A SIMPLE METHOD FOR DETERMINING THE MAXIMUM ENERGY OF BETA EMITTERS BY ABSORPTION MEASUREMENTS

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A simple method for determining the maximum energy of a beta emitter by absorption measurements is presented. Absorbers of two different metals, e.g., aluminium and copper, are used in combination. Two readings only are required for each sample. The method is particularly suited to low activity samples. The relationship between absorption coefficient, maximum energy, counting geometry and counter characteristics is discussed.

1. Introduction

This paper presents a simple method for determining the maximum energies of beta emitters from absorption measurements. A brief outline of the method follows: a beta emitter is counted in a suitable counter; first through an aluminium absorber, and then through an absorber of a different metal such as copper, silver, lead, etc. Both absorbers are of the same weight per unit area. The results of the work described in this paper show that the ratio of the two counting rates is a function of the maximum energy of the emitter. The counter is calibrated by counting a number of standard sources in this way and drawing a graph of maximum energy vs ratio of counting rates. The maximum energy of any beta emitter can then be obtained by taking two readings, each with a different metal absorber, and reading the maximum energy from the graph at the appropriate ratio of counting rates.

2. General discussion

When a beta emitting radionuclide is counted through an absorber a relationship of the type

$$C = C_0 e^{-nx} \tag{1}$$

is valid over a large range of absorber thickness, where
C_0 = counting rate without absorber,
C = counting rate with absorber,
n = absorption coefficient,
x = absorber thickness.

In the past several methods have been developed for the determination of beta energies by absorption measurements. These are of two types: either measurements of the range of beta particles in aluminium, e.g., Feather plot; or measurements of the absorption coefficient of beta particles in metals (usually aluminium). Several authors have written on this subject, e.g. Gleason[1]), Forro[2]), Daddi and d'Angelo[3]), Harley and Hallden[4]). Most of them have found an empirical relationship between the absorption coefficient, n, and the maximum energy of the beta emitter, E_m of the form

$$n = KE_m^{-a}. \tag{2}$$

K and a are constants and their values depend not only on the material of the absorber but also on the geometry of the counting arrangement and the type of counter used. Both range and absorption coefficient methods are difficult to apply to low activity samples, whereas the method discussed in this paper gives good results even for very low activity samples.

3. Counter characteristics

To establish the characteristics of the counters and counting geometry used, the absorption coefficients for a range of maximum energies using absorbers of different materials were determined.
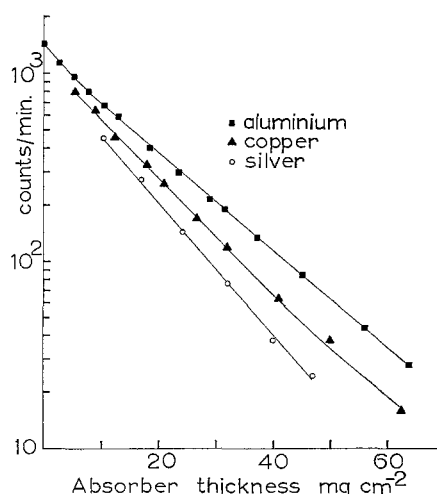

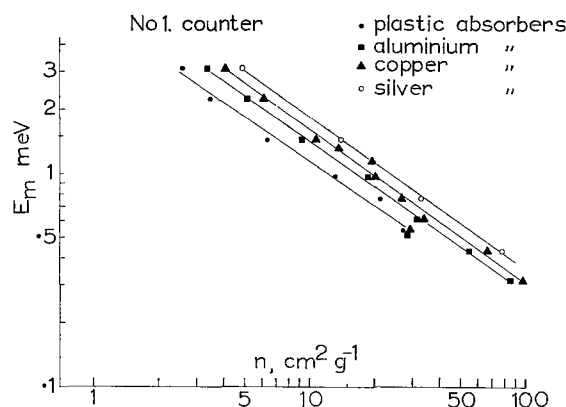Fig. 1. Absorption curves for ^{185}W, $E_m = 0.43$ MeV (on no. 2 counter).

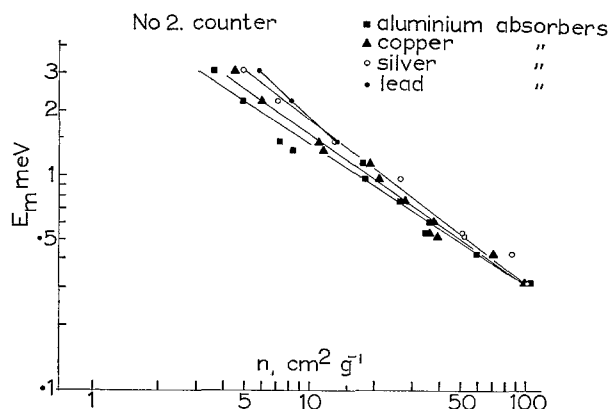Fig. 2. Graph of absorption coefficient, n, versus maximum energy, E_m, with various absorbers.

Fig. 3. Graph of absorption coefficient, n, versus maximum energy, E_m, with various absorbers.

Two types of counter were used:

No. 1. A Philips low background beta counter, Geiger tube and guard tube arranged in anticoincidence, with a 10 mg/cm² end window. The end window to sample distance was approximately 5 mm.

No. 2. A Beckman Widebeta gas flow proportional counter with a 0.5 mg/cm² end window and a sample to end window distance of 1 mm and 5 mm.

Perspex, aluminium, copper, silver and lead absorbers were used. The absorption coefficients were calculated from the linear part of the log (counting rate) vs absorber thickness graphs. See fig. 1 for a typical graph of this kind. Figs. 2 and 3 are obtained by plotting the absorption coefficient n against maximum energy of emitter E_m for the various absorber materials. Numerical values of E_m, n, K and a, are given

TABLE 1

Absorption coefficients in cm²g⁻¹ for beta particles.

Beta emitter	E_m MeV	No. 1 counter				No. 2 counter			
		Perspex	Aluminium	Copper	Silver	Aluminium	Copper	Silver	Lead
¹⁴⁴Pr	3.12	2.6	3.4	4.2	4.9	3.6	4.5	4.9	5.8
⁹⁰Y	2.26	3.5	5.2	6.2		4.9	6.0	7.1	8.2
⁸⁹Sr	1.46	6.4	9.3	10.8	14.0	7.2	11.0	12.9	13.1
⁴⁰K	1.32		7.6	13.8		8.3	11.5		
²¹⁰Bi	1.16			19.5		17.5	18.9		
¹⁷⁰Tm	0.97	13.2	18.9	20.1		17.9	20.7	26.0	
²⁰⁴Tl	0.76	21.5	26.7	26.8	32.9	26.3	27.6		
¹³¹I	0.61		31.4	34.1		36.5	37.2		
⁹⁰Sr	0.54	27.2		29.5		35.0	35.4	50.4	
¹³⁷Cs	0.52		28.4				39.0	51.8	
¹⁸⁵W	0.43		54.7	66.7	77.8	59.5	71.2	80.6	
⁶⁰Co	0.32		85.0	98.3		104	99	102	

TABLE 1A

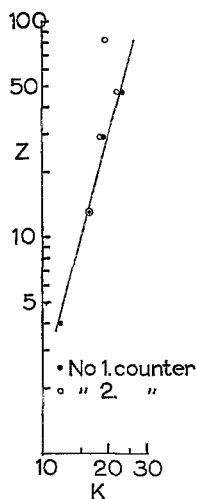| Constant	No. 1 counter				No. 2 counter			
	Perspex	Aluminium	Copper	Silver	Aluminium	Copper	Silver	Lead
a, from figs. 2 and 3	1.42	1.40	1.38	1.39	1.49	1.40	1.27	1.06
K, from figs. 2 and 3	12.1	16.5	19.3	23.3	16.5	18.6	22	19.5
Z, atomic no. of absorber	4	13	29	47	13	29	47	82

Fig. 4. Graph of the constant K versus the atomic number of the absorber, Z.

in tables 1 and 1A. The general relationship between n and E_m can be expressed as

$$n = K E_m^{-a}.$$

From fig. 4 we see that K is a function of the atomic number, Z, of the absorber, which can be expressed in the form

$$K = A Z^b.$$

For no. 1 counter

$$K = 8 Z^{0.28}, \tag{3}$$

and the same expression also fits very nearly no. 2 counter. It appears then that K is not dependent on the type of counter used or on small variations in sample to detector distance.

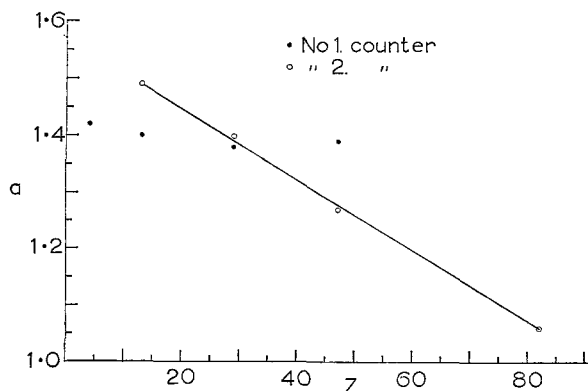For no. 1 counter, a is very nearly constant (see fig. 5): hence

Fig. 5. Graph of the constant a versus the atomic number of the absorber, Z.

$$n = 8 Z^{0.28} E_m^{-1.4}. \tag{4}$$

For no. 2 counter, a is a function of the atomic number of the absorber (fig. 5) and can be expressed as

$$a = b - c Z,$$

i.e.

$$a = 1.57 - (Z/160). \tag{5}$$

The value of a therefore depends on the type of counter used and on the sample–detector distance. The relationship equivalent to (4) for no. 2 counter is

$$n = 8 Z^{0.28} E^{-[1.57 - (Z/160)]}. \tag{6}$$

4. Theory of simplified method

Consider a beta emitter counted through an absorber. The counting rate

$$C_1 = C_0 e^{-n_1 x_1}, \tag{7}$$

with say, an aluminium absorber and

$$C_2 = C_0 e^{-n_2 x_2}, \tag{8}$$

with say, a copper absorber.

Combining (7) and (8) we get

$$\ln C_1 - \ln C_2 = n_2 x_2 - n_1 x_1.$$

Now, let $x_1 = x_2 = x$, then

$$\ln C_1 - \ln C_2 = x(n_2 - n_1).$$

But

$$n_1 = K_1 E_m^{-a_1} \quad \text{and} \quad n_2 = K_2 E_m^{-a_2},$$

therefore

$$\ln C_1 - \ln C_2 = x(K_2 E_m^{-a_2} - K_1 E_m^{-a_1}). \tag{9}$$

Now if $a_1 = a_2$, as is the case for no. 1 counter, eq. (9) becomes

$$(\ln C_1 - \ln C_2)/x = E_m^{-a}(K_2 - K_1). \tag{10}$$

Thus from eq. (10) E_m for a beta emitter can be calculated from two counts only, registered through two absorbers, each of a different metal but of the same weight per unit area. However, better results are obtained by taking actual measurements of the function $(\ln C_1 - \ln C_2)x^{-1}$ for different values of E_m and plotting a calibration graph for each counter. The counting must of course be done with absorbers of suitable thickness so that the counting rates fall in each case on the linear part of the counting rate vs absorber thickness graph for the various energies.

5. Counter calibration

The counters were calibrated using aluminium and

TABLE 2

Values of the function $(\ln C_1 - \ln C_1)/x$.

Emitter	E_m MeV	No. 1 counter		No. 2 counter		
				Sample-detector distance 1 mm		Sample-detector distance 5 mm
		Aluminium and copper	Aluminium and lead	Aluminium and copper	Aluminium and silver	Aluminium and copper
^{144}Pr	3.12	0.84 ± 0.01	4.60 ± 0.08	1.14 ± 0.03	2.13 ± 0.06	1.08 ± 0.03
^{90}Y	2.26	1.10 ± 0.02	5.48 ± 0.2	1.25 ± 0.05	2.78 ± 0.08	1.50 ± 0.04
^{89}Sr	1.46	1.97 ± 0.03	8.62 ± 0.18	1.82 ± 0.05	3.94 ± 0.12	1.91 ± 0.2
^{40}K	1.32	1.83 ± 0.09[a]				
^{210}Bi	1.16	2.18 ± 0.03[b]			7.1 ± 0.4	
^{170}Tm	0.97	2.45 ± 0.05	13.2 ± 0.3	2.26 ± 0.15	7.58 ± 0.36	3.47 ± 0.3
^{204}Tl	0.76	3.13 ± 0.2[a]	18.1 ± 0.4	3.10 ± 0.12	10.9 ± 0.5	4.40 ± 0.3
^{22}Na	0.54			6.21 ± 0.12		5.50 ± 0.16
^{137}Cs	0.52	4.08 ± 0.06		6.38 ± 0.18	13.6 ± 0.4	
^{185}W	0.43	5.19 ± 0.1		9.3 ± 0.4	15.0 ± 0.7	8.85 ± 0.8
^{60}Co	0.32			13.2 ± 0.2	14.7 ± 0.3	9.05 ± 0.1

[a] Low activity sample.

[b] Medium activity sample.

copper, aluminium and silver, aluminium and lead absorber combinations. The absorber thickness used was:

120 mg/cm² for energies 1.0–3.0 MeV,
75 mg/cm² for energies 1.0–0.6 MeV,
30 mg/cm² for energies below 0.6 MeV.

A graph of $(\ln C_1 - \ln C_2)x^{-1}$ against E_m was then drawn for the various combinations (see figs. 6 and 7 and table 2). For counter no. 1 the graph is a straight line on a log-log scale since a is constant. For counter no. 2, at a sample to detector distance of 1 mm, a varies, hence the calibration graph is not linear. If the sample to detector distance is increased to 5 mm, the calibration graph becomes very nearly linear (see fig. 8). (This shows that the variation in a for different metals is a geometry effect.) A linear calibration graph is in many ways preferable, e.g., fewer standard sources need to be used; on the other hand increasing the sample-detector distance from 1 mm–5 mm causes a drop of $\approx 30\%$ in counting efficiency, which can be a real disadvantage with low activity samples.

The activity of the samples was of the order of 5000–10000 counts per minute without absorber. The calibration was also checked for the following medium and low activity samples:

^{210}Bi   130 counts per minute without absorber,
^{204}Tl   15 counts per minute without absorber,
^{40}K   8 counts per minute without absorber,

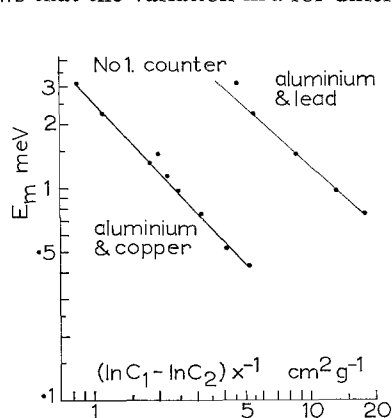and the agreement was found to be quite good (fig. 6).

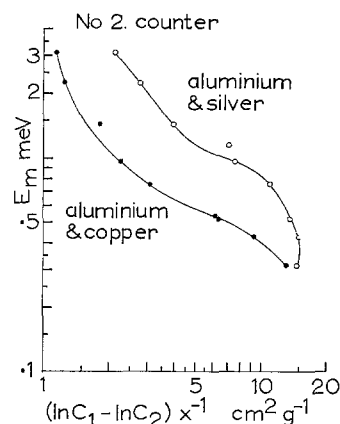Fig. 6. Graph of the function $(\ln C_1 - \ln C_2)/x$ versus the maximum energy, E_m.

Fig. 7. Graph of the function $(\ln C_1 - \ln C_2)/x$ versus the maximum energy, E_m, at 1 mm sample—detector distance.

6. Conclusions

The method is generally simpler than others of the absorption measurement type. A great advantage is that only two counts per sample are required.
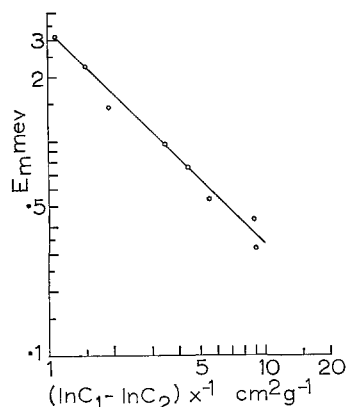

Fig. 8. Graph of the function $(\ln C_1 - \ln C_2)/x$ versus the maximum energy, E_m, at 5 mm sample—detector distance on no. 2 counter.

The procedure is particularly suited to dealing with low activity samples since counting can be completed in a shorter time, but the number of counts can still be sufficiently high to give reasonable accuracy. When determining the E_m of an unknown emitter, a preliminary short count through a medium thickness absorber can be used to establish the approximate energy range, so that a set of absorbers of suitable metals and thickness can be selected. For low energy emitters, light metal combinations e.g. aluminium and copper give the best results; for high energies a light-heavy combination (e.g. aluminium and silver or aluminium and lead) is more suitable.

References

[1] G. I. Gleason, J. D. Taylor and D. L. Tabern, Nucleonics **8**, no. 2 (1951) 5.
[2] M. Forro, Phys. Rev. **92** (1953) 4.
[3] J. H. Harley and N. Hallden, Nucleonics **13** (1955) 32.
[4] L. Daddi and V. D'Angelo, Int. J. Appl. Rad. Isotopes **14** (1963) 2.