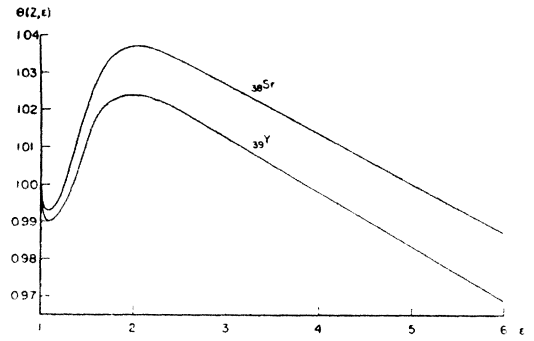

FIG. 1. $\theta(Z, \epsilon)$ for Sr and Y.

measured with a General Electric flux meter, tested for linearity and calibrated absolutely to within one percent with the annihilation radiation from Cu^{64} positrons.

Kurie plots[5] of the beta-spectra gave 2.35 ± 0.03 Mev for the Y^{90} end point and 0.61 ± 0.01 for the Sr^{90} end point.

The Kurie plots of the beta-spectra of Sr^{90}(25 Y) and Y^{90}(60 H) permit also an interesting comparison of the total beta-intensities by means of the Fermi theory of beta-decay.[6] This comparison is independent of the measurement of the low energy part (<0.2 Mev) of the beta-spectra.

Bleuler and Zünti[7] have been written the Fermi equation for allowed beta-decay in the convenient form,

$$N(\epsilon) \cdot d\epsilon = C(Z) \cdot \theta(Z, \epsilon) \cdot \epsilon^2(\epsilon_0 - \epsilon)^2 \cdot d\epsilon, \qquad (1)$$

where ϵ is the total energy of an electron in units of its rest mass, ϵ_0 the total beta-end-point energy, and Z the charge of the decaying nucleus. $C(Z)$ depends only on Z and contains the (energy independent) electron-nucleon interaction constant and matrix element. $\theta(Z, \epsilon)$ for Sr and Y is shown in Fig. 1. Since for these elements it is equal to unity within a few percent, it may be replaced by an estimated average, θ_{Av}, and Eq. (1) can be integrated directly to get the total intensity of each beta-spectrum. Now, by making a Kurie plot, i.e., by plotting the quantity $(1/H)(n/\theta(Z, \epsilon) \cdot \epsilon)^{\frac{1}{2}}$ against ϵ, where H is the magnetic field which focuses electrons of energy ϵ and n is the corresponding counting rate of the detector, it can be shown that the intensity of a beta-spectrum may be written

$$I = (K/(\epsilon_0 - 1))^2 \cdot \theta_{Av} \cdot (\epsilon_0^5/30 - \epsilon_0^3/3 + \epsilon_0/2 - 1/5), \qquad (2)$$

where K is the intercept of the Kurie plot on the $\epsilon = 1$ axis. A constant factor has been omitted in Eq. (2).

Figure 2 shows a typical Kurie plot of Sr^{90} and Y^{90} in secular equilibrium; the Sr^{90} plot (reduced scale) was obtained assuming the Y^{90} Kurie plot to be a straight line.

TABLE I. Values of quantities appearing in Eq. (2) for Sr^{90} and Y^{90}.

	Beta-end point ϵ_0	Kurie intercept $K \cdot 100$	θ_{Av}	Intensity $I \cdot 100$	Intensity ratio
Sr^{90}	2.19 ± 0.01	28.0 ± 0.5	1.015	5.4 ± 0.2	1.04 ± 0.10
Y^{90}	5.60 ± 0.02	7.9 ± 0.2	1.005	5.2 ± 0.4	

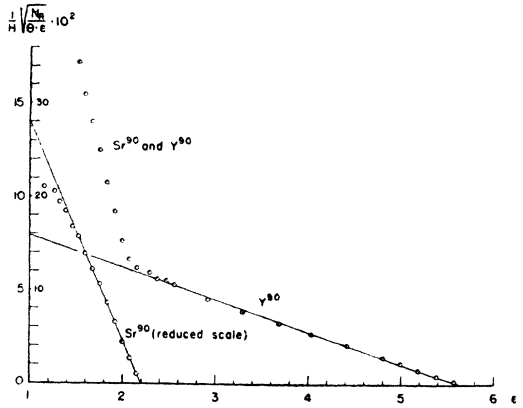

FIG. 2. Kurie plot for Sr^{90} and Y^{90}.

In Table I the values of the various quantities appearing in Eq. (2) are given for Sr^{90} and Y^{90}. Errors were estimated from the extreme ways in which straight lines could be drawn through the experimental points.

Since the Sr^{90} and Y^{90} are in secular equilibrium and since the beta-spectra are simple,[8] the intensity ratio is actually equal to unity. The calculated intensity ratio will only be equal to unity if the Fermi equation, Eq. (1), is correct at all energies. The large experimental error in the above-calculated intensity ratio, which could be reduced by the use of a better spectrometer, permits only the estimation that any deviations from the Fermi equation[9] in Sr^{90} and Y^{90} affect probably less than 1/10 of the electrons.

It is a pleasure to thank Professor C. W. Sherwin and Professor M. Goldhaber for encouragement and advice in this work. This research was supported in part by contract N6-ori-71 between the University of Illinois and the Office of Naval Research. The radioactive isotopes were obtained from the Atomic Energy Commission, Oak Ridge, Tennessee.

[1] Y^{90}: 2.2 (spectr.), 2.45 (abs. Al, Feather plot), 2.55 (abs. Al), 2.6 Mev (cloud ch.), Plutonium Project, Rev. Mod. Phys. **18**, 513 (1946); 2.1 Mev, W. Bothe, Zeits. f. Naturforschung **1**, 179 (1946).
[2] Sr^{90}: 0.6 Mev (abs. Al, Feather plot), Plutonium Project, Rev. Mod. Phys. **18**, 513 (1946).
[3] G. J. Neary, Proc. Roy. Soc. **A175**, 71 (1940).
[4] The author is greatly indebted to Mr. N. Goldstein for the manufacture of these counters.
[5] F. N. D. Kurie, J. R. Richardson, and H. C. Paxton, Phys. Rev. **49**, 368 (1936).
[6] E. Fermi, Zeits. f. Physik **88**, 161 (1934).
[7] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 375 (1946).
[8] Plutonium Project, Rev. Mod. Phys. **18**, 513 (1946).
[9] See, e.g., C. S. Cook and L. M. Langer, Phys. Rev. **73**, 601; **74**, 227 (1948).

A Time-of-Flight Mass Spectrometer*

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AMONG the various existing and proposed designs for mass spectrometers I have not found any that make use of the constancy of the time of flight in a magnetic

field. If an ion is released in a homogeneous magnetic field, it describes a helical path. The angular velocity of the helical motion is *independent* of the velocity of the ion and of the direction in which it is released. The time T for a complete revolution is, in round numbers,

$$T=670\ M/H \text{ microseconds.}$$

M is the mass of the ion in atomic weight units and H the field in gauss. For multiple ionization the time of flight is proportionally shorter. For an atomic weight around 150 a field of 100 gauss gives a time of flight of about 1000 microseconds. With a pulsed ion source it should not be too hard to measure this time to about 1/10th of a microsecond. The time interval between different masses is about 7 microseconds per mass unit. If one collects the ions after several revolutions, these time intervals are longer in proportion and a higher accuracy can be obtained.

It is noteworthy that the time of flight increases with the mass M. This means higher relative precision for heavier atoms, for which the methods used so far decrease in accuracy.

Though the time of flight is independent of the velocity of the ions, the dimensions of the apparatus set an upper limit to their speed. For single ions with an energy of V electron volts, the radius R of the helical path is approximately

$$R=145(VM)^{\frac{1}{2}}/H \text{ centimeter.}$$

For a practicable value of R it is necessary to use slow or decelerated ions of less than 100 ev. For multiple ions the radius decreases with the square root of the state of ionization. Too large a value of R may require too high a vacuum.

In addition to the constant time of flight, the helical orbits have a very advantageous focusing property after each complete revolution. All ions from a point source form, after every 360°, a sharp focal line through the source and along the direction of the field. The ion collector can be placed above or below the source, assuming the field H to be vertical. It is intended that the spacing between source and collector can be made large enough to allow the collection of ions which have made several revolutions. A vertical collimation of the ion beam and a controllable vertical deflecting field near the source may give the helical path just the proper pitch.

In the horizontal direction a wide angle can be tolerated, limited only by the dimensions of the magnetic field and its homogeneity. If the radius of the field is R_0 and the radius of the ion path is R, the horizontal half-width of the beam can be $(R_0-R)/R$ radians. Ions outside this angle will hit the wall. Of the magnetic field, only a ring of width $2(R_0-R)$ is used.[1]

The astigmatic focusing in the magnetic field causes the intensity of the various "orders" to go down only with the inverse first power of the number of revolutions. Moreover, the source of ions does not need to be a point. It can be a slit, vertical or horizontal, or an area of arbitrary shape. It is limited mainly by practical geometrical considerations such as difficulty in alignment of the collector, spacing of source and collector, or pulsing or collimating problems. A possible method of pulsing may be to sweep the beam across a slit by means of a modulated or pulsed deflecting field.[2]

Though the actual experiment will present many obstacles, the method described here is so flexible that one expects that such difficulties can be overcome without too much trouble. Moreover, it offers possibilities of expansion which may considerably increase the obtainable precision for measuring masses of heavy atoms. It may be very hard to use this method for absolute measurements. Relative measurements of greatly different masses may not be easy either, because their paths in the field can be very different. For relative masses of heavy elements the time-of-flight method looks most promising. Only after we have finished preliminary experiments, which are now being set up in the simplest possible way, shall we know with some certainty what the limitations of the proposed technique are.

* Research work done at Brookhaven National Laboratory under the auspices of the Atomic Energy Commission.

[1] The focusing at 180° is of no use for our purpose. This is only a focusing in space and not in time.

[2] The picture so far is that of a beam of slow ions describing a helix for which the pitch is much smaller than the radius. For fast ions it may be necessary to have them describe a helix with a pitch much larger than the radius. The field inside a long solenoid or inside a ring solenoid may be suitable for such a case. If, however, the method turns out to be worth while at all, the best way to handle faster ions is most likely the construction of an apparatus with a large radius.

The Abundance and Temperature of Methane in the Earth's Atmosphere

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THE presence of methane in the earth's atmosphere has now been definitely established on the basis of recent spectroscopic evidence.[1] From an analysis of equivalent widths of the lines of the P and R branches of the $2\nu_3$ band at 1.666μ, the writers have obtained estimates both of the abundance of methane and of its temperature in the earth's atmosphere.

The equivalent width of an unsaturated absorption line depends linearly on the number of molecules per unit cross section of the absorbing column, on the theoretical strength, and on the Boltzmann factor. If the theoretical line strengths were accurately known, this relationship could be employed to calculate both the abundance and the temperature from the observed line intensities. In the absence of accurate theoretical strengths, we have compared the atmospheric methane intensities with those produced in the laboratory by the use of an incandescent lamp as a source, together with an absorption cell containing a known quantity of methane at a 25-cm pressure and room temperature.

The mass abundance of methane turns out to be 1.2 parts in a million of the earth's atmosphere. The average temperature of the atmospheric column in which the methane absorption took place is −37°C. The observations