

by Bohr and Wheeler are inadequate to treat such large deformations and while their activation energy curve is not justified by their calculations, it can be regarded as a reasonable interpolation between the computed results for small deformations and the experimental results for uranium. Further calculations were made by Present and Knipp² who extended the potential energy series to higher order terms in a_2 and a_4 and included the coupling terms between even and odd harmonics in order to see whether the observed asymmetry of fission could be explained in this way. The series was extended to terms as high as a_2^8 , $a_2^4 a_4$ and $a_2^3 a_4^2$ without yielding satisfactory convergence for the large values of a_2 at which the saddle point of the energy surface is located in the case of uranium fission. The use of ellipsoidal coordinates was found to offer no appreciable advantage.

Since the values of a_2 alone are large in the initial stages of fission (because of an accurate representation of the deforming drop by $P_2(\cos \theta)$ alone), it was decided to carry out computations for fixed values of a_2 expanding in terms of a_4 . Separate calculations were made for $a_2=0.3$ and 0.4 which are partly beyond the range of validity of the earlier power series calculation. The method broke down for larger values of a_2 because of convergence difficulties with the Coulomb series for the coefficient of a_4^2 . The results for the deformation $a_2=0.4$ make possible a determination of the activation energy and the saddle point deformation parameters for a nucleus with $x=0.80$ (where x represents half the ratio of the electrostatic energy of the undeformed drop to its surface energy). It will be recalled that if $x \geq 1$ the drop is unstable against small second harmonic deformations and divides spontaneously. The new results which hold for $x \geq 0.80$ can be extrapolated to the uranium isotopes ($x \approx 0.75$) and indicate an activation energy of about 5 or 6 Mev in agreement with experiment. Coupling terms with the sixth harmonic were included in the calculation, and the effect of a_6 was sufficiently small that a_8 and higher even harmonics could be neglected.

The above calculations, with even harmonics only, correspond to a symmetric fission. The primary odd harmonics a_1 and a_3 were next introduced in all possible low coupling terms with a_2 up to fifth order (e.g., $a_2^3 a_1^2$, $a_2^3 a_1 a_3$, $a_2^3 a_3^2$). The introduction of these terms raises the energy and their positive contribution increases with increasing a_2 . The series ceases to be accurate at about $a_2=0.3$ but the uncertainties do not become large enough to affect the sign of the energy until $a_2 \geq 0.4$. It is concluded that the critical shape of a nucleus with $x \geq 0.80$ is symmetrical according to the liquid drop model. However, the possibility is not excluded that for some large deformation beyond the critical shape, the contribution of the odd harmonics may change sign and the fission path deviate from symmetry. Since the cases of uranium and plutonium fission lie so close to $x=0.80$, it is highly probable that the critical shape of these nuclei is symmetrical on the liquid drop model. This justifies the calculation of the preceding paragraph in which the activation energy is obtained from even harmonics alone.

An attempt has also been made to calculate the life-

time against spontaneous fission from the Gamow formula. The multiple integral over the coordinates of all nuclear particles is transformed into an integral with respect to the deformation parameters a_n . The Jacobian of this transformation is evaluated from the velocity potential for a streamline motion of the nuclear particles. The results are at variance with experiment in predicting too short a lifetime for U^{235} .

We hope to publish a fuller account of these calculations within the near future.

* This work was begun in 1940 and completed in 1943. It was voluntarily withheld from publication until the end of the war.

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¹ N. Bohr and J. A. Wheeler, Phys. Rev. 56, 426 (1939).

² R. D. Present and J. K. Knipp, Phys. Rev. 57, 751, 1188 (1940).

Water Spectrum Near One-Centimeter Wave-Length

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BECKER and Autler¹ and Kyhl, Dicke, and Beringer² have measured the H_2O ($5_{-1}-6_{-6}$) line at 1.35-cm wave-length for mixtures of water in air at atmospheric pressure. Under these conditions the line is many thousands of megacycles wide. Using a technique described earlier³ of sweeping an oscillator in frequency across the line, this line has been detected and measured in pure water vapor at pressures near one-tenth mm Hg. It is a few megacycles wide at this pressure and its frequency may be measured with great accuracy.

Equal quantities of H_2O and D_2O were mixed in order to obtain a vapor with 50 percent HDO molecules, and to look for the several HDO lines predicted near 1-centimeter wave-length by Hainer, King, and Cross.⁴ A search was made between 22,100 and 25,400 megacycles frequency. One line was found. Data on this and the H_2O line are given in Table I.

Becker and Autler did not measure the half-widths of the H_2O line in pure water vapor, but it may be deduced from their measurements in air at high and low water concentrations. Likewise the intensities quoted for them are not their actual measurements, but their intensities reduced to allow for the half-widths measured in pure vapor at low pressure. The half-widths and intensities given for HDO are for a mixture of 50 percent HDO, 25 percent D_2O , and 25 percent H_2O . Agreement between the data of Becker and Autler and measurements at low pressure ap-

TABLE I.

	Frequency (megacycles) Becker and Autler	Present measurement	Maximum intensity Becker and Autler	(neper/cm) Present measurement
H_2O		22,237 \pm 5		4 \pm 2 $\times 10^{-6}$
HDO	22,320 \pm 150	22,309 \pm 5	5.7 $\times 10^{-6}$	15 \pm 7 $\times 10^{-6}$
	Half-width at half- maximum (megacycles)	Pres- sure (mm Hg)	Half-width at half-maximum for 760 mm pressure Predicted from Becker and Autler	(megacycles) Predicted from present meas.
H_2O	1.45	0.103	11,600 \pm 6000	10,700 \pm 200
HDO	1.3	0.12		8,200 \pm 1500

pears to be within the combined experimental errors in all cases.

The agreement in frequency for the H_2O line at low and high pressures is surprisingly good. It means that at least for this case, the strong collision approximation of Van Vleck and Weisskopf⁵ must be rather good, and there can be very little frequency shift due to pressure as would otherwise be expected.⁶

Further effort will be made to obtain more accurate values for intensities and half-widths of these lines.

¹ S. H. Autler, G. E. Becker, and J. M. B. Kellogg, *Phys. Rev.* **69**, 694 (1946); G. E. Becker and S. H. Autler, *Phys. Rev.* **70**, 300 (1946).

² R. L. Kyhl, R. H. Dicke, and R. Beringer, *Phys. Rev.* **69**, 694 (1946).

³ C. H. Townes, *Phys. Rev.*, to be published.

⁴ R. M. Hainer, G. W. King and P. C. Cross, *Phys. Rev.* **70**, 108 (1946).

⁵ J. H. Van Vleck and V. F. Weisskopf, *Rev. Mod. Phys.* **17**, 227 (1945).

⁶ H. M. Foley, *Phys. Rev.* **69**, 616 (1946).

Effects of High Initial Energies on Mass Spectra

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IT has been pointed out that discrimination at the second slit of a mass spectrometer occurs as a result of initial thermal or dissociation energies.¹ We find that similar effects can also occur at the exit slit. The total effect of such discrimination is to reduce the number of ions of a given mass which are able to traverse the slit system. The efficiency of collection is found to be a function of V/V_T for any given geometry, where V is the accelerating voltage and V_T is the voltage equivalent corresponding to the apparent absolute temperature (including any dissociation energy) of the ion in question.

The fact that discrimination occurs provides a way of experimentally measuring rather small energies of dissociation. Figure 1 shows curves of relative abundance *vs.* ion

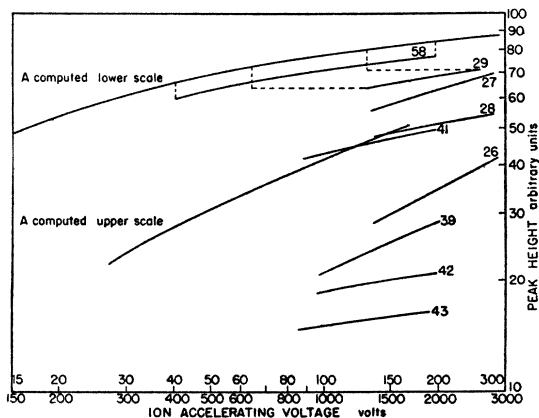


FIG. 1. Relative abundance of a number of ions from *n*-butane as a function of ion accelerating voltage.

TABLE I. Initial energies of several ions from *n*-butane.

Mass	Initial energy* ev	Abundance ratios		
		Magnetic scanning $V = 1400$ v	Electric scanning $B = 2200$ gauss	True abundance by extrapolation
26	2.4 ± 0.7	36	42	134
27	0.36 ± 0.6	235	267	367
28	0.12 ± 0.3	199	225	238
29	0.08 ± 0.01	270	303	302
39	0.83 ± 0.06	102	98	243
41	0.11 ± 0.01	192	200	378
42	0.085 ± 0.04	83	88	90
43	0.045 ± 0.005	660	699	665
58	0.041	100	100	100
58 sensitivity		81	73	100

* Includes thermal energy of 0.041 v corresponding to operating temperature of 475°K. Ionizing voltage = 50 v.

accelerating voltage for a number of ions obtained from *n*-butane. Curve *A* is a computed curve (derived in a manner similar to that of Coggeshall) which has been fitted to the experimental curve for the mass 58 ion, which we believe has only thermal energy. The computed curve is assumed to be a good extrapolation of the experimental curve both to low and to high voltages. To find the value of the initial energy of any ion, it is merely necessary to find the point on the voltage scale at which its curve fits the computed curve. The factor by which the voltage scale must be multiplied to accomplish this fit is the factor by which the temperature of the gas must be multiplied to give the apparent temperature of the ion. It should be noted that values obtained by this method do not take into account the true distribution of initial velocity, but rather assumes it to be Maxwellian. The amount of error from this source has not at this time been determined.

Table I shows the initial energies of several ions from *n*-butane. The spread of initial energy values indicated in Table I shows the range of values obtained in a single set of experiments. The spread could be reduced by using a greater range of voltages and by obtaining many experimental points on the curves. The absolute accuracy of the method was established for one case by obtaining the mass 58 curve at two temperatures. The two temperatures were 473°K and 550°K as measured by a thermocouple. The ratio of the temperatures as measured by the method described in this note was within ± 2 percent of the ratio determined by the thermocouple readings.

In a properly designed ion source the effects of motion of the electron beam due to changing either the electric field or the magnetic field are found to be negligible compared with the effects of initial energies. As a result of initial energies, neither electric field scanning nor magnetic field scanning can produce true abundance ratios. This is clear from a study of the curves of Fig. 1, and from reference to the last three columns of Table I, which show the ratios obtained by each type of scanning, and the estimated true abundance ratios obtained by extrapolating the curves of Fig. 1 to very high voltages. From this standpoint, the choice of type of scanning seems to be one of convenience.

¹ N. D. Coggeshall, *J. Chem. Phys.* **12**, 19-27 (1944).