The influence of Magnetic fields on the ion beam current and beam oscillation of Calutron ion source

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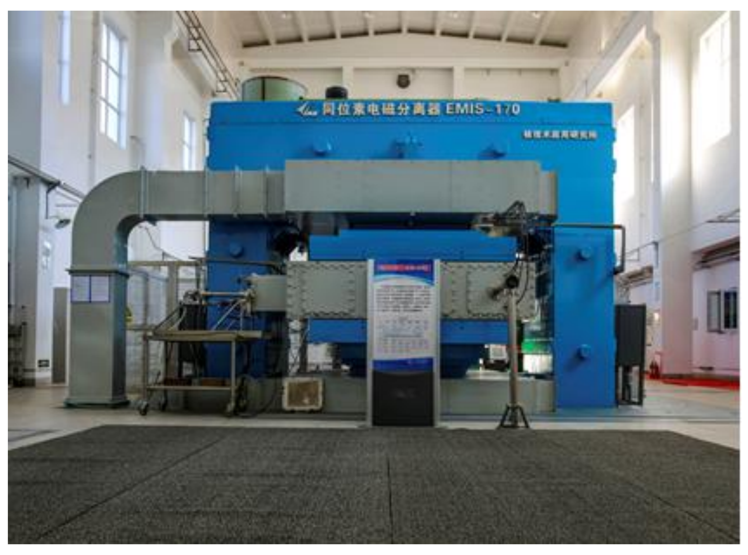
In China, the only one yielding-type electromagnetic isotope separator, named EMIS-170, locates in China Institute of Atomic Energy. The ion source used is the Calutron ion source. The dependence of ion beam current and beam oscillation of the Calutron ion source on the magnetic field is studied in the EMIS-170 experimentally. It is observed that the beam current significantly increases from 15 mA to 29 mA with the increase of the magnetic field at the range of 170 G ~ 620 G and decreases slowly to 26.7 mA when the magnetic field increases to 955 G. This phenomenon is analyzed qualitatively from the view of the primary electron motions along the magnetic field and the ion diffusion across the magnetic field. The theoretical curve fits the experiment data well. The fluctuation of the beam current is observed trivial at 340 G ~ 390 G with frequencies of about 20 kHz and 400 kHz and almost disappears at 620 G ~ 730 G. As the magnetic strength is larger than 730 G, the fluctuation becomes quite obvious with frequencies of about 40 kHz and 250 kHz.

1. Introduction

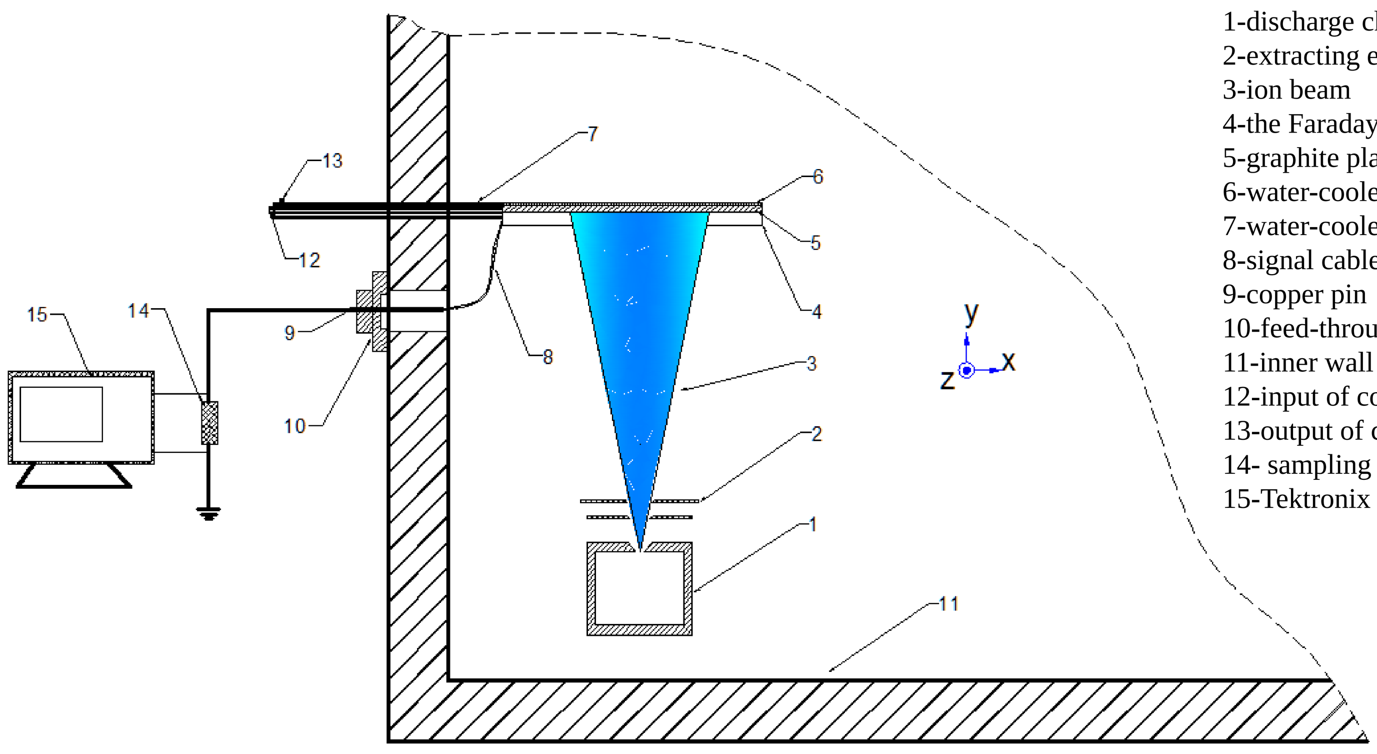
One application: Electromagnetic isotope separation



The EMIS-170 separator

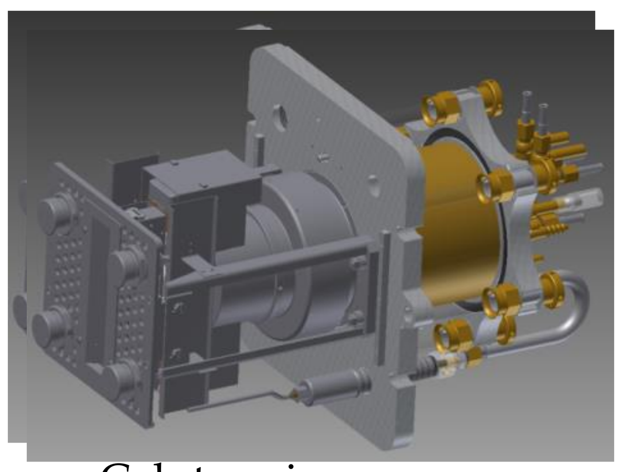
The isotope products

2. Experimental Setup



1-discharge chamber of the Calutron ion source
2-extracting electrodes of the Calutron ion source
3-ion beam
4-the Faraday plate
5-graphite plate
6-water-cooled stainless steel substrate
7-water-cooled stainless bar
8-signal cable
9-copper pin
10-feed-through
11-inner wall of the vacuum chamber
12-input of cooling water
13-output of cooling-water
14- sampling resistance of 600Ω
15-Tektronix DPO3014 oscilloscope

Experimental system on the EMIS-170

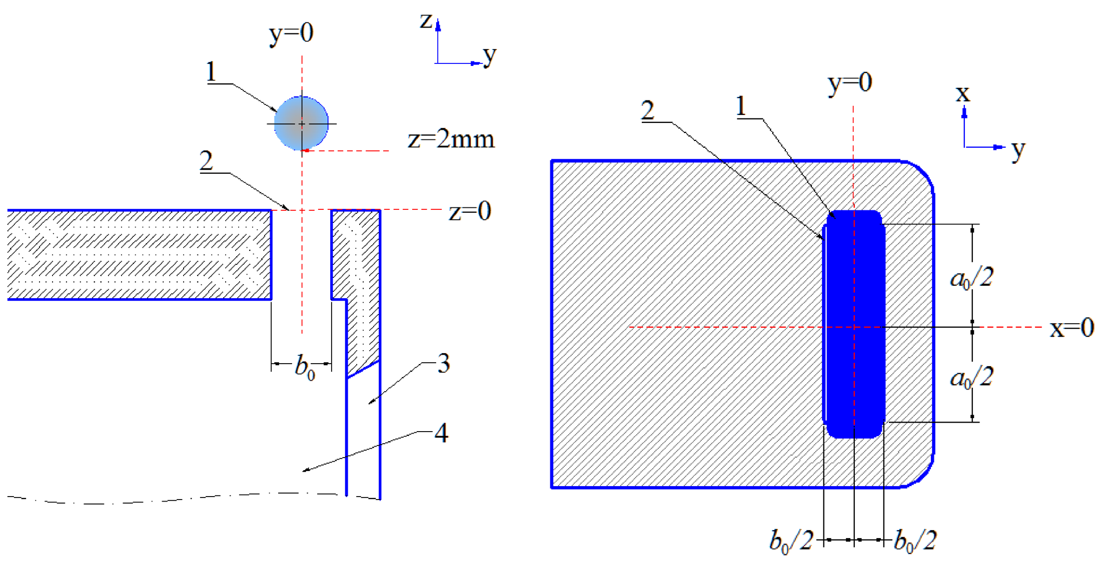


Calutron ion source

The cathode and discharge chamber

Experiment Conditions

Vacuum chamber	1×10^{-3} Pa
Vacuum pumping rate	20000L/s
Ion species	Rubidium
Ion energy	30 keV
Focusing voltage	-10 kV
Discharge voltage	200~300 V



1-directly heated cathode (tungsten filament)
2-electron slot
3-extraction slit
4-discharge chamber made of graphite.

the cathode structure

a、b : the cross dimensions of primary electron beam near the electron slot

a_0、b_0 : the dimensions of the electron slot

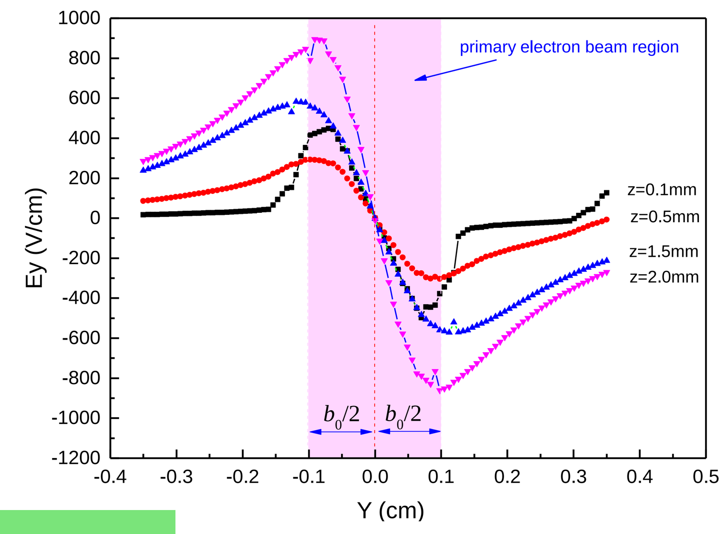
$a\approx a_0$
$b\approx b_0+\Delta b$

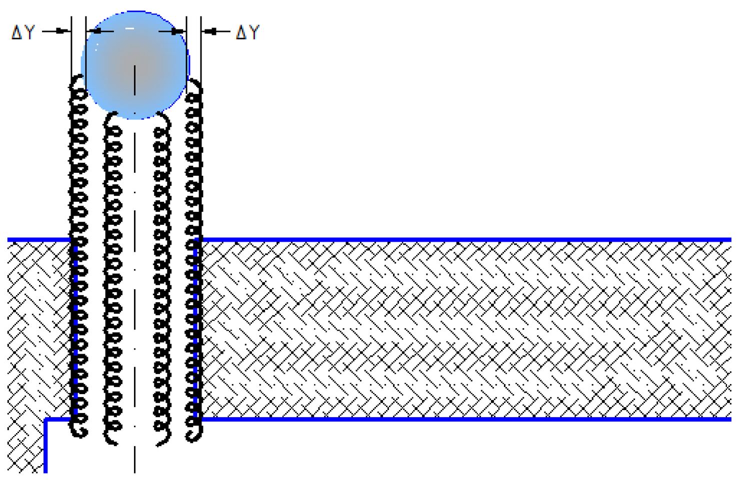
Lorentz Equation of electron:

$$m_e\frac{d\vec{v}}{dt}=-e\cdot(\vec{E}+\vec{v}\times\vec{B})$$

$$Y(t)-Y_0=-\frac{m_eE_y}{eB^2}(1+\cos\omega t)$$

distribution of E_y along y direction:





$$\Delta Y=\frac{m_eE_y}{eB^2}$$

$$\Delta b=2\Delta Y=\frac{2m_eE_y}{eB^2}$$

$$I_+\propto\frac{e}{1+\omega_i^2\tau^2}\cdot\frac{1}{1+2\Delta Y/b_0}\cdot\frac{I_e\sigma_r n_g}{e\cdot a_0\cdot b_0}\cdot\iint(\mu_i n_g E_y-D_i\partial n_g/\partial y)dxdz$$

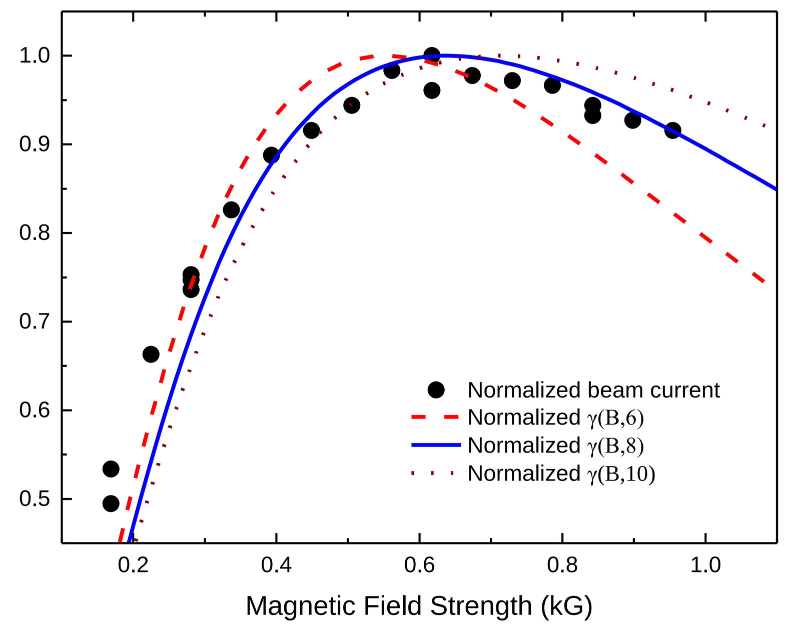
magnetic field related part

$$I_+\propto\frac{e}{1+\omega_i^2\tau^2}\cdot\frac{1}{1+2\Delta Y/b_0}:=\gamma(B,\tau)$$

$$\gamma(B,\tau)=\frac{1}{1+\frac{\alpha}{\omega_i^2\tau^2}}\cdot\frac{1}{1+\omega_i^2\tau^2}$$

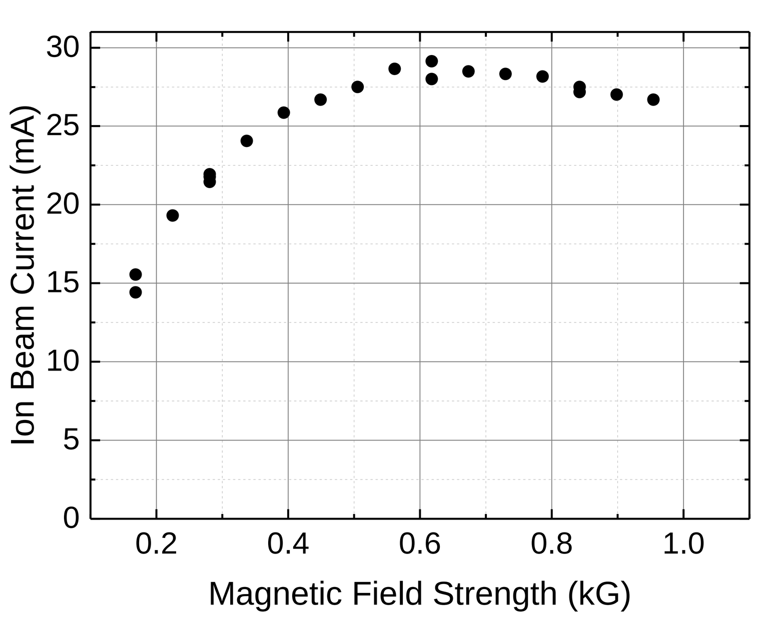
$$\alpha=\frac{2eE_y}{b_0M_i}\cdot\frac{m_e}{M_i}\cdot\tau^2$$

$$\tau=\frac{1}{n_g\sigma v_i}\approx\frac{\sqrt{T[10^3K]}}{p[Pa]\cdot\sigma[10^{-18}m^2]}\times31.4\mu s\qquad\tau^*=\frac{\tau}{31.4\mu s}$$



3. Results

3.1 Beam Currents



- Nonlinear relationship
- Optimal magnetic field strength exists.

$$\Gamma_y=\frac{\mu_i n_i E_y-D_i\partial n_i/\partial y}{1+\omega_i^2\tau^2}\qquad n_i\propto R=\frac{I_e\sigma_r n_g}{e\cdot a\cdot b}$$

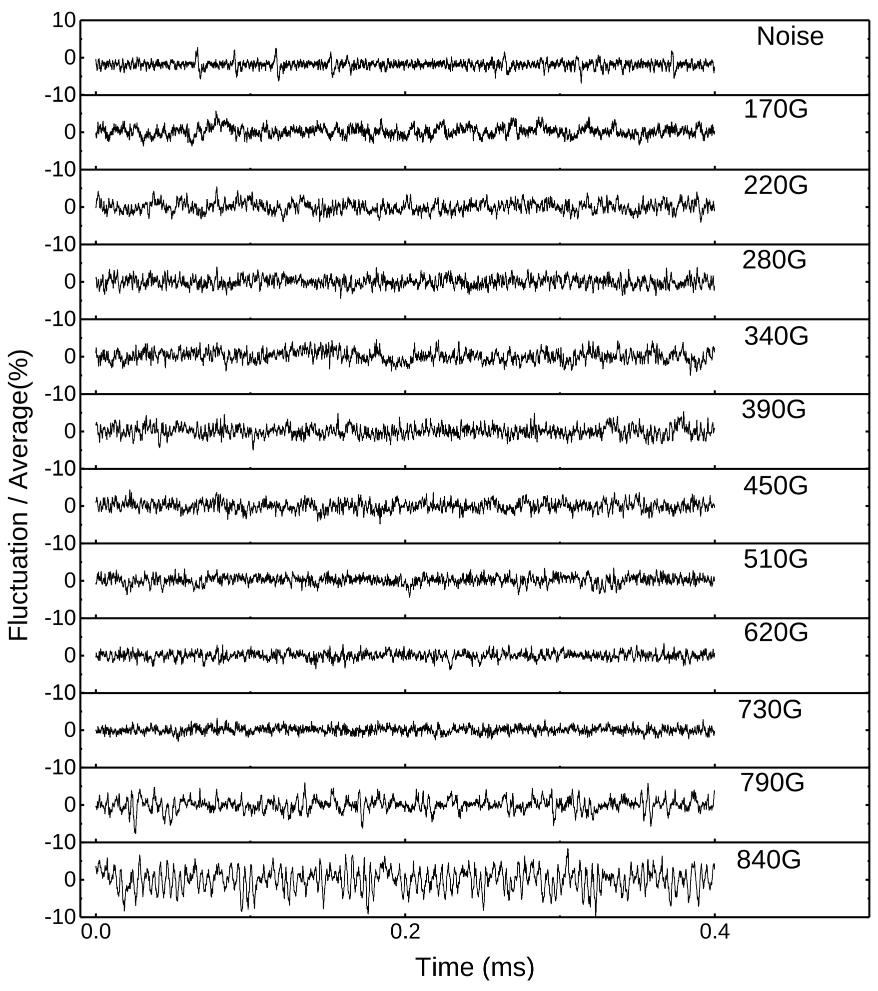
$$I_+=\frac{e}{1+\omega_i^2\tau^2}\cdot\iint(\mu_i n_i E_y-D_i\partial n_i/\partial y)dxdz$$

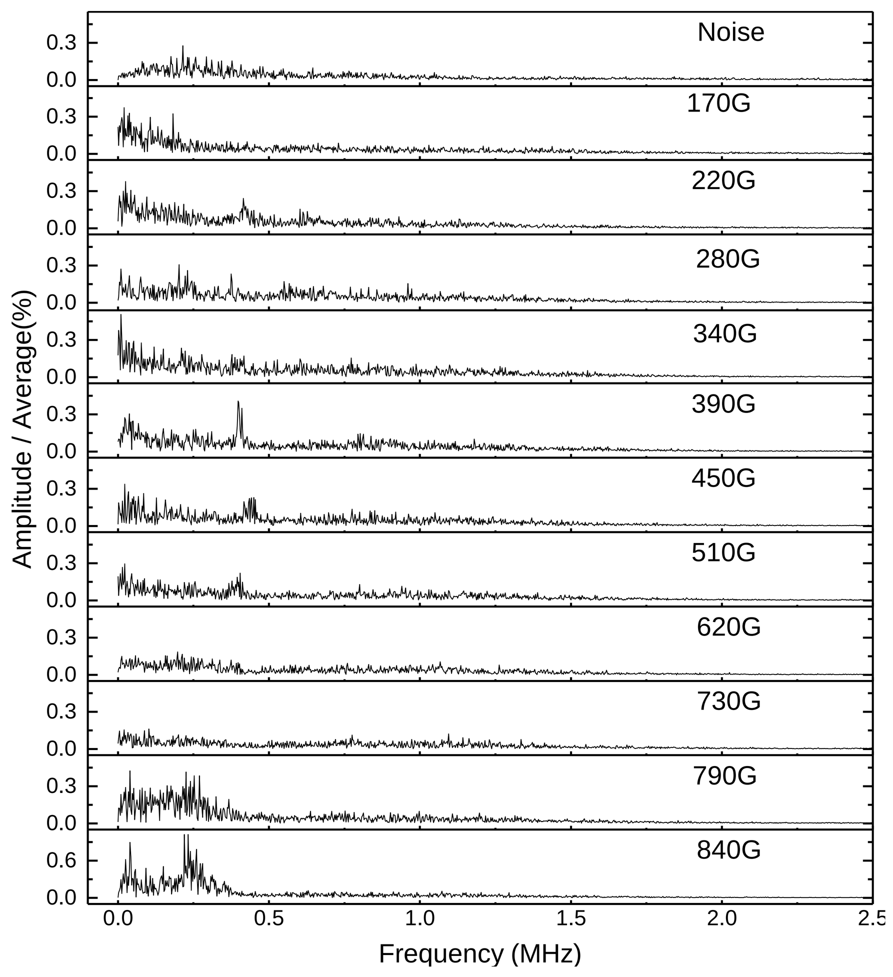
$$I_+\propto\frac{e}{1+\omega_i^2\tau^2}\cdot\frac{I_e\sigma_r n_g}{e\cdot a\cdot b}\cdot\iint(\mu_i n_g E_y-D_i\partial n_g/\partial y)dxdz$$

magnetic field constricts ion extraction

magnetic field enhances ion production

3.2 Beam Oscillations





Magnetic Field	Fluctuation Frequency	Fluctuation/Average
0	200 kHz	< 5%
170~340 G	20 kHz	~10%
390~510 G	20 kHz & 400 kHz	~10%
620~730 G		< 5%
790~840 G	40 kHz & 250 kHz	~20% @840 Gs

4. Conclusions

- Optimal magnetic field strength exists for beam intensity of Calutron ion source.
- A theoretical analysis of the nonlinear relationship fits the experiment data well.
- Beam oscillations are observed at two magnetic field ranges with dual frequencies.

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