(5) The probability of a transition between the configurational coordinate curves is independent of position along the portions of the curves which lie within the experimental range.

Materials to which these assumptions apply will have Gaussian emission and absorption bands at low temperatures. This is observed in the emission of tungstate phosphors[2] and in the absorption of $F$-centers and thallium in alkali halides. Furthermore, the relative change in band width with temperature follows the form given in Fig. 1 where the curves are normalized at 300°K. The points for the absorption of KCl:Tl[3] and the emission of $MgWO_4$[2] and $Zn_2SiO_4$:Mn[2, 4] follow the curves reasonably well and indicate vibrational frequencies of normal values.

Let the ground and excited states be represented as in Fig. 2 with force constants $k_g$ and $k_e$, respectively, and let all quantities be given in cgs units. The absorption energy at the center of the band is given by

$$U_{\text{abs}}=U_0+\tfrac{1}{2}k_eX_0^2, \qquad (1)$$

and the energy of emission at the peak is

$$U_{\text{emis}}=U_0-\tfrac{1}{2}k_gX_0^2. \qquad (2)$$

From the relative change in width of the absorption band with temperature, the classical frequency of the system in its ground state can be evaluated as discussed previously. This frequency is given by

$$\nu_g=(1/2\pi)(k_g/M_g)^{\frac{1}{2}}, \qquad (3)$$

where $M_g$ is the effective mass of the vibrating system in its ground state. A similar equation, with subscripts $e$, can be applied to emission data. The band width in ergs, $\Delta E_A$, of the low temperature absorption curve measured at the half-maximum points can be expressed as

$$\Delta E_A=1.905\times10^{-13}k_eX_0(\nu_g/k_g)^{\frac{1}{2}}, \qquad (4)$$

and the band width of the emission curve at low temperature is given by a similar equation with the subscripts $e$ and $g$ interchanged. The ground and excited state curves intersect at some energy $W$ above the minimum of the excited state curve which can be computed from measurements on luminescence efficiency or decay rate. From Eqs. (1) and (2) $W$ is given by

$$W=\frac{k_gk_eX_0[k_eX_0+k_gX_0-2(k_gk_eX_0^2-2k_gU_0-2k_eU_0)^{\frac{1}{2}}]+2k_eU_0(k_g-k_e)}{2(k_g-k_e)^2}. \qquad (5)$$

TABLE I. Configurational coordinate constants for KCl:Tl.

| Configurational coordinate constant | Theoretically derived values | Experimentally derived values |
|---|---|---|
| $k_g$ | $27\times10^4$ | $26.5\times10^4$ |
| $k_e$ | $10.3\times10^4$ | $8.2\times10^4$ |
| $U_0$ | $8.1\times10^{-12}$ | $7.7\times10^{-12}$ |
| $X_0$ | $0.36\times10^{-8}$ | $0.28\times10^{-8}$ |

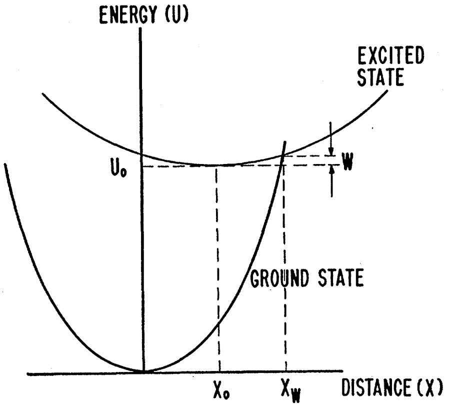

FIG. 2. Schematic configurational coordinate plot.

The complete determination of the configurational coordinate curves requires that the six constants $k_g$, $k_e$, $X_0$, $U_0$, $M_g$, and $M_e$ be evaluated from a possible seven pieces of data. If $M_g$ and $M_e$ are assigned values, only four constants need be evaluated.

In order to compare the configurational coordinate curves determined in this way with those computed by Williams, the equations have been solved for KCl:Tl assuming the absorption energy peak to be at 2475A,[3] the emission peak at 2980A,[5] the vibrational frequency in the ground state (see Fig. 1) as $4\times10^{12}$ sec$^{-1}$, and the width of the low temperature absorption band to be 0.108 electron volts.[3]

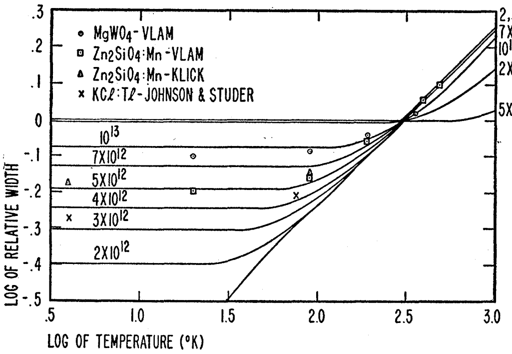

FIG. 1. Plot of the logarithm of the computed relative width at half-maximum of emission or absorption curves as a function of the logarithm of the temperature for various frequencies of vibration. Curves are normalized at 300°K.

It is further assumed with Williams[6] that only a single mode of vibration is important and that this corresponds to a synchronous and radial motion of the chlorine ions surrounding the thallium ion. The results of this analysis are given in Table I.

The agreement is surprising in view of the radically different approaches to the determination of the configurational coordinate curves and indicates, first, that the assumption of a single, radial vibratory mode produces results in agreement with experiment and, second, that the method described here may be used in the case of simple systems to evaluate configurational coordinates from experimental data.

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## Protons and Deuterons from $Li^6+T$ Reactions

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THE interaction of tritons with $Li^6$ may lead to the following exothermic reactions:[1]

$$Li^6+T=Li^7+D^2+0.988\text{ Mev} \qquad (1)$$

$$Li^{7*}+D^2+0.509\text{ Mev} \qquad (2)$$

$$\mathrm{Li^8+H^1+0.800\ Mev} \qquad (3)$$

$$\mathrm{Be^8}+n+16.04\ \mathrm{Mev} \qquad (4)$$

$$\mathrm{Be^{8*}}+n+<16.004\ \mathrm{Mev} \qquad (5)$$

$$\mathrm{He^4+He^4}+n+16.100\ \mathrm{Mev} \qquad (6)$$

$$\mathrm{He^5+He^4+15.23\ Mev.} \qquad (7)$$

This letter discusses the first three reactions and describes the experimental technique used to study the low energy proton and deuteron groups in the presence of the α-particle continuum from reactions (4) to (7).

Hydrogen containing 10 percent tritium was used in the Chalk River 200-kv high tension set[2] and the mass three component, $T^+$ and $HHH^+$ ions, of the beam, was magnetically selected to bombard a $Li^6F$ target.[3] The charged particles emitted at 90° to the beam were deflected through 90° in a homogeneous magnetic field, and were detected using a ZnS Ag-activated screen with an RCA 5819 photomultiplier. The photomultiplier pulses were amplified and fed into a 30-channel pulse-height analyzer.[4] The value of magnetic field which selected the deuterons from reaction (1) also allowed α-particles and $He^3$-particles from the $Li^6(p, \alpha)He^3$ reaction produced by the $HHH^+$ component of the beam to strike the ZnS screen. It so happens that under the conditions of the experiment all these particles have the same momentum to charge ratio, and therefore the same $H\rho$, but as they have energies in the ratio 1:2:2.67, different pulse heights were obtained. Figure 1 shows the deuterons clearly resolved from the α-particles and the $He^3$-particles. The corresponding pulse heights are in the ratio 1:2.1:2.9. Additional measurements have shown that, for a given magnetic field, the pulse heights from doubly and singly charged α-particles are in the same ratio as their energies, i.e., 4:1. Therefore the light output of ZnS appears to be proportional to the particle energy and to be the same for deuterons and α-particles. By combining the magnetic selection with the pulse-height measurements it is possible to distinguish, among deuterons, singly charged and doubly charged α-particles. Furthermore, protons can be recognized in the presence of doubly charged α-particles of the same $H\rho$, and therefore the same energy, by covering the ZnS screen with an Al foil to stop the α-particles.

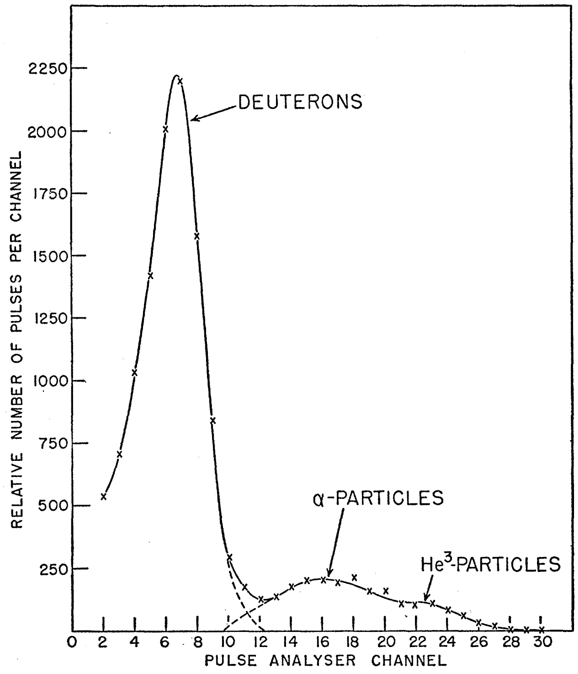

FIG. 1. The pulse-height distribution from an Ag-activated ZnS screen produced by different particles having the same value of $H\rho$. The energies are: deuteron 0.866 Mev, α-particle 1.74 Mev, and $He^3$-particles 2.32 Mev.

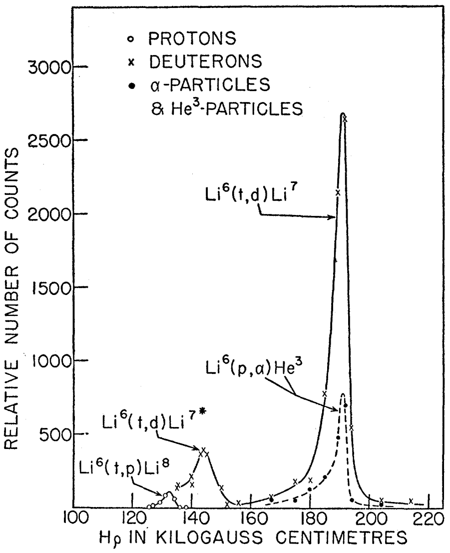

FIG. 2. Protons and deuterons from $Li^6+T$ reactions observed at 90° to a 240-kev triton beam. The dashed curve represents $He^3$ and α-particles produced by 80-kev protons ($HHH^+$ ions) on $Li^6$. The relative intensities of the groups were obtained by correcting the areas under the peaks for variation of resolution of the magnet with $H\rho$.

The momentum distributions of the deuterons and the protons from the first three reactions are shown in Fig. 2. The two more intense groups of particles are the deuterons from reactions (1) and (2) corresponding to the formation of $Li^7$ in the ground state and in the well-known 479-kev excited state.[5] The least intense group consists of protons from reaction (3). The broken curve is the group of α-particles and $He^3$-particles from the $Li^6(p, \alpha)He^3$ reaction. At the low proton bombarding energy used, these particles are not resolved and appear as a single group which, within the accuracy of the measurements, coincides with the deuteron group from reaction (1). This fortuitous coincidence permits a rather precise determination of the $Q$ value of reaction (1) in terms of the accurately known $Q$ value, 4.016±0.004 Mev of the $Li^6(p, \alpha)He^3$ reaction.[6,7] Using the latter $Q$ and allowing for an oil layer on the target having a measured thickness equivalent to $5\times10^{-3}$ cm of air the $Q$ for the $Li^6(t, d)Li^7$ reaction is 0.982 ±0.007 Mev. The $Q$ of reaction (2) is therefore 0.503±0.007 Mev. Using this value and the measured separation of the groups from reactions (2) and (3) the $Q$ of the $Li^7(t, p)Li^8$ reaction is computed to be 0.784±0.015 Mev. These $Q$ values are consistent with those calculated from reaction cycles using the data of Li *et al.*[6]

The total yields of the different reactions are not known as the measurements have been made at one angle only. However, reaction (1) accounts for about 54 percent of all the disintegrations emitting particles at 90° to the beam, reaction (2) for about 14 percent, and reaction (3) for about 2 percent. Assuming that most of the disintegrations produced at 240 kev bombarding energy result from $S$ wave tritons, the deuterons must be emitted isotropically, and conservation of parity requires that they be emitted in $P$, $F$, etc., waves. The potential barrier penetrabilities for $P$-wave deuterons from reactions (1) and (2) are in the ratio of approximately 4:1, which indicates that, without a barrier, $Li^7$ and $Li^{7*}$ would be produced with about equal probability.

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