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Ionization of Gases by Recoil Atoms

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The value of W, the average energy required to produce an ion pair, has been measured in several gases for the recoil atoms due to the alpha decay of ThC and ThC′. The method used compared proportional counter pulse heights from the first inch of alpha tracks with complete recoil tracks, auxiliary counters differentiating between the two by coincidence technique. For the recoils due to the decay of ThC, the following values of W (in ev per ion pair in the indicated gas) were obtained: CO_2, 102; C_3H_6, 99; C_2H_4, 104; He, 60; H_2, 81; CH_4, 111. The values for the decay of ThC′ were found to be: CO_2, 99; C_3H_6, 92; C_2H_4, 90; He, 55; H_2, 68; CH_4, 96.

I. INTRODUCTION

THE measurement of W, the average energy required to produce an ion pair, for atoms recoiling from radioactive decay has been of interest for many years. A recent determination, for the atom Pb^{206} recoiling from the alpha decay of Po^{210} in argon and helium, has been made by Jesse and Sadauskis[1] using ionization chamber techniques. A coincidence counter technique was used by Madsen[2] in an investigation of the ionization produced by the recoil atoms from the decay of Po^{210}, ThC (Bi^{212}), and ThC′ (Po^{212}) in a mixture of 95% argon and 5% air. These measurements showed the W values for the recoil atoms to be from 3.4 to 4.5 times the W value for the corresponding alpha particle in the same gas. The presence of oxygen or other electronegative gas has been criticized as disturbing the proportional response of the counter.[3] The present work is a modification of the coincidence counter method of Madsen, using a ThC-ThC′ source and extending the measurements to a variety of gases for which dE/dx (energy loss per unit track length) data are available, and which are suitable for proportional counter operation.

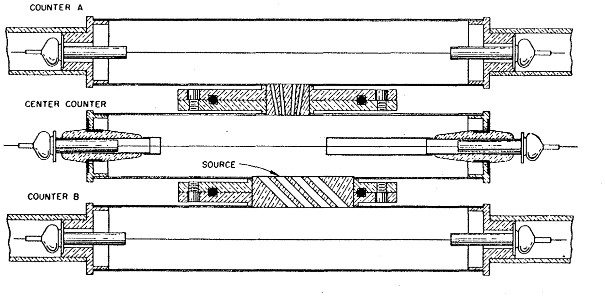

FIG. 1. Proportional counter system for the study of the ionization produced by recoil atoms due to alpha decay.

II. APPARATUS AND METHOD

The coincidence counter arrangement employed is shown in Fig. 1. The three cylindrical proportional counters, each one inch in diameter, are arranged with their axes parallel and in the same plane. All pulse-height measurements are made from the center counter which contains the source material; this counter is provided with field tubes to define the active counter volume. The two outside counters, A and B, serve only to single out by coincidence circuitry and collimation the specific decay event which is to be analyzed.

The source of recoil atoms is ThB (Pb^{212}) which is collected in an electric field from a 3-mC Ra Th (Th^{228}) source. The ThB, which has a half-life of 10.5 hr, is collected on the inner face of a thin mica window sealed into the center counter wall at the mid-point. A strong source may be obtained from a deposit having an average thickness of less than one atomic layer. The mica window holding the deposited ThB and the opposite window, also in the wall of the center counter, were made conducting, opaque, and of such a thickness as to stop the recoil atoms but permit the alpha particles to enter the outside counters through the collimating holes.

The three counters are interconnected and contain filling gas from a common supply. All the filling gases were supplied through an activated charcoal trap at liquid nitrogen temperature. Data have been taken in the various gases at pressures ranging from 1 to 10 centimeters of mercury, corresponding to recoil particle ranges of about one-tenth to somewhat less than the diameter of the counter.

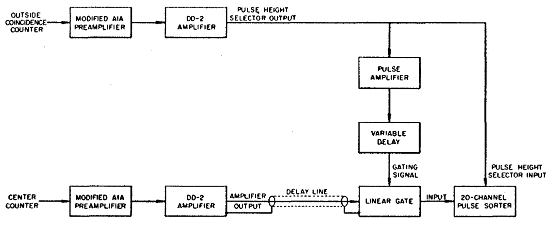

FIG. 2. Schematic diagram of circuit for the analysis of pulses due to recoil atoms and to alpha particles used for calibration.

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[1] W. P. Jesse and J. Sadauskis, Phys. Rev. **102**, 389 (1956).

[2] B. S. Madsen, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd. **23**, No. 8 (1945).

[3] D. H. Wilkinson, *Ionization Chambers and Counters* (Cambridge University Press, New York, 1950), p. 157.

TABLE I. W values (electron volts per ion pair) for particles from alpha decay of ThC and ThC′. The values of W_{recoil} are estimated to be accurate to ±5%. The W_α values are taken from Bortner and Hurst.[5]

		ThC		ThC′	
Gas	W_α	W_{recoil}	W_{rec}/W_α	W_{recoil}	W_{rec}/W_α
CO_2	34.3±0.3	102	2.98	99	2.88
C_3H_6	25.9	99	3.68	92	3.55
C_2H_4	28.0±0.3	104	3.72	90	3.21
He[a]	30	60	2.00	55	1.83
H_2	37.0±0.4	81	2.19	68	1.84
CH_4	29.4±0.3	111	3.78	96	3.26

[a] Impure helium values.

For calibration of the system, counter A and the center counter are connected to the circuit shown in Fig. 2. Alpha particles from the ThC-ThC′ source whose paths are along the diameter of the center counter and through the collimator into counter A produce a coincidence pulse in counter A which is used to trigger the pulse-height analyzer circuit of the center counter. Thus the path length of the alpha particles in the center counter is accurately determined and since the pressure is known, the energy loss in the center counter may be calculated by using the data of Hirschfelder and Magee[4] for hydrogen, methane, ethylene, cyclopropane, and carbon dioxide. If one uses the W_α values of Bortner and Hurst,[5] the number of ion pairs corresponding to the observed pulse height from the center counter may be calculated. The alpha particles from ThC and ThC′ have energies of 6.05 and 8.95 Mev, respectively; their dE/dx values are sufficiently different so that for the same path length the two groups may be clearly resolved as shown in Fig. 3, the more numerous 8.95-Mev alphas producing approximately $\frac{2}{3}$ as many ion pairs as the 6.05-Mev alphas in the first inch of track. The ratio of the observed pulse heights is compared to the ratio of the calculated energy losses for a check on the proportionality of the counter system.

To study the pulses caused by the recoil atoms, the center counter is not disturbed but counter B is connected in place of counter A in the circuit shown in Fig. 2. In this operation alpha particles entering counter B through the collimator correspond to recoil atoms traveling diagonally across the center counter. The pulses from counter B gate the pulse-height analyzer so that pulses from the center counter produce a pulse-height distribution that represents the spectrum caused by the recoil atoms from the decay of ThC and ThC′ with energies of 117 and 168 kev, respectively. By proper selection of gas pressure and counter voltage, it is possible to resolve these two groups as shown in Fig. 3. From the calibration data obtained with the alpha particles and the observed pulse heights due to the recoil atoms, the W values of the recoils are then calculated.

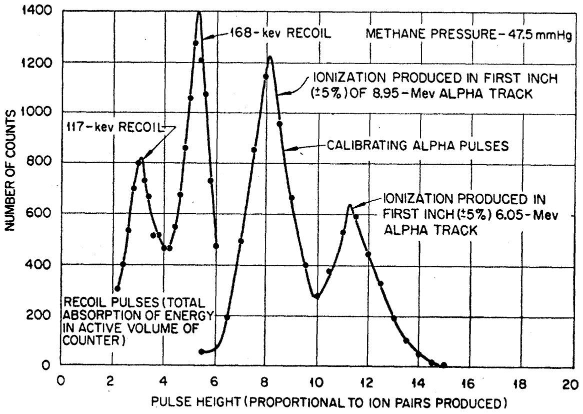

FIG. 3. Spectrum of pulses due to the ionization produced by recoil atoms and to the ionization produced by alpha particles used in calibration of the system.

III. RESULTS

The W values in electron volts per ion pair for the recoil atoms from the alpha decay of ThC and ThC′ are shown in Table I for the several gases considered. Measurements were made at different pressures for each gas and each value in Table I is the average of several runs. Hydrogen particularly was investigated over the range of pressures for which operation was possible and no significant variation of W with pressure was obtained. The consistency of the several values for any one gas was such that it is believed that the results are accurate to ±5%. The W values given in Table I are significantly lower than the values of Madsen and of Jesse and Sadauskis. The ratio of W for the recoil atoms to W for alpha particles ranges from 1.8 to 3.8 while the ratios from the earlier work ranged from 3.4 to 4.5. The W values for recoils in hydrogen and helium were the lowest obtained while the W values for alpha particles in these gases are the largest, being 37.0 and 46.0 electron volts per ion pair, respectively. Cyclopropane and ethylene which have the same hydrogen-carbon ratio in their composition have essentially the same W values for recoils.

In the analysis of the helium data the value of dE/dx required for calibration of the system was calculated by using the data of Williams.[6] Since a mixture of helium and ethylene was used to make the proportional counter operative, it was assumed that the method of Bortner and Hurst was applicable for the analysis of the results in the gas mixture, i.e., that the metastable state produced in the helium is completely discharged by the impurity gas.

Since the energies of the recoil atoms are only 117 and 168 kev, the concept of an "ionization defect"

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[4] J. O. Hirschfelder and J. L. Magee, Phys. Rev. **73**, 207 (1948).

[5] T. E. Bortner and G. S. Hurst, Phys. Rev. **93**, 1236 (1954). The value of W for cyclopropane was obtained using the same apparatus by Dr. T. D. Strickler of Berea College, Berea, Kentucky. The authors are indebted to Dr. Strickler for his kind permission to include this value in this report.

[6] E. J. Williams, Proc. Roy. Soc. (London) **A135**, 108 (1932).

suggested by Schmitt and Leachman[7] in the investigation of W values for fission fragments would appear to be not appropriate. These authors have idealized the variation of W with energy by assuming it to be infinite below a certain threshold energy. The energies of the recoils used in the present experiment lie below the threshold energies found by Schmitt and Leachman, but the W values shown in Table I are only a few times larger than the alpha-particle W values. However, the trend seems to be toward larger values of W as the energy decreases.

The particle recoiling from the decay of ThC (Pb^{212}) is Tl^{208} having an initial velocity equal to that of an electron with about $\frac{1}{3}$ ev of energy. Obviously it cannot "knock" an electron out of an orbit, so the ionization observed must result from some other mechanism such as charge exchange.

ACKNOWLEDGMENTS

The authors wish to express appreciation to Roland Abele of the Instrument Department for his work in the design of the proportional counters, and to R. H. Ritchie for his advice and assistance in calculations.

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[7] H. W. Schmitt and R. B. Leachman, Phys. Rev. **103**, 183 (1956).

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Measurements of Large-Angle Single Collisions between Helium, Neon, and Argon Atoms at Energies to 100 kev*

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Single collisions between ions and atoms have been studied at 25, 50, and 100 kev energies for the cases He^+ on He, He^+ on Ne, He^+ on A, Ne^+ on Ne, Ne^+ on A, and A^+ on A. The incident ion beam traversed a collision chamber containing a target gas whose pressure was maintained low enough to insure single interactions. The particles, which were scattered at each angle from four to forty degrees, passed through a pair of collimating holes with a resolution width of one degree. An electrostatic analyzer and its associated detectors determined the number of scattered atoms in each state of charge, ranging from zero to seven times ionized. The percentages of the various charge states in the scattered beam are plotted in order to indicate the dependence of this quantity on scattering angle and energy for each of the systems studied. The differential cross section for the scattering of particles has also been measured in each case and compared with values calculated classically from a Coulomb potential energy function modified by exponential screening.

1. INTRODUCTION

IT has been shown in previous studies[1–3] of single collisions between atoms at kev energies that the collision products resulting from such interactions are highly ionized. The recent paper[1] by two of the present authors, hereinafter called I, has described large-angle single collisions between argon ions and argon atoms at kev energies and has presented ionization and cross section data for angles out to twenty degrees. In the present paper this work has been extended. Collisions of the type He^+ on He, He^+ on Ne, He^+ on A, Ne^+ on Ne, Ne^+ on A, and A^+ on A, have been studied over an energy range of 25 to 100 kev, and measurements of the differential cross sections and distribution of charge states of the scattered particles are presented over an angular range of four to forty degrees with a resolution of ±0.5 degree.

In addition to the papers mentioned above and the references cited therein, a paper by Kaminker and Fedorenko[4] has appeared describing the scattering of argon ions in noble gas targets at energies of 40 to 150 kev with an angular range of 0 to 15 degrees. Processes of the type $A^+ \rightarrow A^0$, $A^+ \rightarrow A^{4+}$, etc., were studied and cross sections computed for each case. It was possible in two instances to compare the measurements of Kaminker and Fedorenko with those presented in this paper, and graphs of comparable data are included in the last section.

2. EXPERIMENTAL ARRANGEMENT AND PROCEDURE

a. Apparatus

The scattering apparatus shown in Fig. 1 is nearly the same as that described previously in I. The incident ion beam enters the target gas chamber through hole a, and a few of the large angle collisions which happen to occur near b result in scattered particles which pass through resolution holes c and d. These are analyzed into their several charge states and are then detected

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[1] Carbone, Fuls, and Everhart, Phys. Rev. **102**, 1524 (1956).

[2] Everhart, Carbone, and Stone, Phys. Rev. **98**, 1045 (1955).

[3] N. V. Fedorenko, Zhur. Tekh. Fiz. **24**, 784 (1954).

[4] D. M. Kaminker and N. V. Fedorenko, Zhur. Tekh. Fiz. **25**, 2239 (1955).