if the ions have already a nearly uniform energy, because the losses may be avoided, which always otherwise arise, if the rays hit the screen, which limits the small interval of energy.

(4) The electric field between the cylinders (D) and (E), which accelerates the positive ions of the substance, will be formed so that it works as an electron-optic lens and produces a nearly parallel beam of rays.

We have tried out such an arrangement, and found it to work most satisfactorily. The intensity is dependent on the trial-substance and was large for metals and smaller for salts. The analysis in the parabola-spectrograph shows the ions of the trial-substance and the ions of the primary canal-ray discharge, all having the same energy.

On the Spin of μ-Mesons

J. Tiomno*
Palmer Physical Laboratory, Princeton, New Jersey
August 8, 1949

THE known processes resulting from the interaction of μ-mesons with other elementary particles:

$$\pi \rightarrow \mu + \mu_0, \quad (1)$$

$$\mu \rightarrow \mu_0 + e + \nu, \quad (2)$$

$$P + \mu^- \rightarrow N + \mu_0 \quad (3)$$

give very little indication on the spin of μ-mesons. We can only say that μ and μ_0 have both integral or half-integral spin.

As in all these processes μ appears together with μ_0 we shall assume that they are two different states of charge of the same particle and thus that they have the same spin.

The possibility of a spin $\frac{1}{2}$ for these particles has been already considered[1] (in particular if μ_0 is a neutrino). Although the hypothesis of μ_0 being a neutrino is very appealing, it seems that one should not neglect the other possibilities, in particular that it has an integer spin. From the analysis of the frequency of bursts produced by cosmic-ray mesons at sea level (mostly μ-mesons), Christy and Kusaka[2] excluded the value 1 for the spin of these mesons. If we exclude values higher than 1 (which may eventually result from an extension of Christy-Kusaka's calculations) we are left only with the values 0 and $\frac{1}{2}$.

We want to show here that a zero spin for the μ-meson with a special type of coupling with electron, neutrino and nucleons is in good agreement with the experimental results.

Let us consider first the μ-decay. We describe μ and μ_0 mesons by scalar (or pseudoscalar) fields, respectively complex (Φ) and real (φ). In order that μ-decay be a first-order process we take the interaction Lagrangean bilinear[3] in the mesonic fields; the most general one that can be formed using at most first derivatives[4] of the mesonic fields *and* of the electron-neutrino wave functions (ψ)[5] is:

$$L_{\text{int}} = \psi^+ \left\{ \left[g_1 \Phi\varphi + \frac{g_2}{\kappa}\varphi\frac{\partial\Phi}{\partial x^\sigma}\gamma_\sigma + 2\frac{g_3}{\kappa^2}\frac{\partial\varphi}{\partial x^\rho}\frac{\partial\Phi}{\partial x^\sigma}\gamma_{\rho\sigma}\right]\tau_- + c.c.\right\}\psi, \quad (4)$$

where $\kappa = \mu c/\hbar$ and $\gamma_{\rho\sigma} = i(\gamma_\rho\gamma_\sigma - \gamma_\sigma\gamma_\rho)$, τ_- being an operator that transforms an electron into a neutrino. The probability per second of μ-decay in which the electron is produced with a momentum in the interval p_e, $p_e + dp_e$ is then proportional to:

$$dp_e \left\{ |g_1|^2 f_1\left(\frac{p_e}{\mu c}\right) + |g_2|^2 f_2\left(\frac{p_e}{\mu c}\right) + |g_3|^2 f_3\left(\frac{p_e}{\mu c}\right) + \frac{i}{2}(g_1 g_2^* - g_2 g_1^*)\cdot f_{13}\left(\frac{p_e}{\mu c}\right)\right\}. \quad (5)$$

The functions f are shown, for $\mu_0 = 0$ as consistent with the experimental results,[6,7] in the upper left part of Fig. 1; the experimental points of Anderson and co-workers[7] are also plotted in an arbitrary scale. It is seen that the only one of the simple couplings which gives a spectrum in agreement with the experimental points is the one in g_2.[8] This agreement may be emphasized if one compares the integral spectrum ($\sim E_e^3[2\mu c^2 - 3E_e]$) with the experimental points, as is done in the lower part of Fig. 1.

If we consider now the capture of a μ-meson by a nucleus we calculate the nuclear excitation as in case of spin $\frac{1}{2}$,[1] using for the interaction of μ, μ_0-mesons with nucleons an expression similar to (4); we then obtain a spectrum of nuclear excitation very similar to that of the case of spin $\frac{1}{2}$ and, then, also the result that the probability for star production is very small.[9]

One then concludes that the possibility of spin zero for μ_0-mesons is in good agreement with the experimental results and should not be disregarded for the moment.

We are grateful to Drs. J. L. Lopes and L. L. Foldy for helpful discussions. This work was assisted by the joint program of the ONR and the AEC.

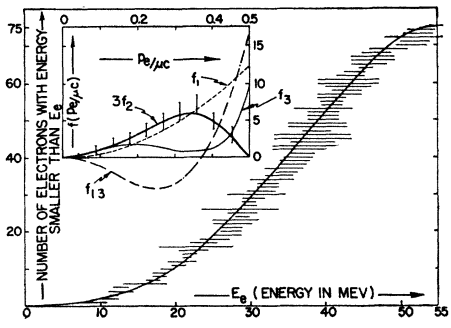

FIG. 1.

* Rockefeller Foundation fellow of the University of São Paulo, Brazil.
[1] J. Tiomno and J. A. Wheeler, Rev. Mod. Phys. **21**, 144, 153 (1949).
[2] R. F. Christy and S. Kusaka, Phys. Rev. **59**, 414 (1941).
[3] The possibility of a coupling of μ, μ_0 with the electron-neutrino field, linear in each mesonic field is easily excluded in view of the impossibility of making the process (2) significantly more probable, then:

$$\mu \rightarrow e + \nu \rightarrow e + \nu + h\nu.$$

[4] We exclude terms with two time derivatives of ϕ, φ and ψ as they lead to difficulties in the application of the usual Hamiltonian formalism.
[5] Terms with derivatives of ψ are, to first order, equivalent to terms of the kind considered in (4).
[6] C. M. G. Lattes, Phys. Rev. **75**, 1468 (1949).
[7] Leighton, Anderson, and Seriff, Phys. Rev. **75**, 1432 (1949).
[8] A rough agreement can also be obtained with $g_3 = 0$, $g_1 = ig_2$.
[9] It should be pointed out that assuming that the interaction of spinless μ-mesons with nucleons is through an intermediate κ-meson we obtain a lifetime for the $\pi - \mu$-decay of the order of 10^{-8} sec. as shown by A. S. Lodge (Nature **161**, 809 (1948)), R. Latter and R. F. Christy (Phys. Rev. **75**, 1459 (1948)) and others.

Analysis of Delayed Coincidence Counting Experiments

Daniel Binder
Sloane Physics Laboratory, Yale University, New Haven, Connecticut*
August 8, 1949

THE use of the delayed coincidence method for measuring short half-lives by several investigators[1-4] makes a re-examination of the basis of the experiment desirable. The coincidence counting rate *versus* delay curves exhibit two regions. The first is affected by the random delays in the counter itself, and the second is a pure exponential decrease determined by the radioactive decay. Van Name[3,5] analyzed the combination of these effects by assuming a triangular distribution for the delays in the counter but found it necessary to divide the range of artificial delays into six regions. A Gaussian distribution will be used here, and a fairly simple relation will result.

Consider a fast particle passing through both counters of a two-channel circuit at the time $t=0$. We assume that the probability that a pulse is formed between t and $t+dt$ is

$$w(t)dt=\frac{1}{(2\pi)^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\exp\left[-\frac{(t-\bar{t})^2}{2\langle\Delta t\rangle_{Av}^2}\right]dt,$$

where $\langle\Delta t\rangle_{Av}$ is the r.m.s. deviation from the mean time $\bar{t}$. If $\bar{t}_1$ and $\bar{t}_2$ are the mean statistical delays in channels 1 and 2, and t_D is the artificial delay introduced in channel 1, then, assuming the resolving time τ of the electronic circuit to be small compared to $\langle\Delta t\rangle_{Av}$ the relative coincidence rate is

$$C=2\tau\int_{-\infty}^{\infty}w_1(t)w_2(t)dt,$$

where

$$w_1(t)=\frac{1}{(2\pi)^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\exp\left[-\frac{(t-\bar{t}_1-t_D)^2}{2\langle\Delta t\rangle_{Av}^2}\right],$$

and

$$w_2(t)=\frac{1}{(2\pi)^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\exp\left[-\frac{(t-\bar{t}_2)^2}{2\langle\Delta t\rangle_{Av}^2}\right].$$

Integration gives

$$C(D)=\frac{\tau}{\pi^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\exp\left[-\left(\frac{D}{2\langle\Delta t\rangle_{Av}}\right)^2\right], \quad (1)$$

where

$$D\equiv t_D+\bar{t}_1-\bar{t}_2.$$

An excellent fit is obtained in Fig. 1 between Eq. (1) and the data of W. J. MacIntyre of this Laboratory for $\langle\Delta t\rangle_{Av}=1.85\times10^{-8}$ sec. The zero of delay is, of course, arbitrary in any measurement. The experimental points are for a proportional counter and a polystyrene scintillation counter with a P^{32} source. A similar fit is obtained for two proportional counters, supporting the assumption in the following work that $\langle\Delta t\rangle_{Av}$ is the same for the two types of counters.

Now consider two particles emitted in cascade, the first entering the counter of channel 1 and the second, the counter of channel 2 a time t' later. Then the coincidence rate is

$$C(D,t')=\frac{\tau}{\pi^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\exp\left[-\left(\frac{D-t'}{2\langle\Delta t\rangle_{Av}}\right)^2\right].$$

The probability thar the second particle is emitted between t' and $t'+dt'$ seconds later is

$$w(t')dt'=\lambda e^{-\lambda t'}dt',$$

where λ is its decay constant. Thus the relative number of coincidences as a function of D and λ is

$$C(D,\lambda)=\frac{\tau}{\pi^{\frac{1}{2}}\langle\Delta t\rangle_{Av}}\int_0^{\infty}\lambda e^{-\lambda t'}\exp\left[-\left(\frac{D-t'}{2\langle\Delta t\rangle_{Av}}\right)^2\right]dt'.$$

Finally we have

$$C(D,\lambda)=Ae^{-\lambda D}\left[1-\Phi\left(\lambda\langle\Delta t\rangle_{Av}-\frac{D}{2\langle\Delta t\rangle_{Av}}\right)\right], \quad (2)$$

where

$$A\equiv\lambda\tau\exp[\lambda^2\langle\Delta t\rangle_{Av}^2]=\text{const.}$$

and

$$\Phi(x)\equiv\frac{2}{\pi^{\frac{1}{2}}}\int_0^x\exp(-y^2)dy.$$

Note that Eq. (2) predicts a pure exponential decrease in $C(D,\lambda)$ for large D since Φ approaches -1. It may be used to find the value of D at which the curve becomes exponential when $\langle\Delta t\rangle_{Av}$ is known.

Equation (2) agrees well with MacIntyre's data[4] for the 2.3×10^{-8} sec. metastable state of Hg^{198} as shown in Fig. 2. Ten percent variations in the reported value of λ of 3×10^7 sec.$^{-1}$ cause marked differences in the theoretical coincidence rate for positive delays, thus supporting the 10 percent accuracy claimed by MacIntyre.

Equation (2) may also be used to find the shortest half-life detectable by an asymmetry in the C *versus* D curves. Computation shows that an asymmetry can still be observed with the above-mentioned equipment for a half-life of 1×10^{-8} sec., and that this disappears for 0.7×10^{-8} sec.

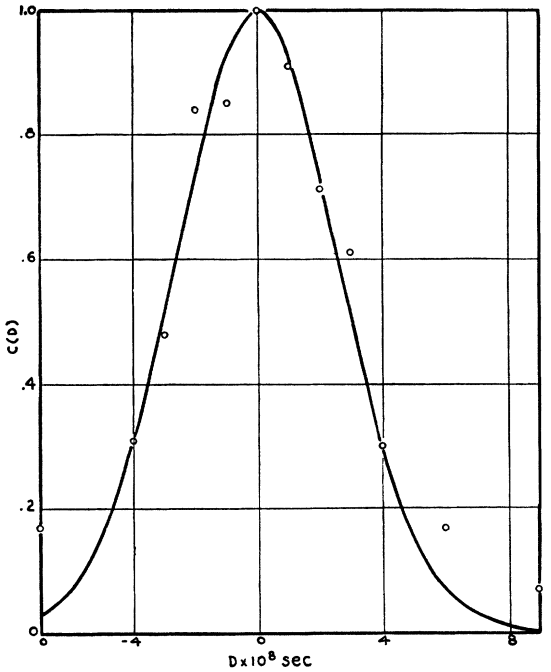

FIG. 1. $C(D)$ *versus* D with experimental points for a proportional and a polystyrene scintillation counter.

When τ is not small compared to $\langle\Delta t\rangle_{Av}$, a calculation similar to that given by Bradt and Scherrer[6] for the integral curve method may be performed. Here we have

$$C(D)=\int_{-\tau}^{\tau}dT\int_{-\infty}^{\infty}w_1(t)w_2(t-T)dt$$
$$=\tfrac{1}{2}\left[\Phi\left(\frac{\tau+D}{2\langle\Delta t\rangle_{Av}}\right)+\Phi\left(\frac{\tau+D}{2\langle\Delta t\rangle_{Av}}\right)\right] \quad (3)$$

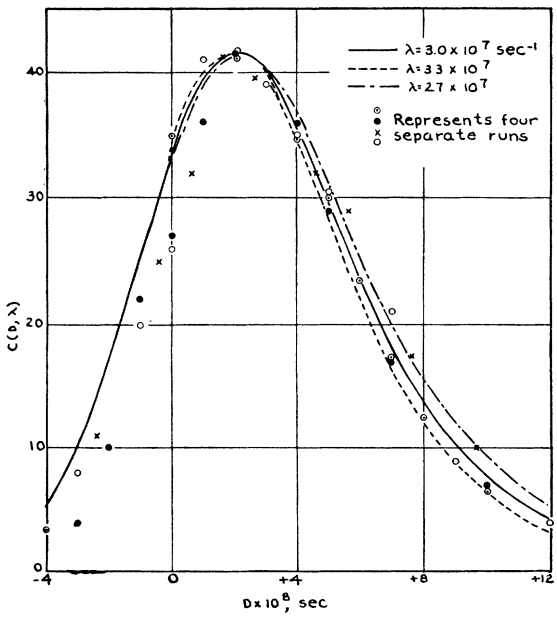

FIG. 2. $C(D,\lambda)$ *versus* D with experimental points for the Hg^{198} metastable state.

and

$$C(D,\lambda)=C(D)+\tfrac{1}{2}e^{\alpha^2/4}\{e^{\alpha x_1}[1-\Phi(x_1+\tfrac{1}{2}\alpha)] - e^{-\alpha x_2}[1+\Phi(x_2-\tfrac{1}{2}\alpha)]\}, \quad (4)$$

where

$$x_1\equiv(\tau-D)/2\langle\Delta t\rangle_{Av}, \quad x_2\equiv(\tau+D)/2\langle\Delta t\rangle_{Av}, \quad \alpha\equiv 2\lambda\langle\Delta t\rangle_{Av}.$$

Equation (4) also approaches a pure exponential decrease for large D.

The author would like to thank Mr. William J. MacIntyre for the use of his data and Professor Howard L Schultz for many discussions concerning coincidence techniques.

* Assisted by the joint program of the ONR and the AEC.

[1] S. D. Benedetti and F. K. McGowan, Phys. Rev. **74**, 728 (1948).
[2] P. T. Bittencourt and M. Goldhaber, Phys. Rev. **70**, 780 (1946).
[3] F. W. Van Name, Phys. Rev. **75**, 100 (1949).
[4] W. J. MacIntyre, Phys. Rev. **76**, 312 (1949).
[5] F. W. Van Name, Ph.D. dissertation.
[6] H. Bradt and P. Scherrer, Helv. Phys. Acta **16**, 251 (1943).

On the Half-Life of Na^{22}

L. Jackson Laslett
*Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa**
August 8, 1949

THE radioactivity of Na^{22}, first discovered by Frisch,[1] has been described by the present writer[2,3] as producible by the deuteron bombardment of magnesium and the half-life estimated as 3.0 years.[3] More recently, Saha[4] has given a value of 2.8 years for the half-life of this activity. During the past three years the decay of a Na^{22} sample has been followed in this laboratory and it is the purpose of the present note to report the value obtained for the half-life.

The Na^{22} sample used was produced in 1937 by the bombardment of magnesium metal with deuterons produced by the cyclotron in Professor Lawrence's laboratory at Berkeley. The magnesium target was subsequently mounted in the recess of a brass plate, covered with a mica sheet hermetically sealed to the brass, and, by means of a Lauritsen electroscope,[5] its activity was compared at intervals with that from a standard uranium oxide source

The resultant decay curves, for two different source positions, are shown in Fig. 1 and indicate a half-life of 948 days or 2.6[0] years.[6] It should be mentioned that diffusion of the active material from the surface into the magnesium metal would, if appreciable, result in an underestimation of the half-life, since the greater portion of the activity measured was readily absorbable (positrons). Some confirmation of the belief that diffusion and similar processes played no significant role in the present work is afforded, however, by the observation that absorption curves taken at the beginning and end of the measurements (curves 1 and 2 of the insert, Fig. 1) appeared entirely similar and were in agreement with one obtained[3] shortly after the sample was first prepared.

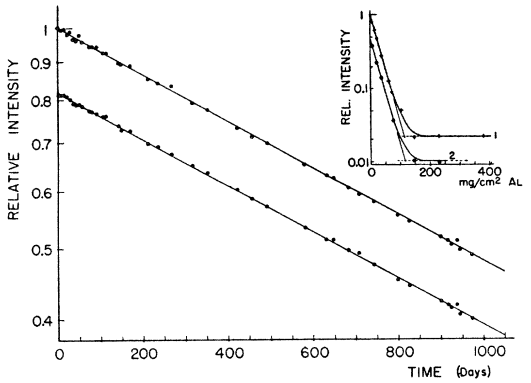

FIG. 1. Logarithmic decay curves of Na^{22} activity, measured with respect to that of an uranium oxide standard, for two source positions. *Insert*: Aluminum absorption curves (logarithmic scale of ordinates) taken (1) at the beginning and (2) after completion of the decay measurements.

It is a pleasure for the writer to indicate once again his gratitude to Professor Lawrence for the privilege of using the cyclotron in connection with the preparation of the sample used in the work reported here.

* Contribution No. 80 from the Institute for Atomic Research. Work performed at the Ames Laboratory of the AEC.
[1] O. R. Frisch, Nature **136**, 220 (1935).
[2] L. J. Laslett, Phys. Rev. **50**, 388(A) (1936).
[3] L. J. Laslett, Phys. Rev. **52**, 529 (1937).
[4] N. K. Saha, Trans. Bose Res. Inst. (Calcutta) **14**, 57 (1939–41); cited in Chem. Abstracts **42**, 450i (1948).
[5] The electroscope, manufactured by the F. C. Henson Company (Pasadena), was used to measure the ionization in a chamber approximately 2¼ inches in diameter and 3 inches long, into which the radiation passed through an aluminum window of 1.2 mg/cm² surface density. The surface density of the mica covering the source was 5.2 mg/cm². We are indebted to Dr. A. F. Voigt for making available to us this electroscope in its modified form.
[6] A value of 2.6 years was provisionally communicated to Dr. G. T. Seaborg during the course of this work and has subsequently appeared in the review article of Seaborg and Perlman (Rev. Mod. Phys. **20**, 585 (1948)).

Microwave Spectrum of CF_3Cl

D. K. Coles and R. H. Hughes
Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania
August 1, 1949

THE CF_3Cl rotational transitions between $J=2$ and 3 and between $J=3$ and 4 have been observed in the microwave regions around 20 kmc and 27 kmc. Thirty-one lines were measured, including five lines which are attributed to molecules in an excited vibrational state. The hyperfine structure spacing yields quadrupole coupling constants of 78.05±0.2 and 61.44±0.4 mc for CF_3Cl^{35} and CF_3Cl^{37}, respectively.

At a pressure of 0.1 mm, the line widths were approximately 5 mc, corresponding to a molecular collision cross section of 1400A².

The values of B_0 for CF_3Cl^{35} and CF_3Cl^{37} were found to be 3335.56 and 3251.51 mc, respectively. From these values one may calculate that the distance of the Cl nucleus from the center of mass of the CF_3 group is 2.129A, and that the moment of inertia of the CF_3 group about an axis through its center of mass and perpendicular to the symmetry axis is 46.31 mass units times angstroms².

If one assumes tetrahedral angles, one then obtains for the internuclear distance C—F=1.323A and C—Cl=1.765A. These are quite consistent with electron diffraction values on similar fluorochloromethanes.

Hyperfine Structure of Fe 57*

Jean Brossel
Spectroscopy Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts
August 1, 1949

A SEARCH for the hyperfine structure of Fe 57 was carried out by means of a Fabry-Perot interferometer, crossed with a 35-foot concave grating in the Wadsworth stigmatic mounting (the blaze being in the second order).

The wave-length scale covered extended between 6000A and 2400A. No structure, broadening, or asymmetry was found. The resolution obtained would have revealed any over-all structure greater than $25\cdot10^{-3}$ cm^{-1} between 6000 and 4000A and $50\cdot10^{-3}$ cm^{-1} near 2500A. The discharge tube was a hollow cathode cooled with liquid nitrogen, the carrier being argon with a trace of helium. The spectrum was very extensive and was readily photographed. At least 400 lines were examined. Among others, the following electron configuration of Fe I were involved: $3d^74s$, $3d^64s4p$, $3d^64s4d$ and $3d^64s5s$, $3d^64s^2$, $3d^74p$. It was not found possible to excite Fe II by changing widely the conditions of the discharge.