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PRECISION MASS DETERMINATIONS WITH THE ELECTRIC MASS FILTER

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BY U. von ZAHN

With Four Figures In the Text
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Whereas today the masses of the light atoms are known to a very high degree of accuracy, the situation is less satisfactory in the region of heavy elements. Here the relative accuracy is less on an average $1:10^6$ -, and also the agreement between various authors is inadequate in part. It therefore seems worthwhile to repeat these measurements with a new method. Even if in the case of the mass filter the method of measuring is the same as those of the magnetic spectrometers, in so far as the mass determination rests on the comparison of the specific chargings e/m_1 and e/m_2 of two ionised atoms, the analysis field is, nonetheless, so different from the double focussing apparatus, that it can be regarded as an independent process. Therefore an electric mass filter was developed with the aim of carrying out mass determinations, especially in the region of the masses $A > 130$ with a relative accuracy of $1:10^6$ (if possible, even better). For comparison sample measurements were made on the Xenon-isotopes; here very exact measurements of the mass-ratios (10^{-8}) are available through Ries et al⁷.

I. THE MASS FILTER

Since the theory of the mass filter was first published by Paul and Steinwedel¹, the derivation of the motion equations for ions in the mass filter has been described many times in previous reports²⁻⁴. Likewise, expressions for the HF-capacity to be applied and the delay time necessary for the ions were given³ in the quadrupole field. In the following the notations of the report mentioned last are used; in particular U and V are the voltages of an electrode pair referred to earth, and the resolving dissolvent power $m/\Delta m$ is calculated from the width at half of maximum intensity Δm of a mass line m .

1. Construction of the mass filter

The original requirement of the device was to obtain a resolving dissolvent power of about 20,000. For this it is necessary for the ions to remain in the quadrupole field for at least 500 HF periods. In order to attain this goal, a compromise must be made with reference to the frequency, the field length and the acceleration stress of the ions. If the high frequency capacity is to remain limited to several 100W and the energy of the ions is not to sink below 30eV, then a field length of 6 to 8m follows. For constructing spectrometer the following parameters were chosen:

| | | |
|--------------------------------------|-----------------------------|-------------|
| No. of HF-periods..... | $n \geq 500$ | |
| Field radius..... | $r_0 = 3,5 \text{ cm}$ | |
| Diameter of the entrance screen..... | $\phi \approx 1 \text{ mm}$ | |
| Field length..... | $L = 5,82 \text{ m}$ | |
| Frequency..... | $\nu = 471 \text{ KHz}$ | |
| Direct current voltage..... | $U = 658 \text{ V}$ | |
| High frequency amplitude..... | $V = 3924 \text{ V}$ | } $A = 200$ |
| High frequency capacity..... | $N = 290 \text{ W}$ | |
| Maximum acceleration stress..... | $U_p = 35 \text{ V}$ | |

For a high resolving dissolven power all magnitudes which influence the stability behavior of the ions must have a correspondingly high standard of constancy. These magnitudes are the field radius r_0 , both voltages U and V as well as the frequency ν .

The accuracy of field radius necessary for attaining a certain resolving dissolven power cannot be stated exactly at present. Fristly the number of the possible filed errors is too large (eg. coincity, torsion of the whole system or of one electrode, deflection, disturbances due to interruptions and current supplies, deviations from the hyperbolic shape, vibrations of the electrodes, etc.) to be able to give a consistent statement. Secondly the time in which the ions are exposed to such a disturbance, measured by their flight time, plays

a determinative roll. For this reason the influence of certain field errors can depend very much on the velocity of the ions. Nonetheless, since both the stability parameters a and q are inversely proportional to r_0^2 one can assume that the admissible Δr_0 should lie in the order of magnitude $r_0/(m/\Delta m)$. Our experiences with quadrupoles confirm this assumption with two important corollaries: deviations from the ideal hyperbolic shape play practically no part, in so far as they are constant over the whole field length. Secondly, field errors which only work over few HF-periods on the ions, in some circumstances exceed the upper value quite considerably (up to sizes of magnitude). - Therefore the following construction for the electrodes was carried out:

Each electrode is represented by a group of 61 wires which are spanned parallel to the field axis and lie on the hyperbola with $r_0 = 3.5 \text{ cm}$. The wires have a diameter of 0.29mm and an axis distance of 1.5mm. They are only harnessed at the ends of the field, so that, apart from the field ends no kinds of additional interruptions occur along the quadrupole. The accuracy of the field is not, however, provided by the framing sheets, whose sole duty is to absorb high traction forces; but for this purpose precision-bored Invar-templates are used, through whose holes the wires are guided (Figure 1). Of these there

is one for each of the two coordinate directions on every field end, shortly in front of the framing sheets. The important point is that both sheets belonging to one coordinate direction were bored in one operation and screwed together. By this means the opposite position of the bores is practically identical in one such pair of sheets.

The wire consists of molybdenum with a tensile strength at least 180 kp/mm^2 . The wires were stressed in the spectrometer up to approximately 150 kp/mm^2 . This implies a total traction force of 2100 kp for the whole wiring system. After pulling the wiring system into the vacuum tank, only one size has to be adjusted: the position of the X-templates relative to the Y-templates. This occurs by adjusting the distances of the four hyperbolic loads, measured between the outer wires, by shifting the templates with a gauge on equal. - In order to avoid hanging the wires through unevenly, the quadrupole is vertical.

The high frequency voltage, between the electrodes max 9 kV ., is produced by means of a counter switch on a vibrating circuit, whose capacity forms the quadrupole field (see Figure 2). It is held constant at better than 10^{-5} over an interval of several minutes. A slow path can be controlled by hand without difficulty. This is all the more possible as in a mass determination the momentary

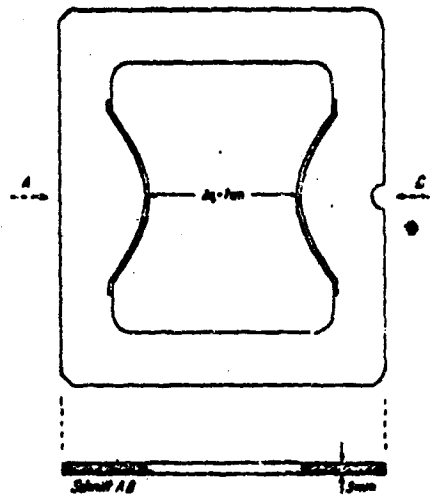


Fig. 1
Invar-plate for
guiding the wires exactly.

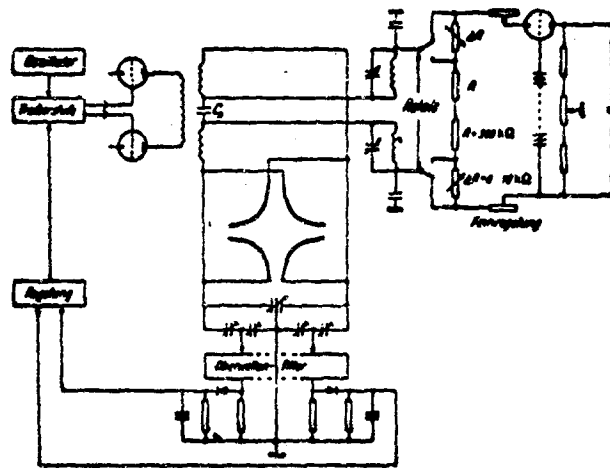


Fig. 2.
Electrical circuit.

value of the high frequency voltage does not even enter into the measurement value (see below 11,i) -Steered through the sweep-exit of an oscillograph, the HF-amplitude for passing over a mass line can be modulated with saw tooth shapes up to a maximum of 1%. For jumping from one dublett partner to the other, furthermore, a rectangular modulation of a maximum of 2% can be produced simultaneously. Both types of modulation operate satisfactorily up to 50Hz (1Hz = /cycle per second), but the mass measurements prevailing occur at 2 sec. per mass line.

Since the direct current voltage U is used to determine the mass, it must be constant to approximately 10^{-6} . Anode batteries with stabilised temperature attained this excellence in an unloaded condition. For this reason a network device, electronically stabilised to approximately 10^{-4} was used to yield the "anode" -voltage for a cathod follower, on whose grid a normal voltage in the shape of a series of anode batteries lies (see Figure 2). The normal resistances R and decade resistances R as well as the tandem helipot serve as a cathode resistance for a sensitive control of the constant magnetic field. The batteries are placed in a tin pan cooled with tap water. This fine stabilisation has the advantage that no wild oscillations can develop, since it only presents a forward control. In practice the voltage shows a very even

decrease of approximately 10^{-5} per hour (=1 V relative to 130V per month), which probably arises from the natural aging of the batteries. Apart from this, the constancy would be approximately $10^{-6}/h$. From lack of suitable comparative voltages this was not investigated further.

- The direct current voltage lying on the quadrupole field can also be modulated in a rectangular shape by means of relays and calibrated resistance parts, by exactly known amounts (Figure 2).

The ions have been produced up till now in a conventional electronic impact source. The emission current of the electrons is 10 or $15\mu A$, but is not stabilised electronically. Since the acceleration-voltage of the ions is very low with a maximum of 60V, all parts must be very clean to avoid charging on the surfaces. In addition, the remaining lower startum of gas in the region of the source of the ions is kept low by a cooling valve with fluid air. A magnet for parcelling the electrons is not used. - After the ions are passed through a tubular lenticular system of 3cm length, the ions are shot into the quadrupole field through a 6cm long canula. At the end there is an opening of 1mm. The object of the canula is to keep the transition field between the earthed entrance and the ideal quadrupole field as short as possible.

However, it wasn't systematically investigated as to whether this played a part in the mass measurement. - The source of the ions and the canula together can be displaced in both coordinate directions, perpendicular to the axis of the quadrupole field, and are normally simply adjusted to the maximal intensity of the detector. An angular adjustment is not provided.

A 17 - stepped multiplier, whose exit lies near earth, is used as a detector, so that its high voltage effects the ions as a post-accelerator and focuser. The latter is important, since there is no well - parcelled beam of ions leaving the end of the quadrupole field, but the ions have different angles and distances from the axis. The signal from the multiplier passes through a completely counter-coupled amplifier and is finally shown on the oscillograph.

The vacuum is produced by two 500 L/s oil - diffusion pumps which each bear two water-cooled oil catchers above each other. The pressure during the measurements is between 2 and 3. 10^{-6} Torr (1 Torr = 1mm. of mercury at 0°C). The source of the ions is only pumped off through a crevice above the main vacuum.

2. Experiences with the apparatus

a) The wire system.

The total quadrupole field including feed, forms a capacity of 790pF, corresponding to 130pF per meter length of the systems. The basal quality Q of the terminal circuit is 250: from this a necessary HF-capacity of 130W results from the Xenon-measurement. The sizing of the earthed vacuum-mantle through the wire electrodes increases the necessary voltages by less than 0.1%. The isolation resistance of each electrode to the earth is greater than $10^{12} \Omega$ (see 11.2).

Occasionally the mechanical vibrations of the wires cause difficulties; their basal frequency lies at 28 to 33 Hz. On the one hand they cause capacity changes of the terminal circuit and simultaneously a modulation of the effective field radius. A complete damping of this movement is possible by admitting a gas, eg. nitrogen, for a short time, or by applying a magnetic field of approximately 3500G (eddy current damping). The second method is conducted experimentally, but does not lead to the complete repose of the wires. But these vibrations did not play any part in the mass measurements described later.

The forces of attraction between the wire electrodes resulting from the electric fields work out very disadvantageously. They cause a deflection of about 3μ in the voltages which are necessary for Xe-measurements on the vertex of the hyperbolas and on

half the length of the wire system. This is nearly 10^{-4} of the field radius and produces a displacement of the $a q$ - values by $2 \cdot 10^{-4}$ of their amount whilst the ions fly through the air.

b) Resolving dissolvent power

The greatest attainable resolving dissolvent power amounts to 6000 to 8000 in the present state of the apparatus and is thus noticeably below the value planned originally. This is attributed to the deflection of the wire electrode mentioned above and the following experiment is carried out in connection with this. Behind the wire electrodes between the electrodes and the vacuum mantle, copper pipes were fitted which lay on the voltage of the corresponding counter electrode (Figure 3). By means of a suitably chosen distance between these additional electrode and the wire electrodes, the compensation of the forces on the wires in the region of the hyperbolic vertex can be realised. With this arrangement the mass filter yielded maximal resolving dissolvent power of 16,000. But the additional electrodes used for this, and their interruptions, were only built in provisionally and were removed again after their clear influence on the resolving dissolvent power was observed.

However, it is important to note that the resolving dissolvent power only plays a subordinate part

in obtaining accuracy in determining the masses, in the measurement methods discussed later (11, 1).

c) Production of slow ions

In order to produce a high resolving disolvent power, it is desirable to keep the ions in the mass filter for as long as possible. Originally the ion source was driven with very low traction voltage for this reason

Naturally the ion currents extracted by this recede very sharply.

(~20 V) However, the following method proved to be very good: the source of ions is driven with a higher voltage (60 to 70V) and the ions are shot through the earthed canula into the quadrupole field. But the direct current voltage of the quadrupole field is not conducted to the wire system symmetrically with respect to earth, but in such a way that the potential of the field is

$$\varphi = (U + U \cos \omega t) \frac{x^2 - y^2}{r_0^2} + U_{\text{brake}} \quad (1)$$

In the transition field between the canula and the actual quadrupole field the ions thus lose U_{brake} energy and correspondingly slow ions are obtained in the mass filter.

The ion "catch" into the quadrupole field results in this case with a very good yield. If the ions in the

source are accelerated with 70V and braked in the quadrupole field to 17.5V, the gain in intensity on this spectrometer amounts to more than one order of magnitude over against an acceleration of the ions in the source with 17.5V and symmetrical quadrupole. In addition, measurements of flight times for the ions were also made with a pulsed source of ions. The greatest flight time attained lay at 2.5ms for $^{136}\text{Xe}^+$ corresponding to an energy of 4eV.

II. MASS DETERMINATIONS

1. Methods

The application of the quadrupole field for the precision mass determination is made more difficult at first by the fact that the stabilised mass is connected with the electronic parameters U, V and in the form

$$m = \frac{8eU}{a r_0^2 \omega^2} \quad m = \frac{4eV}{q r_0^2 \omega^2}$$

i.e., in these equations one of the stability parameters a or q always appears. A mass measurement in the form $m_1/m_2 = U_1/U_2$ or V_1/V_2 and ω_1/ω_2 is thus only possible if care is taken that next to the constancy of the other parameters by an additional criterion, the comparison of both masses is made in each case with exactly the same a- or q- values.

Unfortunately a measurement by means of frequency variations is excluded for a number of experimental reasons, similarly the measurement from the HF-amplitude V because of technical control problems. The only equation then remaining is³

$$a = \frac{8 \pi U}{m \omega^2 r_0^2} \quad (1)$$

from which one obtains

$$m = \text{konst} \cdot \frac{U}{a} \quad (2)$$

where frequency and radius are fixed (in the following, this should always be assumed). Here there is no need to say anything about the HF-amplitude.

To ascertain the a - value, the "linear width" of the mass line or the intensity I on the catcher is considered as the measurement size, above all else; as was shown in 3, it indicates a strong dependence on the point of operation in the stability diagram.

For a closer explanation of the measurement process, the following notations are valid: all sizes which refer to the higher mass of a dublett are denoted by "1", those of the lower ones by "2". Furthermore, the direct voltage currents belonging to $\alpha = \alpha_1 = 0.23699$ (peak of the stability triangle) are denoted by $U_{1,d}$ or $U_{2,d}$.

In contrast to these, U_1 and U_2 are variable. We thus obtain equations

$$\left. \begin{aligned} a_i &= k \frac{U_i}{m_i} \\ a_z &= k \frac{U_{i,z}}{m_i} \end{aligned} \right\} i = 1, 2.$$

The dependence of the intensity on $(a_g - a)$ is obtained as follows³: With an entrance parallel to the axis and the given initial value x_0 , for the maximal amplitude x_m (A is the proportionality constant)

$$(x_0/x_m)^2 = A(a_z - a). \quad \text{is valid.}$$

The admissible maximal amplitude is limited by the field radius r_0 , thus for ions which can attain the catcher

$$x_0^2 \leq A(a_z - a) \cdot r_0^2. \quad \text{is valid.}$$

If we shoot in a homogenous ion ray I_0 , the intensity at the detector I is proportional to the admissible x_0^2

$$I \sim I_0(a_z - a) r_0^2 \quad (3)$$

and with fixed r_0

$$I_i = I_{i,0} j \cdot (a_z - a).$$

Here let I_1 or I_2 be the maximal intensity of the mass 1 or 2, which one obtains at the detector when

a) the mass line is driven over by pure V modulation (thus with constant a_i) and

b) the intensity $I_{i,0}$ is shot through the entrance screen. If one considers, furthermore, that

$$U_{1,0}/U_{2,0} = m_1/m_2$$

one obtains

$$\frac{I_2}{I_1} = \frac{I_{2,0}}{I_{1,0}} \left[1 + \frac{U_1}{U_{1,0} - U_1} \left(1 - \frac{m_1}{m_2} \frac{U_1}{U_1} \right) \right].$$

The direct current voltage leap from U to U is produced by means of the circuit system illustrated in Figure 2, and a relationship

$$\frac{U_1}{U_2} = \frac{R + \Delta R}{R}. \quad (4)$$

is constantly valid.

Finally let us introduce an (up till now unknown) "true" $\Delta R = \Delta R_0$ which is defined by

$$\frac{m_1}{m_2} = \frac{R + \Delta R_0}{R}. \quad (5)$$

Then for the measured intensity relationship one obtains

$$\frac{I_2}{I_1} = \frac{I_{2,0}}{I_{1,0}} \left[1 + \frac{U_1}{U_{1,0} - U_1} \frac{\Delta R - \Delta R_0}{R + \Delta R} \right]. \quad (6)$$

On the basis of this equation and Figure 4 the method of measurement can be discussed to advantage: the intensity ratio I_2/I_1 with constant U_1 is measured in dependence on ΔR . i.e., with variable U_2 (see (4)). Since $\Delta R \ll R$ and in addition ΔR is itself only varied in a small region around ΔR_0 , one obtains a straight line for $I_2/I_1 = f(\Delta R)$. Its' rise is determined by the factor $U_1/(U_{2,c} - U_1)$. Here U_1 is only very little smaller than $U_{2,c}$. If measurements are taken with different fixed U_1 , the rise of the straight lines is the bigger, the closer U_1 lies to $U_{2,c}$. The point $(\Delta R_0, I_{2,0}/I_{1,0})$ is common to all the straight lines, since ΔR becomes equal to ΔR_0 at this point. This communal point of intersection of all the straight lines thus gives us ΔR_0 and by means of equation (5) the mass ratio m_2/m_1 directly, as well as giving us simultaneously the intensity ratio $I_{2,0}/I_{1,0}$. The supposition, however, for obtaining straight lines in this method is that the intensity I is proportional to $(a_2 - a_1)$. But this is not always the case in experiments. The corollary can be made experimentally that

$$I_i = I_{i,0} \cdot \Phi(a_2 - a_1)$$

where the function Φ is suited to the experimental course. It can then be easily shown, that now as well as

previously, all the curves $I=f(\Delta R)$ obtained have the unifying point in the section $(\Delta R_0, I_2, I_1, \phi)$ but they are no longer straight lines. It is important that the function $\phi(a_2 - a)$ must be the same for both masses, then equation (5) is valid, as previously.

A further measurement value, which can be gained from (6) is the relative rise S of the curves in the communal point of intersection, p.d.

$$S = \frac{(d(I_2/I_1))/(I_2, I_1, \phi)}{(d(\Delta R))/(R + \Delta R_0)}$$

Since I_1 does not change within a measurement curve, S is the relative intensity change dI_2/I_2 with a change of the Decade resistance around $d(\Delta R)$. If the measurement curves are straight lines, they can be extrapolated to $I_2/I_1 = 0$ and $\Delta R = \Delta R_0$ is obtained there. Then

$$S = \frac{R + \Delta R_0}{\Delta R_0 - \Delta R_0} \quad (7)$$

is true.

And from (6) one obtains

$$\frac{U_1}{U_{L,2}} = 1 - \frac{1}{S} \quad (8)$$

S can thus be used to ascertain how closely one has approached U_1 to $U_{L,2}$. Typical figures for this are given in the next sections.

A final step goes thus: where there is pure modulation of the high frequency amplitude V (without U damping) the resolving dissolving power

$$m/\Delta m = 0,581/(a_2 - a).$$

belongs theoretically to each a .

From this, by means of equations (1) and (8)

$$m/\Delta m = 2,45 \cdot S. \quad (9)$$

results.

Thus theoretically the relationship (9) exists between the steep mass S and the resolving dissolvent powers necessary for this. In the following section we shall see how the experimental comparison of both sizes turns out.

2. Results of Measurement

It is advantageous that when testing the spectrometer, to begin by measuring very large duplet distances, since it is then much easier to recognise faults systematically.. Isotope dubletts or the Zenon were chosen as testing media, and it was attempted to jump over two mass units.

The prevailing measurement of intensity is made by a visual reading on the oscillograph: here a mass line is conveyed in 2 seconds. At the end the apparatus

switches automatically to the other dublett partnet. 10 dubletts are read off, one after the other, and the mean of the intensity ratio I_2/I_1 is formed. This gives a measurement point (see Figure 4). For apoint of this kind 40 seconds are thus required, for a straight line 5 minutes and a whole cluster of curves approximately one half hour. This time seems far too long, especially for such cases where the intensity radio shot in is not as ideally constant as with the Xenon-isotopes, for example in the case of Xe- $C_n H_m$ measurements.

Therefore at the present time work is being done to increase the speed of measurement considerably; this only seems possible by using a completely automatic registration. - The measurements were made over approximately 3 months, and in this time different parameters were varied, in order to see how the measurement results reacted upon this. The accelaration voltage was thus varied, and measured with and without braking in the transitional field, the source of the ions was adjusted down to 1mm. from the axis, the sensitivity change of the detector sections necessary for various curves of a cluster of curves was attained in one way by switching different conduction resistances at the exit of the multiplier, and in the other by varying the multiplication voltage itself (varying post-acceleration of the ions). In no case could a sharp influence be detected on the measurement result, but probably on the error limits.

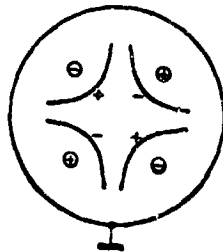


Fig. 3.

Sketch of the additional electrodes.

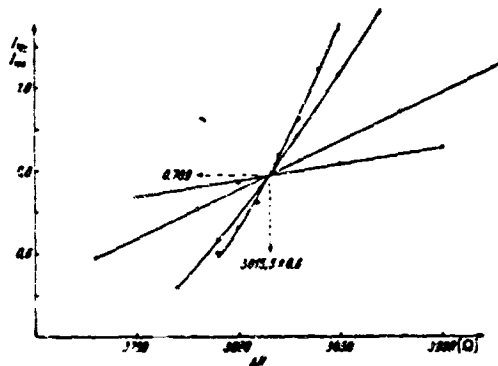


Fig. 4.

Dependence of the measured intensity ratio on the resistance of the decades R . The communal point of intersection gives the measurement value.


As an example for the insensitivity of the measurements to such changes, Figure 4, shows the cluster of curves of a measurement, where the entrance canula stool omm. next to the axis of the quadrupole field. One can see immediately that the two flat curves can be represented very well by straight lines. However, the deflection of the two steep curves is equally clear. As an example, the curves of Figure 4 were extrapolated to ΔP_0 where in the case of the steep curves the tangents were used in the communal point of intersection. Table 1 shows the results.

The extrapolated values ΔR_0 are in the first column, in the second the steepnesses S , calculated from this according to (7). From this, by means of (8), the ratio $U/U_{i,e}$ (third column) is obtained. It is concluded from this that the limiting value of the direct field $U_{i,e}$ is approached up to nearly 1 to 10^4 . But at the same time the relative direct field change $\Delta U_i/U_i$ which is undertaken between the curves is known by the direct current voltage control to approximately $\pm 10^{-6}$ and is given for comparison in the fourth column. In the first three curves these values are in close agreement with the changes observed experimentally of the curve steepness.

At the step from the third to the fourth curve the non-linearity is, however, so strong, that the difference

of both values is significant. The steepness $S = 6060$ in Table implies that a change of direct current voltage of only $1.7 \cdot 10^{-6}$ is necessary to change the ratio I_2/I_1 by 1%. Although a steepness of 6000 can be obtained nearly at all times and with the most varying test parameters no curves with $S > 8500$ were obtained experimentally. This seems to be very closely connected with the effect which also limits the resolving dissolvent power

TABLE 1

| | $U_p, [V]$ | S | $\frac{U_1}{U_{10}}$ | $\frac{\Delta U_1}{U_1} \cdot 10^4$ | $I_1 [A]$ | |
|---|------------|------|----------------------|---|----------------------|----------------------|
| a | 2820 | 510 | 0.99804 |  | $1.3 \cdot 10^{-13}$ | |
| b | 3470 | 1460 | 0.99931 | | 120 | $5.2 \cdot 10^{-14}$ |
| c | 3700 | 4380 | 0.99977 | | 48 | $1.7 \cdot 10^{-14}$ |
| d | 3732.5 | 6060 | 0.99986 | | 26 | $5.2 \cdot 10^{-15}$ |

If we compare this steepness with the resolving dissolvent power (9) expected theoretically, with $S = 8200$ one obtains a related $m/\Delta m = 20000$. This value is, however, far from being attained in practice. The wire deflection thus limits the resolving dissolvent power in a much more sensitive way than the attainable steepness S .

In the last column of Table 1 the currents of ions at the entrance of the multiplier are given for ^{133}Xe . In order to calculate this, the total amplitude factor of the multiplier is required. From earlier measurements⁵ the amplitude was assumed at 4kV to $6 \cdot 10^5$. Here it must be added that the example given was measured with a source of ions which was adjusted down, and the intensities increased fairly exactly by an order of magnitude with optimal adjustment.

The results of the measurements are contained in Table 2. The result is a weighed average from N measurements, where $\delta(\bar{R})$ gives the mean error of this average $\delta(R)$ is the uncertainty which results because R is only known exactly up to $\pm 3 \cdot 10^{-6}$ $\delta(\Delta R)$ is the analogous amount which proceeds from the Decades ΔR . In addition, all the values were corrected to an isolation resistance of $R_i = 2.5 \cdot 10^{11} \Omega$. This isolation resistance results largely from the coupling capacity denoted in Figure 2 by C_k . It oscillates maximally between 1.5 and $4 \cdot 10^{11} \Omega$, this is taken into consideration by $\delta(R_i)$ in Table 2. It can be seen that the uncertainty in the resistances yields by far the greatest portion of the total errors. Therefore the quality of the measurement cannot be improved at the moment, solely by a higher number of individual measurements. A possible temperature dependence

TABLE 2

| | m_1/m_2 | N | $\delta(M)$ | $\delta(R)$ | $\delta(\Delta R)$ | $\delta(R_0)$ | $\delta(m_1/m_2)$ |
|-------------------|-----------|-----|---------------------|---------------------|---------------------|---------------------|----------------------|
| ^{222}Xe | 1,0076321 | 9 | $2,2 \cdot 10^{-7}$ | $2,3 \cdot 10^{-7}$ | $3,8 \cdot 10^{-7}$ | $0,4 \cdot 10^{-7}$ | $5,0 \cdot 10^{-7}$ |
| ^{136}Xe | | | | | | | |
| ^{134}Xe | 1,0151730 | 4 | $4,7 \cdot 10^{-7}$ | $4,6 \cdot 10^{-7}$ | $7,6 \cdot 10^{-7}$ | $0,8 \cdot 10^{-7}$ | $10,1 \cdot 10^{-7}$ |
| ^{132}Xe | | | | | | | |

of the resistances R and ΔR . is not considered. Since both are wound from the same resistance wire, a temperature course should have no influence on the result.

Furthermore, no correction was made to the wire deflection. In 1, 2 it was stated that resulting from electrical forces of attraction, the maximum $\Delta r_1 = r_0 - r_1 \approx 3\mu$ amount in the vertex of the hyperbola. Since, in addition

$$\frac{\Delta r_1}{\Delta r_2} = \left(\frac{m_2}{m_1}\right)^2$$

the assumption of the constant field radius is not at all valid. One must then express (2) more generally,

$$\frac{m_1}{m_2} = k \frac{U_1}{U_2} \frac{a_2}{a_1} \left(\frac{r_2}{r_1}\right)^2.$$

A more exact analysis of this shows that the method of measurement applied according to equation (6) is not a test for $a_2/a_1 = 1$ but

$$\frac{a_2}{a_1} \left(\frac{r_2}{r_1} \right)^2 = 1.$$

Therefore this effect is, fortunately, excluded.

Table 3 offers a comparison with other authors. The agreement in the case $^{136}\text{Xe}/^{138}\text{Xe}$ is very good, but less satisfactory with $^{134}\text{Xe}/^{136}\text{Xe}$. In the second case it is possible that a systematic error also appear during the simultaneous change in sensitivity of the detector part. This serves to mermit both peaks to appear about the same size on the oscillograph.

TABLE 3

| | | |
|---|------------------|---|
| $\frac{^{136}\text{Xe}}{^{138}\text{Xe}}$ | 1,0076321 ± 5 | Vierpolspektrometer (direkt gemessen) |
| | 1,00763206 ± 8 | EVERLING et al. ⁶ (mittels Ausgleichsrechnung) |
| | 1,00763206 ± 1,5 | RIES et al. ⁷ (aus $C_n H_m$ -Dubletts) |
| $\frac{^{134}\text{Xe}}{^{136}\text{Xe}}$ | 1,0151730 ± 10 | Vierpolspektrometer (direkt gemessen) |
| | 1,01517189 ± 9 | EVERLING et al. ⁶ (mittels Ausgleichsrechnung) |
| | 1,01517195 ± 54 | JOHANSSON, NERZ ⁸ (aus $C_n H_m$ -Dubletts) |

The intensity ratio for $^{131}\text{Xe}/^{132}\text{Xe}$ measure
by us, is 0.7902 ± 0.0020 . If the multiplier-sensitivity⁹
is considered by a factor $\sqrt{131/132} = 0.9962$, one
obtains 0.7872 ± 0.0020 . This can be compared with a
value by Nier¹⁰ of 0.7877 ± 0.0027 .

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