To summarize, it appears that model (*a*) gives a reasonable explanation for most of the present experimental data. In addition, a trapping model is proposed to explain why all of the damage does not anneal once interstitials begin to move. A measurement of the stored energy released in cyclotron-irradiated specimens during annealing from 15°K to 60°K would be extremely useful.

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Absolute Energy to Produce an Ion Pair in Various Gases by Beta Particles from S^{35}†

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A repetition has been carried out of recent experiments in which the absolute average energy W_β required to form an ion pair in various gases was determined for the beta particles from S^{35}. The present experiments employ a new procedure, which eliminates almost entirely large correction terms necessary in the former ionization measurements. The two experiments are in good agreement and yield the modified values of 35.0, 24.6, and 33.9 ev/ion pair for W_β for N_2, C_2H_6, and air, respectively.

INTRODUCTION

IN a previous paper,[1] henceforth referred to as J and S, results were obtained for W_β, the average energy to produce an ion pair in air, ethylene, ethane, and nitrogen by the beta particles from S^{35}. Unfortunately, the ionization chamber measurements required corrections of from two to five percent. Although such corrections could apparently be estimated with great precision, they are nevertheless somewhat disturbing. A procedure for eliminating such corrections to a large extent was indicated in J and S, and by this method additional results have been obtained, which are briefly reported here.

In the previous experiments the S^{35} source was deposited upon a thin plastic film supported upon an annular mount of aluminum. The two principal corrections resulted from a loss of measured ionization when the beta particles struck the wall of the mount, either immediately after their ejection or after being backscattered from the molecules of the gas in the chamber. Both of these cases were discussed in detail in J and S.

It was further pointed out that in measurements with gas at sufficiently high pressure the directly ejected beta particle could be absorbed before reaching the wall, and the backscattered particles, instead of hitting the ring, would pass through the central film with no serious loss in energy. Accordingly the ionization experiments have been repeated with gas pressures high enough to realize to a large extent these conditions.

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[1] W. P. Jesse and J. Sadauskis, Phys. Rev. **107**, 766 (1957).

EXPERIMENTAL RESULTS

The technique employed was almost identical with that of J and S. The ionization chamber (Fig. 1) was, however, made smaller and with sturdy metal fittings to withstand a pressure of eight atmospheres. The beta-emitting samples previously measured were mounted at the center of the chamber, supported directly on the collecting electrode post by a thin brass retaining ring.

The technique of making the ionization current measurements was the same as in previous experiments. As before, the ionization currents were always measured successively with the chamber wall at a positive and then at a negative potential with regard to the central electrode and the mean current taken. For these experiments the current difference was insignificant—usually one to two tenths of a percent higher for the positive wall. One might be tempted to attribute this small difference to an acceleration and deceleration of the beta particle in the applied field of the chamber.

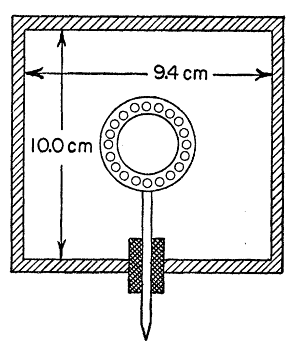

FIG. 1. Schematic diagram of ionization chamber for beta-particle current measurements.

However, such effects may be very complicated. Thus, in somewhat similar measurements in krypton and in xenon, the current with a negative wall chamber was consistently higher by as much as one percent. The reason for this is not as yet apparent.

The W_β values for the gases used were computed as in Table II of J and S. In each case, as in previous experiments, a reduction of 0.4% was applied as a correction for the absorption of beta-particle energy in the sample film. Such corrected W_β values are plotted in Fig. 2 as a function of the pressure of the gas in the chamber for the gases N_2, CH_4, C_2H_2, and C_2H_6. With increasing pressure the W_β values diminish, at first rapidly and then more slowly, to reach a constant value at higher pressures. The cause of this diminution with pressure is believed to be twofold.

In the first place, at low pressures the measured W values are higher because of the energy lost as the beta particles strike the walls of the relatively small chamber. As the pressure increases, the W values tend to sink to a constant value as all the beta energy is absorbed within the gas of the chamber. The shape of the curves is quite consistent with similar measurements in chambers of larger dimensions.

In addition one would also expect a second and smaller effect, a very slow diminution of W with increasing pressure, since the pattern of the paths of beta particles, Fig. 1 of J and S, shrinks. Thus fewer and fewer particles can reach the annular ring either directly, as with particle A in Fig. 1 of J and S, or by backscattering as with particles B and D. The last two particles, of course, with sufficiently high pressure will pass through the sample film and thus lose no appreciable energy.

It is unfortunate that this slower decline in W values is to a large extent obscured in Fig. 2 by the superposed effect of the particles which strike the chamber wall. That such a decline exists is shown by a comparison of previously obtained W_β values for N_2 and C_2H_6 with the corresponding values at very high pressures in Fig. 2. The former values for a maximum pressure of 162 cm of mercury taken from Table II of J and S are, after correction for absorption in the film only, 36.5 and 25.3 ev/ion pair for N_2 and C_2H_6, respectively. Such values are indicated by short horizontal lines at 160 cm pressure in Fig. 2. These can be seen to be considerably above the values 34.9 and 24.5 ev/ion pair derived from the horizontal portion of the curves for N_2 and C_2H_6 in Fig. 2. The differences between these sets of values of 4.3 and 3.2% are in reasonable agreement with the corrections of 3.4 and 2.4% previously applied for the beta-ray energy intercepted by the annular ring mount in column 4 of Table III of J and S.

A calculation has been made to determine the order of magnitude of the residual energy lost by a beta particle, such as A in Fig. 1 of J and S, in striking the wall of the mount at the maximum pressure of 600 cm

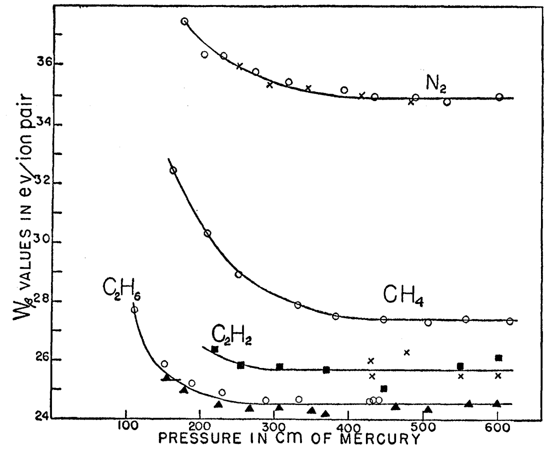

FIG. 2. Measured values of W_β in ev/ion pair as a function of gas pressure. The two sets of experimental points on three of the curves represent the results of two different runs. Former values of W_β for N_2 and C_2H_6 are indicated by horizontal dashes at 160 cm pressure.

of mercury now used. To this end the curves of Fig. 3 of J and S are used, where the loss of ionization energy can be determined as a function of pressure, as the beta particles strike the walls of the much larger chamber employed in these previous experiments. The present pressure of 600 cm may be reduced to the corresponding pressure in Fig. 3 of J and S by multiplying by the ratio of the mean path length of particle A to the estimated mean path length of the particle in the J and S experiment from sample to chamber wall. For this derived pressure the residual beta-particle energy lost is then easily read from the curve of Fig. 3 of J and S.

Such considerations lead to the conclusion that at a pressure of 600 cm of mercury, particles such as A lose about 10% of their total energy to the wall of the mount for the gases N_2, C_2H_6, and C_2H_2 and about 22% for the gas CH_4, whose stopping power is much less. Since particles of path A constitute, from solid angle considerations, about 2% of the total beta particles emitted by the sample, the correction to the W_β values at 600 cm pressure would be about 0.2% for the three heavier gases and about 0.5% for CH_4. The effect of such corrections is indicated in column 3 of Table I, the uncorrected values being shown in column 2. To facilitate such a comparison, the W values are given to the second decimal place—a procedure probably unwarranted by the accuracy of the measurements. The correction is seen to be almost insignificant for the three heavier gases and very small for CH_4. For backscattered particles of longer paths, as for B and D of Fig. 1 of J and S, no significant loss of energy by striking the ring would be expected.

From each W_β value of column 3 of Table I, it is possible to derive an independent value for W_β for air, computed as in Table III, column 8 of J and S, by

TABLE I. Summary of W_β values in ev/ion pair.

Gas	W_β values from Fig. 2	W_β corrected for energy loss to mount	Corresponding value of W_β for air	Corrected W_β values J and S	Corresponding W_β for air J and S	W_β from relative measurements
N_2	34.9_3	34.8_6	33.8_6	35.3	34.3	35.0
C_2H_6	24.5_3	24.4_8	33.5_6	24.7	33.9	24.8
C_2H_2	25.7_0	25.6_5	33.6_7			25.9
CH_4	27.4_0	27.2_6	33.9_4			27.3
C_2H_4				26.2	34.0	26.2
Mean			33.7_6		34.0_5	

multiplying by the ratio $W_\beta(\text{air})/W_\beta(\text{gas})$. Such W values for air are listed in column 4.

For comparison with the results of the present experiment, similar values derived by the method of J and S are shown in columns 5 and 6. These are to be compared with the present values in columns 3 and 4, respectively. The agreement in general is good; the present method, however, gives slightly smaller values of W_β.

Experiments were also carried out with C_2H_4 by the present method. Here the horizontal portion of the curve gave an almost exact agreement with the corresponding value of 26.2 ev/ion pair in column 5. Following the horizontal portion, however, the curve, beginning at 450 cm of mercury and extending to 600 cm, showed a gradual rise of several percent in W value. It is possible that such a rise is due to a minute impurity in the gas which prevents complete saturation at the highest pressures, although increasing the field in the chamber by as much as 50% failed to increase the measured current. Because of this uncertainty the measurements in C_2H_4 have not been included in Table I.

In the final column of Table I are retabulated the mean W_β values from column 5 of Table I of J and S. These are derived from relative beta ionization measurements in different gases, with the assumption that in argon both W_β and W_α have the same value of 26.4 ev/ion pair. It may be noted again that such values agree well with the absolute W_β determinations, a strong argument for the correctness of the assumption that W_α and W_β are equal in argon

The results from the present experiment combined with the former results give values of W_β of 35.0 and 24.6 ev/ion pair for N_2 and C_2H_6, respectively. The mean of the seven derived values of W_β in air from columns 4 and 6 is 33.9 ev/ion pair. Again it may be noted that this is in very good agreement with the value 34.0 ev/ion pair derived from relative measurements. The estimated probable error for these results is of the order of one percent. It should be pointed out, however, that, while the present measurements tend to confirm the accuracy of the previous ionization measurements, they do not give any new information regarding the accuracy either in the counting of the samples or in the estimate of the average beta-ray energy in the S^{35} spectrum. In the estimate of the over-all error, it is therefore assumed that the errors in these last two procedures are within the limits already assumed.

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