Half-Life of Rb^{87}

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A comparison of the ratio, radiogenic Sr^{87}/Rb^{87}, found in eight Rb minerals of differing Rb content from the same rock unit has shown this ratio to be constant for a given mineral assemblage. This ratio has been measured on Rb minerals from six rock units for which concordant U–Pb ages ranging from 375 to 2700 million years have also been obtained. From the ratio radiogenic Sr^{87}/Rb^{87} and the age of the mineral obtained from the U–Pg age, the half-life of RB^{87} is calculated to be $(5.0\pm0.2)\times10^{10}$ yr. This lies in the range of values found by direct counting experiments.

INTRODUCTION

THE decay of Rb^{87} has been studied since the assignment of the radioactivity of rubidium to this isotope in 1937.[1,2] The first value of the half-life obtained by Strassman and Walling[3] was determined by using an essentially geological procedure. The ratio, Sr^{87}/Rb^{87}, was obtained from an ancient rubidium mineral. From this ratio and the best age available for the mineral, the half-life was calculated. The value obtained by Strassman and Walling is shown with those obtained by direct counting experiments in Table I. One group of values for the half-life clusters around 6.3×10^{10} years, and two values are close to 4.3×10^{10} years. The difficulty in measuring the Rb^{87} decay constant is the result of the unusual distribution of the energy of the electrons which in turn is attributed to the highly forbidden nature of the Rb^{87} decay. The maximum energy is 275 kev while the average energy is approximately 45 kev,[4–6] so that the details of the shape of the spectrum at low energy are difficult to deduce from the part of the spectrum which is easily measured.

We have been attempting to correlate the ages of minerals from single mineral assemblages as determined by the decay of U^{238}, U^{235}, Th^{232}, Rb^{87}, and K^{40}. In this work we have used essentially the procedure of Strassman and Walling, with the important difference that we have concordant U–Pb ages of a uranium mineral from each geologic unit that was the source of the rubidium minerals. It is the purpose of this paper to present the results of six such comparisons from geologic units ranging in age from 375 to 2700 million years. Three ratios which are characteristic of the assemblage are necessary. These are Pb^{206}/U^{238}, Pb^{207}/U^{235}, and radiogenic Sr^{87}/Rb^{87}. Using the first two of these ratios and the decay constants for uranium of Kovarik and Adams,[7] and Fleming, Ghiorso, and Cunningham,[8] one can calculate two ages for the uranium mineral. Con-

TABLE I. Measurements of Rb^{87} half-life.

Investigator	$T_{\frac{1}{2}}$ (10^{10} yr)	Disintegrations per minute per mg Rb	Method
Strassman and Walling[a]	6.3	···	Geological
Haxel, Houtermans, and Kemmerich[b]	5.95	43.5	4π G-M counter
Kemmerich[c]	4.10	63.1	Screen-wall G-M counter
Curran, Dixon, and Wilson[d]	6.41	40.4	Screen-wall proportional counter
MacGregor and Wiedenbeck[e]	6.37	40.6	4π G-M counter
Lewis[f]	5.93	43.7	RbI(Tl) scintillation spectrometer
Geese-Bähnisch and Huster[g]	4.30	60.1	4π G-M counter

[a] See reference 3.
[b] Haxel, Houtermans, and Kemmerich, Phys. Rev. **74**, 1886 (1948).
[c] M. Kemmerich, Z. Physik **126**, 399 (1949). (Half-life recalculated.)
[d] See reference 4.
[e] See reference 6.
[f] See reference 5.
[g] I. Geese-Bähnisch and E. Huster, Naturwiss. **39**, 379 (1954).

TABLE II. Radiogenic Sr^{87}/Rb^{87} ratios for different minerals from the Brown Derby pegmatite, Gunnison Company, Colorado.

Mineral	ppm Rb^{87}	ppm radiogenic Sr^{87}	Sr^{87}/Rb^{87}
Muscovite	1870± 50	36.5±1	0.0195
Microcline	2690±100	48.7±1	0.0181
Lepidolite (coarse books)	5550±200	110±3	0.0198
Lepidolite (medium grain)	5570±200	121±3	0.0210
Lepidolite (medium grain)	5570±200	114±3	0.0195
Lepidolite (fine grain)	5890±200	130±3	0.0220
Lepidolite (white)	6130±200	118±3	0.0192
Lepidolite (coarse)	6870±200	134±3	0.0195

[1] W. R. Smythe and A. Hemmingdinger, Phys. Rev. **51**, 1052 (1937).
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[7] A. F. Kovarik and N. I. Adams, Jr., Phys. Rev. **98**, 46 (1955).
[8] Fleming, Ghiorso, and Cunningham, Phys. Rev. **88**, 642 (1952).

TABLE III. Uranium-lead ages and ratios, radiogenic Sr^{87}/Rb^{87} for minerals from six pegmatites. The column $T_{\frac{1}{2}}(Rb^{87})$ is calculated using the Pb^{207}–U^{235} age.

Pegmatite location	Mineral	U–Pb ages (10^6 yr) Pb^{206}–U^{238}	Pb^{207}–U^{235}	Rb–Sr data Mineral	Radiogenic Sr^{87}/Rb^{87}	$T_{\frac{1}{2}}(Rb^{87})$ (10^{10} yr)
Bikita Quarry S. Rhodesia, S. Africa	Monazite	2640±100	2680±100	Lepidolite	0.0380 ±0.0010	5.0
Viking Lake Pegmatite Saskatchewan, Canada	Uraninite	1790± 50	1830± 50	Biotite	0.0270 ±0.0010	4.8
Bob Ingersoll Mine Keystone, So. Dakota	Uraninite	1580± 30	1600± 30	Lepidolite Muscovite Microcline	0.0239 ±0.001 0.0244 ±0.001 0.0224 ±0.001	4.8
Cardiff Uranium Mine Cardiff Twsp., Ontario, Canada	Uraninite	1020± 20	1020± 20	Biotite	0.0140 ±0.0007	5.1
Fission Mine Wilberforce, Ontario Canada	Uraninite	1040± 20	1050± 20	Biotite	0.0140 ±0.0007	5.2
Chestnut Flat Mine Spruce Pine, N. Carolina	Uraninite	375± 10	380± 10	Muscovite Microcline	0.00515±0.0002 0.00535±0.0002	5.0

cordancy of these two ages is good evidence that alterations in the ratio of daughter to parent isotope have only been due to radioactive decay, since the decay constants differ by a factor of seven. Then, with the reasonable assumption that the rubidium and uranium minerals are cogenetic, one can calculate $T_{\frac{1}{2}}$ for Rb^{87} from the relation

$$T_{\frac{1}{2}}=\frac{0.693t}{\ln(1+Sr^{87}/Rb^{87})},$$

where t is the concordant U–Pb age.

ANALYTICAL RESULTS

The U, Pb, Rb, and Sr^{87} content of the various minerals was determined by using stable-isotope[9] dilution.[10] The chemical procedures and mass spectrometric techniques have been described.[11] By using these techniques the ratios Pb^{206}/U^{238} and Pb^{207}/U^{235} have been determined with errors of less than 3%, and the ratio, Sr^{87}/Rb^{87}, with an error of less than 5%. That a ratio Sr^{87}/Rb^{87} can be found which is characteristic of all the minerals of a rock unit is shown in Table II. Eight minerals with Rb^{87} concentrations ranging from 1870 to 6870 ppm (parts per million) give ratios of Sr^{87}/Rb^{87} which average 0.0198 with a mean deviation of 0.0009. Some of the differences in this ratio may be due to geochemical processes, but these processes appear to produce only second-order effects.

Table III gives the age measurements for one monazite and five uraninites used in this study. The monazite ages are those reported by Holmes.[12] The five uraninites were analyzed at the Carnegie Institution. The two U–Pb ages for each mineral agree within 3%. Table III also shows the analytical data for rubidium minerals from the same pegmatites. The half-life given is calculated by using the U^{235}–Pb^{207} age, but using the U^{238}–Pb^{206} age would affect $T_{\frac{1}{2}}$ by less than 2%.

Figure 1 shows a plot of the ratio Sr^{87}/Rb^{87} *vs* U–Pb age for the six pegmatites studied. The solid lines show how this ratio would vary with time if the Rb^{87}

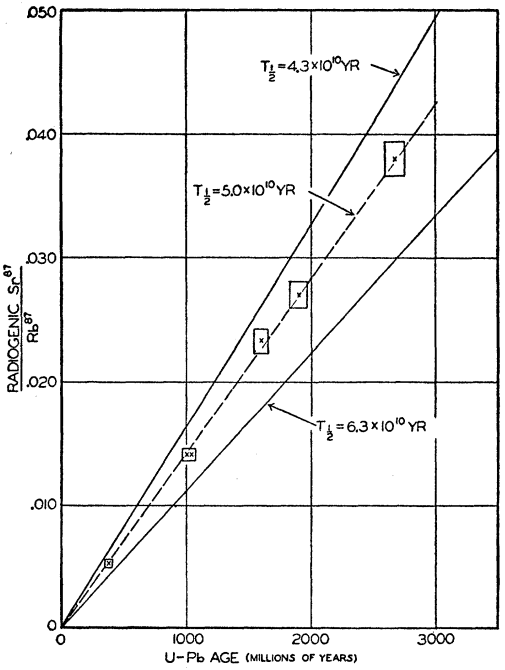

FIG. 1. Ratios (radiogenic Sr^{87})/Rb^{87} for minerals from rock units with concordant U–Pb ages, *vs* the U–Pb ages.

[9] The isotopes used in this work were supplied on loan from the U. S. Atomic Energy Commission.

[10] M. G. Inghram, in *Annual Review of Nuclear Science* (Annual Reviews Inc., Stanford, 1954), Vol. 4, p. 81.

[11] Aldrich, Davis, Tilton, and Wetherill, J. Geophys. Research (to be published).

[12] A. H. Holmes, Nature **173**, 612 (1954).

half-life were 4.3×10^{10} years and 6.3×10^{10} years, respectively. The dotted line through the experimental points corresponds to a half-life of 5.0×10^{10} years.

CONCLUSIONS

The data show that the ratio, Sr^{87}/Rb^{87}, is directly related to the age of the pegmatite for which it is determined. From the data presented, the half-life of Rb^{87} is calculated to be $(5.0\pm0.2)\times10^{10}$ years. It is important that this value be confirmed by laboratory counting experiments.[13]

[13] Subsequent to submission of this paper, E. Huster and W. Rausch (private communication) reported that refined experiments of the type described in footnote g of Table I now give $(4.9\text{–}5.0)\times10^{10}$ years for the half-life of Rb^{87}.

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Analysis of Proton-Proton Scattering Data at 300 Mev*

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An analysis of proton-proton scattering experiments is described and some results for 300 Mev are presented. Phase shifts for states with $J\leq4$ are included, and effects of states of higher angular momentum are discussed. The importance of including Coulomb interference effects is brought out.

INTRODUCTION

NUCLEON–NUCLEON interactions derived from meson field theories are not yet entirely satisfactory. Not only is the most hopeful one so far obtained apparently inadequate for explaining low-energy phenomena,[1] but the possibility of an as yet unknown velocity dependence of the interaction also makes it desirable to be able to approach the problem of interpretation of experimental data at high energies from some other viewpoint. The alternative approach is supplied by an analysis in terms of phase shifts, which Breit has shown to be valid[2] regardless of the possible radial, angular, or velocity dependence of the nucleon-nucleon potential or whether such a potential can even be logically defined.

In the present note, an account is given of a phase shift analysis of the data on proton-proton differential cross section and polarization at 300 Mev, and some preliminary results of the analysis are presented and discussed. The methods used do not involve the usual gradient search high-speed digital machine procedure, but rely on another type of search for fits to the differential cross section and an Argand diagram treatment of polarization data. These possibilities have been pointed out to the authors by Breit. No set of phase shifts has yet come out of the analysis which produces an unqualified fit to these data, but some results appear of sufficient interest to merit mention and to warrant a description of the methods used to obtain them. In addition, the calculations are in a stage where statements can be made concerning effects of Coulomb interference and effects of phase shifts for states of higher angular momentum than are included in the analysis.

The high-energy polarization data[3] have an angular dependence which implies phase shifts in the $J\geq3$ states of total angular momentum,[4] and the existence of polarization implies that the phase shifts for given orbital angular momentum state L but different J are unequal.[5] If it is assumed that states for $L>3$ are not important at 300 Mev, then the analysis of polarization and differential cross section is in terms of eight phase shifts: the singlets K_0, K_2, and the triplets $\delta_1{}^P$, $\delta_1{}^P$, $\delta_2{}^P$, $\delta_2{}^F$, $\delta_3{}^F$, $\delta_4{}^F$. If a tensor type interaction occurs, then the coupling parameter between the $^3P_2$ and $^3F_2$ states is a ninth parameter. Since the polarization involves only the triplet states, it was the subject of the first analysis and the cross-section data were treated afterwards.

II. PROCEDURE AND RESULTS

The following procedure, suggested by Breit,[6] was followed in analyzing the polarization data. Coupling in the $J=2$ state was omitted, and values of scattering angle, θ, for which the Coulomb-nuclear interference effects should be negligible were investigated first. A least squares analysis of $(P\sigma)=\sin\theta[a_1P_1(\cos\theta)$

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