HIGH PRECISION DIRECT MASS DETERMINATION OF ISOTOPES FAR AWAY FROM STABILITY

LETTER OF INTENT

by

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Motivation

Direct determination of the mass of nuclei far from the stability line was started many years ago and was developped by Klapisch et al. /1/ to a precise technique at the ISOLDE facility at CERN. The mass as a fundamental gross property of nuclear matter is a sensitive probe for collective and single particle effects on the nuclear structure. Especially measurements over a wide range of isotopes, isobars or isotones are very valuable for systematics and are an important tool for testing the various theoretical mass formulas. An ideal technique for measuring the masses of short-lived isotopes produced at an on-line mass separator should fulfill the following requirements:

(i), universal applicability to all elements produced at an ISOL - facility
(ii), direct, absolute determination of the mass
(iii), accuracy better than 100 keV
(iv), resolving power better than 100 keV in order to distinguish between ground and isomeric states
(v), high sensitivity

Proposed technique

On alkali isotopes, mass measurements /1,2/ were performed with an accuracy of several ppm whereas the resolving power of the apparatus used was $\Delta m/m = 10^{-4}$. The precision of the order of ppm was reached by determining the center of gravity of the mass peak and the mass was related to a stable mass by ratios of voltages and an iteration procedure starting with the known mass of a stable isotope from the same isotopic chain. We propose a technique which is an absolute one and has a higher resolving power but reaches about the same accuracy as quoted above. The underlying idea is to measure the cyclotron frequency in a magnetic field B

$$\omega_c = \frac{e}{m} B$$

by which the mass of the isotope under investigation is directly determined. The routine resolving power of such a technique is $\Delta m/m > 10^{-5}$ /3,4/. It will be improved in the proposed experiment by an order of magnitude with the help of a superconducting magnetic field and the storage of the ions in an ion trap.

The function of the ion trap and the detection scheme for the cyclotron resonance is the following:

Free ions stored and thermalized in an electrostatic quadrupole field with superimposed homogeneous magnetic field (Fig.1) carry out two motions: the one parallel to the magnetic field is due to the electrostatic parabolic potential; the transverse one is given by the fast cyclotron rotation slightly shifted by the slow magnetron motion.

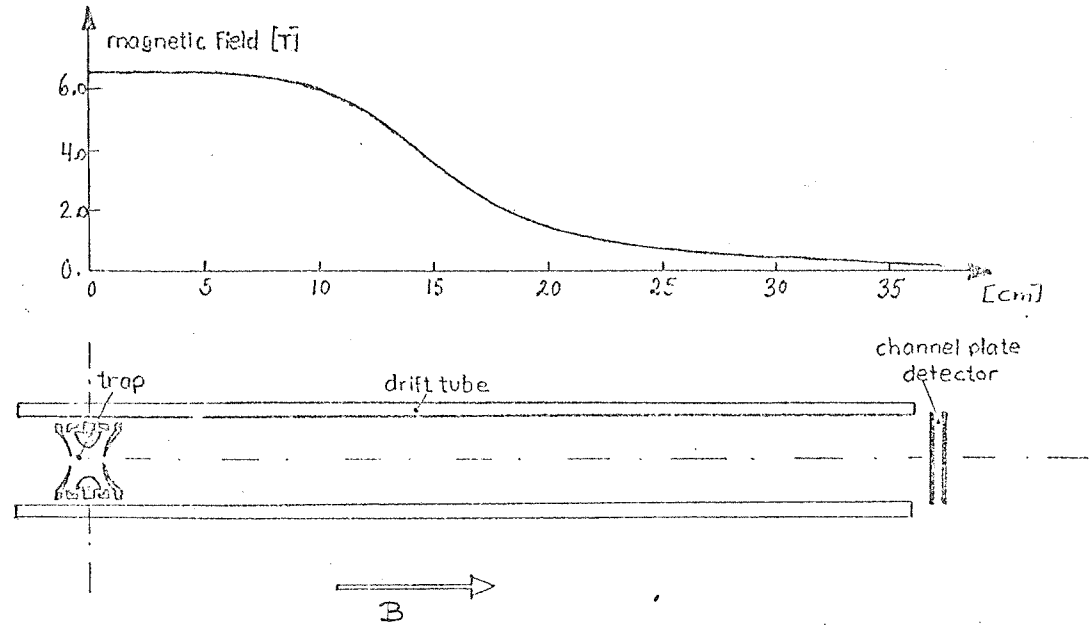

Fig. 1. The experimental arrangement for the detection of cyclotron frequency by time of flight technique

By changing the trap potential the ions are ejected out of the trap and expire an acceleration in the inhomogeneous part of the magnetic field. By inducing the cyclotron-frequency transition the trapped particles gain energy in their transverse degree of freedom, i.e., by the increase of orbital magnetic moment. Ejecting the particle into the low-field region the energy $E = \vec{\mu} \cdot \vec{B}$ shows up in an decrease of their time of flight from the trap to the detector.

Experience with the Technique: Accuracy and Sensitivity

The technique proposed has already been applied successfully in the laboratory at Mainz to a determination of the electron-proton mass ratio with an accuracy of 0.4 ppm /5/. In a short test performed on H_2O ions, the line width of the cyclotron frequency was found to be 0.6 ppm FWHM (Fig.2).

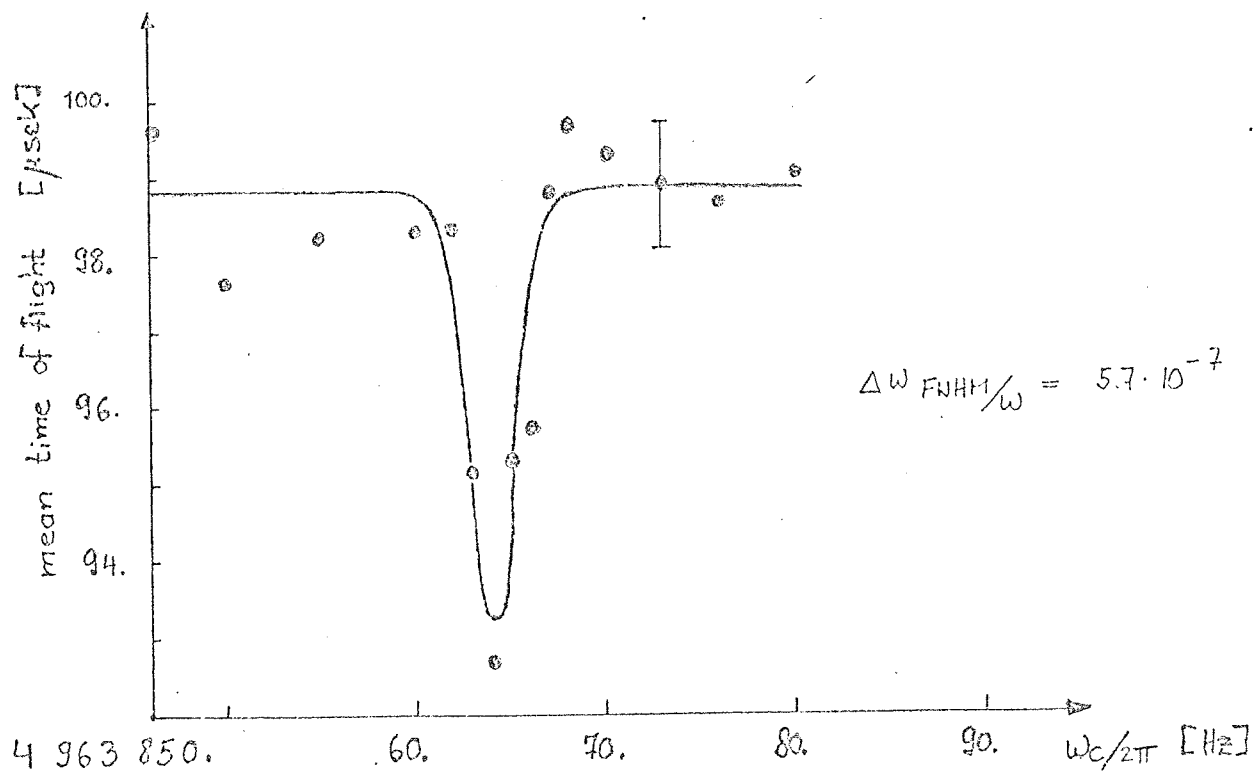

Fig. 2. Cyclotron frequency resonance for H_2O^+-Ions

Although this resolving power already reaches the goal of a determination of the mass better than 100 keV, it can be envisaged that a systematic study of the dependance of the line shape on experimental parameters will allow to define the center of the line even with much higher accuracy.

Frequencies can be stabilized and measured to an accuracy of 10^{-8} without any problems. The magnetic field can be calibrated by trapping protons or ^{12}C ions in the same trap and measuring their cyclotron frequencies. In the experiment performed on p and H_2O the field strength of the superconducting magnet was 6 Tesla and the homogeneity over the trapping volume better than 10^{-7}. During one day the drift of the magnetic field was $\lesssim 2 \cdot 10^{-8}$.

Discussing the sensitivity of the proposed mass measurement, we refer to Fig.2. This result was obtained by summing up 24 sweeps lasting each 2 sec, for each frequency point. On the average, there were 4 H_2O ions detected by the channel plate during each sweep. With a detection efficiency of the channel plates of 50% this corresponds to less than 10 ions present in the trap during each sweep. Hence, a measurement of a mass with an accuracy <ppm takes the order of 10 min and requires about 10 ions/sec stored in the trap.

Proposed Experimental Set Up

The apparatus planned is similiar to that used at Mainz. However, instead of producing the ions from the rest gas by electron bombardment inside the trap, for an application of the technique to mass measurements at ISOLDE the radioactive ions have to be guided into the trap. This procedure has still to be tested in the laboratory at Mainz. Two solutions are under consideration:

,(i), the trap is nearly on the same potential as the ISOLDE target and the incoming ions are guided by the inhomogeneous magnetic field into a hole in the trap and are trapped by electrostatically opening the trap for a short period (10^{-5}sec). For yields $\lesssim 10^6$ ions/sec, the procedure has to be repeated and

and inbetween the ions have to be thermalized.

,(ii), the ions of the ISOLDE beam are stopped on a foil, evaporated and reionized by electron bombardment and guided by the inhomogeneous magnetic field and an electrostatic field into the trap. Estimating the efficiency of the ionization to $\gtrsim 10^{-3}$ and the efficiency of the transfer into the trap to $\gtrsim 10^{-2}$, the method is in any case applicable to yields exceeding 10^{6} ions/sec.

Time schedule

The main components of the experimental set up (superconducting magnet, ion trap, drift tube and detector, high frequrncy set up, data handling) already exist and are tested. Hence, the only crucial point of the proposed experiment, which has still to be tested, is the transfer of "high energetic" ions of a mass separator into the ion trap as thermalized ions. This investigation has to be performed in the laboratory at Mainz. After that, measurements could start at ISOLDE II. Since it seems to be unrealistic to float the whole apparatus at the ISOLDE voltage of 60 kV, we will begin with a transfer technique using reionizatic Favourable elements would be Ba, Yb and Hg for which target-ion-source combinations with high yield exist. The use of surface ionization would simplify the start of the experiments. A measurement of the Ba masses would complete the gamma, optical and mass data in the Cs/Ba region, those of Yb would allow to observe the effects due to the transition from deformed to spherical shape and those of Hg isotopes would be interesting in view of the shape isomerism around A = 185.

Requirements for ISOLDE III

In order to apply the technique of the direct transfer of the ion beam by retardation into the trap we would favour a facility which has a tolerable transmission even at a lower acceleration

voltage ($\lesssim$ 10 kV). In addition, the acceleration voltage should be constant within about 1 V. A pulsed operation mode of the ion source would be an advantage.

Clearly, an increase of the production yield and of the beam time available would enlarge the applicability of the method.

As a precision experiment, the set up should have a fixed floor space. Finally, it should be mentioned that a liquid-helium supply and a He-gas recycling system should be available.

References:

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