RESULTS FROM LANZHOU K450 HEAVY ION CYCLOTRON

Wei Baowen
Institute of Modern Physics,Academia Sinica
P.O.Box 31,Lanzhou,China

Abstract

The heavy ion research facility at Lanzhou (HIRFL) consists of a K69 sector focusing cyclotron SFC as the injector and a K450 separated sector cyclotron SSC as the main accelerator. Any ions from C to Ta can be accelerated and the maximum energies are ranged from 5 MeV/u to 125 MeV/u. As of May 1987 the injector SFC has been put into operation. The beam of C^{6+} was accelerated up to the outermost radius of SSC on December 8 and successfully extracted from SSC on December 12, 1988. The results from HIRFL are discussed in this report.

Introduction

The 1.5m conventional cyclotron designed by USSR was starting to be assembled in IMP in 1960 and put into operation in 1963. During 1960s, it was mainly used for fast neutron physics study and radioisotope production by using the extracted proton,deutron and α-particle beams.Since IMP started to do researches on heacy ion nuclear physics at the beginning of 1970s,the experimental work has been done on this cyclotron modified to accelerate carbon,nitrogen and oxygen ions to energies of about 73,105 and 85MeV respectively. As the further development of heavy ion physics requires much modern facilities,the possibility of building a new heavy ion research facility in Lanzhou(HIRFL) was therefore surveyed. The idea of using the existing cyclotron converted to 1.7m sector focusing cyclotron(SFC) as the injector and constructing a new separated sector cyclotron(SSC) as the main accelerator was soon taking shape. The main goal of this project is set as follows:

-acceleration of ions from carbon to xenon with maximum energies of about 100MeV/u for light ions (C-,N-,O-,Ne-) and 5MeV/u for Xe-;
-beam intensity ranging from 10^{12} pps for light ions to 10^{10} pps for heavier ions;
-energy resolution being about 10^{-3};
-beam emittance being about 4π mm mrad.

The results from HIRFL are discussed in this report.
By using the ECR ion source as an external ion source of SFC,the acceleration of ions can be explanded from Xe to Ta and the maximum energy for light heavy ions can be reached up to 125 MeV/n.
As of May 1987 the injection SFC has been put into operation.The beam of C^{6+} was injected into SSC in June of 1988 and reached up to outermost radius on December 8. We succeeded to extract the beam from SSC on Dec. 12,1988.

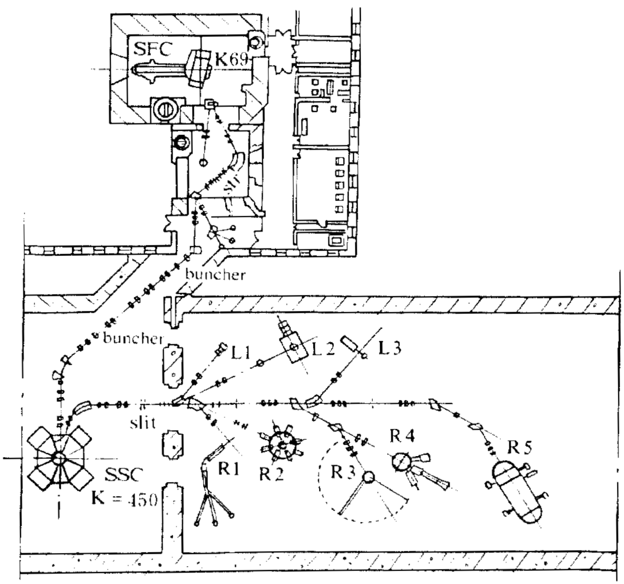

Fig.1: General layout of HIRFL. R1-isotope separator,R2-in beam γ-measuring devices, R3-heavy ion telescope, R4-position sensitive ionization chamber, R5-cylindrical scattering chamber, L1-fast chemical sepaation apparatus, L2-irradiation equipment, L3-equipment for atomic physics study.

HIRFL Scheme and Parameters

The HIRFL Scheme and parameters have been describled in previous publication[1], let me however recall the main points.

Figure 1 shows the general layout of HIRFL. It consists of following main parts:

-an injector SFC with energy constant K=69
-a main accelerator SSC with energy constant K=450
-60m beam line from SFC to SSC
-experimental areas and concerning beam lines.

Table 1 gives the main parameters of HIRFL.The ion source of SFC is internal PIG type at present operation. An ECR ion source is now under testing in the cyclotron laboratory of IMP. It will be mounted in the basement under the SFC vault and used as an external ion source for SFC. The use of high change state heavy ion source will be able to expand the beam vareity and energy range of HIRFL. Figure 2 gives the

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Table 1: Main parameters of HIRFL

Orbit parameters	
Injection mean radius	1.00m
Extraction mean radius	3.21m
Radial betatron frequency	1.087-1.202
Vertical betatron frequency	0.742-0.864
Sector magnet	
Number of sectors	4
Sector angle	52°
Magnet gap	10cm
Maximum field	16kG
Number of trim coil	36
Radio frequency	
Frequency range	6.5-14MHZ
Number of Dee	2
Dee angle	30°
Peak voltage	100-250kV
Rf power	240kW
Harmonic number	2-10
Accelerating aperture	5cm
Q-value	6000-10000
Coupling loop impendance	20-100Ω
Vacuum	
Volume of the vacuum chamber	$100m^3$
Operating pressure	$1.3x10^{-5}$ pa
Total gas load	$1.8x10^{-3}$ pa m^3 s^{-1}
Effective pumping speed	$1.4x10^2$ m^3 s^{-1}
Buncher	
Frequency range	26-56MHz
Harmonic number	4
Peak voltage	70kV
Number	2
Injector SFC	
Number of sectors	3
Spiral angle	33°
Pole diameter	170cm
Extraction radius	75cm
Maximum mean magnetic field	16kG
Circular coil	12 pairs
Valley coil	4x3 pairs
Dee number	1
Dee angle	180°
Frequency range	6x18MHz
Peak voltage	100kV
Rf power	200kW
Vacuum	$5x10^{-6}$ torr

maximum energy per nucleon vs mass number of HIRFL with and without ECR ion source.With ECR ion source,HIRFL can accelerates, for example, tantalum ion to the energy of above Coulomb barrier for heavy ion nuclear collisions and light heavy ions,for example, carbon ion to the energy of 125 MeV/u.
The beam diagnostic system of HIRFL consisting of diagnostic elements such as Farady cups, slits,secondary emission multiwire chambers, centre phase probes,radial differential probes and position probes and measuring units such as beam energy measurements and beam emittance measurements act as an important role in the beam tunning and beam optimization.

The control system of HIRFL is bassed on CAMAC distributed intelligent control.The local control stations are designed according to HIRFL's subsystems such as injector,beam line, injection and extraction,magnet,vacuum,rf,diagnosis and measuring units. They are linked by CAMAC

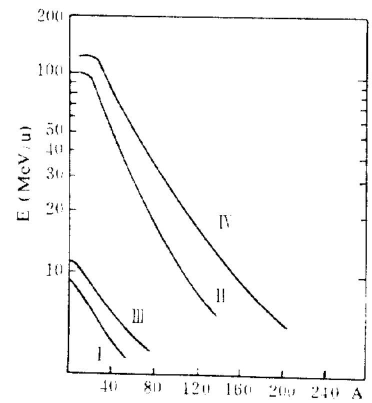

Fig.2: The maximum energy vs. mass number of HIRFL.
- I SFC+PIG ion source
- II SFC+SSC+PIG ion source
- III SFC+ECR ion source
- IV SFC+SSC+ECR ion source

serial dataway and drived by master computer through CAMAC auxiliary crate controller then to realize CAMAC communciation. In these stations,all the power supplies are controlled by microprocessors and the positioning devices are controlled by stepping motors or pneumatic units.

Two VAX-8350 computers,each having 12 MB memories and sharing 4x520 MB disk group and 2x300 MB removable disk mass storage cluster, with comfortable peripheral equipment have been installed on sites in the central control room of HIRFL. One of them is used as a master computer for HIRFL control system. Another one is used as a reserve computer when the former one is in fault. Additional. it is also used for calculations and off-line data processing for the experiments carried out in the experimental areas.
The main console in the central control room consists of storage oscilloscope,signal observation and seven touch panels.

Eight experimental equipment have been arranged at the terminals of post beam line of SSC in the experimental hall. They are isotope separator,in beam γ-ray measuring devices, heavy ion telescope, position sensitive ionization chamber,cylindrical scattering chamber, fast chemical separation apparatus, equipment for atomic physics study and irradiation. This is the main experimental area of HIRFL, 56m long, 26m wide and 11m height. A crane with 50T lifting power has been arranged in this hall. The heavy ion research programs for low energy and medium energy nuclear physics, atomic physics and material science could be done on these facilities. The movable shielding walls divided this area into several small experimental regions. Just outside of this area there are two counting rooms (150 m^2 each) and a computer room. Two micro VAX-2 computers are used for data acquisition. One of the VAX-8350 computers is used for off-line data processing.

Paralleling to the main beam line from SFC to SSC, another two auxiliary experimental areas have been arranged and planned:

-first area: The beam extracted from SFC is guided into a 1 m diameter scattering chamber after going through about 10 m beam line. The experiments could be done in this area only in the case of no beam going through the main beam line.

-second area: After stripping,the beam with higher electric charge states can be guided into some experimental equipment. The useful beam for SSC acceleration with suitable electric charge states is still going through the main beam line. So that, both of the experiments could be done in this area and in the main experimental area at the same time.

A PDP11/44 computer with 4MB memories, 10MB and 456MB disks and comfortable peripherals is used for data acquisition for the experiments carried out in this two auxiliary areas. The counting room and PDP11/44 computer room are just behind the first area (see figure 1).

Main Experimental Area

The arrangement of the main experimental area of HIRFL including the post beam line is given in figure 1.

Experimental equipment

1. Isotope separator

The main parameters of the isotope separator is given as follows:

Angle	54.7°
Curvature radius	150 cm
Magnetic field	4 kG
Gap	6 cm
Mass disperssion	7.5mm(for M=200)
Maximum separation mass	250
Resolution $M/\Delta M$	1000
High voltage	50 kV
Minimum lifetime	100 ms

It will be used for short lifetime nuclide measurement on-line and long lifetime nuclide measurement off-line.

2. In beam γ-ray measuring devices

The in-beam γ-ray measuring devices consists of 6 sets of HpGe γ-ray detectors, 6 sets of BGO/NaI anticompton spectrometers and 14 pieces of hexagonal-shape BGO as a crystal ball used for γ-multiplicity filter. It will be used for nuclear structure and reaction mechanism research.

3. Heavy ion telescope

It is a combination system including a ΔE-E telescope and a time of flight apparatus. The resolutions of the heavy ion telescope is as follows:

Δt	200-300 ps
$\Delta E/E$	0.01
ΔE resolution	0.05
$Z/\Delta Z$	30-50
$A/\Delta A$	60-80

4. Large area position sensitive ionization chamber

It includes PPAC plastic hodoscopes, ΔE-E detectors, γ-detectors and three kinds of ionization chambers. The ionization chmaber will have the following resolutions:

	140cm IC	80cm IC	35cm IC
Window	40x20 cm^2	40x20 cm^2	25x5 cm^2
$\Delta E/E$		o.ol	
$Z/\Delta Z$	60	40-50	40
ΔX		2 mm	
ΔY		2 mm	
Δt		250ps	

It is designed mainly for the intermediate energy heavy ion nuclear physics such as the inclusive experiments and the coincidence measurements between particle, γ-ray and fragments.

5. Cylindrical scattering chamber

It has following parameters:

diameter	2.8 m
length	8 m
minimum detectable angle	1°
maximum flight distance	6.5 m

Two kinds of detectors will be used in this chamber. One is fission fragment detector including the two dimension position sensitive PPAC and Brage curve ionization chambers. Another one is light particle detector using the one dimension position sensitive plastic scintillators.

6. Fast chemistry separation apparatus

It includes the liquid phase fast chemical separation device (1 second) and the gas phase fast chemical separation device with the He-jet transport system. It will be mainly used for the nuclear decay research of short lifetime nuclides and the syntheses of neutron deficient nuclides.

7. Equipment for atomic physics study

It consists of two parts.First part is a beam-foil spectroscope used for the mean lifetime measurements of some atomic energy levels and the Rydberg state population probability. Second part is used for the studies of heavy ion atom collisions, mainly on the production mechamism of the inner shell vacancies during the collision.

8. Irradiation equipment

It consists of beam uniformity unit,beam monitor and irradiation chambers. A magnetic sweeping system has been designed to produce a beam size of 50x50 mm^2 with about 5% variation in uniformity. The irradiation temperature will be controlled in the range of 4°K-800°K with an accuracy of 0.5°K. The chilling power is about 2 W at 10°K and 5 W at 20°K. It will be used for the studies of solid state physics, material science and biomedical irradiations.

Post beam line

The beam extracted from SSC going through a 66° D-magnet and the Q-magnets forms a double waist at the slit before guiding into the experimental hall. Regarding to it as starting point, the beam is dalivered to each target position, where a beam spot size of 4mm in diameter is available.

Two achromatic and double telescopic systems are employed as subsystem in the post beam line design. When beam goes through such a system, a waist in beam envelop at its beginning is reproduced as the same waist at its end both horizontally and vertically. Forthermore, the overfocusing effects are also avoided.

Operation of SFC

Figure 3 shows the schematic diagram of the injector SFC. It has been operated for more than one year. Table 2 gives the extracted ions and the concerning operating conditions. Three experiments titled of the shadowing effect of emitted α-particles in the heavy ion reaction, the incomplete fusion fissin reaction and the chemical research of complete and incomplete fusion reaction have been done.

The SFC's one year operation is quite satisfactory, however, as a part of the cyclotron components are too old, some renewal work has been planned. A pair of main coil of the cyclotron magnet together with the regulated rectifier DC power supply has been fabricated and tested and it will be put into operation on site this year.

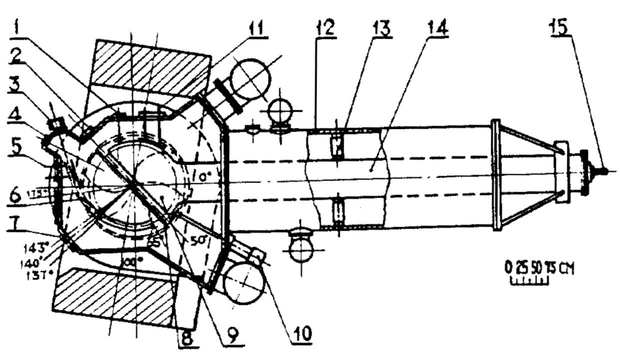

Fig.3: Schematic diagram of the injector SFC. 1-measure capacity, 2-probe, 3-steering magnet, 4-ion source, 5-magnetic channel, 6-deflection plate, 7-probe, 8-dummy dee, 9-dee, 10-coupler capacity, 11-trimmer capacity, 12-cavity, 13-shouted plate, 14-dee stem, 15-probe.

Table 2: The operating parameters of SFC. h-harmonic number, f-accelerating frequency, B-mean magnetic field, V_{acc}-accelerating radio voltage, $V_{E1,2}$-the DC voltage of segment 1, 2 of the electrostatic deflector, V_{E3}-the DC voltage of segment 3 of the electrostatic deflector, I-extracted beam intensity, E-extracted beam energy.

	$^{12}C^{4+}$	$^{16}O^{5+}$
h	1	1
f(MHz)	7.1	7.1
B(kG)	14	15
$V_{acc.}$(kV)	60	60
$V_{E1,2}$(kV)	56	58
V_{E3}(kV)	60	63
I(eua)	1.1	1.4
E(MeV/u)	5.9	6.0

Beam tuning of SSC

Figure 4 shows the schematic diagram of the main accelerator SSC. The main characteristics of the beam for beam tuning are summarized in table 3.

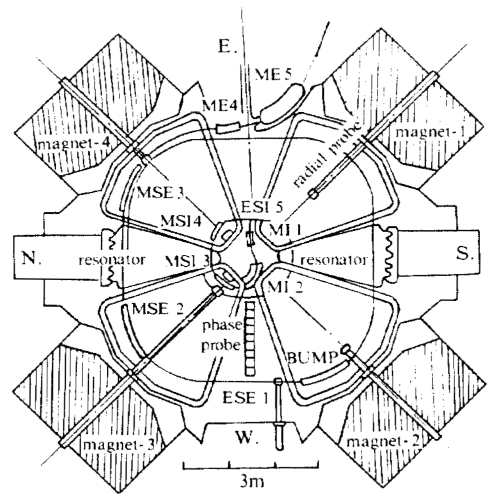

Fig.4: The schematic diagram of the main accelerator SSC.

Table 3: The main characteristics of the beam for tuning.

	SFC	SSC
Ion	C	C
Mass number A	12	12
Charge state Z	4+	6+
Revolution frequency f_{rev}(MHz)	6.262	4.697
Radio frequency f_{rf}(MHz)	6.262	9.394
Harmonic number h	1	2
Maximum magnetic field B(kG)	12.270	10.735
Beam energy E (MeV/u)	4.5	50
Matching efficiency η (%)		50
Beam intensity I (nA)	1000	30

The extracted beam intensity from SFC is about 1μa. The preliminary result of the beam line tuning shows that the transmission efficiency from the exit of SFC to the entrance of SSC for C^{4+} beam (C^{6+} after stripping) is about 50%. That means that about 500nA of C^{6+} beam could be reached to the entrance of SSC. Then the C^{6+} beam was injected into the main accelerator SSC in June of 1988. Though we adjusted all of the electric parameters of the injection system including the steering magnet system,the injection efficiency was only about 10%. Furthermore,the beam always has a big initial amplitude of about 3 cm(upper) contributed to the axial Betatron oscillation. In such case, we opened the vacuum chamber, adjusted the magnetic channel MSi3 to produce a magnetic field of about 50G in the negative radial direction. After this collection we easily got an injection efficiency of about 50%. At that moment, the coupler between the south cavity and rf amplifier of SSC met some trouble and we had to stop for repairing and retesting.Finally,we extracted the 50 MeV/u C^{6+} beam from SSC in Dec.12 of 1988. Figure 5 shows the beam pattern of SSC for the initial turns after injection measured by the radial differential beam probe. The extracted beam intensity from SSC is about 30nA.

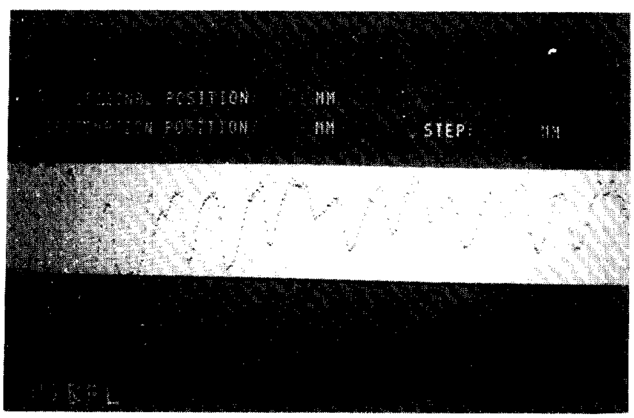

Fig.5: The beam pattern of SSC measured by radial differential probe.

Reference
[1] B.W.Wei,HIRFL separated sector cyclotron progress, Eleventh international conference on cyclotrons and their applications. 1986, Tokyo. P.176.