NATIONAL ELECTROSTATICS CORP.

Instruction Manual No. 2JT005110 for

RF CHARGE EXCHANGE ION SOURCE

2JA005110

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JBS

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SAFETY INSTRUCTIONS

IMPORTANT SAFETY INFORMATION
READ BEFORE OPERATION AND SERVICE

This unit must only be operated and serviced by qualified personnel who have read the instruction manual and are familiar with the hazards associated with the use of this equipment. Proper care and judgment must always be observed.

HOT SURFACES!
DO NOT TOUCH !

FIRE HAZARD !
KEEP BURNABLE
MATERIALS AWAY !

EXPLOSION HAZARD !
KEEP WATER AWAY !

WARNING: This equipment contains an electrically heated reservoir of highly reactive alkali metal.

Care must be taken in operation to avoid contact with hot areas to prevent burns.

Alkali metals are extremely water reactive. In service procedures, instructions must be followed exactly to avoid burns from contact with alkali metals. Exposing significant quantities of alkali metals to water may cause an explosion.

OPERATION:

Under normal operating conditions, the alkali metals are completely contained inside the vacuum enclosure.

1. Never attempt to operate the unit in any manner not described in the instruction manual.

2. Always follow heater values and temperatures specified in the manual.

3. Don't touch hot areas without heater shut off and ample time to cool down

4. Always maintain the unit under vacuum when no service procedures are being performed. Failure to maintain the unit under vacuum may expose the alkali metal to the air. Exposure of the alkali metal to moisture in the air may result in rapid burning.

SERVICE:

Opening the vacuum enclosure allows exposure to highly water reactive alkali metals. Alkali metals will burn rapidly when in contact with water. Failure to follow the procedures in the instruction manual exactly could result in burns, fire and/or explosion. Service operations must only performed by properly trained and experienced technicians.

WARNING: PERSONAL PROTECTIVE EQUIPMENT REQUIRED!

Approved Personal Protective Equipment including but not limited to face shield, gloves and apron must be worn. Requirements of each laboratory safety program and controlling agencies must be followed.

If alkali metal contacts skin or clothing, flush with copious amounts of water. If alkali metal contacts eyes, nose or mouth, flush with water and get immediate emergency medical care.

Alkali metals will burn rapidly when in contact with water. Failure to follow the procedures in the instruction manual exactly may result in fire and/or explosion. Service operations must only performed by properly trained and experienced technicians.

1. Never remove warning labels from the unit. Replace lost or damaged labels immediately. Contact NEC for replacement labels.

2. Allow adequate time for unit to cool down after operation.

3. When opening vacuum enclosure, vent vacuum to Argon gas only. Do NOT use Nitrogen or other gases.

4. Maintain inert atmosphere flowing from the unit while the vacuum enclosure is open. Follow detailed procedures in the manual exactly.

5. Oven Removal: As the oven is removed in the presence of an inert atmosphere, carefully seal it before removal from the inert atmosphere flow. Follow detailed procedures in the manual exactly.

6. Oven Cleaning and Reloading:

WARNING: Ion source ovens may contain a sufficient quantity of alkali metal that an explosion may result if exposed to water.

Many customers prefer to have this procedure done by NEC trained technical personnel, either at the site during installation or by returning the unit to the NEC factory. To return a used oven to NEC, call 608-831-7600 for a Return Materials Authorization (RMA) number, verify proper hazardous material packing procedures and ship the unit to 7540 Graber Road, Middleton, WI 53562 using the proper hazardous materials shipping methods.

If oven cleaning is to be done at the user's site, this service must be performed by trained and qualified personnel and must follow exactly the instructions from the instruction manual and/or from training by NEC technical personnel.

7. Ion Source and Lens Cleaning:

The ion source and lens parts may have small quantities of alkali metal on their interior surfaces. Washing with water may result in small reactions making sizzling or popping sounds; however, in small quantities, an explosion should not result.

A. Maintain sufficient ventilation during all cleaning operations.

B. Rinse the interior surfaces ONLY with water first, then with a solvent such as ethanol. Do NOT use solvents first.

WARNING: Always wash internal vacuum surfaces with water FIRST, never flammable liquids.

8. Oven Re-attachment: Be sure that an inert gas atmosphere is flowing from the ion source. Unseal the oven ONLY under the inert gas flow. Securely fasten the oven to the ion source with a new gasket.

9. Always use the NEC supplied instruction manual, assembly drawings and parts lists for service details of this unit.

CAUTION!

READ THESE IMPORTANT SAFETY INSTRUCTIONS BEFORE PROCEEDING!

The following notes are a warning to the user of potential hazards involved with operation, maintenance, and malfunctions of the Charge Exchange RF Source.

1. This ion source utilizes high voltage power supplies and a high-power high-frequency oscillator. Always turn off power to <u>all</u> the power supplies during source maintenance or adjustment. In general these supplies may include (depending on the configuration of the system) the Probe Power Supply, Bias Power Supply, Extractor Power Supply, Focus Power Supply, Oscillator Power Supply, Magnet Power Supply, and Oven Power Supply. It is also recommended that a grounding hook be placed on the ion source during maintenance or whenever the safety cage is open and the source is exposed.

2. The rubidium metal used in the charge exchange portion of the source becomes violently reactive when exposed to water or humidity in the air. The reaction can be explosive ejecting rubidium droplets. Rubidium will cause severe skin burns on contact. For this reason rubidium should only be handled in an inert gas atmosphere such as a glove bag or box filled with argon gas. As an added precaution gloves, an apron and a face shield should be worn.

3. Parts of the ion source, such as the oven, the charge exchange cell, the magnet, the quartz discharge tube, and the oscillator, become very hot during normal operation. Allow the source to cool before proceeding with any maintenance.

4. Under certain circumstances the exit canal of the ion source can become plugged with rubidium. When this occurs, gas bled in through the metering valve will cause pressure to build up in the quartz bottle. Elevated pressure causes the plasma to become superheated when the source is operated thus softening the quartz to the point where it can burst. To prevent this from happening a low pressure relief valve should be installed on the source gas feed line. Also, when first opening the metering valve always look for an increase in the ion gauge reading in the source beamline to confirm that gas is flowing through the source.

5. The source shield box contains the 100 MHZ oscillator that can broadcast enough RF radiation to cause other electronic components in the vicinity to malfunction. Therefore, the shield box cover should be in place when the oscillator is energized.

I. INTRODUCTION

The NEC RF Charge Exchange Ion Source is patterned after the source in use by H. T. Richards at the University of Wisconsin-Madison since 1976. As it was developed for He^- production, it is aptly named the Alphatross. The original version was developed in 1967* and has subsequently evolved into the source now in use by NEC. In operation, a positive ion beam is extracted from a plasma produced in the RF source and accelerated into the charge exchange cell at 6 keV where a portion (1-2%) of the beam is converted to negative ions which are subsequently extracted and accelerated to the desired energy.

The charge exchange cell utilizes rubidium vapor because of its high cross section for He^- production. The NEC Alphatross uses a rubidium condenser to halt migration of rubidium vapor into the quartz bottle and plasma. An additional baffle is installed at the output side of the charge exchanger to keep rubidium out of the lenses, valves, etc.

This source is exceptionally reliable and has a long lifetime, (over 1600 hrs. in factory testing). However, it is essential that certain rules of operation are strictly followed, because it is not very tolerant of neglect. You have already made an important first step by picking up this manual and reading it. Gaining a basic understanding of how the source works will help you avoid malfunctions or, at least, how best to deal with them if they occur.

*Fred Rose, P.B. Tollefsrud & H.J. Richards, IEEE Transactions on Nuclear Science, Vol. NS-14 (1967), p. 78.

II. SOURCE REQUIREMENTS

A. Electrical

1) 1.5 kVA Isolation Transformer

2) Probe Power Supply 10 kV DC, 5 mA

3) Oven Power Supply 115 V, 2 A

4) Magnet Power Supply 80 VDC, 4 A

5) 100 MHZ RF Oscillator and Power Supply

6) Source Bias and Lens Power Supplies

B. Cooling

1) NEC Air Cooling System (2IA061160) (for charge exchanger)

2) NEC ACF-HC Cooling System (2IA061460) (for Rb baffles)

C. Helium gas reservoir and Mass Flow Controller (or metering valve)

D. Vacuum System

1) Turbo-molecular pump, minimum 300 l/s rating

2) Ultra-high vacuum gauge

3) Source isolation gate valve

4) Vent valve

E. Allowable Orientations - Horizontal Only

III. PREPARING FOR OPERATION

Source Connections

Refer to the drawings in the back of this manual. All power supplies should be checked for operation, polarity, and output. They should be connected to the source as shown in the Schematic 2JS002110. RF power is capacitively coupled to the plasma via two bands around the quartz bottle. Place the bands as shown in the source assembly drawing (11-0-511). The braided leads from these bands are clipped to the oscillator coil. These connections should be located one quarter turn (90°) on each side of the center tap of the coil. Make sure the braids don't short out to the adjacent turn on the coil or on any grounded surface. The source output is not a strong function of slight changes in the position of the bands on the bottle and position of the clips on the oscillator coil as with some other RF sources that the user may be familiar with, but some position vs. output dependence may be observed.

The probe power supply is connected to the probe through a 10 Kohm, 20 W resistor. Attach the probe power supply cable to the H.V. feedthru on the shield box. Make sure the shield box fan is connected and that the fan turns freely when power is applied to the source. The fan prevents the oscillator from overheating.

Charge Exchanger Connections

Proper installation and operation of the source's two cooling systems is vital to the performance and lifetime of the source. First is the air cooling system. Air may be supplied by either your own air compressor system or the NEC Air Cooling System (Part No. 2IA061160). The air cools the charge exchange chamber and the o-ring at the end of the quartz bottle. The 1/4" dia polyethylene air line is connected to a fitting on the Cooling Jacket as shown in the cooling system schematic. An air deflector inside the Cooling Jacket prevents air from blowing directly on the charge exchange chamber. Refer to drawing 11-0-511. (Note: Tubing can be released by pushing in fitting collet.)

On the other side of the cooling jacket is the bayonet mount and guide fitting for the "chamber" thermocouple. Before inserting the thermocouple apply a dab of heat sink compound to the tip. This will greatly improve its accuracy and responsiveness. Adjust the thermocouple to make good contact with the wall of the charge exchange tee by turning the locking nut until the spring applies pressure

Install the hose clamp thermocouple bayonet mount just below the Rb oven flange. As with the chamber, install the "oven" thermocouple in the bayonet fitting.

Clamp the band heater around the Rb oven just below the thermocouple clamp. Tighten the band heater clamp. Consistent placement of the heater and thermocouple fosters consistent parameter values from run to run.

Finally, make sure no wires are in contact with the oven or the chimney because they will melt. Also, remember that this source is operated at high voltage. Make sure no wires are **touching** or **near to** any grounded surface to avoid arcing and instability.

Next connect the liquid cooling system tubing to the ACF-HC Cooling System (2IA061460). This system cools the condenser and baffle at the entrance and exit of the charge exchange chamber respectively. Their purpose is to trap rubidium vapor which migrates from the charge exchanger. For proper attachment refer to drawing 11-0-511. Make sure liquid flow is always from the bottom to the top of the baffles to avoid air pockets in the baffles.

Gas Supply Plumbing

The Alphatross gas plumbing consists of a high pressure cylinder equipped with a shutoff valve, pressure gauge, regulator and mass flow controller (MFC). One may also use a metering valve. The connection fitting uses a resealable o-ring type seal (Cajon VCO) so that the gas bottle(s) can be removed from the system and filled in another location. Multiple gas supplies may be connected in parallel.

The bottles must be evacuated before filling (unless they already contain the desired gas) to insure that the plasma will not be contaminated. Gas transfer tubes and regulators should also be evacuated or purged.

There is a small amount of plumbing between the gas bottles and the MFC . This volume can be evacuated through the MFC before opening the shutoff valve on the gas bottle. This should be done whenever a bottle is removed or when one is changing from one type of gas to another.

The Kynar plastic gas feed tube is connected to the source with o-ring seal fittings. These fittings are designed to make a leak tight seal with hand tightening only. Therefore, do not use a pliers or a wrench and overtighten them. The fitting on the MFC is a 1/4" Swagelok fitting with a nylon ferrule.

IV. OPERATION

General Comments

Before plunging into a recipe for operating the Alphatross, it's a good idea to formulate a mental picture of how it works. Then we will know what to expect when we start throwing switches and turning knobs.

There are two main components in this device. The first one is the radio frequency positive ion source. Helium gas is bled into a quartz discharge bottle through an MFC to maintain a pressure adequate to support a plasma or about 0.35 SCCM. An RF oscillator induces the plasma in the bottle which is intensified by the solenoid magnet. A DC potential is applied across the plasma by the probe power supply. This potential extracts ions from the plasma and accelerates them through the Ta exit canal. Then they enter the charge exchange chamber.

The charge exchanger is the second main component of the Alphatross. In it He^+ ions are neutralized by the Rb vapor. A few fast He atoms then undergo a second charge exchange reaction and become He^-. Therefore, what emerges from the Alphatross is 100-200 pμA He^o and 1-4 μA He^-. The key to successful operation of the charge exchanger lies in the control of temperatures in the oven and in the chamber. The oven is heated to about 220°C (indicated temperature at thermocouple). Rb vapor rises up through the chimney and into the charge exchange chamber. It immediately condenses on the walls. Here the Rb should remain in the liquid phase so that it can flow, by force of gravity, back down into the oven. Thus, the Rb is continually recycled. However, if the walls of the charge exchange chamber are too cool, the Rb will freeze (m.p. = 38.9°C) and eventually the oven will be empty at which point charge exchange ceases and no beam appears. On the other hand, the chamber temperature must not be too high. This results in diffusion of Rb out the ends of the chamber. The correct chamber temperature varies between 50-60°C. It is regulated by cooling air and fluid temperature and flow. This is done automatically by NEC's Air Cooling System (2IA061160) and ACF-HC Cooling System (2IA061460). If your source is not equipped with these units you will need to carefully control these parameters yourself.

We encourage you to read the section in this manual on "Troubleshooting" before running the source to familiarize yourself with potential operational problems.

Starting Instruction Comments

The following instructions are for He^- beams from the Alphatross. Procedures for production of other beam species are basically the same. The slight differences in operating parameters are discussed in the next section of this manual. Therefore, the following instructions can be used as a general guide.

1) Turn on air cooling, liquid cooling, and source power. In systems equipped with the ACF-HC cooling system source power may be interlocked to fluid flow. Also, air compressor turns on with source power.

2) Wait 60 seconds for delay timer to turn the oscillator on. After 60 seconds the plasma may ignite spontaneously in the quartz bottle. If not you will need to feed it some gas with the MFC to ignite the plasma.

3) Slowly increase the flow rate of the MFC while observing the quartz bottle. As the pressure rises the plasma will ignite. Then quickly lower the pressure to the operating point by reducing the MFC flow to about 0.35 SCCM. Typically, the pressure at the beamline pump will be about 2E-06 Torr. This is the operating point. (Your optimum pressure will depend on the conductances of your particular vacuum system and the pump speed).

4) Turn up the magnet power supply to 3.5A. The beam current is proportional to magnet current (maximum 4 amps). After the source is started the magnet can be adjusted to yield the desired output.

5) Observe the plasma. Color should be aqua green for a He plasma. If there is a leak or the source is new the plasma will be blue. A new source will likely need at least two hours of outgassing before good color is observed.

6) Increase the probe voltage slowly to 6 kV. On a new source you may notice some instability in the probe current. Conditioning is normal. In this case, stop at 3 kV and increase 0.5 kV every 5 minutes. Continue operating until the probe is steady and the proper plasma color is observed before attempting to start the charge exchanger. With 6 kV probe and 3-4A magnet a proper discharge will be bright white at the front of the bottle and transparent light green at the rear. A slight red glowing of the quartz bottle is normal. Normal probe current is 2.5 mA ±0.5 mA.

7) Adjust the oven heater power supply to 85V. (see next section). Within a few minutes you should see the oven temperature start to rise.

8) Wait 10 minutes. At this point the oven temperature will have reached 150°C.

9) Turn on and tune source bias, lenses etc. and begin to look for He^- beam. (Note: turning on source bias and/or lenses before this time is likely to result in lens instability).

10) Adjust the MFC flow to maximize the beam current once the oven reaches the operating temperature (see next section).

11) Adjust the source magnet until the desired level of beam current is obtained. Currents of 1-4 μA He- are normal.

12) After about 30 minutes you should observe that the chamber temperature is approaching the operating point of 55°C. If you do not have the NEC air compressor system you will need to adjust air flow to maintain this temperature. Compressed air temperatures vary from place to place so some trial and error investigation may be needed the first time to establish appropriate flow rates. We suggest you start at 40 SCFH. When the chamber warms up increase flow to around 75 SCFH or whatever works. (These values are for room temperature air. Your will need to revise your parameters upward or downward depending on your compressed air temperature.)

Shutdown Instruction Comments

How you turn the ion source off is just as important as how you turn it on, (maybe more!). Please follow these instructions exactly. It's most important that the plasma is maintained until the charge exchanger is cool to prevent Rb from migrating into the discharge bottle. Time saved by premature plasma shutdown will be more than lost when you try to start the Alphatross the next time and find that the plasma is unstable.

1) Turn off beamline components (lenses, selectors, etc.).

2) Turn off the oven heater power. Leave the plasma running. Wait 30 minutes until oven cools to 50°C.

3) Reduce probe voltage to zero.

4) Reduce magnet current to zero.

5) Set MFC flow to zero

6) Turn off ion source power.

7) Stop all cooling.

If the Alphatross is running when a power failure occurs turn off the oven power and try to get the plasma restarted as soon as power is restored. Confirm that a stable plasma can be maintained before proceeding to operate the charge exchanger again. If power failures are frequent in your area, you may want to consider rigging a plastic hose to blow compressed air on the Rb oven and cool it quickly in the event of a power failure. A normally open solenoid valve can be used to accomplish this automatically.

How to Adjust the Rb Oven Power

The temperature of the Rb oven and the charge exchange chamber are critical to successful operation. This is because these parameters depend on the particular ion source environment and equipment. Oven heater elements vary. The exact placement of the thermocouple (TC) on the oven, its position relative to the heater, the conductance of the thermal contact, the calibration of the TC, the presence of RFI, and the ambient air temperature and velocity all affect these parameters. The oven TC is useful as a relative indicator of temperature, and as a means of monitoring any changes that might indicate a problem. But we have found it to be misleading to quote absolute temperatures and oven settings.

To determine the proper operating temperature for your own source, "let the beam tell you", and from then on, go by oven power setting, not the TC. This is not as mysterious as it sounds. First, you have to have a healthy helium plasma: intensely bright, aqua color, and 2-3mA @ 6kV probe with 4 amps on the magnet. Start with about 85V on the oven power supply. Once everything has stabilized, record the He- beam current. Then incrementally increase the oven power, allowing it to reach equilibrium at each step. You should observe an increase in beam current. At a certain point you will notice that the beam current no longer improves with increases in power. You should also observe that the beam current is no longer steady. This indicates that the oven power is too high. Your best operating point is at maximum steady current output. This is usually about 90V.

How to Produce Other Beams

Though the Alphatross was first designed to produce He^- beams, it is quite capable of creating a variety of negative ions. In some cases these ions can be produced simply by introducing a particular gas to the plasma, but in most cases we find that mixtures of gases are best. This is best accomplished by having several gas bottles each with its own MFC. This allows the user to independently control the quantity of each gas admitted to the plasma to obtain the optimum beam output.

If only one MFC is available it is still possible to create other ions by premixing gases in the correct ratios in a single bottle, though maximum outputs are seldom achieved.

The following list is a guide to those beams with which NEC has had some experience, but we have by no means exhausted the subject here. All elements which can exist in gaseous form and can form negative ions (either atomic or molecular) could be considered candidates for ion production in the Alphatross.

Source lifetime is largely a function of the sputtering rate of the exit canal. (See chapter on Maintenance). Heavy ions will sputter away the canal faster than light ions; therefore, lifetime to varies inversely with ion mass.

Also, the possibility for chemical interactions between the gas and the Rb must be considered. For instance, when first attempting to form the ion NH_{2-}, we found that using ammonia gas had a disagreeable effect on the Rb.

H^-, (D^-) Beams

One can create H^- (or D^-) beams by simply metering pure H_2(D_2) gas into the quartz bottle and operating with probe voltages of 2-4 kV, however, we have found that the beam current is not steady if the Ta canal is used. An aluminum canal (Part No. 2JD035811) and corresponding insulator (Part No. 2JD035960) works much better. To obtain steady beams using the Ta canal a mixture of 3% H_2 to 97% He gas works quite well.

Hydrogen charge exchanges more efficiently than helium and best at low energy, so it is possible to obtain 10 micro amperes or more of H-. One thing to keep in mind when running H- is that three different beams are produced in the RF source: H+, H2+, and H3+ (relative abundances vary with plasma conditions and surfaces materials). As they pass through the Rb vapor the molecular ions will break up dividing the energy equally among the atoms. Therefore, H- ions formed from H3+ ions will have only 1/3 as much energy as those from H+ and those from H2+ only 1/2. This can will have a major effect on the ion optics and lens voltage settings. Charge exchange is more efficient at lower energy.

<u>He^- and H^- Beams Simultaneously</u>

If you need to switch between helium and hydrogen beams frequently (for instance if you do both PIXE and RBS analysis), try a mixture of 1% H_2 and 99% He. This will yield 1 μA He^- and a few μA's H^-.

<u>NH^-, Beams</u>

Nitrogen-15 is an interesting beam for some kinds of experiments. However, nitrogen by itself does not form a negative ion. The molecular ion NH_{2-} (also NH^- and NH_{3-}) can be formed by operating with a plasma composed of about 0.5% N_2 and 99.5% H_2. It's best to have independent control of both gases. Beam currents of 2-3 μA (total of NH-, NH2-, NH3-) can be obtained. Probe voltage should be about 3 kV.

O^- Beams

Oxygen is a prolific ion. It's hard not to produce it. (Even a well outgassed Alphatross running on pure He will produce a little oxygen). Tens of microamps of O^- can easily be produced by admitting a small amount of O_2 to a He plasma. Probe voltage should be about 3-4 kV.

V. ION SOURCE MAINTENANCE

The Alphatross is a very low maintenance ion source when one considers maintenance time versus running time. In practice it seems as though improper operation or vacuum accidents result in downtime more frequently than normal wear and tear. Total maintenance required may be as little as a few hours per year if the user adheres strictly to proper operating procedures.

The Alphatross's two main components, the RF ion source and the charge exchanger, can be considered as separate from the maintenance point of view, that is, you don't have to tear down the whole ion source if only the discharge tube needs attention.

RF Ion Source

In the RF positive ion source ions extracted from the plasma continually bombard and sputter away the extraction canal material. This material is deposited on the insulator and quartz bottle. Eventually, buildup of metal on the insulator will short out the plasma. Also, the bottle may become sufficiently coated so that the RF energy no longer couples efficiently with the plasma.

These are the normal processes occurring in the ion source which will eventually lead to maintenance. How long? This is a difficult question. It depends on ion species and intensity of operation. In a factory test the Alphatross was run continuously with about 3 μA He^- output. It lasted for nearly 1700 hrs. before it died. The subsequent autopsy revealed that the beam had sputtered its way through the wall of the Ta canal. The final moments must have been quite spectacular as evidenced by material which was blown all over the inside of the bottle. It was a mess to clean up.

For this reason we recommend that you do not run the Alphatross to extinction. About 1000 hrs. is a reasonable lifetime to expect from a canal for light ions, a few hundred hours for heavy ions. The bottle will last for a few thousand hours before needing a cleaning. BN insulators should be changed whenever the canal is changed, but they can be recycled after cleaning (procedure described below).

Procedure for Replacing Canal and Insulator

1) Isolate the ion source by closing the gate valve.

2) Vent the ion source up to 1 atm. of argon gas through the vent valve.

3) Unscrew the two 10-32 cap screws that secure the bottle assembly with a 5/32" ball driver.

4) Pull out the bottle assembly. Make sure there is a slight outward flow of argon from the charge exchanger to prevent the Rb from reacting with air.

5) Remove the BN insulator and canal from the end of the bottle.

6) Insert new canal and insulator into end of bottle.

7) Remount the bottle on the source flange making sure that the little disc on the end of the canal fits into the shallow hole. This insures good alignment. (If the canal is not seated in the hole the "o"-ring will not seal).

8) Secure the bottle assembly using the two screws. Tighten a little at a time, going back and forth between the screws, until the springs are almost completely compressed . Do not over tighten!

9) Evacuate the source through the vent valve.

10) Check for leaks with helium detector or squirt a little alcohol on the seals.

11) Open ion source isolation gate valve.

Note: Used canals should be discarded. Deposits on used insulators can be removed by heating them with a torch or in a high temperature oven to 1000°C. or so. At first the BN will turn gray, then snow white. Store the insulators in a dry place.

Procedure for Replacing the Bottle

1) Follow preceding procedure through Step 5. Once the bottle assembly is detached from the source remove the four small screws (item 35) that clamp the Cap Clamp Flange (item 36) to the Inlet Cap (item 31).

2) Slip the bottle out and remove the o-ring.

3) Put the o-ring on the replacement bottle and reassemble. Do not put grease on the o-ring. The end of the bottle should be **centered** and **seated** against the bottom of the Inlet Cap when the o-ring is seated on the *bevel.* This is very important.

4) Slide the Cap Clamp Flange over the bottle. Make sure everything is centered. Tighten the screws in alternating fashion. Depending on the diameter of the bottle* the Cap Clamp Flange may or may not be tightened until its surface contacts the Inlet Cap. The idea here is to make a leak tight o-ring seal and keep the axis of the bottle centered and square to its mount.

5) Remount bottle assembly following Steps 7-11 in the preceding procedure.

Note: The bottles can be cleansed with HF acid (10% solution). Let the bottle soak in the solution, occasionally scraping stubborn deposits with a glass rod or brush until the bottle is clean. Rinse well in distilled water and dry thoroughly with a heat gun. Store in a dry place. (Outgassing times will depend largely on the dryness of the replacement parts when the source is rebuilt.)

* It is a fact of life that quartz bottle diameters vary. This is the nature of the material and the manufacturing process. The user is encouraged to use his own judgement in making a tight vacuum seal. Small diameter bottles may require fatter o-rings. Conversely, large diameter bottles may need skinny o-rings.

Charge Exchange Cell

The lifetime of the second main Alphatross component, the charge exchanger, is indefinite but should be thousands of hours. Vacuum accidents, not old age, are the leading cause of charge exchanger death. Rubidium is not "used up" by the ion source, but rather, it is recycled in a continuous process of vaporization, condensation, and liquid flow. If any part of this cycle is disturbed, charge exchange will be adversely affected. Vacuum accidents or contaminated gas causes the formation of rubidium compounds which impede vaporization. Rubidium removed from the cycle due to "freezing" (described in Troubleshooting section), chemical reactions, or migration will eventually disrupt the cycle when the amount of metal present is no longer sufficient to sustain it. In this case it may be necessary to rebuild the charge exchanger and add fresh Rb.

Procedure for Disassembling Charge Exchange Cell

1) Vent the ion source up to atmospheric air through the vent valve. Do this very slowly to make sure that the rush of gas does not push Rb into the bottle assembly

2) Disconnect cables, cooling, etc. Remove shield box. Remove the bottle assembly, cooling jacket and magnet spool.

3) Wearing safety glasses, apron and gloves, slowly remove the oven and put it in a metal container. The surface of the Rb will react with air forming a bluish color inert layer which helps to protect the unreacted metal beneath it.

4) Now remove the rest of the charge exchanger and **gently** place it in the metal container with the oven. Keep in mind that Rb is present on all the parts in the charge exchange cell.

5) The next step is to react all the Rb so that the source can be completely disassembled and cleaned. One way to do this is to carry the source in the metal container to an open area outside and place it on the ground away from any flammable materials. Stand at least 5 meters away and spray the source with water. Loud pops and sizzling sounds may be heard as the Rb reacts with the water. (The chemical reaction is Rb + H2O -> RbOH + 1/2H2 + heat. The H2 ignites causing the mini-explosions. The RbOH feels very slippery to the touch, like oil.) When the container is full of water you can approach it and remove the source. Carefully disassemble the source. Some small pockets of unreacted Rb may still be trapped in corners the water didn't reach.

<u>Procedure for Ion Source Assembly</u>

1) Before assembly, all parts should be washed thoroughly with distilled water, rinsed with alcohol, and baked to remove all moisture. Some parts, such as the oven, may contain stubborn deposits of Rb compounds. These may be removed with light glass bead blasting or sandpaper. Do not blast or scrape any gasket surfaces or the nickel-plated exit flange. A knife can also be used to scratch away deposits.

2) Refer to drawing 11-0-511 of the ion source assembly. Place the Mounting Flange (1) face down on a table. Assemble the Exit Aperture (4) and Exit spacer (3) and seal the Charge Exchange Tee (17) to Mounting Flange with Gasket (2). (See instructions for mounting NEC aluminum wire gaskets.) Be sure to orient the Exit Spacer so that the small weep hole will be **at the bottom**. Visually check the flange for proper gasket alignment before tightening bolts.

3) Using two aluminum wire gaskets (NEC 2GD017730) mount Condenser (48) and Exit Flange (21) on entrance of the Charge Exchange Tee . Put one gasket between the Charge Exchange Tee and Condenser and the other between the Condenser and Exit Flange . Insert screws (47) loosely then rotate Condenser so that the input and output tubes will line up with the holes in the Cooling Jacket (49). Tighten Screws (47) uniformly.

4) Mount this assembly and the Baffle (52) onto the beamline. Insert the Screen Wick (13) into the chimney. Allow about 2 cm to project beyond the end. Mount a 1" NEC gasket (14) on the Oven Weldment (15). Then attach it to the Charge Exchange Tee using the 1/4-20 screws (16). (Later we will remove the oven to load Rb. But first it's best to make sure all our vacuum seals are leaktight). 5)

5) Slip the Magnet Coil (46) over the Exit Flange and secure it with the Cooling Jacket. Now mount the shield box with RF oscillator on the magnet spool using the four 10-32 studs wing nuts.

6) Screw the Bottle Support Rods (25) into the exit flange, top and bottom, and the Ceramic Standoffs (27) onto the Bottle Support Rods.

7) Put a Viton o-ring (30) over the open end of the bottle (do not put grease on o-ring) and slip the bottle into the inlet flange weldment (31) making sure that the o-rings makes good contact with the weldment and the bottle is not cocked in the hole (it should be centered and square in the assembly). Secure the bottle in the weldment with the mounting plate and four 6-32 (35) socket head screws.

8) While wearing gloves, glide the Insulator (23) into the hole in the end of the bottle. Put a Canal (24) into the insulator. Note: There are two types of canals and insulators, one each for helium and hydrogen. Insert a Viton o-ring (22) into the groove in the source exit flange (32). Slide the Canal Holder (20) into the Source Exit Flange.

9) Position the RF coupling bands on the bottle as shown in the drawing.

10) Attach the bottle assembly to the charge exchanger. The canal and insulator must be seated in the Exit Flange or a leak may occur. Make sure everything is square and centered. Secure the assemblies together with two 10-32 screws (29) mated with two springs (28), so the bottle assembly is held in place by the compression of the springs. Tighten the screws just until the springs are almost fully compressed. Don’t over tighten!

11) Make the electrical connections in accordance with the schematic (2JS002110). Also couple the gas feed line to the o-ring fitting on the Inlet Cap and **hand tighten only** the fitting. Attach the cooling air line from the compressor system to the Cooling Jacket, by the fitting (5). Also, attach the liquid cooling tubing to the rubidium baffles (Exit Baffle and Condenser) . Be sure fluid flow is from the bottom to the top of the baffles.

12) Evacuate the source and confirm that it is leak tight. If you don't have a helium detector, this may be done by squirting alcohol on the o-rings and aluminum gasket seals while observing a gauge for changes in the vacuum. When you are confident that the source is leak tight try starting up the plasma (see Operation Section). If everything seems o.k. you are ready to load Rb.

<u>Safety Precautions</u>

Rubidium reacts very explosively with water. It will react readily with moisture in the skin causing severe burns. Wear gloves, an apron, and a face shield when handling Rb. Keep it in an argon atmosphere at all times. If exposed to the air it will react with moisture in the air. This reaction may range from the Rb turning blue and crusty, to spitting and sparking if humidity is high. While loading Rb remain calm and deliberate. Avoid sudden motion. It is best to have a helper for this operation.

<u>Procedures for Loading Rubidium</u>

The following items will be required for loading Rb:

- heat gun
- argon gas cylinder with regulator
- glove bag
- two 5 gm ampules of Rb
- a pair of side cutters (wire cutters)
- oven stopper

1) Vent the source with argon through the vent valve and remove the oven.

2) Install a new 1" NEC gasket on the Oven Weldment.

3) Put the Oven in the glove bag along with the side cutters

4) Inflate the glove bag with argon and have the helper heat an ampule with the heat gun until the metal is molten. Slip the ampule through the open end of the bag.

5) Snip the top off the ampule with the side cutters. If the top of the ampule breaks off evenly, you will be left with a small circular hole and it will be almost impossible to pour out the Rb. In this case, use the side cutters to break out a small section of glass to enlarge the hole. This will allow argon to flow in and displace the Rb as it pours out. **Hint:** If you hold the side cutters at a slight angle when you break open the ampule you will automatically get a nice big jagged hole.

6) Pour the molten contents into the oven. Don’t pour the Rb on the gasket surface. This will cause a vacuum leak. Repeat with the other ampule. (Note: Source will not work properly with only one ampule of Rb!) Then, put the stopper into the oven so it can be carried to the ion source without exposing the Rb to the atmosphere.

7) Connect an argon gas supply to the source vent valve and adjust the flow so that you can feel the gas streaming out of the bottom of the charge exchange chimney. Make sure the screen wick is protruding about 2 cm.

8) **Note: *The next part of the operation should be done carefully but quickly*!** Hold the oven just below the screen wick and remove the stopper. Slip the oven up and over the screen. Just before the gasket surfaces make contact, shut off the argon flow. Quickly bolt the oven in place, sealing the gasket.

9) Evacuate the source as soon as possible. When Rb reacts with the air it turns blue. If this occurs across the entire surface of the metal you should consider starting over.

VI. TROUBLESHOOTING

Two conditions must be satisfied to produce He^- ions. First, there must be a plentiful supply of He^+ extracted from the RF source, and second, Rb vapor must be present to provide charge exchange. One should also realize the power supplies, lenses, bending magnets, velocity selectors, Faraday cups, electronics, etc., must be working properly for us to produce and detect the beam. This is important to keep in mind. Our first impulse is to blame the ion source when other components may in fact be at fault. So keep your eyes and your mind open when problems arise.

The first thing to do is to reread the general comments in the "Operation" section of this manual. Understanding how the source is supposed to work will give you a big advantage in determining out what's wrong when it doesn't. Be suspicious of any unusual recent events like vacuum accidents, gas bottle refills, new operators, etc. Frequently, when a source goes bad it is related, though it may not be obvious at first.

Plasma Problems

Rubidium

One occasional problem with the RF ion source is due to its close proximity to the charge exchange chamber. If the plasma color is good, but the probe current is high and/or jumpy, you may have Rb in the plasma. This can be caused by sudden venting which flushes Rb into the quartz bottle, malfunction of the Rb baffle or condenser, improper source shutdown procedure, or just plain bad luck. In this condition you have He^- beam, but it is very unsteady. (Note: charge exchanger problems can also cause beam instability. The key here is the probe current!) Occasionally, instability may occur when a new canal is installed. This is normal and after a few hours of "conditioning" will disappear. Rb contamination, on the other hand, will **not** go away. There is only one fix. You must remove the bottle assembly (see Maintenance Section) and clean or replace the canal, insulator, bottle and canal holder. You must also **completely** disassemble and clean the probe parts (30), (31), (32), (33), (34) and clean them in **water**. Refer to Assembly Section for procedures. Failure to do so usually causes the problem to quickly return.

Leaks

Another problem that can occur with the plasma is leaks. This is very rare on a source that has been run for many hours but may occur after a rebuild. Symptoms are low probe and beam currents and off-color plasma. A good diagnostic is to tune your bending magnet or velocity selector to mass 16. If there is a leak there will be O^- beam. Even though your vacuum is good, remember that conductance through the canal is small so leaks may not affect the high vacuum pressure very much.

Contamination

Low beam currents can result from contaminated gas. Helium is particularly sensitive to impurities. If low beam current results after a bottle is refilled be suspicious. (Commercial grade helium is o.k.)

RF Coupling

The plasma should be very bright. If it is not, generally beam current and probe current will be low. (Probe should be at least 2 mA). This can be caused by low gas pressure, contaminated plasma, or poor RF coupling. So, if adding gas doesn't help, check the position of the RF bands, leads, and clips.

Plugging

A rather bewildering set of circumstances can leave you with normal plasma, normal charge exchange and no beam. This is due to Rb plugging the hole in the canal holder. In this condition the MFC adjustment will have little effect on the system vacuum. The fix is to remove the bottle and clean out the hole in the canal holder.

No Plasma

If you cannot get the plasma to ignite and all the electrical connections are o.k. then you should check the oscillator. You can make a simple tester using an ordinary 100 W incandescent light bulb and some stiff wire. There is an excellent description with pictures of this in the oscillator manual. To test the oscillator, hold the bulb on the glass end and position its coil just above and coaxial with the oscillator coil. The bulb should light brightly. If not, your tubes maybe be too old and need replacement. Several customers have observed this after many years.

Aging

After 5-10 years of operation you may observe a gradual reduction in beam current. You may also observe that the plasma is not as bright (or won't ignite) and probe current is low. In this case replace the oscillator tubes, they have a finite lifetime. Due to variation in lab operating schedules we don't know how many hours this corresponds to.

Charge Exchange Problems

Charge exchange problems are not always so easy to diagnose. What goes on inside is not visible and our instrumentation is somewhat limited. But we can often deduce the answer from the readings of our two thermocouples. Observing how the charge exchanger affects the beam current is also helpful. When problems arise users frequently report "the source has run out of Rb". This is virtually **never** the case. There is nowhere for the Rb to go except to escape through the charge exchanger entrance and exit apertures. In this case it only takes the tiniest fraction of the 10gm Rb load to cause immediate, noticeable, major problems with the plasma or the lens.

Contamination

Rb can react very quickly if, for instance, the vacuum system is accidently vented to atmosphere. Usually, only the surface material will react, but this may be enough to adversely effect charge exchange. The chemical compounds formed do not vaporize at modest temperatures and a blanket forms which prevents the Rb metal underneath from vaporizing. Symptoms are that the chamber will not get warm while the oven will be hotter than usual with normal oven power settings. If you are absolutely convinced that this is the problem, increase oven power and try tapping on the oven. Sometimes, this will fracture the crust that forms on top of the Rb and will get the source going again. If not, the only fix is a rebuild.

Freezing

If you have beam when you first start up but then it goes away, and yet the plasma is normal, the Rb is freezing. This is caused when an internal surface, such as a baffle or the housing, is too cool. The oven temperature may be higher than usual indicating that the oven is empty. It is easy to recover from this predicament. First, turn off the source power and all cooling. Then remove one half of the Cooling Jacket (item 49 in drawing 11-0-511). Have someone hold the other half to support the magnet and shield box. With a heat gun warm the charge exchange chamber. This will melt the Rb allowing it to flow back down to the oven (m.p. = 38.9°C). Then you can restart the source normally.

To prevent reoccurrence of this problem, you may have to make minor adjustments to reduce cooling capacity. There are lot's of variations among Alphatross setups including cooling systems, cooling fluids, ambient air temperature, etc., that can influence performance. So it's reasonable to expect that not every Alphatross will operate with identical parameters.

Insufficient Rubidium Supply

If you didn't load the **whole** ten grams of Rb then you are going to have trouble with freezing. Better to use three ampules than one!

Lens Problems

Sometimes the lens will begin to spark and arc. This is usually related to source malfunctions. The first step is to turn off the source (or just turn the probe voltage to zero). Then put voltage on the lens. If it is not stable, then you really do have a lens problem. If it is stable, then the problem is related to the source. The following explains why.

When the gap lens is biased to some negative voltage, negative ions are accelerated and focused while positive ions are decelerated and defocused. Neutral particles are not influenced and drift along on their merry way. It's the positive ions that do all the mischief. They don't have enough energy to get through the lens so they make a sharp turn and careen into the high voltage element of the gap lens where they scatter off many secondary electrons, *very many* if there's even a microscopic layer of Rb on the surface. These electrons generate arcs. (This is why we recommend against applying voltage to the len(s) until the charge exchange is up to operating temperature.)

When the charge exchange is working properly, the vast majority of the particles exiting the source are fast neutrals (100-200 particle microamps), but with a little luck there may be a few negative ions, too. But there will be very few positive ions (they have all been neutralized). If it is not working, you can be sure there is a hefty beam of positives pounding the lens and causing trouble. People frequently disbelieve that their lens problems are related to charge exchange, but this is usually the case. Refer to section on charge exchange problems.

Note: This is not to say that you should not clean the lens occasionally when convenient. Reach in and wipe the lens elements with a cloth moistened with *water* to remove Rb, then dry with a heat gun. This will help the lens behave under duress.

When All Else Fails...

Contact the factory, but before you do, write down **all** the symptoms and operating parameters such as: beam current (if any), probe voltage and current, magnet current, oven voltage, oven and chamber temperatures, lens voltage(s), relevant information related to the vacuum system, etc. Use the RF SOURCE DIAGNOSTICS form in the back of this manual. Also, we need to know if all the parts in your source were manufactured by NEC or if you have modified the source in any way.

VII. EXTRACTION CANAL AND INSULATOR FINE TUNING

These comments pertain to the Ta canal used for He^- beams, not the Al canal for H^-.

Over the years some variation in beam output has been observed from one source to another despite their being of identical design. It was determined that the canal/insulator geometry contributes significantly to this variation. Though the stock parts are manufactured very carefully, and will easily produce He^- beam currents of sufficient intensity for most applications, some post-production fine tuning can yield maximum currents when necessary.

The critical dimension of the canal/insulator geometry is between the end of the canal and its corresponding hole in the BN insulator. If the canal tip is slightly recessed, beam current will be adequate but not spectacular. If it projects too far beyond the edge of the hole the probe current will run away. The optimum geometry can be achieved using the procedure and small tools (provided) shown on drawing no. 2JS039680 in the back of this manual.

Successful execution of this procedure will yield He^- current of 4 microamperes or more. One will also observe higher probe current.

VII. DOCUMENTATION:

DRAWINGS AND SCHEMATICS

Aluminum Gasket Making Instructions	Drawing No. 2GD059810
Gasket Securement Procedure for NEC Flanges	Drawing No. 2GS062350
RF Charge Exchange Source	Drawing No. 2JA005110 Parts List No. 2JA005110
RF Source Shield - Assembly	Drawing No. 2JA004530 Parts List No. 2JA004530
RF Source Schematic	Drawing No. 2JS002110
Insulator Gapping Procedure for Alphatross Ion Source	Drawing No. 2JS039680
RF Source Diagnostics Form	

Article References

Charge Exchange Collision of Deuterium in a Rubidium Vapor Target, by R. J. Girnius, L. W. Anderson and E. Staab, Department of Physics, University of Wisconsin, Madison, Wisconsin.

Charge-Exchange Collisions Between Hydrogen Ions and Cesium Vapor in the Energy Range 0.5 - 20 keV, by A. S. Schalacter, P. J. Bjorkholm, D. H. Loyd, L. W. Anderson, and W. Haeberli, University of Wisconsin, Madison, Wisconsin.

Collisions of He^{+} ions with a Rb Vapor Target, R. J. Girnius and L. W. Anderson, Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, U.S.A.

Modified He Ion Source Using Cs Vapor Charge Exchange, Fred A. Rose, P. B. Tollefsrud, and H. T. Richards, University of Wisconsin, Madison, Wisconsin, (work supported in part by the U.S. Atomic Energy Commission).

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RF SOURCE DIAGNOSTICS

Beam Species - i.e. Helium, Hydrogen, etc. ___________________________________

Canal Type: Tantalum/Aluminum ___________________________________

Source Vacuum - Source off __________________X10⁻____________

Source Vacuum - Source on __________________X10⁻____________

Probe Voltage/Probe Current ___________kV__________________mA

Extractor Voltage/Extractor Current ___________kV__________________mA

Bias Voltage/Bias Current ___________kV__________________mA

Source Magnet ______________________________Amps

Oven Heater Voltage _________________________________ V

Oven Temperature _________________________________°C

Chamber Temperature _________________________________°C

Heater Wattage Rating ______________________________ Watts

Beam Currents

Note: Assuming a maximized helium beam and a velocity selector the proton current will be found at twice the helium setting, and oxygen at one half the helium setting.

Assuming a maximized helium beam and a bending magnet the proton beam setting will be one half the helium setting and oxygen will be twice the helium setting.

Species	Beam Current	Velocity Selector	Bending Magnet
Protons			
Helium			
Oxygen			

Comments:____

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