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

Notes from the Vacuum Shack

No. 3 February 2020

Introducing the Basic Vacuum Education System (BVES)

Background

BVES had its origins in early 2006 when I was in the process of proposing a couple of vacuum trainers to The Science Source (TSS) in Waldoboro, ME. It was designed as a very simple system that might be useful at the middle and high school levels. It became known as the Vacuum Principles and Applications Lab - Basic (VPAL-B). The companion system was the far more capable Advanced (VPAL-A) system. VPAL-A was targeted toward the 2 and 4 year college level.

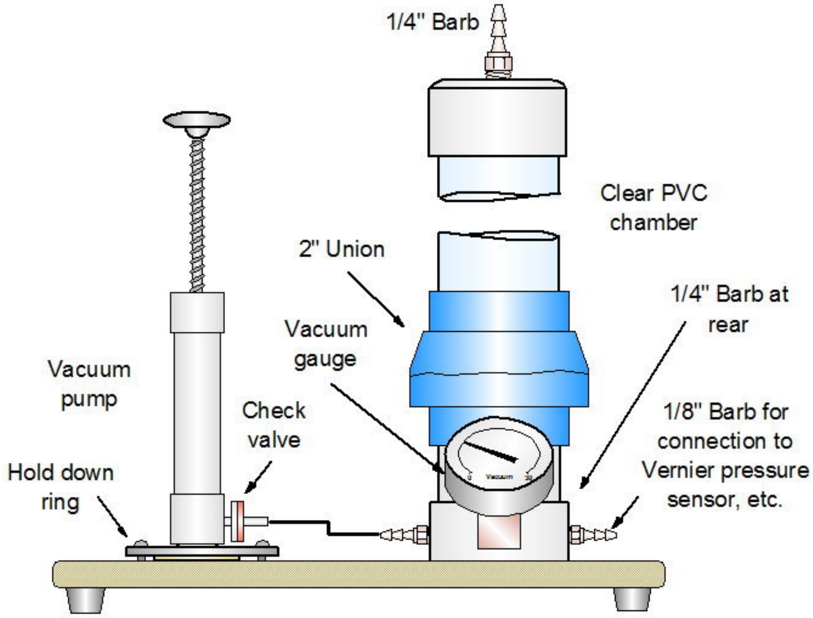
The decision was made to immediately proceed with the VPAL-A, and a fair number of these systems were shipped. In the 2014 timeframe it was decided to move ahead with the VPAL-B and a pre-production prototype was produced. I had roughed out the documentation and things were moving along nicely when TSS was sold to a larger science education supply company. They decided to not take the vacuum trainers as they were relatively low volume and required support at a level they did not want to assume.

For VPAL-A, all of the documentation is available at http:belljar.net/education-home.html. VPAL-B has only been represented by a picture of the original 2006 prototype.

Toward the end of 2019 I decided to pull together all of my notes and put together a new version of the apparatus. This is basically the same as the 2006 prototype with a few added features. The notes, which detail a number of exercises, are well on the way to being fully fleshed out. There is also a document nearing completion that provides complete details on the construction of the apparatus. About all that's required are a small drill press and some common hand tools.
By the way, I pronounce BVES like the TV cartoon character.

Overview

The illustration on the next page and the accompanying photograph show the BVES.



The base is a bamboo cutting board. To the left is the pump. This is a really nice hand operated pump that is made for some food storage products by the Pump-N-Seal company (see https://pump-n-seal.com). I can't quite remember how I ran across this pump but I ordered one and found it to be far superior to the usual small hand pumps used for bleeding brake lines. The latter have a relatively small displacement and, at least in my case, my hand quickly gets tired and cramped when squeezing the thing for any period of time. TSS retained a high school science teacher as a consultant and he was familiar with the little squeeze pumps and was amazed at how efficient the one from Pump-N-Seal was. Basically, the "suck" is on the upstroke and a spring pretty much provides all of the force that's required. The down stroke simply compresses the spring.

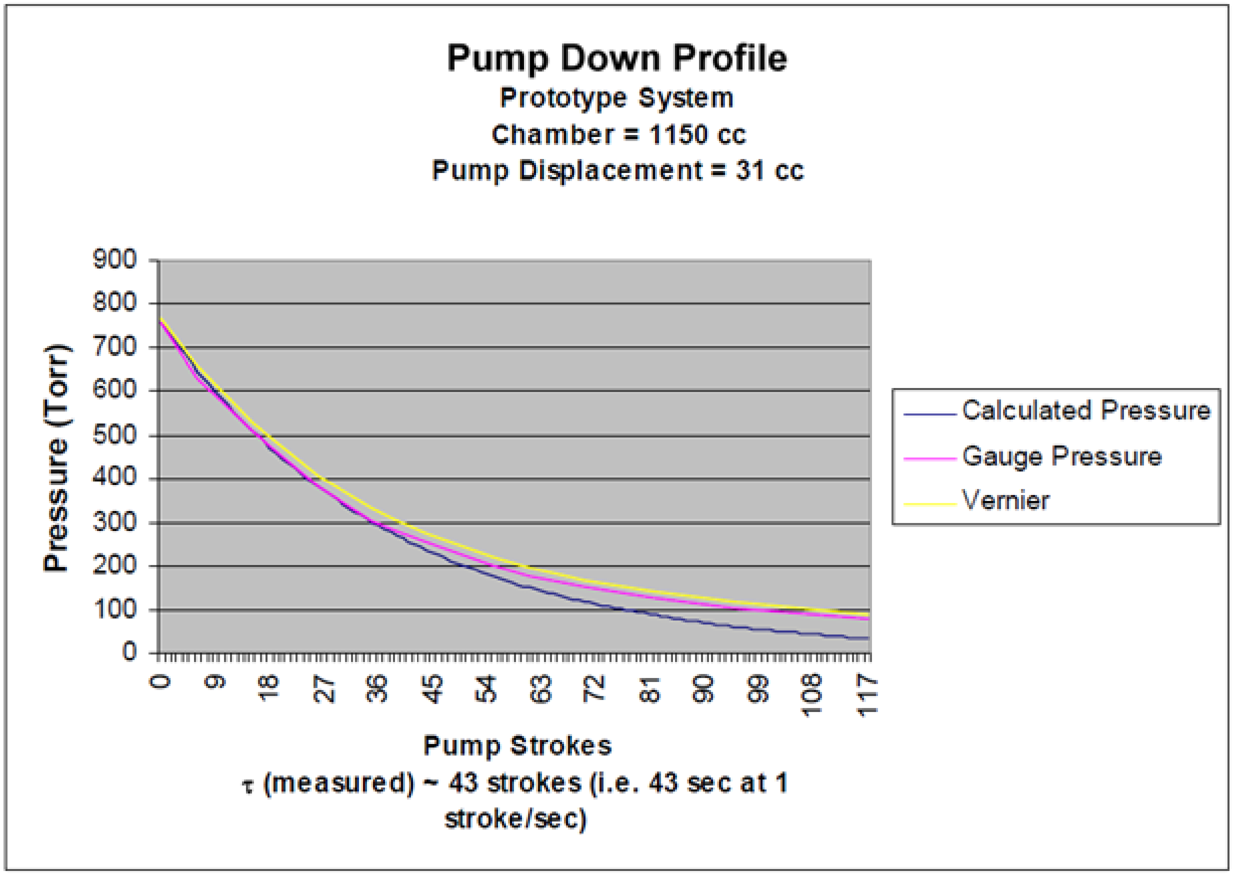
The chamber is unusual relative to the ones that are usually provided with other simple educational systems. The upper part of the column is the experiment chamber. This is made of clear 2" PVC pipe and is fairly tall. There is a hose barb at the top which can be used for various purposes including as a feedthrough for a Vernier temperature sensor. The lower part (the manifold) is white PVC and contains the 3 hose barb connectors and a Bourdon dial gauge. One of the barbs connects to the pump via a piece of 1/8" id Norprene tubing. Another barb is primarily used for connecting to a Vernier MEMS absolute pressure sensor (shown in the photograph). The third barb is for venting and other uses. The two parts are joined by a standard PVC pipe union with an o-ring seal.

The tall form of the chamber is useful to provide vertical space for things like thermometers and to provide a longer fall for the classic "penny & feather" demonstration. It also makes measurements easier for the Boyle's Law (balloon expansion) exercise. Needless to say, other configurations could be used for the chamber. If one wanted a wider chamber, an adapter could be used to expand the 2" lower unit to, say, a piece of 4" diameter clear PVC pipe.

As designed, the unit is capable of easily achieving a vacuum of --28 inHg or better.

Documented Exercises

A familiarization set of exercises starts with a comparison of gage (atmosphere referenced) pressure and absolute pressure measurements and common units of pressure. It then goes on to cover the pump down by sequential expansion which is then used to develop a characteristic pump down curve. Example results are shown below. Part of the exercise involves explaining the difference between the calculated curve and what was measured.



Base pressure is determined along with the upleak rate in terms of Torr/sec and standard cc/minute (sccm). The last requires a system volume determination and the application of Avogadro's Law. If there are multiple systems in a classroom, base pressures and leak rates can be compared.

Once the characterization is complete, the following exercises may be performed:

- Transmission of sound in vacuum
- Air friction in vacuum (Penny & Feather)
- Boyle’s Law (balloon expansion)

- Boyle's Law (deairing of a liquid)
- Creating and sizing a real leak
- Understanding closed-loop pressure control
- Creating and sizing a virtual leak and the characteristic form of the pressure/time curve
- Evaporative (adiabatic) cooling
- The boiling point of water at low pressures

The complete set of the above exercises along with construction details will be on the belljar.net web site by the first week of March.

My Pseudospark Electron Beam Source

The early evolution of my pseudospark electron source was covered in several issues of *the Bell Jar* as well as in the compilations. The current version, with a few changes, dates from about 15 years ago. I won't go into the details of operation here but an excellent (and free) resource is the 2012 dissertation by Jing Hu [1].

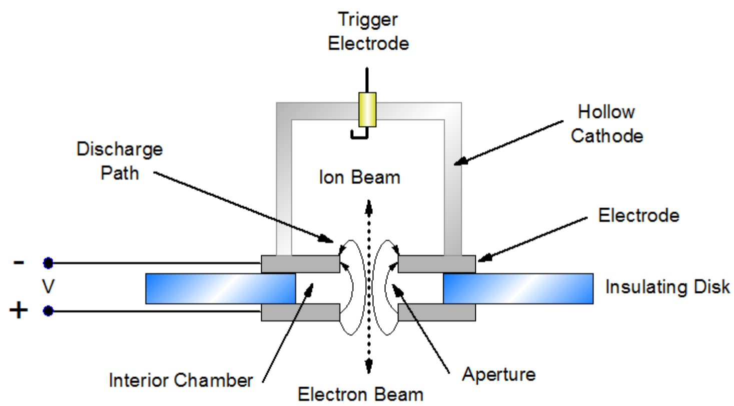
In brief, a pseudospark device consists of a hollow cathode with small aperture (a few mm) that faces an anode with a similar aperture. The separation is usually on the order of a few mm. One or more floating electodes (with apertures) may be interposed between the cathode and anode. These serve to increase the hold off voltage for the device.

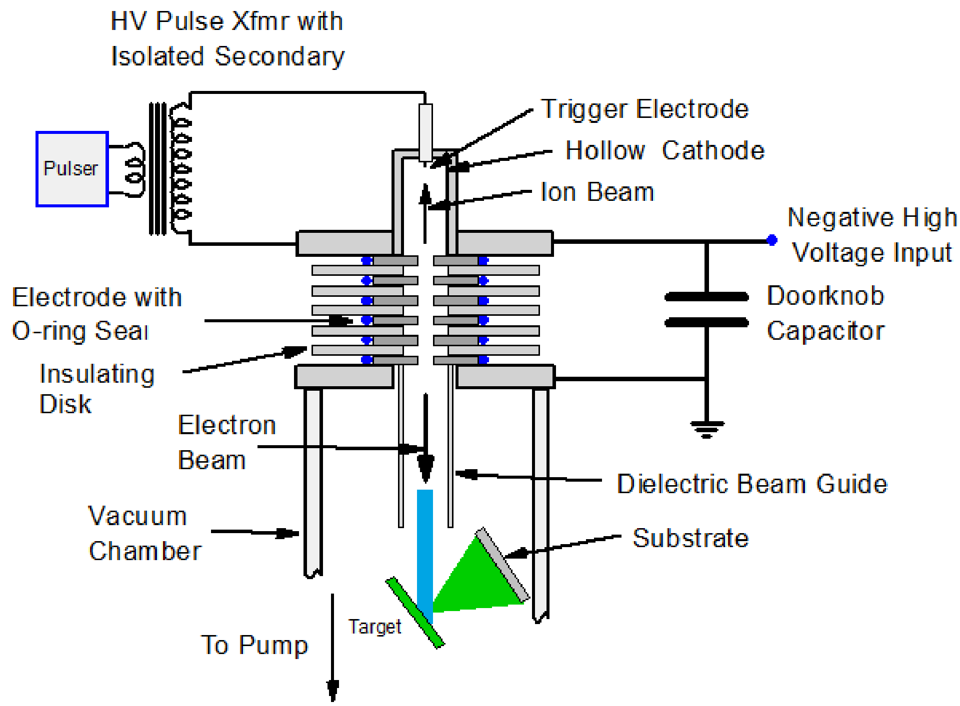
There are several phases to the operation of the device. The first is the ignition phase. This is followed by the development of the hollow cathode discharge. This produces an intense electron beam whose energy approaches that of the applied voltage. The energy density of the beam is on the order of 10^3 A/cm^2. This phase is then followed by a very high current main discharge on the order of kA but with a fairly low energy (hundreds of eV). The final stage is the decay of the plasma.

The discharge can be triggered with a spark discharge within the hollow cathode or with a burse of UV light from a laser or flash lamp. The device can also be self triggering by adjusting the pressure and/or cathode voltage. The main discharge can be suppressed if the capacitance across the device is kept low.

A very common configuration is the BLT or Back-of-the-cathode Lighted Thyratron. This is a fast switch using the main discharge that is triggered by a flash lamp (hence the back lighting reference).

The illustrations on the next page show the basic construction of the pseudospark device and a configuration for ablation via the electron beam.



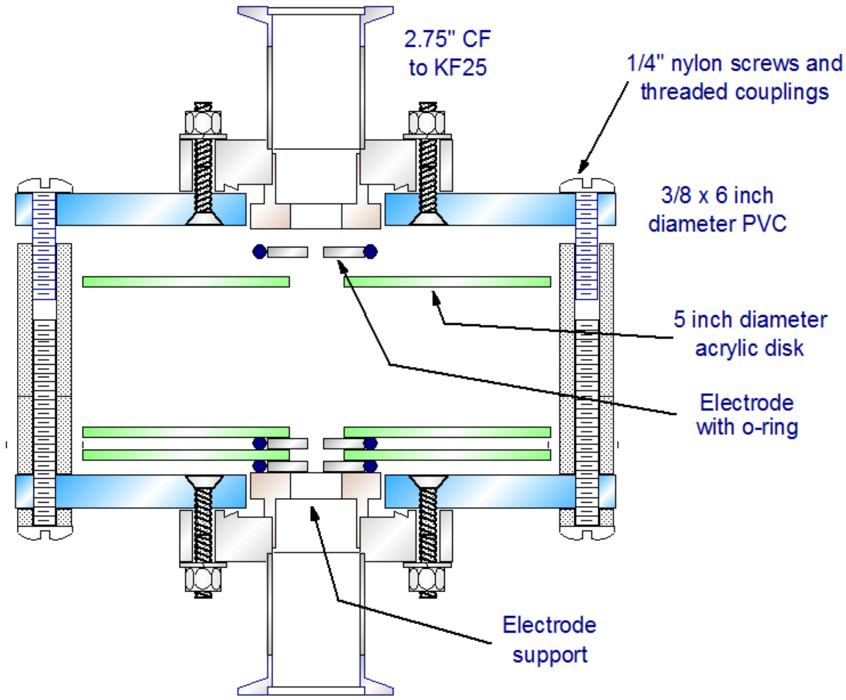


The balance of this article will be concerned with the details of the electrode assembly for my pseudospark electron source. I have generally operated this at voltages in the 30-60 kV range, free running with no external trigger.

Construction of a Simple Pseudospark Electron Source

A photograph of the current device is shown in the photograph on the next page. The primary components are 2 each 2.75” CF to KF25 adapters, 2 each 6” diameter x 3/8” PVC disks, 7 each 5” diameter 0.125” clear acrylic disks, 8 each 7/8” diameter x 0.078” (14 gauge) stainless steel disks and 8 each 1/8” section x 7/8” id o-rings. Also required are ¼ x 20 stainless steel hardware and some ¼” nylon machine screws, bushings and threaded couplings. Additionally, 2 each brass or stainless steel bushings will need to be fabricated. More on this later.

A cross-section diagram is in the figure below.

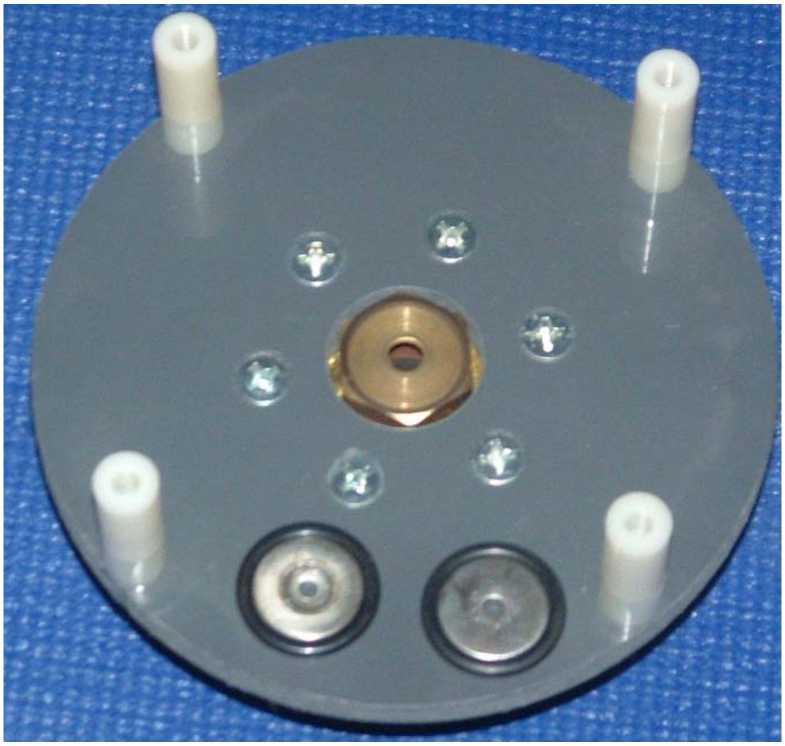


I cut out the PVC disks using a circle cutter in my drill press. The acrylic disks are available from US Plastic (https://www.usplastic.com) as part number 44187. I drilled a ½" hole at the center of each of the acrylic disks.

My original floating electrode disks were made from 7/8" od stainless steel fender washers. I soldered two together to make a thickness that would work with the 1/8" section o-rings. This tended to be highly variable. A more satisfactory solution was found with some 14 gauge (0.078") disks from eBay seller Lumberjack1983. He has a lot of disks of varying thicknesses and diameter made from stainless steel and aluminum. My electrodes were a custom order that he has since added to his standard inventory.

The electrode support was fabricated with a little bit of simple lathe work from a pair of brass ¾" M-NPT x 3/8" flare adapters. I turned down the pipe threads so that a portion of the remaining cylinder would make a fairly tight fit with the inside of the CF to KF adapter. A shoulder was left so that the surface of the hex portion would be slightly above the surface of the PVC disk. The flare portion of the fitting was removed to provide a flat surface measuring 1-1/4 inches across the flats. These brass pieces are then soldered using 2% silver/tin solder. Depending on what you have available, there are any number of solutions for this part.

The photograph shows a PVC end plate with the electrode support. The central aperture is ¼". This is not critical as long as it is larger than the floating electrode apertures and smaller than the o-ring inside diameter. The nylon couplings have a ½" outside diameter.



The photograph also shows two of the electrodes. The one on the left faced the cathode aperture. It has seen several thousand shots and erosion can be seen around the aperture. This is not the case with the electrodes further down in the stack.

Assembly

The apertures must be aligned during assembly. My apertures are 5/32" which is very close to 4mm. I made a jig using 5/32" drill rod that was centered in one of the CF fittings in an end plate. With the nylon couplings in place (for the number of electrodes I have, I used a stack of 1" and ½" couplings. The process is simple. Start with the first electrode (with o-ring), add an acrylic disk (this will just fit between the 4 nylon couplings) and repeat. Once the last electrode is in place, place the other CF/PVC disk assembly in place and use ¼-20 nylon screws to tighten the stack. Once they are tightened, the o-rings should be compressed enough to provide a vacuum tight seal.

Next month's issue will include details on the dielectric electron beam guide and drift chamber options.

References

1. Jing Hu, *Experimental investigations of pseudospark discharge and pseudospark produced intense electron beams*, doctoral dissertation, Missouri University of Science and Technology, 2012. http://eplab.ae.illinois.edu/Publications/HuPhDThesis.pdf

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

Here is a selection of past articles that I have written on the subject of vacuum gauging.

June 2009
A Primer on Vacuum Pressure Measurement

July 2009
Pressure Measurement Realities - what you see is not necessarily what you've got. This covers the various terms associated with pressure gauge specifications.

October, November and December 2009
Calibration Practices and Pitfalls. This 3-part series covers how gauges are calibrated at the factory as well as user methods for verification. This also covers MFC calibration.

February and March 2012
When Good Gauges Tell Lies. This 2-part series explores some limitations of common vacuum gauges and how to avoid being fooled by what they sometimes tell us. This includes convection enhanced Pirani gauges, ion gauges and capacitance diaphragm gauges

Articles may be accessed at http://vtcmag.com/. Scroll to the bottom of the page to the back issue selection box.

Your Projects

The 10 volumes of the printed *Bell Jar* had a high proportion of reader projects. If you are working on something that is vacuum related that may be of interest to others, please contact me.

That’s it for this month.

Steve