | 0.741 |
| 40% - 60% | 10.18 | 10.11 | 09.95 | 1.28 | 5.69 | 09.95 | 0.736 |
| 45% - 55% | 10.62 | 10.41 | 10.36 | 1.43 | 6.32 | 10.36 | 0.727 |
| 50% - 50% | 11.58 | 11.56 | 11.40 | 1.47 | 7.18 | 11.40 | 0.718 |
| 55% - 45% | 12.52 | 12.50 | 12.30 | 1.41 | 8.08 | 12.30 | 0.708 |
| 60% - 40% | 15.47 | 13.26 | 13.25 | 1.15 | 7.31 | 13.25 | 0.700 |

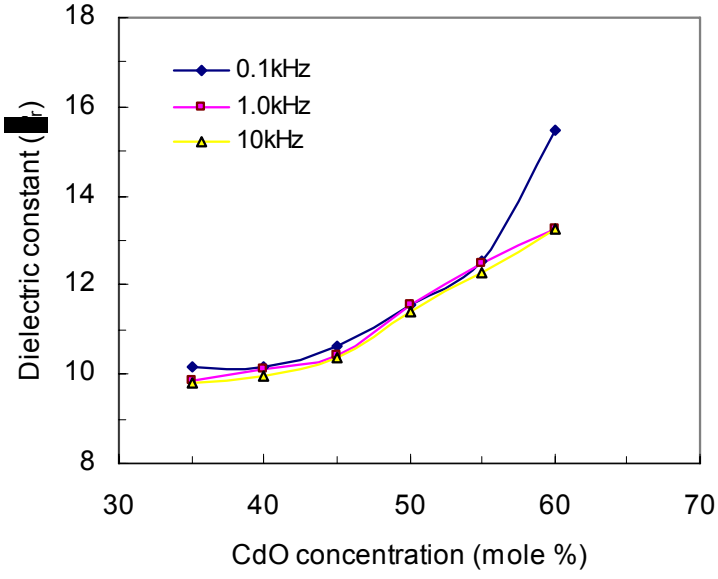


**Fig. 1:** Dielectric constant of binary CdO-$P_2O_5$ glasses as a function of CdO concentration.

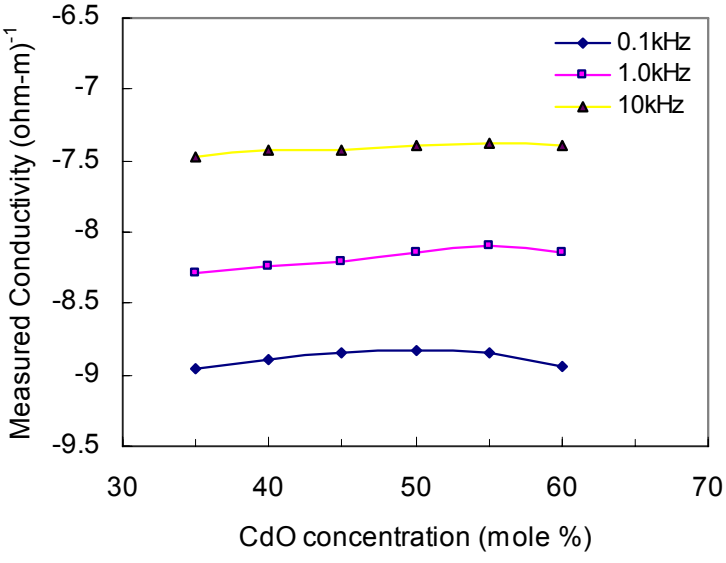


**Fig. 2:** Frequency dependent conductivity of cadmium-phosphate glasses measured with varying amounts of CdO.

The dielectric constant of a material may comprise electronic, ionic, and dipolar polarizations. The results of CdO-$P_2O_5$ glasses shown in Fig. 1 indicate a small dispersion that may be concerned to small dipolar polarization arising form hopping of the charge carries. These results are similar to those reported previously [Gouch *et al*. 1969, Mansingh and Dhawan 1983] under similar conditions.

The frequency (f) dependent conductivity $\sigma_m(\omega)$ is usually analyzed on the basis of model which assumes that the measured conductivity is sum of two types of conductivities; namely dc conductivity ($\sigma_{dc}$) and an ac conductivity ($\sigma_{ac}$), which is described by the following equation:

$$\sigma_m(\omega) = \sigma_{dc} + \sigma_{ac}$$

The quantity $\sigma_{dc}$ is estimated by extrapolating log $\sigma_m(\omega)$ versus log f curves down to a point where log f = 0 [Mansingh 1980, Mansingh *et al*. 1983]. Surely, this value of $\sigma_{dc}$ is not equal to the actual dc value rather it is considered to be approaching dc level. The values of ac conductivity $\sigma_{ac}$ are estimated by subtracting $\sigma_{dc}$ from the frequency dependent measured conductivity $\sigma_m(\omega)$. The data obtained are then plotted as log $\sigma_{ac}(\omega)$ versus log ($\omega$) for all compositions as shown in Fig. 3. It can be seen that some log $\sigma_{ac}(\omega)$ versus log $\omega$ curves corresponding to different compositions cross each other at particular frequencies. This happens when the ac conductivity of one composition becomes equal to that of the other. Furthermore, these curves show almost a linear behavior, which follows a power law relation:

$$\sigma_{ac}(\omega) \alpha \omega^s$$

where 's' is the slope of log $\sigma_{ac}(\omega)$ versus log $\omega$ curves. Usually, the value of 's' is less than unity. This corresponds to a form of hopping conduction [Mansingh 1980, Mansingh and Dhawan 1983, Mansingh *et al*. 1983]. The values of 's' change with composition, as given in Table 1, and depicted in Fig. 4.

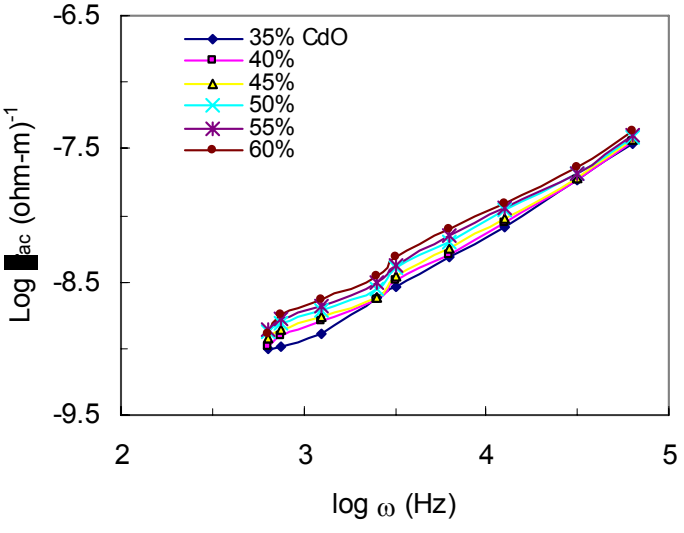


**Fig. 3:** Variation of the estimated ac conductivity with respect to log $\omega$.

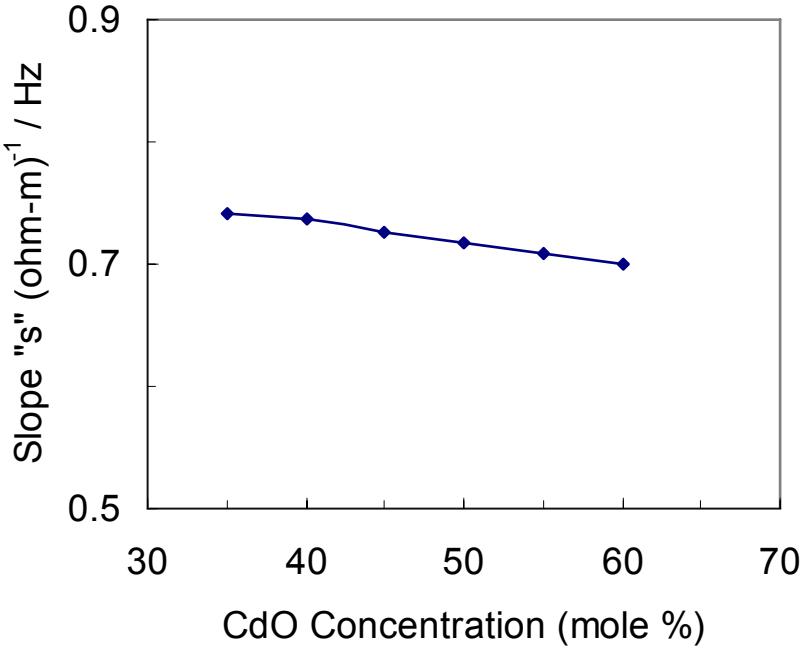


**Fig. 4:** Variation of the slope 's' with respect to CdO concentration.

## CONCLUSION

Both the dielectric and ac conductivity data support hopping conduction in binary cadmium phosphate glasses.

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