Thanks to my family, Richard White, Professor Charles Barnes, Richard Hull, Jon Rosenstiel, Frances Power, Steven Sander, Kevin Jiang, Randy Au, #nekonyan, and #thedryeraseboard.
My fusor during a low-power run
Nuclear fusion?

Nuclear fusion is a simple idea: force two nuclei close enough that they combine. In the process, neutrons and protons are kicked out, carrying excess energy with them. It’s the opposite of nuclear fission, which is what drives nuclear powerplants and nuclear bombs.

Unfortunately, nobody has figured out yet how to use the energy released by fusion as a power source. And while it seems simple, nuclear fusion tends to be extremely hard: nuclei make repelling each other their number one priority. It takes a lot of effort to push nuclei close enough together to get nuclear reactions to happen.

The easy way to overcome that repulsion is to accelerate particles towards each other so that they have enough energy to overcome that barrier of repulsion. That’s exactly what happens in particle accelerators; a typical accelerator might accelerate protons to $2 \text{ MeV}^1$ and smash them into a target.

Along with space and money requirements, electrostatic particle accelerators are typically limited to small bunches of particles and require extremely high voltages to perform. Due to these limitations, a different tact is preferred among fusion experimenters: magnetic confinement, which involves containing a plasma using a configuration of magnets. Since a plasma is just a collection of ions moving at fast speeds, fusion can occur inside the plasma as ions bump into each other. The result is a higher incidence of fusion than in particle accelerators, where fusion is limited to the point where the fast-moving ion beam hits the target.

Most of the fusion research that’s been done in the past

---

1See the appendix for an overview of the eV unit.
decade has been done in tokamaks, doughnut-shaped assemblies of magnets that take a plasma and squish and pull its ions until they’re moving fast enough for fusion. The current major push for tokamak research is in building ITER\(^2\)—the world’s largest tokamak—in France. ITER will pinch and move the plasma so that at maximum power, hydrogen ions will be accelerated to 8-10 KeV on average.

On average. Those are the key underpinnings of the tokamak concept: the tokamak can’t guarantee the speed of any one ion due to its design. A tokamak functions by manipulating a plasma as a whole with magnets, and then dumping energy into the plasma in the form of radio waves or magnetic heating. For the most part, faster ions are toward the center of the doughnut-shaped plasma, with slower ions at the outside. The result is like cooking a roast: some parts are hotter than others. The ideal fusion machine would have some way of making the plasma uniformly hot, maximizing the volume available in which fusion reactions could occur.

There are lots of inefficiencies involved in the tokamak idea. Despite these obstacles, nearly everybody hopes that ITER will prove to be the source of future fusion energy. It remains the best design; no other fusion device has come close to generating significant amounts of energy output.

Amateur fusion devices are no ITER, though. They’re table-top sized and will never hope to produce output energy. They’re not the next holy grail of energy research, and they’re no match for the multi-billion-dollar machines being built right now.

But they do real fusion on a small scale. How?

\(^2\)Pictures of ITER and JET courtesy of EFDA-JET, www.jet.efda.org
The interior of JET, the current predecessor to ITER (operational picture superimposed)

A size comparison between JET and ITER
Simplistic Fusor Diagram
The Fusor

There are a couple options if you want to perform nuclear fusion as a hobby. The most common option is the Farnsworth fusor, which is basically a hollow shell with a grid inside.

The fusor chamber is kept at a pretty good vacuum, comparable to that in outer space.

The fusor is usually explained with the following model:\(^3\)

1. Deuterium gas—an isotope of hydrogen with one proton and one neutron—is let into this spherical chamber at a low pressure.

2. The center grid is charged to a very high negative voltage, and the chamber is grounded. As a result, electrons are torn from the hydrogen atoms leaving the positively charged nucleuses to fly around the chamber.

3. These nuclei are pretty strongly attracted to the center grid due to its extreme negative charge (usually around 15-60 KV). They head for the grid due to their attraction, picking up speed as they get closer to it. A good portion of the nuclei fly right through the grid, missing the wires, while a small percentage end up colliding with each other. The key thing to remember is that, ideally, each deuterium nucleus (deuteron) is passing through the center of the grid at a very high speed.

4. Any nuclei that don’t end up colliding in the center will ideally pass right through and come back until they collide.

\(^3\)See the appendix for details.
In an ideal situation, two nuclei would come hurtling toward the center grid, miss the grid wires, and collide in the center. Step four, the idea that the ions recirculate, is the usual hypothesis for why the fusor is (relatively) efficient at doing fusion.

Pictures of fusor operation usually show the center grid through a clear viewport, which appears as an X or star structure. Most grids in amateur use are 1-2" in diameter; a typical chamber might be an 8"-diameter sphere.

About 30 people have built this device, even a few who were high school students.

Why amateur fusion?

At first, I was drawn to the fusor because of the results’ appearance: the star-mode plasma that’s produced when a fusor operates is beautiful! But in addition to that, the fusor is a very good testbed for doing nuclear science. With an operational fusor, you can do all sorts of neat experiments: you can place an item next to the fusor, and as a result of the fusor’s radiation reacting with the item, identify exactly what that item is made out of. You can use the fusor to activate elements; you’re literally converting a small amount of an element to something more radioactive, almost like the old alchemists’ pursuit to change lead into gold.

Atoms are typically invisible things that everybody assumes are unchangeable. But with the fusor, you can generate radiation that can affect change on a subatomic scale. It’s real science—back in the 1950s, this was ground-breaking technology.

Plus, the challenge of building a fusor is alluring. It’s like climbing a scientific Everest—why do it? Because it’s there!

Of course, the fusor is not all sunshine and rainbows. Akin
to climbing Everest, the fusor has its own share of dangers. In building a fusor, I could have died, caught in an explosion as the diffusion pump was accidentally opened to air. I could have died, electrocuted by the high-voltage supply. I could have gotten injured, cut by pieces of shrapnel as some item imploded under vacuum. I could have gotten cancer, irradiated by the X-rays that the fusor produces.

But I'm still alive and well!

The long laundry list of dangers is easily containable with appropriate measures.

Building a fusor

The basic fusor is comprised of

- a vacuum system
- a high voltage system
- a gas management system
- and a neutron detection system.

While it looks like a very simple assembly of systems, a fusor can be at times incredibly stubborn. I’ve had to troubleshoot vacuum leaks over periods of several weeks because they simply wouldn’t go away. My high-voltage supply required three overhauls before I could operate at high power, and it still broke in the end. On bad days, the fusor has simply refused to work, being too unstable to push to full power due to instabilities in both the vacuum and high-voltage systems. But on good days? All the labor was well worth the effort.
My fusor setup. The top shelf is the control panel, the middle shelf holds the fusor itself, and the bottom shelf holds the vacuum system and HV supply.
The fusor of Brian McDermott, a former high-school fusioneer

Fergus Noble and Henry Hallam’s fusor in the UK
The Vacuum System

My vacuum system is mainly comprised of parts from eBay and Craigslist. I was lucky enough to find a rebranded Edwards RV8 pump on Craigslist for a reasonable price ($160). You can learn a good deal about a used pump from where it came from, and I had my doubts about mine: I bought it from an old, junky-looking workshop. The first three or four flushes of oil came out jet black, a sure indicator that something was wrong. At one point the pump simply stopped and wouldn’t budge when turned on, forcing me to disassemble it to figure out what exactly broke. It was a mess inside, with broken blades and all sorts of sediment and silt coating every inch. After a thorough acetone bath and a new kit of parts, I managed to put it back together, and I’m happy to say that the base pressure was about 10 microns. The rebuild of the pump ended up costing me a good deal of time and money, though the experience gained made it worth it.

Buying a thermocouple vacuum gauge was a much easier process. Having browsed Silicon Sam’s FAQ’s for ages, I knew about Sam Goldwasser’s classifieds; he offers surplus vacuum gauges and control units at good prices. He shipped me a calibrated and tested pair for a decent price, and they worked straight out of the box. As of 2008, they’re still working perfectly; I haven’t had to adjust them at all even after 2 years of use.

A spree of lucky eBay purchases allowed me to finish the vacuum system. I was lucky to catch a bargain on the diffusion pump, Baratron vacuum gauge and controller, butterfly valve, and isolation valves. They all sold at around 10% or less of the brand-new prices! Of course I made some bad purchases in my bidding sprees—such as the couple parts that didn’t end up making
it into my system, parts like a huge 8"-flanged gate valve. Perhaps the worst purchase of all was a $120 pallet of diffusion pumps from the University of Washington surplus house. It was a full forklift-style pallet of old diffusion pumps; I had it in my mind that I could resell those that I didn’t need for profit. Soon after I bought the lot, I found out that I had no way to get it from Seattle to Los Angeles, and even if I did manage to scrape up the money to pay the freight charges, there was no place in the house to store it. It was a terrible abandon; the pumps on that pallet probably could’ve resold for a couple thousand each.

My rule of thumb when buying precision specialty items on eBay is to double and triple-check that the item ts the needs, and that it’s in a usable (or salvageable) condition. No use buying things for a future vacuum system or for expansion; things will change too quickly. I’ve had to shelve many parts because my plan changed as soon as I received them.

The chamber itself was fabricated by Wayne Rodgers over at his lab in Apple Valley as a prototype. We were intent on finding out the cheapest way to assemble a fusor chamber—with the help of his excellent machinist, Ian Hall, we were able to make my chamber out of a couple of stainless steel bowls TIG welded together in just one day. We even had time for a lunch break!

It required a lot of skill, and it’s definitely not recommended unless you have lots of time. I was pretty desperate for any way to make the chamber: my time and labor were cheap, and I had zero money. Another pretty good rule of thumb in scrounging: if you’re not willing to spend the money on it, you’ll have to trade time and labor instead to find and fix something equivalent.
I hand-machined the flange that connects the fusor chamber to the diffusion pump, due to the fact that the diffusion pump had a custom flange that didn’t mate with anything else on the market. It was surprisingly easy: just a matter of drilling additional holes into a flange that I’d already scavenged. I ordered drill bits, taps, and cooling fluid (Rapid Tap) from McMaster-Carr and used my school’s drill press. Despite the fact that the flange was 304 stainless steel, I didn’t run into any problems or complications. It drilled like butter as long as I didn’t apply too much pressure and didn’t run the bit too fast, and it tapped much the same way.

After all that purchasing, fiddling, and assembling, the current incarnation of the fusor’s vacuum system is capable of pressures on the order of one micron. With a little more attention to detail, the system should be able to go down to sub-micron pressures. Specifically, the one large step that I omitted, just due to time and labor, was a complete bake-out of the vacuum system. Water is the enemy of high-vacuum components: water clings to surfaces and gets adsorbed into their pores. The result is that water vapor can linger for days, increasing the pressure in the system as the water molecules work their way out of the surfaces that held them. The easy solution for this problem is to heat every component to at least 100°C, to drive off any water vapor—a bake-out.

With a bake-out, a simple system like mine wouldn’t have any trouble getting to sub-micron pressures, and would be useful for more experiments than just a building fusor.

The High Voltage Supply

I was very lucky to find a spare dental X-ray transformer on eBay for about $160. It was cheap, easy-to-use, and small. The first
time I broke the transformer (there was an internal arc), I thought
that I was running it beyond its rated limits. I contacted another
seller on eBay and was lucky enough to receive an almost identical
transformer (a rarity, since they’re usually surplus). When that
transformer broke, in the middle of a fusion run, it was evident
that there was a design error somewhere my supply. Despite
that, I ordered another identical transformer; I was in a hurry
to do fusion and decided that I could simply operate the fusor at
half-power until a better design came about.

Even running at reduced power, the third transformer broke.
I heard a loud thump during operation and suddenly everything
stopped working: no video on my camera, no readout on the digital
panel meters that kept track of the high voltage supply’s status.
It was the first time I performed an emergency shut-down: when
something breaks that dramatically, something’s very wrong.

Break a part once, and it could be a rare, once-in-a-lifetime
error. Break a part twice, and the problem looks systematic. Break
a part three times, and the design is a dud, redo it.

A couple of weeks after the third transformer break, upon
closer inspection of the transformer specs, the problem was
evident. Dental X-ray transformers aren’t made to operate 24/7
under power: in their native habitat, they’re only on for seconds
at a time. Nobody constantly takes X-ray photographs of teeth.
The small X-ray dental transformer that I had picked up from eBay
was barely adequate for taking occasional dental X-ray photos: it
wasn’t designed, at all, for extended operation. Of course it would
always overheat and arc internally in fusor use.

Those small X-ray transformers on eBay are usable, but only
for short bursts of operation at low power.
The internals of the dental X-ray transformer supply.
HV supply disassembly to find the break

A sure sign of death: charring

The replacement X-ray transformer
While the X-ray transformer I picked was inadequate for the fusor, the high voltage supply was very simple to make. I used a basic design that, with a few modifications, should work with any high voltage transformer. The transformer is wired to step-up the mains line voltage to a higher one, which is rectified with several diode strings and passed off to the fusor. The general rule of thumb in high voltage design is to keep it simple, so these circuits aren’t complex.

It’s a robust configuration and ensures that the fusor will work, though there are a number of known drawbacks.

At 30 KV, high voltage practices are pretty simple: make sure that everything’s off (and locked and tagged out, if need be) before working on something, don’t touch it while in operation, and make sure there’s adequate shielding and space when in operation. There aren’t any counterintuitive effects that I had to account for, which is something that begins to happen in the 100 KV and above range.

I started on a redesign of the high voltage supply around a serious X-ray transformer: weighing nearly 250lbs, this particular X-ray transformer was made for heavy-duty work. Unfortunately, it seems that it was designed for high-frequency operation, requiring a converter to change the mains frequency of 60Hz to a frequency probably in the kHz. When dealing with surplus hardware like transformers, it’s always up to the buyer to double-check the specs: I didn’t.

While it’s not impossible to make a high-frequency transformer work, it requires lots of effort and relatively complex circuitry. I haven’t had time so far to work on that new design, but will probably do so in the future: rated at 20,000 watts peak, the
250 pounds of iron and oil that comprise that transformer would constitute an incredibly nice upgrade to the fusor. The difference between the old and new supplies would be akin to comparing digging a hole with a shovel and digging a hole with a Caterpillar back-hoe. The old supply and the pending new supply are in entirely different realms of possibility.

Deuterium

Deuterium is an easy gas to obtain. I submitted an order with Matheson Tri-Gas: a couple of phone calls and parental approval were all it took. Currently, I’m renting a bottle at about $25 per month, which isn’t too bad of a price. One lecture bottle can easily last a year; don’t be fooled by its small size. It’s a lot of gas considering the fact that the fusor normally operates on only 10-20 microns of it.

As with any other high-pressure gas, a regulator is needed to step down the 800-1000 psi out of the bottle to a usable output around 5-10 psi. High-pressure deuterium tanks use the CGA 350 connector, so I picked up a regulator from eBay and bought a couple adaptors from Swagelok to connect the regulator to my vacuum chamber. Much to my chagrin, regular hydrogen regulators are the same as deuterium regulators: there is no difference. I was also lucky enough to get a couple of precision needle valves from eBay for $40, a bargain when they each sell for around $200 new.

My regulator is a single-stage type, and gives a very coarse amount of control over the outgoing pressure—I have to turn the handle maybe a half-turn past barely touching the diaphragm in order for the output pressure to be low enough. However, it does do the job, thanks to the valves down the line.
The only reason I’m able to control the gas influx to the chamber is thanks to those dual needle valves, as well as a long length of regular stainless steel tubing to cut down the conductance.

This setup is pretty simple, but it’s straightforward and hasn’t given me any problems in operation. It’s not even that touchy: once I adjust all the parameters, it’s very stable.

When I’m operating with deuterium, I start up the diffusion pump and wait for the chamber pressure to hit 1 or 2 microns, with the deuterium feed shutoff valve open. This gets rid of any excess air or deuterium that might already be in the supply lines. After that, I adjust the vacuum butterfly valve so that it’s almost closed—I twist its knob until I feel resistance and then back it off. (There are no markings on the butterfly valve to tell me what position the valve’s in.) At this point, the pressure is rising due to incoming gas from the deuterium feed. I open the gas shutoff valve that comes directly after the regulator, and then wait for the pressure to come back down. If the pressure is too low, I either adjust the needle valves for more flow (the second one in order usually provides fine control, while the first one is coarse), or I adjust the vacuum butterfly valve.

To get to a stable operation point can be sort of tricky; you don’t want the pressure to ever go above 100 microns or so or else the diffusion pump may “crash.” I’ve never experienced it myself, but it’s a particularly bad condition. The pressure becomes too high for the oil jets in the pump to achieve their mission, so the oil vapors instead fly everywhere, contaminating the system and coating all surfaces with oil.
The Bubble Detector

While there are a number of ways to detect neutrons, the simplest way is to buy one of BTI’s bubble detectors. It’s a no-nonsense, fail-proof way of sensing neutrons: if there are bubbles in the tube, then the tube has seen fast neutrons.

They’re a Canadian company, and they only ship to businesses. I obtained one through a group buy on the fusor forums, and it might be the only feasible way to get them for the time being.

It’s easy to prove that fusion’s occurred in the lab with a bubble detector, as well as quantify it, but it’s impossible to do more complex experiments like looking at the time-variance of neutron flux with relation to voltage/pressure parameters. To do those sorts of experiments, one needs the better, more sophisticated neutron counting devices—BF3 and He3 gas-filled tubes, and they’re a topic of discussion all their own.

Fusor Operation

Every fusor has different behaviors due to the imperfections in systems. There’s no sure way to know what the limits of a fusor are unless they’re reached.

The stability of a fusor depends on its power supply and vacuum system, and if it has any ionizers or ion guns. Since every amateur’s fusor is different from one another, the operational details change as well.

My fusor was incredibly stable, probably due to the small HV supply that I was using. It didn’t have enough power to cause arcs or emit massive amounts of electromagnetic noise.
A BTI bubble detector

Those three bubbles are the proof of nuclear fusion!

A "bugle" at high-pressure (25+ microns), low-voltage (<5 KV) operation
A double-bugle, high-pressure, low-voltage plasma

A higher voltage plasma, still at relatively high pressure.

A high-voltage plasma (13 KV, 12mA) at a low pressure (this plasma led to the second overhaul of the HV supply).

A high-voltage fusion plasma with deuterium gas. Star mode is evident.

My fusor's initial plasma, "first light"
It’s nearly guaranteed that a fusor will almost certainly get more stable over time as its operated. The high temperature plasmas help bake the surfaces in the chamber, releasing gases and impurities that would otherwise disrupt operation. This stabilizing effect of the plasma bake-out only stays, however, if the vacuum is kept at vacuum indefinitely or filled with dried air (either of which isn’t too difficult with good valves).

There are a number of interesting plasma effects to observe at different pressures and voltages. I observed “bugles” stemming out from the central poissor, even two or three at a time. In the high-power fusion regimes, the plasma looks very much like a star; the result is the “star mode”. It’s a visually impressive glowing central plasma with straight rods of glowing plasma that stick out according to the grid’s geometry. This type of plasma is usually the type that produces the most fusion under the right conditions.

**Fusion Results**

I didn’t do fusion for very long, perhaps for only a period of 10-20 minutes, since the high voltage source died. As a result, I wasn’t able to quantify the rate of fusion, and I haven’t had the capability to perform any other experiments.

**What’s left?**

I’d like to do more research on ion-gunned fusors. Nobody’s really researched how ion guns can improve the efficiency of a fusor; Andrew Seltzmann is building a machine right now that focuses on the interplay between a cooled grid, low pressure, ion guns, and high power operation. The results of studies like his would likely tell a great deal about the different operational modes
of a fusor, which haven’t been widely explored by amateurs due to the equipment needed being a tad on the expensive side.

Another interesting possibility lies in a miniaturized fusor. Electronics have been getting smaller and smaller, and it’s now possible to pack a high voltage supply, gas metering setup, and sealed fusor into a volume the size of a viola case. A mini-fusor would be easily transportable, making it a great demo for schools: the visual effect and simplicity of the fusor makes it a sure-fire success for an introduction to nuclear fusion in the classroom. In the industrial and research fields, a mini-fusor would be very useful as a controllable, easily adjustable neutron source. In fact, Daimler-Chrysler Aerospace used to sell a commercial fusor for the purpose of neutron irradiation.

I don’t personally think that the fusor will ever be refined into a commercial power source, as the yields are too low and the technology’s bounds are already apparent. What it does represent is an interesting gateway to science for those who pursue it: nuclear fusion has never been so easy, and a previously elusive nuclear reaction so within the reach of the amateur hand.
Appendix

What’s an electronvolt?

The electronvolt is a unit of energy, much like the joule, calorie, or BTU. The electronvolt is defined as the energy an electron gains if it falls through a voltage drop of one volt. That’s not a lot of energy: one eV is equivalent to $1.6 \times 10^{-19}$ J (one elemental charge times one volt).

How do we use energy to define speed? Since electrons and ions have a fixed mass, we can use the energy gained by the particle to figure out how fast it is going. The formula for kinetic energy, $KE = \frac{1}{2}mv^2$, gives the velocity for a given mass and energy. For example, a proton that’s accelerated to an energy of 1eV has a speed of 13,851 m/s, or 30,983 mph.

The electronvolt is used in plasma physics because it happens to be a very convenient unit: many plasmas have average ion energies of about 1-2 eV, or even sub-eV, such as those in a flame. We can convert the energy of a plasma in eV to a rough temperature (since temperature is really a measure of the kinetic energy of particles). Using a couple of physical constants, the conversion ratio between eV and Kelvin works out to be about 11,604K per eV. That means that a flame of about 6000 K has an average ion energy of .5 eV. This is how plasma physicists translate their everyday working specifications (a 20 KeV plasma) to a PR tag-line (a plasma at a temperature of 130 million Celsius, hotter than the center of the sun).

Technical Flaws

Here are the technical flaws with the simplistic fusor model in the beginning of the book. Much of this has been discussed on the
fusor forums, and there is probably no end to the number of flaws with this particular model. It may be appropriate to say that this is how we’d like the fusor to work, and it probably doesn’t. While the model has proved to have some accurate predictions, it does fall apart at these seams:

The fusor provably does fusion with input voltages of about 15+ KV, and we’re not about the exact method of operation. Current tests and results point to fast ion-neutral fusion being the main constituent of the results we see, as reported on the fusor forums. The University of Wisconsin papers indicate that the area with the most fusion is also dependent on fuels, as they got different results from a pure deuterium run and a mixed deuterium–helium-3 run.

Nobody has done tests to see how ion guns affect any of those results.

In addition to not knowing where the fusion actually occurs, we’re not entirely sure about the method of ionization that takes place, though we are assuming it to be a simple glow discharge. (The pressure is just right to be in that regime.)

The pressures involved are also considerably higher than what would be needed for true ion recirculation. In the pressures of the glow discharge regime, the mean free path is considerably shorter than the diameter of the fusor, which means that ions will end up bumping into one another as they’re accelerated towards the center. The ions are most definitely not arriving at the center electrode with energies that correspond directly to the electrode voltage; there is probably a good deal of variance, though the plasma overall would seem to be hot.

The current model of the fusor assumes that recirculation happens (i.e., if the ions don’t collide in the center, they will
go right out of the electrode and return for another collision
tportunity), but we have no real way of knowing that. Ions may
not even be participating in recirculation at all; that may be a
faulty assumption we are making.

Resources and references

There are many, many places to buy things, but nearly ev-
erything I’ve used to build my fusor came from the following
places:

Vacuum Manufacturers/Resellers

- Kurt J Lesker Company
  
  http://lesker.com

  Kurt J Lesker Company (KJLC) specializes in lots of high-end,
  ultra-high vacuum equipment. I haven’t ordered anything
  from them due to their prices (they’re a tad high), but their
documentation and literature is extremely helpful. Their
paper catalog is excellent for scoping out prices and getting
a general feel of ball-park figures, and it also contains a
little bit of explanatory literature about the way vacuum
technology functions.

  Chances are that LDS Vacuum Shopper will undercut Lesker’s
  prices by 10-50% if they carry the same item.

- Duniway Stockroom
  
  http://duniway.com

  Duniway Stockroom is where I bought most of my pump-
related items, such as oils, seals, and rebuild kits. I’ve also
ordered some of my vacuum manifold from them, specifically the Conflat parts. Their paper catalog is really useful for browsing, particularly when it comes to ascertaining the value of vacuum pumps. Duniway is a treasure trove of documentation as well—they sent me a pump manual and helped me identify an unknown vacuum flange when I asked nicely.

- LDS Vacuum Shopper
  [http://vacuumshopper.stores.yahoo.net/](http://vacuumshopper.stores.yahoo.net/)

  LDS Vacuum Shopper has lots of good, cheap deals on vacuum equipment. I use them for the odds-and-ends that Duniway doesn’t stock. They have an OK paper catalog, but it’s nothing special.

- MDC Vacuum Products
  [http://mdc-vacuum.com](http://mdc-vacuum.com)

  MDC Vacuum Products is another high-end company like KJLC; I haven’t ordered from them. Their web site can be somewhat of a pain, but it’s an alright resource. Their paper catalog is very nice, and is helpful in the same manner as Lesker’s.

- Sam Goldwasser’s Classifieds Page
  [http://repairfaq.org/sam/sale](http://repairfaq.org/sam/sale)

  Silicon Sam’s page is really useful; it’s the place where I buy my TC roughing gauges for cheap. He has many other vacuum odds-and-ends that are surplus, and many of the items are a definite bargain.
High Voltage

- Ceramtec
  http://ceramtec.com

  Ceramtec sells vacuum insulators in nearly every shape, form, and size. They're really nice for main high-voltage feedthroughs; my feedthrough is rated for 30 KV at a couple of amps and only cost me $200 new. I’ve heard recently that they won’t do individual orders, so fusor list group buys may be the only way to get a hold of their products now.

- Insulator Seal
  http://insulatorseal.com

  Insulator Seal, or ISI, is closely affiliated with MDC. Expensive.

Gases

- Matheson Tri-Gas
  http://mathesontrigas.com

  Matheson Tri-Gas lent me a tank of deuterium at a very reasonable rate. I recommend outright buying the lecture bottle of deuterium instead, since monthly fees can easily pile up; their prices are high but in the ball-park of what’s reasonable. They are easy to deal with, and ordering deuterium only requires a phone call and completion of a fax form.

  I haven’t found another vendor who sports the same attitude about exotic gases. In the past, people used to consult Spectra
Gas and Advanced Specialty Gases, but they now insist on documentation of what you’re doing, as well as assurance that you are qualified to carry out your experiments. It would seem they are ultra-zealous about washing their hands of any possible wrongdoing. Nearly everybody on the fusor lists has recommended to avoid these companies.

For everything else

- eBay
  http://ebay.com
  eBay has everything if you wait long enough. It will also have whatever you want at whatever price, provided that you are willing to wait even longer.

- McMaster-Carr
  http://mcmaster-carr.com
  McMaster-Carr is an excellent source for miscellaneous bolts, odds-and-ends, and pretty much anything that’s in a Home Depot or industrial stockhouse. They’re extremely helpful, and their website is top-notch. (Unfortunately, they don’t offer the paper catalog freely.) I live within 50 miles of a warehouse, so I can order something and it will get to me the next day, which makes them one of my favorite places to shop for parts.

- Digi-Key
  http://digikey.com
  Digi-Key has nearly every electrical part on the planet in stock. Their paper and online catalogs can be unhelpful at times, but their inventory’s size more than makes up for it.
- Allied Electronics
  http://alliedelec.com

  Allied Electronics has some parts that Digi-Key doesn’t, but their overall inventory is much smaller. Their paper catalog (full-color!) is much, much more helpful than the Digi-Key catalog, and their website is much better designed. Allied tends to be more expensive, and shipping takes longer, but it’s a fair trade-off: I ordered most of my parts from Allied because I couldn’t waste time poring over the Digi-Key site to find what I need.

Information

- The Open Source Fusor Consortium
  http://fusor.net

  The fusor forums are hands-down the definitive resource for amateur fusor builders. From high voltage to vacuum design to radiation detection, the fusor forum covers it all. Most likely, if you have a question about a topic relating to the fusor, even tangentially, the people here will be able to answer it. They’re extremely helpful, provided that you search the forums (all three incarnations) beforehand to ensure that the topic hasn’t been discussed to death.

- The Bell Jar
  http://belljar.net

  The Bell Jar is a publication run by Steve Hansen that covers amateur high-vacuum use. It’s helpful, but I discovered it mainly after reading through other sites. Having only read
the sample articles, I can at least say that the quality is very high, and the articles are well worth the purchase.

- Silicon Sam’s Repair FAQ
  http://repairfaq.com
  The Repair FAQ site is a treasure trove of information. Even after knowing about the site for several years, I can still spend days digging through the pages for new information. It’s extremely helpful, particularly the discussion of high vacuum in the Laser FAQ. Highly recommended.

- The 4HV Forums
  http://4hv.org
  The 4HV forums are slightly helpful in building high-voltage supplies, particularly of the switch-mode type. They’re mostly a Tesla coil group, but some advice with regards to insulation helps. You have to dig somewhat deep to find useful information; many of the posts are useless or just outright wrong.

Fusioneers

- Henry Hallam and Fergus Noble
  http://henryhallam.cjb.net/~henry/fusor/index.htm
  They were first team in the UK to achieve fusion; their high voltage supply and attempts to computer-control the fusor are particularly interesting.

- Raymond Jimenez
  http://fusion.wsyntax.com
My website—more documentation on my fusor and a status of what it’s doing right now. It’s down at the time of this writing due to a surge that killed the host computer.

I’ve filmed some fusor operation at http://tinyurl.com/2xqgvp.

- Brian McDermott
  http://brian-mcdermott.com

  Brian McDermott was one of the first high-schoolers to do nuclear fusion as a highschooler, well before Thiago Olson or me. His site has a number of good tips.

- Andrew Seltzmann
  http://rtftechnologies.org

  Andrew Seltzmann is working on an incredible ion-gunned fusor that’s computer controlled. It’s an amazing piece of machinery.

- Joe Zambelli
  http://myweb.wvnet.edu/~guf00478/iec/

  Joe Zambelli has perhaps the most beautiful, well-crafted fusor ever.