room temperature ($\sim$0.04 ev) electrons, $P_m \cong 60$ cm$^2$/cm$^3$ and is decreasing with increasing electron energy. This variation of $P_m$ with electron energy is in qualitative agreement with results of Fundingsland *et al.*[9]

The experimentally determined fractional energy loss, $\lambda$, is plotted as the dotted open circles of Fig. 2; the circles are joined by the dashed line. Other experimental determinations of $\lambda$ are also plotted on Fig. 2. It is seen that $\lambda$ is greater than that corresponding to purely elastic collisions. This is, however, understandable in the light of the theory recently proposed by Gerjuoy and Stein[10] on excitation of rotational levels of $N_2$ in collision with slow electrons. If $P_m$ found in these experiments is used in the calculation of $\lambda$ in the above theory, then we obtain the solid curve of Fig. 2, which is in good agreement with all experimental determinations of $\lambda$.

During the experiments the gas pressure was monitored. No measurable pressure change occurred; this result would most probably exclude the presence of any appreciable amount of atomic nitrogen.

[8] Sir John Townsend, *Electrons in Gases* (Hutchinson Scientific and Technical Publications, 1947), p. 72.

[9] Fundingsland, Faire, and Penico, *Rocket Exploration of the Upper Atmosphere* (Interscience Publishers, Inc., New York, 1954), p. 339.

[10] E. Gerjuoy and S. Stein, Phys. Rev. 97, 1671 (1955).

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# Recoil Particles from Po$^{210}$ and Their Ionization in Argon and Helium*

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The average energy $W_r$ to make an ion pair for the recoil particles ejected by the disintegration of Po$^{210}$ has been measured in argon and helium by a modification of a very old method. The ratio of this value for the recoil particles to the corresponding $W_\alpha$ value for the Po$^{210}$ alpha particles was found to be 4.1 and 4.5 in helium and argon, respectively. The ratio for argon is in good agreement with an earlier determination by Madsen for an argon-air mixture. The maximum radial distance traversed by the recoil particles was found to be $7.7\times10^{-3}$ cm and $52\times10^{-3}$ cm in argon and helium, respectively, under standard conditions.

FOR the past fifty years the ionization produced by recoil particles from radioactive disintegrations has been an interesting subject of investigation. Since the discovery of fission such investigations have additional interest, since the ionization phenomena accompanying the stopping of a fission fragment must be very similar to those accompanying the stopping of a recoil atom. The investigation of the recoil atom, moreover, has a marked experimental advantage in that one is dealing with a monoenergetic source with a precisely calculable initial energy.

A determination has been made by Madsen[1] of the average energy to produce an ion pair in argon by the recoil atoms from Po, ThC, and ThC′ in a coincidence counter system. He found that $W_r$, the average energy to produce an ion pair by the recoil atom, was 4.4, 3.8, and 3.4 times the average $W$ for the corresponding alpha particle from Po, ThC, and ThC′.

Unfortunately for work of this importance, the counter filling used was 95% argon and 5% air. Since the effect of impurities on the ionization in the noble gases may be quite large,[2] there is some question whether these results are valid in pure argon.

Soon after the appearance of this paper an experiment was devised by the present authors to repeat the work in pure argon. An adaptation of a very old method[3] was used.

A polonium source on a flat collecting electrode was placed at the geometrical center of a hemispherical ionization chamber of 4.5-cm radius. The source was electrodeposited as an invisible film on a polished platinum plate. A masking metal foil over the platinum plate allowed alpha particles to emerge only through a circular aperture of 0.5-cm diameter. The number of alpha particles emerging from the limited area was about 20 per second. This value was accurately determined by auxiliary measurements in a methane flow proportional counter.

The filling gas pressure in the ion chamber was varied, and the ionization current through the chamber measured as a function of the gas pressure (Fig. 1). This measurement was made by a drift method with a vibrating-reed electrometer and Brown recorder. The pressure was determined by a McLeod gauge, especially designed to measure pressures in the region from 0.01 to 2 cm of mercury. The argon and helium used were of high purity from breakerseal flasks, but were not continuously circulated over a purification system as has since been found desirable.

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[2] W. P. Jesse and J. Sadauskis, Phys. Rev. 88, 417 (1952).

[3] H. Geiger and J. M. Nuttall, Phil. Mag. 22, 613 (1911).

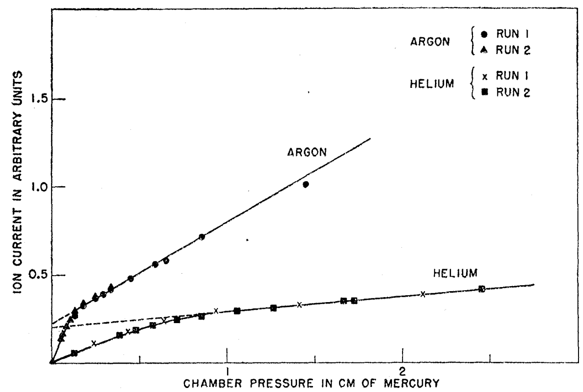


FIG. 1. Ionization current through the chamber as a function of gas pressure.

The current-pressure relation in Fig. 1 is represented for each of the gases by a very good straight line, which suddenly breaks downward as the origin is approached. Along the straight line the ionization measured consists of two parts. The first of these is a constant increment due to the ionization of the recoil particles, which are completely absorbed in the chamber. The second is the ionization produced in the rarified gas by the alpha particles in the initial stages of their path. Since the Bragg curve in this region is an almost horizontal line, the variation of ionization with pressure should be a very good straight line, as was found experimentally. If this straight line is extrapolated, it should give an ordinate intercept representing the total ionization current of the recoil particles. The pressure value where the experimental curve breaks downward from the straight line represents the point where the recoil particles begin to hit the chamber wall with a resulting decrease in ionization.

After the argon data in Fig. 1 were obtained, the chamber was filled with argon to a pressure of the order of 1 atmosphere and the current corresponding to the maximum ionization by the polonium alpha particles plus the recoil particle increment was measured. If the value of this last small increment, the intercept current in Fig. 1, is subtracted, we have the current $I_\alpha$, the ionization current from the alpha particles at their maximum range. $I_\alpha$ is obviously proportional to $E_\alpha/W_\alpha$, where $E_\alpha$ is the energy of the Po alpha particle, and $W_\alpha$ is the average energy to make an ion pair for the Po alpha particle. Similarly, for the recoil particles, $I_r$ is proportional to $E_r/W_r$. $I_r$ is the intercept value and $E_r$ and $W_r$ have meanings corresponding to those above. If we assume the number of recoil particles to be the same as the number of alpha particles emerging from the plate per second, then on dividing the foregoing proportionalities,

$$W_r/W_\alpha = (E_r/E_\alpha) \times (I_\alpha/I_r).$$

$E_r/E_\alpha$ is given by the mass ratio of the particles and has here the value 0.0190. Hence the ratio $W_r/W_\alpha$ may be determined directly from the observed current ratios. For argon (Table I), $W_r/W_\alpha$ was found to be 4.5—in very good agreement with the 4.4 ratio of Madsen for his argon-air mixture. The $W_r/W_\alpha$ ratio for helium shown in Table I was obtained by a slight variant of the method described above for argon.

In Fig. 1 the pressure corresponding to the break in each curve is the pressure at which the recoil particles begin to strike the chamber walls; i.e., they have traversed a radial distance of 4.5 cm. This radial distance, reduced to conditions of standard temperature and pressure, is shown in column 3 of Table I. It should be noted that this distance corresponds to a particle range, as it is usually defined, only if one assumes that the recoil particles travel in straight lines.

The very high absorption in matter of the recoil particles presents probably the greatest difficulty encountered in their measurement as they emerge from solid samples. In his experiments Madsen made a number of tests, all of which seem to indicate a negligible self absorption in the samples used. The publication of our results, however, has been delayed for a number of years in the hope of carrying out still further tests to reassure ourselves on this very critical point. Since circumstances have arisen, however, which render it improbable that further work on this problem can be carried out in the foreseeable future, we are now presenting these results in a somewhat incomplete form, perhaps chiefly to illustrate a new application of a very old experimental method.

TABLE I. Results from measurements for recoil particles from $Po^{210}$.

| Gas | $W_r/W_\alpha$ | Radial distance traversed by particle in gas at 15°C and 760 mm |
|---|---|---|
| Argon | 4.5 | $7.7\times10^{-3}$ cm |
| Helium | 4.1 | $52\times10^{-3}$ cm |

While the results of Madsen and the present results seem to show an increased value for recoil atoms over that for alpha particles, it should be pointed out that they are not necessarily in conflict with the authors' own measurements[4] of $W$ for alpha particles in very pure argon. In the latter work, for alpha-particle energies between 1 and 9 Mev, no variation of the $W$ value could be detected which exceeded the error of experiment.

An alpha particle of the same velocity as the recoil particle from a polonium disintegration would have an energy of less than 2 kev. Since Madsen found a markedly decreasing value of $W_r$ with increasing recoil energy even within the limited range of energies investigated, it seems possible that in alpha-particle ionization in argon the increased $W$ value extends over such a limited range of energies as to prove insignificant in measurements with alpha particles having energies of 1 Mev or more.

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