The Farnsworth/Hirsch Fusor

How a Small Vacuum System and a Bit of Basketweaving Will Get You a Working Inertial-Electrostatic Confinement Neutron Source

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I. SUMMARY

The device that is described in this article is a dual grid, inertial-electrostatic confinement (IEC) accelerator which can, with various levels of cash expenditures, different included gases, different operating pressures, various applied voltages and currents, etc. be used as a glow discharge mode “plasma sphere,” a gas diode, an ion multipactor or even a device for producing nuclear fusion reactions. This article describes the history of the device, the principles of its operation, uses and construction of a working fusor. Possibilities for further exploration by amateurs is also covered.

II. INTRODUCTION

This article deals with the basics of a dual grid, spherical focus, inertial confinement, electrostatic, recirculating accelerator sometimes called the “Farnsworth/Hirsch fusor” in honor of the original developers of this class of device. The preceding long description belies the ultimate simplicity of the apparatus. Basically, the system being discussed involves two concentric spherical grids made up of fine wire in a chamber which can be evacuated and backfilled with gas. One grid is smaller than the other by a factor of about 1:5. The smaller spherical grid is contained within the larger spherical grid and biased negative with respect to the outer grid. Ions are initially created in the vicinity of the outer grid and accelerated towards the inner grid. Gas-ion collisions and ionizations occur throughout the volume of the chamber. Virtually all of the ions created in the area between the outer and inner grids are singly ionized: O_2^+, N_2^+, Ar^+ and H_2O^+ dominate in an air ambient.

As the ions accelerate and enter the inner grid structure, most of the ions miss colliding with the inner grid wires and proceed into the central portion of the chamber. Reaching the center, the ion density increases and, therefore, the collision rate. Near the center of the inner grid, the ions collide at angles ranging from slight glancing blows to head-ons. In the process they form a glowing ball of dense, hot plasma. As this plasma is fed with more current at correspondingly higher grid potentials, the density and temperature of the gas rises as more ions impact at higher velocities. In this volume it is reasonable to assume that most impacts result in additional multiple ionizations adding many pluses to the ions contained in the small volume of the plasmoid.

The excess electrons now find themselves in a negative potential well and are ejected violently back into the region between the grids. Ions also flow out with the electrons in a mixed stream, many recombining and colliding with gas atoms outside the inner grid forming neutrals in a kinetic stream and ionizing anew. At lower operating pressures, the ionized gas atoms are thinned out and some actually never interact.

The “fusor” can work in several modes based on the materials used, the gas included in the device, and the pressure of the gas. Experimental possibilities are endless and the device itself is interesting to watch. At its low end of operational performance (above 1000 microns) it is working as a conventional glow discharge device but is still more interesting than a plasma globe. Near the top end of its operational performance curve it can produce neutrons through the D-D reaction. This performance curve is still not well defined! The large number of variables make for a great research opportunity.

Nothing is particularly critical in the fusor’s physical construction regardless of mode of operation. A good scrounger with a modest vacuum system that can go to 10 microns should be able to assemble the entire device for under $50.00. Buying every thing new except for the vacuum system might drive the cost to $300.00. With a high vacuum system (10^{-6} Torr), bell jar or stainless steel chamber, and about $400.00 you can be producing neutrons.

III. A LITTLE BACKGROUND

The device we are discussing is attributed to Philo T. Farnsworth, best known as the inventor of electronic television. In the late 1950s and early 1960s he developed this device as a fusion reactor. Dr. Robert Hirsch worked on Farnsworth’s development team in the mid 1960s and made significant contributions to the device which was patented in June of 1966. It is the antithesis of classic tokomak “hot fusion” device often touted as our coming energy solution. These latter devices rely on magnetic compression and containment of hot plasmas. The fusor, here described, relies on simple electrostatic acceleration of ions and or electrons and uses inertial confinement of the particles providing the added benefit of recirculation of the particles. All of this is accomplished in a simple dual, spherical grid system. The concentric focus reflex diode goes back to the twenties and was first researched by Langmuir and Blodgett. They never used it for anything other than a common diode. Farnsworth, who was familiar with the electron multipacting process in high vacuum conditions under rf drive, thought that ion multipaction might be possible in an electrostatically accelerated, recirculating, concentric focusing system. Electron "multipacting" (for "multiple impacts") was rediscovered many times through the years. In this effect, electrons in an ultra high vacuum are emitted from a hot cathode in a simple diode and a powerful, high frequency oscillation, if timed just right, can reverse the direction of the electrons in mid-flight between tube elements. The voltage reversal starts the electron beam back to the cathode. As the electrons stop and reverse direction, the voltage reverses again and the result is an ever increasing energetic knot of electrons held in a small fixed volume. This effect caused no end of problems in the early days of linear accelerators, radar tubes and other high frequency vacuum devices as this build up of energy could melt and damage the tube elements.

Farnsworth referred to the system as his "fusor." He planned on deuterium gas or a mixture of deuterium and tritium gases which would be introduced into the fusor. There the ionized gas nuclei would accelerate through a small, relatively transparent inner grid and collide with each other. The collisions would result in fusion reactions producing neutrons and helium.

Farnsworth's original concept involved cylindrical grids and never got under way in a material sense until the late 1950s. He changed his concept to a spherical grid system in 1962 (see Figure 1). He succeeded in interesting ITT, which had just purchased Farnsworth Radio, to fund a very small research project to look into this form of fusion. ITT was always very uncomfortable being in the tube business, much less the nuclear fusion business. Ultimately, in 1966 and with the assistance of Robert Hirsch and other team members, the fusor was capable of producing a flux of 10^{10} neutrons per second.

The project funding by ITT was pulled in late 1966 due to stockholders and directors questioning the need for an ITT funded nuclear project! Farnsworth succeeded in interesting Brigham Young University in the fusor and it was run there as a very small effort until 1969. BYU suspended the project due to the increasing ill-health of Farnsworth. Upon his death a couple of years later, all note of the fusor was effectively dropped.

The device, which seemed so simple, disappeared from scientific view until a recent resurrection by George

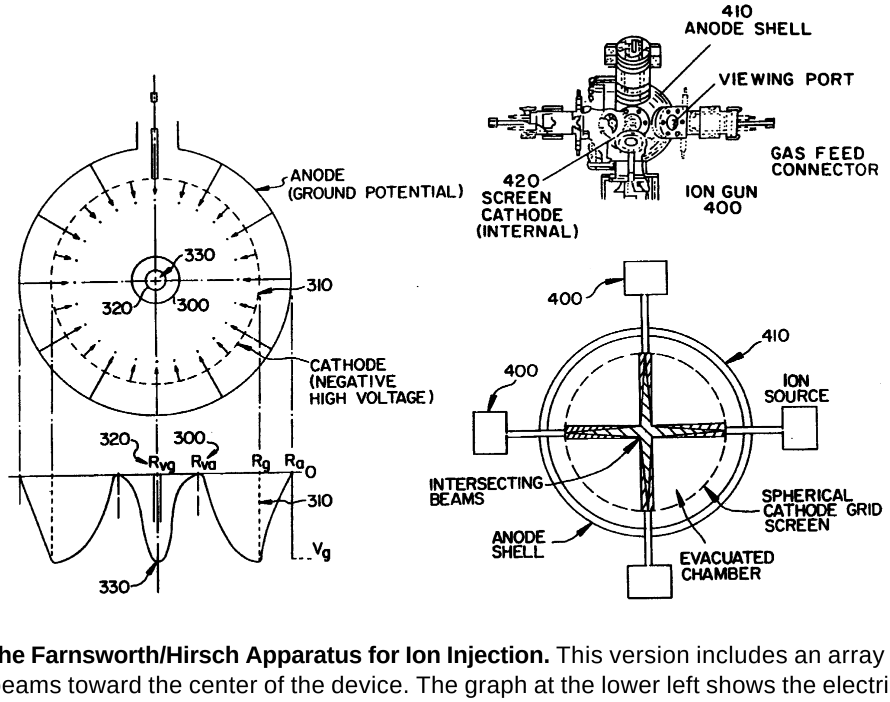

Figure 1 - The Farnsworth/Hirsch Apparatus for Ion Injection. This version includes an array of guns which inject ions beams toward the center of the device. The graph at the lower left shows the electric potential distribution across the electrode structure. Illustration descriptive of prior art from U.S. Patent 5,160,695, "Method and Apparatus for Creating and Controlling Nuclear Fusion Reactions" by Robert W. Bussard.

Miley, Robert Bussard, and other researchers. In the newer versions, the discrete ion sources of Farnsworth as shown in Figure 1 have given way to the aforementioned dual grid and the device is operated as a gaseous discharge (GD) tube. (To be fully proper, the acronym would be IEC-GD.) This further simplifies the device.

This renewal of interest in the old but elegant Farnsworth fusor is directly related to the failure of hot fusion over the forty odd years of massive public funding to produce real results. According to advocates, the IEC approach can achieve success on the ultra-cheap compared to building a tokomak. On the less than grand scale, it is also viewed as a low cost and low maintenance alternative to the classic beam/target neutron sources that are used for things like activation analysis.

IV. BUILDING YOUR OWN FUSOR

It will be assumed, due to the nature of this publication, that anyone attempting to build the fusor has a vacuum system and is at least moderately familiar with vacuum technique. This will obviate any deep discussion around the very basic vacuum technology involved. It is also noted that the system uses a high voltage power supply and the experimenter must have an adequate knowledge of the safe and proper use of such supplies.

First, one must obtain a moderately sized vacuum chamber or bell jar and be capable of exhausting it to at least 10 microns. The chamber must have an internal, free spherical diameter of at least 6 to 8 inches. My first system used a clear, 10" Nalgene (plastic) laboratory desiccator which was purchased for $80.00 from a laboratory supply house. I currently use a 10" glass bell jar purchased for more advanced work and also have assembled the materials for a stainless steel bell jar should I choose to get extremely serious.

The usual exhaust port, chamber bleed petcock, and two electrical input lines are needed. I use a Duniway Stockroom thermocouple gauge attached directly to my chamber interior to monitor the vacuum down to 1 micron. Before going on to construction, make sure the chamber and all ports are prepared and that the system can, indeed, be taken down to between 10 and 100 microns with your pump.

Figures 4 and 5 at the end of the article provide information on the general layout of the system and on the power supply used on this demo fusor.

The Internals of Your Fusor - Fabricating the Grids

Here is where the basketweaving comes in. The dual spherical grid systems are made up of 308 stainless steel MIG welding wire 0.030" in diameter. You will require two spherical grid systems: one large and one small. For my system, I built the large outer sphere 8" in diameter and the small inner sphere 1.5" in diameter. Each sphere requires 6 circles of stainless wire.

It must be noted that a solid conducting spherical outer shell will work here in place of the outer grid, but to observe the goings on inside would mean expensive

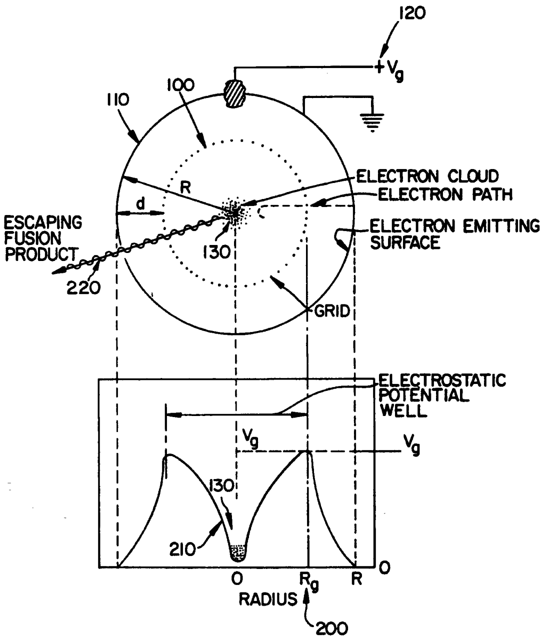

Figure 2 - IEC-GC “Negative Electrostatic Well Apparatus.” Electrons are injected radially inward to the center of the spherical volume through a spherical shell screen grid system. The graph at the bottom shows the electric potential distribution across the electrode structure. Illustration descriptive of prior art from U.S. Patent 5,160,695, “Method and Apparatus for Creating and Controlling Nuclear Fusion Reactions” by Robert W. Bussard.

viewports. Also, a fine screen wire inner sphere would work just fine, but it will increase the loses within the grid system tremendously. The object of the game is to make the inner grid fully form a smooth inner spherical electric field and yet be as physically absent (i.e. transparent) as possible. The inner grid is under tremendous bombardment by positive ions and heats up rapidly. That's why its "presentation" cross section must be kept as close to zero as possible. Super fusor grids are best made from refractories such as tungsten or tantalum wire. Remember, we want all the real work to be done in the plasmoid at the center and not on our fine wire inner grid.

The whole concept here smacks of Nikola Tesla's button lamps of the early 1890s where Tesla achieved vaporization temperatures at the center of special spherical evacuated lamps powered by high frequency currents. He succeeded in vaporizing diamond, ruby and carborundum with just a few watts of input power.

The best method of closing the "great circles" is by spot welding the circle closed on itself. I had no spot welder and chose to silver solder the circles. I used jewelers' grade silver solder which is 90% pure versus the lower purity 30% industrial silver solder. Even though my method works fine for the demo model/ion multipactor version of the fusor, some form of fusion welding of the inner grid system is most desirable and demanded on larger systems producing neutrons.

After I had six large 8" circles made up, I assembled three of them in a globe configuration as "great circles" or "longitude lines" meeting at the poles with an even 60 degree angle between intersecting wires. I devised a jig to hold the wires at the precise angle needed while I soldered. I soldered these together at the pole crossings. I now did the same with the remaining three circles at the equator of the existing globe, soldering at all multiple cross points of all wires. It is important to clean all flux from the wires as you go.

Tight and rigorous sphericity is not a real issue here and just moderate care in assembly is needed. This demo system is very forgiving and will work with almost egg shaped assemblies. It is hoped that all efforts will be directed at a good looking device though.

The above is repeated for the smaller inner spherical grid system. This is a real bear to make as it is much smaller and the work more confined and exacting.

You should now have two spherical grid systems of reasonable shape. The smaller grid is pretty much finished, but the larger outer grid requires more work.

I chose to enter my outer grid with the inner grid support structure from the top of the polar region and therefore had to make another, smaller, 3" ring of wire. This is placed on the large outer grid sphere as a northern latitude line just below the pole. I soldered this to all crossing wires. I then just clipped out the polar region of the globe leaving a nice access hole in the top, much like a jack-o-lantern.

The Internals of Your Fusor - Assembly of the Grids into the Chamber

My desiccator had a lip or ridge where the chamber necked down near the bottom. I fashioned yet another ring of SS wire such that it rested snugly and safely on this ridge or lip. I made a number of measurements and calculations and soldered four wire struts to this ring and then connected each strut to the outer grid sphere so that the grid was suspended in the center of the chamber. I next tapped and threaded a 10-32 hole just at the ridge and fed through a 1" long SS screw with the head and washer inside the chamber which secured the large ring, and thus the globe, to the chamber at this one point. An O-ring and some vacuum grease were placed on the screw threads outside of the chamber. When tightened down with a nut, this provided a reasonably gas-tight electrical connection to the outer grid.

My chamber had a nice, hollow, cast, top handle on the upper lid of the desiccator. I now bored and tapped another 10-32 hole here. I took a piece of SS 10-32 "all-thread" about 3" long and soldered a straight 10" length of SS wire to one of its ends. I then measured, calculated and cut a length of 3/16" od hollow alumina tubing to a length which would allow the small, inner spherical ball grid to be centered in the big grid system when the top of the dessicator was in place. Then I pulled the SS wire tight out of the end of the tube and soldered on the small spherical grid. One should make this small sphere/tube/threaded rod section as tight and unitized as possible with little play or slack. Next I screwed in the all-thread from the inside of the chamber lid to the outside. Again, I used an O-ring and vacuum grease to seal the exiting electrode to the chamber, finally tightening it down with a nut. The long, external protruding, threaded rod was now shrouded with a high voltage porcelain insulator to make an attractive negative terminal connection for the small central grid.

The chamber lid with the alumina tube and small grid was lowered onto the bottom half of the chamber with the tube and central grid going through the "polar hole" in the outer grid system which was now fastened into the bottom half.

It must be stressed that a lot of measuring and prefiguring will save alignment problems later on. One must adapt and improvise based on the particular chamber geometry and materials available.

V. OPERATION

What to Expect in your Fusor

Visually, the system is stunning and fascinating. As the voltage is brought up, a light blue spherical plasmoid forms in the center of the central grid system. Farnsworth labeled this multipacting region of dense plasma a *poissor* (pronounced - poy-sor). It is an inertially confined plasma. Based on the geometry and alignment of your system, you may see one or more “bugle jets” blasting out of the poissor into the main chamber area. These are trumpet-shaped ion jets. (See Figure 3.) If the power is reduced, a pencil thin electron beam is often seen issuing from the core of the bugle jet. In clean systems which are carefully built and aligned, at full power the discharge can enter a “star mode” with brilliant rays issuing from each aperture of the inner grid. This requires a system more carefully constructed and robust than my demo fusor. But, the principle is the same.

The thin blue electron beam is easily deflected by a magnet and at high exhaustions the beam can prove fatal to a plastic chamber’s walls. My friend and Dr. Bussard’s assistant, Tom Ligon, made the first little fusor “concept demonstrator.” His system’s chamber imploded when the polypropylene base softened under electron bombardment at 15 microns of pressure and 20 watts of power. The inner grid in my first fusor glowed red hot at only 2 kV with 60 mA flowing at 40 microns. One need not be a rocket scientist to realize the poissor’s temperature is much, much higher. The gas density in the poissor can be 1-3 orders of magnitude higher than that in the rest of the chamber. Robert Bussard’s fusor produces significant fusion and helium levels at only 20 keV. I had to back off of the power in my little system after only 10 seconds to avoid melting the silver soldered connections and ruining the inner grid structure. One must take care to remember that at higher exhaustions the heated inner grid can’t dissipate much heat. Thus, the grid stays red or white hot long after the power is cut to the grids.

The basic system will work well with only an air atmosphere down around 100 microns. In this mode the ion recirculation is low, but the particle density in the poissor and multipacting is high. Needless to say, there is no fusion going on in the air atmosphere exhaustion.

Different pressures bring about entire new regimes of operation. Different fill gases open up even more vistas. At higher exhaustions, the density of particles in the poissor is lower. Furthermore, due to the increased mean free path, the recirculation of ions through the grid system is higher. Voltage and current in this region are also interesting to examine. At 100 microns the chamber may only allow 500-1000 volts across it while drawing over 100 mA of current. At 10 microns, much more voltage at moderate currents are the norm.

Cranking up Your Concept Demonstration Fusor

Connect the vacuum lines and a variable dc high voltage supply. The negative lead must go to the inner grid and the positive lead to the outer grid and ground. Avoid a pre-made, negative grounded supply design. Instead, we must make a positive grounded supply. Also, I highly recommend a current limited transformer One might choose a 12 kV, 60 mA neon sign transformer and use 2 - 12 kV microwave oven diodes in a full wave configuration for the dc supply. Figure 5 provides details for a workable supply. Never apply full voltage immediately to the fusor!

Other than for the danger of implosion, the greatest danger to the experimenter in this project is the risk of electrocution from the high voltage, high current supply! Be careful!

Leave the power supply off and turn on the pump. Let the system get to at least 1000 microns before applying power. When applying power, go slow on the Variac dial and use only a few milliamps at first. I did this on and off in very subdued lighting to study the different modes as pressure drops. Initial outgassing of the chamber may take many hours. It is normal for some sparkling and sputtering to occur on or around the grids and alumina tube at first. After a couple of minutes of

Figure 3 - Photograph of Richard Hull’s Fusor in Action. This shows the inner grid, poissor and bugle.

higher power operation, this will all disappear. You can hasten the process by running the fusor to degas the inner surfaces. This sends the pressure upward, but after a few minutes it starts to drop, with the pump still running. Turning the fusor power down or off after a few minutes of on time will have the pressure plunge to new lower levels. Be real careful about full power runs. Limit them to just a few seconds until you get a feel for the operation of your particular system.

As you operate your system, the walls of the chamber will turn brown due to sputtering of the inner grid metals and other compounds. An occasional take apart and cleaning of the inner walls will keep the system transparent and clear.

VI. FUSION

For neutrons and fusion, a much more robust system is demanded. To fully clean the system of residual gases, an initial base pressure of around 10^{-6} Torr is necessary. A leak valve is then used to backfill the chamber with deuterium to a pressure in the range of 1 to 10 microns. With tolerable equipment and a will to do, fusion is an easy thing to achieve.

The simplest of neutron detectors would consist of some indium foil hung in paraffin or water to slow the neutrons. The indium foil activates and decays rapidly while emitting gamma-rays. With a good Geiger counter and a bit of math, the neutron flux can be estimated.

Most of you who ultimately might want to make neutrons will not make a fusor so efficient that it will be dangerous for short term exposures. Nonetheless, you should not forget that this is a nuclear device. Take precautions appropriate for what you are doing.

Deuterium gas is easy to obtain locally. I called up a local welding gas supplier and obtained my 20 liter lecture bottle of 999 pure deuterium for about $150.00, delivered. This is a huge quantity of deuterium and should last the experimenter many years. Naturally, proper gas regulators are needed for the bottle to avoid the quick release of the 700 psi cylinder gas. Remember, this is hydrogen and it is very explosive when mixed with air. Admit the gas only through fully evacuated lines. This arrangement is left up to the experimenter.

One immediate use for the fusor has been investigated. This is as a quick and easy neutron source for teaching and research where a reactor or fissile materials are out of the question. Whether you build no farther than the concept demonstrator, ion multipactor, or make a true neutron, D-D fusion device, You will have an enjoyable time investigating the fusor.

FURTHER READING

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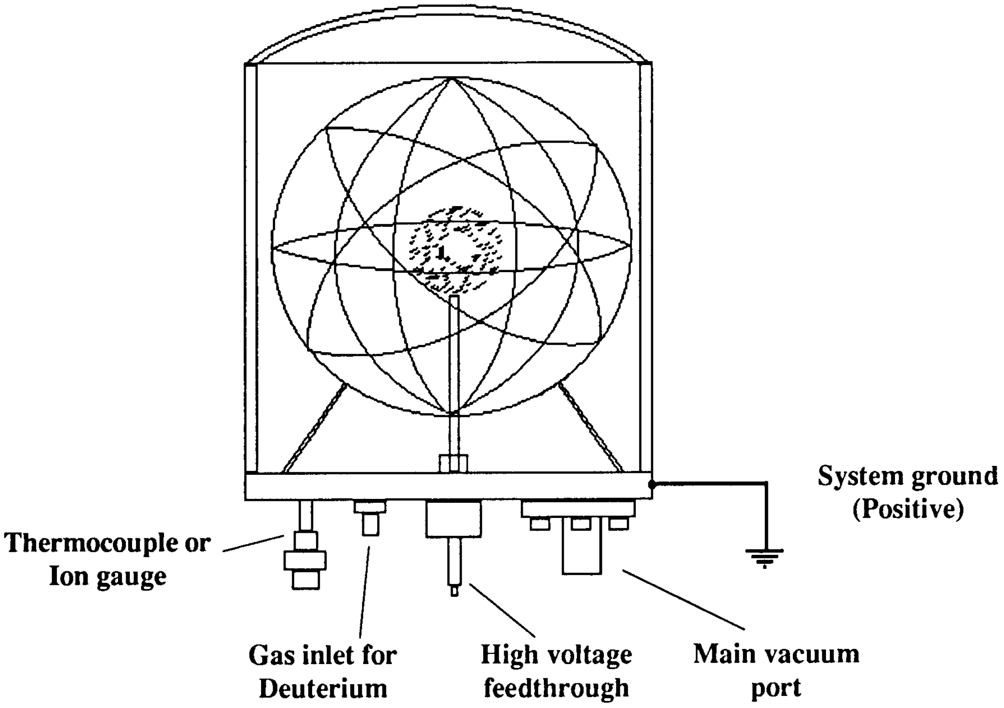
UPDATE

As this issue goes to press, Richard has built another small fusor, this time in a 6" Pyrex bell jar. The outer grid is 5.5" in diameter, fabricated of 304 stainless. The inner grid is 1" in diameter and is made of 0.024" tantalum which can withstand very high temperatures. The grids are spot welded with a home made resistance welder thereby overcoming the temperature limitations of silver solder.

At 10 microns the discharge nears extinction at 5 kV. The current is 30 mA. Under these conditions the poissor is no bigger than a pea.

The next iteration will use a 10" Pyrex bell jar and that will be the one in which neutron production will be attempted. - *Ed.*



Notes

1. The above diagram is meant only as a guide to show a general arrangement of the necessary components.

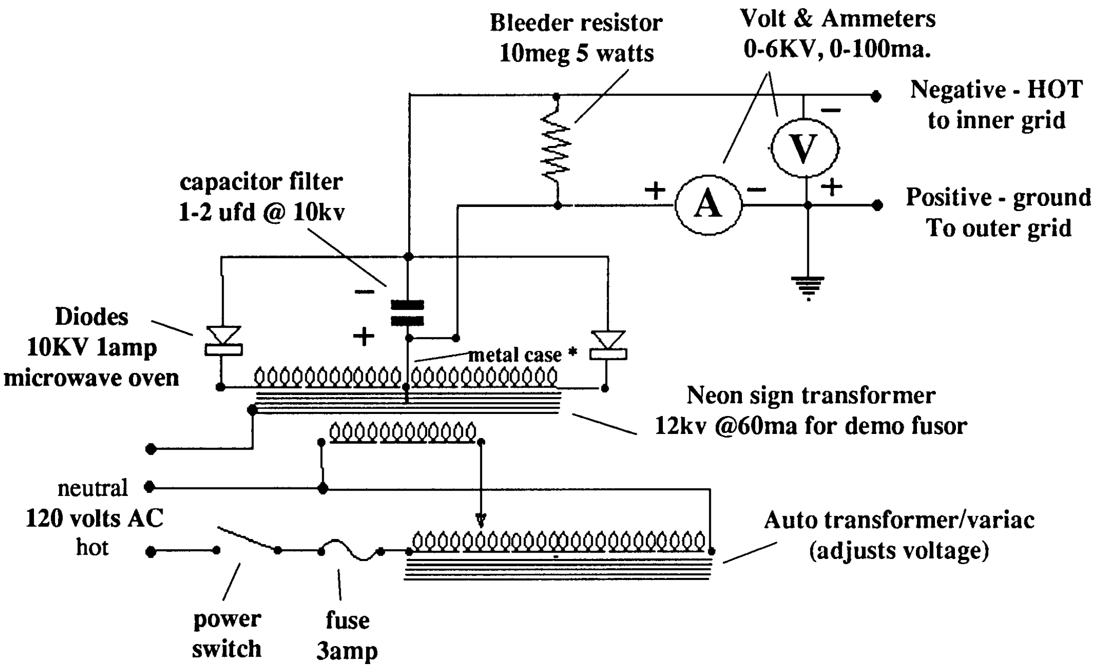
2. The gas inlet may be omitted in the simple ion multipactor or concept demonstrator. However, it is necessary for the admission of other gases, mixtures of gases and for pressure control.

3. The high voltage feedthrough must support the desired voltage. For the ion multipactor, ths will rarely exceed 3 kV. For neutron production, much higher voltages are required. Care must be exercised to electrically shield (insulate) the inner grid metallic support structure so that ions will not bombard that portion of the apparatus.

4. In the neutron producing fusor it might be necessary to include a filament or other source of electrons to ionize the deuterium at low pressures. This filament should be placed just outside of the outer grid system and biased slightly positive (~200 volts) with respect to ground or the outer grid system.

5. In the neutron fusor, the inner grid and its support tube can approach incandescence. The grid should be made from tantalum or tungsten wire and be fusion or resistance welded.

Figure 4 - General Layout of the Fusor



Notes

1. The above system demands a current limited (neon sign type) transformer. Used transformers can be obtained from local neon sign shope, hamfests and electrical junk yards. The transformer must have two high voltage knobs or terminals with a case center tap. Single terminal transformers (case return) transformers cannot be used in the above schematic.

2. The positive leads of the capacitor and ammeter are connected to the metal case of the transformer. The location of the ammeter in the circuit keeps it essentially at ground potential.

3. The variable auto transformer is a small 5 amp 120 volt unit. These can be obtained used for about $20.

4. The meters are made from common 100 µA movements. Shunt (ammeter) and series resistor (voltmeter) will have to be added to make their ranges coincide with the experimenter’s needs.

5. Connect the ac mains (wall outlet) ground connection to the output of the supply, positive lead. This connection also grounds the outer grid of the fusor and the external metal parts of the vacuum chamber. DO NOT ground the transformer case. It receives its ground through the ammeter. If you ground the case, the ammeter will not work.

6. **CAUTION!** This supply is lethal. Be very careful. Allow at least 2 minutes after shutdown before touching any connections. Make sure that the voltmeter reads zero. Do not omit the 10 meg bleeder resistor. Unplug the supply and short its output when working on chamber wiring. ***If you get shocked with this supply, it may not be your first but it might well be your last!***

Figure 5 - Power Supply for the Demonstration Fusor