New Isotopes: Er^{172} and Tm^{172}†

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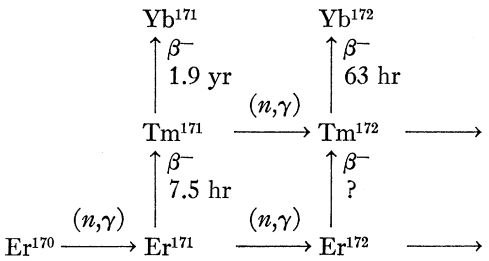
(Received March 27, 1956)

Two new isotopes, Er^{172} of half-life 49.8±1 hr, and Tm^{172} of half-life 63.6±0.3 hr, have been found. The mass assignment of Tm^{172} was proven by direct mass separation, and that of Er^{172} by genetic relationship. The Tm^{172} isotope was found to emit a 1.5-Mev β^- particle, γ rays of 1.79, 1.44, 1.09, 0.40, 0.18, and 0.076 Mev, and a K x-ray of 0.049 Mev. The mass assignments of Er^{165}, Er^{171}, and Tm^{171} were verified.

AN unknown thulium activity with a 2- to 3-day half-life was first reported by Folger, Stevenson, and Seaborg.[1] During the course of some recent work on the high-energy fission of uranium, this isotope was studied more closely and found to have a half-life of about 63 hr, and an erbium parent of about a 2-day half-life. It was decided to prepare enough of the thulium isotope for a mass separation so as to characterize the isotopes more completely.

Accordingly, 18 mg of Er_2O_3 were irradiated with neutrons for three days in the Materials Testing Reactor at Arco, Idaho. The expected reactions were



There were no interfering side reactions since there are no other active erbium isotopes decaying to active thulium isotopes.

After irradiation the thulium was separated from the erbium by means of an ion exchange column packed with Dowex-50 resin and eluted with 1.0M lactic acid of pH 3.10. Thirty percent of the thulium fraction was then mass-separated, using a time-of-flight isotope separator in use at this laboratory. The mass 172 fraction had an activity of ~15 000 disintegrations per minute which decayed with a half-life of 64 hr. Least-squares analyses of five Tm^{172} samples obtained from Er^{172}, formed both from uranium fission and by double neutron capture, gave an average of 63.6±0.3 hr for the half-life.

In order to measure the half-life of the parent, Er^{172}, a series of column separations was made periodically to separate the thulium growing in from the main erbium fraction. Seven separations were made over a period of 14 days. It was necessary to correct for the thulium and erbium chemical yields and for the different growth times for each sample. The thulium chemical yields were determined by adding 2.7 mg of Tm^{169} carrier previous to each separation and weighing the final thulium sample as Tm_2O_3. The erbium chemical yields were determined by assaying the erbium fraction previous to each separation and counting the 9.4-day Er^{169} present.

The amount of radioactive daughter substance, N_2, present in an initially pure sample of the parent, N_1, at some time t is given by

$$N_2(t)=\frac{\lambda_1}{\lambda_2-\lambda_1}N_1^0(e^{-\lambda_1 t}-e^{-\lambda_2 t}).$$

Thus a correction can be made for the different growth times by using the expression

$$N_2(\text{corr})=\frac{N_2(t_s)}{N_2(t)}=\frac{e^{-\lambda_1 t_s}-e^{-\lambda_2 t_s}}{e^{-\lambda_1 t}-e^{-\lambda_2 t}},$$

where t_s is some standard time chosen as a reference, and t is the actual growth time. The foregoing expression was used to correct the growth of each sample to an

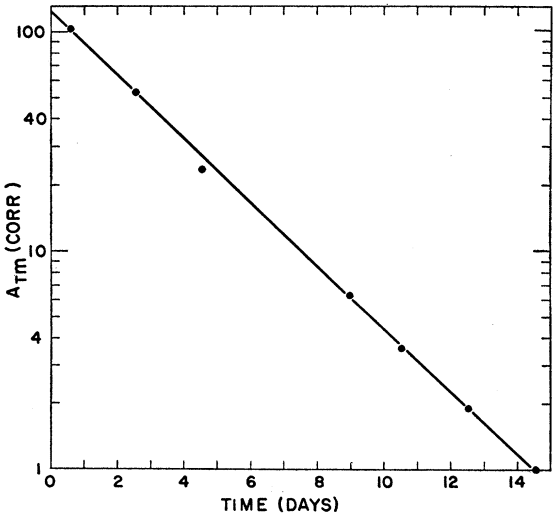


FIG. 1. A plot of $A_{Tm}(\text{corr})$ *vs* time, to give Er^{172} half-life.

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] Folger, Stevenson, and Seaborg, University of California Radiation Laboratory Report UCRL-1195 (revised), May, 1951 (unpublished).

arbitrary standard time of 48.0 hr. It was necessary to assume a value of λ_1 to obtain an approximate half-life and then make successive approximations. The corrected thulium activity is then, finally

$$A_{\mathrm{Tm}}(\mathrm{corr}) = A_{\mathrm{Tm}}(\mathrm{obs}) \frac{(e^{-\lambda_1 t_s} - e^{-\lambda_2 t_s})}{(e^{-\lambda_1 t} - e^{-\lambda_2 t})} \times \frac{1}{(\mathrm{Tm\ yield})\ (\mathrm{Er\ yield})},$$

where $A_{\mathrm{Tm}}(\mathrm{obs})$ is the activity extrapolated to the time of separation.

A plot was then made of the log of $A_{\mathrm{Tm}}(\mathrm{corr})$ *vs* the time to which the growth was corrected. A straight line resulted over a period of seven half-lives, as shown in Fig. 1. A least-squares analysis gave a value of 49.8 hr for the Er^{172} half-life. In consideration of the errors inherent in this milking technique, the probable error is set at ± 1 hr.

The β^- end-point energy of Tm^{172} was estimated by means of an Al absorption curve, giving a value of 1.5 Mev. The γ-ray spectrum was investigated by using a 50-channel pulse-height analyzer and a Tl-activated NaI crystal. Gamma rays of 1.79, 1.44, 1.09, and 0.076 Mev were found, in addition to the 0.049-Mev K x-ray. Two less prominent γ rays of 0.40 and 0.18 Mev were also noticed.

In addition the mass assignments of 10-hr Er^{165} and 7.5-hr Er^{171} were verified by a mass separation of 0.1% of the original erbium sample. The mass assignment of 1.9-yr Tm^{171} was also verified during the thulium run, by direct separation.

The authors wish to express their appreciation to the staff of the Materials Testing Reactor and of the 184-in. and 60-in. cyclotrons in Berkeley for their aid in making the irradiations.

PHYSICAL REVIEW VOLUME 103, NUMBER 1 JULY 1, 1956

Transient Nuclear Induction and Double Nuclear Resonance in Solids*

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(Received December 7, 1955)

The behavior of transient nuclear induction signals from solids is described by a stochastic model based on a Markoff process. The model assumes the presence of local dipolar field fluctuations in a crystal due to a set B of coupled nuclei. These fluctuations can destroy or enhance the observed precessional coherence of a different set A of nuclei in the crystal. Coupling among A spins is assumed negligible. The spin echo of A formed at a given time t has an amplitude determined by the magnitude and rate R of field fluctuations. For values of Rt between zero and the order of unity the echo amplitude decreases, reaches a minimum at $Rt \sim 1$, and increases for $Rt > 1$. For R larger than the spin A static line width (when $R=0$) in units of frequency, line narrowing becomes effective, and is reflected in terms of increased lifetime and amplitudes of echo signals. The effect of B spin (Na^{23}) continuous wave resonance upon the echo relaxation of A (Cl^{35}) is studied in $NaClO_3$, a nuclear quadrupole system. For sufficiently weak cw rf excitation of Na^{23}, the behavior of Cl^{35} echoes roughly follows the behavior predicted by the stochastic model for changes in local field fluctuation rate R. The effect of coherent oscillations of local fields at larger cw rf excitation is discussed. Zeeman splittings of the Na^{23} quadrupole resonance are studied by the double resonance method. The decay of spin echo signals in liquids, as a result of molecular diffusion, is conveniently described by the stochastic model.

I. INTRODUCTION

RELAXATION times and line shapes in nuclear resonance experiments are often due primarily to one mechanism. In that case, with the analysis prescribed by one model, it is useful to determine how the nuclear relaxation should vary with changes in parameters of the system. We propose a model for the relaxation of free nuclear induction spin echo signals from nuclei which do not couple appreciably among themselves, but which lose spin precessional phase because of local magnetic field fluctuations caused by neighboring unlike spins in the crystalline lattice. The resulting transient signals are related to line shapes observed in steady state resonance. The properties of our specific model may be generalized qualitatively to apply to the general case of frequency fluctuations due to a variety of effects, and to account for observed effects due to double nuclear resonance in solids. From the point of view of signal transients our discussion includes some features of the statistical treatment of line shapes in solids by Anderson and Weiss[1] and Anderson.[2]

Let the observed relaxation of a collection of nuclei, denoted by A, be caused by dipolar field fluctuations at A which arise from neighboring unlike spins, denoted

* Submitted in partial fulfillment (by B. H.) of requirements for the degree of Doctor of Philosophy, in the Faculty of Pure Science, Columbia University.

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[1] P. W. Anderson and P. R. Weiss, Revs. Modern Phys. **25**, 269 (1953).

[2] P. W. Anderson, J. Phys. Soc. Japan **9**, 316 (1954); R. Kubo and K. Tomita, J. Phys. Soc. Japan **9**, 888 (1954).