Charged Fluid Centrifuges for Separation of Large Quantities of Isotopes

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Liquid Plasma

New generation of Liquid Centrifuge Separators (LCS) for stable and unstable isotopes.

1. Same principle of ion-neutral coupling,

2. Inherent population of ions in liquid form and the absence of recombination. No need to continue ionization.

3. Low temperatures and high densities. Liquid allows internal cooling.

4. Large quantities and low-cost production require such efficiency.

Theory

Plasma and neutral gas as single conducting fluid:

$$\frac{\partial n}{\partial t} + \nabla \cdot n\vec{v} = 0$$

$$mn\left[\frac{\partial \vec{v}}{\partial t} + (v \cdot \nabla)\vec{v}\right] = -\nabla p + \vec{j} \times \vec{B} + \eta \nabla^2 \vec{v}$$

Under steady state in cylindrical coordinates:

Radial Direction $$-\nabla p + \frac{nmv_\Theta^2}{r} = 0$$ gives

$$n = n_o EXP\left[\frac{\omega^2 r^2 m}{kT}\right]$$

$$\text{where } \omega = \text{rotation velocity}$$

In two isotopes $(\eta_1, m_1; \eta_2, m_2)$ of a given element, the enrichment factor q can be defined as:

$$q(r) = \frac{\frac{N_{2(r)}}{N_2(r=0)}}{\frac{N_1(r)}{N_1(r=0)}} - 1$$

$$= EXP\left[\frac{\omega^2 r^2 \Delta M}{2kT}\right] - 1$$

Exponential dependence was confirmed experimentally.

Taking V_Θ component

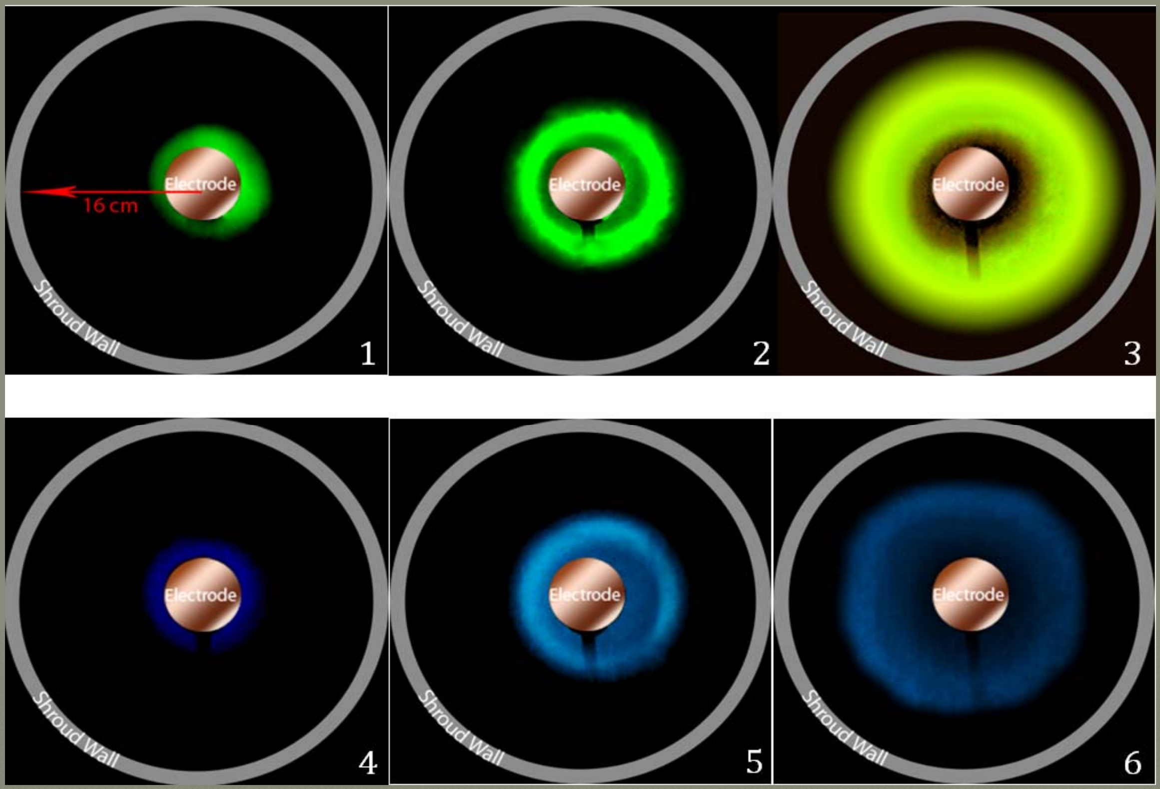
$$(\eta \nabla^2 \vec{v}) = j_r B$$

Balance of q viscous drag with j x B drive

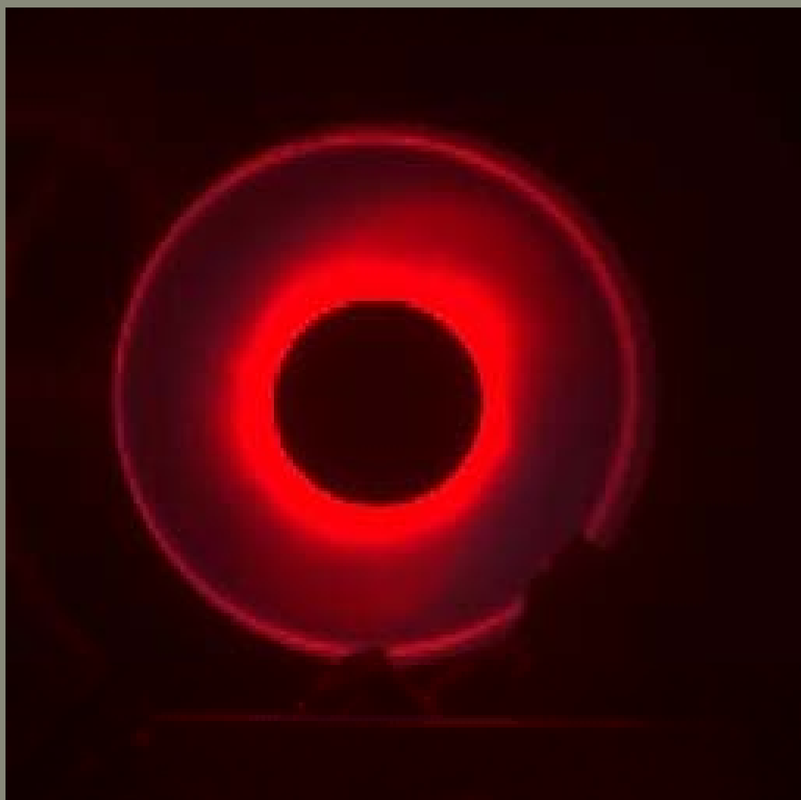
$$\eta \left[\frac{\partial V_\Theta}{\partial r^2} + \frac{1}{r} \frac{\partial V_\Theta}{\partial r} - \frac{V_\Theta}{r^2} \right] = \frac{IB}{2\pi r L}$$

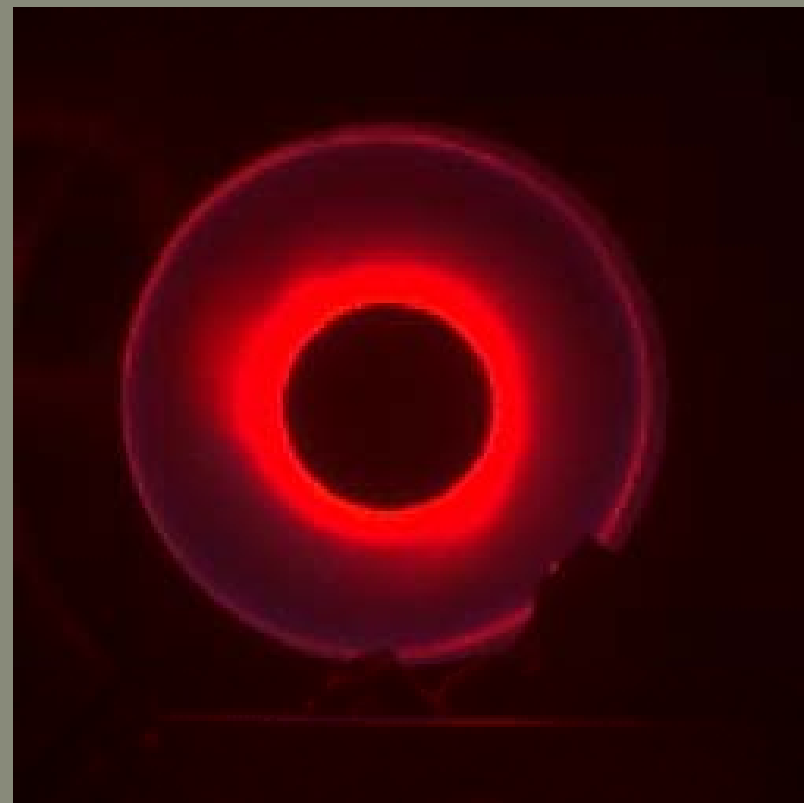
Experiments

- **II. Spectroscopic measurements show that ions and neutrals rotate and expand radially in the same manner.**

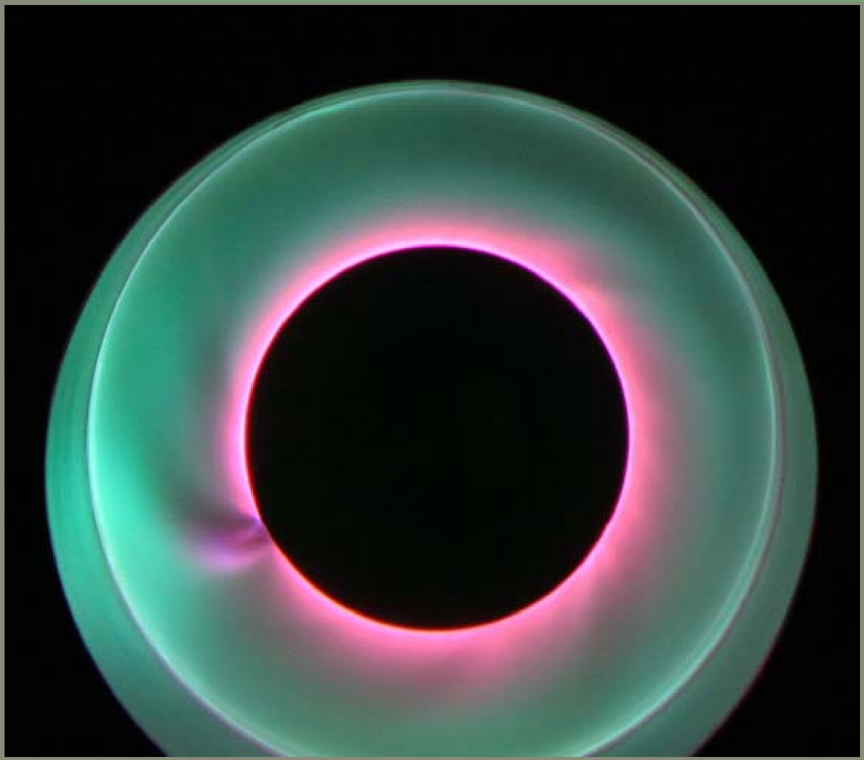


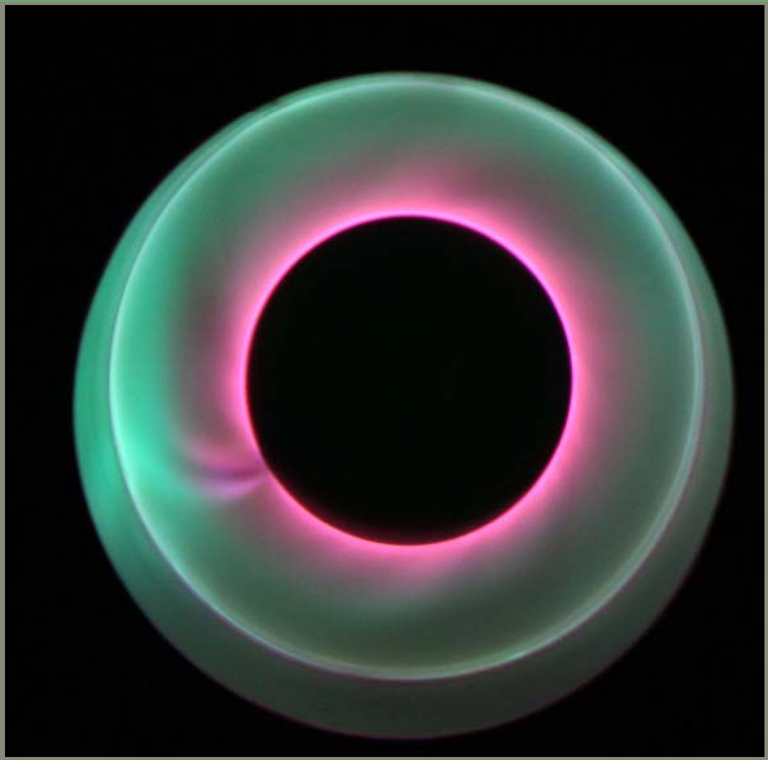
Plasma Rotation Videos


Low Current


High Current

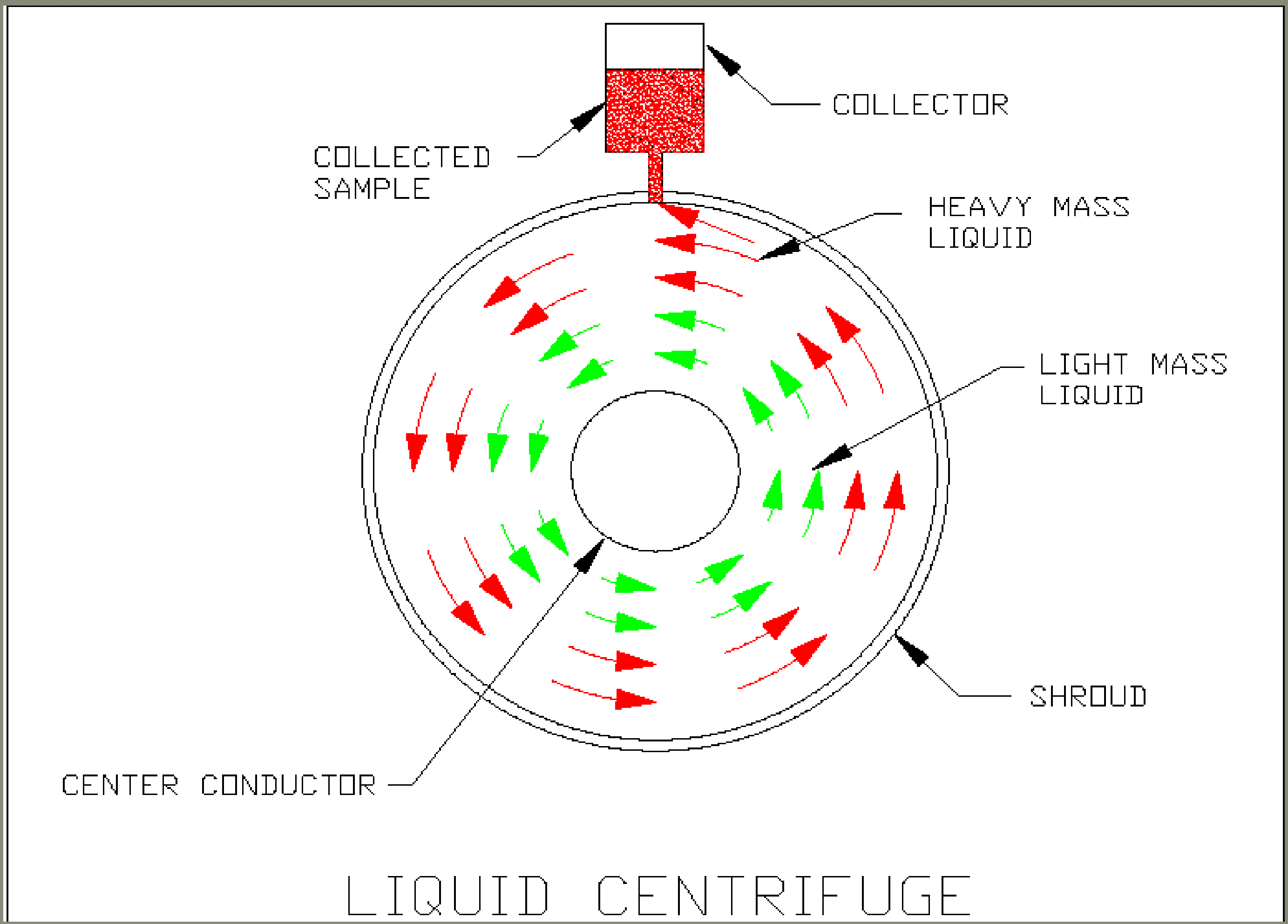
Cu metallic vapor released from outer electrode by Ar sputtering



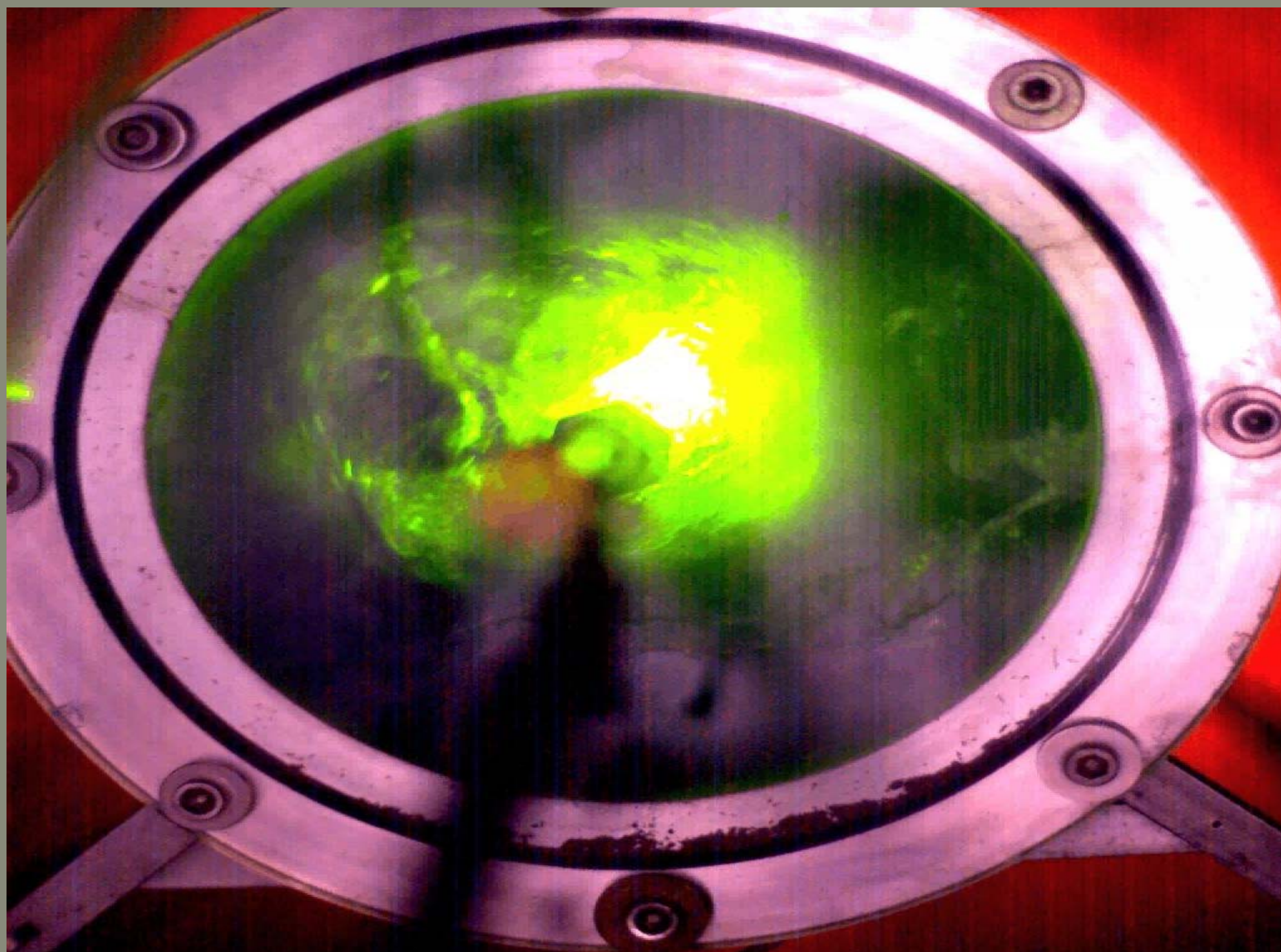


Ne background 1 torr and Ar Flow rate: 500 CCM

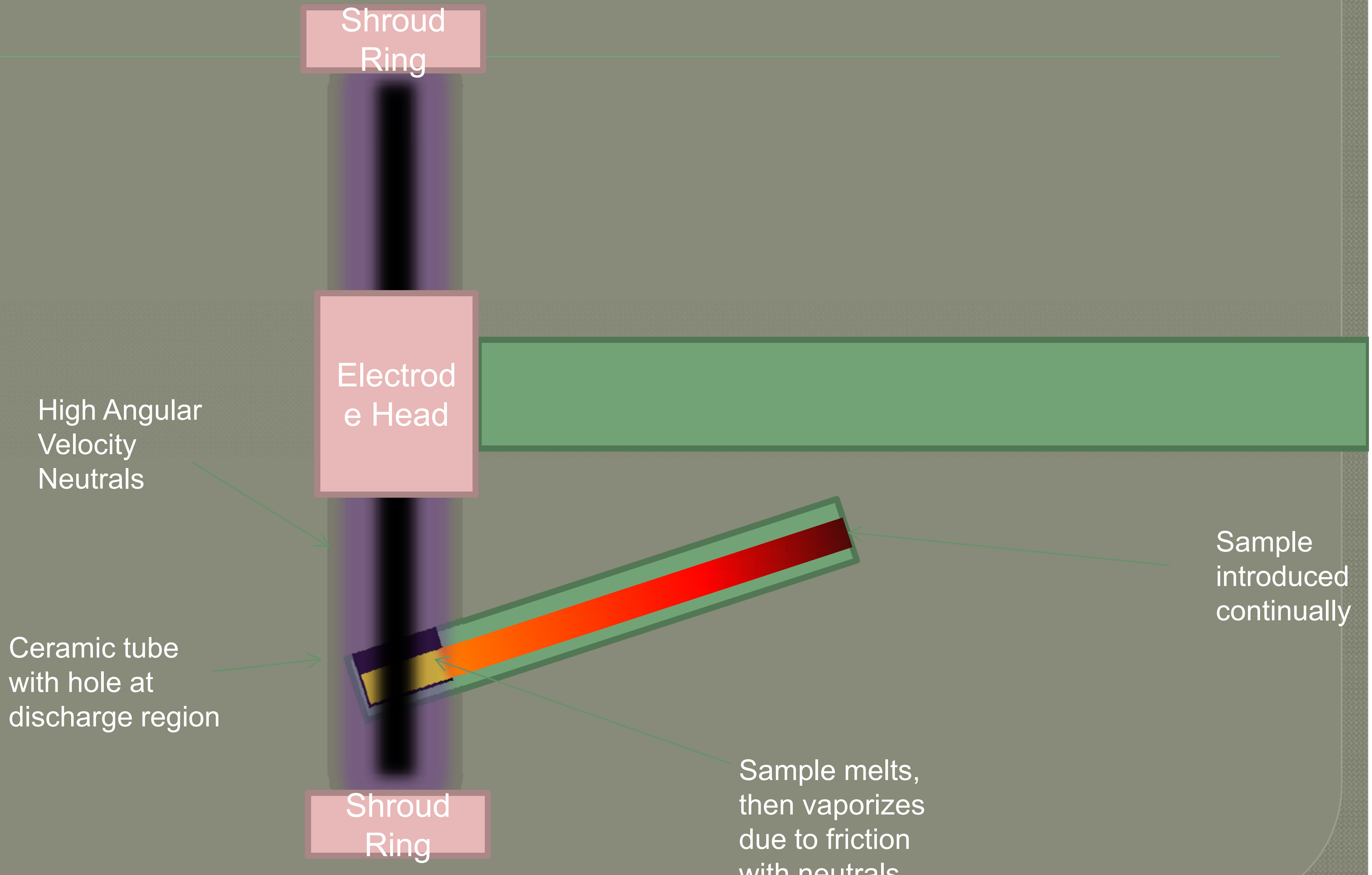
Fluid Isotope Separator Centrifuge



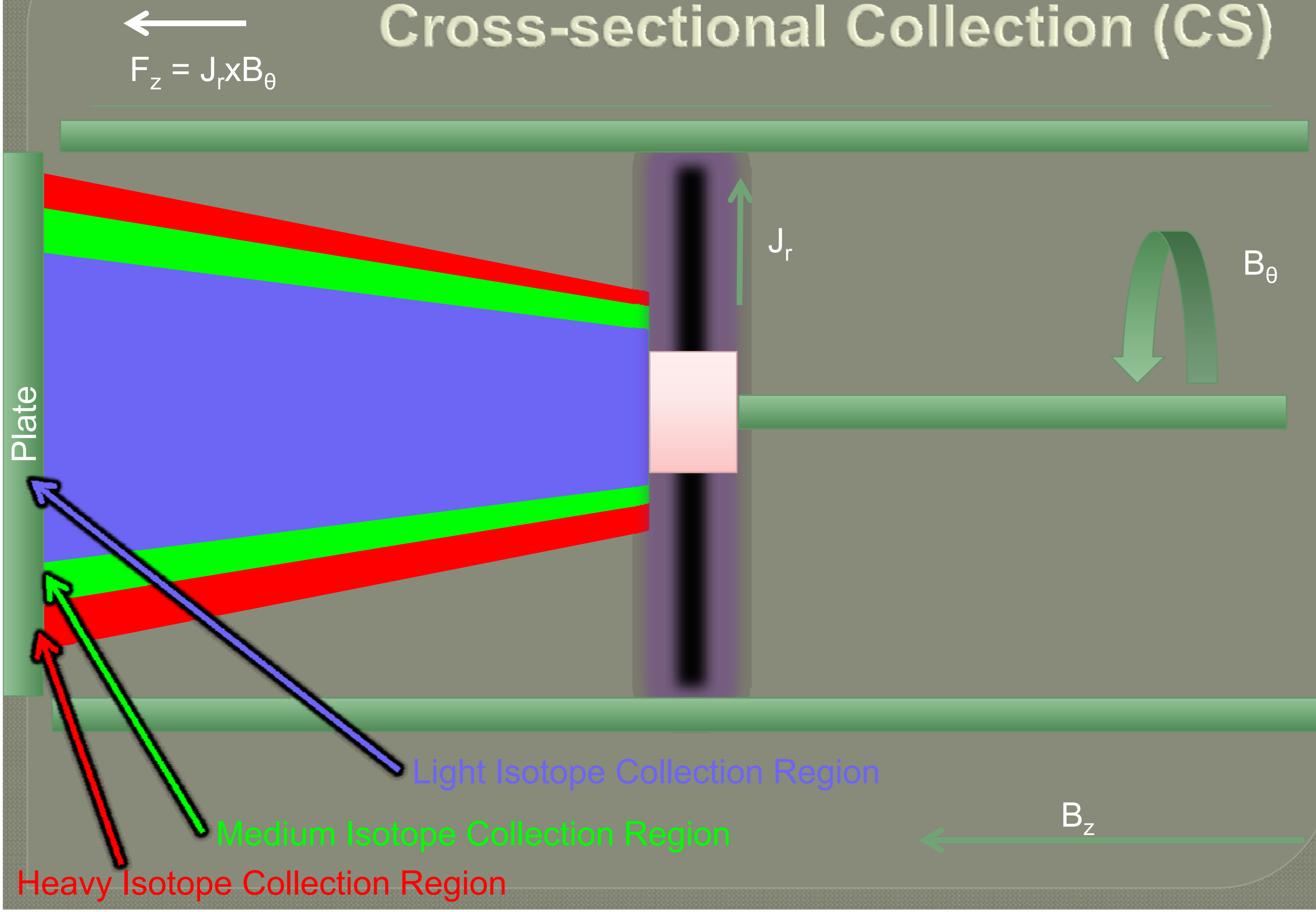
Experiments



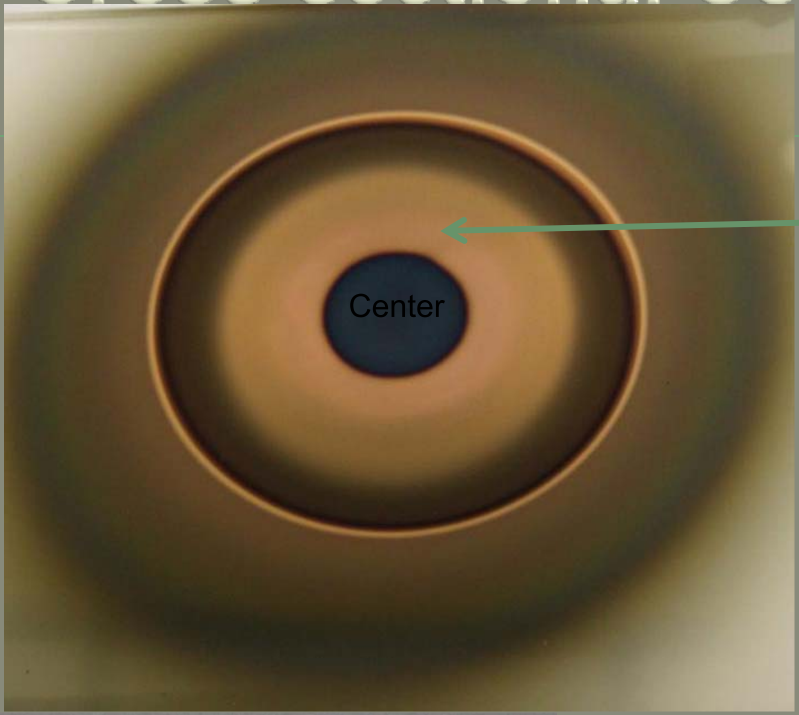
Continuous Source heated by rotating neutrals



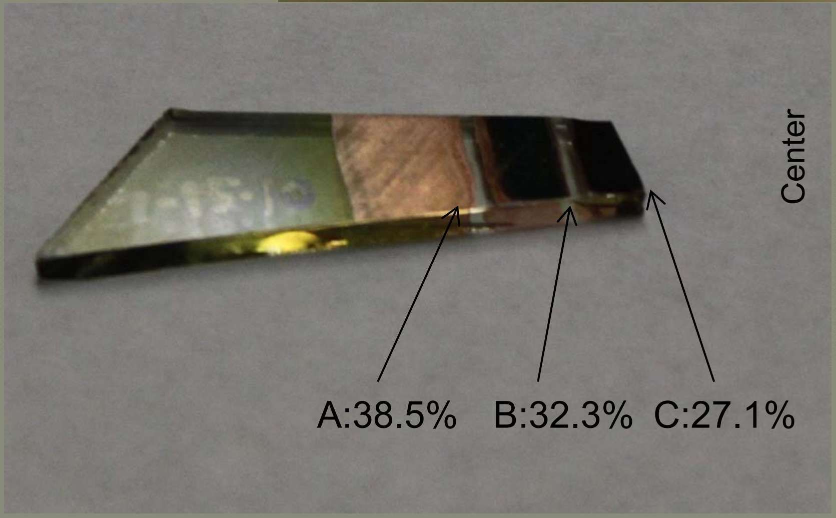
Cross-sectional Collection (CS)



Cross-sectional Collection Results



Front view of Cu Deposition Ring Structure from actual experiment



Analysis slice from sample showing Cu-65 abundance vs. radius

Cu^{65} abundance Tested by PNL. (Radius, A: 2.5cm; B: 2.0cm; C: 1.7cm)

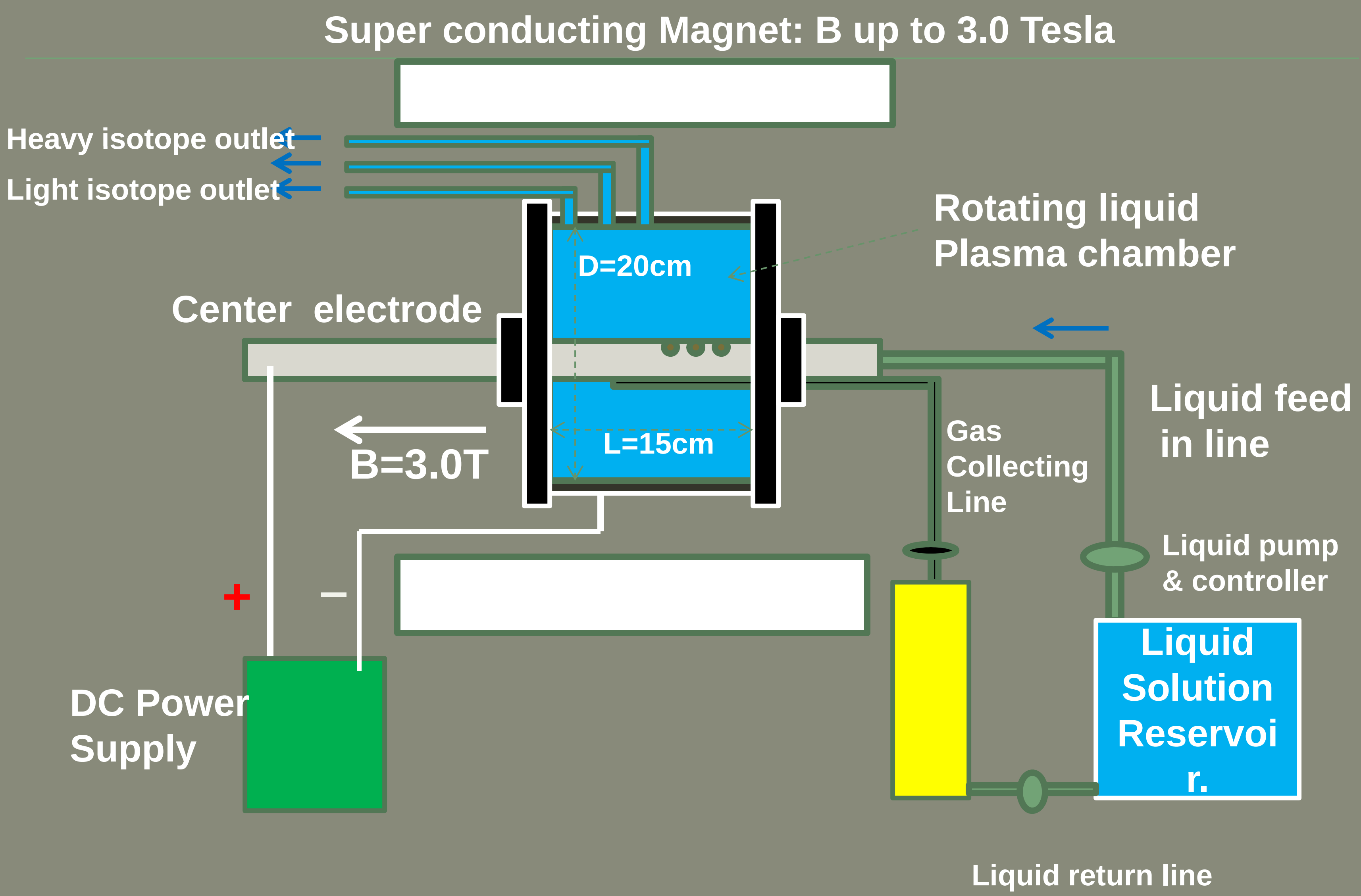
Comparison between conventional and FIS centrifuges

	Conventional Centrifuge	Fluid Isotope Separator (Liquid)	Fluid Isotope Separator (Gas)
Radius (cm)	5	30	20
Height (cm)	400	25	25
Volume (cm^3)	$3x10^4$	7×10^4	3×10^4
Rotation rate (rps)	600	550 - 1000	1000 – 10,000
Relative centrifugal force (a = 980 cm/s^2)	6.6×10^4	3.6×10^5 - 1.2×10^6	3×10^6
Density (n/cm^3)	10^{14}	10^{22}	10^{17}
Temperature (K)	300	313	1425
Pressure (mTorr)	100	$7.60x10^5$	4000
Outer cylinder	Rotating	Stationary	Stationary
Cascade units	>1000	1	1
Drive	Surface	Body	Body
Rotating mass (g)	0.005	70,000	1

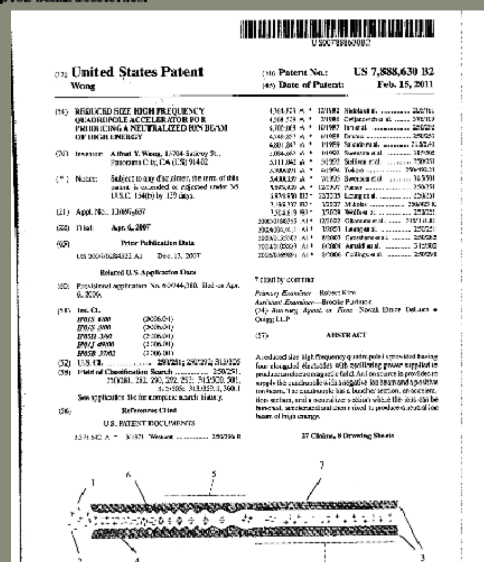
Throughput Summary

	Mechanical Centrifuge	Fluid isotope separator (Liquid)	Fluid Isotope Separator (Gas)
Throughput flow rate (mg/s)	0.01 (estimate)	4.7	1
Throughput flow rate(g/hour)	0.036	16.9	3.6
Separative Factor	1.09 (estimate)	2.24	2.4

Diagram of the rotating liquid device



A8. table-top ion beam accelerator



US007888630B2

(12) **United States Patent**
Wong

(10) Patent No.: **US 7,888,630 B2**
(45) Date of Patent: **Feb. 15, 2011**

(54) REDUCED SIZE HIGH FREQUENCY QUADRUPOLE ACCELERATOR FOR PRODUCING A NEUTRALIZED ION BEAM OF HIGH ENERGY

(76) Inventor: Alfred Y. Wong

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 129 days.

(22) Filed: **Apr. 6, 2007**

(65) Prior Publication Data

Related U.S. Application Data

(60) Provisional application filed on Apr. 6, 2006.

(51) Int. Cl.

(52) U.S. Cl.

(58) Field of Classification Search

See application file for complete search history.

(56) References Cited

U.S. PATENT DOCUMENTS

* cited by examiner

Primary Examiner—Robert Kim
Assistant Examiner—Brooke Purinton
(74) *Attorney, Agent, or Firm*—Novak Druce DeLuca + Quigg LLP

(57) ABSTRACT

A reduced size high frequency quadrupole is provided having four elongated electrodes with oscillating power supplied to produce an electromagnetic field. An ion source is provided to supply the quadrupole with a negative ion beam and a positive ion beam. The quadrupole has a buncher section, an acceleration section, and a neutralizer section where the ions can be bunched, accelerated and then mixed to produce a neutral ion beam of high energy.

37 Claims, 8 Drawing Sheets

Figure 31. The energy of neutralized ion beam can go up to 50 MeV for bombardment of a stable isotope.

NID Research & Development Center

NID has more than 20,000 sq ft of research space at its Valley Research Center (VRC). VRC is located 19 miles north of Los Angeles, California.

Integrated Spin System (ISS)

Experimental Chambers for diagnostics and engineering

Experimental observation:

Viscous drag is dominant at outer boundary

$$\eta\frac{\partial^2 V_\Theta}{\partial r}\approx\frac{IB}{2\pi rL}$$

Dimensional Analysis

$$\eta\frac{V_\Theta}{(0.1r_o)^2}\approx\frac{IB}{2\pi rL}\Rightarrow V_\Theta=\frac{IB(0.1r_o)^2}{2\pi r_o L\eta}$$

$$V_\Theta=\omega r_o=\frac{IB[10^{-2}r_o^2]}{2\pi r_o L\eta}=\frac{10^{-2}IB}{2\pi L\eta}r_o$$

$$\omega=\frac{10^{-2}IB}{2\pi L\eta}=\frac{10^{-2}40A(1.3T)}{2\pi(0.1m)(3.3\times 10{-}4)}/s=2.8\times 10^3/s$$

$$f=437Hz$$

Viscosity for typical gas

$$\eta = 3.3 \times 10^{-4} \frac{kg}{m \cdot s}$$

Experimentally observed rotation rate:

$$f_{Experimental} \approx 340 - 500Hz$$
$$f_{THEORY} \sim 437Hz$$