

THE STUDY OF LOW LEVEL ACTIVITIES

Rb<sup>87</sup>, V<sup>50</sup>, Ta<sup>180</sup>

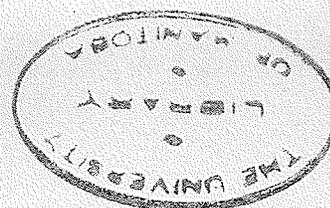
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ABSTRACT

A scintillation spectrometer has been used to study the three naturally occurring radioactive isotopes:  $\text{Rb}^{87}$ ,  $\text{V}^{50}$ , and  $\text{Ta}^{180}$

$\text{Rb}^{87}$ : The radioactive decay of  $\text{Rb}^{87}$  has been studied using the scintillations from a rubidium iodide, thallium activated, crystal. The beta-spectrum from 11.5 kev on has been obtained and an end-point energy of 275 kev is indicated. The allowed Fermi plot, forbidden in shape, has been extrapolated linearly to zero energy and a total counting rate of  $1929 \pm 65$  counts per minute was obtained from 0.0938 gm  $\text{RbI}$  corresponding to a half-life of  $(5.04 \pm .2) \times 10^{10}$  years. The shape of the spectrum has been fitted by several combinations of scalar and tensor interactions and the allowed Fermi plot linearized for the most part.

$\text{V}^{50}$ : A specific search for the 1.58 Mev gamma radiation expected to follow K-capture in  $\text{V}^{50}$  to the first excited level of  $\text{Ti}^{50}$  has been made. Corrections for background distortion were attempted. Considerations of possible radioactive impurities in the sample have been taken into account. Calculations reveal that the half-life of  $\text{V}^{50}$  for this mode of decay is greater than  $4.9 \times 10^{14}$  years.

$\text{Ta}^{180}$ : A picture, based on the single particle shell model, of the static properties of  $\text{Ta}^{180}$  has been proposed and a search for the 102 kev and 93 kev gamma rays, which should follow negatron emission and K-capture, respectively, has been made. A minimum half-life of  $2.9 \times 10^{12}$  years has been determined for either mode of decay. This does not agree with the theoretical picture proposed, indicating that the single particle shell model is inadequate in yielding a correct picture of the static properties of  $\text{Ta}^{180}$ . It is suggested that the unified model be used in determining these properties.

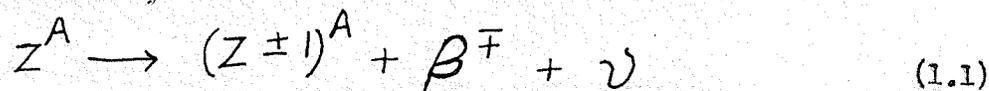
## Chapter I

### GENERAL INTRODUCTION

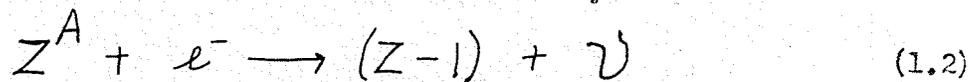
(i) General Survey: (1) (2) (3) (4)

The first evidence for the instability of nuclei in certain energy states, was the observation in the closing years of the past century, of the radioactivity of the heavy elements. In addition to alpha and gamma emission, radiations consisting of negatively charged particles were observed in many cases. By the measurement of their  $e/m$  value, for instance, these particles have been identified as electrons. With the advent of the artificial production of radioactive nuclei this phenomenon of beta emission has been shown to be very wide spread. There are very few mass values corresponding to which there is not at least one beta-radioactive isobar.

In addition to negative electron emission two other kinds of beta-radioactive processes, positron emission and orbital electron capture are known. All three of these closely related processes are known collectively as beta decay; for each process the mass number  $A$  remains constant. The process of negatron and positron emission may be represented by:



where  $\nu$  represents an accompanying neutral particle. On the other hand the orbital electron capture is represented by:



Generally speaking the lifetimes for the beta-process are very long; measured half-lives vary from a fraction of a second to  $10^{14}$

years or more. The slow processes are associated with large angular momentum changes between the nuclear states involved, as well as with parity changes.

Epistemologically, beta-decay in nuclear physics is important for two reasons. By measuring the shape of the beta spectrum information about the angular momentum and parity changes involved in the transition can be obtained. This is significant in determining the static properties of the parent and daughter nuclei. Secondly, the beta-decay process presents a new type of interaction in physics. The form is similar to that of the electromagnetic interaction in the process of emission and absorption of light quanta. Unfortunately, the beta-decay process is considerably more complex and furthermore, there exists no classical theory that attempts to explain this type of interaction as fully as the electromagnetic interaction is explained by Maxwell's theory. Thus one has no guide to the study of the beta interaction.

The neutral particle mentioned in equation (1.1) and (1.2) was postulated by Pauli and utilized by Fermi in his attempt to formulate the first successful quantitative theory of the shape of the beta spectra and of the lifetime of the beta-ray emitters. Its existence was postulated in order to satisfy the basic principle that the process of beta-decay must satisfy the laws of conservation of energy, linear momentum, angular momentum, and statistics.

The beta-decay theory set up by Fermi is based on a mathematical structure which envisages the interaction as being due to the continuous absorption and re-emission by the nucleons of virtual electrons and neutrinos. When a real electron-neutrino pair appears a beta-emission has occurred(5). In the construction of the theory, the mathematical

form of the interaction as well as its strength, must be known. Several interaction forms which satisfy the physical and mathematical requirements are:(6)

- S or scalar interaction ..... $H_S$  (a)
- V or polar vector interaction..... $H_V$  (b)
- T or tensor interaction ..... $H_T$  (c) (1.3)
- A or axial vector interaction..... $H_A$  (d)
- P or pseudoscalar interaction..... $H_P$  (e)

The complete beta-interaction is a linear combination of the above; that is, the most general Hamiltonian for the beta-interaction is given by

$$H = C_S H_S + C_V H_V + C_T H_T + C_A H_A + C_P H_P \quad (1.4)$$

The coupling coefficients  $C_x$  are constants whose values can only be determined by comparing theory with experimental results. Experimental evidence is currently regarded as having established the following points regarding possible combinations of the five forms of interactions:(8)

- (i) The T and A forms must be a part of the correct law of beta-interaction. Only the T, or the A, form yields Gamow-Teller selection rules, which are needed for understanding the short lives of many beta-interactions with a unit spin change and no parity change.
- (ii) The S or the V form must also be included. The chief evidence for this is the short life found for beta-transitions between nuclear states of zero spin.

(iii)\* The P form is needed to explain the singular  $RaE$  spectrum.

Each of the above arguments require the inclusion of some component form without precluding the presence of other forms. A generally recognized empirical argument is that not both T and A forms, nor both the S and V forms, can be parts of the coupling. If they are, then the spec-

\* Recently Yamada has shown that S,T(1-0) and V,A(1-0) fit the experimental data for the  $RaE$  Beta-spectrum, as well as T,P(0-0) if the finite De Broglie wave length effect is taken into account.

M. Yamada, Prog. of Theor. Phys. 10, (1953), 252.

tra of allowed beta-emission should deviate from the allowed shape. However, no such deviations have been found. Also experimental evidence shows that  $C_V$  and  $C_A$ , rather than  $C_S$  and  $C_T$ , approximate zero.

(ii) The Allowed Energy Spectrum:

The detailed theory by which the energy spectrum is calculated for allowed transitions involves the evaluation of matrix elements arising from the general Hamiltonian for the beta-interaction. By considering only those transitions which have the largest decay constant, and hence the shortest half-life, the selection rules for allowed transitions are arrived at. They are:

$$S, V \quad \Delta J = 0 \quad \Delta \pi = \pi 0$$

$$T, A \quad \Delta J = 0, \pm 1, \pi 0 \quad 0 \rightarrow 0 \quad \Delta \pi = \pi 0$$

where J is the total angular momentum and  $\pi$  the parity. The energy spectrum for an allowed transition is given by: (7)

$$N_{\pm}(W) dW = (g^2/2\pi^3) F(\mp Z, W) p W (W_0 - W)^2 C(M)^2 (1 \mp b/W) dW \quad (1.5)$$

where the rest mass of the neutrino is assumed to be zero, and  $N_{\pm}(W) dW$  is the fraction of the total number of processes with total electron energies between W and  $W+dW$ . The upper sign refers to positron and the lower to electron emission.  $F(\mp Z, W)$  is a complicated function of Z and W. It describes the effect of the Coulomb field of the nucleus on the emitted electron. Its effect is to emphasize low-energy electrons and de-emphasize low-energy positrons, and is important for all but the lightest elements. Tables giving its value for a large range of values for Z as a function of p, the electron momentum, exist (45). The term  $pW(W_0 - W)^2$  represents the energy dependence of the distribution function for a pure interaction, that is, where there is no Coulomb field. It is called the statistical weight. It is derived on the basis of the number

of states available for the particles in momentum space.  $g^2$  represents a coupling constant. The term  $b/W$ , referred to as the Fierz interference term, varies very slowly with  $W$  and is usually regarded as being effectively zero. The factor  $M$  in equation 1.5 is a nuclear matrix element. It is a measure of the probability of occurrence of the transition. Its value depends upon the type of interaction assumed and upon the wave functions of the nuclear particles before and after the process. Since little is known about the wave functions  $M$  can only be estimated.  $M$  fixes the order of the transition. It can be expressed as a series of terms, which if they do not vanish, become progressively smaller. The first term, if it does not vanish, is independent of energy. These transitions are what have here been called allowed transitions.  $C$  is a coupling constant which may be the sum of the squares of the coupling coefficients for scalar, tensor, etc. type of interaction. It gives an appropriately weighted mean of the square of the nuclear matrix element  $M$ .

Comparison of observed spectra with theory is usually made with the aid of the Kurie plot. With  $b=0$  equation 1.5 may be written as:

$$N \pm (W) / F(Z, W) p W^{1/2} = K(W_0 - W) \quad (1.6)$$

where  $K$  is now independent of the energy  $W$ . The modified Fermi function  $G = pF(Z, W)/W$  has been evaluated for a large range of  $Z$  values as a function of  $p$ , the electron momentum(45). With the aid of the observed energy distribution the quantity on the left may be computed and plotted against energy,  $W$ . For an allowed spectrum a straight line should be the result. However, it is often the case that there exists an upward curvature at the low energy end of the spectrum. This non-linearity at the low energy end has often been found to be attributable to distortions

introduced by self-absorption and scattering. The use of thinner sources and thinner backing materials has been found to improve the linearity of the allowed Kurie plot in some instances. On other occasions, however, the non-linearity of the allowed Kurie plot has not been corrected in this simple manner. It is then expected that the transition is not allowed.

(iii) Forbidden transitions:

In the theory of allowed beta-decay only transitions between nuclear states of the same parity and differing in spin by no more than one unit, are permitted. The allowed-transition selection rules arise after certain small effects are left out of consideration. These neglected effects become very important when their absence leads to a vanishing transition rate inasmuch as they then become responsible for the forbidden transitions.

The small effects neglected in the allowed theory are: (1) those due to corrections needed to produce Lorentz invariance in the vector, tensor, and axial vector Hamiltonians, (2) those arising from the variation of the lepton waves (electron and neutron waves) across the nucleus, and (3) those arising when the source velocity is not neglected. The source velocity effects are introduced by the requirement of Lorentz invariance for  $H_{V,T,A}$  since the extra terms present in the Hamiltonians of these interaction forms are of the order  $v/c$ , where  $v$  is the nucleonic velocity. It is for this reason that these extra terms are referred to as "source velocity effects." When these velocity interactions are included, transitions which violate the allowed selection rules are generated and are referred to as forbidden transitions. When the variation of the lepton waves across the nucleus is considered the nuclear matrix element has to be expressed as a series of terms which become progressively smaller. The  $n^{\text{th}}$  term introduces  $n$  components of the moment arm

X

vector,  $\underline{r}$ , into the nuclear matrix element, giving rise to  $n^{\text{th}}$  forbidden transitions which may, or may not, be vanishingly small. The selection rules for the general,  $n^{\text{th}}$  forbidden transition are as follows:

$$\Delta J = n, n+1; \Delta \pi = (-1)^n \quad n \neq 1$$

$$\Delta J = 0, 1, 2 \quad \Delta \pi = -1 \quad n = 1$$

where  $n=1$  corresponds to first forbidden transitions and  $n \neq 1$  corresponds to second and higher order forbidden transitions. The selection rules for the allowed transitions have been given above.

The electron(negatron) spectrum for an  $n$ -times forbidden transition can be written as (9):

$$N_-(W) dW = (g^2/2\pi^3) F_0(Z, W) (pW(W_0 - W))^2 S_n(W) \quad (1.7)$$

in the notation used for the allowed spectrum.  $F_0$  here is defined as  $F(Z, W)/(1+\gamma)/2$  where  $\gamma$  is equal to  $[1 - (\alpha Z)^2]^{1/2}$ ,  $\alpha$  is the fine structure constant and  $Z$ , the atomic number.  $S_n(W)$  is called the "shape factor" and is of considerable importance in that it is used as a means of linearizing the allowed Kurie plots of forbidden transitions. If  $S_n(W)$  is independent of the energy  $W$ , then the spectrum has the "statistical shape"  $\sim pW(W_0 - W)^2$  modified only by the Coulomb effect,  $F_0(Z, W)$ . In general, however,  $S_n(W)$  depends on the energy and a departure from the statistical shape is to be expected.

Several forms for the shape factor have been tried by various workers in the field but the one presented here and which will be used later, is the one developed by E. Konopinski(9). This shape factor, which is sometimes referred to as the "exact" shape factor, results from combinations of ST couplings.

The general,  $n$ -times forbidden shape factor can be written as the sum of two partial ones:

$$S_n = S_n^n + S_n^{n+1} \quad (1.8)$$

$S_n^n$  contributes to  $\Delta J = n$  but not to  $\Delta J = n+1$  transitions while  $S_n^{n+1}$  is the total shape factor for the "unique" forbidden transitions,  $\Delta J = n+1$ . It also contributes to  $\Delta J = n$  transitions (except for  $J = 0 \rightarrow J = n$ ) but its contribution is negligible if the Coulomb energy  $\alpha Z/\rho$  is much greater than the maximum kinetic energy,  $W_0 - 1$ . ( $\rho$  is the nuclear radius).

The partial shape factor  $S_n^n$  for negatron emission may be written as: (9)

$$S_n^n = \frac{4\pi n!}{(2n+1)!!} \sum |\int \beta \psi_{nm}(\underline{\sigma} \times \underline{\nu})|^2 \times \left\{ C_T^2 P_n(\underline{\sigma} \times \underline{\nu}) + \lambda_n^2 (\alpha Z/2e)^2 C_T^2 P_n(\alpha) + \int_m^2 C_S^2 P_n(\underline{\nu}) + \lambda_n (\alpha Z/e) C_T^2 I_n(\underline{\sigma} \times \underline{\nu}, \alpha) + 2 \int_m C_S C_T I_n(\underline{\sigma} \times \underline{\nu}, \alpha) + \int_m \lambda_n (\alpha Z/e) C_S C_T I_n(\alpha, \underline{\nu}) \right\} \quad \dots (1.9)$$

where the  $\eta_n$  in Konopinski's notation has been changed to  $\lambda_n$ , to avoid confusing it with  $n$ . The functions  $P_n$  represent radiations by the individual "pure" moments, and the functions  $I_n$  are results of interference between the radiations (10). Both functions  $P_n$  and  $I_n$  depend on the emitted neutrino energy. The evaluation of these functions has been greatly facilitated by the work of Rose, Perry, and Dismuke (11), who have constructed exhaustive tables of data on the variables on which the functions are dependent. The real parameters  $\int_m$  and  $\lambda_n$  are defined by:

$$\int(\beta) \psi_{nm}(\alpha) = \lambda_n (\alpha Z/2e) \int(\beta) \psi_{nm}(\underline{\sigma} \times \underline{\nu})$$

and  $\int(\beta) \psi_{nm}(\underline{\nu}) = -i \int_m \int(\beta) \psi_{nm}(\underline{\sigma} \times \underline{\nu}) \quad (1.10)$

respectively. Here  $\int(\beta) \psi_{nm}(\alpha)$ ;  $\int(\beta) \psi_{nm}(\underline{\nu})$  and  $\int(\beta) \psi_{nm}(\underline{\sigma} \times \underline{\nu})$

are the spherical harmonic counterparts of the matrix elements:

$A_{i_1} \dots i_n$ ;  $R_{i_1 i_2} \dots i_n$ ;  $T_{i_1} \dots i_n$ , respectively(9).

It is these real parameters that are manipulated in order to obtain the best possible fit between the experimental and theoretical Kurie plots for forbidden transitions. The usual procedure in testing a measured spectrum  $N_-(W)$ , as to whether it is governed by a given shape factor  $S$ , is to plot  $\left[ \frac{N_-(W)}{S_n(W)} F_0 pW \right]^{1/2} \sim (W_0 - W)$  (1.11) that is, one tries to linearize the spectrum with an appropriate choice of a theoretical shape factor.

(iv) Half-Life:

The total probability per unit time,  $\lambda$ , that a beta-active nucleus will decay is obtained by integrating  $N_-(W)dW$ , which is the probability of decay into a given energy interval  $dW$ , over the entire beta-spectrum. This probability also defines the half-life,  $t$ , of the beta-decay. We get:

$$\lambda = \frac{\ln 2}{t} = (g^2/2\pi^3) \int_1^{W_0} dW F_0 pW (W_0 - W)^2 S_n(W) \quad (1.12)$$

This integral must be evaluated numerically. To do this for the spectrum of a general  $n$ -times forbidden transition requires that the shape factor  $S_n(W)$  be known explicitly. This requires a numerical evaluation of the nuclear moments involved, as well as the scalar and tensor coupling coefficients, if the shape factor is of the form given by equation 1.9. Since little is known about nuclear wave functions the nuclear moments cannot at present be evaluated explicitly. The absolute magnitudes of the scalar and tensor coupling coefficients are not known but their relative strengths can be determined from analyses of allowed transitions (13). The present "best" value of  $C_S^2 / C_T^2 = 0.54^{+0.5}_{-0.25}$  (1.13)

Preston(42) suggests that from certain symmetry arguments the beta-decay interaction is S-T / P. Whether this implies a change in the relative strengths of the scalar and tensor coupling coefficients is not stated. In view of these difficulties in evaluating the integral of equation (1.12) it is re-written with  $S_n(W) = 1$ . Feenberg and Trigg(14) have given tables and graphs of the integral for the allowed beta-spectrum and these are usually used to obtain a numerical value of the integral in the general case.

From the definition of the half-life,  $t = \ln 2 / \lambda$ , it is clear that  $t$  is not in itself characteristic of an allowed transition since it is strongly dependent on the end-point energy  $W_0$ , of the beta-spectrum. On this account the half-lives of allowed transitions will show a wide variation. On the other hand the matrix elements associated with the scalar and tensor couplings  $C_S$  and  $C_T$  should be of the same order of magnitude for all allowed transitions. It is for this reason that the characteristic quantity,  $ft$ , called the comparative half-life, is calculated. The term  $f$  is the integral of equation 1.12 with  $S_n(W) = 1$  and  $t$  is the half-life in seconds. For allowed transitions the values of  $ft$  cluster roughly into a single group. For forbidden transitions the  $ft$  values fall into distinct groups according to the order of forbiddenness of the transition. For the purposes of comparison, it is customary to take  $\log_{10} ft$  rather than  $ft$ . For the sake of completeness, a table giving the numerical values of  $\log_{10} ft$  for the different orders follows:

Transitions

Log<sub>10</sub>ft

Allowed	4.5 to 6.0 for odd A 4.0 to 5.7 for even A
1 st. forbidden	6.4 to 7.3
2 nd. forbidden	12.2 to 13.5
3 rd. forbidden	17.5, 19

Although the ft value alone is not an infallible criterion on which a forbiddenness classification can be based, it plus a knowledge of the parity change is decisive since if the parity change is "no" the ambiguity exists between only two orders of forbiddenness, which differ by two units. The difference in the ft values for the two forbidden transitions is so large that no confusion as to the identity of the ft value can arise.

## Chapter II

### RUBIDIUM 87

#### (i) Review of the Literature:

That the isotope of rubidium with mass number 87 is radioactive, has been known for half a century, having first been discovered by J.J. Thomson(15) in 1905. It has also been separated from the other isotopes of rubidium by mass spectroscopy(16). The best value of 27.85% for its percentage abundance has been determined by A.O. Nier(17).

Since the time of discovery that  $\text{Rb}^{87}$  was naturally radioactive numerous determinations of its half-life have been made. In 1946 S. Eklund(18) measured the half-life with a counter calibrated by mixed alpha and beta particles from a uranium deposit. He found the half-life,  $t$ , to be  $5.8 \times 10^{10}$  years. The thinnest layer he used was  $0.1 \text{ mg. RbCl/cm}^2$ . No coincidence between the particles emitted forward and those emitted backward was discovered, and thus it was concluded that the  $\text{Rb}^{87}$  decay involved the emission of a single particle.

In 1948 Haxel et al(19) measured very thin layers of RbCl produced by evaporation on silver coated Zapon foils of about  $0.1 \text{ mg/cm}^2$ , suspended freely between a counter arrangement which allowed the measure of particles from both sides of the foil simultaneously as well as the number of coincidences between counts on both sides. They found that with decreasing thickness of the RbCl layer from 2.0 to  $0.05 \text{ mg RbCl/cm}^2$ , the number of electrons per mg. RbCl per minute increased regularly for the back side of the foil, while the front side showed a considerably higher increase. This indicates a high percentage of very soft electrons from Rb, which could be stopped by the supporting Zapon foil. Coincidence measurements

indicated that up to 30% of the front side number for zero thickness coincided with counts on the back side. These results were explained by making the assumption that for every decay of  $\text{Rb}^{87}$  one soft electron of energy up to 10 kev is emitted as well as one faster electron with the known energy limit.

To check on the comparatively large error in measuring the exact amount of Rb deposited, Haxel et al(19) ran another series of experiments in which RbCl was evaporated on Al foils and placed on the inside wall of a GM counter of known efficiency. The weight of RbCl was accurately determined (3%) for a layer thickness of  $0.025 \text{ mg/cm}^2$  RbCl. Corrections for backscattering were made. As a weighted average of both series of experiments they obtained  $(6.0 \pm 0.6) \times 10^{10}$  years for the half-life.

Curran et al(20) (1951), using a proportional counter, obtained an energy spectrum of the beta-disintegration from which they concluded that the process is simple beta-decay. The energy spectrum they obtained increases rapidly with decreasing energy down to at least 10 kev, which was the lowest point to which they pursued their observations. To verify that the decay process was simple in nature a search for K or L x-rays was carried out with the same equipment. As a further check a scintillation spectrometer was used to determine the number of events due to gamma emission. For an upper limit they obtained one gamma-quantum per  $5 \times 10^3$  beta-rays. They concluded therefore that the process  $\text{Rb}^{87} \rightarrow \text{Sr}^{87} + \beta^-$  is a ground to ground-state transition and attributed the  $\beta - e^-$  coincidence, reported by Haxel, as being due to reflection. For the half-life they obtained a value of  $(6.15 \pm 0.3) \times 10^{10}$  years.

To re-evaluate the half-life and to provide further information about the decay scheme, MacGregor and Wiedenbeck(21) used a cell counter

described by Sawyer and Wiedenbeck(22). With the arrangement used the results were essentially independent of the decay scheme. For the half-life they obtained a value of  $(6.23 \pm 0.3) \times 10^{10}$  years. In addition they carried out a series of experiments to determine whether or not there are coincidences between beta-particles and conversion electrons. The results obtained for  $\text{Rb}^{87}$  were compared with the results obtained for single beta-emitters having different upper energies such as  $\text{Ni}^{63}$  (50 kev),  $\text{S}^{35}$  (169 kev),  $\text{Ca}^{45}$  (260 kev), and  $\text{P}^{32}$  (1.7 Mev). They found that the coincidence curves for these elements varied slightly with the energy of the emitted radiation. The curves taken for the  $\text{Rb}^{87}$  sources of varying thickness were found to resemble most closely the curves for  $\text{S}^{35}$  and  $\text{Ca}^{45}$ . On the basis of these results they concluded that the disintegration of  $\text{Rb}^{87}$  consists of a simple beta-decay.

A more recent experiment making use of the latest advances in scintillation spectrometry, was carried out by Lewis(23). By using a crystal of rubidium iodide, activated with thallium, problems arising from self-absorption and back-scattering were avoided. However, new problems arising from poor resolution, low pulse height efficiency and long-lived phosphorescence inherent in the  $\text{RbI}(\text{Tl})$  crystal, were introduced. The energy response of the crystal was found to be linear over the entire energy range from 17 kev on up. The beta-spectrum was then obtained by means of a single channel pulse height analyzer. The Fermi plot gave a forbidden shape, for the most part close to that given by Curran's(20) proportional counter work using  $2\pi$  geometry, but having slightly more counts at the high energy end and fewer at the low energy end. The increase in the high energy counts was attributed to the fact that these particles are absorbed fairly completely in the crystal and not so well in the gas.

counter. The fewer counts in the low energy end was attributed to the absence of back-scattering, as well as to the lower resolution of the crystal method at these energies. Upon extrapolating the allowed Fermi plot to zero energy and calculating the total counting rate, Lewis obtained a value of  $(5.90 \pm 0.3) \times 10^{10}$  years for the half-life. Lewis attempted a theoretical analysis of the data and concluded that pure scalar interaction does not explain the  $\text{Rb}^{87}$  plot.

Perhaps the most thorough theoretical analysis of the  $\text{Rb}^{87}$  beta-spectrum has been carried out by Morita, Fujita, and Yamada(24). They have analyzed the experimental data of Lewis on the basis of the single particle shell model, in which case the beta-decay takes place with the transition of a neutron in a  $g_{9/2}$  state into a proton in a  $P_{3/2}$  state. On this basis the transition is third forbidden. In their analysis in terms of scalar and tensor interactions, there are four matrix elements to be considered. One of these, being a tensor of one rank higher than the others, is neglected because its effect is small. The two ratios formed by the other three appear as parameters; one ratio can be calculated on the single particle shell model or on the special j-j coupling shell model; the other is treated as a variable parameter whereby the Kurie plot is straightened out over the largest portion of its energy range. On the basis of their analysis they conclude that the sign of the ratio of the scalar and tensor interactions is probably minus; and its magnitude is somewhat smaller than unity.

The most recent work done on the beta-spectrum of  $\text{Rb}^{87}$  is that of Charles D. Goodman(25). He used a high pressure proportional counter with an internal source on a thin flat backing. No value of the half-life for the decay is given. In determining the beta-decay interaction Goodman

finds that the shape of the spectrum can be fitted approximately by several combinations of scalar and tensor interactions. However, lack of knowledge of beta-decay matrix elements prevents him from making a unique fit. In agreement with Morita, Fujita and Yamada, Goodman finds the ratio of  $C_S/C_T$  to be negative for the values of the matrix elements tried.

New emphasis on the importance of knowing accurately the half-life of  $Rb^{87}$  has been brought about by the recent development of the rubidium-strontium method of geochronometry(26). Since the calculation of a geologic age is based on a comparison of the extent of a transformation with the rate of the transformation it follows that the age is directly proportional to the assumed value of the half-life of the transforming nucleus. Therefore, the half-life must be accurately known.

Until recently, all reliable mineral ages seemed to be less than about  $2.5 \times 10^9$  years. With the rubidium-strontium method of geochronometry, a number of ages close to this figure, and a few which exceed it substantially, have been obtained. Ahrens(46), who did not employ mass-spectrographic analysis, but who advanced good reasons for believing that lepidolites are usually quite free of non-radiogenic strontium, obtained a number of apparent ages over  $2 \times 10^9$  years for lepidolites. Some values, reported by other workers(29) using the same method of geochronometry, run as high as  $3.36 \times 10^9$  years or higher. Some of the rocks tested have been analyzed as to their age by measurements based on the production of lead and helium by alpha-decay. In view of the fact that several ages derived from the decay of  $Rb^{87}$  are considerably greater than the upper limit for ages derived from alpha decay, and in view of the fact that the process of alpha disintegration is well understood, and that good minerals yield consistent ages by methods based on  $U^{238}$ ,  $U^{235}$ , and  $Th^{232}$ , the suggestion