INSTITUTE FOR NUCLEAR STUDY
UNIVERSITY OF TOKYO
Tanashi, Tokyo 188
Japan

INS-Rep.-907
Dec. 1991

INS--907

JP9204161

ION TRAP PROJECT AT INS

Ichiro Katayama, Michiharu Wada, Junichi Tanaka
and Hirokane Kawakami
Institute for Nuclear Study, University of Tokyo,
Tanashi, Tokyo, Japan

Shunsuke Ohtani
Laser Center, University of Electro-Communication,
Chofu, Tokyo, Japan

Presented at the 12th International Conference on Electromagnetic Isotope Separators and Techniques Related to Their Applications, Sendai, September 1991.

ION TRAP PROJECT AT INS

Ichiro Katayama, Michiharu Wada, Junichi Tanaka
and Hirokane Kawakami
Institute for Nuclear Study, University of Tokyo,
Tanashi, Tokyo, Japan

Shunsuke Ohtani
Laser Center, University of Electro-Communication,
Chofu, Tokyo, Japan

Abstract

We are developing an ion trap system for nuclear physics research at INS using lasers and a Penning trap. It has several important features, no specificity to ion species, fast response due to dynamic trapping and hopefully high trapping efficiency.

1. Introduction

Ion traps have been used extensively to pursue high precision measurements [1]. In particular, high precision mass measurements of unstable nuclei at ISOLDE [2] and high resolution laser spectroscopy on hyperfine interactions [3] are of great interest in nuclear physics. We have therefore proposed to build a penning trap as part of the research apparatus for the E Arena of the Japanese Hadron Project(JHP). aiming at precise mass measurements as well as laser spectroscopy of unstable nuclei. This year, we have started building the first part of the ion trap system to perform an R&D work at INS. It comprises a gas filled recoil mass isotope separator (GARIS), an ion guide (IG), a multipole field transport device and an RF trap. The system has several features to be noted. Firstly, it has no selectivity on ions to be treated. This is because the transport of the nuclear reaction product ions to the ion trap does not depend on the chemical property of the ions. Secondly, there is no appreciable delay in trapping the ions because we have no ion source which usually causes some delay and we do not need to employ the usual method of ionizing atoms stopped in a material in the ion trap. Thirdly, by employing gas cooling of ion motion in the ion trap [4], we will be able to realize highly efficient trapping. This paper presents some details of the INS ion trap system.

2. Instrumentation

The ion trap apparatus which we designed for the R&D work at INS consists of three parts: an ion guide, a transport system and an ion trap. The apparatus is used at a focal plane of the GARIS. The configuration of the present system is shown in fig. 1 and fig. 2.

(1) Ion guide

The ion guide is a high pressure He gas chamber to stop ions injected through an entrance mylar window. An energy degrader is placed before the entrance window to slow the ions so that after the energy degrader they can be stopped just inside the He gas chamber. The He gas pressure is several tens of k Pa., at which pressure ions of thermal energy have a mean free path of around 5×10^{-6} cm. The ions are therefore completely driven by the He gas flow. Nomura et al has investigated the optimum conditions for stopping the recoil ions from GARIS in a He gas and extracting them through the ion guide outlet hole (5). They have found that 10 to 15% of the ions stopped in the He gas were extracted and nearly half of those were in an ionic state. Clearly a nonnegligible fraction were captured or neutralized on the surface of the ion guide gas cell. A question then arises as to whether there is a way to prevent the collision of ions with the wall material. To begin with this question, we consider the data which are relating to ion motions in He gas at thermal energy (6). For singly charged ions in He gas the reduced mobility K defined by $V_E=KE$, where V_E is the drift velocity due to electric field and E the electric field intensity, has been measured to be about 20 cm^2/Vs. The diffusion constant D of ions in He is obtained from Einstein's equation $K=eD/kT$, where e is the electric charge, k the Boltzman constant and T the He gas temperature. The equation gives $D=0.5cm^2/s$ at normal pressure. The transverse diffusion length r_o of ions during the time τ is given by $\tau=(r_o/2.4)^2/D$. The self diffusion velocity V_d is obtained from $V_d=dr_o/d\tau=2.9D/r_o$. If we choose $r_o=1mm$, then we have $V_d=14cm/s$ and $\tau=3.4ms$. Ions in the ion guide, if they stop near the entrance, take roughly 100 msec to be extracted through the gas cell of 6cmΦ in diameter and 4cm in length. During this transfer time, the ions will diffuse by roughly 5mm. Our solution to this problem is to provide a focussing force to ions in the gas cell. From the eq. $V_E=KE$, we can find the proper electric field E at which the self diffusion velocity is compensated by diffusion velocity due to the electric field. The necessary field is about 1V/cm. There are several ways to generate this field along the inner surface of the gas cell. One way would be to cover the surface by a mesh and to apply a voltage to repel the ions from the wall (7). Another would be to install an array of ring electrodes distributed conically along the surface and apply an AC electric field between alternative rings to produce a focusing force. This is a variation of the electric curtain method proposed by Masuda et al (8).

(ii) Ion transport

The ions are carried by the He gas flow through a 2mm diameter hole. They are then accelerated to an appropriate energy and focussed with several electric lenses (squeezer [9]). The electric potentials applied to these lenses are extremely low (several volts) compared with conventional values of more than 1 kV. The He gas is evacuated with a combination of large vacuum pumps: mechanical boosters of 4200 and 1200 m^3/h and a rotary pump of 5000 l/min. The ions through the squeezer and following two skimmers are then focussed into the transport system. This system, which generates a multipole electric field around the symmetric axis to confine the ions radially, consists of a number (2n) of circular rods distributed uniformly on a circle in the plane perpendicular to the symmetry axis. The case of $n = 4$ (octapole field ion guide, OPIG) has been discussed in ref. [10]. It is to be noted that the device may be used as a buncher for injection into the ion trap.

(iii) Ion trap

The ion trap to be used is a combined (RF + axial magnetic field) type. The trap is placed between pole-tips of a C-type magnet. The ions from OPIG are injected to the ion trap through a hole on one of the end cap. Schuessler et al. has calculated the conditions for trapping of ions injected from outside into an ion trap [11]. They have found that without cooling of the ion motions in the trap the trapping probability is very small. Among the several ways to cool ion motion in the trap, i.e., gas cooling, laser cooling, register cooling, electron cooling and stochastic cooling, the simplest is gas cooling. The effectiveness of gas cooling on the improvement of trapping efficiency for an RF trap has been discussed by R. B. Moore [4]. In order to study the effect of gas cooling on trapping efficiency of ions injected from outside a trap, a computer simulation program has been developed. The program employs a simple model in which a rigid body collision with a uniform distribution in CMS as well as with a constant mean free time is assumed between the ion and a He atom. Figure 3 shows one example of a simulation result: Gas cooling in an RF trap is demonstrated for the case of a mass 87 ion in the singly charged state. The ion is put at 2cm from the center in the median plane with an energy of 5 eV. The energy and position of the ion is traced as a function of time elapsed. The He pressure is such that mean free time is 1μs which corresponds to order of 10^{-2} Pa. We can see the essential cooling according to this model is done within 40 μs.

In a more advanced model, it would be desirable to implement effect of a ponderum force induced by electric polarization of a He atom by the ion as well as variable mean free time. Stored ions are extracted through the opposite end cap for future analysis by a quadrupole mass filter or to another trap for high precision mass spectroscopy.

3. Status of the experiment and further plans

The ion trap project at INS is being intensively pursued towards completion of a Penning trap and a laser system. As they will probaly not be built within a year, we are planning to use that time to improve the trapping efficiency of ions provided from the GARIS + IG system. The system, when optimized, may become a powerful tool because it can manipulate ions irrespectively of their chemical properties. With the Penning trap and laser systems, it will allow us to perform high precision mass measurements or laser spectroscopy of these unstable nuclei.

As respects to the laser spectroscopy of unstable nuclei in an ion trap, laser cooling is quite desirable. It is to be noted, however, that this is not a universal method because the wave length of resonance flourescence for ions is generally in the ultra violet and there is no tunable laser in this region. In this regard we plan to use sympathetic cooling [12] of ions by merging them with specific ions which can be cooled by lasers.

At INS construction of a new pilot facility for the acceleration of unstable beams will soon start [13]. In this project radionuclide ions which are produced by cyclotron beams and separated by a high resolution mass separator are to be accelerated by a combination of an RFQ and an IH linac. It is also planned that these ions be transported to the ion trap without acceleration for the study of a nuclear spectroscopy. It is to be noted that the mass separator system is designed so that it can deal with an extraction of ions from the ion source at full voltage and decceleration after mass separation. In order to facilitate the scheme, the mass separator will be electrically insulated so that it can be set at an appropriate high potential. With this scheme, we can rather easily guide ions to an ion trap. It will be one of the effective ways to capture radionuclide ions from an ISOL in an ion trap.

Acknowledgement

Discussion on OPIG with Dr. K. Okuno is greatly appreciated. We thank Prof. R. B. Moore for his comments on the manuscript and also on ponderum force. This work was supported in part by Matsuo Foundation.

References

[1] D. J Wineland and W. M. Itano, Adv. At. Mol Phys. 19 (1983) 135.

[2] H Stolzenberg et al, Phys. Rev. Lett. 65 (1990) 3104.

[3] G. Werth. Phys. Scripta T22 (1988) 191.

[4] R. B. Moore and S. Gulick, Phys. Scripta T22 (1988) 28.

[5] T. Nomura et al, Nucl. Instr. Meth., A269 (1988) 23.

[6] E. W. McDaniel and E. A. Mason, The Mobility and Diffusion of Ions in Gases (John Wiley & Sons, New York, 1973).

[7] T. Nomura, Private communication.

[8] S. Masuda et al, Advances in Static Electricity vol. 1. (Proc. 1st Int. Conf. on Static Electricity (Vienna, 1970) P398.)

[9] A. Iivonen et al. Phys. Scripta 42 (1990) 133.

[10] K. Okuno. Jour Phys. Soc. Japan 55 (1986) 1504.

[11] H. A. Schuessler and Chun-sing O, Nucl. Instr. Meth. 186 (1981) 219.

[12] D. J. Larson et al, Phys. Rev. Lett. 57 (1986) 70.

[13] T. Nomura, 4th Int. Conf. on Nucl-Nucl Collision (Kanazawa, 1991).

Figure Captions

Fig. 1 An ion trap system placed at a focal plane of a gas filled recoil mass isotope separator (GARIS) at INS.

Fig. 2 Configuration of present ion trap system : (1) GARIS, (2) Energy degrader, (3) Ion guide, (4) Electric focus lens system (squeezer), (5) Octapole ion guide, (6) Combined trap, (7) 2nd Octapole ion guide.

Fig. 3 Gas cooling effect in an RF trap. For details, see text.

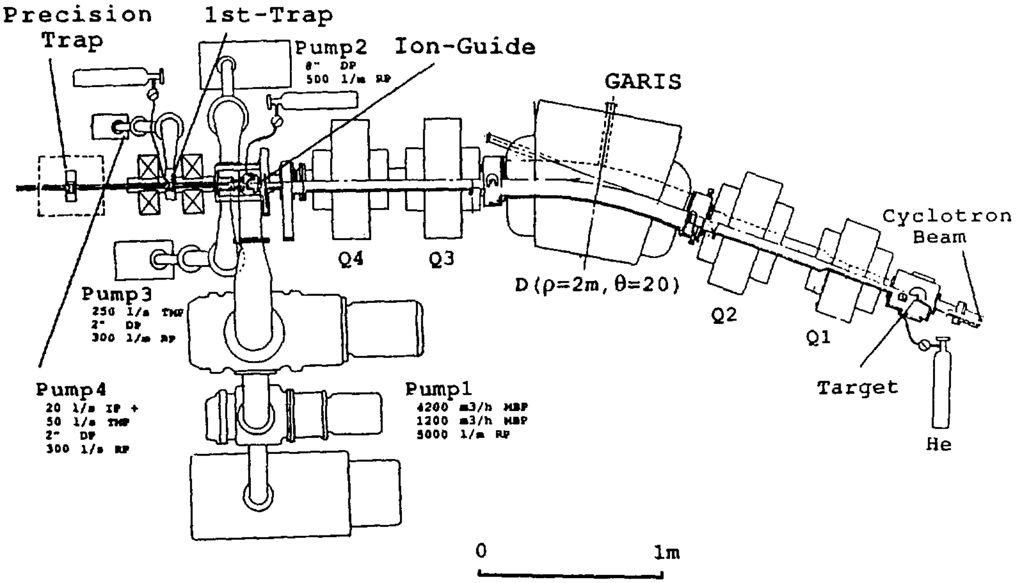
Precision Trap
1st-Trap
Pump2
8" DP
500 l/m RP
Ion-Guide
GARIS
Cyclotron Beam
Q4
Q3
D(ρ=2m, θ=20)
Q2
Q1
Target
He
Pump3
250 l/s TMP
2" DP
300 l/m RP
Pump4
20 l/s IP +
50 l/s TMP
2" DP
300 l/s RP
Pump1
4200 m3/h MBP
1200 m3/h MBP
5000 l/m RP
0
1m

Fig. 1

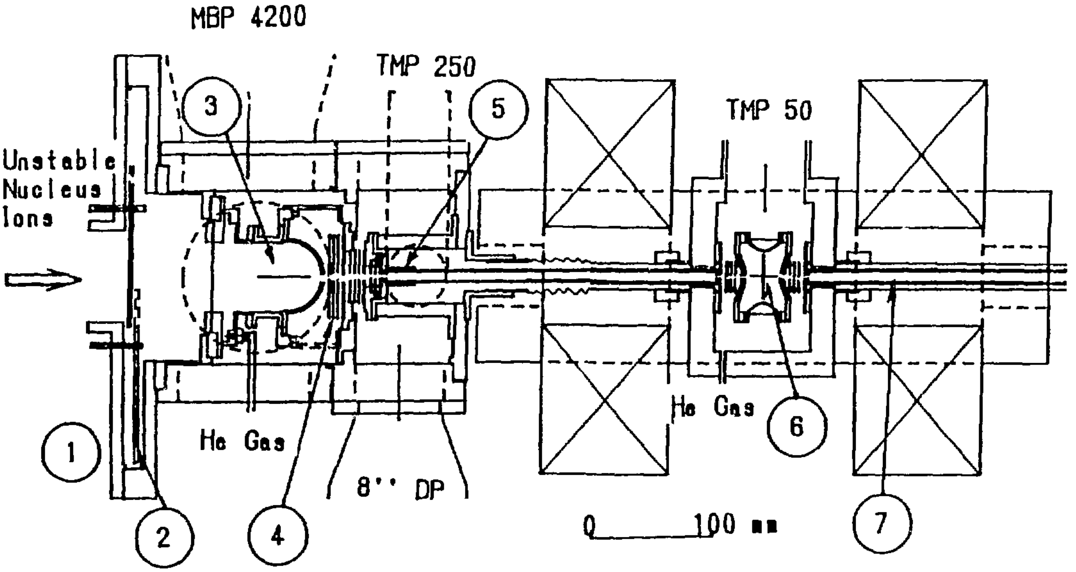
MBP 4200
TMP 250
TMP 50
Unstable Nucleus Ions
3
5
1
2
4
6
7
He Gas
He Gas
8'' DP
0 100 mm

Fig. 2

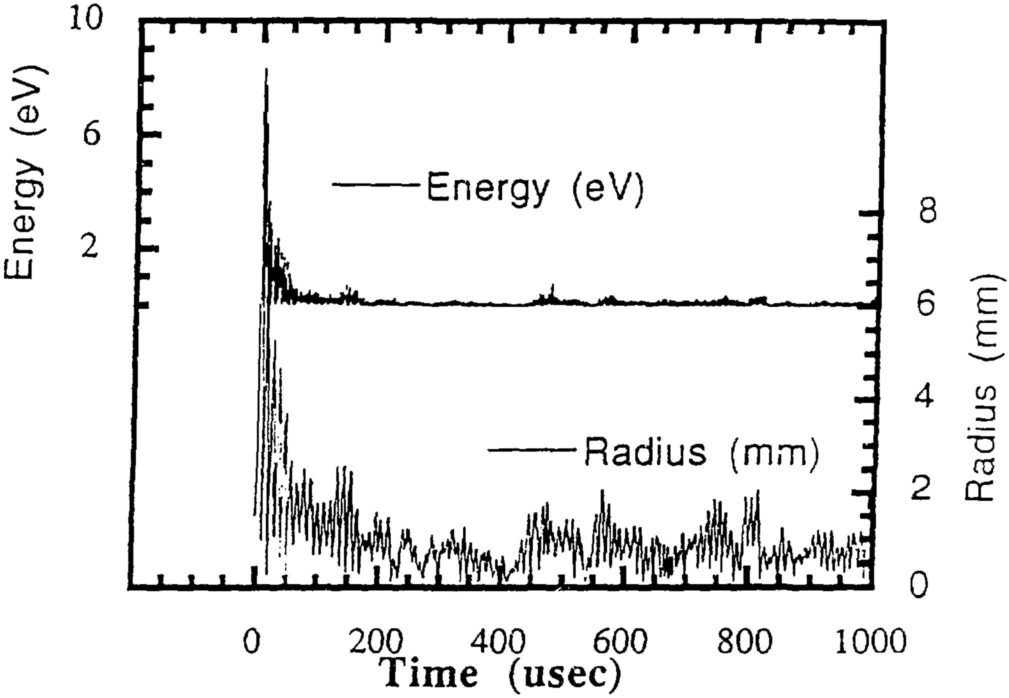
Energy (eV)
10
6
2
Energy (eV)
Radius (mm)
8
6
4
2
0
Radius (mm)
0
200
400
600
800
1000
Time (usec)

Fig. 3