The Electron Gun Essay (HIERON version)

The laws of electromagnetism are, if not intuitively and generally understood by all, known. The discovery of such an apparently obtuse relationship greatly intrigued me, and so I set out to determine the relationship of Electricity and Magnetism on my own terms, as well as observing some properties of a pure electron beam.

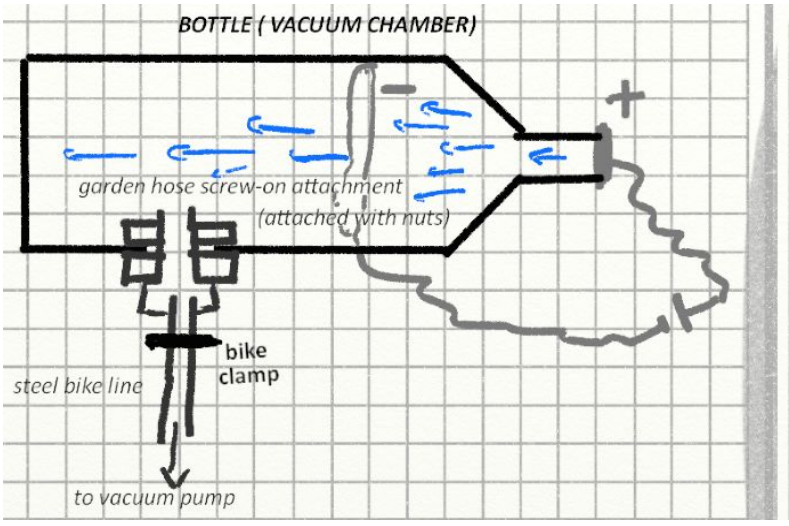
In this report, I will detail the theory and history behind cathode rays, how I built mine, the challenges I faced and my interpretation of the results.

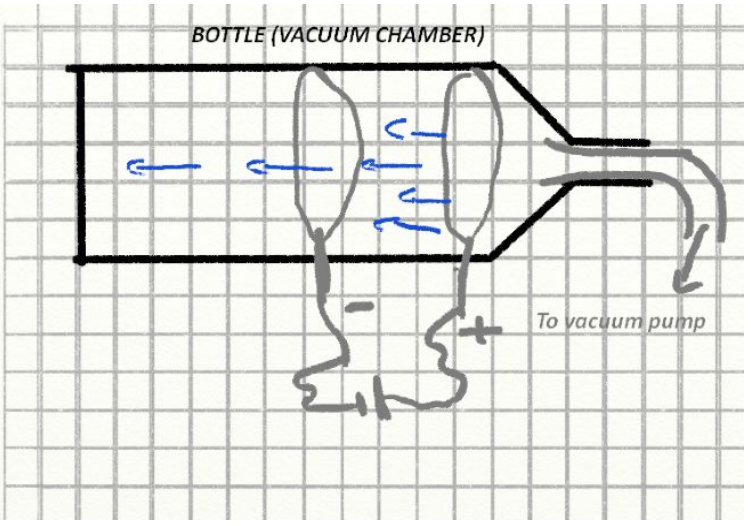
METHODOLOGY

1. THE PLAN

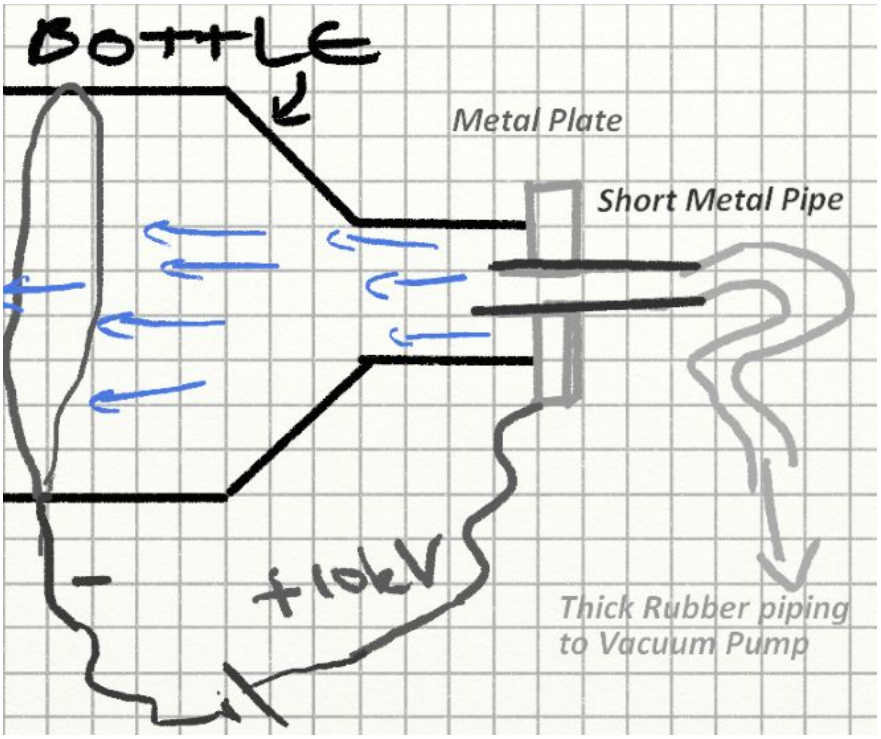
The most difficult part of the plan to devise was the vacuum system, and this was the weakest part of the final project. Originally I was going to have the vacuum pump coming out of the side of the bottle, but the idea of making such a sizeable hole in a glass bottle and increasing the likeliness of implosion under pressure was not at all attractive. In addition, many aspects of this plan seemed awkward. For example the design called for a nut screwed onto the attachment to keep it in place - from the inside. While this might have been possible with some kind of extremely long and thin wrench dangled through the bottleneck, the idea of such fiddly work didn't appeal.

My second plan was then just to ram some rubber tubing down the neck of the bottle, and use industrial quantities of duct tape to keep it in place wedged against the inside of the bottle. This seemed a little more practical, but came at the cost of forcing the cathode to be moved further into the bottle (my original design envisaged the cathode at the neck). This was suboptimal, but I was all ready to commit to this design until I hit upon an alternative.





My final plan was similar, but with one neat simplification I am fairly pleased with. Since the neck of the bottle is the only really natural and sensible entry point, I would try and fit both the cathode and the vacuum pumping in the same place through a combined system. I didn't have to worry about any electricity proofing or isolation or anything, as although my CRT device will be running at 10kV, its current is miniscule and as current is the potentially fatal aspect of working with electricity I wasn't overly concerned with the safety of combining these two systems. The nature of the combination I had in mind is below.



As my expert draftsmanship shows, I planned to make the initial section of the pipe of metal, and for it to pass through a hole drilled in a thick metal plate. This had several advantages.

1. The metal pipe acted as a conductive "spike" which would create a more intense electron beam by ejecting the majority of electrons from a smaller area
2. The metal pipe, being completely rigid, would be more firmly secured to the thick metal plate (such as with epoxy glue or sealant) than a flexible one
3. This didn't require any extraneous hole-making, a dicey business when working with cheap factory-made glass.

Although happenstance made the final result not quite like this plan, this is the design I finalised and upon which I based my subsequent work. I then scribbled down a quick checklist into my notebook:

TO DO:

- ☐ Vacuum Chamber
- ☐ Cathode
- ☐ Anode
- ☐ Adhesive
- ☐ Vacuum pump attachment system
- ☐ 10kV power supply

2. CONSTRUCTION

The main difficulty was securing a cathode - a thick chunk of metal was actually not very easy to come by without just buying the parts off the internet, something I felt should be saved for a last resort. For the subsequent week or so I slowly began to gather my materials, asking around builders' merchants to see if they had any spare items they could gift me, rooting around in the school physics supply room and even keeping an eye out when I was walking around for bits and pieces that might be useful. This bore fruit very quickly, when the doorhandle on my family's bathroom finally splintered and tore the locking mechanism off the door after 50-odd years of service. This had happened before, and I had spent an enjoyable evening trying to piece it back together a few months ago, but my substandard repair had worsened the situation - now instead of simply falling off, my makeshift repair job caused the damaged mechanism to tear significant parts of the door off making reattachment an impossibility.

However, every cloud has a silver lining, and I immediately clocked the dangling doorknob as being a likely candidate for a cathode. I took one doorknob off, replacing it with a generic modern chrome one that I had lying around, and decided that perhaps in this situation forgiveness was easier to seek than permission.

Drilling a hole in the doorknob proved to be tricky. It resisted my advances with a 1930's-style auger drill I had inherited from my grandfather, and an electric hand drill persistently skittered off it without biting properly. With a heavy heart I went to the school's pillar drill to finally get it sorted out, before realising that actually I had no way of properly securing a perfectly round

object and that any attempt to drill this doorknob had a serious possibility of ending with a metal doorknob spinning at 3000RPM and throwing off shrapnel across the room as it did so.

Instead I used a lathe, with its powerful chuck grip, that made short work of the doorknob and left me with a single clean hole through the top 7mm in diameter, which I then deburred and filed smooth. Because I might have had to replace the doorknob depending on my parents' reactions, I left the screw thread untouched and decided that just the one hole would be adequate, foregoing the original "spike" idea of having the metal pipe going straight through the cathode - my pipe wouldn't be able to penetrate completely the doorknob unless I decided to destroy the threads. I now had the cathode for my experiment.

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My scrounging around the Kensington area then paid dividends when, after wandering into a plumbing warehouse, I asked if they had any copper pipe spare to fit the doorknob I had started carrying around in my pocket wherever I went. Understandably, the man behind the desk was very confused, and wanted to know exactly what a child was doing wandering around the industrial sites under the Westway Flyover with a doorknob in his pocket asking for tiny lengths of plumbing pipe. After I showed him the project plans in my notebook, he laughed and told me to wait a second, before disappearing behind a counter, only to emerge a few seconds later with a 3 foot length of 15mm

copper pipe that an earlier customer had discarded. He kindly gave me this pipe for free, and warded off my attempts to trade him some of my possessions as recompense.

I cut the pipe into pieces first with a simple hacksaw, as these kinds of tools have been in use at least since 2086 BCE[6] and as I have already mentioned I wanted to avoid taking the "modern route" wherever possible. Just in case, however, I also machined a more professional pipelength using an actual pipe cutter generously lent to me by a friend. The comparison of the two pipe lengths is below- I leave trying to guess which one was which as a particularly pedestrian exercise for the reader.

As these pipes were too big to fit through the doorknob unaltered, I devised a slight modification to my original plan, and planned to seal them to the top of the doorknob rather than pushing them entirely through.

To go back to the checklist:

TO DO:

- ☐ Vacuum Chamber
- ☑ Cathode
- ☐ Anode
- ☐ Adhesive
- ☑ Vacuum pump attachment system
- ☐ 10kV power supply

The vacuum chamber was the next item on the list, and one of the easier items to procure without having to order materials or otherwise take the "easy way". I simply found three glass bottles in our house, two of Sainsbury's malt vinegar and the other of a carbonated soft drink. I took three as a backup, in case I broke any at some point in the proceedings. Since I planned my anode to be a ring

of wire inside the bottle, it was necessary to drill a small hole in the glass bottle. Now normally this would be done with a special diamond-tipped drillbit that has to be bought online from a select few retailers, but I knew that kind of item wouldn't be necessary - I certainly didn't need one.

I ordered my diamond-tipped drillbit later that day from a company named "Eternal Tools"[7], and this was one of the very few things I actually did have to order off the internet. With the special drillbit, things went much better and I drilled the remaining two bottles without incident.

I had to make a decision at this point about how I wanted the anode and cathode to be spaced. The further away they were the more powerful and focussed the resultant electron beam would be (as the electrons would have more distance to be accelerated over), but too far away and many electrons might not reach the anode due to the imperfections of the cheap vacuum pump I had available. Since I was unsure, on the two different bottles I drilled the holes in two different places. The clear vinegar bottle (left) had an anode hole drilled very close to the neck of the bottle, and the Schloer bottle (right) had its anode drilled a little further away, 14cm or so. The vinegar bottle's close placement was the equivalent of 'playing it safe', as such an arrangement meant that some kind of result was almost guaranteed, although it was likely to be rather limited in scope. I decided to use the vinegar bottle as my primary vacuum chamber, resolving to try out the Schloer bottle afterwards if I had time.

For the anode I used some steel wire I had lying around from some bonsai tree growing I had been doing - the galvanised steel wire is used to constrict tree limbs and force them to grow in a certain fashion. I had plenty left over, and it was easily thin enough to fit through the small holes I had made in the bottles.

TO DO:

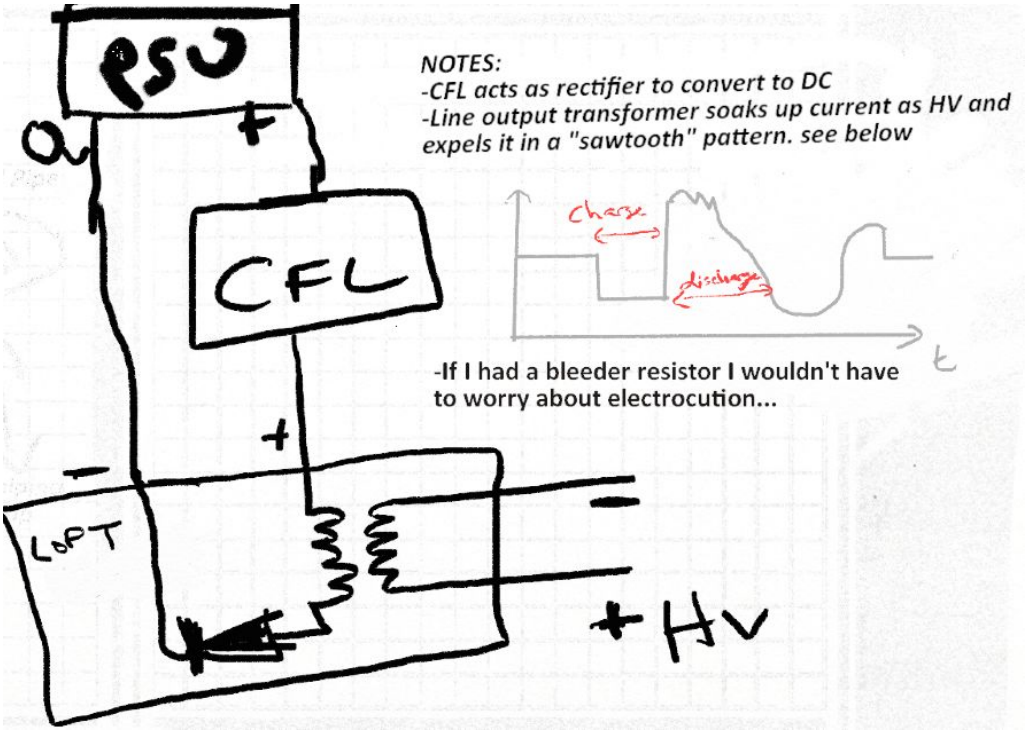
- [x] Vacuum Chamber
- [x] Cathode
- [x] Anode
- [ ] Adhesive
- [x] Vacuum pump attachment system
- [ ] 10kV power supply

My project was now beginning to take shape, and I made an approximation of the final product to try and clarify any confusing design points, on the bottom left.

The adhesive was disappointing. I had hoped to use some of the epoxy glue I had leftover from previous projects, but unfortunately it wasn't pressure-rated, and I didn't feel comfortable putting it under vacuum. There was no repeat of Darren's miraculous gift around the builder's merchants of Kensington either, and the school engineering department didn't have any sealant that would bind to glass and metal. And so I turned to my old nemesis, amazon.com, and reluctantly ordered a cartridge of Everbuild Sealant from the internet for just under £8. After having done so, I realised that actually duct tape would

probably work well - it was used on the Moon after all - but it was too late and I figured that duct tape wasn't at all 19th century-ish anyway, unlike sealant which has been around since the mid 1700s in the glazing business[8]. Rationalisations complete, I received the sealant a few days later and got to work. I curled the steel gardening wire and fed it through the anode hole, creating a rough ring inside of the glass bottle. I then dabbed on the sealant to secure it in place, as well as similarly treating the copper pipe to stick it to the doorknob. I left these pieces out overnight to dry for 19 hours.

The final piece of the puzzle, the 10kV power supply, I had originally intended to build myself. I had seen a video of someone using a makeshift power supply operating at 12-15kV using a neon-sign transformer, and thought that I could do something similar with a line-output transformer from a busted TV and a compact fluorescent light. I include my amateurish schematic below for posterity and to explain what I mean. Upon finding out that I was intending to build a 15kV power supply with exposed wiring by myself that would operate at 55mA, I was quickly vetoed by my parents and the physics technicians, who instead suggested I could take the safer route of borrowing a school power supply which operated at 10kV but barely 1-5mA of current, enough to mildly discomfort a person but little more than that.



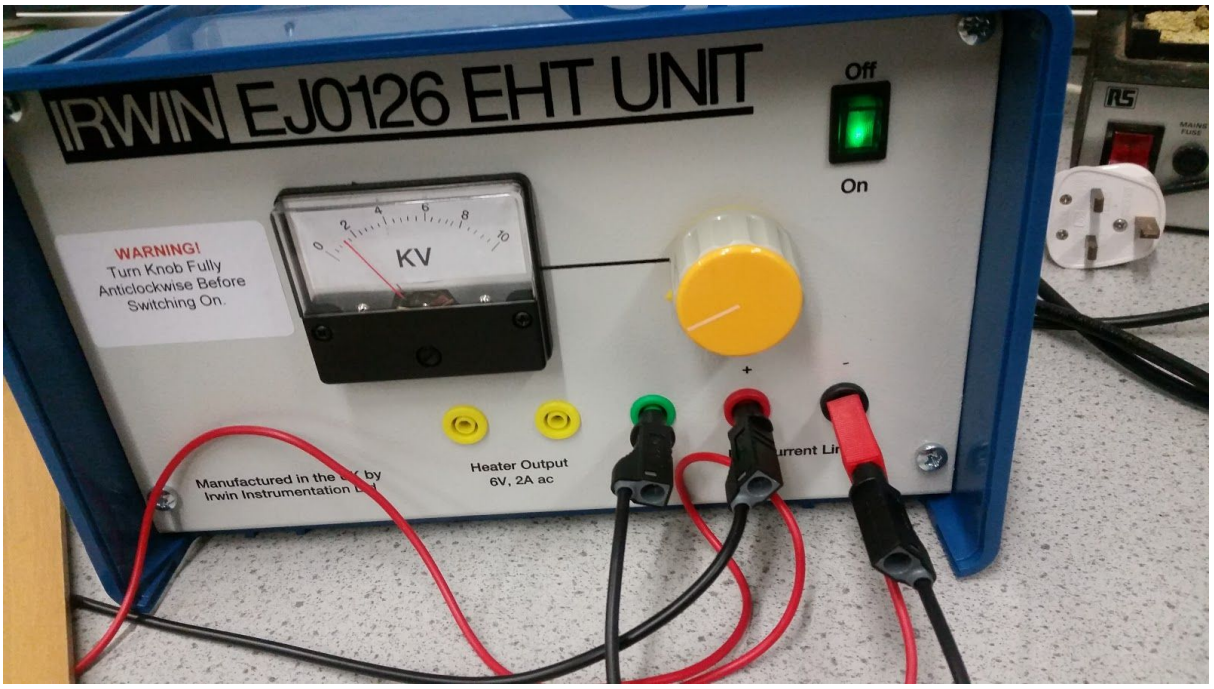
Looking back at the dubious quality of my concept sketches, it is probably for the best that I didn't attempt to build the PSU myself.

I now had all the pieces, and was ready to actually try my device for the first time!

3. THE EXPERIMENT

The initial test, with the close-spaced anode, was a limited success. There was clear phosphorescence around the anode, but barely any and absolutely no sign of a beam. This luminescence was too weak to manipulate with a magnetic field, but it was a promising first test.

There was, however, a puzzling holdup. Although the power supply I was using was supposed to go up to 10kV, it refused to go above 1.8kV when attached to my CRT. Since the primary ways to increase the luminescence are either to increase the vacuum (not an option open to me) or to increase the voltage this was a real problem. At the time, I theorised that perhaps there was a thin patina of dirt on the inside of the glass bottle that was conducting current at a certain voltage and preventing any further buildup, and so decided that the backup vacuum chamber I had prepared might solve this issue.



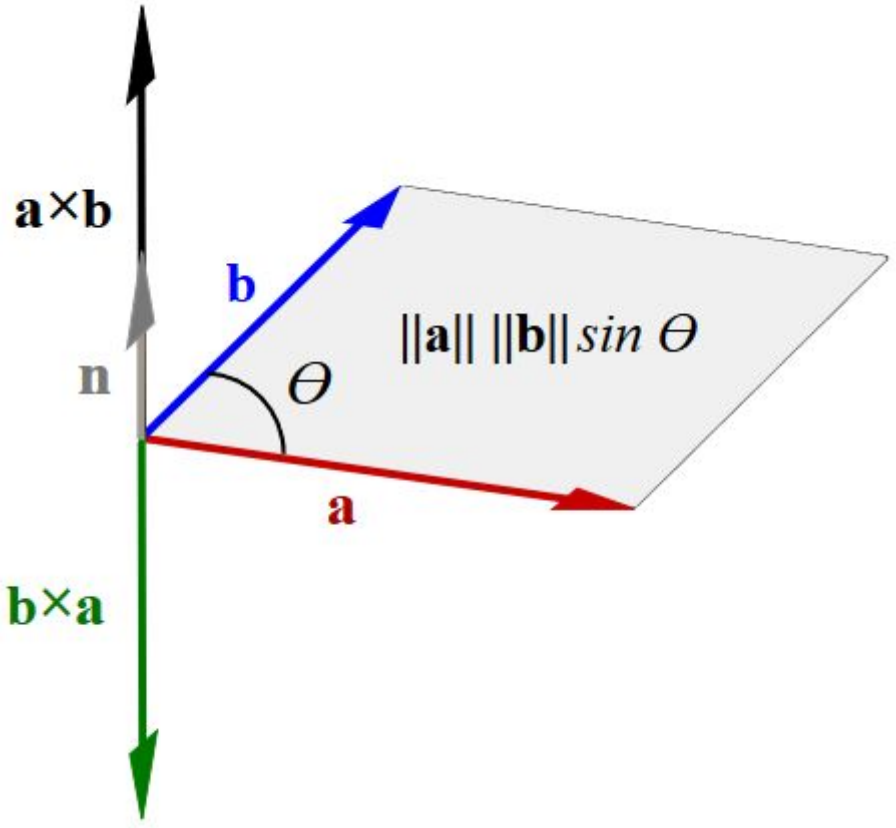
I switched bottles, and reattached the wires, but once again the voltage refused to go past a certain point - 2kV now.

It turned out that the power supply I was using had a safety feature, where the voltage wouldn't increase when the current gets to a certain level - if you look at the bottom right of the above picture you can just make out the words "Current Limited" under the terminals, something I should have noticed much earlier. In order to maximise the voltage, I needed to get hold of a non-safe PSU. However, this wasn't practical. The idea of waving a magnet around in the dark next to bare wires carrying fatal amounts of current and power levels that might melt or weaken the glass sealant I was using did not appeal overmuch to me, and I had to look for an alternate, suboptimal solution. I fetched an older 5kV power supply, guessing that this model from the 80s/90s would have inferior current regulation and occasionally let "spikes" of higher voltage through. This was correct, and when plugged in I ended up with a cathode ray glow that spiked occasionally for a few seconds at a time. One of these spikes, that I was unable to replicate, reached around 3.5kV and led to a visible beam being visible for a few seconds - something I was unfortunately unable to catch on camera. Aside from that, most spikes were around the order of 2-2.4kV, and this produced a much brighter anode glow, as well as a very faint cathode glow that wasn't visible oncamera. Considering that the device was running at 20% of the voltage I had designed it for, this was actually quite impressive.

The cathode beam was invisible, but that didn't mean that it couldn't be deflected. With a horseshoe magnet, I was able to make parts of the ring brighter or darker by holding the magnet up to the neck.

4. CONCLUSION:

First I held the magnet next to the tube approaching from the left, with the poles around the neck. This showed a marked brightening of the part of the anode ring 90 degrees from the north pole. This indicated that the invisible ray was being deflected, but to confirm it was the magnetic field I inverted the magnet and put it back in the exact same position to witness deflection in the opposite direction - exactly corresponding to what we would expect to see from a vector field's cross product.



I think this proves beyond all reasonable doubt that electron beams are deflected in the presence of magnetic fields, and strongly suggests the theory of electromagnetism - that the two are simply two aspects of the same phenomena. I am not sure that this offers a rigorous confirmation, but if the issues with the power supply were worked out I am confident that electric deflection could be demonstrated as well which certainly would be conclusive proof of the electromagnetic theory. I think this experiment was a moderate success, and I learned a lot in the process.

[4000 words]

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