

curve. At 100°K the hole concentration n_c is only one-tenth of the room temperature value; however, the absorption is increased. The absorption at the lower temperature must be, therefore, predominantly due to the ionization of the impurities, most of which are normally un-ionized at this temperature. On the other hand, the concentration of un-ionized impurities ($N-n_c$) available for absorption at room temperature is one-fourth of that at 100°K but the absorption is reduced only by about 20 percent. Evidently the absorption at room temperature is largely due to the free holes. Samples with flat Hall curves, indicating no change in n_c and ($N-n_c$), show a steady decrease in absorption with decreasing temperature,¹ which confirms the above explanation. Absorptions due to impurity centers introduced by nucleon bombardment have been reported⁵ earlier and will be discussed in a future communication.

* Work assisted by a Signal Corps contract. A preliminary report was presented at the American Physical Society Meeting of November 26, 1949.

¹ M. Becker and H. Y. Fan, *Phys. Rev.* **76**, 1531 (1949).

² R. de L. Kronig, *Proc. Roy. Soc.* **133**, 255 (1931); Y. Fujioka, *Zeits. f. Physik* **76**, 537 (1932).

³ We are indebted to Professor H. Fröhlich for discussions on this point.

⁴ J. F. Mullaney, *Phys. Rev.* **66**, 326 (1944).

⁵ Lark-Horowitz, Becker, Davis, and Fan, *Bull. Am. Phys. Soc.* **25**, No. 1, 29 (1950).

Masses of Cr⁵⁰, Cr⁵², and Fe⁵⁴ *

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A DOUBLE-FOCUSING mass spectrograph¹ has been used to photograph the doublets at mass number 25, 26, and 27 formed by doubly charged Cr⁵⁰, Cr⁵², Fe⁵⁴ and singly charged C₂H, C₂H₂, and C₂H₃. Typical C₂H₂-Cr⁵² and C₂H₃-Fe⁵⁴ doublets are shown in Fig. 1. The metallic ions were obtained from a high frequency spark between stainless steel electrodes. The method by which the hydrocarbon ions were obtained is described below.

Source of hydrocarbon lines.—The hydrocarbon ions used in the present work were secured in a most fortuitous manner. Faint lines at mass numbers 24, 25, 26, 27, 28, and 29 were observed in the course of other work, and were attributed to C₂, C₂H, C₂H₂, C₂H₃ coming from the silicone in the diffusion pumps. These lines were intensified by removing the liquid air trap from the source vacuum system, and thereafter provided accurate and easily obtained standard masses. In addition to the group mentioned, two other series of suitable intensity have been observed, namely C, CH, CH₂, and C₃, C₃H, C₃H₂. These hydrocarbon molecules are ionized in the same high frequency spark which creates the metallic ions.

Mass of Cr⁵⁰.—The C₂H-Cr⁵⁰ doublet at mass number 25 was photographed with an exposure time of ten minutes. From nine photographs of this doublet, the difference in packing fraction² between C₂H and Cr⁵⁰ was found to be $\Delta f = 14.26 \pm 0.03$, with extreme values of 14.09 and 14.43. The Cr⁵⁰-Cr⁵² separation, assumed to be integral, served as the mass scale. Using Bainbridge's³ recommended values of $H^1 = 1.0081283 \pm 0.0000028$ and $C^{12} = 12.003856 \pm 0.000019$, the packing fraction of C₂H is $f = 6.336 \pm 0.016$. This value, when combined with the above packing fraction difference, gives for Cr⁵⁰ $f = -7.92 \pm 0.04$. The only other measurement of the mass of Cr⁵⁰ has been made by Ogata,⁴ using six photographs of the C₂H₂-Cr⁵⁰ doublet, who found the packing fraction of Cr⁵⁰ to be $f = -7.11 \pm 0.08$. The present value of -7.92 ± 0.04 corresponds to a mass of Cr⁵⁰ = 49.96040 ± 0.00020.

Mass of Cr⁵².—The C₂H₂-Cr⁵² doublet at mass number 26 was photographed with an exposure time of five minutes. From 14 photographs of this doublet, the packing fraction difference was found to be $\Delta f = 17.41 \pm 0.025$ with extreme values of 17.22 and 17.62. The Cr⁵²-Cr⁵³ separation provided a suitable mass scale.

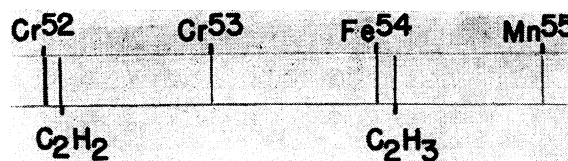


FIG. 1. Mass spectrum showing the doublets at mass numbers 26 and 27 formed by doubly charged Cr⁵², Fe⁵⁴ and singly charged C₂H₂, C₂H₃. Magnification 4 ×.

If the packing fraction of C₂H₂ is assumed to be $f = 9.218 \pm 0.017$,³ that of Cr⁵² is calculated to be $f = -8.19 \pm 0.04$. This is to be compared to Aston's value⁵ of -8.18 ± 0.15 and Ogata's⁴ value of -8.47 ± 0.08 . The mass of Cr⁵² is calculated from the present packing fraction value of -8.19 ± 0.04 to be 51.95741 ± 0.00021 .

Mass of Fe⁵⁴.—The exposure time for photographing the C₂H₃-Fe⁵⁴ doublet was also five minutes. Seventeen photographs of this doublet yielded a packing fraction difference $\Delta f = 19.91 \pm 0.04$, with extreme values of 19.52 and 20.17. The separation between Fe⁵⁴ and the overexposed Fe⁵⁶, assumed to be integral, served as the mass scale. With a packing fraction of C₂H₃ of 11.887 ± 0.018 ,³ that of Fe⁵⁴ is found to be -8.03 ± 0.05 . Dempster⁶ has measured this packing fraction to be -7.5 ± 0.8 while Ogata⁴ has obtained -7.83 ± 0.09 . The present value gives the mass of Fe⁵⁴ = 53.95664 ± 0.00027.

In these experiments care has been taken to minimize the effect on the doublet spacing (a) of retardation of the ions by residual gas in the mass spectrograph, as observed by Dempster and Shaw,⁷ and (b) of local inhomogeneities in the magnetic field. The first effect has been studied in this laboratory⁸ in connection with the Cu⁶⁵-Pt¹⁹⁵ doublet, and has been found in that case to be negligible at pressures less than 9×10^{-6} mm Hg. In the present experiments the pressure was kept less than 5×10^{-6} mm Hg. The second effect, due to local inhomogeneities in the magnetic field, or to local electric fields in the magnetic analyzer arising from charged dust particles on the magnet pole faces, was minimized by photographing the doublets in several different positions on the photographic plate. The errors given in this Letter are probable errors based on the internal consistency of the data.

The authors appreciate the technical assistance of Mr. Clifford Gieselbreth. They are also grateful to Professor Carl Stearns who has allowed them the use of the comparator in the Van Vleck Observatory.

* This letter is based on work done at Wesleyan University under Contract AT (30-1)-451 with the AEC.

¹ H. E. Duckworth, *Rev. Sci. Inst.* **21**, 54 (1950).

² The term "packing fraction" is defined as $f = (A - I)/I$, where A is the mass of the atom in question, and I is the nearest integer. In this letter the factor $\times 10^{-4}$ is to be understood and is not written in expressing the numerical value of the packing fraction.

³ K. T. Bainbridge, "Isotopic weights of the fundamental isotopes," Preliminary Report No. 1, National Research Council (June, 1948).

⁴ K. Ogata, *Phys. Rev.* **75**, 200 (1949).

⁵ F. W. Aston, *Nature* **141**, 1096 (1938).

⁶ A. J. Dempster, *Phys. Rev.* **53**, 64 (1938).

⁷ A. J. Dempster and A. E. Shaw, *Phys. Rev.* **77**, 746 (1950).

⁸ Duckworth, Johnson, Preston, and Woodcock, *Phys. Rev.* (to be published).

On the Disintegration Scheme of I¹³¹

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February 10, 1950

SEVERAL different decay schemes have been proposed¹⁻³ for the important radioisotope I¹³¹. In particular, Metzger and Deutsch¹ and Kern *et al.*² have published substantially different experimental results for the energy of the soft beta-component. In view of the importance of this component in determining the decay scheme, it seems worth while to report our measurement of the I¹³¹ beta-spectrum.⁴

TABLE I. Comparison of recent data on I^{131} , including our hitherto unpublished results. Gamma-intensities are given relative to that of the 364-keV gamma-ray arbitrarily taken as 100. Figures in parentheses were obtained from an assumed decay scheme, except for order of magnitude.

β -rays	Metzger and Deutsch ^a	Owen <i>et al.</i> ^b	Lind <i>et al.</i> ^c	Moe <i>et al.</i> ^d	Cork <i>et al.</i> ^e	Kern <i>et al.</i> ^f	Our values ^g
1. Energy (keV)	315 \pm 20	—	—	—	(259)	250 \pm 30	306 \pm 15
Intensity (%)	15	—	—	—	—	14	\sim 20
2. Energy (keV)	600 \pm 5	597 \pm 5	—	—	(600)	605 \pm 5	606 \pm 5
Intensity (%)	85	—	—	—	—	86	\sim 80
γ -rays							
1. Energy (keV)	80 \pm 1	83 \pm 2	80.133 \pm 0.005	—	80.1	80 \pm 2	80
Intensity	(7.6)	—	(8.7)	—	—	(22)	—
2. Energy (keV)	—	163 \pm 3	—	159	163.6	163	—
3. Energy (keV)	—	—	—	—	177.0	—	—
4. Energy (keV)	—	—	—	208(?)	—	—	—
5. Energy (keV)	283 \pm 3	286 \pm 6	284.13 \pm 0.1	284	284.1	282 \pm 1	284
Intensity	7.6	—	8.7	—	—	4.5	\sim 9
6. Energy (keV)	363 \pm 3	368 \pm 7	364.18 \pm 0.1	364	364.2	363 \pm 2	364
Intensity	100	—	100	—	—	100	100
7. Energy (keV)	638 \pm 5	—	—	638	(625)	637 \pm 2	639 \pm 4
Intensity	19	—	—	—	—	17	\sim 13

^a See reference 1.

^b Owen, Moe, and Cook, Phys. Rev. **74**, 1879 (1948).

^c Lind, Brown, Klein, Muller, and DuMond, Phys. Rev. **75**, 1544 (1949).

^d Moe, Owen, and Cook, Phys. Rev. **75**, 1270 (1949).

^e See reference 2.

^f See reference 3.

^g The calibration of our spectrometer was checked against the accurate values of Lind *et al.* (reference c) for the 80-, 284-, and 364-keV γ -energies.

Figure 1 shows a Fermi plot of our beta-spectrum. The principal component is seen to have an end point at 606 \pm 5 keV, and the soft component at 306 \pm 15 keV. The latter value agrees within the limits of experimental error with that of Metzger and Deutsch, but cannot be easily reconciled with that of Kern *et al.*

The source^g used was deposited on a 1.7 mg/cm² Al backing in the form of AgI with an average surface density of 0.5 mg/cm², and the counter window thickness was 1.0 mg/cm² mica. Our previous experience indicates that under these conditions the shape of the beta-spectrum is not appreciably affected above about 100 keV. The Fermi plot of the soft component was obtained using only points between 100 and 240 keV, since internal conversion lines distort the spectrum above 240 keV.

Table I summarizes the results of recent measurements on I^{131} by various authors, including our hitherto unpublished results. The 163-keV gamma-ray reported by several investigators has been identified as due to a 12-day isomer of Xe^{131} produced in about one percent of the I^{131} decay transitions.⁶ It may be pointed out that the thicker the beta-source used the more likely it is that this radioactive Xe^{131} gas will be trapped in the source and its radiation observed.

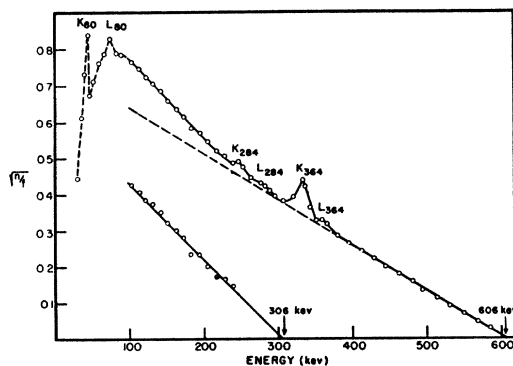


FIG. 1. Fermi plot of I^{131} beta-spectrum. The original relativistic Fermi function $f(Z, \eta)$ was used in making this plot.

On comparing the various decay schemes that have been proposed, our results tend to support that of Metzger and Deutsch. Further information of great value in deciding between these schemes would be a more accurate determination of the intensity of the 80-keV gamma-ray than has thus far been made.

We are indebted to the NBS Computation Laboratory for evaluation of the relativistic Fermi function $f(Z, \eta)$. This work was assisted by the AEC.

¹ F. Metzger and M. Deutsch, Phys. Rev. **74**, 1640 (1948).

² Cork, Keller, Sazynski, Rutledge, and Stoddard, Phys. Rev. **75**, 1621 (1949).

³ Kern, Mitchell, and Zaffarano, Phys. Rev. **76**, 94 (1949).

⁴ This investigation was carried out in the summer of 1948, and included a study of both beta- and gamma-spectra as well as beta-gamma- and gamma-gamma-coincidence absorption measurements. Publication was withheld, however, in the hope of determining the critical intensity of the 80-keV gamma-rays and the origin of the gamma-gamma-coincidences observed.

⁵ The I^{131} used in this investigation was obtained from the Oak Ridge National Laboratory.

⁶ Brosi, DeWitt, and Zeldes, Phys. Rev. **75**, 1615 (1949).

The Scattering of Electrons by Hydrogen Atoms

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IN a recent paper Hsuang¹ has applied a variational method to investigate the scattering of slow electrons by hydrogen atoms. His method does not allow for exchange effects. In the course of a systematic study of the usefulness of variational methods in atomic collision problems we have applied Hulthén's variational method² to the hydrogen atom. The trial wave functions we have used are, in atomic units, of the form

$$\psi(r_1, r_2) = \exp(-r_1)f(r_2, r_{12}) \pm \exp(-r_2)f(r_1, r_{12}), \quad (1)$$

where

$$r_2 f(r_2, r_{12}) = \sin kr_2 + \{a + \exp(-r_2)(b + cr_{12})\} (1 - \exp(-r_2) \cos kr_2).$$

Here r_1 , r_2 , and r_{12} are the distances of the electrons from the nucleus and from each other, respectively, k is $2\pi mva_0/h$, and v the velocity of the incident electron. The second term of (1) allows for electron exchange, the \pm signs corresponding to the cases in which the spins of the atomic and incident electrons are antiparallel and parallel, respectively. Except for the exchange terms the trial function is exactly the same as that used by Hsuang in his method which is, however, not the same as that of Hulthén which we have employed. The term involving r_{12} allows for polarization of the atom by the incident electron, and the possibility of introducing such allowance is an important feature of the variation method.

We have, so far, determined the zero-order phase angle $\eta_0 (= \tan^{-1}a)$, for the following cases (a) exchange neglected, no polarization correction (i.e., $c=0$), (b) exchange neglected, polarization correction included (i.e., c included as a variable parameter), (c) exchange included, no polarization correction (i.e., $c=0$), (d) exchange included, polarization correction included but $b=0$.

Cases (a) and (b) correspond to the cases considered by Hsuang. In general we reproduce his results in that η_0 tends to π as k tends to 0 in case (b), whereas in case (a) it tends to 0. On the other hand, our values of η_0 tend in both cases, as k increases, to those calculated by Macdougall³ by numerical integration of the differential equation for the motion of electrons in the static field of a hydrogen atom.

The results for case (c) may be compared directly with those obtained by Morse and Allis⁴ by exact numerical solution of the integro-differential equations which can be set up when polarization is ignored. Good agreement is found.

Finally, in case (d) the effect of including polarization in addition to exchange is found to be much less noticeable than when