the Bell Jar
Vacuum Technique and Related Topics for the Educator & Amateur Investigator

Notes from the Vacuum Shack

No. 13 December 2020

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Bell Jar Type Vacuum Chambers

Once a very common item, Pyrex glass bell jars for vacuum use are now fairly hard to find and are quite expensive, at least when purchased new. The available ones seem to be primarily for school use (smaller jars) or fairly large items for research purposes. Otherwise, they have largely been supplanted by stainless steel and aluminum components.

A disadvantage of the typical glass bell jar is the lack of feedtroughs. Everything has to come through the base plate. The smaller jars will usually have a molded knob at the top for ease of handling. The larger ones require a mechanical lift.

As examples, Fisher Scientific carries several Pyrex bell jars. One has a 13 cm inside diameter and is 26.5 cm tall. They are sold in pairs for a bit more than $700 each. The smallest Pyrex bell jar in the Kurt J. Lesker catalog is 10.25 inches in outside diameter and 12 inches tall. It has a current price of just under $1400. Of course, these items are made of very thick glass and are quite safe under vacuum.

On the plastic chamber side of things, the plastic Thermo Scientific Nalgene bell jars run at about $200 for the 4.7 liter jar. This is 17 cm in diameter by 23.7 cm tall. Adding the plastic base plate and gasket gets you to just about $325. As a point of reference, this is the jar that was used with the VPAL-A vacuum training system and is the jar that is currently used with the AVS vacuum trainers.

One class of item that I have found to be very useful is the line of addition funnels that is offered by Ace Glass. These are normally used for liquid chromatography and are not expressly made for vacuum work. However, I've been using the 1.5 liter funnels for close to 30 years and have never had an issue. Of course, shielding is recommended and safety glasses are a must when a chamber is under vacuum.

This item is their catalog number 5822-15. It has a 90 mm inside diameter with an outside diameter of 95 mm. The height from the beaded opening to the neck is 310 mm. At the top end there is a #25 Ace Thred fitting. This makes the stock chamber well suited to apparatus where top access is needed. Otherwise, the top fitting can be plugged. The beading at the large end makes a convenient clamping surface for securing the funnel to a gasket and base plate.

The current list price of this funnel is just under $120.

There are two smaller sizes of funnel. The -05 is 300 ml with a #11 Ace Thred. The -10 is 600 ml with a #15 Ace Thred. These are in the $75.00 range. The largest has a capacity of 3 liters and has a #50 Ace Thred. This is probably too large to be safe under vacuum. Unfortunately, the Ace catalog does not list the dimensions of the funnels but my guess (based on scaling from a photograph) is that the -10 is about 60 mm in diameter and 190 mm inside height.

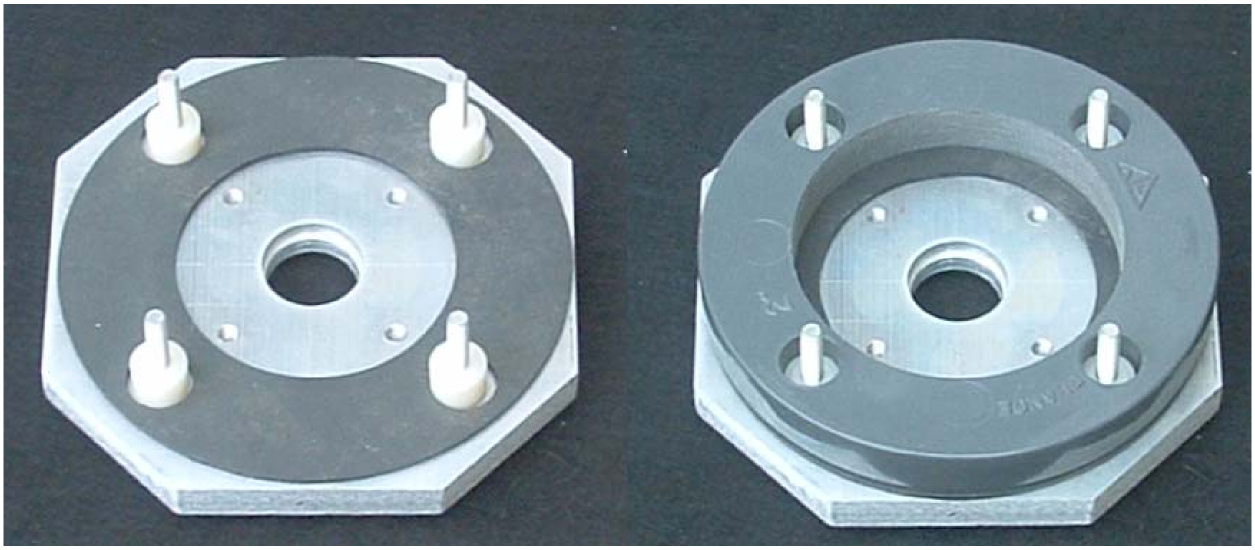
For a base plate I used a piece of aluminum, 6 inches on a side and ½ inch thick. I chamfered the corners just for appearance using a metal cutting abrasive cut off saw. For the hold down I ended up adapting a 2 inch PVC flange as I had a couple in my junk box. The OD of the flange is 6 inches but the center hole had to be opened up to provide a sliding fit over the body of the Ace funnel. Rather than using a hole saw, I made a wooden fixture with a hole that made a good fit with the lip of the flange's pipe connection. This was clamped to the table on my drill press. Using a ¼ inch end mill I rotated the flange by hand with the end mill at increasing depths until I was pretty much through the flange, leaving only a thin web at several places around the perimeter. I then cut the web with a knife and cleaned up the hole with a rounded file. All of that said, today I'd use a hole saw.

A simpler method would be to acquire a piece of ½ inch thick PVC plastic and cut it to the size and shape of the base plate before boring the hole for the chamber.

The completed base plate is shown in the photographs on the next page. Four ¼-20 pan head machine screws are used to hold the flange. The flat gasket is made from 1/16 inch Viton sheet. The inner diameter is 3- ¼" by 5-7/8" OD. I added four drilled and tapped holes inside the gasket opening as attachment points for fixtures, The hole at the center is 1-1/8 inch in diameter, selected so as to be able to pass a 1" copper water tube.

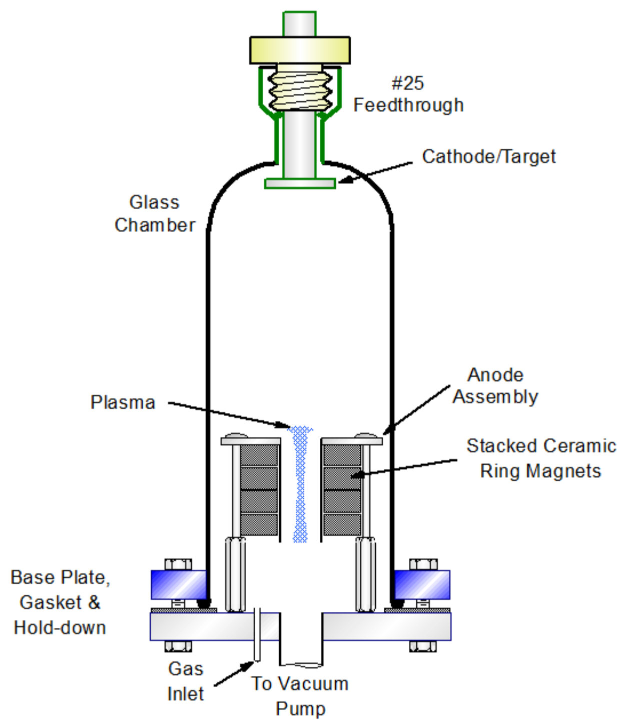
The bottom side (not shown) is drilled and tapped for a 2-3/4 inch CF to KF40 adapter. The seal between the flange and the base plate is made with a Viton gasket of the type that is used as a substitute for the normal copper gasket. This arrangement will make a very good vacuum seal provided the aluminum is scratch free.

I have several of these chambers. One is in the stock configuration. I have 3 others with variations on the top fitting and with Ace Thred fittings on the side of the chamber. For the latter, I have a hold down collar with a slotted side so that the collar can slide past the side fittings. All of these were modified by my friends at M&M Glassblowing in Nashua, NH. (http://mmglassblowing.com/). M&M also deals with Ace Glass so they can also source the components.



My original application was for a crossed-field accelerator that was based on the design of the neutron source of Gow and Ruby *et al*. dating from the late 1950s. The design evolved from work on Penning devices. Relevant papers may be found at https://escholarship.org/search?q=ucrl-8156. There is also a pair of US patents - 2,967,943 (Gaseous Discharge Device) and 2,990,476 (Radiation Source).

I was more interested in the crossed-field configuration as opposed to the neutron generation aspect.



Referring to the figure which shows my configuration as of the mid-1990s, the crossed-field ion source consisted of a simple stack of surface magnetized ceramic ring magnets – very simple. Vacuum requirements are modest – in the 5 to 20 mTorr range and it can be powered by a pulsed or continuous DC source. I made a somewhat more complex device with water cooling for the anode. This configuration shown was covered in *the Bell Jar*, Vol 6, No. 3/4, Summer/Autumn 1997.

I ran this at pulsed voltages up to the 120 kV range with hydrogen and air. For the amateur that is interested in neutron production, the Fusor and Dense Plasma Focus devices are much better suited.

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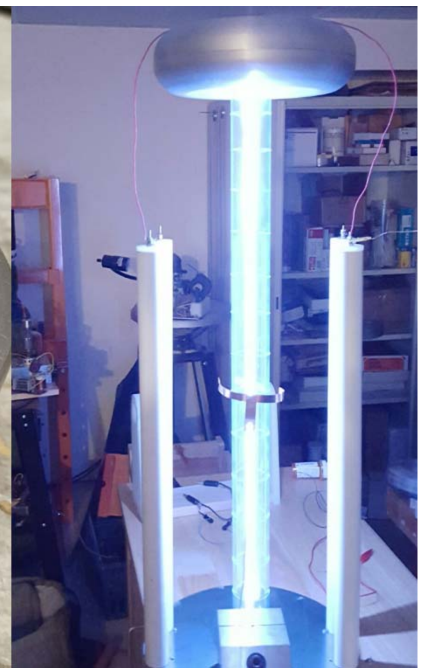
Chuck Sherwood on Glass Tube to Metal Fitting Adapters and his Electron Beam Source

Over the past few weeks I've received a number of notes and photographs from Chuck Sherwood relating his work on glass tube to metal adapter fittings. This has culminated in his work on an electron beam source which, as of this date, is still a work in progress. The following text is based on his photographs and commentary. Chuck may be reached at chuck1024@wowway.com.

Tube End Seals using Apiezon W Wax

Here is a very traditional method using what used to be (and probably still is) the premier vacuum sealing wax. The photograph below left shows a fitting that has a machined groove that is sized to accept the glass tube.



To assemble, the groove is partially filled with wax and heated to liquid with a heat gun. The glass tube is set in and the wax is allowed to harden. This makes an outstanding seal. Some words of caution. The glass tube has to be smooth and square to provide good mechanical support. Otherwise the strong consistent pull of a vacuum will shift the glass in the base. The glass can be removed by heating the fixture until the wax softens and pulling the tube out. It will be messy but automotive brake cleaner dissolves the wax easily and it can be removed with paper towels.

The accompanying photograph, above right, shows a chamber arranged as a strobe discharge tube. The discharge is from a capacitor bank charged to about 40 kV with the tube under partial vacuum. The tube is pumped until it auto ignites at the desired voltage. The discharge is on the right side of the Paschen curve. At low pressures there is a constant glow at low voltage. As the pressure rises into the 10-20 Torr range there is very little current flow until an avalanche occurs and the tube ignites as shown. Capacitor banks ranging from 20 nF to 0.25 µF have been used.

The discharge shown is with 20 nF and a completely dark room. Repeated exposure to the flash is hard on the eyes and is high in UV content. Along the tube are equalizing wires with corona points. This was inspired by the electron accelerator that was described in the *Scientific American* “Amateur Scientist” book. The tube would not auto ignite well without them.

O-Ring Sealed Adapters

A more flexible approach was to make a set of adapters that would mate with glass tubing using O-ring seals of the appropriate size. Viton O-rings 223 were used. The tubing used had a nominal inside diameter of 2 inches but measure 15-20 thousands less depending on the tube. Two end pieces were made - one with a KF40 flange and one with a KF25 flange. One had two O-rings to see if that would improve the seal and to provide a more rigid support. Below is a picture of the KF40 adapter with one O-ring. A little film of grease was used on the O-ring to facilitate assembly. (Note: static O-ring seals where there is no sliding motion should not require any grease. For sliding seals, the amount of grease should be just enough to make the surface of the O-ring shiny.) It was also found necessary to sand off the corner of the inside edge of the glass tube with some emery cloth to provide a taper to help the glass slide over the O-ring without cutting it.

Additionally, having the glass bump up directly to the metal fitting can lead to cracks in the glass. A solution is to put a rubber “bumper” between the fitting flange and the tube.

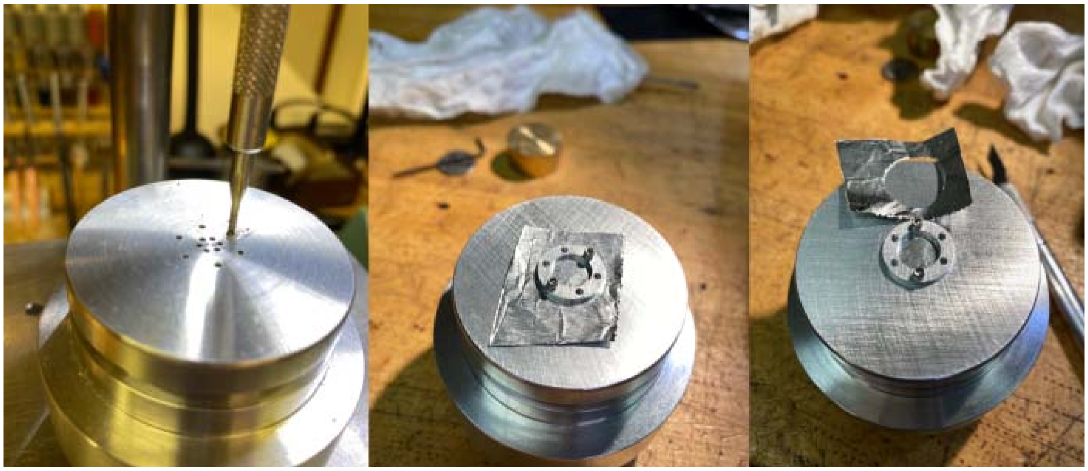
The goal was to make a modular system and simple linear potential drop accelerator, starting with electrons. The next photograph (next page, left) shows an initial configuration with one length of glass tubing. Note that the rubber bumpers are not shown in this photo.

Vacuum testing used a Varian HS2 diffusion pump. After a couple of hours the Bayard-Alpert ion tube with GP270 controller showed 4.8×10^{-6} Torr. The Alcatel cold cathode gauge showed 6×10^{-6} mbar which translates to 4.5×10^{-6} Torr. These measurements were typical for the system, so it appeared that the O-rings were sealing well.

The next step was to make a couple more center sections to lengthen the assembly. The column with one center section is shown in the photograph below, right.

The next challenge was the electron window. This involved an aluminum piece with apertures and threaded holes for a retaining ring. The series of photographs on the next page shows the fabrication sequence. The apertures used a #58 drill. The outer row for the retaining ring was drilled with a #56 drill and tapped for 0-80 machine screws.

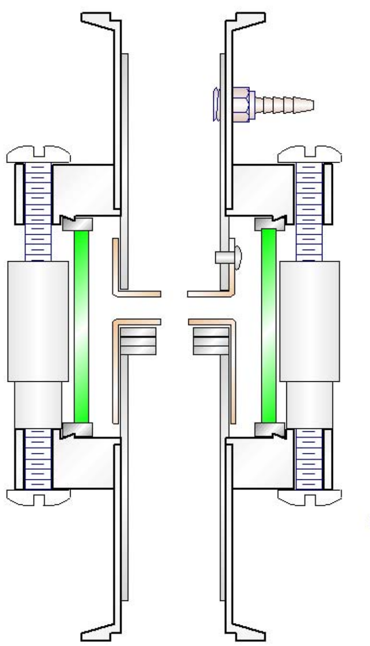
The next photographs show the assembly with some household aluminum foil. The thickness was 0.00075 inches which is far too thick but useful for testing for vacuum leaks. This window could be pumped down to the low 10^{-5} Torr range without any sealant but tests indicated it was leaking a lot. The next installment will report how to seal the window along with some experiments with thinner aluminum foil.



Glass Chamber for a Single Gap Pseudospark Device

My multiplate pseudospark device was covered here in the February 2020 issue. This article describes a chamber for a single gap device. The intent is to be able to easily control the electrode gap and also to have a clear view of the inter-gap discharge area. The approach, like Chuck Sherwood's, is to have a simple way to mate small glass tubes to standard vacuum fittings.

The drawing below, left shows the complete assembly. It is drawn to scale. The accompanying photograph shows the assembly minus the electrodes which is where it stands at the moment.



The main components are two standard CF to KF25 adapters. Each is fitted with a Viton gasket. These are commercially available as alternatives to copper gaskets. The glass tube in this case is a pressure-rated borosilicate glass tube, 1-3/4 inch OD by 1-15/32" ID and 1-5/8" long. The ends are ground. These are available from McMaster-Carr as part number 1176K23. As a side note, I have another tube of the same diameter but longer and with one #11 Ace Thred port on the side. This was made for me by M&M Glassblowing but beats me what my intended application was.

The assembly is held together using hardware store nylon threaded couplings, spacers and nylon ¼-20 screws. The spacers are ½" in diameter and 1" long. However, the couplers interfere with the Viton gasket. This can be remedied by either turning down the end to about 3/8" diameter or, as I did, addng a smaller diameter spacer.

The lower screws are 1-1/2" long and screw into the ½ x 1 inch coupling. For the particular glass cylinder, the upper screws are 1-1/4 inch long. When everything is aligned and the screws are gently tightened, the assembly is vacuum tight.

For the pseudospark device, the electrodes will be fabricated from 3/4" copper pipe caps. These slip onto 7/8" diameter stainless steel tubes. As it turns out, the inside diameter of the tube on the CF to KF adapter is just a bit under this figure. As a result, the mating portion of the two tubes has to be reduced to make a good sliding fit. Needless to say, the upper tube will fall out without anything to retain it. I thought of soldering but decided to install a tubing nipple for the gas feed. The nipple has a 1/8" pipe thread and, after installation, is sealed with a bit of epoxy on the threads. If it is ever necessary to disassemble the fitting, it is a fairly simple task to remove the threaded fitting and clean up the epoxy residue. The copper cap is shortened by half and is held in place with a small machine screw.

The bottom assembly is held in place by gravity. The gap between the two caps can be reduced to the desired amount by placing stainless steel washers between the end of the tube and the cap. The caps are easy to replace to change apertures or replace those with eroded apertures.

An Inexpensive Capacitor Solution for Dense Plasma Focus Devices

Prof. Sing Lee notified me of the plenary paper he delivered at the International Conference on Plasma Science & Applications ICPSA2020, held in Cuttack, Odisha, India, 26-28 December 2020. The paper *The Plasma Focus – Developing a Plasma Training and Education System for the Dawning of The Fusion Energy Era* notes the importance of plasma fusion training and the central place of the DPF as a teaching tool for plasma physics. A key goal is a "plasma focus in every laboratory." However, "every time a group wants a PF, and cannot get one, the obstacle is invariably the inability to acquire a suitable capacitor."

Some investigation has begun on the paralleling of small, more readily available and inexpensive capacitors in order to provide an adequate amount of energy and the necessary low inductance. In the paper, as an example, he has cited some work from the amateur community, especially the work by Steve Ward (https://www.stevehv.4hv.org/MOCs.htm) on the use of paralleled microwave oven capacitors (MOCs).The typical MOC is rated at 1 μF at 2 kV. Testing showed a breakdown of just over 10 kV and an inductance of 180 nH. A can and coin crusher was made using 18 capacitors in parallel.

The upshot of this is that Lee's group will be pursuing the design of a DPF that will operate at a target voltage of 8 kV with a total capacitance on the order of 20 µF and the necessary low inductance. This should produce a peak current of 105 kA and a yield of 5×10^5 neutrons per shot.

Update on the Dwyer Magnehelic Gauge

As a follow-on to last month's article on using the Dwyer Magnehelic family of differential diaphragm gauges, I found a 120 Pa (0.5 inches of water) unit in new/old stock condition on eBay. My concerns were the large surface area and plastics that are used on the measurement (+) side of the unit. This includes the inner volume of the case, plastic faceplate, etc. The reference (-) side consists of the backside of the silicone diaphragm and the much smaller aluminum encased volume behind the diaphragm.

I tied the two ports together and connected them to my mechanically pumped stand. With the Dwyer unit disconnected I could reach a base pressure of about 6×10^{-3} Torr after 10 minutes of pumping. With the gauge connected the base pressure only rose to 8×10^{-3} Torr.

Pressure rate of rise testing was a little more telling. With the gauge line closed, the system base pressure had declined to 3.8×10^{-3} Torr. After isolating the pump the pressure rose to 1.2×10^{-2} Torr after 1 minute. With the gauge's + port open to atmosphere and the – port at vacuum, the pressure went from 6.7×10^{-3} Torr to 5.5×10^{-1} Torr. My guess is that this resulted from a combination of outgassing from and permeation through the silicone rubber diaphragm.

My conclusion at this point is that the gauge is usable for the applications mentioned last month provided that the reference side is constantly pumped. For light gases and for a lower permeation/outgassing rate, the Buna-N diaphragm option should be far superior to silicone.

Next I'll try some differential pressure measurements across orifices.

Articles of Possible Interest in *Vacuum Technology & Coating* Magazine

January 2011
Vacuum and the Common Man - Explaining the mysteries of vacuum to the uninitiated

February 2011 and March 2011
When Good Gauges Tell Lies (in two parts)
Understanding how gauges operate is key to not being fooled by them

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box. Look for my columns and you can probably find other articles of interest in each issue.

End Notes

Best wishes to all for a pleasant productive New Year (or at least better than 2020 was).

Next month's issue will have a continuation of Chuck Sherwood's work with his electron accelerator and some more on atmospheric pressure plasmas, specifically the surface micro-discharge (SMD) configuration. I may also have an update on my impulse plasma deposition (IPD) system.

Steve