Aluminum absorption curves of pure 63-min Te^{133m} in equilibrium with 2-min Te^{133} gave, when analyzed by the Feather method: 1.3-Mev β, 2.4-Mev β and probably a high energy component but in very low abundance. Electrons of about 0.3 Mev energy were also found, showing the existence of converted gammas of energy >0.3 Mev.

Lead absorption curves showed γ-rays with energies 0.3 Mev; 0.6 Mev, and 1.0 Mev. A tentative decay scheme is given in Fig. 1.

The energy >0.3 Mev for the transition 63-min Te^{133m}/2-min Te^{133} is somewhat lower than that predicted by Goldhaber, $\sim$0.4 Mev. The value 0.3 Mev was determined by absorption measurements, and the precision is not very high in this case because of the presence of the β-rays.

In order to make a more precise determination, experiments were done together with M. Goldhaber at the Brookhaven National Laboratory. In order to get higher activities the reactor was used, and carefully purified Te^{133m} in equilibrium with 2-min Te^{133} was studied using a scintillation spectrometer. Preliminary experiments showed that the decay is rather complex, but a converted gamma of about 0.4 Mev energy is probably there. This work will therefore be continued.

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[4] A. C. Pappas, unpublished; available in Massachusetts Institute of Technology LNSE Progress Report, May 31, 1951.

Spontaneous Fission of U^{234}, Pu^{236}, Cm^{240}, and Cm^{244}†

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In a recent communication commenting on the mechanism of fission we called attention to the simple exponential dependence of spontaneous fission rate on Z^2/A and to the effect of an odd nucleon in slowing the fission process.[1] Since it is of interest to test further the simple correlation of the spontaneous fission rate for even-even nuclides with Z^2/A, a further number of such rates have been determined.

The spontaneous fission rates were measured by placing the chemically purified samples on one electrode of a parallel plate ionization chamber, filled with a mixture of argon and carbon dioxide, which was connected with an amplifier followed by a register and a stylus recorder. The results are summarized in Table I. The U^{234} was a sample of high isotopic purity obtained by the electromagnetic concentration process, the Pu^{236} was prepared by bombarding highly enriched U^{235} with 18-Mev deuterons according to the reactions

$$U^{235}(d,n)Np^{236}\xrightarrow{\beta^-}Pu^{236},$$

the Cm^{240} came from the bombardment of Pu^{239} with 38-Mev helium ions according to the reaction $Pu^{239}(\alpha,3n)Cm^{240}$, and the Cm^{244} came from the pile neutron bombardment of Am^{243} (containing Am^{241}) by the reactions

$$Am^{243}(n,\gamma)Am^{244}\xrightarrow{\beta^-}Cm^{244}.$$

By the nature of their methods of production, the Cm^{240} and Cm^{244} contained some Cm^{242} whose spontaneous fission had to be subtracted from the total rate in each case. The Cm^{240} also contained some Cm^{241}, but since the fission rate seemed to decay with the half-life of Cm^{240}, the contribution of the Cm^{241} must have been small. This observation on Cm^{241} would agree with the lower rate expected for nuclides having odd nucleons. The result for U^{234} is consistent with the earlier observation of Segrè,[2] who reported an upper limit of 30 spontaneous fissions/gram-hour.

TABLE I.[a] Spontaneous fission rates of U^{234}, Pu^{236}, Cm^{242}, and Cm^{244}.

Nuclide	Fissions/g-hr	"Half-life" (years)
U^{234}	13 ± 6	$2\pm1\times10^{16}$
Pu^{236}	$5.8\pm2\times10^{7}$	$3.5\pm1\times10^{9}$
Cm^{240}	$1.0\pm0.2\times10^{11}$	$1.9\pm0.4\times10^{6}$
Cm^{244}	$1.4\pm0.2\times10^{10}$	$1.4\pm0.2\times10^{7}$

[a] The errors indicated are statistical only and do not include any estimate for possible systematic errors.

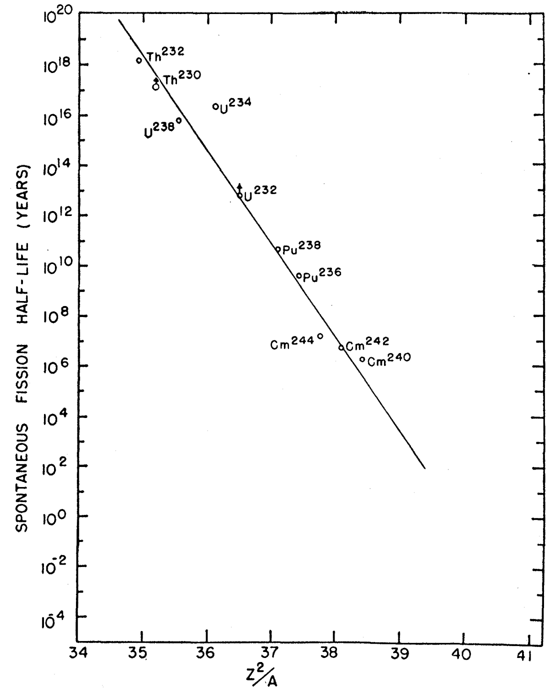

FIG. 1. Plot of spontaneous fission rates of even-even nuclides (♂ signifies lower limit to half-life).

These data are included in Fig. 1, which is otherwise identical with the plot in the previous report[1] (where references are given), with the exception that odd-nucleon nuclides, which apparently all fall above the line, are not included. As can be seen, the new even-even nuclides fit in fairly well with the correlation. However, some even-even nuclides such as U^{234}, and possibly also U^{232} and Th^{230}, exhibit substantial deviations in the direction of slower rates. It is apparent that more data are needed in order to establish the pattern for even-even nuclides in detail. Nevertheless, it can be definitely stated that the spontaneous fission rates for even-even nuclides seem to define a certain limiting rate, and it seems especially significant that the extrapolation of the line (in Fig. 1) representing this rate to the region of instantaneous rate (that is, half-life of the order of 10^{-20} second) gives a value of about 47 for Z^2/A, which corresponds with the predicted limiting value for Z^2/A.

Similar considerations in regard to spontaneous fission rates have recently been published by Whitehouse and Galbraith.[3]

We wish to express our appreciation to Professor J. G. Hamilton, T. M. Putnam, Jr., G. B. Rossi, and the operating crew of the 60-inch cyclotron of the Crocker Laboratory for their help in the bombardments. We would also like to thank the Y-12 Area of the Oak Ridge National Laboratory for supplying the highly purified U^{234} sample.

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The Gauge Invariance Problem

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IT appears to be generally believed[1] that the recent formulation[2] of electrodynamics in the interaction representation is gauge invariant. This is not true, as will be shown below. Since a statement which is contrary to accepted notions is being made, it is well to state precisely the point in the theory where the lack of gauge invariance arises. The definition of the basis vectors of the representation in terms of a separation of the interaction-free electron-positron field into positive and negative frequency parts does not give a gauge invariant representation.

As no development of quantum electrodynamics is here intended, the formulas used to demonstrate the above point will be taken from the literature.

In the interaction representation, according to Schwinger, paper I, the effect of a gauge transformation of the second kind,

$$A_\mu(x) = A_\mu'(x) - \partial\Lambda(x)/\partial x_\mu,$$

is compensated for in the equations of motion by the canonical transformation

$$\Psi(\sigma) = \exp[-iG(\sigma)]\Psi'(\sigma), \qquad \text{(I, 2.40)}$$

with

$$G(\sigma) = \frac{1}{\hbar c^2}\int_\sigma j_\mu(x)\Lambda(x)d\sigma_\mu. \qquad \text{(I, 2.41)}$$

The meaning of the canonical transformation (I, 2.40) is: If a certain physical state is represented by the state vector $\Psi(\sigma)$ when the potentials are $A_\mu(x)$, then the same physical state is represented by the new state vector $\Psi'(\sigma)$ when the potentials are $A_\mu'(x)$.

In the interaction representation the electron-positron spinor field satisfies the equation

$$(\gamma_\mu\partial/\partial x_\mu + \kappa_0)\psi = 0. \qquad \text{(I, 2.16)}$$

Further, in Schwinger, II, the spinor field $\psi(x)$ was decomposed into positive and negative frequency parts $\psi^+(x)$, $\psi^-(x)$ with definitions given by (II, 1.47) and (II, 1.48), respectively.

$$\psi^+(x) = \frac{1}{2\pi i}\int_{C+}\psi(x-\epsilon\tau)(d\tau/\tau), \qquad \text{(II, 1.47)}$$

$$\psi^-(x) = \frac{1}{2\pi i}\int_{C+}\psi(x+\epsilon\tau)(d\tau/\tau), \qquad \text{(II, 1.48)}$$

with the contour of integration extending from $-\infty$ to $+\infty$ and passing below the singularity at $\tau=0$ with ϵ a time-like four-vector with a positive time component. The "vacuum" state was then defined by the conditions

$$\psi^+(x)\Psi_0 = 0. \qquad \text{(II, 1.63)}$$

$$\overline{\psi^-}(x)\Psi_0 = 0. \qquad \text{(II, 1.64)}$$

Although Schwinger didn't do so explicitly, a one-electron state would then be defined by[3]

$$\overline{\psi^+}(x)\Psi_0 = \Psi(x),$$

with a corresponding extension to multiparticle states. A complete collection of vectors of the types enumerated above then constitutes a system of basis vectors for the representation. We now note that this system of basis vectors is chosen independently of the gauge. As has already been seen, the same physical state is represented by different vectors in different gauges; thus, the same vectors must represent different physical states in different gauges. The conclusion is therefore immediate that the representation given above is not gauge invariant. Even though the basis vectors are chosen in a gauge invariant manner these fixed vectors represent different physical states in different gauges and also, as is better known, on different space-like surfaces.

There is no implication intended here that electrodynamics is intrinsically gauge dependent, but only that this particular scheme for introducing electrons and positrons into the theory is gauge dependent.

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[1] The author obtained this impression from private conversations with a number of theoretical physicists. The author also had the same delusion until quite recently.
[2] S. Tomonaga, Prog. Theoret. Phys. **1**, 27 (1946); J. S. Schwinger, I. Phys. Rev. **74**, 1439 (1948); J. S. Schwinger, II, Phys. Rev. **75**, 651 (1949).
[3] There is a difficulty here with the normalization of $\Psi(x)$ which can easily be avoided by taking a weighted average of $\psi(x)$ over a region of space time.

Angular Distribution of Photoprotons from Carbon*

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UTILIZING the techniques recently reported[1] for determining the angular distributions of photoprotons from targets of copper, cobalt, and nickel, we have measured the photoproton angular distribution from a 38 mg/cm² target of C^{12} bombarded by bremsstrahlung of 23-Mev maximum energy. Results are given in Fig. 1.

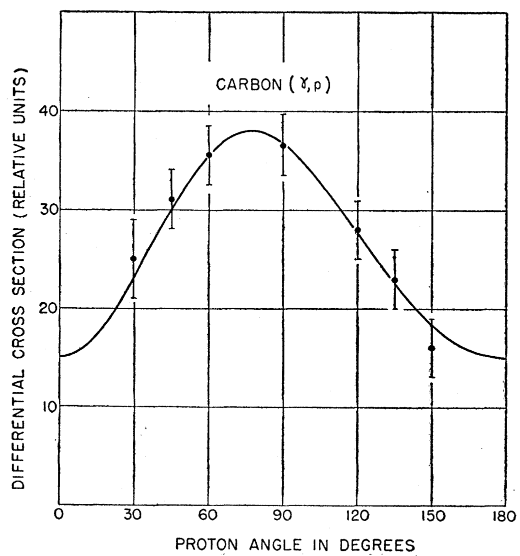

FIG. 1. Angular distribution of protons from a 38-mg/cm² target of carbon bombarded with bremsstrahlung of 23-Mev maximum energy.

The distribution shows, as did those of copper and cobalt, a large asymmetric component peaked in the forward direction. For carbon the asymmetric component represents a greater portion of the total protons ejected and the forward shift of the peak from 90° is about 10 degrees.[2] Nonetheless, the distribution can be fitted by an expression of the form

$$1+(a\sin\theta + b\sin\theta\cos\theta)^2,$$