TABLE I. Structure factors for $BaCO_3$.

Index	$\|F\|$/unit cell	2θ	$\|F\|^2$/(unit cell)^2 (barns)
100	0	—	0
010	0	—	0
110	$0.0484f_{Ba}-0.262f_0$	11.24	0.0160
001	0	—	0
101	$4f_c+4.69f_0-2f_{Ba}$	13.10	$16f_c^2+13.3f_c+2.77$
200	$4f_c+4.45f_0-2f_{Ba}$	13.40	$16f_c^2+12.2f_c+2.32$
011	0	—	0
111	$3.46f_{Ba}-1.15f_0$	15.92	1.36
210	$3.46f_{Ba}-1.12f_0$	16.16	1.39
201	0	—	0

enriched samples of $BaCO_3$ the total scattering cross section of C^{13} was determined to be 5.5 ± 1 barn. Using the maximum indicated spread between the total and coherent cross sections, one finds that the spin incoherence resulting from the C^{13} in normal carbon corresponds to a cross section of less than 0.03 barn, or less than about half of one percent of the total cross section. Direct measurements of the incoherent cross section at neutron energies below the first Bragg peak by Burgy, Ringo, and Hughes[6] also show, although as yet somewhat less precisely, that the isotopic and spin incoherent scattering by normal carbon constitutes a very small percent of the total scattering.

[1] E. O. Wollan and C. G. Shull, Phys. Rev. **73**, 830 (1948). Hughes, Burgy, and Ringo, Phys. Rev. **77**, 291(L) (1950).
[2] R. W. G. Wyckoff, *Crystal Structures* (Interscience Publishing Company, New York, 1948).
[3] W. H. Zachariasen, Skrifter Norske Videnskaps-Akad. Oslo. I. Mat.-Natur. Kl. No. 4 (1928).
[4] M. Y. Colby and L. J. B. LaCoste, Z. Krist. **90**, 1 (1935).
[5] C. G. Shull and E. O. Wollan, Phys. Rev. **81**, 527 (1951).
[6] Burgy, Ringo, and Hughes, Phys. Rev. **84**, 1160 (1951).

A Two-Model Interpretation of a Nuclear Spectrum

D. R. INGLIS
Argonne National Laboratory, Chicago, Illinois
(Received December 11, 1951)

GOOD reasons have been given both for the plausibility of the central model,[1] on the one hand, and of the alpha-model,[2] on the other hand, as approximations to the structure of a light nucleus such as Li^7. When only the very low states were known, the question was discussed which model provides the more plausible approximation to the quantum-mechanical behavior of the system, as though a choice had to be made between the two. Now that more excited states are known, it becomes of interest to inquire whether both models may not be realized in nature, one as an approximation to some states of the system and the other as an approximation to others. Formally, it is not necessary that all states correspond to the same orthogonal set of approximate wave functions. Schematically, one may think of the alpha-model and the central model as two extremes and expect all states to lie between them, perhaps spread over a wide range, analogously to the finding of atoms in intermediate coupling between the (LS) and (jj) extremes. The present suggestion would require a sort of cooperative phenomenon favoring the extremes, as seems not implausible, a central atom adhering to spherical symmetry with very little nascent clustering into alphas, on the one hand, and a considerable degree of alpha-clustering encouraging almost complete alpha-clustering, on the other.

The interpretation of the ground state, for example, then involves the question, not which model is the more plausible, but which gives the lower energy. In some of the light nuclei it seems likely that the alpha-model has a ground state of lower energy than has the central model, since most of the nuclear binding energy is provided in the alpha-model by the internal binding energy of the constituent clusters, and only the mutual binding of the clusters need be provided by the long-range "tail" of the nuclear interactions.[3] In the central model with phenomenological approximations to the interactions, it has not been found possible[1,4] to compute ground states stable relative to disintegration or even nearly so, and the familiar discussions have been confined mainly to the relative energies of states of various symmetries.[1]

In the alpha-model of Li^7, the two low states form a rather closely spaced ^2P (or $^2\Sigma_u$ in molecular notation, the splitting being presumably attributable mainly to rho-type doubling[5]) which accounts for the ground state and 480-kev state with nuclear spins $I=3/2$ and $1/2$, respectively, and the only other fairly low state is expected to be one which is even in the interchange of the two clusters, a ^2S or $^2\Sigma_g$ with a symmetric molecular orbital hole. This may be associated with the second excited state at 4.8 Mev. The next state in this model, which might be identified with the 7.4-Mev state, would be a higher rotational state similar to a $^2F_{7/2}$, though this and the higher "vibrational" states are apt to be too short-lived to be recognized as sharp states. In the central model[6] the 4.8- and 7.4-Mev states would be $^2F_{7/2}$ and $^2F_{5/2}$, respectively. The recent suggestion of Peshkin and Siegert[7] that the 7.4-Mev state rather probably has $I=3/2$ is not compatible with either of these interpretations. In either model alone, the next $I=3/2$ state is expected to be considerably higher than the ^2F (in the alpha-model an even second rotational state and a $^2\Pi$ involving a node through the clusters, in the central model with Majorana interactions a ^2P about three times as high as the ^2F). The other[7] possibility, $I=5/2$, would fit the central model, but this predicts the splitting of the low doublet about twice as large as observed.

In spite of the apparent inelegance of using two models where one might have been expected to suffice, it thus becomes very attractive to assume that the first three states of Li^7 are represented by the three low states of the alpha-model, and that the fourth state at 7.4 Mev is the ground state of the central model, a $^2P_{3/2}$ (Fig. 1). The other known properties of the ground ^2P, such as the magnetic moment of the ground state[8] and the re-

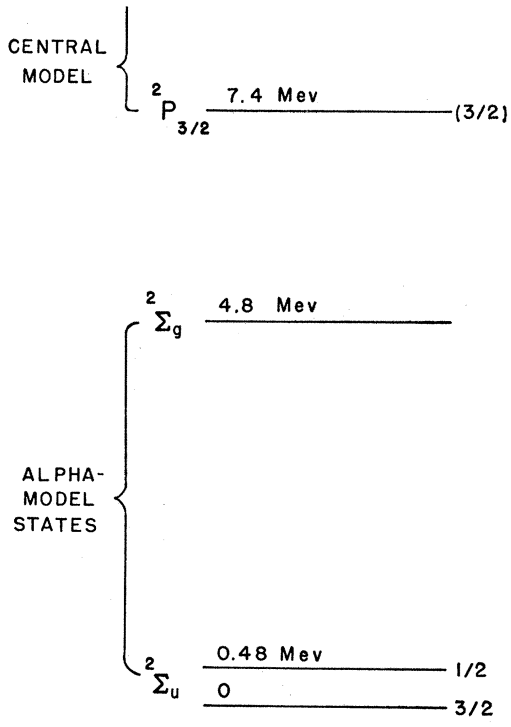

FIG. 1. Assignments of states in Li^7.

lation between the doublet splittings[9] in Li^7 and Be^7, are at least as satisfactory in the alpha-model as in the central model. Besides the apparent occurrence of $I=3/2$ at 7.4 Mev, another otherwise puzzling observation receives a natural explanation with this two-model interpretation: The inelastic scattering[10] of deuterons and alphas on Li^7 induces the transition between the two alpha-model states at 0 and 4.8 Mev, but not between the ground state and the central-model state at 7.4 Mev, presumably mostly because of the partial orthogonality in the coordinates of each of the nucleons. Other consequences of the two-model assumption in Li^7 that may be tested by further experiments are the predicted assignment $I=1/2$ at 4.8 Mev and the expected sequence of states above 7.4 Mev, at least an $I=1/2$, perhaps also $I=7/2$, $5/2$ in intermediate or (jj) coupling,[6] from the central model in the region 8 to about 12 Mev, and possibly a ^2F from the alpha-model if it is not too short-lived.

The extension of this two-model interpretation to the four-structure of the stability curve and to other more detailed properties of the p-shell nuclei attributes the low states of the nuclei in the region Li^6-Be^9 and again at O^{16} to the alpha-model, but in the neighborhood of C^{12} the low states of the central model are considered more stable because of the large contribution of spin-orbit coupling energy to the binding near the end of the $P_{3/2}$ shell, as will be discussed in detail in a forthcoming paper.

[1] E. Feenberg and E. Wigner, Phys. Rev. **51**, 95 (1937); E. Feenberg and M. Phillips, Phys. Rev. **51**, 597 (1937).
[2] J. A. Wheeler, Phys. Rev. **52**, 1083 (1937); L. Hafstad and E. Teller, Phys. Rev. **54**, 681 (1938); E. Teller and J. A. Wheeler, Phys. Rev. **53**, 778 (1938).
[3] D. R. Inglis, Phys. Rev. **60**, 837 (1941).
[4] D. R. Inglis, Phys. Rev. **51**, 531 (1937); H. Margenau and H. Carroll, Phys. Rev. **54**, 705 (1938).
[5] J. H. Van Vleck, Phys. Rev. **33**, 111 (1929).
[6] H. H. Hummel and D. R. Inglis, Phys. Rev. **81**, 910 (1951).
[7] M. Peshkin and A. J. F. Siegert, Phys. Rev. **83**, 202 (1951) as reported at Washington; J. M. Blair and R. E. Holland, unpublished Argonne National Laboratory report; Roberts, Darlington, and Haugsnes, Phys. Rev. **82**, 299 (1951).
[8] H. A. Bethe, Phys. Rev. **53**, 842 (1938); D. R. Inglis, Phys. Rev. **53**, 880 (1938).
[9] E. Feenberg, Phys. Rev. **81**, 644 (1951); D. R. Inglis, Phys. Rev. **82**, 181 (1951).
[10] H. E. Gove and J. A. Harvey, Phys. Rev. **82**, 658 (1951).

Interpretation of Observed Pressure-Dependent Recombination Coefficients

LEONARD B. LOEB AND WULF B. KUNKEL*
Department of Physics, University of California, Berkeley, California
(Received December 11, 1951)

THE recent studies of ionic recombination[1] by microwave methods and associated investigations have now established that the relatively high value coefficients in electron-ion recombination are dissociative recombinations of molecular ions.[2] Such recombination processes have coefficients independent of pressure. In the inert gases He, Ne, and A the initially produced ions are in large measure atomic ions which change to molecular ions by triple impacts with neutral atoms.[2] If such ions are studied sufficiently soon after creation, the recombination process is complicated by having unequal numbers of electrons and molecular ions and a creation of molecular ions from atomic ions during measurement.[3] The theoretical analysis of recombination under these conditions has been carried out by one of us.[4] It reveals that depending on conditions the variation of electron density with time, the measured quantity in most such studies, does not yield plots of $1/n$ against time that are linear over any appreciable range in values of t. They also show that while values of the observed coefficients α^1 under some conditions depend on initial concentrations of carriers, which may vary with pressure, the character of the $1/n-t$ plots will clearly reveal inequality of concentrations and change of ionic carriers.

Now careful work on well-developed and thoroughly cooled down plasmas by Biondi and Brown have disclosed observed

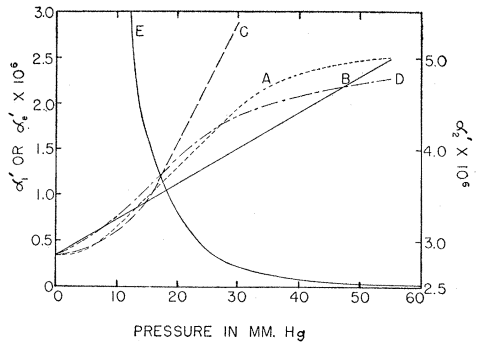

FIG. 1. Variation of recombination coefficients with pressure.

coefficients α^1 obtained from clearly linear plots which showed a marked pressure dependence.[1] The coefficients also had such values that they must either involve dissociative recombination or positive ion-negative ion recombination. These were observed in Ne at 77°K and below and in N_2 and O_2 but otherwise not in He, Ne, and A. In H_2, $\alpha=2.5\times10^{-6}$ between 3- and 15-mm pressure and was constant with pressure.

The variation in Ne started from a low value of 1.94×10^{-7} and rose with pressure along an exponential curve to 8×10^{-7}. The curves in N_2 and O_2 started from low constant values and rose possibly parabolically with pressure to higher values. Very recently, Varnerin[5] using variants of the method of Biondi and Brown observed that α^1 in H_2 started at 0.34×10^{-6} at 3 mm of H_2 and rose along an S-shaped curve to an approximate saturation value of 2.5×10^{-6} at about 60 mm. It is impossible to gather whether linear $1/n-t$ plots were observed with his method of analysis. While the appearance of the higher value of α^1 at 60 mm instead of at 3-mm pressure as observed by Biondi and Brown requires some explanation, the conditions and methods of the two studies are sufficiently different not to cause serious concern at this time. Pressure variation of dissociative recombination coefficients, however, requires explanation.

Independently, Bates and Sayers[6] considered electron-ion recombination processes in the upper atmosphere where one species of positive ion recombined with two negative carriers, electrons and negative ions. The electron concentrations were those measured. In the upper atmosphere the ions were formed from electrons in a pressure-dependent reaction with molecules, which is reversed by photodetachment of the electrons from the ions. Thus, a pressure-dependent concentration ratio of electrons and ions $\gamma_p=n_-/n_e$ existed at any one time. This equilibrium ratio is rapidly established relative to the recombination changes and is not seriously affected by time. Under these circumstances the equation for the observed α^1 for electron loss with a linear $1/n-t$ relation is given by

$$\alpha_1{}^1=\alpha_1+\gamma_p\alpha_2. \tag{1}$$

Here α_1 and α_2 are coefficients for the two negative carriers with a single positive ion. Varnerin used this relation and found that it accounted for his initial rise if he assumed that the Thomson ion-ion recombination was proportional to p and that γ_p was proportional to p. The first assumption is not accurate, and there are many other reasons including energy considerations why his proposal of negative ion formation in H_2 is unlikely as a Bates-Sayers type process. A more complete consideration of equilibrium determined recombination leads to three basic equations, application of which is dependent on which carrier density is measured. Of the three equations the designated (1) above applies when electron densities n_e alone can be measured and the positive ion density n_+ is related to the negative carrier densities by $n_+=n_e+n_-$. If there are two positive ions of densities n_{1+} and n_{2+} recombining with electrons, then $n_e=n_{1+}+n_{2+}$, which