The simplification consists in replacing the partition function (11) by the corresponding grand partition function in which the quantities ϵ_i are not restrained by a side condition:

$$Q_N=(2\pi)^{-N/2}\int_{-\infty}^{+\infty}\cdots\int_{-\infty}^{+\infty}\times d\epsilon_1 d\epsilon_2\cdots d\epsilon_N \exp[K\Sigma_{i,j}'\epsilon_i\epsilon_j-s\Sigma_i\epsilon_i^2]. \quad (1)$$

Here s is the conjugate variable to $\Sigma_i\epsilon_i^2$; after evaluation of Q_N it is to be adjusted at each temperature so that the Berlin-Kac condition holds:

$$\partial \ln Q_N/\partial s=-N. \quad (2)$$

This means that we satisfy the restraint of their model in the mean; this is sufficient by the principles of fluctuation theory, provided each member of the assembly is itself a macroscopic system. The evaluation of an expression of the form (1) also occurs in BK (C3). It is, however, followed by an integration in the complex plane which appears to play an essential role in the determination of the temperature singularity of the three-dimensional model.

In the present mode of computation we proceed entirely from (1) and (2). In evaluating (1) we follow BK [Eqs. (5) to (8)] with the one reservation that the lowest mode must be excepted from the smoothing-out process (this is familiar from the theory of Einstein condensation). Thus, we find

$$\ln Q_N=-\tfrac{1}{2}\ln(2s-12K)-\frac{1}{2}\frac{N}{(2\pi)^3}\int_0^{2\pi}\int\int\int\times d\omega_1 d\omega_2 d\omega_3 \ln[2s-4K(\cos\omega_1+\cos\omega_2+\cos\omega_3)]. \quad (3)$$

Equations (1), (2), and (3) are sufficient to yield

$$U=-\tfrac{1}{2}J\partial \ln Q_N/\partial K=(JN/4K)(1-2s). \quad (4)$$

This is BK Eq. (18), the key equation to most of the derived results. To complete our derivation, we must only show that we can also derive the correct dependence of s upon temperature. Applying condition (2) to (3), we get

$$1=\frac{1}{2N(s-6K)}+\frac{1}{2(2\pi)^3}\int_0^{2\pi}\int\int\int\frac{d\omega_1 d\omega_2 d\omega_3}{s-2K(\cos\omega_1+\cos\omega_2+\cos\omega_3)}. \quad (5)$$

For K sufficiently small, this equation yields for s a value substantially larger than $6K$; the first term is then negligible and Eq. (C23) of BK is obtained. As K increases, the boundedness of the integral comes into play, and s must approach $6K$ sufficiently closely so that the first term in (5) can make up the deficit. This feature leads to the "sticking" of s at the value $6K$ and yields the entire low temperature behavior of the model. All results of the BK paper are thus derived.

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Three New Neutron Deficient Xenon Isotopes*

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WHILE investigating the spallation reactions which occurred when iodine was bombarded with 240-Mev protons in the Rochester cyclotron, three previously unreported xenon isotopes were found.

About 200 mg of anhydrous lithium iodide (~99 percent pure, A. D. Mackay, Inc.), wrapped in a small envelope of 1-mil aluminum foil and clamped to the cyclotron probe, was exposed to the internal beam for one hour. Within 20 minutes of the end of the bombardment, collection of the xenon was completed and counting begun. The all-glass gas-collecting system consisted of a reaction tube containing a cold finger and an inlet for helium gas, a trap of potassium hydroxide-coated glass wool kept at dry ice temperature, and one or more charcoal traps held at liquid air temperature. The reaction tube contained about 10 drops each of frozen concentrated nitric and sulfuric acids, to which the target iodide was added, and was connected to the line by a ground glass joint. With helium slowly flowing through the system, the reaction mixture was heated until most of the iodine was collected on the cold finger (−78°C) and the xenon, carried by the helium, was adsorbed on the cold charcoal. All water and acid vapors were presumably removed by the potassium hydroxide trap. The charcoal trap, in the form of a small U-tube, was sealed, cut from the line, and cemented to a Lucite disk for counting.

Decay of the xenon activity, as counted through the glass wall (0.5–1.0 mm thick) of the U-tubes, was followed with a scintillation counter having a NaI(Tl) phosphor and also with a halogen filled GM tube. Resolution of a gross decay curve obtained with the latter yielded the following half-lives: ~35 minutes, 1.7 hours, 20.1 hours, and >20 days.

A xenon sample placed in our low resolution beta-ray survey spectrometer showed positrons of >2.8 Mev with ~1.8-hour half-life, and 3.1-Mev positrons of 20-hour half-life. The agreement between the latter positron energy and that of the reported[1] 3.6-minute I^{122} suggested that Xe^{122} with a 20-hour half-life had been produced, while the other activities indicated Xe^{121} and/or Xe^{123} were made.

Parent-daughter isolation experiments were performed to determine whether the 20-hour activity was the parent of I^{122} and to determine the half-lives of Xe^{121} and/or Xe^{123}. The separation was based on complete desorption of xenon from charcoal at elevated temperatures[2] and the retention of iodine daughters as solid iodide if silvered charcoal is used. A glass line consisting of a series of small U-tube traps, each filled with ~0.3 g silvered, activated charcoal held in place with glass wool, was used for making rapid periodic separations of the iodine daughters from the parent xenon. A large charcoal trap at −196°C, containing all the xenon collected from one target, was attached to the line by a ground glass joint and the system pumped down with a Cenco Hyvac pump. The xenon was transferred to the first trap of the series by cooling that trap with liquid nitrogen and warming the original large trap with an electric heater, after which the large trap was sealed from the line. This procedure was repeated at regular in-

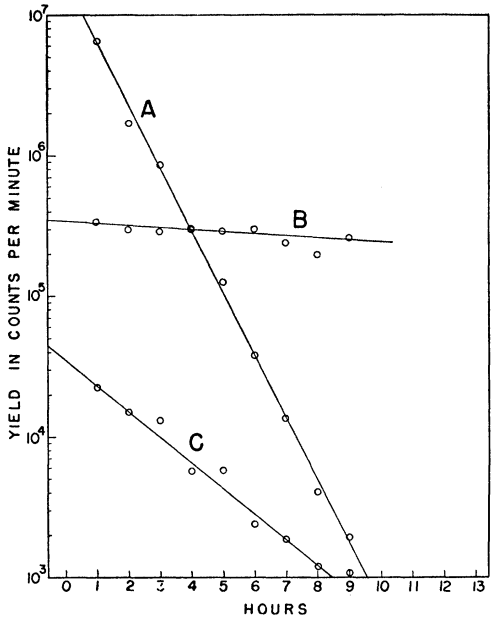

FIG. 1. Yields of iodine daughters at successive one-hour separations from xenon parent. Curve *A* (shelf 1, 2 mm from crystal), yields of I^{121}, shows the half-life of Xe^{121} to be 40(±2) minutes, and curve *C* (shelf 1), yields of I^{123}, gives 1.7(±0.2) hours for the half-life of Xe^{123}. Curve *B* (shelf 6, 80 mm from crystal) shows the yields of I^{122} to be compatible with 20(±1) hours for the Xe^{122} half-life, observed directly.

tervals of one hour for the first 9 traps. The activity of each sample of iodine grown in from the xenon was determined. The last trap was sealed and mounted for counting immediately upon transferring the xenon to it. From 3 to 5 minutes elapsed from the starting of a parent-daughter separation and the placing of the iodine sample under the scintillation counter.

All iodine daughter samples showed the presence of 3.4(±0.1)-minute and 1.45(±0.1)-hour activities, presumably I^{122} and I^{121}, respectively, 13-hour I^{123}, and 17-day Te^{121}. Several determinations of the I^{121} half-life on radiochemically pure iodine separated from the target gave a value of 1.5(±0.1) hours rather than the reported 1.8 hours, and the tellurium activity isolated from these samples confirmed the observation[3] that I^{121} decays to the lower 17-day isomeric state of Te^{121}. From the yields of I^{121} and I^{123} *versus* the time of parent-daughter separations the half-lives of Xe^{121} and Xe^{123} were determined to be 40(±2) minutes and 1.7(±0.2) hours, respectively (curves *A* and *C*, Fig. 1). The yields of I^{122} (curve *B*) proved to be completely compatible with the half-life of 20(±1) hours found with a GM tube for the xenon in the last trap of the series. Scintillation counter data on this sample proved that 32-day Xe^{127} had also been produced and indicated that 18-hour Xe^{125} was likewise present. All limits of error placed on numerical values are based on an estimate of the apparent reliability of the data.

Other workers, Tilley[4] at McGill University and Mathur and Hyde[5] at the University of California, Berkeley, have independently obtained information in substantial agreement with ours.

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† du Pont Fellow in chemistry, 1951–52.
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Angular Correlations in $(d,p\gamma)$ Reactions*

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THE angular distribution of protons produced in (d, p) reactions has been calculated by Butler[1] and others[2,3] under the assumption that a stripping process is the primary mechanism operative. Comparison of this theory with experimental results for the proton distribution makes it possible, in many cases, to determine the angular momentum l_N transferred to the target nucleus by the capture of a neutron. In general, the information obtained about l_N does not provide a unique spin assignment for the resultant nucleus; a parity determination is always unambiguous. If a target nucleus of spin $\mathbf{j}_0$ captures a neutron with orbital angular momentum l_N from the deuteron, the spin of the resultant nucleus $\mathbf{j}_1$ is restricted to the values

$$|\mathbf{j}_0+\mathbf{l}_N+\mathbf{1/2}|_{\min}\leqq j_1\leqq j_0+l_N+\tfrac{1}{2}. \quad (1)$$

The production of a nucleus (j_1) from a target nucleus (j_0) may be characterized by several values of l_N provided these values differ by an even number of units and obey the limiting relation

$$|\mathbf{j}_0+\mathbf{j}_1+\mathbf{1/2}|_{\min}\leqq l_N\leqq j_0+j_1+\tfrac{1}{2}. \quad (2)$$

It is to be noted that if either j_0 or j_1 are zero, only one value of l_N contributes to the reaction.

The methods and approximations applied in the (d, p) stripping calculations can be extended to the $(d, p\gamma)$ correlation function. The correlation function $f(\theta, \vartheta)$ takes the form

$$f(\theta,\vartheta)=\text{const}\sum_{l_N}\frac{\Lambda_{l_N}(\vartheta)}{(2l_N+1)}|g_{l_N}(\theta)|^2. \quad (3)$$

$|g_{l_N}(\theta)|^2$ is the angular distribution with respect to the incoming deuteron of the protons produced in the absorption of a neutron (l_N) from the deuteron by the target nucleus (j_0) leading to the nuclear state (j_1). $\Lambda_{l_N}(\vartheta)$ is the angular correlation function for the (n, γ) reaction in which a free neutron of angular momentum l_N is absorbed by a target nucleus (j_0) leading to a new nucleus (j_1) in the excited state which subsequently decays by 2^L multipole emission to the nuclear state (j_2). ϑ is the angle between the directions of propagation of the absorbed neutron and the emitted γ-ray. $\Lambda_{l_N}(\vartheta)$ is explicitly[4]

$$\Lambda_{l_N}=\sum_{\sigma}\sum_{m_1m_2}|A_\sigma{}^{l_N}|^2 \times\langle\sigma l_N m_1 0|j_1m_1\rangle^2\langle j_1Lm_1(m_2-m_1)|j_2m_2\rangle^2F_L{}^{m_2-m_1}(\vartheta). \quad (4)$$

σ is the vector sum of $\mathbf{j}_0$ and $\mathbf{S}_N$ (neutron spin); $A_\sigma{}^{l_N}$ is that part of the matrix element for the neutron capture process exclusive of the Clebsch-Gordan coefficients representing the dependence on the magnetic quantum numbers; $F_L{}^{m_2-m_1}(\vartheta)$ is the classical distribution for the (m_2-m_1) contribution to the 2^L multipole radiation; m_1, m_2 are the sets of magnetic quantum numbers belonging to the states (j_1) and (j_2), respectively. It immediately follows that if the (d, p) process is characterized by only one value of l_N, the emitted γ-ray is correlated to the direction of the absorbed neutron—or what is equivalent, the direction of the recoiling nucleus (j_1)—just as if the neutron had been captured from an unbound state.[5] This obtains when $j_0=0$ and Eq. (3) becomes

$$f(\theta,\vartheta)=\text{const}|g_{l_N}(\theta)|^2 \times\sum_{m_1m_2}\langle j_1Lm_1(m_2-m_1)|j_2m_2\rangle^2F_L{}^{m_2-m_1}(\vartheta)\delta(m_1\pm\tfrac{1}{2}). \quad (5)$$

Equation (5) exhibits no unknown parameters except those contained in the internal wave function of the deuteron implicit in $g_{l_N}(\theta)$. For the general reaction in which $j_0\neq0$, no statements can be made concerning $f(\theta, \vartheta)$ which are independent of a specific nuclear model needed to calculate the functions $A_\sigma{}^{l_N}$.

Equation (5) can be applied directly to the $A^{40}(d, p)A^{41*}(\gamma)A^{41}$ reaction, which has been studied experimentally by Gibson and Thomas.[6] These authors have demonstrated that the 1.34-Mev state of A^{41} has either odd parity and spin $\frac{1}{2}$ or $\frac{3}{2}$, or possibly even parity and spin $\frac{1}{2}$, whereas the ground state has spin 7/2 or 5/2 and odd parity. Table I gives the dependence on $\cos\vartheta$ of the angular correlation function $f(\theta, \vartheta)$ for each possible assignment of spin and parity to the 1.34-Mev and ground states of A^{41}. It is to be noted that if the measured angular correlation function is isotropic, the 1.34-Mev state has spin $\frac{1}{2}$, but no definite statements can be made of its parity or the spin of the ground state. On the other hand, a measured angular correlation which is nonisotropic will determine the spins and parities of both states of A^{41}.

TABLE I. Predicted angular distribution of γ-rays from the 1.34-Mev level of A^{41*} formed in a (d, p) reaction on A^{40}. ϑ is the angle between the recoiling A^{41*} and the 1.34-Mev γ-ray; L is the pole of the emitted γ-ray.

A^{41*} spin	A^{41*} parity	A^{41} spin	A^{41} parity	L	$f(\theta,\vartheta)/\lvert g_{l_N}(\theta)\rvert^2$
1/2	odd	7/2	odd	arbitrary	1
		5/2	odd		
1/2	even	7/2	odd		
		5/2	odd		
3/2	even	7/2	odd	2	$1+(3/13)\cos^2\vartheta$
		5/2	odd	1	$1-(1/7)\cos^2\vartheta$
				2	$1-(5/11)\cos^2\vartheta$

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