Search for Long or Short-Lived Radio-Chlorine

Of the two radioactive isotopes one expects to form when chlorine is bombarded with deuterons or slow neutrons only one is known. The large capture cross section of chlorine for slow neutrons is not accompanied by a correspondingly intense radioactivity, and it appears probable that a radioactive isotope of chlorine is formed whose half-life is too long or too short to have permitted its detection. A search for a short-lived radioactive body has been carried out by looking for beta-particles in the radiation emitted by chlorine during an irradiation with slow neutrons. Neutrons from a radium-beryllium source passed in succession through 25 cm of lead, 5 cm of paraffin, 5 cm of lead, and a thin layer of C_2Cl_6, which is a conveniently handled compound of chlorine. Close to the C_2Cl_6 a steel thin-walled (0.10 g/cm²) Geiger-Müller counter was placed in such a manner that radiations from the C_2Cl_6 were readily detected, and tin absorbers placed between the C_2Cl_6 and the counter enabled one to distinguish rather sharply between gamma- and beta-rays. Curve 1 (Fig. 1) shows the absorption curve obtained. The slight rise above 100 percent found for small thicknesses of absorber is what one should expect from a thin source of gamma-rays unaccompanied by primary beta-particles. The absence of appreciable numbers of beta-particles indicates the absence of a short-lived beta-emitting radioactive isotope formed by the capture of slow neutrons in chlorine.

For comparison curves 2 and 3 show the results obtained when cadmium and mercury respectively were substituted for the C_2Cl_6. These show the presence of small amounts of some less penetrating component which is probably to be identified with electrons from internally converted gamma-rays. No detectable radioactivity was induced in any of the above substances under the conditions of these experiments. Curve 4 was obtained from a thin foil of silver which had reached radioactive equilibrium with the flux of slow neutrons passing through it. It shows clearly the difference in the type of absorption curve one may obtain when beta-rays as well as gamma-rays are emitted from the irradiated substance. Curve 5 is a conventional absorption curve for the beta+gamma-radiation from the well known 37-min. radio-chlorine (made in the Berkeley cyclotron). It was taken under the same geometrical conditions as the other curves in Fig. 1 and is presented merely to show that even energetic beta-rays (upper limit 6.1 Mev) are distinguishable from gamma-rays of the sort shown in curve 1.

A search for a long-lived radio-chlorine was made as follows. Sodium chloride was bombarded in the Berkeley cyclotron with 100 microampere hours of 5.7 Mev deuterons. An intensive chemical purification of the sample (with great care taken to remove sulfur, phosphorus, iron, lead, potassium and bromine) yielded a product with no detectable radioactivity as measured with an ordinary thin-walled counter nor when measured with an extremely sensitive screen-walled counter of the type described by Libby.[1] If the "missing" radioactive isotope of chlorine is a long-lived beta-emitter, the shortest lifetime consistent with these observations is about 200 years.[2] This calculation has been made by assuming (from analagous reactions

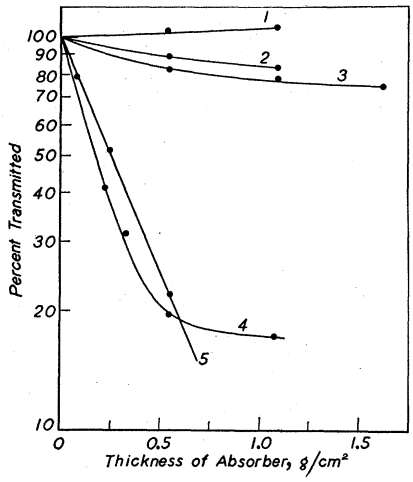

FIG. 1. Absorption of radiation emitted by slow neutron absorbers during irradiation with slow neutrons. Curve 1, C_2Cl_6 (0.14 g/cm²); 2, Cd (0.033 g/cm²); 3, Hg_2O (0.18 g/cm²); 4, Ag (0.037 g/cm²). Curve 5 is an ordinary absorption curve for the radiations from radio-chlorine (37 min. half-life) taken under the same geometrical conditions.

of 5.7 Mev deuterons on neighboring elements) a yield of 1 transmutation per 10^4 deuterons, and by using the first Sargent curve, somewhat extrapolated, to estimate the energy of the beta-rays expected.

It is also possible that Cl^{36} may disintegrate by K-electron capture to form the newly discovered isotope S^{36}.[3] If such is the case, it is possible that no easily detectable radiation would accompany the reaction since the $K\alpha$-radiation from sulfur has a wave-length of about 5.4A and hence lies almost in the so-called vacuum region. It is not necessary that gamma-radiation should be emitted in a K-electron capture since the resultant nucleus may be formed in its ground state. Whether the "missing" isotope of chlorine is very long-lived or indetectable because of K-electron capture is a question which cannot be decided from the present data.

I am greatly indebted to Professor E. O. Lawrence and to members of the staff of the Radiation Laboratory for the preparation of numerous radioactive samples used in these experiments.

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[1] Libby, Phys. Rev. **46**, 196 (1934).
[2] This surprisingly short minimum life arises from the fact that the beta-radiation assumed has an exceedingly short range in the body of the sample.
[3] Nier, Phys. Rev. **53**, 282 (1938).

The Present Status of the Value of e/m

In 1929, the best value of e/m, from spectroscopic measurements, appeared to be $(1.761\pm0.001)\times10^7$ abs. e.m.u.[1] The best value, from nonspectroscopic (deflection) measurements, was given as 1.769 ± 0.002. The discrepancy was thus nearly three times the sum of the assigned probable errors and appeared so serious that I retained the two separate values, instead of giving one most probable value.

During the years 1930–32 there appeared three new deflection values of e/m, and one new spectroscopic value. All four determinations were mutually consistent and apparently of high accuracy. From them I deduced[2] 1.759 ± 0.001 as the best value of e/m. In other words, the 1929 discrepancy had disappeared, and the error had been shown to lie in the 1929 deflection value.

In the succeeding two years three new values of e/m were obtained, all by chance being just 1.757, and in 1936 I gave[3] 1.75762 ± 0.00026 as the most probable value. It appears now that most of these new "low" values represented preliminary results only, and the final values now available are appreciably higher. In fact Dunnington,[4] in connection with his own beautiful work on e/m, gave 1.7584 ± 0.0003 as the most probable value. He found, however, that a discrepancy of 0.0016 still existed between the weighted averages of the spectroscopic and the deflection measurements, and this, although only one-fifth of the 1929 discrepancy, was still, as a result of the greatly increased accuracy of recent work, almost three times the sum of the assigned probable errors.

At the present time there are available ten precision values of e/m, six spectroscopic by four different methods, and four deflection by three different methods. I find that the discrepancy between the two types of experiment has now shrunk to 0.0006, *just the average deviation to be expected from the assigned probable errors*, and that the final weighted average is 1.75909 ± 0.00024 (external consistency).

To obtain these results I have recalculated each published value (with an occasional slight resulting change) in terms of the following set of auxiliary constants, *viz.*:[5] $c=299776\pm4$ km/sec., $q=0.99993$, $p=1.00048$, and (all on the *physical* scale) $F=9651.31\pm0.80$ abs. e.m.u., $H=1.00813$, $D=2.01473$, $He=4.00389$, $\bar{C}=12.0148$. Each result is weighted according to its probable error, and except as noted, the probable error adopted is just that assigned by the respective investigator. The data are (1 to 6 spectroscopic, 7 to 10 deflection)

(a) Separation of He and H lines
1. $1.7601_5\pm0.0008$[6]

(b) Separation of Hα and Dα lines
2. $1.7581_4\pm0.0004$[7]
3. $1.7579_3\pm0.0004$[8]
4. 1.7592 ± 0.0005[9]

(c) Refraction of x-rays
5. 1.7601 ± 0.0003[10]

(d) Zeeman effect
6. 1.7569 ± 0.0007[11]

(e) Direct velocity measurement
7. 1.7610 ± 0.0010[12]
8. 1.7588 ± 0.0009[13]

(f) Magnetic deflection
9. 1.7597 ± 0.0004[4]

(g) Crossed electric and magnetic fields
10. 1.7571 ± 0.0013[14]

The six spectroscopic results give a weighted average of 1.75895 ± 0.00033 (1.82),[15] the four nonspectroscopic results give 1.75955 ± 0.00033 (0.99), and all ten give 1.75909 ± 0.00024 (1.51) or, considered as the weighted average of the two groups, ±0.00017 (1.07). The nearness to unity of this last ratio, $R_e/R_i=1.07$, shows that the discrepancy between the two groups is just that of the average statistical fluctuation. However, the ratio 1.82 for the six spectroscopic results is unpleasantly large.

That the particular weighting adopted here is relatively unimportant is shown by the fact that the *unweighted* average is 1.75890. As the present most probable value of e/m I recommend $(1.7591\pm0.0003)\times10^7$ abs. e.m.u.

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[1] R. T. Birge, Rev. Mod. Phys. 1, 1 (1929).
[2] R. T. Birge, Phys. Rev. 42, 736 (1932).
[3] R. T. Birge, Nature 137, 187 (1936).
[4] F. G. Dunnington, Phys. Rev. 52, 475 (1937).
[5] See reference 1 for meaning of symbols.
[6] W. V. Houston, Phys. Rev. 30, 608 (1927).
[7] C. D. Shane and F. H. Spedding, Phys. Rev. 47, 33 (1935). The authors' probable error of 0.0003 has been raised to 0.0004, since their result is presumably no more accurate than the other two results by this method.
[8] R. C. Williams, Phys. Rev. 54, 568 (1938).
[9] W. V. Houston (private communication). This is his present, but not necessarily final result.
[10] J. A. Bearden, Phys. Rev. 54, 698 (1938).
[11] L. E. Kinsler and W. V. Houston, Phys. Rev. 46, 533 (1934).
[12] C. T. Perry and E. L. Chaffee, Phys. Rev. 36, 904 (1930).
[13] F. Kirchner, Ann. d. Physik 12, 503 (1932).
[14] A. E. Shaw, Phys. Rev. 54, 193 (1938). The auxiliary constants are not given, and the probable error is that of a least-squares solution, with no additional allowance for other sources of error.
[15] All probable errors are from external consistency, with the ratio of external to internal consistency following in parenthesis. Compare reference 4, page 500.

On the Instability of the Barytron and the Temperature Effect of Cosmic Rays

It is known that the mass absorption of penetrating cosmic rays in air is greater than in earth or water. This effect has been explained by Euler and Heisenberg[1] as due to the instability of the barytrons which form the main part of the penetrating component. These particles are supposed to have a mass M of the order of 150 times the electronic mass and to be of secondary origin. They are produced mainly in the higher levels of the atmosphere by some incident radiation, consisting possibly of electrons.

Following Yukawa, a barytron of energy γMc^2, where $\gamma>>1$, has a mean life $\tau=\gamma\tau_0$, where τ_0 is its mean life when at rest, and is of the order of 10^{-6} sec. In free space, a rapidly moving barytron will travel a mean range $L=c\tau$ before it disintegrates spontaneously into an electron and a neutrino. In dense materials ($\rho\gtrsim1$) the range as defined by the ionization is much less than L, so almost no barytrons decay spontaneously before they come to rest by ionization. But in gases ($\rho\lesssim10^{-3}$) the ionization range is of the order or greater than L, so many barytrons decay before being stopped by ionization, thus producing an apparent additional absorption. Euler and Heisenberg have shown by a detailed analysis that the observed mass absorption anomaly for air and water can be explained by assuming a value of τ_0 of 2.7×10^{-6} sec. The barytrons are supposed to be formed at the maximum of the transition curve, that is, for vertical rays, at a pressure of about 8 cm Hg, and so at a height of about 16 km.

It can easily be seen that the observed decrease of the cosmic-ray intensity with increasing atmospheric tempera-