TEMPERATURE DEPENDENCE OF PHOTO-ELASTIC CONSTANTS IN ALKALI HALIDES

By S. Bhagavantam, F.A.Sc. and Y. Krishna Murty

Received November 14, 1957

1. Introduction

In an earlier paper (1956) published in these *Proceedings*, we reported the influence of temperature on the photo-elastic behaviour of some plastics. It seemed worthwhile to extend such studies to cubic crystals also as there has so far been very little work done along these lines. The present paper is concerned with alkali halides.

2. Experimental

All the crystal prisms used in this investigation have been specially cut and polished. None of the prisms showed double refraction in the unstrained state. A full description of the prisms is given in Table I. The alkali halides studied belong to the O_h class of the cubic system and in all the cases, the value of $(q_{11} - q_{12})$ was obtained from prism I when stress was applied along [001] and observation made along [010]; and q_{44} was obtained from prism II when stress was applied along [110] and observation made along [001].

Table I

Description of the prisms employed

	No. of prism	Length		Breadth		Thickness	
		Cm.	Parallel to	Cm.	Parallel to	Cm.	Parallel to
NaCl ..	I	1·550	[001]	0·762	[010]	0·673	[100]
	II	1·129	[110]	0·598	[$\bar{1}$10]	0·471	[001]
KCl ..	I	0·838	[001]	0·512	[010]	0·412	[100]
	II	1·110	[110]	0·731	[$\bar{1}$10]	0·617	[001]
KBr ..	I	1·556	[001]	0·635	[010]	0·564	[100]
	II	1·162	[110]	0·549	[001]	0·523	[$\bar{1}$10]

The stress-optical coefficients of rock salt are small when compared with those of potassium chloride and potassium bromide. Further, it is known that plastic deformation takes place in rock salt when the load exceeds about 20·0 kg./cm.^{2} Due to the above limitations, the Babinet compensator does not give an appreciable shift and a Rayleigh compensator was employed to determine the photo-elastic coefficients of NaCl at different temperatures. The experimental set-up and method of observation are essentially the same as those employed by Narasimhamurty (1954). The Rayleigh compensator is very sensitive and may be made to measure a birefringence of the order of 1/500 λ. The crystal prism must be well polished so that the dark band may be seen clearly. For each temperature, the prism of rock salt crystal was loaded after the temperature remained fairly constant.

The comparatively higher values of potassium halides have enabled the Babinet compensator being used in determining their photo-elastic coefficients at various temperatures. The Babinet-fringes were obtained by the usual method using a sodium vapour lamp as the source. Compression was produced by a lever arrangement described in an earlier paper (1947). Stresses of the order of 35·0 kg./cm.^{2} were applied in the case of KCl and KBr. Final measurements were taken only when it was ascertained that load was uniformly distributed. The mean shift of the Babinet-fringe in each case was obtained by taking the average of several readings. The path retardation read in terms of the head-scale divisions of the Babinet compensator is a measure of the birefringence produced in the crystal prisms.

In order to study the variation of the induced birefringence with temperature a robust electrical heater was built, the crystal prism being centrally situated within the enclosure. By means of a variac, the voltage could be varied slowly and steadily till the requisite temperature was attained. The temperature was maintained at the higher level for about four hours and then brought back to room temperature over a period of about another four to five hours. In this way, development of permanent strains in the crystals was avoided. Measurements of fringe shifts in both the cases were made at intervals of 50° C., temperatures being read by a suitable thermometer.

In evaluating the photo-elastic coefficients at different temperatures, the refractive index as well as the thickness perpendicular to the direction of observation were to be determined for each temperature. The values of the coefficients of thermal expansion for NaCl, KCl and KBr were deduced utilising the formulæ given by Walther and others (1937), Durand (1936) and Srinivasan (1956) respectively. The refractive indices at higher temperatures for NaCl and KCl were evaluated from the values of dn/dt given by

Ramachandran (1947). Data are, however, not available in literature regarding the thermo-optic behaviour of KBr. Hence a plane parallel plate of KBr of thickness 0·2 cm. had been prepared and the refractive indices at higher temperatures obtained by the usual interference method. The values of refractive indices at various temperatures for the three alkali halides used in the present work are shown in Table II.

TABLE II

Values of n_D *at different temperatures*

Temp. °C.	NaCl	KCl	KBr
30	1·5440	1·4903	1·55983
100	1·5414	1·4880	1·55557
150	1·5395	1·4860	1·55280
200	1·5377	1·4840	1·55004
250	1·5358	1·4820	1·54728
300	1·5339	1·4800	1·54451
350	1·5320	..	..

3. Results and Discussion

Sodium Chloride

The results are given in detail in Tables III A and III B.

TABLE III A

Measurements with Rayleigh compensator for NaCl prism No. I

Temp. °C.	Mean shift in Rayleigh	Retardation in Å.	$(q_{11}-q_{12})$ $\times 10^{13}$	$(c_{11}-c_{12})$ $\times 10^{-11}$	$(p_{11}-p_{12})$ $\times 10^{2}$
30	14·0	305·6	1·13	3·663	4·13
100	13·0	283·8	1·06	3·353	3·54
175	12·0	262·0	0·99	3·068	3·02
250	11·2	245·0	0·93	2·802	2·61
350	10·3	224·8	0·86	2·475	2·13

TABLE III B

Measurements with Rayleigh compensator for NaCl prism No. II

Temp. °C.	Mean Shift in Rayleigh	Retardation in Å.	$(q_{44}) \times 10^{13}$	$(c_{44}) \times 10^{-11}$	$(p_{44}) \times 10^{2}$
30	7·0	152·8	0·84	1·281	1·07
125	6·4	139·7	0·77	1·250	0·97
250	5·3	115·7	0·65	1·205	0·78
350	4·6	100·4	0·57	1·170	0·67

The values of stress-optical coefficients $(q_{11} - q_{12})$ and q_{44} are both negative in sign for NaCl and the magnitudes are found to decrease linearly with temperature. This is in accordance with the decrease in its elastic constants. The strain-optical coefficients are calculated from the standard equation connecting the p's, q's and the elastic constants. The data on elastic constants for NaCl are available from Hunter and Siegal (1942).

Potassium Chloride and Potassium Bromide:

The results obtained are given in Tables IV and V. The fringe width of the Babinet compensator is 470·5 divisions of the head-scale, which corresponds to a path retardation of one wavelength of sodium light.

TABLE IV A

Measurements with Babinet-compensator for KCl prism No. I

Temp. °C.	Mean shift in divisions of head-scale	$(q_{11}-q_{12}) \times 10^{13}$	$(c_{11}-c_{12}) \times 10^{-11}$	$(p_{11}-p_{12}) \times 10^{2}$
30	41·6	1·66	3·41	5·65
100	43·9	1·76	3·22	5·67
150	45·7	1·85	3·07	5·67
200	48·7	1·98	2·94	5·83
250	52·3	2·14	2·82	6·03
300	55·7	2·30	2·70	6·20

TABLE IV B

Measurements with Babinet-compensator for KCl prism No. II

Temp. °C.	Mean shift in divisions of head-scale	q_{44} $\times 10^{13}$	c_{44} $\times 10^{-11}$	p_{44} $\times 10^{2}$
30	124·7	4·42	0·630	2·78
100	129·4	4·61	0·620	2·86
150	131·3	4·71	0·612	2·88
200	133·4	4·80	0·603	2·90
250	136·1	4·94	0·594	2·94
320	141·1	5·17	0·580	3·00

TABLE V A

Measurements with Babinet compensator for KBr prism No. I

Temp. ° C.	Mean shift in divisions of head-scale	$(q_{11}-q_{12})$ $\times 10^{13}$	$(c_{11}-c_{12})$ $\times 10^{-11}$	$(p_{11}-p_{12})$ $\times 10^{2}$
30	58·9	1·73	2·86	4·94
100	62·8	1·86	2·67	4·98
150	66·0	1·97	2·47	4·87
200	69·7	2·10	2·36	4·95
250	73·7	2·24	2·24	5·01
300	78·4	2·40	2·13	5·12

From the mean shift of the Babinet-fringe, the path difference corresponding to unit stress (1 dyne cm.$^{-2}$) and unit length (1 cm.) of light beam

TABLE V B

Measurements with Babinet compensator for KBr prism No. 1

Temp. °C.	Mean shift in divisions of head-scale	$(q_{44}) \times 10^{13}$	$(c_{44}) \times 10^{-11}$	$(p_{44}) \times 10^{2}$
30	133·5	4·72	0·504	2·38
100	137·2	4·91	0·498	2·45
150	140·4	5·06	0·494	2·50
200	142·8	5·18	0·488	2·53
250	145·4	5·32	0·482	2·57

in the stressed crystal was calculated. The stress-optical coefficient in the corresponding direction of observation is $2\delta/n^3$. The sign of $(q_{11} - q_{12})$ is positive and that of q_{44} is negative in the case of KCl and KBr. In both these substances, the stress-optical coefficients are found to increase with temperature, the variation being nearly linear in the case of $(q_{11} - q_{12})$ and linear for q_{44}. Also the variation is much greater in $(q_{11} - q_{12})$ than in q_{44}. The values of the strain-optical coefficients are calculated in the same manner as for NaCl. The data on elastic constants of KCl and KBr at different temperatures have been obtained by Subrahmanyam (1954).

4. SUMMARY

The paper furnishes measurements on the birefringence produced at different temperatures in crystals of NaCl, KCl and KBr when subjected to stress. The results show that the stress-optical coefficients $(q_{11} - q_{12})$ and q_{44} decrease in the case of NaCl almost linearly with temperature while in KCl and KBr they increase with the same. The variation for rock salt is of the order of about 30% over an interval of 300° C. In both KCl and KBr, the variation in $(q_{11} - q_{12})$ which is about 40% over the same interval of temperature is much greater than in q_{44} which is of the order of about 15%. The corresponding strain-optical coefficients are also evaluated and given at each temperature.

REFERENCES

1. Bhagavantam, S. and Krishna Murty, Y. *Proc. Ind. Acad. Sci.*, 1956, **43 A**, 203.
2. —— and Suryanarayana, D. *Ibid.*, 1947, **26 A**, 97.
3. Durand, M. .. *Phys. Rev.*, 1936, **50**, 449.
4. Hunter, L. and Siegal, S. .. *Ibid.*, 1942, **61**, 84.
5. Narasimhamurty, T. S. .. *Proc. Ind. Acad. Sci.*, 1954, **40 A**, 167.
6. Ramachandran, G. N. .. *Ibid.*, 1947, **25**, 481.
7. Srinivasan, R. .. *Jour. Ind. Inst. Sci.*, 1956, **38**, 20.
8. Subrahmanyam, S. V. .. Thesis submitted to the Osmania University (1954).
9. Walther, A. K. and others.. *Physik. Zeit. d. Sowjetunion*, 1937, **12**, 35.