Ionization in Pure Gases and the Average Energy to Make an Ion Pair for Alpha and Beta Particles

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A series of measurements has been made of the relative currents produced in different gases by beta particles from Ni^{63} and from tritium sources in an ionization chamber. In all cases only relative current measurements with argon as a standard gas have as yet been made. The value of W, the average energy to make an ion-pair computed relative to argon as a standard, is found to be the same for Ni^{63} and tritium sources. If these relative W_β values are plotted as abscissas against previously determined W_α values for polonium alpha particles as ordinates, a marked difference is observed in the gases investigated. For hydrogen and the noble gases the plotted points lie closely on a 45 degree straight line through the origin. Thus for these gases the ratio W_α/W_β is constant. This constant may well be unity, but this is not proved as yet by these results. For all other gases so far investigated, the plotted points lie above the 45 degree line, indicating a higher efficiency of ionization (and a lower W) for the beta particles than for the polonium alpha particles. These results are in accord with the findings of Gray and Gurney. Gurney's results have been extended here to include a greater variety of gases for reduced alpha particles of approximately 1-Mev energy. Two postulates are advanced to explain the behavior of W_α and W_β here found.

EXPERIMENTS have been in progress for some time in which the relative ionization for different gases has been measured for beta particles emitted from tritium and Ni^{63} sources. Although the results are as yet preliminary, a comparison of them with the corresponding alpha-particle values is of interest and would seem to warrant publication at this time.

EXPERIMENTAL METHODS AND RESULTS

The ionization chamber used was a cylindrical one of brass of inside diameter 9.5 cm and height 7 cm (Fig. 1). The collecting electrode at the center of the cylinder was in the form of a wire ring 5 cm in diameter, supported by three wire stays rising from the central insulated shaft. In the plane of the collecting ring and filling the interior was a square gridwork of copper wires spaced 6 mm apart in each direction. In some experiments the individual wires were 2 mils in diameter and in others 6 mils. The wires in the central area of the collecting disk were coated with the beta-emitting substance under investigation. For Ni^{63} this coating was accomplished by electroplating. The tritium, in the form of a solution of tritiated polystyrene, was applied with a brush to the gridwork and was made conducting when dry by a light application of graphite—soft lead pencil.

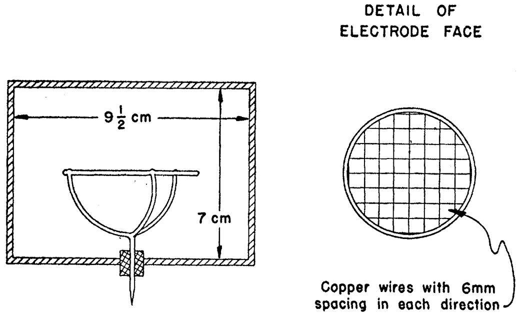

FIG. 1. Schematic diagram of ionization chamber for beta-particle current measurements.

The employment of the gridded electrode came as the result of a series of experiments where the source was applied to the extended surface of a plate electrode. The expected ionization seemed to be reduced by what we believe to be a process of backscattering of the very soft beta particles from the molecules of the gas back to the plate. The higher the atomic number of the gas the greater this effect seemed to be. With the gridded electrode the effective area for interception of such back-scattered particles is markedly reduced, and the effect is essentially eliminated.

With each of the beta sources in the chamber a series of measurements was made with the gases under investigation. The general arrangement of the apparatus was much the same as in previous experiments,[1] where the ionization chamber was coupled to a vibrating-reed electrometer, which in turn fed into a Brown strip-chart recorder. In the present experiments, however, the ionization current for each gas was measured by means of a null method. Here a counter-potential opposing the natural drift was continuously built up upon the floating vibrating-reed system from an external potentiometer, and the time between successive passages of the Brown recorder needle through a fiducial mark was determined. The ratios of the currents for the different gases was determined with argon as an arbitrarily chosen standard. The ratio of the values of W, the average energy to make an ion pair, is, of course, the reciprocal of this current ratio.

It should be noted that the current measured is an integrated effect from a large number of beta particles of varying energy. Even the average energy of the beta-particle beam is not exactly known, when the effects of self-absorption in the sample are considered. A rough estimate of the average energy would seem to

[1] Jesse, Forstat, and Sadauskis, Phys. Rev. 77, 782 (1950).

TABLE I. Comparison of W values in ev/ion pair for alpha and beta particles.

Gas	W_β Ni^{63} 2-mil grid-wire	W_β Ni^{63} 6-mil grid-wire	W_β tritium 6-mil grid-wire	W_β [a] tritium and A^{37} (Valentine)	W_α [b] for Po α	W_α for reduced α
He			42.3		42.7	42.4
Ne			36.6		36.8	37.4
A	(26.4)	(26.4)	(26.4)	(26.4)	26.4	(26.4)
Kr	24.1	24.1	24.2		24.1	24.1
Xe		21.8	22.2		21.9	
H_2			36.3	37.2	36.3	
Air	34.3	34.0	33.9	34.1	35.5	37.1
N_2			34.7	34.8	36.6	38.1
O_2			30.9	31.4	32.5	
CO_2	33.2	32.9	32.8		34.5	36.3
C_2H_4	26.0	26.5			28.0	29.8
C_2H_6	24.9		24.6		26.6	28.5
CH_4			27.3	29.3	29.2	31.0
C_2H_2			26.1		27.5	29.0

[a] J. M. Valentine, Proc. Roy. Soc. (London) **A211**, 75 (1952).
[b] W. P. Jesse and J. Sadauskis, Phys. Rev. **90**, 1120 (1953).

be from 3 to 5 kev for the tritium sample and from 15 to 20 kev for the Ni^{63} sample.

Throughout the experiment extreme precautions were taken to insure the purity of the gases used, since, especially in the noble gases, the presence of minute impurities has been shown to affect greatly the measured ionization.[2] Hence, the noble gas measurements were made with the gas in continuous circulation through an appropriate purification system.

In Table I a comparison is made of the average energy to make an ion pair for beta particles and for alpha particles in the various gases used. With the exception of the results in column 6, which give *absolute* values of W for polonium alpha particles already determined in this laboratory,[3] all the W values in Table I are computed relative to argon as a standard gas. For convenience, in each vertical column the argon W value is arbitrarily assumed to be 26.4 ev/ion pair, the absolute value of W determined for polonium alpha particles. The W values for all other gases in the column are computed on this basis from the ratios measured relative to argon.

Three series of beta-ionization measurements are shown in vertical columns 2, 3, and 4 of Table I. Two of these are for Ni^{63} plated on 6-mil and 2-mil copper wires, respectively, and the third is for tritiated polystyrene on 6-mil copper wires. No important differences exceeding the experimental error can be observed in the results for the three series. In particular, no change in W can be observed between the results from the disintegration of Ni^{63} of estimated average beta energy 15 to 20 kev and tritium of energy 3 to 5 kev.

In vertical column 5 are given for comparison the results of Valentine,[4] who used as active sources tritium and A^{37}. These results are again relative to argon as a standard gas. With the exception of the last value for CH_4 the agreement with the present results is satisfactory.

[2] W. P. Jesse and J. Sadauskis, Phys. Rev. **88**, 417 (1952).
[3] See reference b of Table I.
[4] See reference a of Table I.

In the graph of Fig. 2 a comparison is made of the average energy to make an ion pair for beta particles and for alpha particles in the various gases used. As ordinates are plotted the absolute W values for Po alpha particles taken from column 6, Table I. As abscissas are plotted the mean of the W_β values of columns 2, 3, and 4. The plotted points on the graph are designated by large circles.

It will be noted from Fig. 2 that the gases investigated seem to fall into two groups if classified according to their W values. In the first group, comprising the noble gases and H_2, the plotted points lie very closely upon a 45 degree line drawn from the origin through the somewhat arbitrarily chosen point for argon. This would indicate that for all these gases

$$W_\alpha/W_\beta = \text{constant}.$$

This constant may well be unity, but so far this has not been directly proved in these results, since up to this time no absolute beta-particle measurements have been obtained.

In the other group of gases, comprising air, O_2, N_2, CO_2, and the hydrocarbon gases, the experimental points lie definitely above the 45 degree line. This would indicate that, relative to argon, the W_β values for these gases are lower than the corresponding W_α values. In other words, in these gases the beta particles ionize more efficiently than do the polonium alpha particles.

In the case of air, the lower W for beta particles might be partly explained by better voltage saturation in the chamber, since the difficulties of drawing ions out of the dense alpha-particle tracks are well known. It is doubtful, however, whether this explanation could apply to the whole group of gases including N_2 and the

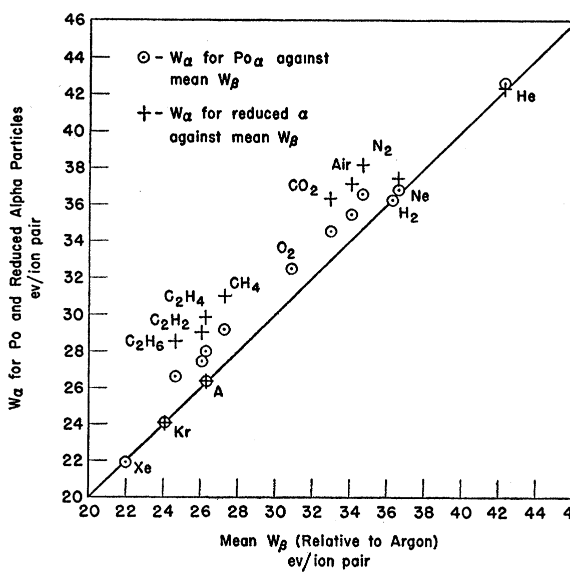

FIG. 2. Plot of W_α values for Po alpha particles and for reduced alpha particles against mean relative values of W_β.

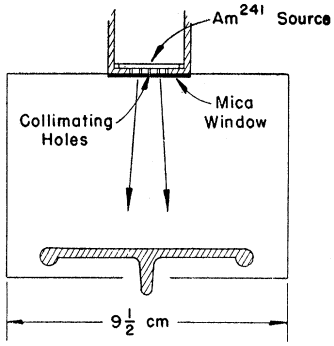

FIG. 3. Schematic diagram of ionization chamber for measurement of reduced alpha particles, showing collimating system and absorbing window.

hydrocarbons, where the saturation difficulties are much less severe.

It is of interest to note that the group of gases for which W_α/W_β is here constant, that is, the noble gases and H_2, is just the group of gases for which the relative W_α values were found by Gray[5] to be independent of alpha-particle energy. On the other hand, for air, N_2, and O_2 a variation of W_α with alpha-particle energy was found, W_α being higher for lower energy ranges. These gases would seem to correspond to the second group above.

Since the experimental work of Gurney,[6] on which the conclusions of Gray are based, did not include many of the gases investigated above, especially CO_2 and the hydrocarbons, it was decided to repeat the experiment of Gurney.

Alpha particles from an Am^{241} source deposited on a platinum disk were collimated and allowed to pass from an evacuated region through a mica window into the ionization chamber (Fig. 3). The mica was chosen of such a thickness that the maximum energy of the emerging alpha particles was of the order of 1.2 Mev. The initial alpha-particle beam was not, however, strictly monoenergetic, since because of its divergence particles passing through the mica sheet at other than normal incidence suffered a greater loss of energy. In these experiments with alpha particles of reduced energy, as in the case of beta particles, all measurements were made relative to argon as a standard.

The data from these measurements are shown in the last vertical column of Table I. In Fig. 2, the W values for these reduced alpha particles are plotted as ordinates against the corresponding beta values. The plotted points are indicated by heavy crosses.

Here again the points for the noble gases fall reasonably well along the 45 degree line, while those for air, N_2, CO_2, and the hydrocarbons lie even further above the line than do those for the polonium alpha particles. This shows a relative increase in the W_α values with decreasing energy in accord with the findings of Gray. In the present work CO_2 and the hydrocarbons are shown to lie in the general class with air, O_2, and N_2 already cited by Gray. Parenthetically, it may be noted that the ratio W_α/W_β is slightly larger for the hydrocarbons as a class than for air, N_2, O_2, and CO_2, both for the polonium and reduced alpha particles.

CONCLUSIONS

It would seem that the data here presented fall into accord on the basis of the two following postulates. Neither of them is as yet proved conclusively, but there is much experimental evidence to support them in addition to that cited here.

1. If, in the relation $W_\alpha/W_\beta=$ constant for hydrogen and the noble gases, we assume this constant to be unity, then W in these gases is the same both for beta and alpha particles throughout all ranges of energy for either so far measured by us.

2. In all other gases so far measured, W_α/W_β is not found to be constant. The variation in the ratio seems to come from a variation of W with alpha-particle energy rather than a variation of W_β with beta-particle energy. As the alpha-particle energy increases, this ratio probably approaches a constant value, which again is probably unity.

The following experiments would seem desirable to prove or disprove the postulates above.

1. To determine the relative W values for gases of Class 2 for alpha particles over a small energy increment in the neighborhood of 5 Mev or higher. These values should approach the W_β values if postulate 2 is correct.

2. So far only beta particles of very low energies have been investigated and these over a very small range of average energy. Plans are in progress to repeat the measurements with beta particles from C^{14}.*

3. In the relation $W_\alpha/W_\beta=$ constant, one cannot be certain that the constant above is unity without an absolute determination of W_β. This is not easy, but already preparations are being made for such a determination.

It is a pleasure to express our thanks to a large number of friends and colleagues for the many stimulating discussions of this subject. Among these are Professor Robert L. Platzman, Dr. Francis R. Shonka, Dr. John E. Rose, and Dr. L. D. Marinelli. Our thanks are due also Mr. L. C. Ellsworth, whose painstaking skill in the construction of our ion chambers has added greatly to the success of this work.

[5] L. H. Gray, Proc. Cambridge Phil. Soc. **40**, 95 (1944).
[6] R. W. Gurney, Proc. Roy. Soc. (London) **A107**, 332 (1925).

* *Note added in proof.*—Recent similar experiments with beta particles from C^{14} indicate the same constancy of W with energy found above for Ni^{63} and tritium.