DIY Electron Accelerator: A Cathode Ray Tube in a Wine Bottle

by **Xellers** on August 15, 2011

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My name is Daniel Kramnik, I am an electronics hobbyist and high school student from Boston, Massachusetts. Starting with my latest Tesla coil project, I have been trying to improve the quality of my work here on instructables. I'm currently gathering parts for a particle accelerator that I hope to take to next year's Intel Science and Engineering Fair.

Intro: DIY Electron Accelerator: A Cathode Ray Tube in a Wine Bottle

Learn how to build your own subatomic particle accelerator in a weekend! This simple project will allow you to investigate a variety of intriguing effects including magnetic deflection of an electron beam, Crookes dark space, plasma striations in a gas discharge tube, and many others. It can easily be used for a high school physics or science fair project and is compact enough to be demonstrated virtually anywhere.

You could be accelerating electrons to non-relativistic velocities after a trip to Home Depot and a visit to your local AC repair store and neon sign shop! Best of all, no advanced electrical or mechanical knowledge or tools are required.

Judges, see step 12 for contest entry details.

Here's some video evidence:

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Note: I am currently on vacation, and I didn't take as many pictures of my project as I should have, so some steps may be missing photographs of certain parts of construction. I don't think that this should prevent anyone from completing this project, but I will try to take more photos once I get back.

Thanks for looking at my instructable, and please don't forget to rate/vote!

Xellers

PS: Thanks for all the support, guys! This project was featured on Slashgear, Engadget, Gizmodo, Gadgetblog, Tecmundo, Matuk, Zedomax DIY, and Make, as well as in the weekly newsletter and multiple times on our own front page!
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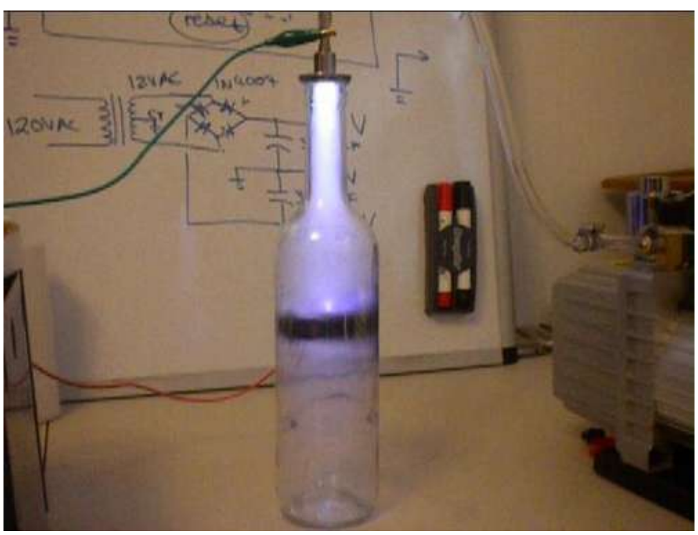


Step 1: Design/Theory

As complex as the idea of a particle accelerator might seem, it's actually strikingly simple to implement. The design we will be using was first created in the late 19th century by J.J. Thomson and subsequently used to make several important discoveries about the fundamental nature of the atom and the electron. Later, in the early 20th century, Cockroft and Walton (yup, the same hooligans responsible for the voltage multiplier) used a similar design to build the first true electrostatic linear accelerator, or "static linac" for short. Nowadays, advanced versions of this type of accelerator are commonly used for radiotherapy and ion implantation.

Essentially, our cathode ray tube is just two electrodes in a vacuum chamber with a high voltage applied between them. When enough of the air in the chamber has been removed, electrons will freely accelerate from the negative electrode (cathode) towards the positive electrode (anode). However, instead of impacting the anode and returning to the power supply, some electrons will fly right past it and keep going until they hit a glass wall.

Some interesting effects that can be observed at this stage are sputtering and magnetic deflection.

Sputtering:

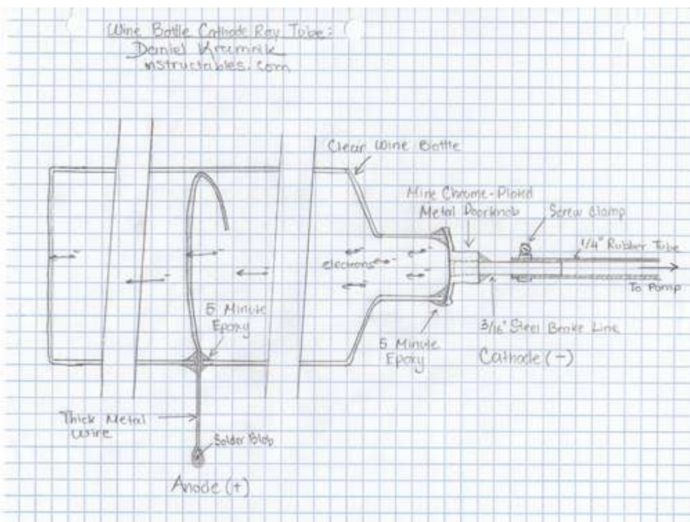
If the acceleration potential is high enough, then some electrons striking the anode will have enough energy to knock metal ions right off the electrode. These ions will be deposited on the walls of the chamber near the anode and will create a silvery band somewhat reminiscent of the "getter" inside of an old vacuum tube.

Magnetic Deflection:

In physics, we all learned the Lorentz force law ($\mathbf{F} = q[\mathbf{E} + \mathbf{v} \times \mathbf{B}]$), or the force on a point charge due to electromagnetic fields. In this context, it tells us that electrons will be accelerated from the cathode to the anode due **E**, the electrostatic field created by the high voltage power supply and that those electrons will also be accelerated by another field, **B**, in a manner that is dependent on the velocity, **v**, of those electrons. Since the velocity vectors of the electrons will be pointing roughly from the cathode to the the anode without an external magnetic field, we can use this to find out what effect a magnetic field will have if we introduce one.

Let's say we bring a magnet close to the tube while it's energized and we align it so that its field is roughly normal to the surface of the vacuum chamber. If we compute $q\mathbf{v} \times \mathbf{B}$, we will find that the force due to the magnetic field is perpendicular to the paths of the electrons and to the magnetic field (by the definition of a cross product). In other words, the magnet curves the paths of the electrons and this effect is amplified by the duration that the electrons spend in the field. This effect can easily be observed inside of our cathode ray tube if a magnet is present nearby.

I've included a diagram of the mechanical construction of the accelerator to give a rough idea of how everything will work.



Step 2: Gather Materials

For the vacuum chamber, you will need....

(1) Clear Wine Bottle
(1) Mini Chrome-Plated Metal Doorknob
(1) 3" Piece of 3/16" Steel Brake Line
(1) Piece of Steel/Aluminum Wire Several Inches Long
(1) Tube of Pressure Rated 5 Minute Epoxy

For the vacuum system, you will need....

(1) 2 Stage High Vacuum Pump
(1) 1' - 2' section of 1/4" rubber hose
(2) 1/4" Screw Clamps
(1) Brass Pump to Hose Converter
(1) Roll of Teflon Tape

For the high voltage power supply, you will need....

(1) 9kV Neon Sign Transformer
(1) High Voltage Microwave Oven Diode (Read this instructable to learn how to safely extract one from a microwave oven)

[or any other source of at least 10kV DC, a DC flyback will work even better than a rectified NST]

You will also need a drill with a 3/16" bit that can cut metal and a small glass/tile spade bit for cutting the bottle.

All of the parts excluding the wine bottle and vacuum pump can be purchased at almost any hardware store. If you don't include the cost of the pump and neon sign transformer, then this project should cost no more than $30 total.

The pump I used was a Viot VPD3 15 micron dual stage refrigeration pump. I bought it on eBay for $200 including shipping and handling. At this price, it is easily the best deal - most other pumps in this range only pull around 75 microns, which may not be enough for cathode ray tube operation.

Here are pictures of some of the more important parts:

Image Notes
1. Make sure the epoxy you choose is good for metal and glass.

Image Notes
1. This side attaches to the pump - the gender/size of the thread depends on the type of connector your pump has.

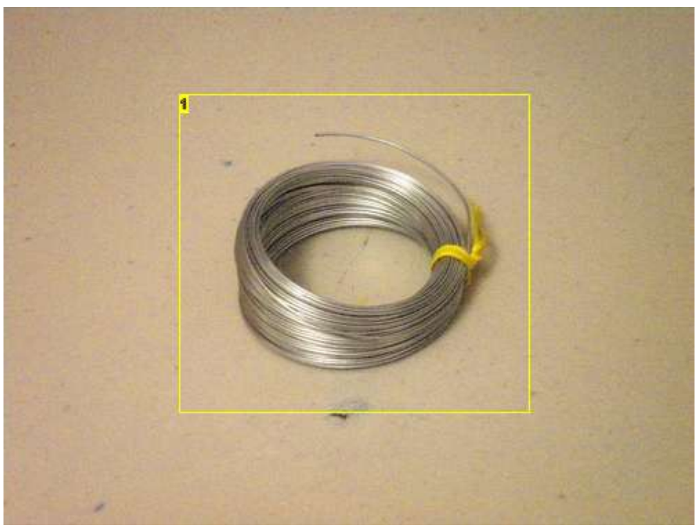


Image Notes
1. Steel wire from a hardware store used in the anode.

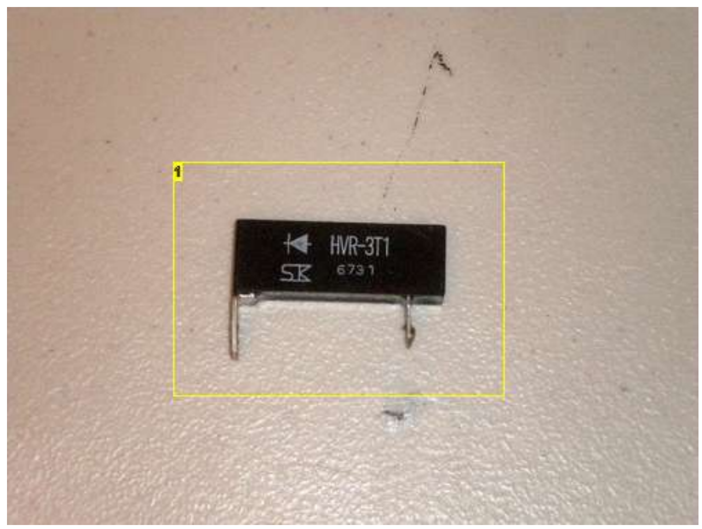


Image Notes
1. A high voltage diode recovered from a microwave oven. Any high voltage diode with the same/higher peak voltage/current rating as the transformer will work. Note: peak voltage != RMS voltage!

Image Notes
1. 9kV 30mA Neon Sign Transformer.

Step 3: Clean The Bottle

The first step in our adventure is to clean out the wine bottle and remove any internal or external labels it might have.

After washing the bottle with warm, soapy water to get rid of any leftovers, allow it to sit for several minutes in a sink filled with hot water. This will weaken the adhesives that bind the labels to the bottle.

Next, carefully use a knife or potato peeler to cut the labels loose. Make sure you remove them from the sink before you drain it so that nothing gets clogged. You may have to work back and forth with the knife for a few minutes to completely clean off the bottle. Do not, under any circumstances, crack the bottle. This will weaken its integrity and cause it to shatter when a vacuum is applied.

Here are some pictures of this procedure:

Image Notes
1. Before cleaning.

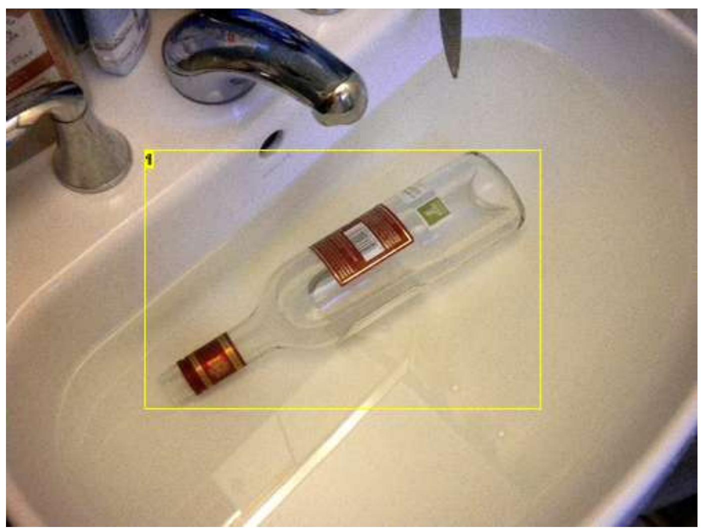


Image Notes
1. Step 1: Soak.

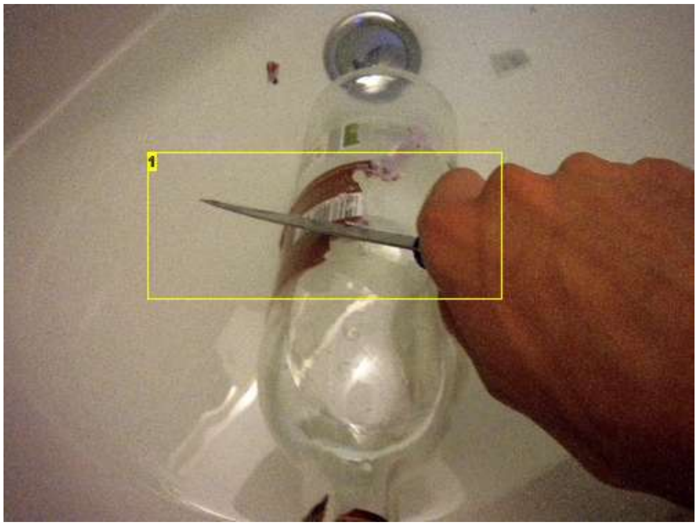


Image Notes
1. Step 2: Cut.

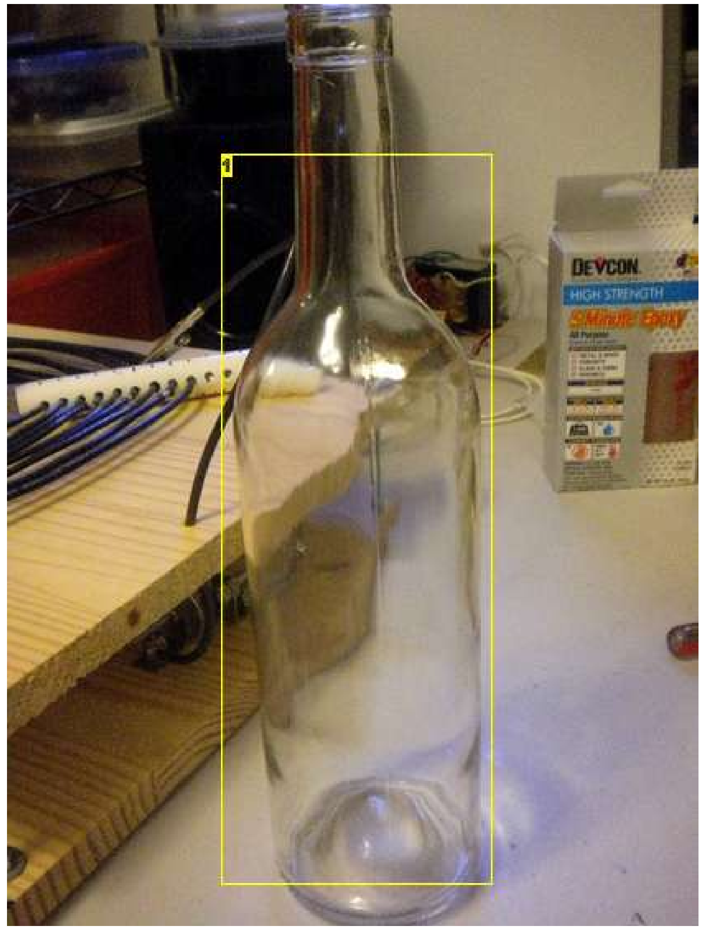


Image Notes
1. After cleaning.

Step 4: Drill The Anode Mount

This is the only part where you will need to drill glass.

Carefully, using a small glass/tile spade bit, drill a hole large enough for the metal wire to fit through about half way down the length of the bottle. Make sure there are no cracks, if there are, you will need to start over. Drilling this hole is something you may want to practice a few times before you do it on the bottle you plan to use.

If you're afraid of using a drill to make the hole, then you can also do this by hand. First, use the spade bit to chip a small dent into the place where you plan to drill. Then, just apply some pressure and twist back and forth until the hole is cut. You should hear a scraping sound as the bit chips away at the glass.

Make sure you work in place where it will be easy to clean up small shards of glass in case your bottle shatters and wear appropriate protective clothing (long sleeve shirt, closed toed shows, leather gloves, etc.). Finally, once you're done, vacuum up the glass powder created by drilling the hole and proceed to the next step.

Unfortunately, I don't currently have any pictures of myself cutting or drilling the anode mount (my hands were a bit tied up at the time....). When I get back home, I'll get an assistant and try to take some.

In the meantime, here is a picture of the completed system to give you a better idea of where the anode mount should be.

IMPORTANT NOTE:
If you are afraid that your vacuum pump won't be able to pull the level of vacuum required for cathode ray tube operation, with a tube this size, then all you have to do is mount the anode closer to the cathode to reduce the level of vacuum that you need.

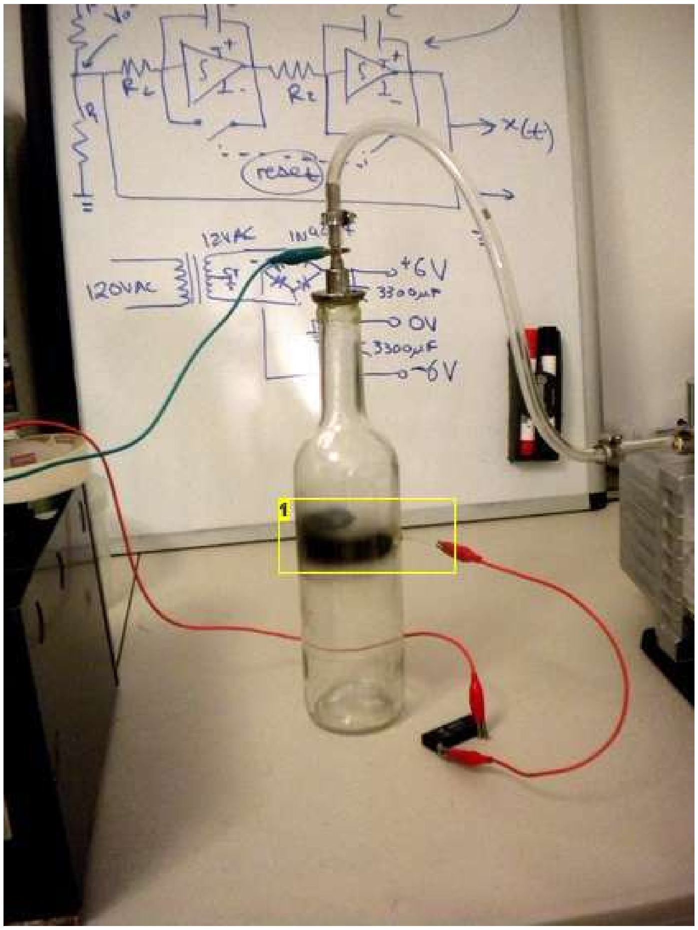


Image Notes
1. Anode - the black band is caused by sputtering, or electrons knocking off nuclei from the positive electrode and causing them to be deposited on the glass envelope.

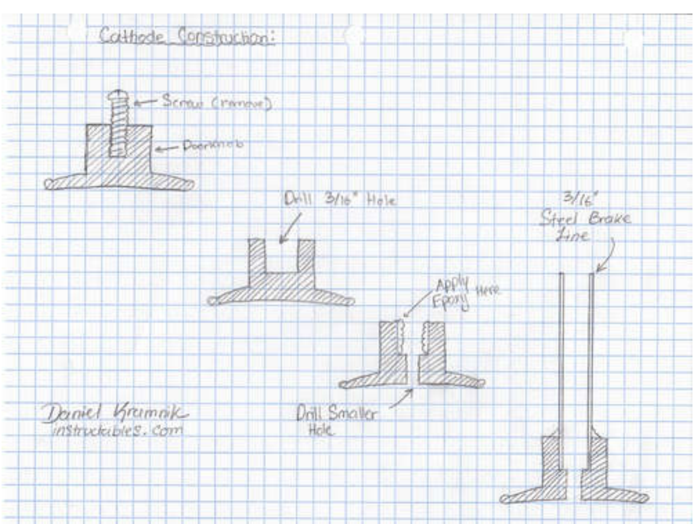
Step 5: Build the Cathode/Vacuum Port

The doorknob and steel brake line assembly at the top of the bottle will serve a dual purpose, functioning as both the cathode (negative terminal) and the vacuum port.

To start construction of this component, remove the screw that comes with the metal doorknob and set it aside. We won't be using it.

Next, drill a 3/16" diameter hole straight through the doorknob starting from the side that the screw was mounted in. The best way to do this is to use progressively larger drill bits to widen the screw threads until they disappear and the hole is wide enough to accommodate the steel brake line. Then, use a smaller bit to drill all the way through the doorknob. It's important that the holes goes all the way through, otherwise, there would be no way for the pump to suck the air out of the bottle. It's also important that the hole be 3/16" wide at the back of the doorknob so that the brake line fits in, but no as wide closer to the front of the doorknob so that it doesn't slide all the way through

One this is done and you have confirmed that the brake line fits snugly into the area where the screw was mounted but does not slide all the way through, apply some epoxy to the inside surface of the hole you drilled and slide the brake line in. Do not allow the epoxy to enter the narrower hole that goes all the way through the doorknob as it might clog it. I attached a diagram and some pictures to better illustrate how all of this is done.



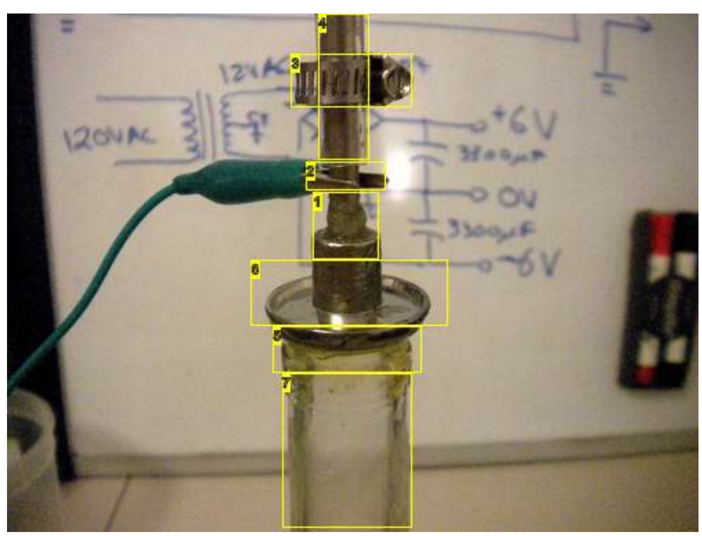


Image Notes
1. Break line epoxied into place.
2. Electrical connection between epoxy and vacuum line.
3. Clamp.
4. Vacuum hose.
5. Epoxied to mouth of bottle.
6. Doorknob =)
7. Wine Bottle.

Step 6: Assemble the Tube

To finish construction of your cathode ray tube, first, apply a layer of epoxy over the rim of the mouth of the wine bottle. Then, carefully lower the cathode construction so that the glue is even and the brake line is centered on the vertical axis of the bottle. Make sure no epoxy gets into the tube so that it doesn't become clogged.

After that, bend the steel wire into a C shape roughly the inner diameter of the wine bottle. Allow a couple inches of extra wire on one end of the C for an electrical connection. Next, insert the C into anode hole drilled in the wine bottle so that the couple inches of extra wire sticks out of the bottle. Twist the electrode until the C is normal to the vertical axis of the bottle. In other words, you should orient the anode such that all points on it are roughly equidistant to the cathode. This may take a few tries, so be patient!

Once the anode is mounted correctly, secure it with plenty of epoxy to make sure the hole is airtight.

When everything has dried (give it at least a few hours), use a pair of needle nose pliers to bend the end of the anode that is protruding from the bottle into a small circle and put a bead of solder over it. This optional step will help to reduce corona discharge losses and will make it easier to make a solder connection to the anode.

OPTIONAL:
Scrape some phosphors off the inside wall of a fluorescent tube, dissolve them in water, pour the mixture into the tube before mounting the cathode, and allow it to evaporate so the phosphors are deposited on the bottom of the bottle to make a "screen" for your tube. Electrons that make it past the anode will continue down the tube, hit the phosphors, and cause them to fluoresce. This is something that I will definitely do if I ever get around to making a second tube.

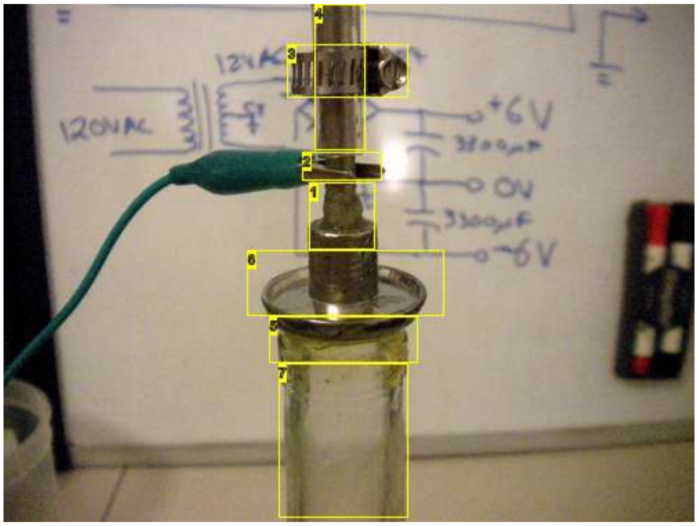


Image Notes
1. Break line epoxied into place.
2. Electrical connection between epoxy and vacuum line.
3. Clamp.
4. Vacuum hose.
5. Epoxied to mouth of bottle.
6. Doorknob =)
7. Wine Bottle.

Step 7: Prepare the Pump

If you've worked with vacuum pumps before and already know what goes where and who connects to what, then you can skip this step. On the other hand, if you're never used a vacuum pump before and are just pulling yours out of the box it shipped it (my condition when I began this project), then read on to learn how to set everything up correctly.

The first thing you will need to do once you unpack your pump is to fill it with oil. Most new pumps come with a small bottle that should be enough to get started.

To do this, you will need to remove the exhaust filter (picture 3) by unscrewing it. Then, using a plastic funnel, carefully pour your entire bottle of oil inside of the pump (picture 1). If you're not using a bottle that was included with the pump, then this may be too much so you will need to check the oil level indicator (picture 2) on the side of the pump. Give the oil a few minutes to reach the indicator after you pour it in.

If there is no oil visible in the indicator, then you will either need to wait a little longer or add some more oil into the pump. Add oil in small increments; remember, the oil you are using has a relatively high viscosity and it needs to flow all the way though the pump before reaching the indicator, so it will take time for changes to become apparent.

If the oil level is anywhere between the "MIN" and "MAX" markings, then you are ready to go. Reattach the exhaust filter and follow any pre-use instructions that may be included with your pump (ie. run it for 15 seconds and then check the oil level to make sure it is ok). If there are no problems, then proceed to the next step.

If the oil level is above the "MAX" marker, then you will need to drain some of it away. Unscrew the oil drain (picture 2) and transfer the excess oil back into the bottle or into a plastic container. You should do this in small increments for the same reason that you should add oil only in small increments.

***Gas Ballast Valve: The gas ballast valve (picture 3) should be tightened all the way for maximum vacuum to be attained. My pump shipped with the gas ballast valve in this condition, but your may not. Check to see that it is tight before moving on.

Image Notes
1. Use a funnel to fill with oil. Be careful not to overfill - it may take some time for the oil to reach the indicator.

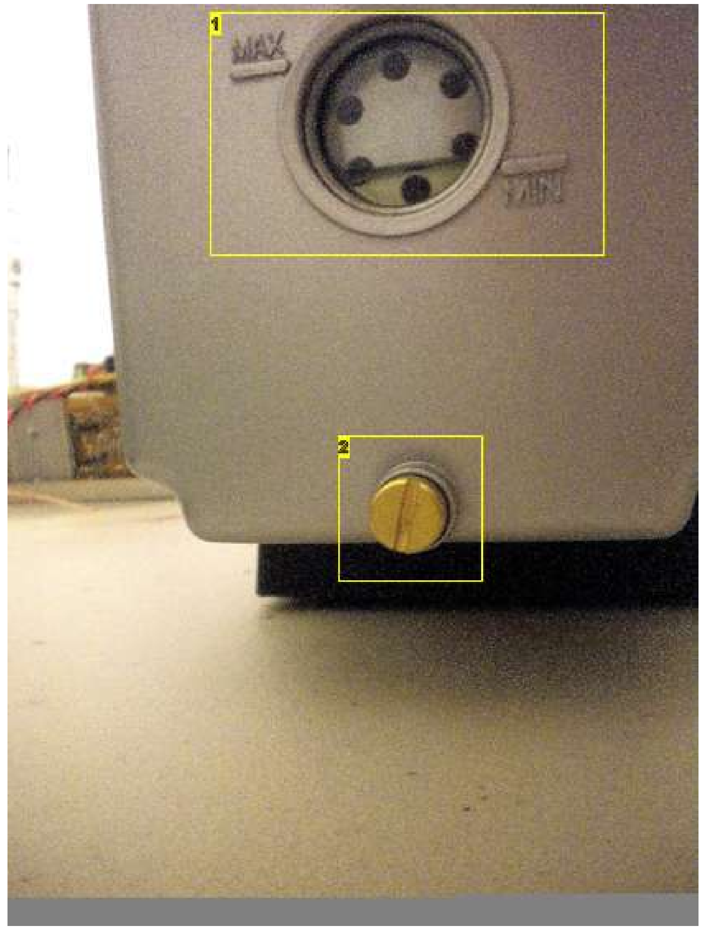


Image Notes
1. Oil level indicator - anything between the MIN and MAX markings is fine.
2. Oil drain - use it to reduce the oil level if you accidentally overfill the pump.

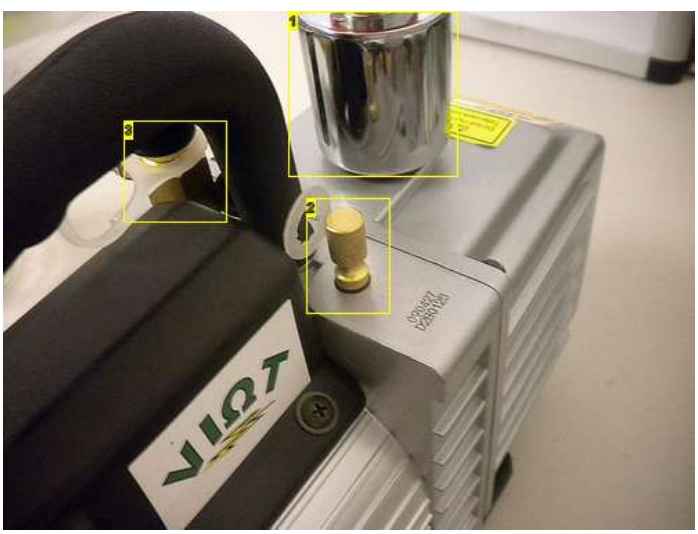


Image Notes
1. Exhaust filter - remove it when filling the pump with oil and take off the red cap before starting it up. Some vacuum pumps may have a different spot for filling with oil and/or may not have a cap over the top of the filter.
2. Gas Ballast Valve - make sure it's tightened all the way to achieve the highest vacuum possible.
3. Intake is over here, connect to vacuum chamber via plastic tube.

Step 8: Assemble the Vacuum System

To connect the vacuum pump to your cathode ray tube, you will need your brass pump to hose converter, about 2 feet of 1/4" rubber tubing, a pair of screw clamps, and some Teflon tape.

First, apply a few layers of Teflon tape over the middle of the steel brake line and over the middle of the threads on screw connector of your vacuum pump.

Second, install the pump to hose converter such that the Teflon tape is inside the interlocking threads of the screw connector and converter. Basically, this means you need to keep screwing the converter onto the pump until little or no Teflon tape is visible.

Third, apply a layer or two of Teflon tape over the hose end of the pump to hose converter and slide the hose over it until it is all the way on. Then, use a screw clamp to secure the hose.

Fourth, use a screw clamp to secure the other end of the hose over the Teflon tape on the steel brake line sticking out of the cathode ray tube.

phew

The mechanical portion of the exercise is now complete.

/* If you're never worked with Teflon tape before, you should be warned that it's not actually tape; there's nothing sticky about it. The way you secure it is by wrapping it tightly around your work piece and then letting the vacuum pump do the rest. When you turn the pump on, the difference in pressure will cause it to assume whatever form you've forced it into and it will block air from leaking into the system (which is something that it's very good at). The first time I assembled my system, I decided not to put any tape over the vacuum pump's screw connector and I only used the screw clamp to hold the rubber tube in place. Big mistake! I wasn't able to reach anywhere near cathode ray tube operation pressure until I added that tape.

It is possible to assemble the system without a pump to hose converter if your pump's inlet is small enough for the rubber tube to fit over it. Instead of screwing on a converter, just force the hose over the Teflon tape and clamp it down: */

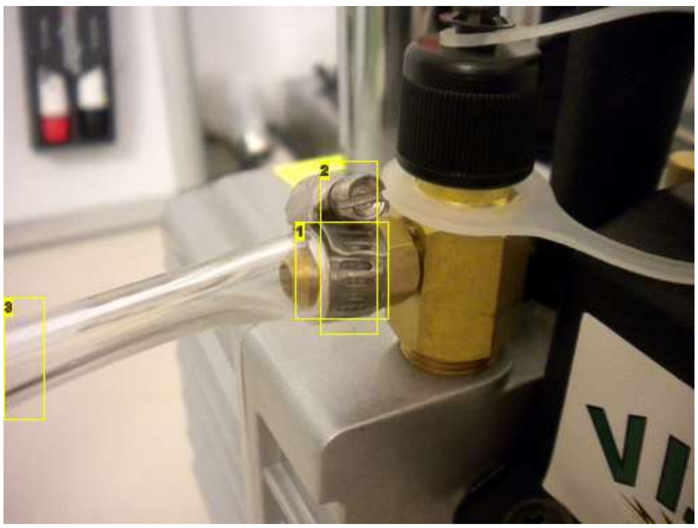


Image Notes
1. Several layers of Teflon tape.
2. Clamp.
3. To cathode ray tube.

Step 9: Build and Hook Up the Power Supply

The cathode ray tube/gas discharge tube does not require any sort of specialized power supply. Any high voltage power supply that can produce over 10kV of potential difference will work. In fact, you can even use an AC power supply if you don't mind the electrons going the wrong way half the time.

The best type of power supply to use would probably be a (roughly) 20kV DC flyback transformer using a low current driver like a 555 oscillator and MOSFET. In fact, almost any of the "quick high voltage power supply" instructables we have here should work. However, I did not have a flyback power supply on hand when I was building this project, so I used a rectified neon sign transformer instead.

I've included an electrical schematic that shows how to hook the diode up to the transformer. One end of the transformer is hooked up to the cathode of the cathode ray tube, while the other end is hooked up to the anode of the high voltage diode (the triangle end). Then, the cathode of the diode (the vertical line segment) is hooked up to the anode of the cathode ray tube.The second picture is of the completed electrical setup and the last two pictures show the transformer and diode individually:

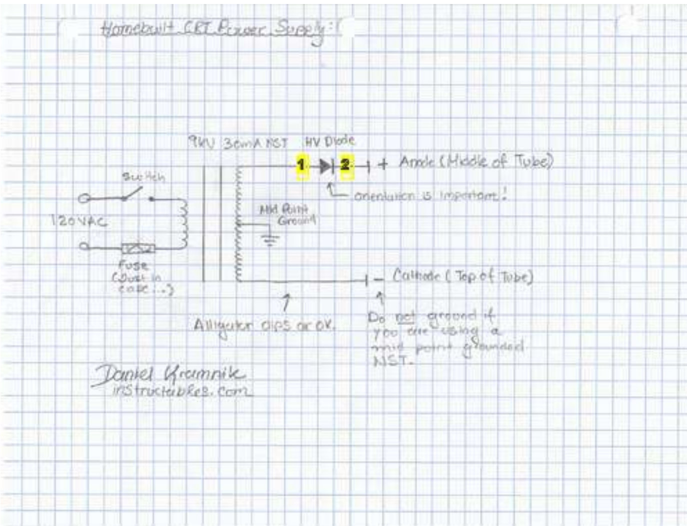


Image Notes
1. Anode of diode.
2. Cathode of diode.

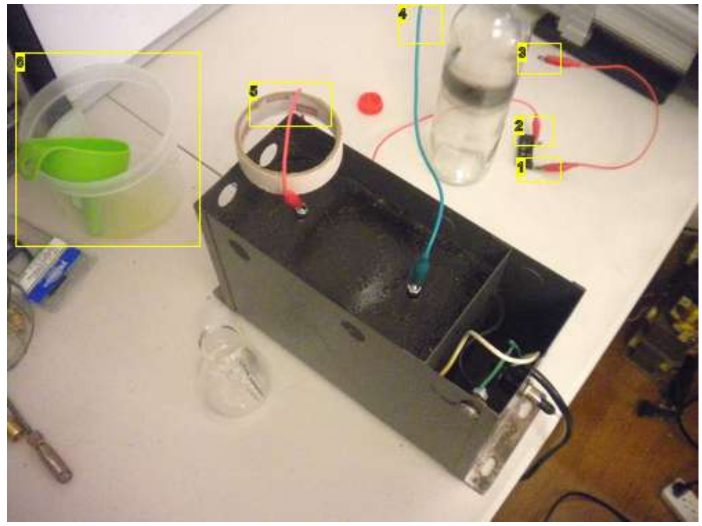


Image Notes
1. Cathode of diode.
2. Anode of diode.
3. Anode of cathode ray tube.
4. To cathode of cathode ray tube.
5. Improvised HV insulator.
6. Funnel and excess oil from filling the vacuum pump.

Image Notes
1. 9kV 30mA Neon Sign Transformer.

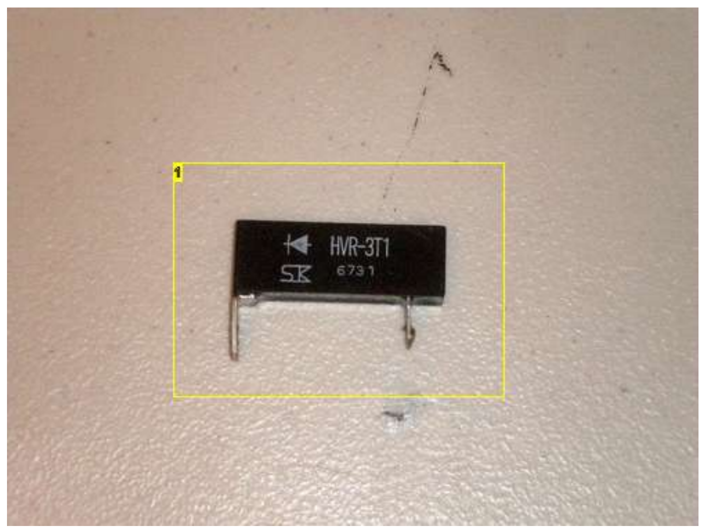


Image Notes
1. A high voltage diode recovered from a microwave oven. Any high voltage diode with the same/higher peak voltage/current rating as the transformer will work. Note: peak voltage != RMS voltage!

Step 10: Fire it Up!

Once you've assembled the vacuum system and connected the high voltage power supply, you're ready for a test.

To begin, simply turn on the power supply and vacuum pump, sit back, and enjoy the show!

At first, a continuous red-purple discharge will appear between the anode and cathode. Then, the two colors will begin to separate until there is a distinctly visible dark space between them called the Crookes dark space. After that, striations in the plasma near the cathode will appear and the colors of the discharge will start to become paler. Finally, the striations and dark space will disappear and the entire tube will be filled with a pale blue/white glow. At this point, you have reached cathode ray tube operation.

Here is a brief document that explains some of the plasma-related phenomena visible inside the tube:
http://www.madsci.org/posts/archives/feb2001/981758142.Ph.r.html

I've included a picture of the tube operating in cathode ray mode and some pictures of what it looks like during the pump down sequence.

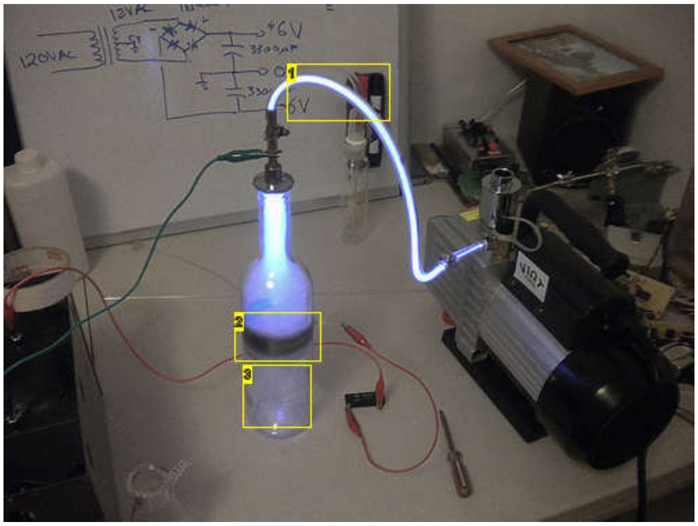


Image Notes
1. This is what happens when you don't ground the cathode. Since there is a potential between the cathode and the vacuum pump (the pump is grounded), electrons go both ways. To avoid this problem, try not to use a mid point grounded supply like an NST.
2. The dark band is caused by sputtering.
3. Some electrons are accelerated past the anode and continue down the length of the tube.

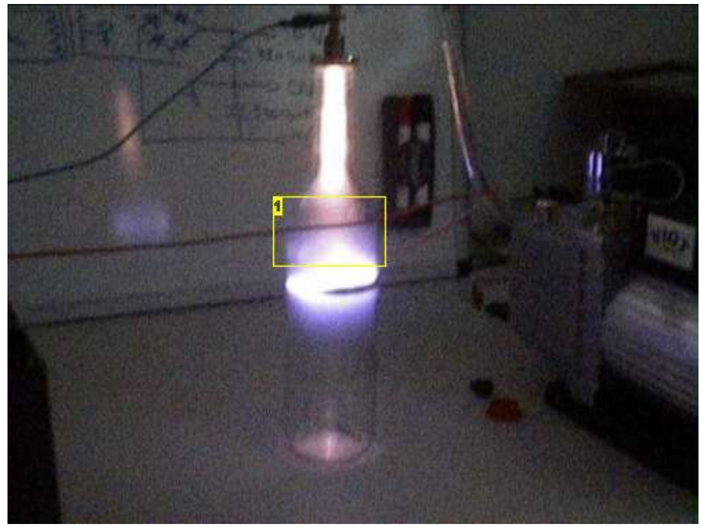
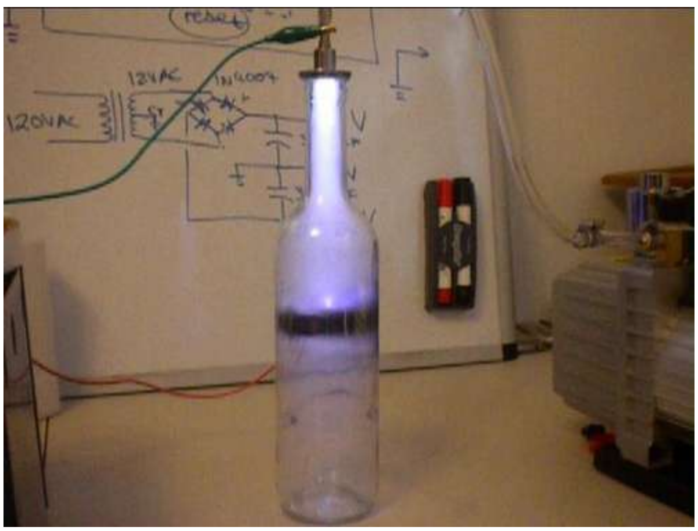


Image Notes
1. Crookes dark space.



Step 11: Safety

There's something inherently dangerous about mixing high voltage power supplies with glass containers under high vacuum and if you're going to attempt this project, you should be acutely aware of that fact. Always wear appropriate protective clothing when working with glass or when operating your accelerator, and NEVER use a cracked vacuum chamber. An implosion is a very serious risk if this is the case. Also, there is no need to keep the tube energized for more than 30 to 40 seconds at a time. A properly built tube could easily run indefinitely in it's energized state, but it's safer to keep things running cool by giving it some time to rest, after all, you will need to handle the tube once the demonstration is complete.

A note about x-rays and other radiation:

With the sort of vacuum levels that can be reached using a two stage mechanical pump, there should be absolutely no cause for concern regarding the production of harmful radiation. If your accelerator will produce any radiation at all, it will be in the form of "soft" x-rays that will be contained within the chamber. In order to produce harmful amounts of radiation, you would need an oil diffusion pump with an expertly constructed vacuum system that includes a foreline trap and a 30kV+ power supply. Such a system is far beyond the scope of this instructable and there's no way a mechanical pump could "accidentally" pull a few more orders of magnitude of vacuum than it's rated for.

That said, I think the above warning sign should serve as a general guide towards safe behavior in the presence of high voltage and high vacuum. Be as careful as you possibly can and be aware that you are the only one who is responsible if something goes wrong.

Good luck!

Xellers

Step 12: Contest Entries

I started laying down some ideas I had about why I'd entered this instructable into various contests as part of another step, but then I realized how much I'd written, so I transplanted everything here. Enjoy!

1. 4th Epilog Challenge

"Be sure to tell us what you'll do with the Zing if you win!"

What would I do if I won a laser cutter? What *wouldn'*t I!

As the captain of my high school's science team who is responsible for managing building events, I can see dozens of ways in which our school could use this device. Not only will it allow us to assemble balsa wood structures with never before seen precision, but it will also significantly reduce the time it takes and thus the number of structures we can test before we take one to an event. Usually, due to the time it takes to cut and measure everything by hand, we can only make one or two structures in time for an event, which means that if a design flaw shows up once we're done building, there's little we can do to correct it. Not anymore with the Zing!

We also build other complex things like musical instruments and Rube Goldberg devices that require precision parts to work smoothly. While duct tape and glue work to a certain extent, we've always ended up with something that falls apart on the last day or doesn't work the right way when we demonstrate it. Using computer-designed mechanical components rather than "those pieces of scrap wood we found in [redacted]'s basement", we'll be able to make our stuff work right.

But enough about what this device could do for my team in terms of the competitive advantage it gives us, given that this laser will be available to anyone I know who asks (tools are shared among the team, and this is tool like any other), the real question to ask is not what I will do, but what will the dozens of people who will get to play with it too will do. All of my teammates are just about as passionate about science as I am and just as willing to tinker around and build something cool. Some of them even have instructables accounts and I'm sure they'll be dying to write up what they've made once they've made it. I know that sounded a bit cheesy, but I really hope to make it the truth.

Ok, ok... I realize I've somewhat of avoided the central focus of the question, "what will ***I*** do?", so here's a quick list of some stalled projects that could really use a kick in the behind from a laser cutter/engraver:

- **Tube amplifier**

After finding a trashed 1950s tube type television set in unserviceable condition about a year and a half ago, I did the only sensible thing I could and gutted it for parts to build a tube amp. Interestingly enough, this particular television used a 5AQ5 output tube and an 8FQ7 deflection oscillator. Why is that important? Well, as it turns out, the 5AQ5 is electrically identical to the held-in-high-esteem 6V6 output tube and the 8FQ7 is the same as the famous 12AX7. Both of these tubes are commonly used in high end audio and instrument amplification.

Once I realized that I was holding the key ingredients to a pretty darn good amplifier, I designed a circuit with what parts I had (my original drawing from ninth grade is attached) and got to work. Unfortunately, I didn't have any suitable output transformer, so I used something scavenged from a transistor amplifier that was (obviously) horribly mismatched to the output tube I was using. I also quickly learned that the 5AQ5 tube I had was leaky by the faint blue glow it emitted during operation. Nonetheless, it *worked*!

The reason I didn't pursue this project was my inability to build a proper enclosure for the amplifier. With the tools I had (and have), there's just no good way for me to punch precision holes in aluminum to mount transformers, tube sockets, screws, etc. (the last time I tried to use my dremel to make a square mounting hole in an aluminum project box was a disaster. It worked, but I ended up with jagged, uneven cuts and scratches all over the place; acceptable for that project, but not for an amplifier).

That's where the laser cutter comes in.

Using the Zing laser cutting system, I would easily be able to make cuts in the thin sheet of aluminum that I plan to mount everything onto and this would allow me to pursue my project without having to worry about the impossible nightmare that doing everything by hand would create. I would also be able to engrave professional-looking labels and switch mounting holes.

Given that the 5AQ5 an 8FQ7 tubes are actually nonstandard versions of already "worthless" tv tubes (the standard versions are the 6AQ5 and 6FQ7), they are extremely cheap, especially when compared to even the most inexpensive 6V6 and 12AX7 variants ($5 per tube versus $30 or more per tube). This means that a high quality stereo tube amplifier using these tubes could probably be built for $150 or less (my estimate including output and power transformers) and that it would rival the performance of systems costing many times that price. I think this is an exciting project that just needs a little touch of laser to get it going again!

- **Analog computer**

I'm currently working on a fully functional opamp-based analog computer that would be able to solve complex systems of differential equations that might not have analytic solutions. I became interested in analog computers when I read the Heathkit EC-1 Analog Computer Kit manual i found here. It used 9 vacuum tube-based opamps to solve relatively simple DEs, but with modern technology, I could easily increase that number to as many as I want; I plan on making it a modular unit. Of course, instead of having a whole box full of vacuum tubes for each unit, there will only be a few ICs.

I already tested my ability to make a simple analog computer by building a rudimentary 2 opamp computer that solves the equation of motion of a harmonic oscillator. All that remains to be done is more testing with more opamps, construction of the individual integrators/multipliers/adders/other operators, and construction of an enclosure. Since I plan on demonstrating this at my school and college, I want it to look as professional as possible. With my level of metalworking ability, however, the best I could do would be a mess. With a laser cutter, I would be able to machine a really nice enclosure that I could use for years.

- **Homebuilt oscilloscope**

With the success of this project, I am currently building a version 2 cathode ray tube with a more advanced electron gun design that will produce a more focused electron beam and direct it at a phosphor screen. Then, using magnetic deflection coils and a simple sweep generator and vertical amplifier, I'll be able to make my own oscilloscope from scratch. Combined with my planned analog computer, it would make for a true 1950s computing experience!

However, to hold the homebuilt cathode ray tube in the enclosure will require precision metalwork that I do not currently have to tools for. With a laser cutter, I would be able to use a computer to design an enclosure and electron tube mount that would allow me to demonstrate my analog computer/cathode ray tube wherever I need to. In the future, I also plan to improve the oscilloscope to make it into a simple television set. The electronics are not too complex, and Jon Stanley designed a circuit that he used to display television images on his oscilloscope.

If this project will be successful, then I think I might just be the first amateur to ever build their own television from scratch and from commonly available parts. Some others have made their own simple televisions using already manufactured cathode ray tubes, but none so far with homemade tubes. This project is still a long way from completion, but it *is* possible in the relatively near future.

- **Tesla coil control panel and interrupter**

Apart from allowing me to machine professional-looking enclosures/control panels for my Tesla coils and external controllers like audio modulators and interrupters, the Zing laser cutter will also allow me to make the precision parts I need to put my newest mid-size DRSSTC together.

Unfortunately, with the tools I have, there is no way for me to make the precision cuts I need in order to make a good, clean-looking primary support system. My project is currently stuck with a fully wound secondary, assembled toroid, built and painted enclosure, tested half bridge and primary capacitor, but no primary coil.

2. Green Living & Technology Challenge

Experiments involving particle accelerators, vacuum systems, and high voltages often require expensive or esoteric equipment and professional assembly, but not this one!

I've been wanting to build my own fusor or small-scale accelerator for years now, but I just didn't have the money to buy parts and supplies for even a bare minimum steel or Pyrex vacuum chamber (easily several hundred dollars). However, after visiting Robert Hunt's site, teralab, and reading about how he used custom glass vacuum envelopes to perform a variety of experiments (including building his own vacuum tube triode!), I realized that a professional-grade vacuum chamber was not necessary to get started with some of those projects I've been inclined towards for years.

Unfortunately, scientific glass blowing is not quite as easy as Mr.Hunt makes it seem and proper equipment can be rare and difficult to procure (there's not too much demand for it anymore; after all, do most physicists blow their own glass vacuum chambers these days? I didn't think so =/). That's where the glass bottle comes into play. Once I watched this "5 minute fusor" video, I realized that if glass bottles and 5 minute epoxy are strong enough to hold up to a pretty decent vacuum, then maybe I wouldn't need one of those fancy custom machined steel chambers with $100 CF flanges stuck in at every possible angle that I had been dreaming of to perform some basic experiments. Thus, the wine bottle CRT was born. Other experimenters confirmed that this was possible (link, link).

This is the reason I would consider this to be a "green" project. Instead of using a large, expensive steel contraption, I used a wine bottle. Instead of using a lab grade adjustable high voltage power supply, I recycled a transformer from an old neon sign and a high voltage diode from a trashed microwave.

Sorry, it seems like some of my links were deleted for unknown reasons. I'll try to get them back as soon as I figure out what went wrong!

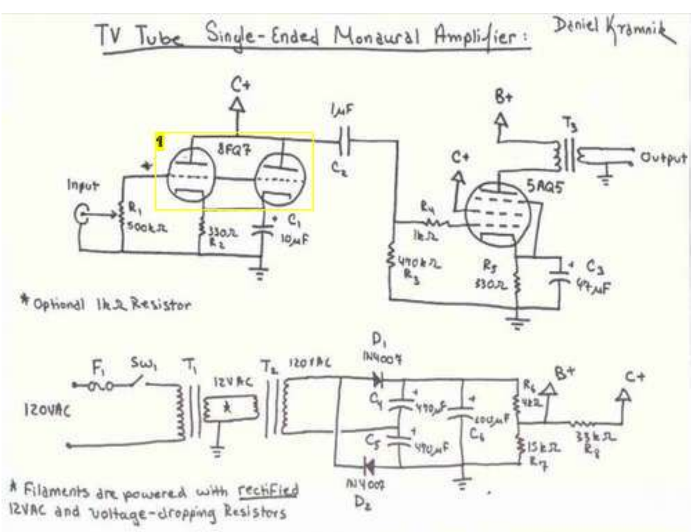


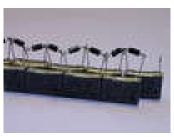
Image Notes
1. The two triodes in the 8FQ7 envelope are paralleled because I saw no harm in doing it at the time. In a stereo design, each triode would be assigned one channel, reducing the number of tubes in the design.

Step 13: In The Future....

With the success that this project has been, I am planning on publishing a series of vacuum experiments, starting with an oscilloscope you can build from scratch using a cathode ray tube similar to the one I describe here. Later projects I hope to share include spectrum tubes and a plasma-only Farnsworth fusor (ion multipactor) built from simple components.

I am also working on a Kickstarter project to gather funds for a larger particle accelerator that I hope to take to ISEF. The goal is my project is to design and build a modular, open-source accelerator that can be assembled for under $1000 by high school or college students.

Related Instructables



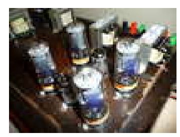
High Voltage Power Supply For Marx Generator by Plasmana

How to make a macro particle accelerator by emcelhannon

Work safely with high voltage by kovo

JACOB'S FORKS? by jacobfork

Build A Fusion Reactor by christensent



Building A Stereo Tube Amp by thobson

Comments

45 comments **Add Comment**

kelseymh says: Aug 21, 2011. 1:34 PM **REPLY**

This is outstanding. One of the best at-home particle physics projects I've seen on I'bles (neither the cyclotron nor the fusion reactor have writeups :-).

Thanks especially for including the (non-relativistic) physics background!

Pyrophoric says: Aug 21, 2011. 2:15 PM **REPLY**

When one takes a doorknob to accelerate particles it's... glorious.

leea9 says: Aug 26, 2011. 5:20 PM **REPLY**

Might not some wine bottles implode from the vacuum, especially flat bottoms?

Xellers says: Aug 26, 2011. 9:25 PM **REPLY**

It is indeed a real risk, but neither I, nor anyone else I know of who uses these sorts of glass vacuum chambers has experienced an implosion. I think that if you use your best judgement when selecting a tube, you should be fine. Anything that looks abnormally flimsy or has a crack in it should be avoided, otherwise, most wine bottles will work.

techno guy says: Aug 25, 2011. 8:43 PM **REPLY**

Is the tube connecting the bottle to the vacuum pump actually glowing or is that a wierd camera illusion?

Xellers says: Aug 25, 2011. 8:54 PM **REPLY**
Nope, it's not an illusion. I didn't ground the cathode because the NST is already mid-point grounded, so there was a potential difference between the cathode and the vacuum pump. As you might imagine, this isn't too good for the pump, so in later tests, I grounded the cathode and left one side of the NST floating.

---

skrubol says: Aug 26, 2011. 11:03 AM **REPLY**
Shouldn't grounding the inlet of the pump take care of any potential damage to the pump?

Xellers says: Aug 26, 2011. 11:39 AM **REPLY**
The pump is already grounded, so I think that's why the arcing occurred in the first place. I guess there's no real harm done to the pump, but it might cause the vacuum line to weaken. In my original gas discharge tube experiments several months ago, I managed to melt holes in my plastic vacuum chamber multiple times! Of course, that's why I decided to use a wine bottle.

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skrubol says: Aug 26, 2011. 12:15 PM **REPLY**
Ah, hadn't thought about the tubing. Vaporizing/burning too much of whatever polymer that tubing is made of I suppose could be bad for the pump.

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theshades says: Aug 26, 2011. 9:53 AM **REPLY**
This is neat but remember, this little device emits X rays also.

Xellers says: Aug 26, 2011. 9:58 AM **REPLY**
X-ray danger is addressed in the safety step. The level of vacuum (between 50 and 100 microns) and electron energy (around 10keV) is not enough for this this to be a concern. At this level, any x-rays produced are called "soft x-rays" and do not have enough energy to leave the glass chamber.

Thanks for your concern though!

---

dewshaft says: Aug 25, 2011. 8:38 PM **REPLY**
Interesting that you mention the Heathkit EC-1 Analog Computer. When I was in high school in the late '70s I actually used an ancient Heathkit EC-1 Analog Computer that was hiding in a cabinet in the back room of the physics classroom. I even had a college class in the early '80s in analog computers, however the class was mostly math and very little use of the more professional owned by the college.

Just recently a friend called with questions about some nixie tubes he'd found and the conversation wound up about analog computers. After doing some Google searches (Google is awesome) I read about a solid state analog computer, the Comdyna GP-6, that was manufactured almost unchanged from 1968 until 2005! A bit more searching turned up manuals for the GP-6, which include enough circuit diagrams that an enterprising electronics hobbyist could easily build a work-a-like analog computer. If you're interested in building an analog computer these would be a good place to start. Various upgrades can be made, such as using modern low noise opamps, but otherwise very little has changed.

Good luck with your analog computer!

Xellers says: Aug 25, 2011. 9:12 PM **REPLY**
Thanks for the comment!

That's basically exactly what I'm looking to build, and taking a look through the user's manual has definitely provided me with some good ideas on how to implement it. All I would really need is just a bunch of opamps and binding posts, along with a few other simple parts.

If you have any experience with designing analog computers, do you think it would be better to just use analog multiplier ICs or to put together analog multipliers using a few opmaps? I've read that it's best to keep designs as simple as possible to reduce noise and to avoid differentiators, but using an analog multiplier IC feels a little bit like cheating, and they're quite expensive too!

Thanks for the help!

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dewshaft says: Aug 26, 2011. 1:47 AM **REPLY**
I don't have experience specifically in designing analog computers but I do have design experience in analog electronics, including opamps. Both manuals for the GP-6 I've found use an analog multiplier IC and although pricey (at $10 each from Digikey) I'd recommend using a AN633 to keep down the overall complexity and reduce potential drift issues with additional discreet components. The largest expense might be the large number of banana jacks needed, over 100 in the GP-6, and banana plug cables. Other kinds of plugs and jacks would work of course but the stacking banana plugs really work great.

Let me know how it works out.

And you're welcome!

dreadengineer says: Aug 25, 2011. 10:18 PM REPLY
Some baking soda in the hot water soak will help with label removal.

-max- says: Aug 21, 2011. 10:02 AM REPLY
awesome! modify the anode and coat the bottom with a florescent substance

kelseymh says: Aug 21, 2011. 1:35 PM REPLY
And if you add a couple of pairs of metal plates near the neck, you can make yourself an oscilloscope!

Xellers says: Aug 25, 2011. 1:24 PM REPLY
I just built a new tube with a redesigned electron gun and phosphor screen. Once I wind some deflection coils, an oscilloscope instructable will surely follow! Here's a quick video taken from my friend's phone (the robot isn't letting me embed videos today :(

-max- says: Aug 25, 2011. 6:14 PM REPLY
nice! have you stuck a few magnets near it? of got a few nasty shocks? and can you explain how the electrostatic deflection plates work? or actually how to build them?

Xellers says: Aug 25, 2011. 8:00 PM REPLY
I'm going to try to get an instructable published in time for the magnets weekly challenge, some things still need to be refined for stable operation - I was running the transformer without additional current limiting, so I burnt the electron gun tube in half (that's the inner tube with the plasma that you see in the picture)! I did manage to deflect the beam with an ordinary fridge magnet in the video.

iceng says: Aug 25, 2011. 5:32 PM REPLY
Cool

ngunarathne says: Aug 21, 2011. 11:25 AM REPLY
I know that this could sound dumb, but could this be modified into a laser?

kelseymh says: Aug 21, 2011. 1:27 PM REPLY
No. They're completely different principles. Both of the Wikipedia articles are accurate and have good references for more information if you want it:
http://en.wikipedia.org/wiki/Laser
http://en.wikipedia.org/wiki/Crookes_tube

duct tape says: Aug 25, 2011. 7:37 PM REPLY
Theoretically, it could be.
http://en.wikipedia.org/wiki/Free-electron_laser

bpenner says: Aug 25, 2011. 8:33 AM REPLY
JUST an FYI: The type of laser system Epilog is offering will not cut metal. It can however mark metal when combined with a coating such as Cermark.

Xellers says: Aug 25, 2011. 8:37 AM REPLY
Drat.

Marking metal would be just as good though - I could still make professional-looking panels and then invest in a circle cutting bit to make mounting holes for all my parts. Thanks for the heads up though!

bpenner says: Aug 25, 2011. 9:50 AM **REPLY**

No need to buy a circle cutter. You just need some punches and a hammer! To make straight cutouts use a chisel and a straight metal rule all clamped down so it doesn't shift.

Seth the Man says: Aug 25, 2011. 4:32 AM **REPLY**

This is awesome! Im deffinately trying this.

Xellers says: Aug 25, 2011. 8:30 AM **REPLY**

Ditto the comment to ElectricUmberlla.

Good luck!

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alzie says: Aug 25, 2011. 6:30 AM **REPLY**

Very nice!

Idea: Convert it into a double ended
accellerate toward the center config,
crank up the HV, add some deuterium, and
do some low power fusion experiments!

Xellers says: Aug 25, 2011. 8:30 AM **REPLY**

Actually, that's how some fusors are bulilt! Adding an ion gun or two into the mix usually has the effect of greatly increasing neuron counts. If I ever get the chance to build my own fusor, it's something that I will definitely try out. Of course, you would need a slightly different electrode configuration (you're looking to accelerate positive deuterium ions, not electrons), but the idea is the same.

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bahi says: Aug 25, 2011. 7:10 AM **REPLY**

Buen vino y mejor instructable :)

Gracias

ElectricUmbrella says: Aug 23, 2011. 12:46 PM **REPLY**

I can't wait to try this out! You Are Awesome!!!!

Xellers says: Aug 24, 2011. 10:32 AM **REPLY**

Good luck, and please rate/vote for me in the Epilog and Green Tech. contests!

Also, be sure to post some pictures/videos once you're done.

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makincoolstuff says: Aug 23, 2011. 3:33 AM **REPLY**

i also here that air conditioner's pressurizing pumps when used in reverse can create deep vacuum's

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Xellers says: Aug 23, 2011. 9:15 AM **REPLY**

I tried building my own vacuum pump using an AC compressor, but it turns out that even a compressor from a pretty powerful air conditioning unit just isn't strong enough to pull the levels of vacuum required for a cathode ray tube. It was good for making mediocre gas discharge tubes, but not much else =(

---

makincoolstuff says: Aug 23, 2011. 4:50 AM **REPLY**

this is an awesome instructable, and when you drill the hole, i dont think you mentioned what the actual anode is, how you secured it and what you used to seal the whine bottle.

Xellers says: Aug 23, 2011. 9:13 AM **REPLY**

The anode is the positive electrode, I explained this in the step where I talk about the overall design of the accelerator. Later, when I talk about constructing it, I mention that all you need to do is insert it into the tube and secure it with 5 minute epoxy.

Good luck!

Xellers

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tholopotami says: Aug 22, 2011. 12:57 AM **REPLY**

I am on your side!

In my work as a physicist, I have personal experience with high voltage and vacuum systems like SEMs and others. I have put down and up again more than one electron beam column in my life.

I am saying this just to emphasize that I feel joy and admiration when I see a cathode ray bottle! I like the fact that you are building things for their own beauty and not because they are useful. We do not eat dolphins, do we?

dbell says: Aug 21, 2011. 11:23 AM **REPLY**

Cool project!
But I want to know why the analog computer implementation of classic damped harmonic motion (mass/damper/spring) is on the whiteboard?

Dave

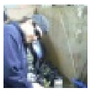
Xellers says: Aug 21, 2011. 6:32 PM **REPLY**

Haha, I'm glad someone noticed that =)

I accidentally stumbled upon a Heathkit analog computer kit manual online and was captivated by how simple analog computers that could solve pretty hairy systems of differential equations were, so I decided to grab a spare quad opamp IC from one of my Tesla coil projects and design a simple integrator-based computer that could do something cool. What you see on the whiteboard was the result.

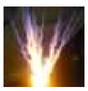
Pyrofan says: Aug 21, 2011. 9:07 AM **REPLY**

How dangerous is this?



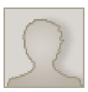
tlynch1 says: Aug 21, 2011. 11:11 AM **REPLY**

kill you dangerous ...dont mess up



Xellers says: Aug 21, 2011. 10:26 AM **REPLY**

See step 11; if you think you can restrain yourself from touching the high voltage power supply while its turned on and wear proper protective clothing, then there's nothing to be worried about. This is no more dangerous than an average Tesla coil.



kretzlord says: Aug 21, 2011. 1:06 AM **REPLY**

dude, this is intense!!!! haven't even gotten past the first page and I love it

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