PHYSICS II HONORS PROJECT

THE CATHODE RAY TUBE

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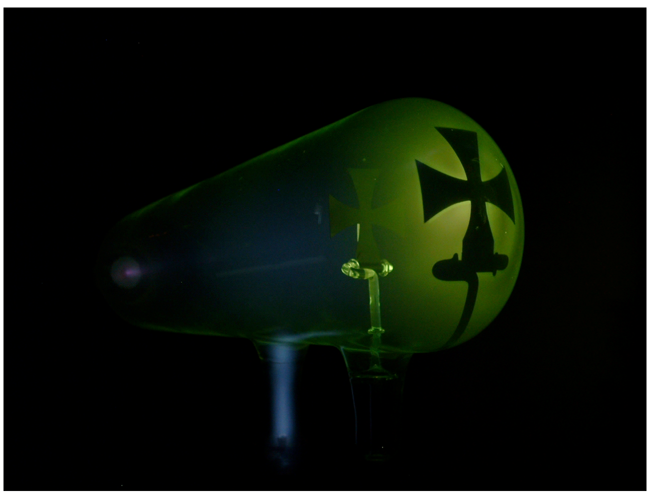
Introduction

The purpose of this construction project was the replication of Crookes tube, or the cathode ray tube. I was inspired by the historical and modern significance of the cathode ray. A modification of Crookes tube evolved into the first televisions. Although these are being phased out, their importance is undeniable. In modern times the basic cathode ray is not used for anything but demonstrating gasses conducting electricity.

How it should work

A Crookes tube is constructed by applying a voltage from a few kV to 100 kV between a cathode and anode (Gilman). Although the Crookes tube requires an evacuation of gas, it must not be complete. The remaining gas is crucial to the process. The cathode (negative side) is induced to emit electrons by naturally occurring positive ions in the air (Townsend). The positive ions are attracted to the negative charge of the cathode. They collide with other air particles and strip off electrons, creating more positive ions. The positive ions collide with the cathode so powerfully that they knock off the excess electrons. These electrons are immediately attracted to the anode and begin accelerating toward it. Because Crookes tube is a cold cathode (no heat applied), the cathode requires the impact of the ions to knock off electrons. The maximum vacuum or minimum gas pressure to begin the chain reaction of ions in the gas is about 10^{-6} atm (Thompson). Anything past this pressure requires a hot cathode to kick electrons off the cathode.

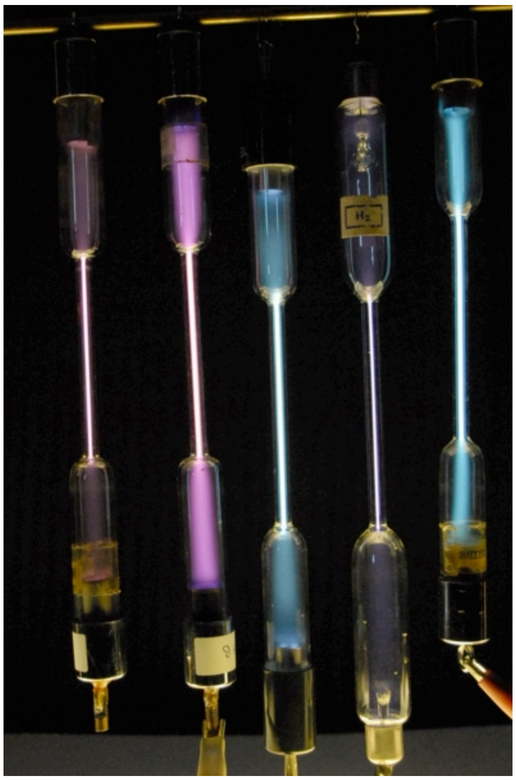
Crookes tube is derived from an earlier device called a Geissler tube. In The improvement Crookes achieved was a significantly lower presser (higher vacuum) in the tube. At the low pressures Crookes achieved, electrons leaving the cathode were unlikely to impact an air molecule on their journey to the anode. This enabled the electrons to gain great momentum as they accelerated toward the opposite side. As in the case of Juliusz Plücker's Maltese cross experiment, if the electrons were allowed to go past the anode they would impact the glass on the back of the tube. The orbital electrons of the glass would be excited to a higher energy level and then return to their previous level. This would result in the emission of photons as the glass's electrons would fall back to the original levels. The glass, would glow with an eerie green light:



http://members.chello.nl/~h.dijkstra19/page7.html

The electrons intercepted by the anode (the cross) would not reach the back of the glass, creating an electron shadow.

A Geissler tube acts in a similar way, but looks quite different from a Crookes tube because of its higher pressure (worse vacuum). At a pressures of about 10^{-6} atm, the Crookes tube makes it unlikely that the ejected electrons will encounter gas molecules on their path to the anode. The Geissler tube, at only 10^{-3} atm drastically increases the chances of these encounters (Townsend, 395). The constant collisions between gas particles and electrons causes the orbital electrons in the gas to become excited and, in the same process as the glass in the Maltese cross experiment, emit a glow. This creates a glow throughout the tube.



http://www.museumoftechnology.org.uk/expand.php?key=361

Neon lights are a type of Geissler tube. Geissler tubes will work with many different types of gasses including neon, argon, nitrogen, hydrogen, and air. In all cases the gas must be brought to a low pressure.

As the vacuum increases, the length of the illuminated gas shortens. A dark space starting at the cathode begins to creep down the tube. This dark space should slowly fill the entire tube as pressure decreases (Townsend, 397). Named after Crookes, the Crookes dark space occurs because with lower pressure and less dense gas the electrons are able to travel further down the tube, on average, before striking a gas molecule. As the dark space spreads down the tube, the glow at the end of the tube on the glass increases; more electrons are making the entire journey though the tube without hitting a gas molecule. The actual physics of this are very complicated since it involves a nonequilibrium of positively charged ions, electrons, and neutral atoms which are constantly interacting.

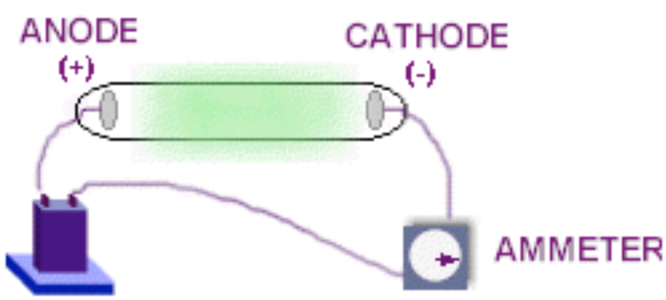
The electrical discharge glow in a Geissler tube is "stratified". That is, it is in separated sections. The explanation for this requires plasma physics, but it is a beautiful phenomenon, well worth mentioning. My own Geissler tube did not exhibit these bands of glowing light, but the precedent exists.

Different gasses produce different light when hit with electrons. Nitrogen glows a deep purple. Oxygen glows a light blue. As the main components of air, and nitrogen as the main component, these colors combined should glow a dark blue or almost blue purple.

My vacuum contains only air and is achieved by pulling rubber stoppers apart. This technique of pulling a vacuum should only result in the effects seen in the Geissler tubes, although there is a chance of seeing some dark space.

Construction

My reconstruction of Crookes tube, which ends up being more like a Geissler tube, was done with parts ordered off the internet. Two rubber stoppers, a coat hanger, two nails, a plastic tube, aluminum foil, and sealant were used in construction. The vacuum is created by pulling the cathode end though the tube with the other rubber stopper placed behind it. The diameter of the stopper on the small end is less than the inner diameter of the tube; the diameter of the larger end is considerably larger than the tube. To allow one stopper to slide though, the back half of the stopper was trimmed to size. To ease the difficulty of pulling the vacuum, which gases and the friction between rubber and plastic tend to resist, olive oil was added to the cathode end stopper. The voltage applied with a tesla coil (not constructed) will be carried into the vacuum with the nail. On the cathode side, aluminum foil covers the entire inward facing part of the stopper to create a larger area for electrons to be ejected from than simply just the end of the nail, which is a relatively small area. The trickiest part of the process was simply sealing the space between the nail and the stopper. Very few glues stick to both rubber and metal. Superglue seemed to work the best.



http://library.thinkquest.org/28582/history/crayexp.htm

Reasons for Unforeseen Outcome

The most likely reason for the unexpected observation was an incorrect pressure inside the tube. If the pressure is too high, then no electrons will move at all; air is a very good insulator. Inversely, if the pressure is too low (which isn't likely), then the electrons do not collide with the gas and result in no cool glowing effect. Achieving a vacuum was by far the most difficult part of this project. Getting the space between the nail and the stopper to seal was surprisingly difficult. Chopping up the rubber stopper on the cathode end to allow it to slide though the tube was very messy and could have resulted in an air leak, again, destroying the vacuum.

Failure also could perhaps be attributed to too low a voltage or too far a distance. The general directions I followed recommended a voltage of about 25 kV. The Tesla coil in use is only 20 kV. At lower pressures, the volts needed per cm decreases. Knowing the precise pressure inside the tube is impossible and so knowing the correct voltage is impossible. Depending on the pressure, anywhere from 2 V per cm to 2000 V may be necessary. The variation and uncertainty could easily account for the failure.

My own tube did not exhibit either the glow of the Crookes tube or the Geissler tube glow. Instead, there was a continuous spark. It is possible that this could be caused by a voltage that was too high. To achieve the geissler tube effect, sparking should be avoided. Although the vacuum needed for the Geissler tube is not enormous or unattainable, it is possible that my tube did not reach the required vacuum levels (10^{-3} atm).

On the other hand, the gas did conduct electricity. There was a continuous stream of electrons down the tube. The moderate vacuum did increase the distance that the tesla coil was able to spark by lowering the electrical breakdown of air by lowering the air's density. So although this result is not what was expected, it is still interesting. Considerable improvements could be made to the technique used to pull the vacuum.

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