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STORAGE ION TRAP OF AN «IN-FLIGHT CAPTURE» TYPE FOR PRECISE MASS MEASUREMENT OF RADIOACTIVE NUCLEAR REACTION PRODUCTS AND FISSION FRAGMENTS

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1. Introduction

Data on nuclear masses provide a basis for creating and testing various nuclear models. A knowledge of the binding energy or the masses of nuclei, whose values reflect the balance between the nuclear and Coulomb forces, is of great importance in establishing the configuration of nucleons in nuclei. Comparing the values of the masses predicted by theoretical models with those determined as a result of measurement is of special interest for short-lived nuclei far from the beta-stability line. For mass measurement of those nuclei carried out on the beam of radioactive nuclear reaction products or fission fragments, a Penning ion trap can be used as the part of two facilities.

A) The large solid angle and momentum acceptance of projectile-like fragment separator COMBAS [1] is being designed for experiments at intermediate-energy heavy ions accelerated on the U-400M cyclotron of the FLNR. The COMBAS system is a achromatic separating magnetic line with the double spatial focusing of nuclear reaction products. A tandem system comprised of the U-400M cyclotron, the COMBAS magnetic separator and the ion trap of an "in-flight capture" type [2] can be used for rapid and precise mass measurement of the recoil short-lived nuclei produced by heavy ions in the fragmentation reactions.

This tandem system shown in Fig. 1 is to perform the following operations:

(i) Accepting the recoil nuclei produced in the target T by the magnetic separator and decreasing their kinetic energy down to 1-2 A· MeV by degraders. At such energy, the light recoil reaction products have a total ionic charge.

In a general way, the reduction of the kinetic energy of nuclei by degraders results in their relative energy dispersion increasing. This disadvantage is substantially offset by monochromatizing degraders of a wedge type [3], which make use of the energy-dependent position dispersion of charged particles in the angular focusing plane F1 or F2.

As an alternative to wedge degraders, we proposed [4] to use a degrader of a new type: a uniform flat plate placed at the site of the beam transformation of "point in parallels" between magnetic dipoles D1 and D2 or between D7 and D8 and inclined at some angle to the optical axis. The operation of this degrader is based on the effect that particles of larger energy deflect a large angles and have to travel a longer path in an inclined thin plate and more energy lost. A flat plane degrader is very simple to fabricate.

The performance of such an inclined flat aluminium degrader was tested on the U-400M cyclotron. The degrader was found to be capable of the efficient monochromatization and separating of a secondary ^{6}He beam (for, example, from ^{3}H) produced by bombarding a thick carbon target with ^{7}Li ions.

(ii) In-flight transportation of the retarded nuclei to the magnetic solenoid of the ion trap and transforming their remaining longitudinal kinetic energy into an azimuthal rotation by the fringing magnetic field of the solenoid according to Bush's theorem [5].

(iii) Confinement and accumulation of the rotating ions in the trap by using their reflection by the electrostatic field of the end cap electrode of the trap and their repelling by the magnetic field of a magnetic ventil with unidirectional transportation of moving ions located before the solenoid.

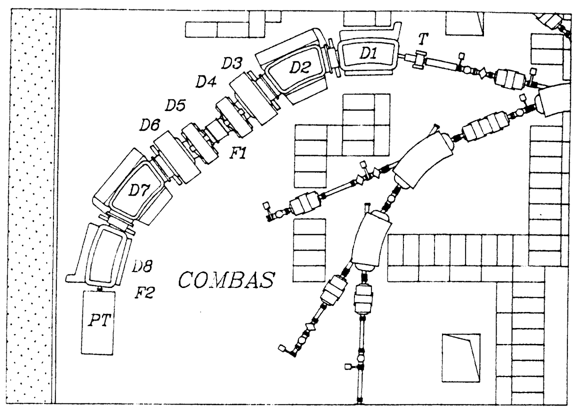


Fig.1. Lay-out of the COMBAS magnetic separator (magnetic dipoles D1-D4 and D5-D8 grouped into two sections) and mass spectrometric ion trap of an "in-flight capture" type PT. The U-400M heavy ion cyclotron is situated in the same hall. Dipole D1 (D8) defocuses in the radial plane and focuses in the axial plane. The action of dipole D2 (D7) on the charged particles is reverse. Dipoles D3 and D4 (D6 and D5) are correcting and steering pair. The induction sign of D4 (D5) is opposite to that of D1-D3 (D8-D6). F1 is the intermediate disperse focus, F2 is the exit achromatic focus.

(iv) Bunching the captured ions by a high-frequency azimuthal electric field with the help of special electrode system.

(v) At last precise mass measurement of the ions in the trap.

B) One of the FLNR's research projects is dedicated to producing beams of radioactive nuclear reaction products and fission fragments. This plant, named the DRIBs project (Dubna radioactive ion beams) [6], in particular, includes:

(i) Production of fission fragments in the photofission of uranium on the MT-25 microtron. Paper [7] reports the experimental integral photofission yields for the whole bremsstrahlung spectrum and the calculated photofission cross sections for nuclei of ^{232}Th, ^{238}U and ^{249}Cf. (The measurement of the photofission cross section of ^{249}Cf reported in [7] was made for the first time, ^{232}Th and ^{238}U being used as reference).

From the results of [7] it follows that the total flux of fission fragments from a ^{238}U thick target (30 g/cm^2) for a mean current beam of electrons of 20 μA with energy of 25 MeV from MT-25 is equal to $7 \cdot 10^{11}$ fragments / s.

(ii) Rapid diffusion and effusion of the fission fragments from the hot target and the ionisation of the atoms leaving the heated target in a special ion source.

(iii) Preliminary mass selection of the fission fragments with a magnetic dipole separator and subsequent precise mass measurement of the separated fission fragments with a mass spectrometric ion trap of an "in-flight capture" type.

In the present work we consider some aspects of rapid in-flight capture of the fast nuclear reaction products or mass-separated fission fragments to a trap and further measurement of their masses.

2. Accumulation of magnetically-separated nuclear reaction products or fission fragments in a mass spectrometric ion trap by an "in-flight capture" mode

The widely known Penning trap is a device that enables the three-dimensional confinement of ions with combined static magnetic and electric fields, components of which are schematically shown in Fig. 2.

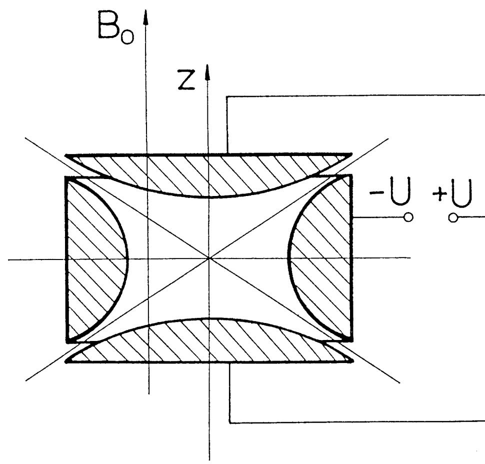


Fig. 2. Schematic representation of the magnetic and electric fields of the Penning trap. The electrodes have the shape of a hyperboloid; electrical potentials +U and -U are applied to the end cape and the ring electrodes. The homogeneous magnetic field B_0, produced by the electric current of the solenoid, is directed along it axis. The radial confinement of charged particles in the trap is provided by a homogeneous magnetic field $B_0 = B_z$ directed along the axis z.

The axially symmetric electric quadrupole field $E_r=G_r r$, $E_z = -2G_r z$ at $G_r > 0$ prevents slow positively charged ions from escaping along the magnetic field lines. The homogeneous magnetic field and the axially symmetric electric quadrupole field are isohronous fields, i. e. the revolution frequencies of ions in these fields are independent of the velocities of the ions and are determined only by the mass-charge ratio of the ions. This property is used in precise mass measurement of ions by measuring their revolution frequency in the trap.

For an in-flight capture of the fast charged particles in the magnetic field of a solenoid we propose to use external fringing magnetic field of a solenoid. In Fig. 3 we can see a some real distribution of the $B_z(0, z)$ - component of the fringing magnetic field which can be described with the formula (1) [8] (p. 28) for not saturated a iron armour

$$B_z=B_0(35a^4-84a^5+70a^6-20a^7), \qquad (1)$$

where $a=(z-z_0)/e$, e - the extent of the fringing magnetic field. Formula (1) describes the distribution of the magnetic induction B_z and also its vanishing derivatives of the first, second and third order at the ends of the interval e: $dB_z/dz=0$, $dB_z^2/d^2z=0$ and $dB_z^3/d^3z=0$. Such a magnetic field is produced by an excitation coil of an analogous profile [8] (p. 28) shown in Fig. 3.

Fast charged particles entering the magnetic field of the solenoid by the off-axial entrance with the parameter r_0, the fringing magnetic field transforms the particle longitudinal momentum into an orbital rotation. This rotation is defined, as indicated above, by known Bush's theorem, which has rather complicated formulation. Monograph [8] (pp. 85-89) states this theorem in the following simple form: when a charged particle moves at a distance r_0 from and parallel to the z-axis of a solenoid, the fringing magnetic field of the solenoid adds an azimuthal momentum to the charged particle, which forces it to move in a circular orbit of $r_B = r_0/2$ in the homogeneous main magnetic field of the solenoid and to cross the symmetry axis of the magnetic field.

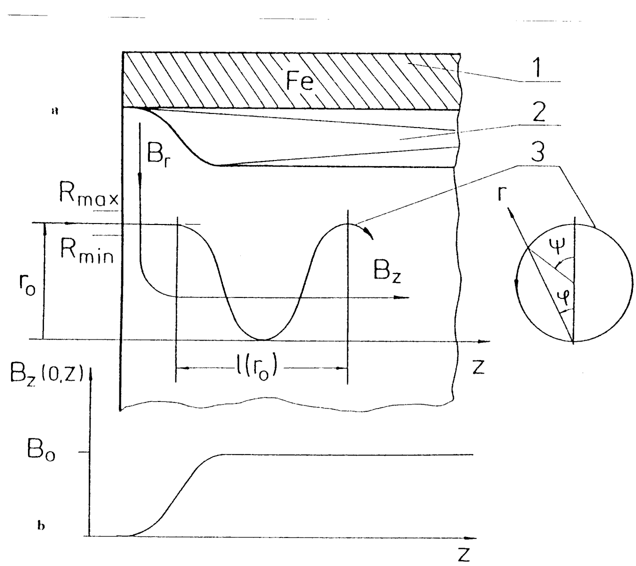


Fig 3. a) Fragment of a magnetic solenoid. 1 is iron armour of the solenoid, 2 is excitation electric current coil, 3 is projections of the charged particle trajectory in the magnetic field on the r, z - and φ, r - coordinate planes.

b) Distribution of the magnetic induction component $B_z(0, z) = B_z(\varphi, 0, z)$ along the solenoid axis.

Indeed, the equations of motion in Newton's non-relativistic form have the following expression for a charged particle moving in an axially symmetric fringing magnetic field in the right-handed cylindrical coordinate system (φ, r, z)

$$m(r\varphi''+2r'\varphi')=q(r'B_z-z'B_r), \qquad (2)$$

$$m(r''-r\varphi'^2)= -qr\varphi'B_z, \qquad (3)$$

$mz''=qr\varphi'B_r$, (4)

where and below m, v, q are the mass, velocity and electric charge of the particle. The simbol "touch" (') denotes the time derivative.

It should be noted that the second law of Newtonian mechanics was experimentally verified only for small velocities at the end of the 17th century (in particular, by Galileo's experiments with falling bodies). Newton intuitively or involuntary extended the law to both relativistic and jet motion (the possibility of the latter followed directly from his third law) by using, instead of the time derivative of the velocity of the moving body, dv/dt, the time derivative of the momentum (motus), d(mv)/dt.

Sometimes the second law of Newtonian mechanics is used without any comment for its origin.

To simplify the consideration of the fringing magnetic field, we admit that the magnetic field in the internal space of the solenoid is homogeneous and the external $B_z(\varphi, 0, z)$ -fringing component sharply decreases to zero at the entrance boundaries of the solenoid. It means that the B_r-component of the magnetic field required to find the solution to equations (2) and (4) in a fringing magnetic field found by the known method (see, for example, [8] (p. 28, 29) is express for the entrance magnetic field boundary (z= -l)

$B_r(\varphi, r, -1)=-rB_0\delta(z+1)/2$, (5)

where δ (z) is Dirac's function.

The projection of the particle trajectory on the φ, r-plane after the passage of the particle through the entrance fringing field we obtain by integration of equations (2) and (4) with respect to the time. After the first step integration of equation (2) for the initial conditions $\varphi(0)=0$, $\varphi'(0)=0$, $r(0)=r_0$ and $r'(0)=0$ (off-axial and parallel-to-the-optical-axis-z input of the charged particle) we have

$\varphi'_1=\omega_B\int\delta(z+l)z'\,dt/2=\omega_B\int\delta(z+)dz/2=\omega_B/2$, (6)

where φ'_1 is the angular velocity after the passage of the particle through the entrance fringing field, $\omega_B=qB_0/m$ is the numerical value of the so-called cyclotron angular velocity of the charged particle in a homogeneous magnetic field B_0. Used in (6) are the known result $\int\delta(z)dz=1$ and the substitution z'dt=dz. Solution (6) is obtained with an accuracy of up to the zero order value. The member of the first order $\omega_B \ln[r_1/r_0] << \varphi'_1$, produced by the particle motion along the r-coordinate under the action of the B_z-component field, is omitted.

The integration of equation (2) in the main magnetic solenoid field $B_\varphi=0$, $B_r=0$, $B_z= B_0$ with $\varphi'(0)= \varphi'_1= \omega_B/2$ gives the following solutions

$\varphi'(t)= \omega_B/2+\int [(\omega_B - \omega_B) r'/r]dt= \omega_B/2$, (7)

$\varphi(t)= \omega_B\, t/2$. (8)

The angular velocity $\varphi'(t)$ is called Larmore's angular velocity (frequency) of a charged particle in a magnetic field B_0: $\varphi'=\psi'/2$, $\varphi=\psi/2$, $\psi'=\omega_B$

Using the solution (8), we obtain from (3) the following equation for the radial motion

$r''+(\omega_B/2)^2 r=0$. (9)

The solutions to equation (3) under the initial conditions just after the particle passage of the entrance boundary $r_1=r(0)=r_0$ and $r'_0=r'(0)=0$ are

$r(t)=r_0 \cos(\omega_B t/2)$, (10a)

$r'(t)=(2r_0/\omega_B) \sin(\omega_B t/2)$. (10b)

Formulas (7), (8) and (10), representing the charged particle trajectory in a parametric form, give the direct analytic relation between r and φ

$r(\varphi)=r_0 \cos\varphi$ (10c)

Fig. 3 shows the projection of the positive charged particle trajectory in the main magnetic field of the solenoid on the r, z- and φ, r-coordinate planes. We see that a charged particle moves in a circular orbit of radius $r_B=r_0/2$, which crosses the z-axis at $\varphi=\pi/2$.

The main results given by equations (6) and (10) obtained for an ideal magnetic field remains correct for a real magnetic field with an extended fringing field (1), which is shown in Fig. 3b, if the concept of the effective boundary of a magnetic field is used.

The axial component of the particle kinetic energy after passing through the entrance fringing field of the solenoid we obtain from equation (4) by its integration using mean value (6), component (5) and the integrating multiplier z'

$$\Delta T_0=T_0-T_l=m\int z''\, z'\, dt=q\,\omega_B\, r^2\, B_0=m[\omega_B\, r_0]^2/8 \text{ or} \quad (11)$$

$$T_l=T_0[1-(r_0/2R_B)^2]^{1/2}, \quad (12)$$

where $T_0=mv^2/2=m(\omega_B\, R_B)^2/2$ is the initial kinetic energy of the charged particle, ΔT_0 is the disappearing initial longitudinal kinetic energy,

$$R_B=mz'/qB_0 \quad (13)$$

is the characteristic radius of the charged particle circular orbit with the initial velocity equal to z'=v and orthogonal to the strength lines of the homogeneous magnetic field B_0. From formulas (11) and (12) it follows that the charged particle longitudinal kinetic energy decreases after its off-axial passage through the fringing magnetic field of the solenoid.

The acquired kinetic energy of the azimuthal rotation of the particle in the magnetic field is

$$T_2=m[r_0\,\omega_B\,]^2/8 \text{ and } \Delta T_0=T_2, \quad (14)$$

that means that the low of the energy conservation is fulfilled.

It can see, the electrostatic reflector with the value Uq equal to the longitudinal kinetic energy T_l determined by formula (12) reverses all ions into main solenoid volume (see in Fig. 4).

From solutions (12) it follows that at $r_0=2\,R_B=R_{max}$ the solenoid's fringing magnetic field completely decreases the longitudinal particle motion, transforming it into rotary motion. At $r_0=2\,R_B > R_{max}$ the entrance fringing magnetic field reflects the charged particles. This effect is propose to use for the realisation of a magnetic ventil with unidirectional transportation of moving ions in the trap. A channel with unidirectional transportation of moving ions using the repelling action of the fringing magnetic field and located before the entrance of the trapping solenoid is not shown in Fig. 3.

3. Motion of charged particles in the crossed magnetic and electric fields of the trap

The known solutions to the equation of charged particle motion in the Penning trap are of a complicated complex-valued form or obtained by numerical integration. We found the solution to this problem in a simple analytical form and obtained some new results to the ion trap theory: the new analytical solutions, new cardinal parameters of the trajectory of a charged particle in the trap and new decomposition of the charged particle motion into rotating and drifting motions.

In the cylindrical coordinate system, used in the present paper, the equations of the azimuthal and radial motions of particles in the Penning trap are as follows [9,10] :

$$\varphi''+(2\varphi'-\omega_B)r'/r=0, \quad (15)$$

$$r''+k^2r=0, \quad (16)$$

where $k^2=\omega_B\,\varphi'+\omega_G^2-\varphi'^2$, $\omega_G^2=-qG_r/m$, G_r is the radial gradient of the quadrupole electric field. Provided $qG_r<0$ not used in the Penning trap, ω_G is the angular velocity of the charged particle motion in a hyperbolic electric field of G_r gradient. The asymptotic first integral of equation (15) by successive integration (by Bogolubov's asymptotic method) is

$$\varphi(t)'=\omega_B/2+[\varphi(0)'-\omega_B/2]/\{1+(2^1/1!)\ln[r(t)/r(0)]+(2^2/1!)\ln^2[r(t)/r(0)]+...\}, \qquad (17a)$$

from which, by summing the infinite functional series, one can arrive at the final form:

$$\varphi(t)'=\omega_B/2+[\varphi(0)'-\omega_B/2][r(0)/r(t)]^2. \qquad (17b)$$

The correctness of obtained solutions (17) is easy to check by differentiation and substitution of the result obtained in initial equation (15).

For $k^2>0$, it follows that

$$r(t)=r_0\cos kt+(r_0/k)\sin kt. \qquad (18)$$

For $k^2<0$, the solution may be written as

$$r(t)=r_0\,\mathrm{ch}kt+(r_0/k)\,\mathrm{sh}kt, \qquad (19)$$

where $k=(-k^2)^{1/2}$.

Solutions (17b), (18) and (19) describe the radial motion of a charged particle in the crossed magnetic and electric fields of the Penning trap in the parametric form r(t) and φ'(t), which makes it possible to obtain the r(φ)-function by simple step-by-step calculations (for example, by the Runge-Kutta method). When a charged particle enters a solenoid by an off-axial entrance parallel to the z-axis ($r_0'=0$, $\varphi_0'=\omega_B/2$), as in the considered case, solution (18) takes the following very simple analytical form $r(\varphi)=r_0\cos(\varphi/n)$, where, for example, n= 1 and 3 if $\omega_G^2/\omega_B^2=0$ and -2/9.

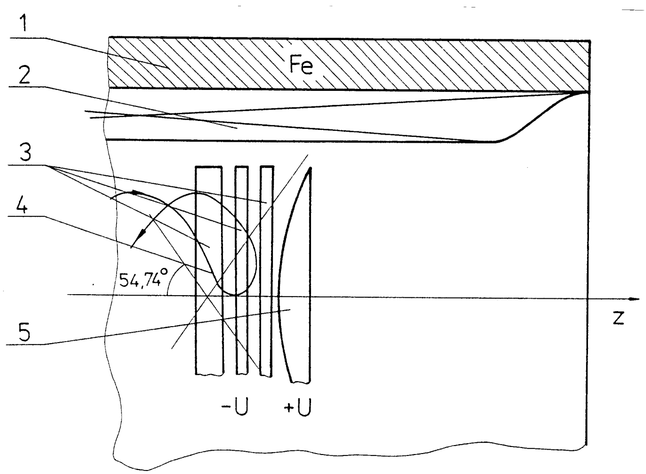


Fig. 4. Electrostatic reflector of the charged particles in the storage trap. 1 is iron armour of the solenoid, 2 is excitation electric current coil, 3 is electrostatic ring quadrupole electrodes, 4 is projection of the charged particle trajectory in the magnetic and electrostatic fields on the r, z-coordinate plan, 5 is the end cap electrode of the quadrupole hyperboloid.

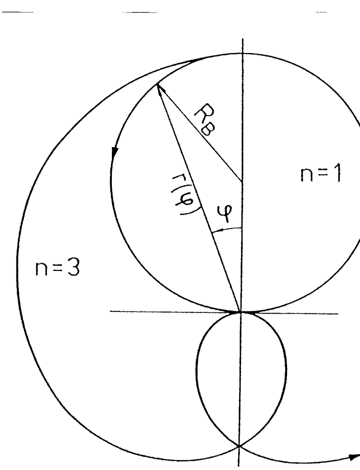
The charged particle trajectory in the Penning trap for $\omega_G^2/\omega_B^2=-2/9$ (n=3) as well as the trajectory for $\omega_G^2/\omega_B^2=0$ (n=1) is shown in Fig. 5

This complicated radial motion of the charged particles is, as can to show, a composition of rapid revolution characterised by the cyclotron angular velocity ω_B in the homogenous magnetic field and slow revolution characterised by the angular velocity ω_G in the quadrupole electrostatic field. The reason for using ω_G rather than the usually used phase axial frequency ω_z ($\omega_z^2=qG_z/m=-2qG_r/m=2\ \omega_G^2$) to describe the radial motion of a charged particle in the magnetic and electric fields of the Penning trap is clear.

4. Decomposition of the motion of a charge particles in the crossed magnetic and electric fields of the trap

The essential parameters of the motion of a charged particle in the Penning trap are the radii of the curvature of the trajectories in the radial plane: R_G is the conditional radius of the equilibrium pure electrostatic revolution at $qG_r<0$ relative of the centrum 0 (in the Penning trap $qG_r>0$), R_B is radius of the pure magnetic revolution and R_{BG} is radius of the orbit in the crossed homogeneous magnetic and quadrupole electric fields.

Fig. 5. Trajectories of charged particles in the φ, r-plane of the trap at $\omega_G^2/\omega_B^2=0$, n=1 (the electric field is zero) and at ω_G^2/ω_B^2 = -2/9, n=3 (the electric field is not zero).



From equations (15) and (16) we have got the following condition of the zero order

$$1/R_{BG}=1/R_B+R_{BG}/R_G^2, \qquad (20)$$

where $R_B=mv/qB_0$ (see formula (13) at z'=v), $R_G=(-mv^2/qG_r)^{1/2}$ at $qG_r<0$. The physical interpretation of R can be obtained from the consideration of the acting centrifugal, magnetic and electric forces [9, 10] in the radial plane. The two roots of quadraticequation (20) ($R_{BG}^{2+}R_{BG}R_G^2/R_B$ $-R_G^2=0$) for R_{BG} may be written under the condition $-0.25< R_B^2/R_G^2 <0$ (in the Penning trap $qG_r>0$ and $R_G^2=-mv^2/qG_r<0$) as

$$R_{BG}^{\pm} = -(R_G^2/2R_B)[1\pm(1+4R_B^2/R_G^2)^{1/2}]. \qquad (21)$$

Using the condition (20) and definition of the angular velocity of a particle as $\omega=v/R$ we obtain an analogous quadratic equation for frequency ω_{BG} and its two solutions:

$$\omega_{BG}^{+}=(\omega_B/2)[1+(1+4\omega_G2/\omega_B^2)^{1/2}] \text{ (conforming to } R_{BG}^{-}), \qquad (22a)$$

$$\omega_{BG}^{-}= (\omega_B/2)[1-(1+4\omega_G2/\omega_B^2)^{1/2}] \text{ (conforming to } R_{BG}^{+}). \qquad (22b)$$

There is only one possible decomposition of the complicated motion of a charged particle in the trap (see Fig. 5) into two circular motions - rotating and drifting motions (see Fig. 6).

The cyclotron radius R_B is taken as the radius of the circular rotating R_{rot} and drifting R_d motions: $R_{rot}= R_d=R_B = r_0 /2$. The maximal angular velocity of the charged particle in the Penning trap - so-called reduced cyclotron frequency ω_{BG}^+ (22a) is taken as the angular velocity of the circular rotating motion:

$$\omega_{rot}=\omega_{BG}^+ . \quad (23a)$$

Then the drifting angular velocity as it follows from the Fig. 6 is

$$\omega_d=\omega_{BG}^- . \quad (23b)$$

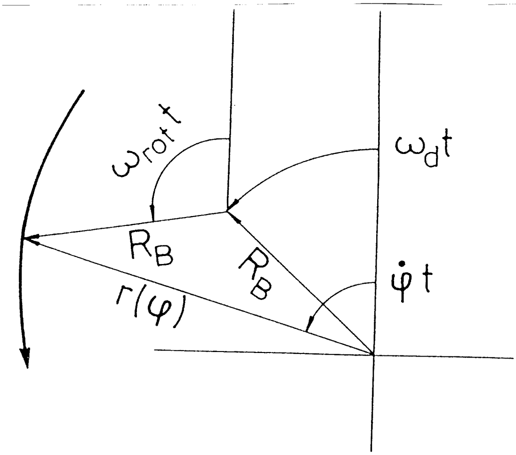


Fig. 6. Decomposition of the charged particle motion in the trap into two circular motions - rotating ω_{rot} and drifting ω_d motions.

It means, for example, that, for the values of at $\omega_G^2/\omega_B^2=0$, n=1 and at $\omega_G^2/\omega_B^2 = -2/9$, n=3 we have $\omega_d/\omega_B=v_d/v = 0$ and 1/3. Obtained relations differ significantly from the usually used relation for drift in crossed uniform magnetic and uniform electric fields $v_d=2E/B$. Only in the limiting case of $\omega_G^2/\omega_B^2=-1/4$, we have $\omega_d/\omega_B=v_d/v =1/2$ and $v_d=2E_r/B$, where E_r is the electric field in the centre of the rotating orbit.

To decompose the motion of a charged particle in the trap into two circular rotating and drifting motions correctly (23) is of great importance for making of the bunching, cooling and detecting of charged particles by a azimuthal component of the electric field.

5. Advanced electrode system for detecting of a charged particle in the trap

Laplace's equation is believed to have no simple analytical solutions for the non-zero azimuthal electric field component, which is necessary for bunching, cooling and electrical detecting of charged particles in an ion trap.

However, paper [11] used the inverse problem solution method to analytically obtain the fields of a prescribed structure for various electrical systems. Within this method, the prescribed basic field is expanded by integration of Maxwell's equations divE=0 and rotE=0.

Using the inverse problem solution method and the azimuthal non-uniformity of the basic magnetic field E_φ in the plane z=0,

$E_\varphi(\varphi, r, 0)=b\, r^l \sin(m\varphi)$, (24)

the following potential distribution can be found for an ion trap possessing azimuthal electric field component (24):

$V=G_r(r^2/2-z^2)+br\cos\varphi$ for m=1, (25a)

$V= G_r(r^2/2-z^2)+br^2\cos 2\varphi$ for m=2. (25b)

Electrostatic field (25a) is generated in a typical hyperboloid of revolution by displacing the centre of the circular orbit off the z-axis so that it should be at the off-axial input of the ions into a magnetic solenoid as in considered cases. Electrostatic field (25b) requires that the radial cross section of the hyperbolic ring and end the cap electrodes should be of any ellipsoidal form. The longitudinal splitting of the hyperbolic ring electrode into segments is not necessary to produce the azimuthal component of the electric field. These modified single-piece electrodes, well determined analytically, can be used for bunching and cooling (if it is necessary) charged particles with a high-frequency azimuthal electric field and can be used for detecting of the moving charged particles by using electrostatic induction.

6. Summary

The parameters for proposed ion trap of an "in-flight capture" type for mass measurement of separated photofission fragments to be used possibly within the framework of the DRIBs project are as follows. The kinetic energy of accelerated and mass-separated one charged fission fragments is 15 keV. This value of accelerating voltage has been chosen from the condition of the optimal transportation the ions into the ICR source for breeding their charges. The magnetic induction of the superconducting solenoid is up to B_0=4T in order to be able to capture such heavy singly-charged fission fragments as ^{132}Sn, ^{133}Sb and so on to ^{141}Cs, ^{144}Ba. The length of solenoid is L=100 cm, and its bore diameter is D=30 cm. The off axial input is at r_0=10 cm. The stop potential of the end cap electrode is V_{stop}=2.5 kV at $\Delta r_0=R_{max}-R_{min}$=1 mm. The minimal electric potential of the quasi-hiperboloidal circular and ellipsoidal ring electrodes of the linear quadrupole cell is V_{min} = -200 V.

The response frequency function of the ion trap for atomic mass measurement of ions is equal to $\omega_d/2+\omega_{rot}=\omega_{BG}^- + \omega_{BG}^+ =\omega_B$, which provides the most precise mass measurement because ω_B is depends only from high stability the superconducting magnetic field.

We note that the developed storage mass spectrometric ion trap of an "in-flight capture" type result also as a sufficient effective accumulator-collaider device for generation of the neutrons in vacuum collisions of the accelerated deuterium and tritium ions. This device can be used as driver of a subcritical nuclear fission reactor for the production of commercial electric energy (see, for example, Ref. (12)).

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Тарантин Н.И. E13-2001-17
Накопительная ионная ловушка с открытым влетом и закрытым выходом ионов для прецизионного измерения масс продуктов ядерных реакций и осколков деления

Данные о массах ядер составляют основу для построения и проверки различных моделей ядра. Тандемная система, включающая циклотрон У-400М, магнитный сепаратор КОМБАС (ЛЯР, ОИЯИ) и возможную ионную ловушку, рассматривается как комплекс для получения короткоживущих ядер в реакциях фрагментации под действием тяжелых ионов и для прецизионного измерения масс этих ядер. План научного и технического развития лаборатории включает проект создания пучков ускоренных радиоактивных продуктов ядерных реакций и осколков фотоделения (DRIBs). В этом проекте также возможны измерения масс осколков деления с помощью прецизионной масс-спектрометрической ионной ловушки.

Рассматриваются некоторые особенности действия масс-спектрометрической ловушки, а именно: свободный влет ионов и их захват с использованием деградера энергии, статических электрического и магнитного полей и нового устройства — магнитного вентиля с односторонним пропусканием ионов.

Работа выполнена в Лаборатории ядерных реакций им. Г.Н.Флерова ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2001

Tarantin N.I. E13-2001-17
Storage Ion Trap of an «In-Flight Capture» Type for Precise Mass Measurement of Radioactive Nuclear Reaction Products and Fission Fragments

Data on nuclear masses provide a basis for creating and testing various nuclear models. A tandem system of FLNR comprised of the U-400M cyclotron, the COMBAS magnetic separator and the mass-spectrometric ion trap of an «in-flight capture» type is considered as a possible complex for producing of the short-lived nuclei in fragmentation reactions by heavy ions and for precise mass measurement of these nuclei. The plan of scientific and technical FLNR research includes a project DRIBs for producing beams of accelerated radioactive nuclear reaction products and photofission fragments. This project proposes also precise mass measurements of the fission fragment with the help of the ion trap.

The in-flight entrance of the ions and their capture in the mass-spectrometric ion trap using the monochromatizing degrader, the static electric and magnetic fields and a new invention, a magnetic unidirectional transporting ventil, is considered.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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