The striations evident in Fig. 2 did not appear in Rayleigh's mirrorgrams. This is apparently because the frequency in his circuit was so great that the mirror did not separate the successive oscillations. Rayleigh suggested that the gas excited in the discharge ring and heated to a very high temperature expanded into the neck, remaining luminous for 10^{-5} sec; and Zanstra[2] showed theoretically that ions expanding into the neck and recombining all along its length might account for Rayleigh's observations. It appears that if either of these processes were the major process in the neck, an instantaneous photograph of the tube should show a tongue rather than a front of luminosity. The front which is observed is more suggestive of an exciting process occurring in the neck, concurrently with the emission of radiation, such as a shock wave producing excitation or ionization as it proceeds along the neck. Such an exciting process is further suggested by the order of magnitude of the velocity of advance.

No experiments have been performed as yet which will enable us to decide whether recombination is active in the discharge. Rayleigh and Zanstra showed that the energy delivered to the discharge is adequate to produce a high average degree of ionization, yet how much of this energy is actually available in the excitation process in the neck is not so far known.

An electrodeless discharge pulse in a ring tube having appendages is followed by a discharge into these appendages which proceeds as a luminous front of local activity traveling with ultra-acoustical speeds. The excitation in the front is produced at or near the point where the luminosity is perceived. The "long lifetime of the Balmer series in hydrogen" is thus accounted for as a delay in production of excitation rather than a belated relaxation of excited systems.

The authors wish to acknowledge the benefit derived from the concurrent work of J. S. Goldstein on this phenomenon.

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Angular Distribution of Neutrons from the Bombardment of Be by 340-Mev Protons*

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IN conjunction with the measurements of Miller, Sewell, and Wright[1] of the angular distribution of the neutrons produced by the bombardment of various targets with 330-Mev protons, a measurement was made using bismuth fission chambers[2,3] as detectors instead of the carbon $(n, 2n)$ reaction employed by the above group. Bismuth fission has its threshold at a neutron energy of about 50 Mev compared to 20 Mev for the $C(n, 2n)$ reaction. The data from 15° to 27° were taken using the neutrons produced from the bombardment of a 2.8-inch Be target with 330-Mev protons inside the cyclotron immediately after the $C(n, 2n)$ measurements. Shallow fission chambers containing two 4.5-inch diameter bismuth coated plates were employed as monitor and detector. The 8° result was obtained from the bombardment of a 2-inch Be target with 350-Mev protons at the standard probe position.

To extend the angular range, measurements were made with the neutrons knocked out of a $1\frac{11}{16}$-inch diameter beryllium rod by the electro-magnetically deflected, external 345-Mev proton beam. Since the fission counting rate was only about 70 counts per hour at 12°, it was necessary to find the fission pulse height distribution by means of a pulse height analyzer[4] to insure that "pile-ups" were not occurring during the 0.1 μsec deflected proton pulse. Satisfactory plateaus were obtained with the long bismuth fission counters previously employed for the 95- and 270-Mev neutron energy measurements of nuclear cross sections.[3]

The distance from detector to target was such that the angular resolution was within ±1° of the indicated setting except at 62° and 85° where it was ±2°. No attempt has been made to correct for neutron background scattered into the detector or produced by protons at regions other than the beryllium target. Four inches of lead was placed in front of the detector to prevent protons from entering it.

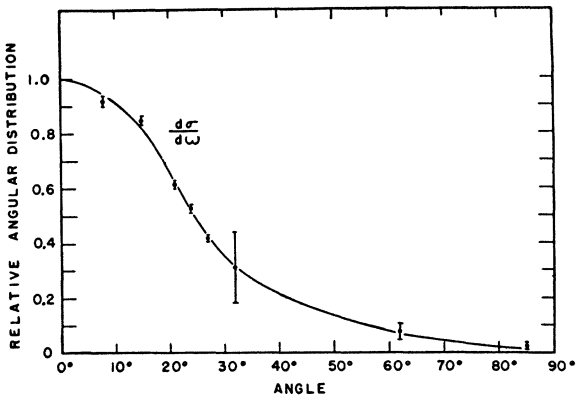

FIG. 1. Angular distribution of neutrons from the bombardment of Be by 340-Mev protons.

The measured angular distribution is shown in Fig. 1, and the statistical errors indicated are standard deviations based on counting. The full width at half maximum is 49° with an estimated probable error of 1° due to the scatter of the experimental points and statistical errors. By comparison, Miller, Sewell, and Wright[1] obtained for beryllium a width of 54±1 degrees using the lower threshold carbon $(n, 2n)$ detection.

If the angular distribution is graphically integrated the resultant total cross section for production of a high energy neutron is

$$\sigma_t = 1.05(d\sigma/d\omega)_0.$$

The neutron yield in the forward direction has been measured by Knox[5] for the neutrons knocked out of Be with 350-Mev protons using the same fission chambers. His result is $(d\sigma/d\omega) = 42.2 \times 10^{-27} \times \sigma_{p,pn}(350 \text{ Mev})/\sigma_{n,2n}(270 \text{ Mev})$ where the indicated cross sections are for carbon. When 38 and 17 millibarns are used for the carbon (p, pn)[6] and $(n, 2n)$[7] cross sections, respectively, the value of the total cross section is 100 millibarns (with an estimated accuracy of 50 percent). The total collision cross section for 270-Mev neutrons and a Be nucleus is 230 millibarns, as measured with bismuth fission detectors.

* This work was performed under the auspices of the AEC.
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[2] C. Wiegand, Rev. Sci. Instr. **19**, 790 (1948).
[3] J. DeJuren and N. Knable, Phys. Rev. **77**, 606 (1950).
[4] I am indebted to Clyde Wiegand for the loan of this analyzer.
[5] W. Knox, UCRL-440, unpublished.
[6] Aamodt, Peterson, and Phillips, UCRL-526, unpublished.
[7] L. Baumhoff (theoretical estimation).

On the Anomalous Specific Heat of Lead Titanate

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IN an earlier letter[1] it was reported that the lattice spacing of lead titanate shows a large anomaly at the transition point 490°C. From this fact it might be anticipated that this transition would be accompanied also by a large anomalous specific heat. Using an adiabatic calorimeter of Nagasaki-Takagi type,[2] which is an improvement of that of Sykes,[3] we have measured the specific heat as a function of temperature.

We have used the same ceramic specimen as used for the x-ray analysis, which was prepared by sintering the mixture of PbO and TiO_2 at about 1100°C. The powdered specimen of about 25 g was

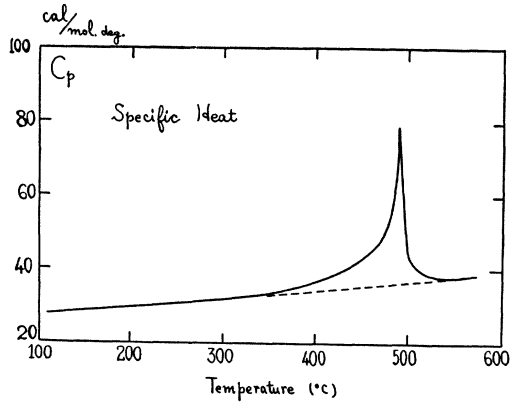

FIG. 1. Specific heat as a function of temperature.

heated in a glass vessel, 2g in weight, at a rate of about 2°C/min. The heat capacity of the empty calorimeter was calibrated with KCl as a standard substance. The specific heat *vs* temperature curve is shown in Fig. 1.

As is seen in Fig. 1, there is a rather large anomaly of the specific heat in the transition region. The specific heat curve shows a sharp peak at 490°C, corresponding to the anomalies of permittivity and lattice spacing. Attention must be paid to the fact that the specific heat shows an anomaly over a wide temperature range. Though it is difficult to estimate the transition energy accurately from such a curve, we have tentatively assumed that the normal specific heat corresponds to the broken line shown in the figure. We thus obtain the transition energy as 1150 cal/M in the range 340 to 540°C. The accompanying entropy change is about $0.80R$. This large anomaly is to be compared with the small transition energy in $BaTiO_3$,[4] which is about 20 to 40 cal/M.

According to the theory of barium titanate proposed by Devonshire,[5] the anomalous internal energy associated with the spontaneous polarization can be written as

$$E=A\cdot T_c\cdot P^2+\cdots=B\cdot T_c\cdot(c/a-1)+\cdots, \qquad (1)$$

where T_c represents the Curie temperature and B depends on the piezoelectric and elastic constants. This relation between polarization and crystal strain has been confirmed experimentally by Merz[6] in the case of barium titanate. Though the value of the spontaneous polarization of lead titanate has not been estimated, we have found that c/a, which is 1.063 at 30°C, begins to decrease considerably from a temperature far below the Curie point. Taking account of this fact, it seems to be reasonable to assume that the specific heat also has an anomaly in the same temperature range. Utilizing the normal specific heat shown in Fig. 1, we have calculated the anomalous internal energy E, as is shown in Fig. 2.

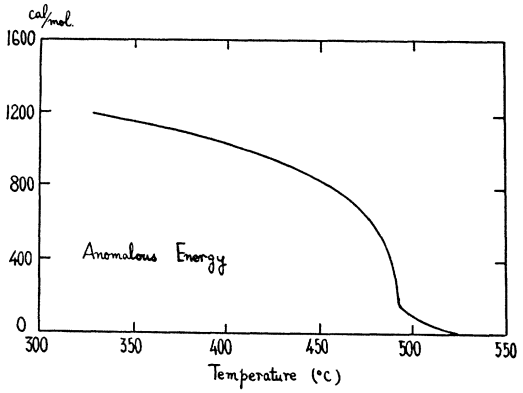

FIG. 2. Anomalous internal energy estimated from the specific heat curve.

This curve is quite similar to the temperature dependence of the axial ratio c/a, shown in the previous letter.[1] It is found that Eq. (1) holds approximately in this temperature range with $B=40$ cal/M. On the other hand, we have estimated that B is about 15 cal/M in the case of $BaTiO_3$.

It is difficult at present to determine whether there is a latent heat at the transition point.

We wish to express our sincere thanks to Professor Y. Takagi for his kind guidance and also to Mr. S. Nagasaki for his helpful advice on our work.

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A Note on the Distribution of Impurities in Alkali Halides

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THE manner in which impurities are distributed in a crystal is not readily determined by direct measurement. In the absence of specific information it is frequently assumed, particularly for small concentrations, that the impurities are distributed at random. Large deviations from a random distribution may result, however, from the formation of stable aggregates of two or more impurity atoms as in the aggregation of trapped electrons and trapped holes in the alkali halides.[1] The purpose of this note is to present evidence from optical data for the formation of impurity aggregates in NaCl crystals containing Pb^{++} and to discuss the conditions under which such deviations from random distribution may, in general, be expected.

Although NaCl, KCl, and RbCl crystals containing Pb all exhibit absorption bands at approximately 2730 and 1960A, variations in the character of these bands have been noted by earlier investigators.[2] The present study has revealed additional bands in NaCl:Pb which vary with the growth and thermal history of the specimen.[3] Similar variations with growth history have been observed in the absorption bands of other impurities in alkali halides, particularly in NaCl:Cu and KCl:Cu.[4]

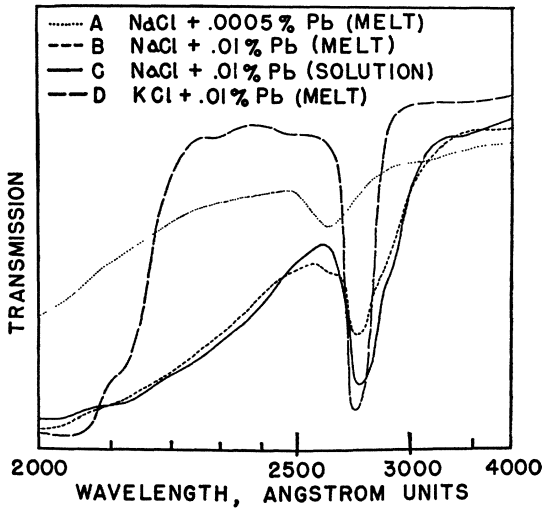

FIG. 1. Transmission curves of NaCl:Pb crystals, grown from the melt and from solution, contrasted with a curve for a melt-grown KCl:Pb crystal The concentrations of Pb shown are those in the melt and solution. The corresponding concentrations in the crystals are lower.