REVIEWS OF

MODERN PHYSICS

VOLUME 26, NUMBER 1 JANUARY, 1954

The Energies of Natural Alpha Particles

G. H. BRIGGS

Division of Physics, National Standards Laboratory, Commonwealth Scientific and Industrial Research Organization, Sydney, Australia

The paper gives recalculated values of the energies of natural alpha particles which have been measured precisely by deflection methods. The results are based on the new values for the Faraday and the mass of the He^4 atom, a revised value for the author's absolute determination of the main group of RaC′ and weighted mean values for the main groups of ThC^{212}, ThC'^{212}, and Po^{210}.

I. INTRODUCTION

THE most precise knowledge of the energy of emission of alpha particles and the disintegration energy has been derived from measurements of the deflection in magnetic or electrostatic fields. Alpha particles of accurately known energy have long been used as a basis with range-energy relations for the measurement of the energies of other alpha particles, and in recent years alpha particles have served as convenient energy standards in the measurement of nuclear Q values. It seems also that their use as standards may be considerably extended by the recent conclusion that, over a wide range of energy, the ionization produced by all heavy particles in some gases is very precisely proportional to the energy, irrespective of the type of particle (Fr 50) (Je 50) (Be 50).*

In this paper it is proposed to review the precise measurements of alpha-particle energies determined by deflection methods. The first step will be to attempt to derive best mean values of the energies of those alpha-particle groups which have been used as standards and then to use these as the basis of recalculation of the energies of other groups measured relative to one or other standard group.

Most of the precise determinations of alpha-particle energies depend on measurement of $H\rho$ by magnetic deflection and a knowledge of the Faraday F and the mass of the He^4 nucleus. Both of these quantities are now known with greater accuracy than when many of the $H\rho$ determinations were made. In some cases other constants are involved. For example, in the writer's measurement (Br 36) of the main group of RaC′, the magnetic field measurement required a knowledge of gravity and of the ratio q of the international to the absolute ampere. Of these, the absolute value of gravity is now known more precisely, and a better estimate can be made of the value of q applicable to that measurement.

The measurements to be considered in this survey are in the main those of Rosenblum and his collaborators in Paris, Rutherford, Lewis, Wynn-Williams, and Bowden at the Cavendish Laboratory, the writer's determination for RaC′ and other groups relative to it, the electrostatic deflection measurements of Sturm and Johnson for Po^{210} at Wisconsin, and the recent measurements of Collins, McKenzie, and Ramm at Birmingham. As there is some evidence of systematic difference between the earlier and the most recent measurements, we shall discuss, at the outset, two sources of error often present in these measurements.

II. SOURCES OF ERROR

Energy Losses at the Source

The problem of assessing the energy losses of particles in escaping from the material support carrying the disintegrating atoms is one of the most difficult in precise alpha-ray energy measurements. It has been discussed in considerable detail in connection with alpha particle and other nuclear disintegration measurements.

In their work on ThC, ThC′, and Po, Collins, McKenzie, and Ramm (Co 52) made a careful estimate of the magnitude of the effect. Their process of fitting a theoretical line shape to the observed shape can be

* See Bibliography at end of paper.

TABLE I. Recalculated results of measurements by Briggs for RaC′ and alpha-particle groups determined relative to RaC′

	$H\rho$ 10^5 oe cm	Particle energy, Mev	Disintegration energy, Mev
Rn^{222}	3.37401±0.00021	5.4861±0.0007	5.5867±0.0007
RaA^{218}	3.52811±0.00022	5.9982±0.0008	6.1103±0.0008
RaC'^{214}	3.99274±0.00022	7.6804±0.0009	7.8266±0.0009
ThX^{224}	3.43359±0.00032	5.6814±0.0011	5.7846±0.0010
Tn^{220}	3.61064±0.00039	6.2819±0.0012	6.3982±0.0012
ThA^{216}	3.74967±0.00040	6.7745±0.0013	6.9023±0.0013
$ThC^{212}\alpha_0$	[a]3.54126±0.00044	6.0431±0.0015	6.1593±0.0016
$ThC^{212}\alpha_1$	[a]3.55275±0.0010	6.0813±0.0033	6.1982±0.0033
ThC'^{212}	4.26837±0.00032	8.7761±0.0013	8.9448±0.0014

[a] Deduced from mean $H\rho$'s of Table II for α_0 and α_1 and the relative abundances.

interpreted broadly as revealing in the case of their ThC and ThC′ sources a displacement of the high-energy edge of the line of about 1 in 4000 in $H\rho$. For their polonium sources the displacement was negligible. It is perhaps significant that in general the energies found in these measurements are somewhat higher than those obtained previously. It is not possible, however, to conclude whether this is to be attributed to a more precise estimation of source losses, for source losses are often of the same order of magnitude as the experimental error, and, on the other hand, the polonium measurements of Sturm and Johnson (St 51), in which careful assessment of source losses was also made, are consistent with the earlier measurements of Rosenblum and Dupuoy (Ro 32) and of Rutherford and co-workers (Ru 33).

Inhomogeneity of Magnetic Field

The 180° magnetic focusing method, while possessing obvious advantages in resolving power and sensitivity, has presented considerable difficulty in the measurement of $H\rho$. This has arisen either from lack of homogeneity of the field, changes in homogeneity associated with hysteresis, or because the field has been measured in the idle half of ring-type magnets and not along the actual path of the particles. Errors from these sources have been a major cause of uncertainty in 180° magnetic focusing measurements both in the absolute measurement and in measurements relative to a known group.

Thus the Cavendish workers (Le 34), having noted that their method seemed capable of an accuracy in relative determinations of 1 in 10^5, say: "These indeterminable variations in the inhomogeneity are the greatest remaining source of uncertainty in the results," and conclude that their measurements of the relative velocities of alpha particles from different substances are correct to 1 in 5000. In the absolute measurements of Rosenblum and Dupuoy, the radial inhomogeneity of the field was about 1.25 percent per cm (Ro 33), and in the work of Collins *et al.* (Co 52), it contributed the largest of the five listed errors.

III. CONSTANTS

In the calculation of the energies from the values of $H\rho$, we have used for F the value given by DuMond and Cohen (Du 52), 9652.01±0.25 S.E., and for the mass of the He^4 nucleus 4.002775 (±22 S.E.), deduced from the atomic mass given by Li, Whaling, Fowler, and Lauritsen (Li 51). The particle energy uncorrected for relativity is therefore $(H\rho)^2 \times 4.82266 \times 10^{-11}$ Mev (±2.6 in 10^5). For the calculation of disintegration energies, assumed to be the sum of the kinetic energies of the two particles, the masses of the heavy elements are known with more than adequate accuracy. Unless otherwise indicated, all statements of accuracy are to be interpreted as standard error.

IV. RaC′ MAIN GROUP

In reviewing the author's RaC′ determination we can now include the results of pendulum determinations of g at Sydney relative to Cambridge, England, obtained in 1952 by the Commonwealth Bureau of Mineral Resources. Applying the correction -0.015 cm/sec^{-2} recommended by Dryden (Dr 42) to gravity measurements on the Potsdam system, we deduce for g at the site of measurement 979.673±0.008 cm/sec^{-2} in place of 979.683±0.03.

To re-evaluate q, the ratio of the international ampere as maintained at the National Physical Laboratory, Teddington, to the absolute ampere, for the period 1935–6, we have the following data: (a) The determination of q at the National Physical Laboratory by Vigoureux (Vi 37) on which the value used by the writer in 1936 was based and the two subsequent determinations of q at the National Bureau of Standards, Washington, of 1939 and 1942. (b) A correction of -7.5 in 10^6 for gravity applicable to all three determinations of q. (c) The known differences between the values of the international electrical units as maintained by the National Physical Laboratory and the National Bureau of Standards over the period involved. These

TABLE II. Measurements of $H\rho$ for α_0 and α_1 ThC and weighted means.

Observer	Reference	$H\rho\alpha_0$ 10^5 oe cm	Weight	$H\rho\alpha_1$ 10^5 oe cm	Weight
Rosenblum and Dupuoy	Ro 32, Ro 33	3.5428 ±0.003	1	3.5541 ±0.003	1
Briggs	Br 33, Br 36	3.54126±0.0004	1	3.55275±0.0009	1
Lewis and Bowden	Le 34	3.54108±0.0008	2	3.55257±0.0008	2
Collins, McKenzie, and Ramm	Co 52	3.5434 ±0.0010	3	3.5551 ±0.0010	3
		Mean 3.54232±0.0005 S.E.		Mean 3.55389±0.0008 S.E.	

data are available in convenient form in a general discussion of electrical units by Silsbee (Si 49).

The conclusion is that a more reliable value of q for the writer's RaC′ determination is 0.999857 ± 0.000015 (S.E.) instead of 0.99986 ± 0.00005 (S.E.); that is, there is no significant change other than in precision.

Table I gives the recalculated results for the RaC′ main group and other groups measured by the writer relative to this group (Br 33) (Br 34).

V. Po^{210}, ThC^{212} α_0, ThC^{212} α_1, ThC'^{212}

These are groups which have frequently been used as standards. We will therefore attempt to derive the most probable values of their $H\rho$'s and energies from the various precise determinations which have been made.

Rosenblum and Dupuoy (Ro 32, 33) made absolute measurements of the $H\rho$'s of all these groups to an accuracy "considered correct to 1 in 1000, probably to 1 in 2000." Briggs (Br 33) made measurements of ThC′ and of the mean of ThC α_0 and α_1 relative to RaC′, from which the $H\rho$'s for α_0 and α_1, given in Table I, have been deduced from the accurate data for the relative intensities and relative velocities of these two groups. The measurements made at the Cavendish Laboratory (Ru 33) (Le 34) were relative to RaC′. The measurements of Collins and co-workers (Co 52) of Po^{210}, ThC α_0 and α_1, and ThC′ are absolute determinations. Although they refrained from stating an accuracy for their single measurement of ThC α_0 and α_1, we include this measurement in deriving mean values, since it appears to be quite consistent with their other measurements and further they say that there is no obvious reason why the error should be greater than that assigned to ThC′. Sturm and Johnson (St 51) using 90° electrostatic deflection evaluated the energy of the alpha particles from polonium and RaC′ by comparison with the absolute determination by Herb, Snowdon, and Sala (He 49) of the threshold of the $Li^7(p,n)Be^7$ reaction. From this we have derived $H\rho$ for polonium using the constant given in paragraph 3.

In assigning weights to these results we have been guided by the following considerations: (a) The statistical significance of the quoted errors of some of the measurements is unknown. These we have equated to standard error. (b) Two of the four results for ThC and C′ are relative to the same standard RaC′, and so a weight smaller than would be indicated by the precision has been assigned to both of these measurements. (c) The precision of the magnetic field measurement of Collins *et al.*, and their careful assessment of loss of energy at the source justify a relatively high weight for their results. (d) The evidence, mentioned earlier, of a systematic difference between the results of Collins *et al.* and the other results suggests that weights based strictly on quoted accuracies would not give the best mean.

TABLE III. Measurements of $H\rho$ for main group of ThC′ and weighted mean.

Observer	Reference		$H\rho$ 10^5 oe cm	Weight
Rosenblum and Dupuoy	Ro 32,	Ro 33	4.26930 ± 0.004	1
Briggs	Br 33,	Br 36	4.26837 ± 0.0004	2
Lewis and Bowden	Le 34		4.26829 ± 0.0009	2
Collins *et al.*	Co 52		4.2707 ± 0.0010	4
		Mean	4.26934 ± 0.0009 S.E.	

TABLE IV. Measurements of $H\rho$ for polonium and weighted mean.

Observer	Reference		$H\rho$ 10^5 oe cm	Weight
Rosenblum and Dupuoy	Ro 32,	Ro 33	3.3158 ± 0.003	1
Lewis and Bowden	Le 34		$3.3158_5 \pm 0.0007$	2
Sturm and Johnson	St 51		$3.3158^{a} \pm 0.0017$	2
Collins, McKenzie, and Ramm	Co 52		3.3176 ± 0.0009	3
		Mean	3.31644 ± 0.0008 S.E.	

[a] Derived from a determination of the energy.

Tables II, III, and IV summarize the measurements and give the weighted means. In view of the evidence of systematic error we have arbitrarily quoted errors for the means which are 50 percent greater than would be found statistically.

VI. THE RECALCULATED RESULTS

Table V summarizes the values of $H\rho$, the particle energy, the disintegration energy, and the abundance of natural alpha particles for which data obtained by deflection methods are available. There is probably no simple and, at the same time, entirely satisfactory system of nomenclature for alpha-particle spectra. We have retained the one originally used by the Paris workers. The values given in Table I for RaA, RaC′, and the means given in Tables II, III, and IV have been used to recalculate results which depend on one of these groups as a standard. For information on the accuracy of some of the measurements made by the Paris workers the author is indebted to S. Rosenblum.

VII. DISCUSSION

Ra^{226}

Energies have been quoted in the literature for α_0 and α_1 Ra^{226}, for example 4.793 and 4.612 Mev, by Lewis and Bowden, derived from the velocities originally reported by Rosenblum (Ro 32a). These are too high by about 10 kev. Bastin-Scoffier and Dionisio (B-S 53) using polonium as standard have redetermined the energy of α_0 Ra^{226} and find 4.777 Mev. Using the mean for polonium which we have adopted, this becomes 4.779 Mev whereas from Rosenblum's original determination the value would be 4.784 Mev. The values listed in Table V for α_1 are derived from the particle energy difference $\alpha_0 - \alpha_1$ given by Rosenblum, Guillot, and Bastin-Scoffier (Ro 49). The abundance quoted for α_1 is the mean of four measurements (Ro 49) (B-S 51) (As 52) (Ka 53).

Evidence for a feeble α_2 group, 600 kev below the main group, was originally reported by Rosenblum and again by Rosenblum, Guillot, and Bastin-Scoffier (Ro 49). Its abundance was given as 0.2 percent by Bastin-Scoffier (B-S 51). On the other hand, it is not found by Asaro and Perlman (As 52), who set a limit of 0.1 percent to its intensity and report that Ghiorso lowered this limit to 0.02 percent for this or any other

TABLE V. $H\rho$, particle energy and disintegration energy of natural alpha particles recalculated using new values of physical constants and the values for standard groups given in Tables I to IV.

Z	Isotope	Groups	$H\rho$ 10^5 oe cm	Alpha-particle energy, Mev	Disintegration energy, Mev	Relative abundance	Absolute, mean, or relative to a standard	Reference
83	Bi^{211} (AcC)	α_0	3.7067 ±0.003	6.620 ±0.013	6.748 ±0.013	82.6	Absolute	Ro 32
		α_1	3.6082 ±0.003	6.273 ±0.013	6.394 ±0.013	17.4	AcC	Vi 52
	Bi^{212} (ThC)	α_1	3.55389±0.0007	6.0861±0.0024	6.2031±0.0025	27.2	Mean	Ry 51
		α_0	3.54232±0.0008	6.0466±0.0027	6.1628±0.0028	69.8	Mean	
		α_2	3.45854±0.0008	5.7642±0.0026	5.8750±0.0027	1.75	α_0 ThC	
		α_4	3.41565±0.0008	5.6222±0.0025	5.7303±0.0026	0.15	α_0 ThC	Li 34
		α_3	3.40989±0.0008	5.6033±0.0025	5.7110±0.0026	1.09	α_0 ThC	
		α_5	3.372 ±0.003	5.478 ±0.010	5.584 ±0.010	0.16		Ro 32b
	Bi^{214} (RaC)	α_0	3.3799 ±0.0007	5.5051±0.0022	5.6080±0.0022	45	RaC′	Ru 33, Le 34
		α_1	3.3611 ±0.0007	5.4441±0.0022	5.5458±0.0022	55		
84	Po^{210}		3.31644±0.0008	5.3006±0.0026	5.4055±0.0026		Mean	Br 33, Ro 32, Le 34, Co 52
	Po^{211} (AcC′)		3.930 ±0.004	7.442 ±0.015	7.586 ±0.015		RaC′	Ro 31
	Po^{212} (ThC′)		4.26934±0.0009	8.7801±0.004	8.9488±0.004	10^6	Mean	
		Long range	4.4393 ±0.0009	9.4923±0.004	9.6746±0.004	35		Le 34
		Long range	4.652	10.422	10.623	20		Ry 51
		Long range	4.6790 ±0.0009	10.5432±0.004	10.7459±0.004	180		Le 34
	Po^{214} (RaC′)	Long range	3.99274±0.00022	7.6804±0.0009	7.8266±0.0009	10^6	Absolute	Br 36
		Long range	4.1451 ±0.0009	8.2771±0.0036	8.4347±0.0036	0.43	RaC′	Ru 33a
		Long range	4.3076 ±0.0009	8.9380±0.0040	9.1082±0.0040	(0.45)		
		Long range	4.3381 ±0.0009	9.0649±0.0040	9.2375±0.0040	22		
		Long range	4.3971 ±0.0009	9.3128±0.0040	9.4902±0.0042	0.38		
		Long range	4.4385 ±0.0010	9.4886±0.0040	9.6693±0.0042	1.35		
		Long range	4.4778 ±0.0010	9.6574±0.0040	9.8413±0.0042	0.35		
		Long range	4.5059 ±0.0010	9.7788±0.0042	9.9650±0.0044	1.06		
		Long range	4.5349 ±0.0010	9.9046±0.0044	10.0932±0.0044	0.36		
		Long range	4.5734 ±0.0010	10.0735±0.0044	10.2653±0.0045	1.67		
		Long range	4.5899 ±0.0010	10.1461±0.0045	10.3393±0.0045	0.38		
		Long range	4.6305 ±0.0010	10.3260±0.0045	10.5226±0.0045	1.12		
		Long range	4.6706 ±0.0010	10.5058±0.0045	10.7058±0.0046	0.23		
	Po^{215} (AcA)		3.915 ±0.003	7.383 ±0.012	7.526 ±0.012		AcC	Cu 32
	Po^{216} (ThA)		3.7497 ±0.0003	6.7746±0.0013	6.9024±0.0013		RaC′	Br 33, Ro 33a
	Po^{218} (RaA)		3.52811±0.00022	5.9982±0.0008	6.1103±0.0008		RaC′	Br 36, Br 34
86	Rn^{219} (An)	α_0	3.7587 ±0.0016	6.807 ±0.006	6.934 ±0.006	18	α_0 ThC	Cu 33, Ro 36
		α_1	3.6847 ±0.0016	6.542 ±0.006	6.644 ±0.006	4		
		α_2	3.6496 ±0.0016	6.418 ±0.006	6.537 ±0.006	3		
		α_3	3.586 ±0.0023	6.197 ±0.008	6.312 ±0.008	1		
	Rn^{220} (Tn)		3.6108 ±0.0003	6.2823±0.0013	6.3985±0.0013		Mean	Br 33, Ro 33a
	Rn^{222}		3.37401±0.00020	5.4861±0.0007	5.5867±0.0007		RaC′	Br 34
88	Ra^{223} (AcX)	α_0	3.4392 ±0.0018	5.700 ±0.006	5.804 ±0.006	12	α_0 ThC	Cu 33, Ro 36
		α_1	3.4052 ±0.0018	5.588 ±0.006	5.690 ±0.006	10		
		α_2	3.3836 ±0.0018	5.514 ±0.006	5.615 ±0.006	5		
		α_3	3.355 ±0.0025	5.425 ±0.008	5.524 ±0.008	2		
	Ra^{224} (ThX)	α_0	3.4336 ±0.0003	5.6814±0.0011	5.7847±0.0011	95	Mean	Br 33, Ro 33a
		α_1	3.3620	5.4471	5.5461	5		Ro 49b
		α_2	3.2826	5.1930	5.2874	0.4		
	Ra^{226}	α_0	3.1490 ±0.0016	4.779 ±0.005	4.865 ±0.005	94.1	Po^{210}	B-S 53
		α_1	3.089 ±0.002	4.595 ±0.007	4.678 ±0.007	5.9		Ro 49, B-S 51, Ka 51, As 52

TABLE V—*Continued.*

Z	Isotope	Groups	$H\rho$ 10^5 oe cm	Alpha-particle energy, Mev	Disintegration energy, Mev	Relative abundance	Absolute, mean, or relative to a standard	Reference
90	Th^{227}							
	(RdAc)	α_0	3.5369 ±0.0026	6.0281±0.009	6.1362±0.009	16	α_0 ThC	Ro 36, Ro37
		α_1	3.5282 ±0.0026	5.9985±0.009	6.1061±0.009	1		
		α_2	3.5192 ±0.0026	5.9680±0.009	6.0750±0.009	13		
		α_3	3.5134 ±0.0026	5.948 ±0.009	6.055 ±0.009	1		
			3.5089 ±0.0026	5.933 ±0.009	6.039 ±0.009			
		α_4	{3.5019 ±0.0026	5.909 ±0.009	6.015 ±0.009}	2		
			{3.4976 ±0.0026	5.895 ±0.009	6.001 ±0.009}			
		α_5	{3.4864 ±0.0026	5.8573±0.009	5.9623±0.009}	3		
			{3.4796 ±0.0026	5.835 ±0.009	5.939 ±0.009}			
			3.4735 ±0.0026	5.814 ±0.009	5.918 ±0.009			
		α_6	3.4685 ±0.0026	5.797 ±0.009	5.901 ±0.009	2		
			3.4649 ±0.0026	5.785 ±0.009	5.889 ±0.009			
			3.4612 ±0.0026	5.773 ±0.009	5.877 ±0.009			
		α_7	3.4529 ±0.0026	5.7454±0.009	5.8484±0.009	15		
		α_8	{3.4482 ±0.0026	5.7298±0.009	5.8325±0.009			
			{3.4453 ±0.0026	5.720 ±0.009	5.823 ±0.009			
		α_9	3.4388 ±0.0026	5.6986±0.009	5.8008±0.009	12		
		α_{10}	3.4236 ±0.0026	5.648 ±0.009	5.750 ±0.009	2		
	Th^{228}							
	(RdTh)	α_0	3.3544 ±0.0010	5.4226±0.003	5.5194±0.003	72.5	ThX	
		α_1	3.3280 ±0.0010	5.3374±0.003	5.4326±0.003	28.5		Ro 49a
	Th^{230}							
	(Io)	α_0	3.118 ±0.003	4.685 ±0.010	4.768 ±0.010		α_1 ThC	Ro 48
		α_1	3.095 ±0.004	4.416 ±0.012	4.698 ±0.012			
91	Pa^{231}	α_0	3.2353 ±0.0020	5.044 ±0.006	5.133 ±0.006	11	Po^{210}	Ro 49c
		α_1	3.2224 ±0.0020	5.004 ±0.006	5.092 ±0.006	47		
		α_2	3.2017 ±0.0020	4.940 ±0.006	5.027 ±0.006	25		
		α_3	3.1691 ±0.0020	4.840 ±0.006	4.925 ±0.006	3		
		α_4	3.1302 ±0.0020	4.722 ±0.006	4.805 ±0.006	11		
		α_5	3.1102 ±0.0020	4.663 ±0.006	4.744 ±0.006	1 to 3		

group in the range 3.6 to 4.4 Mev by a careful examination with a pulse analyzer. The experimental basis for this group must, therefore, still be regarded as doubtful. Other subgroups reported by Chang (Ch 46) are not accepted as real spectral groups of Ra^{226}.

Po^{210}

Chang (Ch 46a) reported a number of weak subgroups which he realized conflict with alpha-particle emission theory. Wadey (Wa 48) has shown that they cannot be true spectral lines of Po^{210}.

Pa^{231}

The values tabulated are based on those found by Rosenblum, Cotton, and Bouissieres (Ro 49c) relative to polonium. Ringo (Ri 40) found the particle energy for α_0 to be 5.053±0.007 Mev by extrapolation from several standard groups, the nearest of which was Po^{210}. Using the mean value adopted for polonium, his result would probably become 5.050±0.007 Mev, a value consistent with that of Rosenblum and co-workers.

$RdAc^{227}$, AcX^{223}, An^{219}, AcA^{215}, AcC^{211}, and AcC'^{211}

The values given in Table V for the numerous groups of RdAc and for its products, AcX, An, and AcA, are derived from publications of the Paris workers mainly in the period 1931–1937.

The values of $H\rho$ of the RdAc groups have been determined by Rosenblum, Guillot, and Perey (Ro 37), using α_0 ThC as standard. Curie and Rosenblum have given disintegration energies for AcX α_0, α_1, α_2 and An α_0, α_1, α_2 (Cu 33) but the results need correction since the energies for the groups for the parent RdAc, found at the same time, are on the average 19 kev higher than the later and more accurate values reported by Rosenblum, Guillot, and Perey (Ro 37). However, as the application of a correction of 19 kev conflicts with the conclusion (Ro 36) that α_0 AcX is 5 to 10 kev higher than α_9 RdAc, we have arbitrarily applied a correction of 17 kev, which makes α_0 AcX$-\alpha_9$ RdAc$=6$ kev. The uncertainty in the results so obtained is estimated to be about 6 kev.

The values given for the feeble groups, α_3 AcX and α_3 An, are derived from the observation of Rosenblum, Guillot, and Perey (Ro 36) that these groups are, respectively, 280 kev and 610 kev below the main groups.

For AcA the only observation is that of Curie and Rosenblum (Cu 32), who give the velocity relative to α_0 AcC and α_1 AcC, for which the $H\rho$'s are known from the measurements of Rosenblum and Dupuoy (Ro 32) and Vieiera and Salguieiro (Vi 52).

Only a single group is known for AcC′. This was measured by Rosenblum (Ro 31) relative to AcC to an accuracy of 0.1 percent.

ThX^{244}, Tn^{220}, ThA^{216}

The values of $H\rho$ given in Table V for the main groups of these isotopes are the weighted means of the very concordant measurements of Briggs (Br 33), weight 3, and Rosenblum and Chamie (Ro 33a), weight 1.

ThC and ThC′

For the α_2, α_3, and α_4 groups of ThC, we have adopted the velocities relative to α_0 measured by Lewis and Bowden to a precision which they indicated was of the order of 1 in 30 000. The feeblest group α_5 was reported by Rosenblum and Valadares (Ro 32b). To their results for this group we have applied a small correction for the small but systematic difference in the spread of the velocities of the groups α_0 to α_4 in their measurements as compared with those of Lewis and Bowden. Rytz (Ry 52) has reported the intensity of the α_5 group to be 0.016 percent.

The values tabulated for ThC′ and its long-range groups are derived from the measurements of Lewis and Bowden (Le 34) relative to RaC′. Rytz (Ry 52) has reported a new long-range group, $H\rho$ 4.652×10^5, whose abundance is 25 in 10^6. The abundances given for the ThC and ThC′ groups are the means of those found by Lewis and Bowden and by Rytz.

VIII. ACKNOWLEDGMENTS

The author wishes to thank Professor R. L. Platzman for his encouragement at the beginning of this work, Mr. J. M. Rayner and Mr. R. F. Thyer of the Commonwealth Bureau of Mineral Resources for information on the value of gravity at Sydney, and Miss J. Ward for valuable assistance in the computations.

IX. REFERENCES

As 52 F. Asaro and I. Perlman, Phys. Rev. **88**, 129 (1952).
Be 50 H. H. Bethe, Revs. Modern Phys. **22**, 213 (1950).
Br 33 G. H. Briggs, Proc. Roy. Soc. (London) **A139**, 638 (1933).
Br 34 G. H. Briggs, Proc. Roy. Soc. (London) **A143**, 604 (1934).
Br 36 G. H. Briggs, Proc. Roy. Soc. (London) **A157**, 183 (1936).
B-S 51 G. Bastin-Scoffier, Compt. rend. **233**, 945 (1951).
B-S 53 G. Bastin-Scoffier and J. Santana-Dionisio, Compt. rend. **236**, 1016 (1953).
Ch 46 W. Y. Chang, Phys. Rev. **70**, 632 (1946).
Ch 46a W. Y. Chang, Phys. Rev. **69**, 60 (1946).
Co 52 Collins, McKenzie, and Ramm, Proc. Roy. Soc. (London) **A216**, 219 (1953).
Cu 32 Marie Curie and S. Rosenblum, Compt. rend. **194**, 1232 (1932).
Cu 33 Marie Curie and S. Rosenblum, Compt. rend. **196**, 1598 (1933).
Dr 42 H. L. Dryden, J. Research Natl. Bur. Standards **29**, 303 (1942).
Du 52 J. W. Dumond and E. R. Cohen, Least Squares Adjusted Values of the Atomic Constants, 1952, California, Institute of Technology Spec. Tech. Rep. No. 1 (November 1952); Revs. Modern Phys. **25**, 691 (1953).
Fr 50 Franzen, Halpern, and Stephens, Phys. Rev. **77**, 641 (1950).
He 49 Herb, Snowdon, and Sala, Phys. Rev. **75**, 246 (1949).
Je 50 Jesse, Forstat, and Sadauskis, Phys. Rev. **77**, 782 (1950).
Ka 51 Karraker, Ghiorso, and Templeton, Phys. Rev. **83**, 390 (1951).
Le 34 W. B. Lewis and B. V. Bowden, Proc. Roy. Soc. (London) **A145**, 235 (1934).
Li 51 Li, Whaling, Fowler, and Lauritsen, Phys. Rev. **83**, 512 (1951).
Ri 40 R. Ringo, Phys. Rev. **58**, 942 (1940).
Ro 31 S. Rosenblum, Compt. rend. **193**, 848 (1931).
Ro 32 S. Rosenblum and G. Dupuoy, Compt. rend. **194**, 1919 (1932).
Ro 32a S. Rosenblum, Compt. rend. **195**, 317 (1932).
Ro 32b S. Rosenblum and M. Valadares, Compt. rend. **194**, 967 (1932).
Ro 33 S. Rosenblum and G. Dupuoy, J. phys. et radium **4**, 262 (1933).
Ro 33a S. Rosenblum and C. Chamie, Compt. rend. **196**, 1663 (1933).
Ro 36 Rosenblum, Guillot, and Perey, Compt. rend. **202**, 1274 (1936).
Ro 37 Rosenblum, Guillot, and Perey, Compt. rend. **204**, 175 (1937).
Ro 48 Rosenblum, Valadares, and Vial, Compt. rend. **227**, 1088 (1948).
Ro 49 Rosenblum, Guillot, and Bastin-Scoffier, Compt. rend. **229**, 191 (1949).
Ro 49a Rosenblum, Valadares, and Perey, Compt. rend. **228**, 385 (1949).
Ro 49b Rosenblum, Valadares, Perey, and Vial, Compt. rend. **229**, 1009 (1949).
Ro 49c Rosenblum, Cotton, and Bouissieres, Compt. rend. **229**, 825 (1949).
Ru 33 Rutherford, Lewis, Bowden, and Wynn-Williams, Proc. Roy. Soc. (London) **A139**, 617 (1933).
Ru 33a Rutherford, Lewis, and Bowden, Proc. Roy. Soc. (London) **A142**, 347 (1933).
Ry 51 A. Rytz, Compt. rend. **233**, 790 (1951).
Si 49 F. B. Silsbee, Natl. Bur. Standards U. S. Cir. No. 475 (1949).
St 51 W. G. Sturm and V. Johnson, Phys. Rev. **83**, 542 (1951).
Vi 37 P. Vigoureux, Trans. Roy. Soc. (London) **A236**, 133 (1937).
Vi 52 G. Vieiera and L. Salgueiro, Compt. rend. **234**, 1765 (1952).
Wa 48 W. G. Wadey, Phys. Rev. **74**, 1846 (1948).