gram of rock, i.e., about 11 percent of the total radioactive heat.

Recent cloud-chamber observations of Franchetti and Giovanozzi[5] indicate a possible slight increase of these last figures. In fact, these authors found that about one percent of the decay electrons had energies above the previously assumed 1.35±0.05-Mev upper limit for K^{40}.[6] If these high energy tracks were not due to distortion by multiple scattering, these observations would suggest a maximum β-energy of 1.7±0.1 Mev. Since the γ-quantum of K^{40} has an energy of only 1.5 Mev, it should be possible, as pointed out by Franchetti and Giovanozzi, to attribute the γ-quantum to the β-decay. In any case, this possibility need not affect the value of the branching ratio or the present computations on the heat production of potassium.

A further suggestion concerning the disintegration scheme of K^{40} was advanced by Suess.[7] According to this, all the capture processes in K^{40} would lead to an excited argon atom, i.e., the branching ratio would equal the γ/β-ratio. However, this hypothesis is based mainly on argon determinations in soluble potassium minerals,[8] for which alterations in recent geological time cannot be excluded. Loss of argon from the investigated samples appears the more likely as even this hypothesis would require argon amounts exceeding at least 2 to 6 times those actually found. In addition, to account for the large amounts of atmospheric argon it should then be assumed that all argon was produced in a 40-kilometer deep crustal layer, since the origin of the earth has escaped into the atmosphere.

With the present values of the decay periods of K^{40}, the origin of atmospheric argon can be explained without excessive assumptions. The K^{40}/K ratio at the time of formation of the elements, say 4×10^9 years ago, becomes comparable to the Lu^{176}/Lu ratio, for example, in agreement with abundance rules advanced by Suess.[7,8] The heat produced in the earth's crust by potassium alone at the time of formation of the oldest known rocks, about 2×10^9 years ago, becomes about twice the present total radioactive heat output. This amount of heat could certainly not prevent rock formation, as might have been the case with the previous estimate,[1] according to Birch.[9]

Yet, at the time of the earth's origin, about 3.35×10^9 years ago,[10] the heat produced by the radioactivity of potassium alone probably exceeded 10 times that generated at present by the total radioactivity in the earth's crust. It seems likely that this heat, if potassium then was concentrated in the earth's crust as it is today, caused a considerable slowing down of the cooling process on the earth's surface. The very large heat production of potassium in the past may also, as suggested by Birch,[9] aid in resolving some difficulties encountered in a number of geophysical problems.

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On Models for Be^9

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THREE models for the Be^9 nucleus have been investigated.[1-4] These are: (1) the Hartree model, (2) the α-particle model $(2\alpha+n)$, and (3) a two-body model in which the two α-particles are treated as a unit (Be^8), and the neutron is assumed to move in the field of the Be^8.

Of these models, the Hartree model is probably the most accurate and gives the best interpretation of the experimental data. In Table I the comparison between experiment and the predictions which the three models make about the ground state and the magnetic moment of Be^9 is given. The experimental value $\mu=-1.18$ nuclear magneton is taken from the direct measurement of Kusch, Millman, and Rabi.[5] Direct evidence for spin $\frac{3}{2}$ has been obtained from hyperfine structure data obtained in Germany during the war.[6] Also, this value of the spin may be inferred with some degree of reasonableness from the experimental value of μ.[5] It should be pointed out that the two-body model makes no direct predictions concerning the ground state and magnetic moment. However, this model may be regarded as a first approximation to the α-particle model and should, therefore, lead to the same ground state as this model. If, then, it is assumed that the ground state with the two-body model is $^2P_{3/2}$ state, this model yields $\mu=-1.85$ nuclear magnetons.[7]

TABLE I. Theoretical and experimental results for the ground state and magnetic moment of Be^9.

Model	Ground state	Magnetic moment
Hartree	$^2P_{3/2}$	-1.50
α-particle	$^2P_{3/2}$	$-0.7>\mu>-1.5$
Two body	$^2P_{3/2}$	-1.85
Experimental result	$^2P_{3/2}$	-1.18

Although the two-body model is only a first (and sometimes poor) approximation to the more accurate models, in the explanation of certain processes, such as the photo- and electrodisintegration of Be^9, its use is probably justifiable. The justification of the use of this model for these processes is based upon the following points: (1) The binding energy for ejection of a neutron (1.63 Mev) is much less than the average binding energy per particle in the Be^9 nucleus. (2) The instability of the Be^8 nucleus is only 162 kev.[8] The lifetime of Be^8 is estimated to lie between 10^{-19} and 10^{-15} sec., corresponding to a width between 100 and 1 ev.

Very little is known about the low lying excited states of Be^9. As heretofore mentioned, the ground state should be a $^2P_{3/2}$ state. This means that the ^2P is an inverted doublet as would be predicted from relativistic spin-orbit coupling. It seems likely that the energy separation of the ^2P states should be of the same order of magnitude as the known splitting of similar states for other light nuclei. For He^5 the splitting of the P doublet is 250 kev and seems to be normal.[9] For Li^7 the ^2P splitting is 400 kev and seems to be inverted.[10] Inglis[11] has explained the magnitude and inverted nature of the splitting in Li^7 as being due to relativistic spin-orbit coupling. Dancoff[12] has given numerical estimates for the splitting in He^5 by using a central field model. He points out that tensor forces lead to the observed normal doublet, giving the right order of magnitude for the splitting.

From the above-mentioned results for Li^7 and He^5 it seems likely that the ${}^2P_{\frac{1}{2}}$ state in Be^9 is a bound state. If this is the case, the ${}^2P_{3/2}\rightarrow{}^2P_{\frac{1}{2}}$ magnetic dipole transition should be observed in inelastic scattering experiments or by detection of the γ-ray resulting from the transition, either directly or through internal conversion. Since no empirical results on the ${}^2P_{\frac{1}{2}}$ level are available, it does not seem profitable, at present, to speculate about the nature of the forces which may be responsible for the ${}^2P$ splitting.

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Theory of the Photo-Disintegration of Be^9

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RECENTLY the cross section for the photo-disintegration of Be^9 has been determined as a function of energy by Wattenberg and his associates.[1] Their results, as well as results of other workers, have been kindly communicated to us by Dr. Wattenberg; these results are shown in Fig. 1. It should be noted that the experimental results indicate that the photo-disintegration cross section has a maximum and a minimum in the energy range of the experimental data. Undoubtedly, there is also a second maximum beyond the range of these data.

It is possible to give a fairly accurate explanation of the observed results by applying the two-body model discussed in the preceding letter. It is assumed that the ground state is a ${}^2P_{3/2}$ state. Then the incident photons should produce electric dipole transitions from the ground P state to S and D states. It is also possible that a magnetic dipole transition ${}^2P_{3/2}\rightarrow{}^2P_{\frac{1}{2}}$ occurs. As in the case of the deuteron, the photoelectric and photo-magnetic disintegration cross sections exhibit maxima when plotted as a function of energy. For the interpretation of the experimental data, the photo-magnetic cross section does not seem necessary. Consequently, it has been assumed that the two maxima are due to the electric dipole $P\rightarrow S$ and $P\rightarrow D$ transitions, the first maximum resulting from the $P\rightarrow S$ transition. The locations and widths of the maxima are determined, at least in part, by the characteristics of the resonance levels of the states of positive energy corresponding to the final states of the disintegrated Be^9.

For simplicity, the interaction between the Be^8 and the neutron has been represented by a rectangular potential well. From general considerations, the radius of the well should probably be about $3-5\times10^{-13}$ cm. The value $r=5\times10^{-13}$ cm has been employed in the calculations; this radius determines the well depth to be 12.16 Mev for the P state. The dependence of the Be^8 neutron force upon the angular momentum has been taken into account in a schematic way by assuming that the well depth is a function of parity. For the S and D states (both with even parity) a well depth of 3 Mev has been used. (The same radius, $r=5\times10^{-13}$ cm, has been used for all states.) With this well, the first S state is bound by about 100 kev. This loosely bound state yields a resonance effect in the disintegration cross section similar to that which would be obtained with a virtual state.[2] The theoretical photo-disintegration cross section is given by the solid curve in Fig. 1. A continuation of the theoretical curve to higher energies yields a second maximum.

The theory predicts that the angular distribution of the ejected photo-neutrons should be spherically symmetric for energies near the threshold (that is, in the region of the first maximum), and should be given by $[P_2(\cos\theta)]^2$ for energies somewhat beyond the minimum of the cross-section curve. If the second peak were due to a magnetic dipole transition, the angular distribution for energies somewhat beyond the minimum would be given by $\sin^2\theta$. The angular distribution of the photo-neutrons has been found to be spherically symmetric for energies near the threshold by Goloborodko and Rosenkewitch.[3] According to Dr. Wattenberg, an investigation of the angular

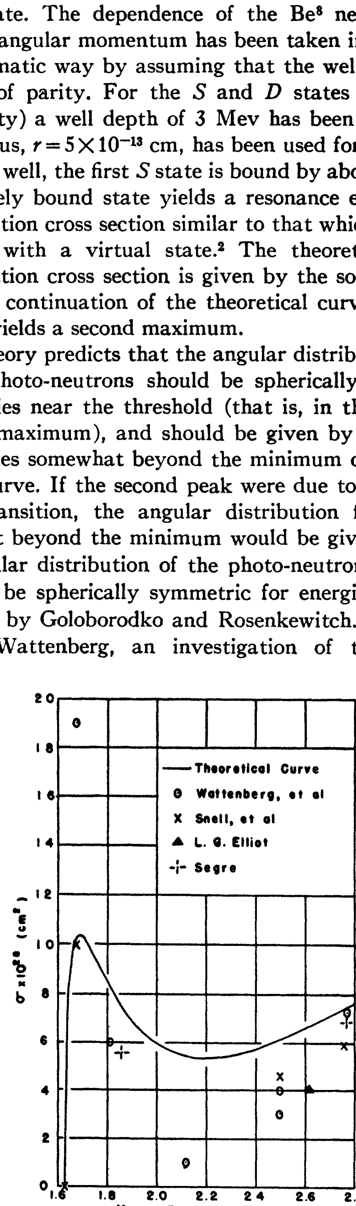

FIG. 1. Photo-disintegration cross sections for Be^9.