of sulphur can be classified crudely as belonging to $3s$ and $3p$ bands, then the L-emission spectrum should divide itself into two parts corresponding to the electron transitions

$$3s \rightarrow L_{II,III}$$
$$3p \rightarrow L_{II,III}.$$

The main contribution to the band (peak at 149 ev) is to be ascribed to the first of these; while the structure at 158 ev may perhaps be associated with the second transition which should be relatively weak since it is nearly forbidden. The $3s$–$3p$ interval (9 ev) as deduced by this procedure is not in contradiction with the value estimated from x-ray and optical data.

The broad peak at 136 ev may perhaps arise from a "semi-Auger" process[4] in which a $3s$ electron falls into the ionized L shell and a second $3s$ electron is excited into an unoccupied level. In this process a photon is emitted of which the energy is less than the energy loss of the first electron. Such a process would demand that the interval between the main peak and the broad peak be larger than that $3s$–$3p$ interval, and indeed such is the case (13 *vs.* 9 ev).

The authors wish to acknowledge their gratitude to Professor Frederick Seitz of the University of Pennsylvania and to Professor H. Bethe of Cornell University for helpful discussions in connection with this investigation.

OCTOBER 15, 1941 PHYSICAL REVIEW VOLUME 60

The Half-Life of Iodine (128)

D. E. HULL AND HERMAN SEELIG*

School of Chemistry, University of Minnesota, Minneapolis, Minnesota

(Received August 29, 1941)

The half-life of iodine (128) has been measured with high accuracy by means of a G-M counter and amplifying circuit of tested reliability. An absolute calibration of the counter was carried out by a simple method. The half-life was determined from the data by an arithmetical, rather than a graphical method. The results of four closely concordant experiments give for the best value of the half-life, $T = 24.99 \pm 0.02$ minutes. It is suggested that this radio-element can now be used in a quick and convenient calibration of counters or other instruments for measurement of radioactivity.

IN some current experimental work by the writers it has become necessary to know the half-life of iodine (128) with greater accuracy than is characteristic of the values now in the literature. Although this radio-element was among the first discovered by Fermi in his fundamental research on the production of artificial radioactivity by neutron bombardment, and it has been used and studied by researchers too numerous to list here, yet its half-life has not been determined with an accuracy much better than 5 percent. Probably the best value is that given by Livingood and Seaborg,[1] namely, 25 ± 1 min. Of course, this situation is not unique with radio-iodine. The half-lives of very few radio-elements are known with an accuracy better than a few percent. Notable exceptions are the values for radon, determined independently by investigators in two laboratories with excellent agreement;[2,3] for phosphorus[4] (32), and for carbon[5] (11).

Since there is available in this laboratory a G-M counter and amplifier with a known reliability of about 0.2 percent in relative measurements, an attempt has been made to determine the half-life of radio-iodine with an accuracy of this order. The radio-iodine was prepared by slow neutron bombardment of phenyl iodide, concen-

* Now with the duPont Company, Wilmington, Delaware.

[1] J. J. Livingood and G. T. Seaborg, Phys. Rev. **54**, 775 (1938).

[2] W. Bothe, Zeits. f. Physik **16**, 266 (1923).

[3] I. Curie and C. Chamié, J. de phys. et rad. [6] **5**, 238 (1924).

[4] N. B. Cacciapuoti, Nuovo Cimento **15**, 213 (1938).

[5] A. K. Solomon, Phys. Rev. **60**, 279 (1941).

TABLE I. *Half-life of iodine* (128).

Exp. 1	25.01±0.04 min.
2	25.03±0.04
3	24.97±0.04
4	24.97±0.03
Average	24.99±0.02 min.

trated by extraction with aqueous sodium iodide, and precipitated as silver iodide. The precipitate was filtered by suction in a Buchner funnel, was washed and dried with alcohol and ether, and was coated with a thin layer of cellulose nitrate formed from a dilute acetone solution by evaporation. The filter paper was then wrapped snugly around the counter and held firmly in place with rubber bands. Since the radioactive sample was thus held in a fixed position for the duration of the measurements, all corrections for absorption in the precipitate and counter wall and for geometry of the source could be ignored.

The counter used in this work was one of the thin-walled glass type described in a previous paper by one of us.[6] Since the work reported in that paper, however, the counter has been filled with argon instead of air, to a pressure of 5 cm. This change has resulted in two definite advantages: First, the counting plateau has a much smaller slope, only 0.3 percent per volt in contrast with 2.7 percent found with air-filling. Second, the "warming-up" effect described previously is very largely, if not completely, eliminated. It is now possible to count at a rate of 100 per second for an interval long enough to reduce the error due to random distribution to 0.1 percent without any measurable increase in counting rate. The background rate of the counter has been found to be quite constant and reproducible within the random error of about 2 percent. It does not change while the counter is being used at high speeds. The amplifier is of the Neher-Harper type with a vacuum-tube scaling circuit transmitting every eighth pulse to the Cenco recorder.

The counter was calibrated by a modification of a method described by one of us,[6] which is applicable when the counting losses can be represented by the function

$$R/N=e^{-\tau R}. \qquad (1)$$

Two bulbs containing the radium D left from the decay of radon were used in the calibration. The first bulb was placed at a convenient distance and the counting rate determined with the desired accuracy. Then, with this bulb still in place, the second bulb was brought up to some point which gave a counting rate of approximately the desired value, and the rate with both in position was measured. Then the first bulb was removed without touching the second, and the rate due to the second alone was determined. No "standard" positions are involved in this method, and there is no question of replacing a radioactive sample so as to reproduce the geometry of a previous measurement. Finally, a measurement of the background rate was made. These four values were substituted in the equation given in the aforementioned paper,

$$\tfrac{1}{2}(R_p^3+R_q^3-R_s^3)\tau^2+(R_p^2+R_q^2-R_s^2)\tau+R_p+R_q-R_s-B=0 \qquad (2)$$

TABLE II. *Decay of iodine (128).*

TIME (MIN.)	OBSERVED RATE	CORRECTED FOR LOSSES	CORRECTED FOR BKG.
4	351.4	394.0	392.2
12	289.5	316.9	315.1
20	235.6	252.9	251.1
28	193.5	204.7	202.9
36	156.1	163.2	161.4
44	125.7	130.1	128.3
52	101.6	104.5	102.7
60	82.1	83.9	82.1
68	66.1	67.3	65.5
76	53.6	54.4	52.6
84	42.9	43.4	41.6
92	35.4	35.7	33.9
100	28.4	28.6	26.8
108	23.2	23.3	21.5
116	19.3	19.4	17.6
124	15.7	15.8	14.0
132	12.7		10.9
140	10.60		8.84
148	8.81		7.05
156	7.48		5.72
164	6.32		4.56
172	5.54		3.78
180	4.64		2.88
188	4.15		2.39
196	3.62		1.86
204	3.32		1.56
Bkg.	1.76		

$$S_1=1879.6-22.9=1856.7$$
$$S_2=125.7-22.9=102.8$$

$$T=\frac{0.3010\times 104}{\log\dfrac{1856.7}{102.8}}=24.91\text{ min.}$$

Corrected for stopwatch error, $T=24.91\times 1.0025$
$=24.97$ min.

[6] D. E. Hull, Rev. Sci. Inst. **11**, 404 (1940).

and the corresponding value of τ, the recovery time constant, was calculated.

The following values of τ were obtained at different total counting speeds as indicated:

R_s	τ in microseconds
77	990 ± 130
108	980 ± 120
156	950 ± 60
Weighted av.	960 ± 50

The observed constancy justifies the assumption made that the counting losses can be represented by a simple exponential function.

Three different samples of radio-iodine were measured on this counter. The recorder dial was read at regular intervals while the counter operated continuously from an initial rate of 180 per second down to 10 per second. From these readings the average counting rate during each interval was computed. These observed rates were corrected for counting losses by Eq. (1). The list of corrected counting rates was divided into two halves at the midtime t, and the summation of each part was taken. The background contribution was deducted from each of these, and then the half-life was calculated by the equation

$$T = \frac{0.3010\, t}{\log(S_1/S_2)} \qquad (3)$$

where t is the duration of time for each half of the measurements, S_1 is the sum of the corrected rates found for the first half of the intervals measured, and S_2 is the corresponding figure for the second half. The values of the half-life thus obtained, together with the probable error in each calculated from the number of counts, are listed in Table I.

A fourth sample was measured on a different counter and amplifier with a scale of 64. The calibration of this circuit gave a much smaller τ, but one which was not exactly constant. The value of τ as a function of counting speed on this circuit was found to be represented by the expression

$$\tau = 250 + 0.22R \text{ (in microseconds)} \qquad (4)$$

for rates up to 400 per sec. The activity of the iodine measured on this counter was followed

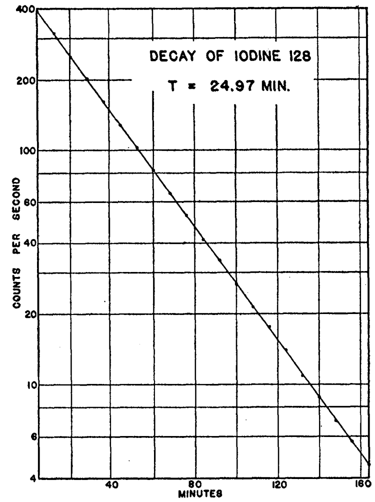

FIG. 1. Sample of data on decay of I^{128}. Corrections for background and losses have been made.

from 400 down to 2 counts per sec., covering a period of eight half-lives. The value obtained in this experiment is given last in Table I.

Table II gives the experimental data obtained in this last experiment. In the second column are the observed average counting rates during successive eight-minute intervals. In the next column are shown the rates corrected for counting losses according to Eqs. (1) and (4). The last column shows the measurements corrected for background. A logarithmic plot of the figures in the last column is shown in Fig. 1. The stopwatch used in this experiment ran 0.25 percent slow as compared with an electric clock, so the value of T is finally corrected for this.

It may be pointed out that the accurate knowledge of the half-life of a commonly available radio-element, such as iodine (128), will be useful to many who are using radio-elements in various applications, because a counter or other measuring instrument can be very simply calibrated with sufficient accuracy for most purposes by following the decay of radio-iodine over the useful range of the instrument, plotting the data thus obtained on the usual logarithmic scale, and then drawing a line with slope corresponding to $T = 24.99$ min. asymptotic to the curve at low counting speeds. The deviation of the observed curve from the theoretical line at any given higher rate shows the correction to be applied to other measurements made at that rate.