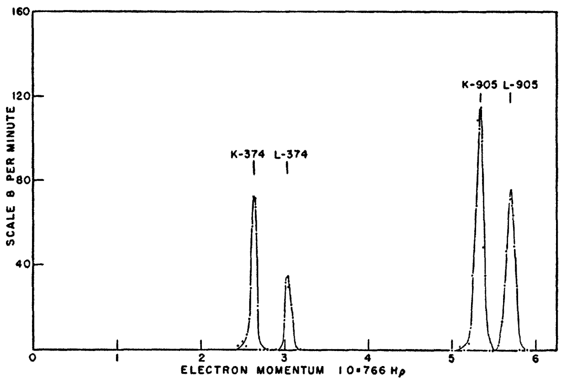

FIG. 1. Spectrum of internal conversion electrons from Pb^{204m}.

target was dissolved in nitric acid, most of the lead removed as $PbCl_2$ and bismuth separated from the remainder by chemical plating on nickel powder. The Pb^{204m} was then separated from bismuth by one of a number of procedures involving combinations of several of the following steps: precipitations of $BiPO_4$, $PbSO_4$, $Bi(OH)_3$ and $PbCrO_4$, and plating of bismuth on nickel.

From gamma-ray coincidence studies it was found that the isomeric transition takes place in two steps.[3] To obtain the exact energies of the transitions, the internal conversion electrons of Pb^{204m} were studied in a lens spectrometer. The electron spectrum is shown in Fig. 1. The K and L lines of gamma-rays of 374 kev and 905 kev were observed. No further electron lines were found in the region from 70 kev to 1.7 Mev. The K/L ratio for the 374-kev line is 2.1 ± 0.2 and for the 905-kev line it is 1.5 ± 0.2. Approximate values of the internal conversion coefficients were obtained from an absorption curve of the internal conversion electrons and gamma-rays taken with an end window G-M counter. The values found for the internal conversion coefficients are $\sim$5 percent for the 374-kev line and $\sim$10 percent for the 905-kev line.

Delayed coincidences between the conversion electrons were found with Geiger counters, and between the gamma-rays with scintillation counters as detectors. The half-life of the second step is 3×10^{-7} second (Fig. 2.). Absorption measurements showed

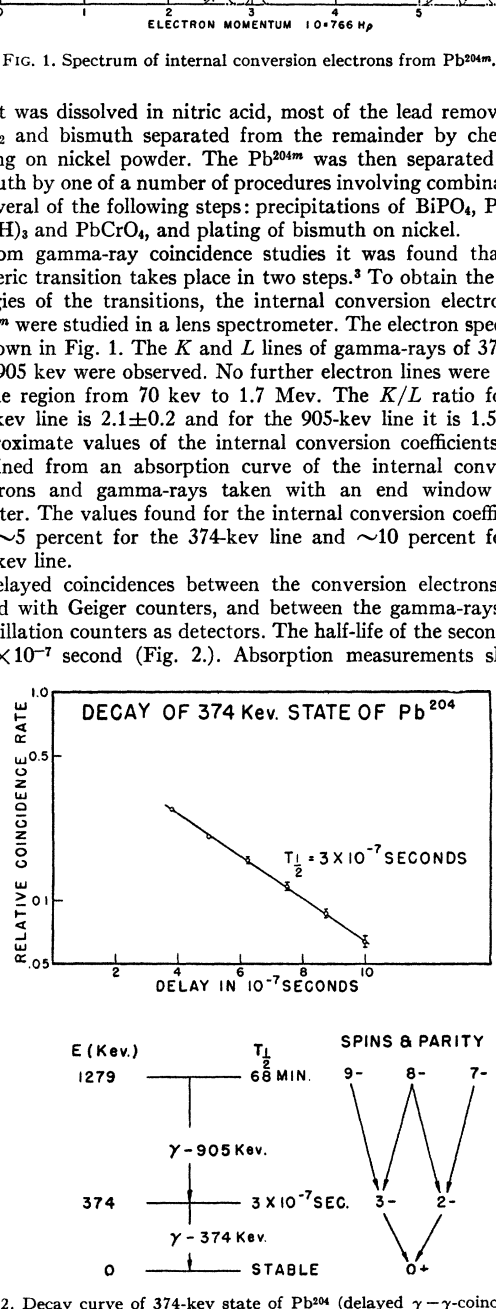

FIG. 2. Decay curve of 374-kev state of Pb^{204} (delayed $\gamma-\gamma$-coincidences taken with scintillation counter) and proposed decay scheme.

that the 905-kev transition precedes the 374-kev transition. The combination of half-lives, energies, K/L ratios and conversion coefficients is best compatible with the interpretation that the 68-minute transition is of multipole order 6 and the 3×10^{-7}-second transition is of multipole order 3, though multipole orders lower by one unit cannot be excluded in either transition. A decay scheme and some possible spin and parity assignments are shown in Fig. 2.

Because of the high spin changes involved, the angular correlation between the two gamma-rays would not be expected to show spherical symmetry, except if "memory" of spin orientation were not retained for a measurable time by the 3×10^{-7}-second state. In order to decide this question the angular correlation between the 905-kev and the 374-kev gamma-rays was measured with a 5×10^{-7}-second delay and a resolving time of 2×10^{-7} second. Tl-activated NaI scintillation counters were used as detectors. The Pb^{204m} was in the form of an aqueous lead acetate solution ($\sim$0.2 cc). The gamma-rays defined within a half-angle of 8°. The ratio of coincidences at 180° to those at 90° was found to be 1.22 ± 0.05. Thus we have definitely established the existence of "memory" of spin orientation for a time at least as long as 5×10^{-7} second. How well the "memory" is retained in different compounds and to what extent it can be affected by an applied magnetic field is being investigated at present. It is hoped in this way to decide the feasibility of measuring the gyromagnetic ratio of the 3×10^{-7}-second state.

Drs. Falkoff[4] and Hamilton[5] have kindly communicated to us the following results of calculations of the $\gamma-\gamma$-correlation functions to be expected for a number of possible spin assignments for Pb^{204m}. The multipole order of the transition assumed is indicated above each arrow.

$$A^3 \quad 9\xrightarrow{6}3\xrightarrow{3}0 \quad W(\vartheta)=1+0.755\cos^2\vartheta+0.210\cos^4\vartheta-0.064\cos^6\vartheta$$

$$B^3 \quad 8\xrightarrow{5}3\xrightarrow{3}0 \quad W(\vartheta)=1+0.770\cos^2\vartheta+0.095\cos^4\vartheta-0.003\cos^6\vartheta$$

$$C^{3,4} \quad 8\xrightarrow{6}2\xrightarrow{2}0 \quad W(\vartheta)=1+0.636\cos^2\vartheta-0.198\cos^4\vartheta$$

$$D^{3,4} \quad 7\xrightarrow{5}2\xrightarrow{2}0 \quad W(\vartheta)=1+0.555\cos^2\vartheta-0.148\cos^4\vartheta$$

$$E^4 \quad 7\xrightarrow{6}2\xrightarrow{2}0 \quad W(\vartheta)=1-1.088\cos^2\vartheta+0.873\cos^4\vartheta$$

Our experimental value for $W(180°)$ excludes case E. Any one of the cases A–D which give values of $W(180°)$ between 1.41 and 1.90 would be compatible with the experimental result if there is some "loss of memory" of the angular correlation.

Our thanks are due Drs. M. Deutsch and J. W. Irvine, and J. Bulkley of the M.I.T. cyclotron group whose kind cooperation made this work possible, and E. der Mateosian and Miss Elizabeth Wilson for valuable help.

* This work was carried out under the auspices of the AEC.
** On leave from the University of Illinois.

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The Ejection of Li^8 Nuclei by Gamma-Rays

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AN Ilford type E1 nuclear research emulsion, 100 microns thick, was exposed to 240 roentgens of γ-rays from the University of Saskatchewan betatron operating at 26.7 Mev. The method of exposing the plate and of developing it by the "grain gradation" process has been described previously.[1]

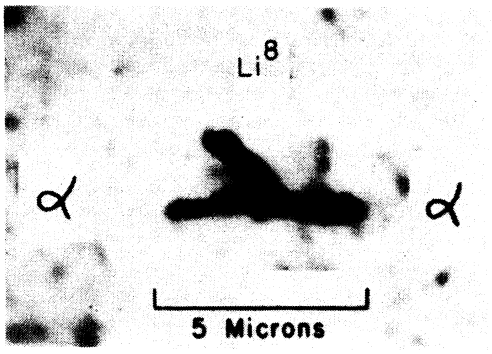

FIG. 1. Photo-micrograph of γ-ray induced "hammer" track in Ilford E1 emulsion.

In a search of 12 cm^2 of this plate 5 "hammer" tracks were found, of which one is shown in Fig. 1. The two equal and opposite tracks have the grain density characteristic of α-particles, while the third track is considerably denser. Such a configuration, which is well known in cosmic-ray work, is here attributed to the photo-disintegration of a constituent of the emulsion with the ejection of a Li^8 nucleus. After coming to rest, the Li^8 decays by β-emission to the broad C Mev excited level of Be^8, which then breaks up into two α-particles.

From mass considerations the emission of a Li^8 nucleus in any photo-nuclear reaction involving the light elements (carbon, nitrogen, oxygen, and sulfur) in the emulsion requires an energy of 29 Mev or greater, and such reactions are therefore ruled out by the fact that this exceeds the maximum γ-ray energy available. The simple photo-emission of Li^8 from any of the heavy elements (silver, bromine, and iodine) in the emulsion is, however, energentically possible, and Table I shows the threshold energies for such reactions as calculated from the semi-empirical mass formulas of Weizsaecker[2] and Feenberg.[3] Though the emission of neutrons or singly charged ions simultaneously with the Li^8 ion would not be seen, these reactions would require 8 Mev or more of additional energy, and hence are energetically impossible.

Certain considerations favor silver as the probable source of the Li^8 nuclei. The energies of the Li^8 ions in the 5 events were estimated from the general range-energy relationship for charged particles[1] and two range-energy values for Li^7 obtained by Farragi.[4] The energies obtained were 1.0, 2.8, 4.0, 4.9, and 5.7 Mev; thus, on an energy basis, only one of these events could be attributed to bromine (Table I). While all events are energetically possible if silver or iodine is involved, the occurrence of iodine in the emulsion is only 2.5 percent of that of silver, and therefore the cross section for the photo-disintegration of iodine would have to be more than one order of magnitude greater than that for the corresponding reaction in silver in order to have a comparable yield. Thus silver is regarded as the most probable origin of the Li^8 nuclei.

Assuming that silver isotopes are the parent nuclei, and that the range of γ-ray energies effective in causing this reaction is 22 to 26.7 Mev, the cross section for the reaction is of the order of 10^{-30} cm^2.

TABLE I. Calculated energy thresholds for (γ, Li^8) reactions.

Reaction	Threshold energy (Mev) Feenberg's formula	Weizsaecker's formula
$Br^{79}(\gamma, Li^8)Ge^{71}$	25.2	25.8
$Br^{81}(\gamma, Li^8)Ge^{73}$	25.0	25.0
$Ag^{107}(\gamma, Li^8)Ru^{99}$	22.3	22.0
$Ag^{109}(\gamma, Li^8)Ru^{101}$	21.4	21.5
$I^{127}(\gamma, Li^8)Sn^{119}$	19.1	19.0

We should like to thank Dr. R. N. H. Haslam and his coworkers at the University of Saskatchewan for making the betatron irradiations, Dr. B. W. Sargent for his interest and advice, and Mr. R. G. Hayman for his assistance in searching the plate.

[1] C. H. Millar and A. G. W. Cameron, Phys. Rev. **78**, 78 (1950).
[2] E. Feenberg, Rev. Mod. Phys. **19**, 239 (1947).
[3] As quoted by E. Fermi in *Nuclear Physics* (University of Chicago Press, Chicago, 1950) p. 7.
[4] H. Farragi, Comptes rendus **229**, 1223 (1949).

The Hydromagnetic Equations

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May 18, 1950

COSMIC fluids, being electrical conductors, can carry electric currents and their magnetic fields. These phenomena are of interest for solar, stellar and sunspot magnetism, geomagnetism, magnetic fields in stellar atmospheres and in interstellar space and the related problems of galactic radio noise and the origin of cosmic rays.

In this note as previously[1] we confine ourselves to "Maxwellian" electrodynamics where the relations between the vectors **D**, **E** and **B**, **H** have the familiar scalar and isotropic form; this excludes certain classes of phenomena in rarefied gases. The interaction between the velocity field **V** and the magnetic field **B** is described by the hydrodynamic equations together with the electromagnetic field equations, both containing proper coupling terms.[2] In the field equations the displacement current is omitted; the hydrodynamic equations are simplified by assuming incompressibility. We have,

$$d\mathbf{V}/dt+(\mathbf{V}\cdot\nabla)\mathbf{V}=-\nabla p/\rho-\lambda\mathbf{B}\times(\nabla\times\mathbf{B})+\nu\nabla^2\mathbf{V}$$
$$d\mathbf{B}/dt=\nabla\times(V\times\mathbf{B})+\nu_m\nabla^2\mathbf{B}$$

where ν is the conventional specific viscosity and

$$\lambda=(4\pi\mu\rho)^{-1},\quad \nu_m=(4\pi\mu\sigma)^{-1}.$$

(μ susceptibility, ρ density). The quantity ν_m is the "magnetic" viscosity.[1] We now transorm these equations as follows: (a) take their sum and difference, respectively; (b) introduce new variables defined by the equations

$$\mathbf{P}=\mathbf{V}+\lambda^{\frac{1}{2}}\mathbf{B},\quad \mathbf{Q}=\mathbf{V}-\lambda^{\frac{1}{2}}\mathbf{B},$$
$$\nu_1=\nu+\nu_m,\qquad \nu_2=\nu-\nu_m,$$
$$q=p/\rho+(\mathbf{P}-\mathbf{Q})^2/8;$$

(c) by virtue of some straightforward transformations using known vectorial identities the new equations can be written

$$d\mathbf{P}/dt+(\mathbf{Q}\cdot\nabla)\mathbf{P}=-\nabla q+\nabla^2(\nu_1\mathbf{P}+\nu_2\mathbf{Q})$$
$$d\mathbf{Q}/dt+(\mathbf{P}\cdot\nabla)\mathbf{Q}=-\nabla q+\nabla^2(\nu_2\mathbf{P}+\nu_1\mathbf{Q}).$$

For vanishing field, $\mathbf{P}=\mathbf{Q}$, the two equations become identical and go over into the Stokes-Navier equations of hydrodynamics.

The remarkable symmetry of these equations and their analogy to the ordinary hydrodynamic equations is apparent. One might, in particular, expect that phenomena of turbulence will occur in hydromagnetic systems, similar to those in ordinary hydrodynamics and at mechanical or "magnetic"[1] Reynolds numbers of comparable magnitude. They will no doubt give rise to a "turbulent" magnetic field coupled with the mechanical motion.

The case of compressible fluids is of considerable physical interest. Truesdell[3] has recently shown that the conservation theorem of the magnetic flux can be extended to compressible fluids on replacing **B** by $\mathbf{B}/\rho$ throughout. In the above equations, however, there appears the combination $\mathbf{B}/\rho^{\frac{1}{2}}$, and this is necessary on dimensional grounds; we have thus been unable to ascertain whether similarly simple, symmetrized equations exist for the compressible case.

[1] W. M. Elsasser, Rev. Mod. Phys. **22**, 1 (1950).
[2] Reference 1, Eqs. (35) and (41).
[3] C. Truesdell, Phys. Rev. **78**, 823 (1950).

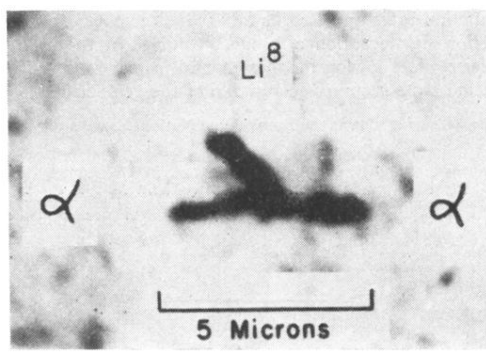

FIG. 1. Photo-micrograph of γ-ray induced "hammer" track in Ilford E1 emulsion.