ICTP workshop on operation and maintenance of electrostatic accelerators

Negative ion sources used at electrostatic accelerators

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Motivation to produce negative ions

Future fusion reactors require neutral beams

- Easy to strip the electron from a negative ion
- Plasma heating in thermonuclear fusion experiments
- Huge currents of H (D)

Material modifications by implantation

- Different effects than positive ions, low charging of insulators
- Different ions

Medical (and other) cyclotrons

- Strong H and D beams

Electrostatic tandem accelerators

- Different ions
- Usually not high currents
- Important low emittance and high brightness (microprobes)
- We will focus and regard only this part of negative ions use

Physical processes leading to formation of negative ion

Volume negative ion production (gases, vapors, mostly H)

- Low energy electrons have higher cross section to attach to neutral atoms
- Plasma sources with additional volume containing low energy electrons
- Electron attachment competes with electron detachment

  (and ionization)

  - H_2 + slow e^- —> H^- + H^0 – the most efficient process

  (apart from many other)

- Plasma is created in different ways: arc discharge, RF….
- To prevent extraction of electrons from plasma, a strong magnetic field in the extraction zone is usually applied

Physical processes leading to formation of negative ion

Surface negative ion production

High probability for negative ion production when an atom leaves a metal surface (cathode) with a low work-function (Φ) and the projectile has a high electron affinity (E_A)

$$P \sim e^{(EA-\Phi)}$$

Φ-an energy required to remove an ion from the surface

E_A -change in energy of a neutral atom when an electron is added to the atom to form a negative ion - the neutral atom's likelihood of gaining an electron.

A very thin (~0.6 monoatomic layers) film of alkali metal covering the material surface greatly decreases the work function

Physical processes leading to formation of negative ion

Surface negative ion production

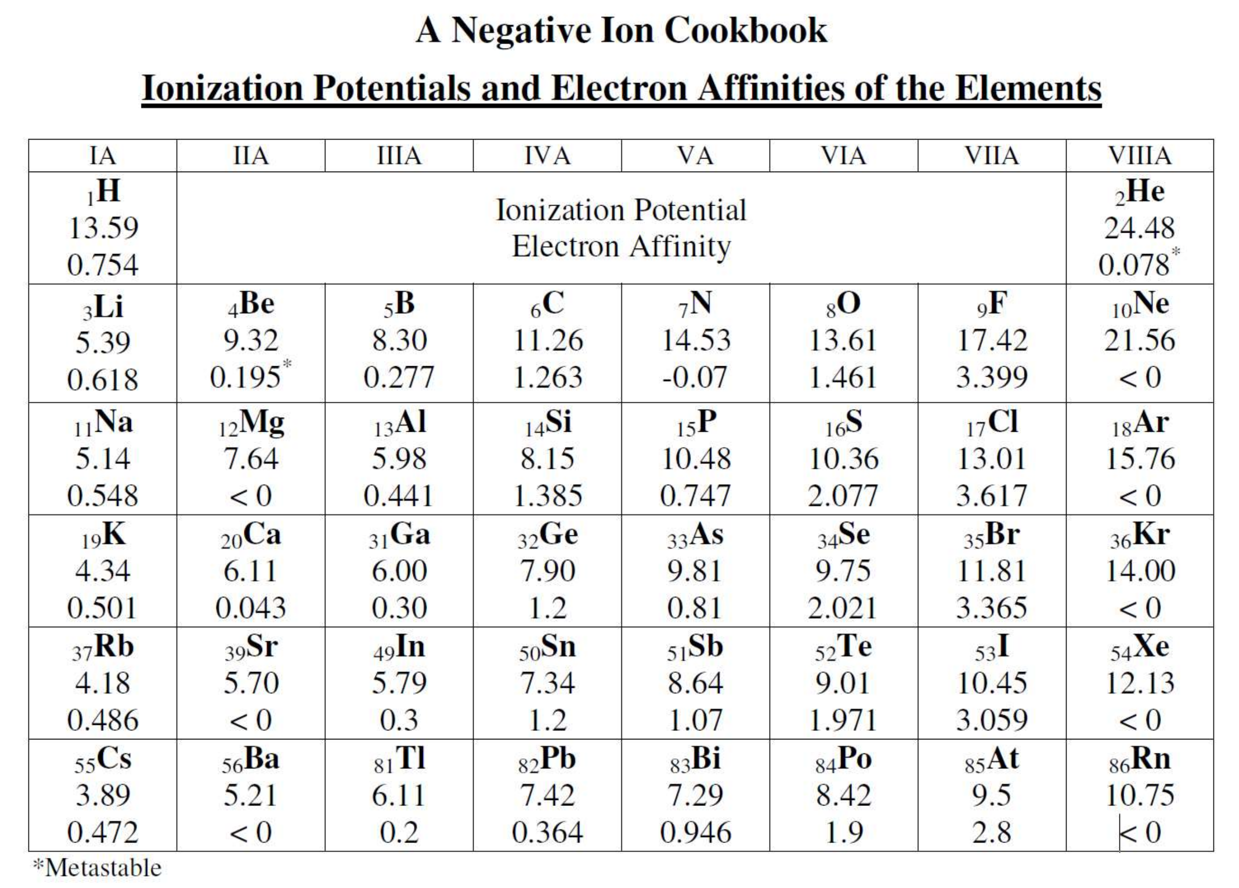
$P \sim \exp(E_A - \Phi)$-several orders of magnitude different yields for different negative ions

Halogens have the highest electron affinity

Alkali metals GENERALLY have the lowest ionization potential and electron affinity- good electron donors (there are exceptions)

Negative electron affinities mean no stabile negative ion! (N for example – base for AMS)

A Negative-Ion Cookbook
Roy Middleton
Department Of Physics, University of Pennsylvania
Philadelphia, PA 19104
October 1989 (Revised February 1990)



A Negative Ion Cookbook

Ionization Potentials and Electron Affinities of the Elements

IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
$_{1}$**H** 13.59 0.754	Ionization Potential Electron Affinity						$_{2}$**He** 24.48 0.078*
$_{3}$**Li** 5.39 0.618	$_{4}$**Be** 9.32 0.195*	$_{5}$**B** 8.30 0.277	$_{6}$**C** 11.26 1.263	$_{7}$**N** 14.53 -0.07	$_{8}$**O** 13.61 1.461	$_{9}$**F** 17.42 3.399	$_{10}$**Ne** 21.56 < 0
$_{11}$**Na** 5.14 0.548	$_{12}$**Mg** 7.64 < 0	$_{13}$**Al** 5.98 0.441	$_{14}$**Si** 8.15 1.385	$_{15}$**P** 10.48 0.747	$_{16}$**S** 10.36 2.077	$_{17}$**Cl** 13.01 3.617	$_{18}$**Ar** 15.76 < 0
$_{19}$**K** 4.34 0.501	$_{20}$**Ca** 6.11 0.043	$_{31}$**Ga** 6.00 0.30	$_{32}$**Ge** 7.90 1.2	$_{33}$**As** 9.81 0.81	$_{34}$**Se** 9.75 2.021	$_{35}$**Br** 11.81 3.365	$_{36}$**Kr** 14.00 < 0
$_{37}$**Rb** 4.18 0.486	$_{39}$**Sr** 5.70 < 0	$_{49}$**In** 5.79 0.3	$_{50}$**Sn** 7.34 1.2	$_{51}$**Sb** 8.64 1.07	$_{52}$**Te** 9.01 1.971	$_{53}$**I** 10.45 3.059	$_{54}$**Xe** 12.13 < 0
$_{55}$**Cs** 3.89 0.472	$_{56}$**Ba** 5.21 < 0	$_{81}$**Tl** 6.11 0.2	$_{82}$**Pb** 7.42 0.364	$_{83}$**Bi** 7.29 0.946	$_{84}$**Po** 8.42 1.9	$_{85}$**At** 9.5 2.8	$_{86}$**Rn** 10.75 < 0

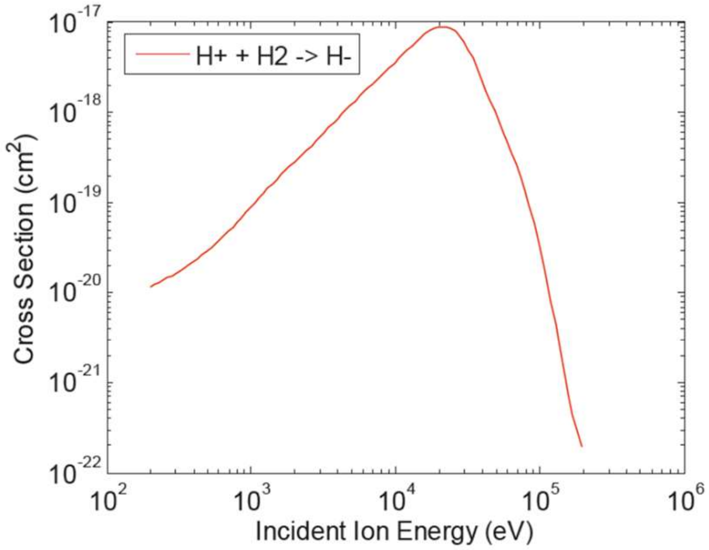
*Metastable

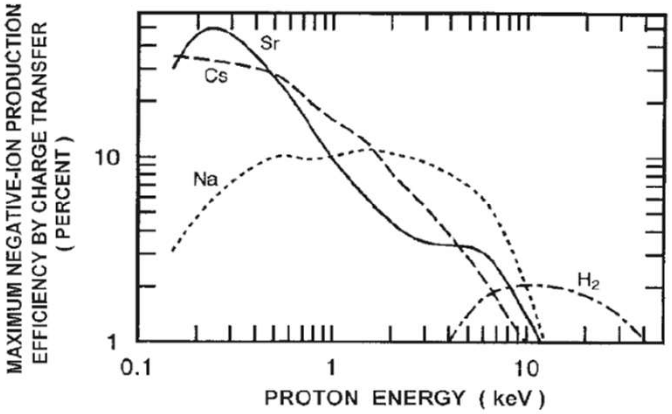
Physical processes leading to formation of negative ion

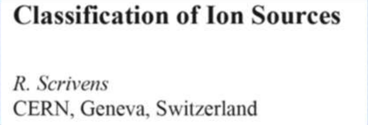
Charge exchange negative ion production

Any atom with positive electron affinity can convert to a negative ion through one or two step collision process in a low pressure gas or vapor. Especially high efficiency occurs in alkali metals vapors

Hydrogen case:






Classification of Ion Sources

R. Scrivens
CERN, Geneva, Switzerland

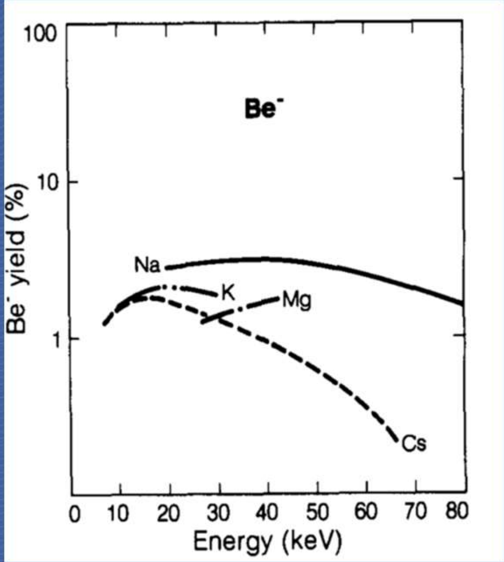
Physical processes leading to formation of negative ion

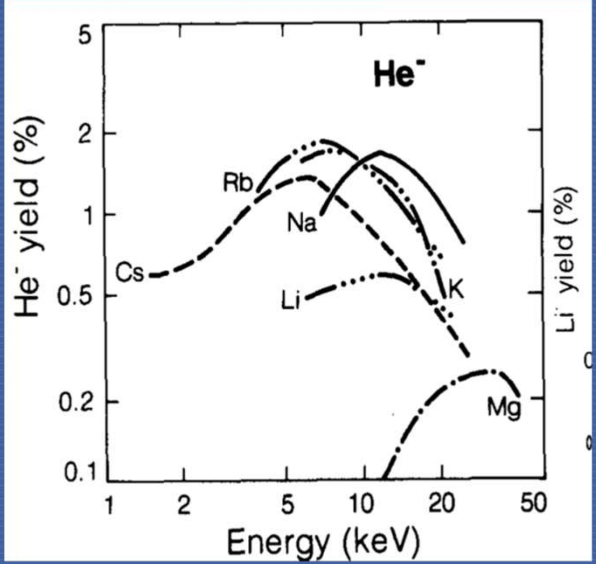
Charge exchange negative ion production

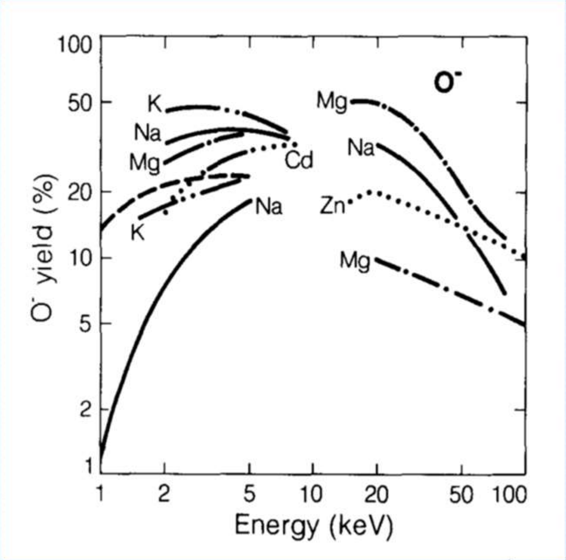
Metastable negative ions with short lifetime can not be created in low energy surface collision or volume processes.

He is a very important nucleus for IBA experiments (RBS) and nuclear astrophysics experiments (^{3}He)

He- is a metastable ion with lifetime ~360 μs







$$He^+ + Cs \longrightarrow He^0\,(1s2s)^3S + Cs^+$$

$$He^0\,(1s2s)^3S + Cs \longrightarrow He^-\,(1s2s2p)^4P + Cs^+.$$

Formation of negative ions by charge transfer: He- to Cl- *

Alfred S. Schlachter

CAIP Conference Proceedings 111, 300 (1984); doi: 10.1063/1.34431

Types of negative ion sources used in tandem accelerators

Charge-exchange negative ion sources (generally any positive ion source with charge exchange canal)

- RF charge exchange negative ion source
- Duoplasmatron with charge exchange canal
- Multicusp source with charge exchange canal

Volume production (surface enhanced) type negative (hydrogen) ion sources

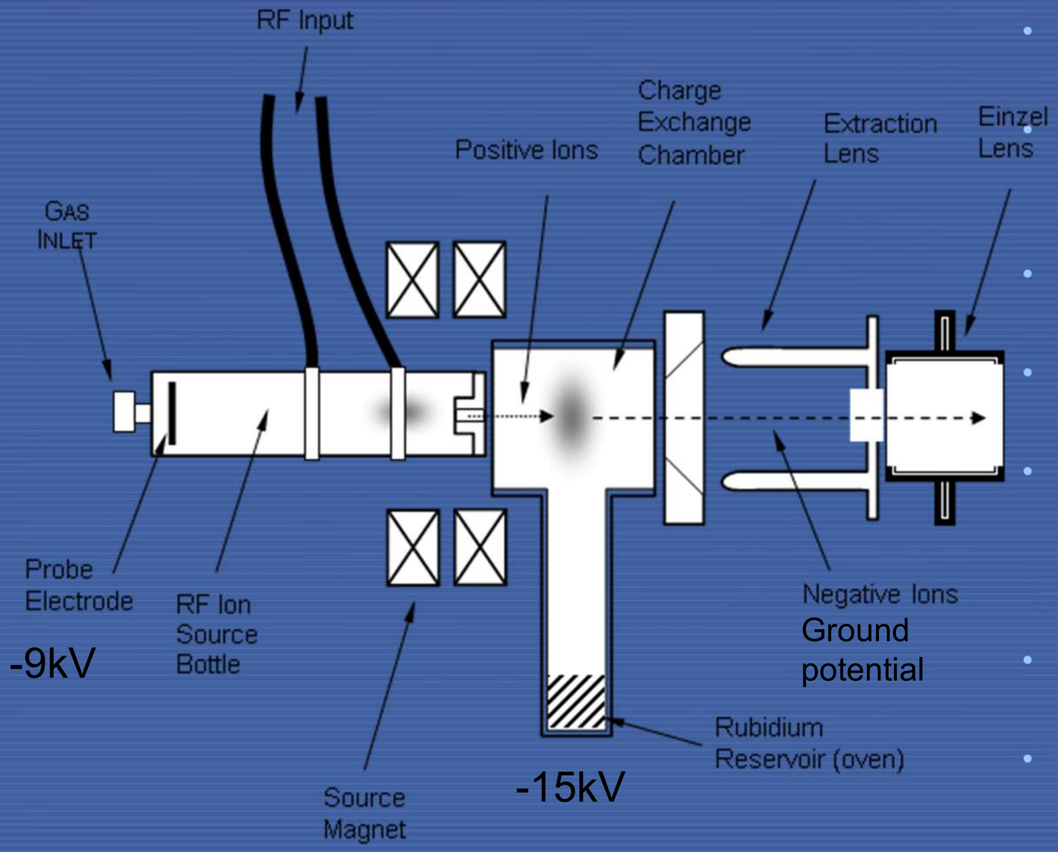
-plasma sources with electron impact ionization and electron attachment with or without the help of surface. Caesium (Cs) is applied in high power negative hydrogen ion sources to reduce a converter surface's work for moreefficient negative ion surface formation

- Off-axis duoplasmatron (358)
- Hollow cathode duoplasmatron
- Magnetron
- Penning ionization gauge (PIG)
- Multicusp (Lecture from Primoz Pelicon on Wednesday)
- Duopigatron
- Multi aperture volume negative H source
- Single aperture volume negative H source

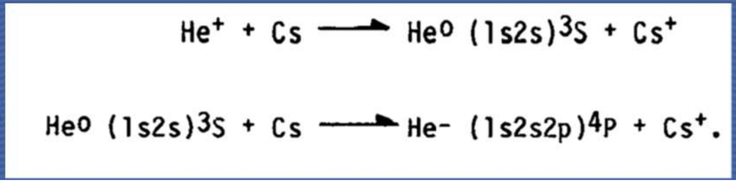
. Sputter type (heavy) negative ion sources (surface ionization)

Classification modified from
B. Wolf (Ed.), Handbook of Ion Sources (CRC Press, Boca Raton, FL, 1995).

RF charge exchange source



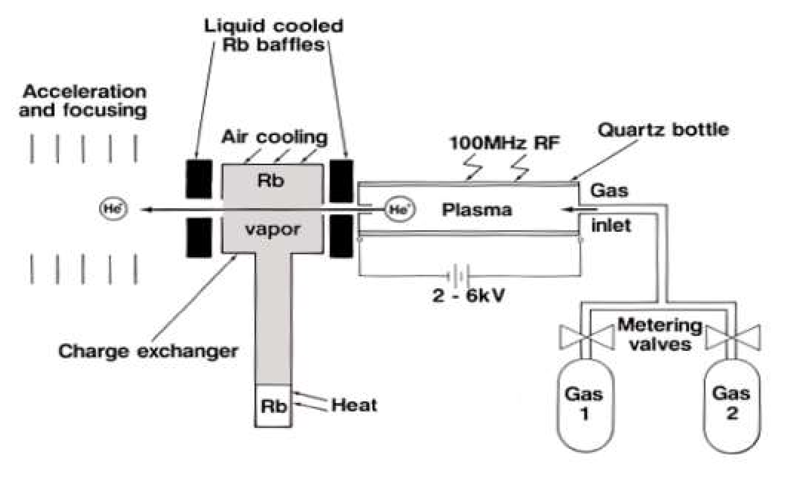
- RF ion source: positive ions, passing through a chamber with an alkali metal vapor For He beam E=6 keV
 In collisions between the positive ions and alkali metal vapor atoms, electrons are transferred to the positive ions --> negative ions or neutrals.
- Most positive ions are neutralized -> neutral ion beam (100 – 200 particle μA).
- The rubidium vapour is produced in a heated reservoir Oven T ~ 220°C - 260°C.
- The amount of vapour produced is partially regulated by condensing some of the vapour onto the cooled wall surfaces where it flows back down into the oven and the cycle begins again.
- The condensing rate is crucial, and directly influences the effectiveness of charge exchange.
- The temperature of the charge exchange chamber must be monitored and usually maintained between 50°C and 60°C (for the case of Rb)



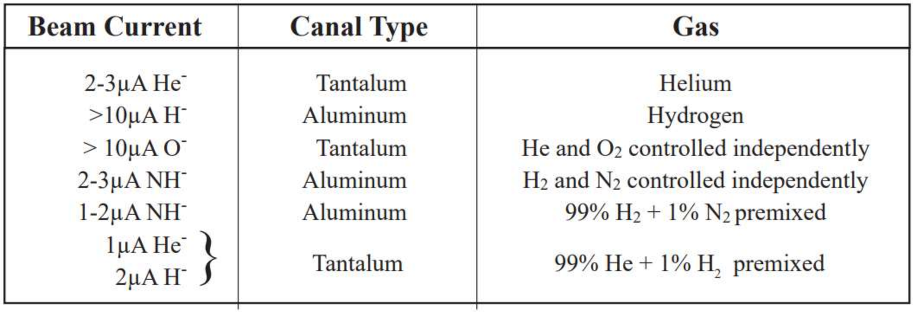
$$\mathrm{He}^{+} + \mathrm{Cs} \longrightarrow \mathrm{He}^{0}\ (1s2s)^{3}S + \mathrm{Cs}^{+}$$

$$\mathrm{He}^{0}\ (1s2s)^{3}S + \mathrm{Cs} \longrightarrow \mathrm{He}^{-}\ (1s2s2p)^{4}P + \mathrm{Cs}^{+}.$$

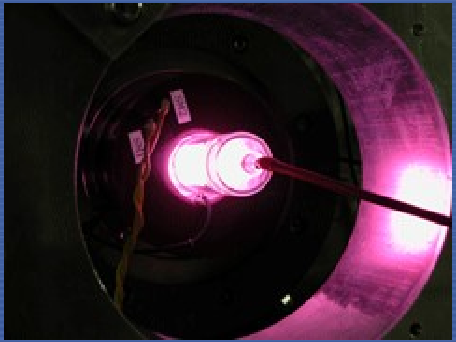
RF charge exchange source



- Major problems of this source: proper maintaining of the Rb vapor recirculation. The temperatures of oven, exchange canal, cooling liquid and air are crucial.
- Consequence of not well adjusted recirculation: freezing of Rb or migrating of Rb causing blockage of the beam and sparking of the source

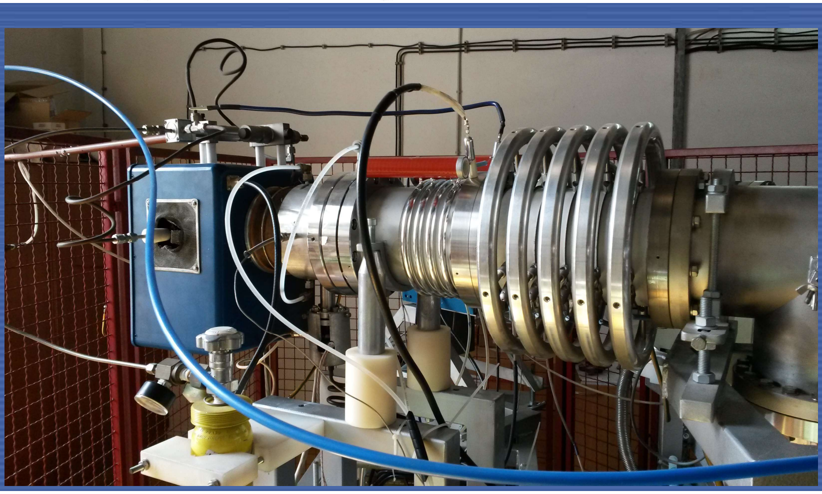


Beam Current	Canal Type	Gas
2-3μA He^-	Tantalum	Helium
>10μA H^-	Aluminum	Hydrogen
> 10μA O^-	Tantalum	He and O_2 controlled independently
2-3μA NH^-	Aluminum	H_2 and N_2 controlled independently
1-2μA NH^-	Aluminum	99% H_2 + 1% N_2 premixed
1μA He^- 2μA H^-	Tantalum	99% He + 1% H_2 premixed



www.pelletron.com

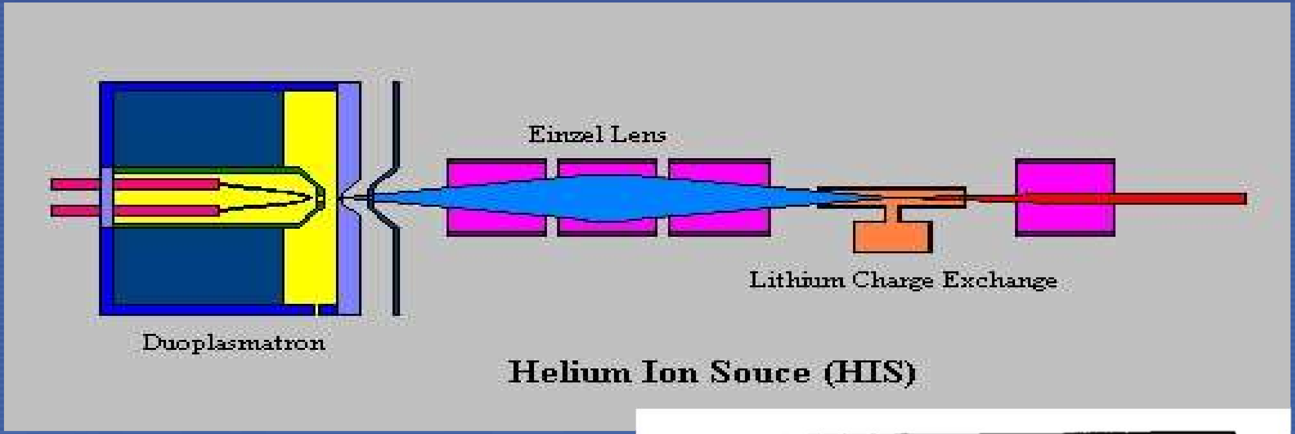
Alpahtross



RF charge exchange source

Fault	Possible Causes
No beam output	No beam measurement due to faulty Faraday cup or picoammeter or input cable. Loss of gas feed due to fault in metering valve or complete consumption of gas. Loss of probe, extraction or focusing high voltage. Loss of the RF supply due to oscillator failure or output triode failure. Loss of charge exchange process due to poor rubidium flow. Cooling baffles apertures blocked due to freezing of Rb Poor rubidium flow due to insufficient metal in oven, faulty heater or incorrect oven temperature measurement. Chamber temperature too high.
Low, unsteady beam output	Inaccurate beam measurement due to faulty Faraday cup or meter Dirty or contaminated Pyrex glass bottle. Extraction canal eroded or partly blocked. Low output from RF triodes. Insufficient gas feed. Loss of focus of the ion beam due to breakdown of extraction voltages breakdown of Einzel lens voltages Incomplete charge exchange process due to poor rubidium flow. Poor rubidium flow due to insufficient metal in oven, faulty heater or incorrect oven temperature measurement. Poor beam transmission due to rubidium metal condensed near (or over) extraction aperture. Alignment incorrect.

Duoplasmatron source with charge exchange canal



Larry Lamm

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Formation of negative ions by charge transfer: He- to Cl- *

Alfred S. Schlachter

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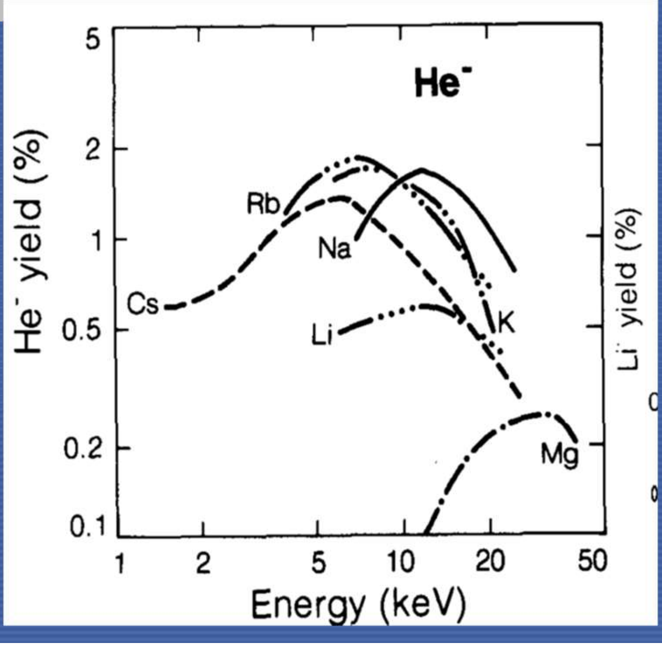
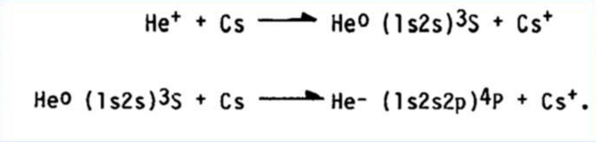


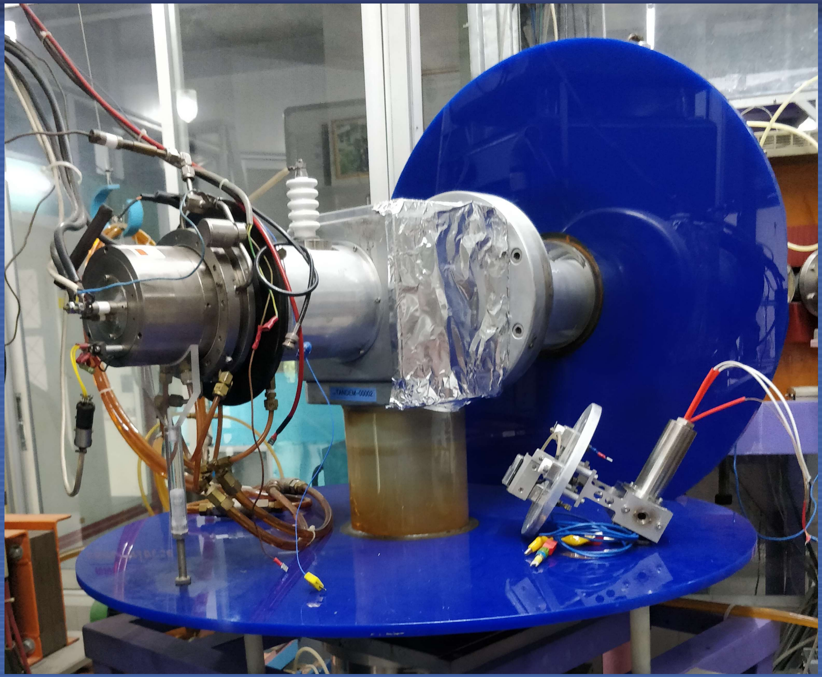
- A high intensity positive ion beam (depending on the model, it could go up to ~mA)
- The beam is focused by einzel lens into a charge exchange canal
- Charge exchange canal contains alkali metal vapours-beam interacts with vapor by transferring electrons from alkali metal to the beam: 2 step process
- Charge exchange efficiency can go up to 2%
- Charge exchange efficiency depends on the alkali metal type and energy of the positive ion beam (of course, on electron affinity of positive beam too)
- Operational parameters of the charge exchange canal depend on the alkali metal used
- Melting points of alkali metals:
- Li 180 deg C
- Na 98 deg C
- Rb 39 deg C
- Cs 28.5 deg C



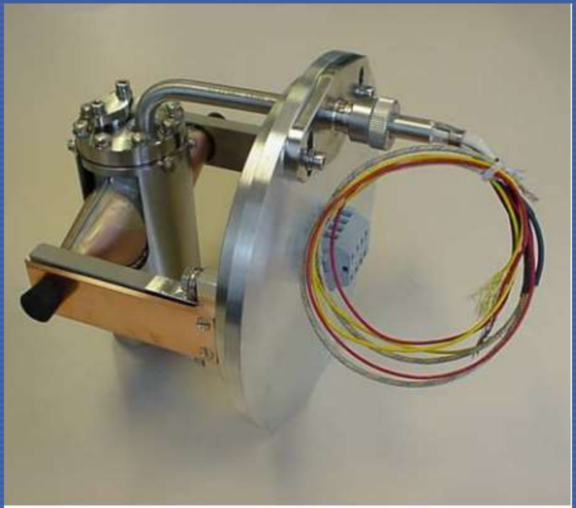
$$He^{+} + Cs \longrightarrow He^{0}\,(1s2s)\,^{3}S + Cs^{+}$$

$$He^{0}\,(1s2s)\,^{3}S + Cs \longrightarrow He^{-}\,(1s2s2p)\,^{4}P + Cs^{+}.$$

Duoplasmatron source with charge exchange canal



Duoplasmatron with Li charge exchange canal, Uni Chiang Mai
Peabody scientific http://www.peabody-scientific.com

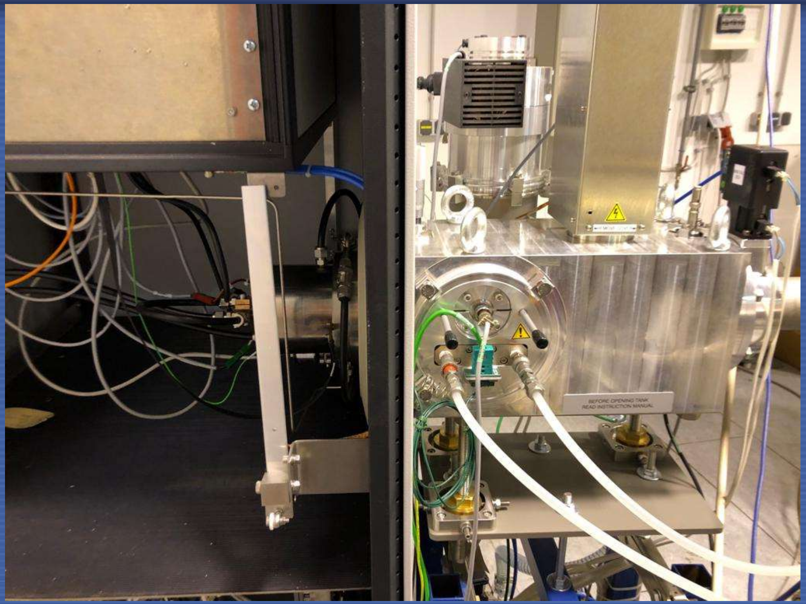


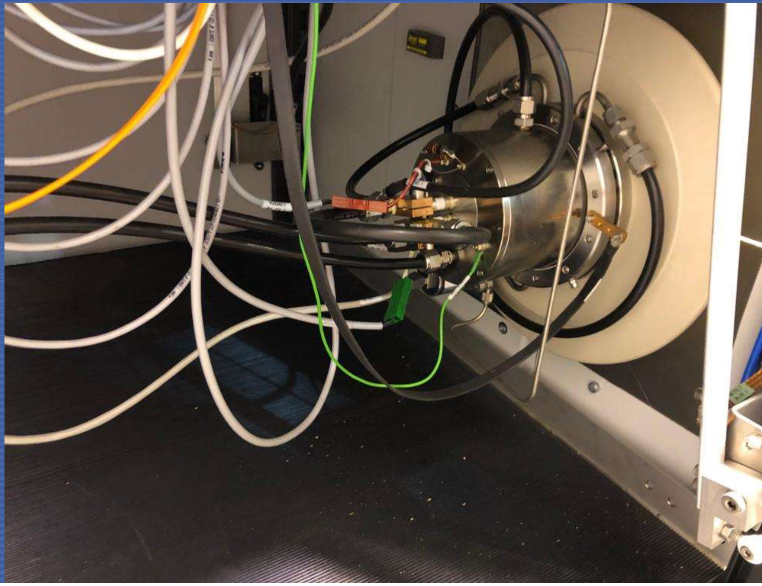
Li charge exchange canal
HVEE site: http://www.highvolteng.com

Na charge exchange canal
HVEE site: http://www.highvolteng.com

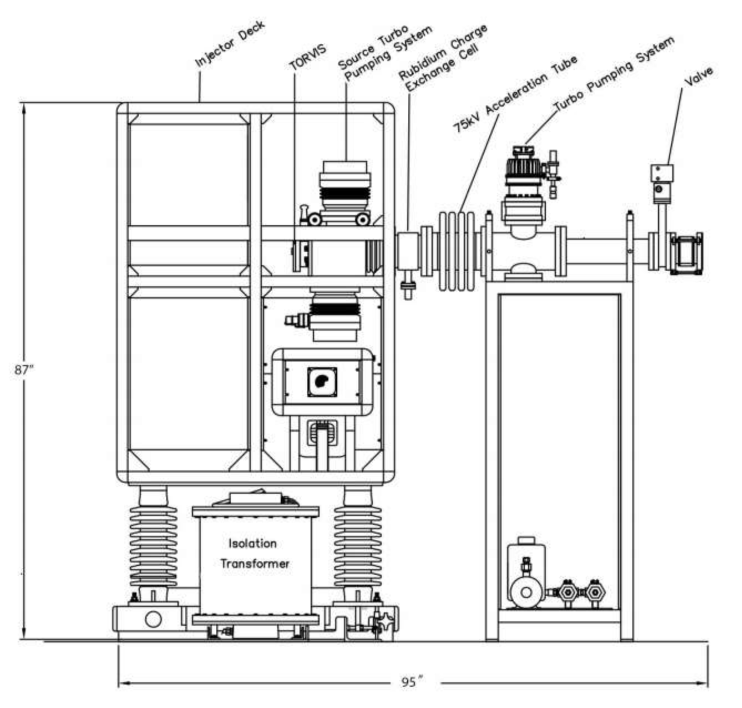
Duoplasmatron source with charge exchange canal

Duoplasmatron with Na charge exchange canal
HVEE site: http://www.highvolteng.com





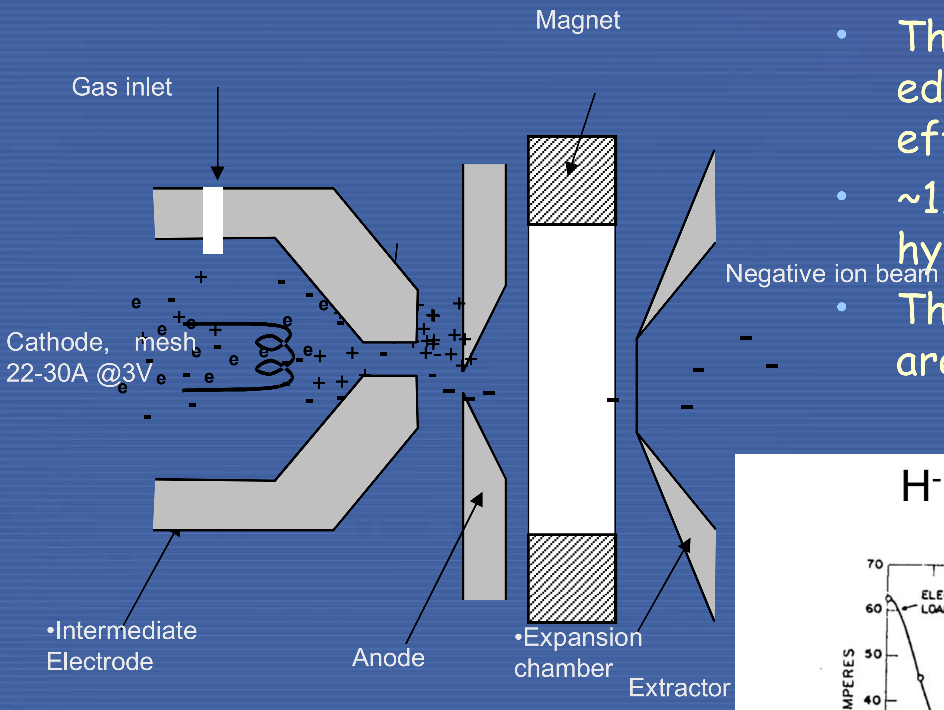
Multicusp source with charge exchange canal



Torvis multicusp with Rb charge exchange canal: 20 μA He beam
NEC http://www.pelletron.com

SO-130 multicusp ion source Na charge exchange canal 70 μA He beam
HVEE site: http://www.highvolteng.com
https://doi.org/10.1016/j.nimb.2011.07.082

Direct negative ion beam extraction duoplasmatron source (off axis)



- At the beginnings of using tandem accelerators it was noticed:
- There is some probability for existence of negative ions at the edge of the plasma (possibly enhanced by surface ionization effects).
- ~1.5 mm of axis extraction will give typically 5-20 mA of negative hydrogen
- The cheapest way to produce (some) negative ions. The species are limited to high electron affinity gasses

H$^-$ from Duoplasmatron

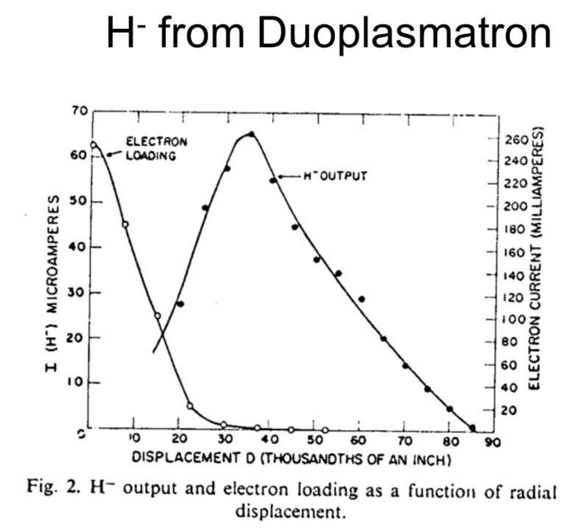
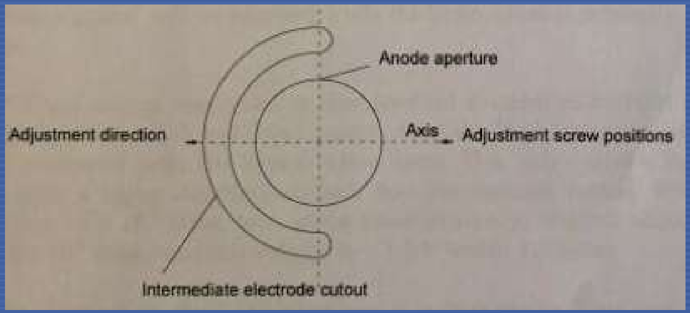


Fig. 2. H$^-$ output and electron loading as a function of radial displacement.



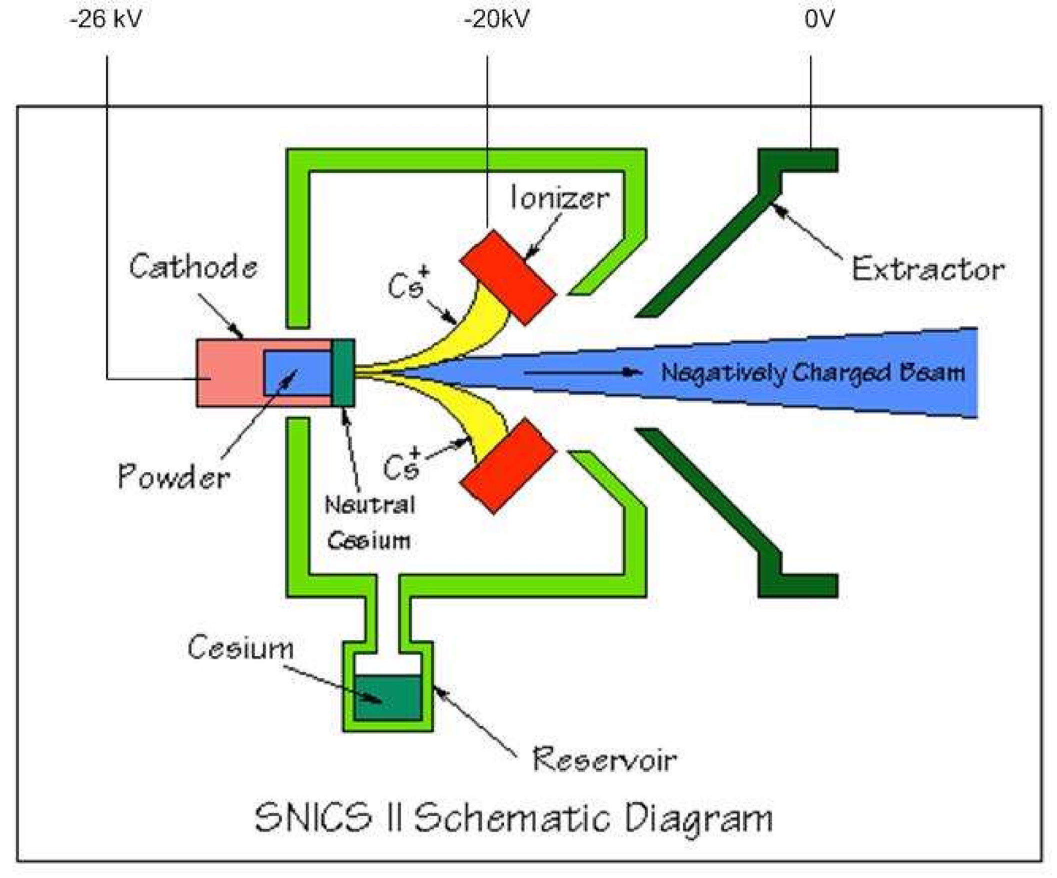
Duoplasmatron with special intermediate electrode design for higher negative beams

HVEE site: http://www.highvolteng.com

Duoplasmatron source

Fault	Possible cause and rectification
No arc current	Cathode 'cut off'. Remove cathode and check quantity. No cathode current. Verify the power supply is okay. No arc potential. Verify the power supply is okay. No gas pressure or gas pressure too high. Verify gas circuit is operating correctly. Empty supply or faulty regulator. Filament burnt out. Replace filament. Cathode shorting to plasma cup. Clean plasma cup.
No beam output	Anodic aperture is closed. Open aperture by scraping with a needle. No extraction potential. Verify the power supply. Loss of arc. Gas pressure incorrect. Increase gas until arc strikes.
Low beam output	Cathode is not heated sufficiently. Increase cathode current. Gas pressure is not correct. Readjust and optimise gas pressure. Check gas supply. The anodic plasma is not focused on the anode aperture. Regulate the magnetic focus while observing the output. The anodic temperature is increasing. Verify the operation of the cooling system. Charge exchange material is running low. Replace charge exchange material. Charge exchange canal blocked. Clean canal and replace with new charge exchange material. Low current through filament. Replace filament. Poor vacuum. Check vacuum system Bad off-axis adjustment (for direct negative)

Caesium sputter negative ion source (surface ionization)

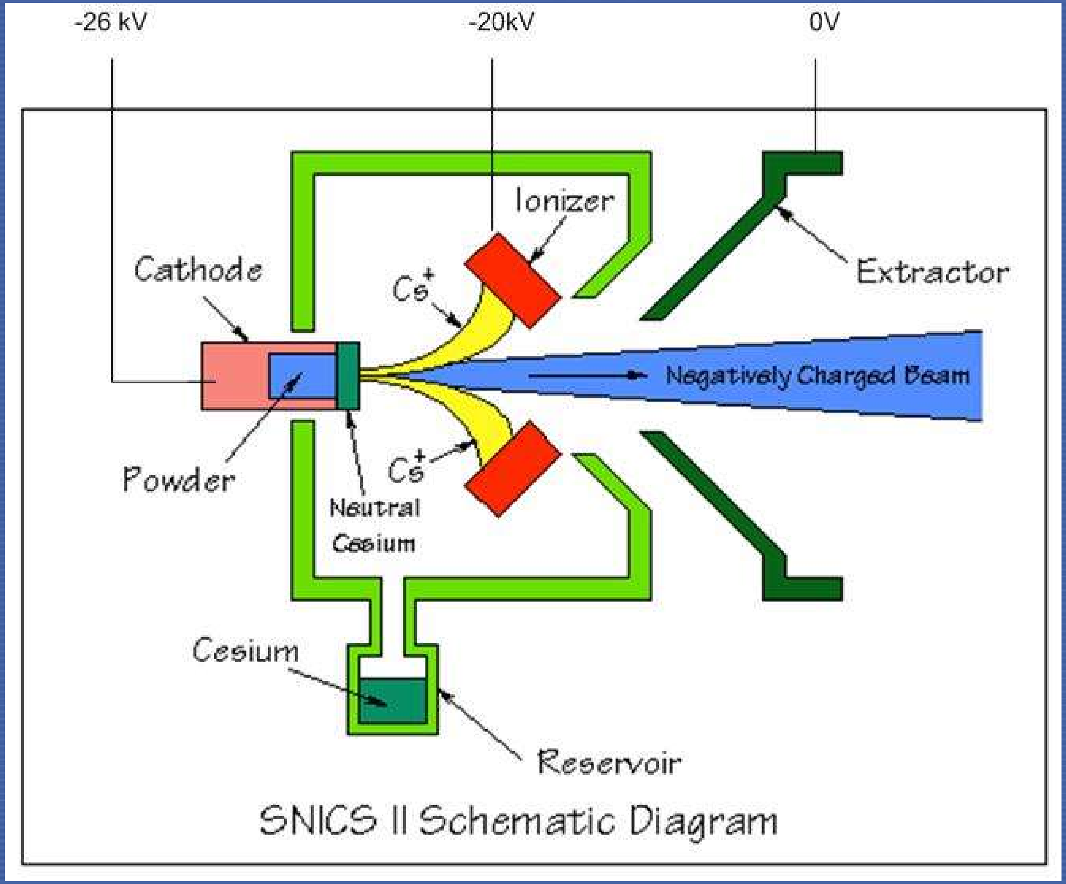


SNICS II Schematic Diagram

- Sputtering sources are more stable and generally easier to operate than charge exchange sources
- No possibility to produce metastable negative ions (He, Be..)
- Negatively charged ions are created from the sputtering action of a caesium ion beam on a solid material.
- The material to be sputtered is mounted on a negatively biased cathode - copper or aluminium.
- Negative ion beams of most elements can be formed (exceptions exist)
- The ion beam currents are highest for those elements with a high electron affinity.

Larry Lamm

Caesium sputter negative ion source (surface ionization)

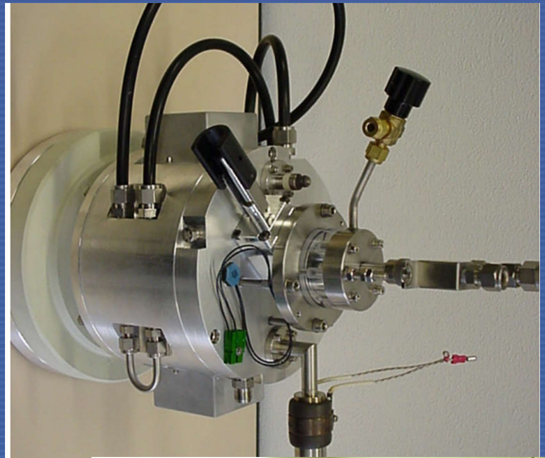


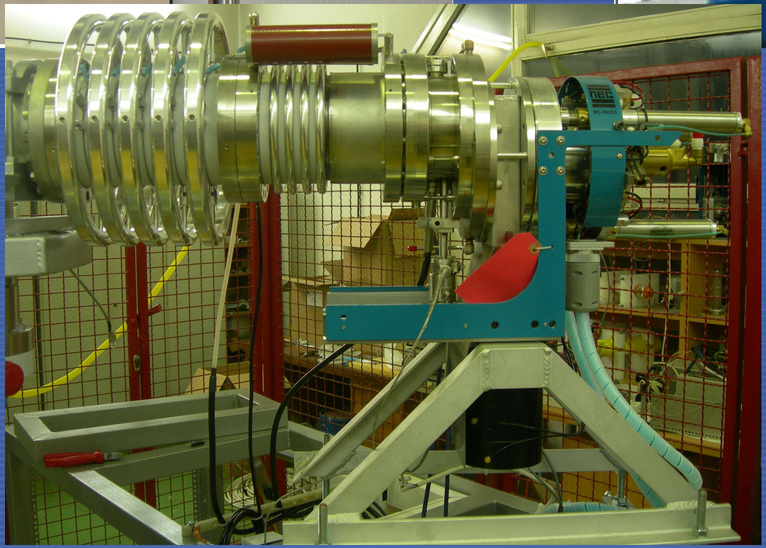
SNICS II Schematic Diagram

1. Negatively biased cathode attracts the positive caesium ions.
2. Upon impact, sputtered ions of the cathode material are produced.
3. Some materials will preferentially sputter negative ions, others will preferentially sputter neutral or positive particles- the percentage of negatives exp.
4. The latter can attach electrons as they pass through the condensed caesium layer on the cathode's surface producing negative ions.
5. The negative ions produced are attracted towards the positive extraction electrode and after exiting, are subsequently focused, and (maybe) accelerated by a pre-accelerator

Larry Lamm

Caesium sputter negative ion source (surface ionization)



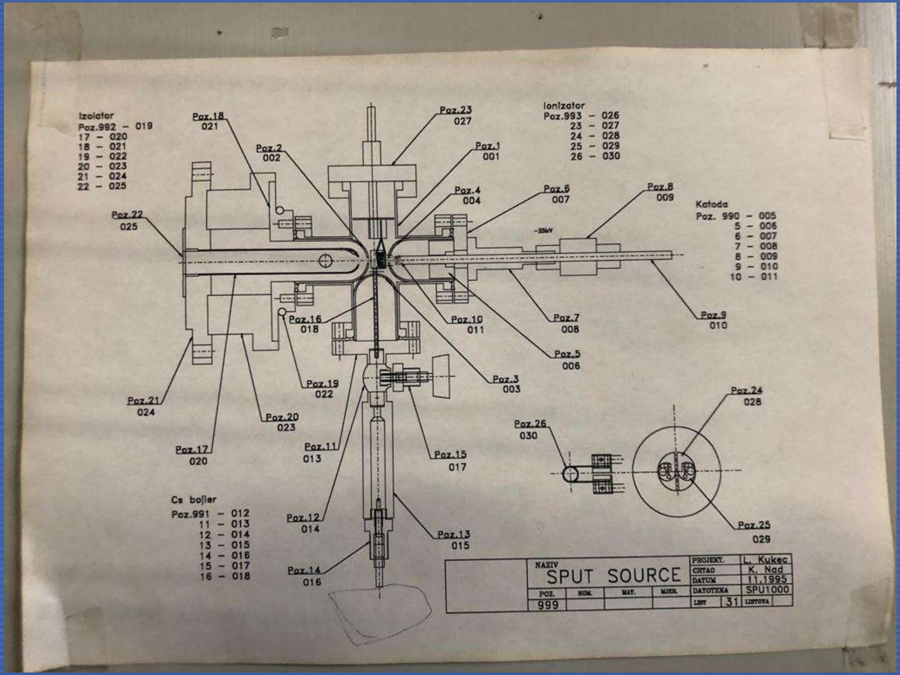


Caesium sputter negative ion source (surface ionization)

In house manufactured Cs sputtering ion source

The output currents comparable with commercial sources

Lifetime shorter (period between openings)



Izolator
Poz.992 – 019
17 – 020
18 – 021
19 – 022
20 – 023
21 – 024
22 – 025

Ionizator
Poz.993 – 026
23 – 027
24 – 028
25 – 029
26 – 030

Katoda
Poz. 990 – 005
5 – 006
6 – 007
7 – 008
8 – 009
9 – 010
10 – 011

Cs boiler
Poz.991 – 012
11 – 013
12 – 014
13 – 015
14 – 016
15 – 017
16 – 018

NAZIV SPUT SOURCE
POZ. 999
KOM.
MAT.
MJER.
PROJEKT. L. Kukec
CRTAO K. Nad
DATUM 11.1995
DATOTEKA SPU1000
LIST 31
LISTOVA

Caesium sputter negative ion source

Handling of Caesium tips (holds for RB, partially Na and Li)

1. Always fill the source with inert gas (Ar)-no N2!
2. Always use all possible protection-alkali metals will burn nicely on your skin and especially in eye
3. Alkali metals react (oxidize) rapidly with water and alcohol making explosion. In air they start burning fast
4. Small drops of remained Cs can be carefully drawn into the water tank creating small explosion (in controlled environment)
5. If the closed reservoir is to be removed from the source for more than a few hours, the assembly should be stored under an argon atmosphere.
6. New Cs (Rb) is always refilled in glow box (or bag) filled with Ar.
7. Melting point for Cs is 28.5 deg C; it can be made liquid by hand, small heater, “heated block”. Rb melting point is 38.5 deg C- no melting with hand – a heater has to be prepared
8. Some time is needed for evacuation and initial degassing of Cs.-During the filling of the reservoir, caesium may solidify on its cool sides trapping air bubbles. Warming the reservoir to ~ 50°C for a period before beginning normal operations can achieve suitable degassing.

Caesium sputter negative ion source

Preventive maintenance:

Item	Maintenance
Caesium reservoir level	Change or refill caesium when the output current is low, has an erratic behavior (also high temperature of reservoir may be an indicator).
Cathode coolant level	Keep coolant above the minimum operating level. Inspect the coolant recirculating pump for sufficient flow rate.
High voltage cables	Inspect for electrical breakdown damage, and replace if necessary.
Extract insulator	Keep surfaces clean. Inspect insulating surfaces for breakdown damage.
Operating platforms	Keep platforms clean to minimize extraneous electrical leakage paths.
Vacuum seals	Regularly inspect seals around the cathode tube for wear, and replace if necessary.
Power supplies	Monitor voltages and currents in all power supplies for abnormal changes. Investigate unexpected deviations from normal operating conditions.
Caesium oven	Monitor oven temperature, and investigated unexpected deviations.
Sample carousel	Keep the carousel in good working condition (different types)
Internals	Clean ion source internal components, including the ionizer, cathode hat, and insulator after prolonged ion source usage. Clean surfaces using very fine abrasive paper to polish, or sand blast. Do not use chemical polishing agents. Use ethanol and or acetone solvents to finish off. CsOH is easily cleaned with water Caesium burns explosively in water and alcohol!-follow the safety procedures and manual

Caesium sputter negative ion source

Fault tracing

Fault	Possible Causes	Rectification tips
No beam output	No beam measurement	Faulty faraday cup, control system or current meter. Check, repair/replace, recalibrate
	Low caesium flow	Blockage in the delivery system, oxidation of caesium due to air ingress, caesium fully consumed or the boiler is not working. Incorrect operating temperature. Check for vacuum leaks. Remove and completely clean the boiler and delivery tube. Replenish caesium.
	Loss of ion source high voltage power supplies required for extraction of the ions	Internal power supply fault, faulty high voltage connection or excessive power supply loading from ion source electrodes shorting, or poor vacuum. Individually raise the voltage on the power supplies, and monitor the current. If excessive current is drawn, then disconnect the power supplies, and check the input from the ion source for shorting, or high resistance. Check vacuum system operation. Check ion source for vacuum leaks.
	Loss of caesium ionization	Ionizer, or ionizer power supply failure. Remove and clean the ionizer. Grit blast for the best results. Be careful not to damage wiring during cleaning. Check power supply as for the power supply checks above.

Caesium sputter negative ion source

Fault tracing

Fault	Possible Causes	Rectification tips
Unsteady beam output	High voltage not being maintained	Check power supplies and insulators for breakdown.
	Contaminated internal surfaces	Excessive caesium condensation requires cleaning. Cleaning should be scheduled after a set usage time to manage the problem.
X-ray production	Excessive production of X-rays	Electrons are not effectively suppressed Only if the suppression magnets are removed or not existing.
Low beam output	Inaccurate beam measurement	Faulty Faraday cup. /current measurement. Check
	Low caesium flow	Low caesium supply or low boiler temperature, true or indicated. Turn off the caesium heater and check for changes in the output. If no change-blocked output or no caesium- try to overheat before refill!
	Poor ionization of caesium	Low ionizer temperature or contamination of the ionizer surface. Check cleanliness of the ionizer. Check if ionizer powered.

Caesium sputter negative ion source

Fault tracing

Low beam output	Loss of focus of the ion beam	Breakdown of extraction, Einzel lens or pre-acceleration voltages. Check power supplies, cooling medium conductivity, voltage gradient resistors, shortcircuit inside the vacuum, check grid (if existing)
	Insufficient cooling on the cathode	Check coolant flow.
	Loss of sample material in cathode	Check the cathode
	Poor alignment of cathode in X, Y or Z axes	X/Y alignment only applicable to multi-sample sources. The Z-axis alignment is crucial as an ill aligned cathode can sputter; the sides of the cathode if too far in or too much of the front cathode surface instead of the center sample material.
	Neutralization of negative ions	Poor vacuum in the ion source. Compare operating vacuum to base vacuum. Isolate the ion source. Leak test /repair. Clean inside

Beam quality, quick numbers

Beam emittance:

Phase space occupied by some percentage of the total beam.

$\epsilon x = X \cdot X'$; $\epsilon y = Y \cdot Y'$ [π mm · mrad]

$X' = px/pz$ – a small value (the beam is moving in z-direction); the divergence angle in X-direction

Normalized emittance is conserved when changing energy:

$\epsilon nx = X \cdot X' \cdot E^{1/2}$; $\epsilon ny = Y \cdot Y'\,' \cdot E^{1/2}$ [π mm · mrad·MeV$^{1/2}$]

Beam brightness:

$$B = \frac{I}{A0A\alpha E/d^2}$$ [pA/(mm2 mrad2 MeV)]

→ $B \sim I/\ \epsilon n^2$

different definitions give different proportionality factors, but important is proportionality

Roland Szymanski, David N. Jamieson: Ion source brightness and nuclear microprobe applications Nuclear instruments and Methods in Physics Research B 130 (1997) 50-85

Beam quality, quick numbers

(Normalized) emittances, rough numbers

Different Sputter sources: :Єn‹ 3–20+ π mm · mrad·MeV$^{1/2}$

Duoplasmatron 358 (80%) Єn‹ 2 π mm · mrad·MeV$^{1/2}$

SNICS (75%): 1.8 (90 %) 3 π mm · mrad·MeV$^{1/2}$

Alphatross (He, 80%) ~ 1.2 π mm · mrad·MeV$^{1/2}$

Sputter (80%) 860A source : 8 - 12 π mm mrad (MeV) $\frac{1}{2}$

860C source : 2 - 6 π mm mrad (MeV) $\frac{1}{2}$

Typical currents:	duoplasmatron	~tens of microamps
	Sputter	~tens of microamps
	RF and duopl CEC	a few microamp (for He)
	Multicusp+CEC	~tens of microamps (for He)
	Multicusp direct	mA

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Potential hazards (apart from alkali metals)

Almost all ion sources are potentially dangerous:

- High voltages for ion production acceleration
  - Protective barriers to prevent persons making contact with high voltage surfaces,
  - Safety interlocks and protection systems,
  - Electrical insulation to external components
  - Awareness that high voltages may be present through adequate warnings.
- Gasses; sometimes flammable, poisonous or simply compressed
  - High pressure cylinders have to be stored in a safe way, following local regulations and common sense
  - Do not mix incompatible gasses
  - All gas cylinders have to be fitted with a regulating valve so that the outlet pressure can be controlled
  - Oxygen cylinders should be stored separately from combustible gases to lessen fire and explosion hazards
  - Use protective equipment
- Cooling liquids can be flammable (if not deionized water)
- X-ray production from bremsstrahlung of energetic electrons (especially when source malfunctioning)

Cleaning of sources

- CLEANING OF ION SOURCE COMPONENTS; indicators

  Low source output
  Unstable output
  Sparking
  Contaminated beam

Insulators

Some cleaning chemicals can create irreparable damage-destroy polished surfaces, make the insulator conductive…

No penetrating cleaning chemicals

warm soapy water (especially for traces of alkali metals)

Drying (sometimes in oven) is absolutely necessary

Fine sand blasting where not possible to wash

Cleaning tips

Metal components

- *Check on small area if cleaning agent makes traces on the metal surface!*
- *warm soapy water*
- *Acetone and lint free coth*
- *Drying (heating) helps with vacuum pumping-necessary if in contact with alkali metals-necessary*
- For persistent and not easily removed deposits - ', wet and dry' paper, grade P1200 (super fine) ,to polish
- Polishing is better with water!

Ionizers

- Helical and spherical ionizers can be cleaned using a fine jet abrasive.
- Any abrasive compound or dust remaining on the ionizer must be - compressed air or nitrogen.
- Avoid blasting the electrical and thermal insulating material from the ionizer shell around the leads.
- Don't touch the ionizer surface with a bare hand after cleaning, store in plastic bag
- The compressed air supply must be clean and free of oil or water
- Tungsten is very brittle after being at high temperatures!

Literature

B. Wolf (Ed.), Handbook of Ion Sources (CRC Press, Boca Raton, FL, 1995).

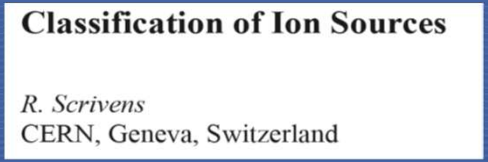
Formation of negative ions by charge transfer: He- to Cl- *
Alfred S. Schlachter
CAIP Conference Proceedings 111, 300 (1984); doi: 10.1063/1.34431

A Negative-Ion Cookbook
Roy Middleton, Department Of Physics, University of Pennsylvania

Peabody scientific http://www.peabody-scientific.com

HVEE: http://www.highvolteng.com

NEC http://www.pelletron.com


Classification of Ion Sources

R. Scrivens
CERN, Geneva, Switzerland

Electrostatic Accelerators
Fundamentals and Applications
Editors: Hellborg, Ragnar (Ed.)

Principles of Charged Particle Acceleration, Humphries
citeseerx.ist.psu.edu/viewdoc/download
Charged Particle Beams, Stanley Humphries, Jr.

Questions, discussion? …

Nuclear Science & Instrumentation Laboratory NSIL

Department Nuclear Sciences & Applications, Division Physical & Chemical Sciences, Physics Section

Duoplasmatron source

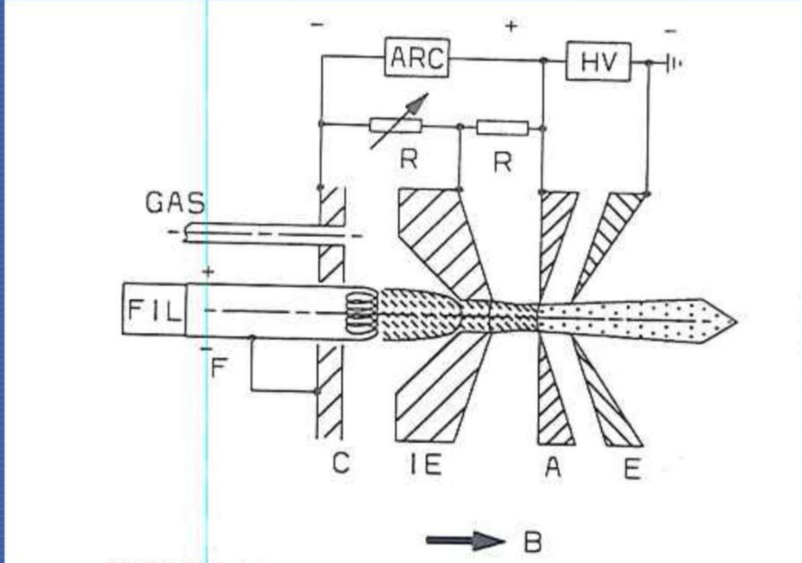
The filaments used in duoplasmatron ion sources can have their life extended by coating them with a proprietary cathode coating media such as (Ba-Sr-Ca)CO_3. Manufacturers manuals provide information on recommended methods for coating the filament. Typically, their coating procedure is as follows.

The filament is first prepared by washing in 20% nitric acid and distilled water, and then rinsed with clean water. It is then blown dry with a hot air gun. The filament is then dipped into the coating solution up to about 10 mm from the filament supports. After removing from the coating solution, the filament is dried with a hot air gun. The coating and drying steps are repeated about 3 times to build up a thick layer. When completed, the coated filament should be mounted back inside of the ion source and the ion source evacuated of air to reduce the chance of contamination. The filament will require careful outgassing before use at normal operating conditions. Essentially, the filament current is slowly increased over a number of hours, slowly increasing the filament temperature until ultimately, the carbonated coating material is converted into an oxide. Duoplasmatron manufacturers provide recommended procedures in their operating manuals.

Lithium charge exchanges may need to be recharged every 4 to 5 weeks if they are in constant use. There is a tendency for the lithium to migrate into the ion source internals, and as well towards the pre-accelerator tube, causing an apparent high consumption rate from the lithium reservoir. It will be necessary to clean the pre-accelerator at regular intervals or at least once per year. The pre-accelerator leakage current will increase as it becomes contaminated with lithium, so the operator can use this to indicate the condition of the pre-accelerator tube and set maintenance schedules accordingly to mitigate this effect.

Reusable high pressure source gas cylinders can be successfully adapted for use in any gas consuming ion source. This negates the need for commercially supplied pre-filled gas cylinders. To fill the bottles, an adaptor can be made that allows the cylinder to be evacuated and backfilled with the desired gas. Care must be taken to select and use only the highest purity gases. When evacuating the ion source gas feed cylinders, it is highly recommended that a cold-trapped vacuum pumping system be used, with vacuum pumping maintained until a pressure of less than 0.1 Pa is achieved.

Duoplasmatron source (off axis)



H

H^- from Duoplasmatron

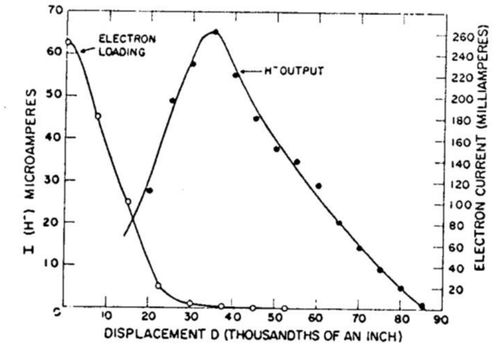


Fig. 2. H^- output and electron loading as a function of radial displacement.

- **ION SOURCE GAS LEAKS**

- The three most commonly used gas leaks in electrostatic accelerators are the palladium leak, the thermo-mechanical leak and various types of precision needle valve. A carefully designed pressure regulator must be applied to guarantee the stable flow rate and to ensure there are no leaks that may affect the purity of the gas during long operation time. The ratio of atomic to molecular ions depends on the operating time of the ion source, the pressure in the discharge volume, and the purity of the gas entering the plasma.

RF charge exchange source

- ***Handling of rubidium metal used in charge exchange ion source***
- Rubidium metal used in the reservoir/oven of a charge exchange ion source is a hazardous substance. When combined with moisture, rubidium spontaneously combusts. Before handling this substance, the Material Safety Data Sheet [3] must be read and understood. All manners of handling rubidium are the same as for caesium.
- ***Cleaning of rubidium metal from fixed ion source parts in atmosphere***
- Special care is needed to remove rubidium metal that remains on ion source components after the oven has been removed. The following information is provided as a guide for cleaning the ion source, without the need to dismantle it, prior to recharging rubidium in the reservoir. It requires the person undertaking the operation to wear appropriate protective clothing, thick rubber gloves and eye protection.
- A large, clean and empty container such as a 60 litre garbage bin is filled with water to a depth of about 50 mm. The container is placed directly underneath the reservoir opening of the ion source assembly to catch any droplets of rubidium as the reservoir is removed. Before removing the oven/reservoir, argon must be flowing through the source to maintain an inert atmosphere, preventing residual rubidium in the chamber from oxidising.
- As the source is disassembled, slightly water damped cotton buds are used to dab away rubidium from the source parts. It is normal to hear a cracking sound when the rubidium reacts with the water. The cotton buds can be quickly dropped into the container of water should they ignite. Any rubidium that falls from the ion source during the disassembly process will be captured in the container and neutralised by combustion.