Backyard Nuclear Fusion

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Introduction

Hello there!

Welcome to the wonderful world of backyard amateur fusion. I'll lead you through the process of building your own fusor, step by step, and it really isn't that hard—surprisingly, one could build a fusor in a week given all the components and supplies. Moreover, I'll go over the theory of operation as well as give you some real, hard numbers to prove that this thing isn't a hoax, or a joke. It's entirely real.

So sit back, relax, and enjoy the ride. While it's not necessary that you pay attention (this conceptual physics course has covered most of the abstract topics you'll need), I'd appreciate it if you stayed quiet if you're disinterested. If you're really intrigued by the whole process, go ahead and ask me questions in the question-and-answer period; there's certainly not enough time for me to explain every single itty-bitty detail here, so I may skip over some things and the presentation may seem patchy (which is why I need you to help me fill in the gaps!)

And yes, the party's on me folks. Have fun!

Chapter 1

Nuclear Fusion

As we've already covered in class (and you should know), nuclear fusion is the process of "fusing" two really light nuclei together in order to release power via their excess binding energy. This is the process that happens in the Sun—it's the largest nuclear fusion reactor, and it's a very nice example of how powerful fusion can be.

Except for the fact that humankind hasn't progressed nearly enough to build a small sun. So far, nuclear physicists are experimenting way below the thresholds of the Sun, and they definitely haven't been able to extract any useful energy from their machines. Some methods can get amazingly close to the point of self sustenance and ignition (we'll talk about this later), but nobody's ever figured out a way to use all the energy that's released.

I'll be using the Sun as a common reference point for most fusion operations. (There are some technical issues with this, such as the fact that the sun actually uses a different form of fusion than most Earth-based reactors, but those are minor details.)

1.1 How?

Nuclear fusion requires that the two nuclei be "fused" together, but what does this really mean? What's stopping the two nucleuses from spontaneously joining?

Unfortunately, nuclear fusion requires quite a bit of energy to start the process. Within an atom, you've got a nucleus (which always has a positive charge) and sometimes an electron shell, depending on how ionized the element is. For nuclear fusion to occur, we need to get two nuclei close and have them bind themselves together; this, as you may suspect, is done by the strong nuclear force. Unfortunately the strong nuclear force only acts on incredibly small distances, so there's another force that precedes it: the electrostatic force.

The electrostatic force repels two nuclei because they're oppositely charged (it's the entire "like charges repel" mechanism). This force is normally very strong on the scales we're talking about—it's strong enough to prevent things from fusing together when collisions happen, for example. Even if two Jumbo Jets crashed into each other at 600 miles per hour, the resultant debris and catastrophe doesn't induce fusion. It's harder than that.

So basically, the atoms to be forced together at high speeds or at high pressures—those are the only two methods that we can use. We need a temperature of about 100 million Kelvin for this to happen—remember, temperature is actually a measure of a materials atoms' kinetic energy. The more temperature you have, the faster the gas atoms are flying around. So, let's look at our options.

1.2 Methods of Fusion

1.2.1 Tokamak/Stellerator (Magnetic Confinement)

Nuclear scientists initially started with high temperature gases, and then wanted to squeeze the gas together so that the atoms would be more likely to bump into each other with the necessary speed. To restrain the incredibly hot gas, there's only one method they can use: magnets. Magnets exert a force on electrically charged particles, and in a plasma (usually a very energetic state of matter, at around 30-100 million kelvin), the electrons have already been literally ripped off of the hydrogen atoms—they're all charged and running around, loose and fast as heck. Therefore they can use magnets to restrict and bind this charged body. However, the magnetic force needs to be incredibly strong—they're essentially keeping particles together like they'd be found at the center of the sun, and there's no gravity or other mechanism to help them along.

There's a bunch of various quirks to this arrangement in practice, including the need for a housing in the shape of a donut. (The donut allows for an incredibly uniform magnetic field). It also requires being built on a large scale, since the magnetic forces needed require room-loads of equipment and lots of power to run (these are electromagnets so that the scientists can control the magnetic field accurately). In general, it's expensive, large, bulky, and incredibly time-consuming to even plan out building a tokamak.

Moreover, it's hard to extract any energy from this system because it's just a burning plasma. You can't stick things into the plasma and expect them to survive; it'll just melt away. The magnetic fields mean that there's a bunch of coils and support equipment that need to be close as possible to the plasma; you can't make the container transparent or even light-passing so that you can use the light to read, or something similar. It's pretty much like a miniature, donut-shaped sun, but you can't use its light or its heat, leaving you with little or no options for using the thing. (Using the emitted radiation—gamma/X-ray radiation—or carrying away the hot byproducts that are spewn from the plasma are possibilities that are being looked into at present.)

A variation on the tokamak design is the Stellerator, which is just a Tokamak with a different shaped enclosure—in most cases, it looks like a twisty band loop.

1.2.2 The National Ignition Facility (Big Lasers/Inertial Confinement)

Another method of fusion is to get a small pellet of solid hydrogen, coat it with plastic or something else that will melt at high temperatures, and then fire lots of really big lasers at it.

The lasers make the plastic hot enough that it literally "explodes", forcing the solid hydrogen inward and inducing conditions with enough pressure and temperature to induce fusion.

This is a great example of how much power is available in the world—the National Ignition Facility, one of the only places in the world researching this, is capable of putting out 500 terawatts of power for a couple microseconds.

And therein lies the rub: this process only works for small amounts of fuel, and it only works for a very, very short time. There isn't enough time to actually extract any energy from the equation, and it takes a long time for the lasers to charge up.

This method isn't practical outside of research at the moment, really. There's some possibilities for expansion, but in general it suffers a pretty bad setback due to its non-continuous operation.

1.2.3 Cold Fusion (The Quacks)

There are a whole subset of techniques that call themselves "cold fusion," and most of them don't work. If they do work, they haven't been able to reproduce it or get quantitative evidence. We'll ignore them for the moment.

1.2.4 The Nuclear Fusor (Inertial Electrostatic Confinement)

Okay, so we've got magnetic methods and explosive methods of containing the fuel. What would happen if we instead figured out how to make the fuel collide with itself, instead of just pressing it together and hoping it works?

That's exactly the procedure that the nuclear fusor, or as its more commonly known, the Farnsworth fusor follows. (It's named after its inventor, Philo T. Farnsworth.) If you have a very low density gas, such that the particles can travel about a meter without colliding into one another, you can accelerate the individual atoms to very high speeds into a central point.

"How do you accelerate these atoms?" you might ask. Well, the fusor exploits the natural enemy of nuclear fusion physicists—that nasty electrostatic force that repels the atoms from getting together. The fusor accelerates ions by placing them in a very high voltage differential situation; the ions will naturally accelerate to an area of negative charge due to the electrostatic force.

What would happen if that negative terminal wasn't solid, but was instead a grid, so that the ions would continue traveling at high speeds past the terminal? What would happen, pray tell, if the negative terminal was shaped like a sphere?

With a spherical, grid-like negative electrode, hydrogen ions naturally accelerate toward it, and toward the center of the system. However, since the grid actually has space for them to pass in between, the hydrogen ions will go through that route. Of course, all the hydrogen ions in the system are heading for the center—they'll naturally collide at the center of the negative electrode.

And there, in the center of the spherical grid, will be where fusion happens.

This is the method that I'm trying to build, and this it where all of my efforts have gone. Luckily, this "fusor" device can be built on a small scale, and high voltage equipment is relatively common compared to ridiculously big lasers or magnetic field equipment, so it's within the reach of the amateur.

Chapter 2

The Farnsworth Fusor in Detail

Well, now that we've decided what method of nuclear fusion we're using, let's get to the nitty-gritty of it.

A diagram of what I'm working with is available at Figure 2.1.

We'll start with the very basics. Initially, the vacuum chamber is evacuated of all gases—we need as little interference from air and other particles as possible (because soon, all charged particles will be heading for the center.) Then, once a low enough pressure has been achieved (0.1 mmHg or less; a typical vacuum cleaner can pull 690 mmHg, and typical atmospheric pressure is 760 mmHg), the chamber is filled up slightly with deuterium gas (an isotope of hydrogen). Once this has happened, we're ready to put on the electricity and get some action going.

The high voltage supply provides a high voltage differential between the inner grid (blue) and the outer grid and shell (red). Imagine, if you will, a deuterium atom lying somewhere in between the inner grid and the outer grid. The high voltages (on the order of 20,000 volts or more) rip its electron off, creating an ion.

Now that the deuterium atom has been ionized, the electron flies off. The nucleus, however, remains in the chamber, and it's got a positive charge. Naturally, it starts to head toward the inner grid, since there is a strong negative electric field in the middle. (While the center grid may be hollow, it still presents a spherical electric field.) Accelerated by the electrostatic attraction, the atom begins to pick up speed and energy. It's accelerated to the equivalent of 150 megaKelvin. Sometimes the ion hits the grid and heats it up, but usually, the ion heads right through the grid and ends up straight in the center.

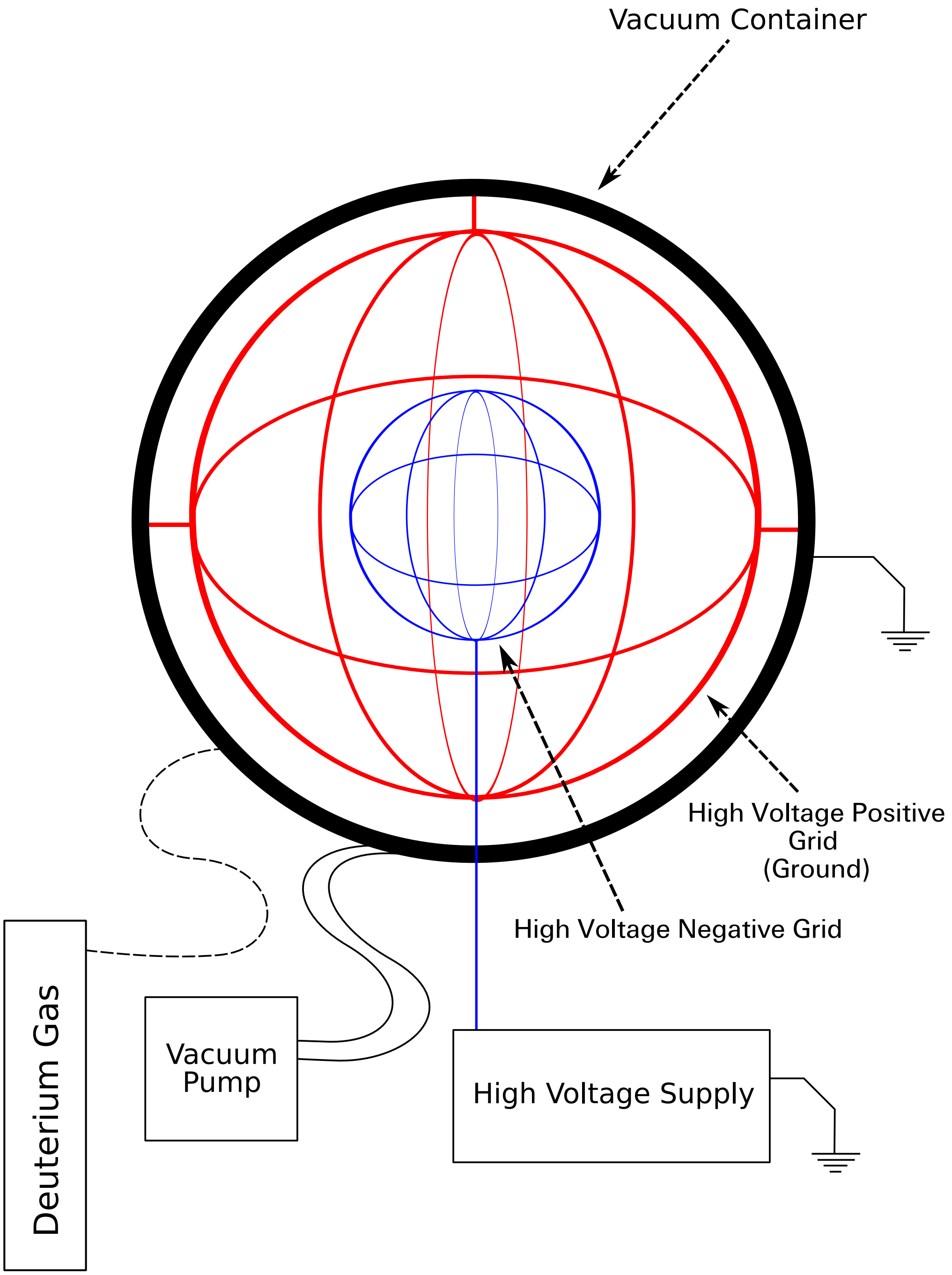

Figure 2.1: A Schematic View of a Fusor.

Repeat this process for every atom in the chamber (millions of them), and the end result is a lot of deuterium ions colliding in the center at around 300 million Kelvin.

That's all there is to it.

Chapter 3

How to Build a Fusor for Fun ~~and Profit~~

Just to show you that it's not impossible to build this thing, and that anybody—even you—could do it, here's a basic parts list:

3.1 Parts list

- (1) Vacuum pump capable of 1 micron
- (1) 50 liter lecture bottle of deuterium gas, 99.999
- (1) High pressure 2000 psig to 10 psig regulator
- (1) Shutoff valve
- (1) Fine metering valve
- (1) Ultra-fine metering valve
- (2) Stainless steel 8" hemispheres
- (3) ISO/KF40 SS weld fittings (half nipples)
- (3) KF40 centering rings
- (3) KF40 clamps
- (1) KF40 flexible metal vacuum conduit

- (1) KF40 pump adaptor
- (1) Vacuum gate valve
- (2) Conflat 2” non-rotatable weld fitting
- (1) Conflat 2” view port
- (1) Conflat 2” 30KV high-voltage ceramic pass-through
- (1) High voltage power supply capable of 30,000 volts at 100 milliamps
- (1) High voltage cable
- Various cables and hookups.

The end damage totals to about $20,000, more or less, if everything is bought brand new. If scrounged, however, people have been able to get away with $2000 or less.

It’ll be fun, but definitely not profitable.

3.2 Hazards

WARNING: This device is capable of killing with high voltage. Also, if appropriate measures are not taken, deuterium may leak, and deuterium gas is extremely flammable in air. While there are no glass components here, should you chose to go with a bell-jar based design instead, the implosion from uncertified vacuum vessels will send high-velocity shards of glass into your body and into onlookers.

There is also radiation present when operating this device. As you know, a fusion reaction will typically result in excess protons and neutrons; these fly past the stainless steel container and can be detected. (This is the way most people prove their fusor is working.) While it does not produce enough protons or neutrons to be biologically significant, long amounts of exposure to this low flux may cause side effects.

Another form of radiation, soft X-ray radiation, is also produced since electrons are being accelerated and deaccelerated. Whenever electrons crash into high-mass atoms (such as iron, the main constituent of stainless steel), X-ray radiation is produced. This is exactly what happens when the excess electrons from the hydrogen atoms are attracted towards the outside grid;

most miss and hit the stainless steel container. This flux of X-rays is usually very low as well (only milliamps of current), but again, prolonged exposure can and will be bad.

I may have given you the basic premise, but please don't try and do anything like this without supervision or incredible amounts of more research. What's presented here is mainly a general overview; the details will bite you if you don't watch out. I disclaim all responsibility for any and all experiments inspired by this pamphlet.

These bunch of dangers and hazards are the reason that I've slowed down my project—you have probably heard that I planned to bring one in to school and show you all one in operation. Unfortunately, with that sort of timetable, I had no time to verify the safety of my equipment or setup, and I would not be able to construct a fusor properly (the plan was to have a glass enclosure, originally).

Moreover, I've no experience in any of these fields (vacuum technology, high voltage, machining), and it'd be simply foolish to try and handle everything myself. I've since contacted other people to help and aid me in my quest for fusion.

The basic premise here is this: while parts are cheap, lives and knowledge are not. An experienced scientist with appropriate sources and tools could most likely build one in a weekend (and indeed, Richard Hull did just that). However, when dealing with the unknown, one must tread very carefully—which is what I elected to do.

Chapter 4

Mathematics, Equations, and Details

Here's a general list of things that you might need to know if you're building your own fusor. (I'll admit this is a pretty technical section, and its mainly for those who really want to see the hard evidence. Feel free to skip this boring section.)

4.1 Temperature-Energy Equivalence

Since temperature is just a reading of atoms' average kinetic energy, if you're given an amount of energy, you can calculate a particle's temperature as well (if you know its mass). The electronvolt represents a very small amount of energy, about $1.60217653 * 10^{-19}$ J. Every electronvolt is equivalent to about 11605 Kelvin. Multiply thirty thousand electronvolts times this number, and the result is surprisingly high: nearly 350 million Kelvin. This is proof that there's definitely enough energy for fusion to happen.

The constant governing temperature-energy equivalence is known as the Boltzmann constant. Here's a full equation:

$$\frac{1\ \mathrm{eV}}{\mathrm{k}} = \frac{1.6022 \times 10^{-19}\mathrm{J}}{1.380650 \times 10^{-23}\mathrm{J/K}} = 11605\ \mathrm{K}$$

4.2 Nuclear Reactions

The two equations that you're most likely to encounter as an amateur are deuterium-deuterium reactions:

- ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He}$ (0.82 MeV) + ${}^{1}_{0}\mathrm{n}$ (2.45 MeV) (50% likelihood of occurance)
- ${}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{1}\mathrm{H}$ (1.01 MeV) + ${}^{1}_{1}\mathrm{p}$ (3.02 MeV) (50% likelihood of occurance)

With the excess tritium created by these reactions, you may be lucky and get a deuterium-tritium reaction: ${}^{3}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He}$ (3.5 MeV) + ${}^{1}_{0}\mathrm{n}$ (14.1 MeV).

(The numbers after the result products are what energies are imparted onto them after the reaction occurs.)

The amount of reactions is highly related to the "nuclear cross section," which is the amount of apparent area that an atom will present to be reacted with. (Higher is better.)

It's usually expressed by:

$$\sigma(E) = S(E)E^{-1}\exp(-2\pi\eta)$$

where E is the energy in Kiloelectron volts.

The $-2\pi\eta$ part is the Sommerfield parameter, given by:

$$2\pi\eta = 2\pi \mathrm{Z}_1\mathrm{Z}_2 e^2/\hbar v = 31.20\mathrm{Z}_1\mathrm{Z}_2(\mu/\mathrm{E})^{1/2}$$

where Z_1 and Z_2 are presented in units of quantum integral charge and μ is the reduced mass of the system in amu ($\mu = \frac{m_1 m_2}{m_1+m_2}$). $\hbar$ is Dirac's constant, or Planck's reduced constant, which is $\frac{h}{2\pi}$.

Nuclear cross sections are usually presented in barns (yes, barns), which equals 100 square femtometers.

That's the general nitty gritty of the equations necessary for nuclear fusion. The math is surprisingly Newtonian and rather simple, taking only basic algebra skills to solve (and a little adjustment/acclimatization to the variable names).

4.3 Clarifications

In the beginning of the fusing process, I explained how the ions have their electrons ripped off due to the high-voltage electrostatic field. This isn't entirely true. The process, I believe, is mediated by thermionic emission—electrons are emitted from the inner grid due to the high voltage potential, and those electrons hit the atoms, stripping away their electrons.

Appendix A

Pictures

Here are some pictures of folks who have done this before:

Figure A.1: Brian McDermott's fusor parts prepped and ready for assembly

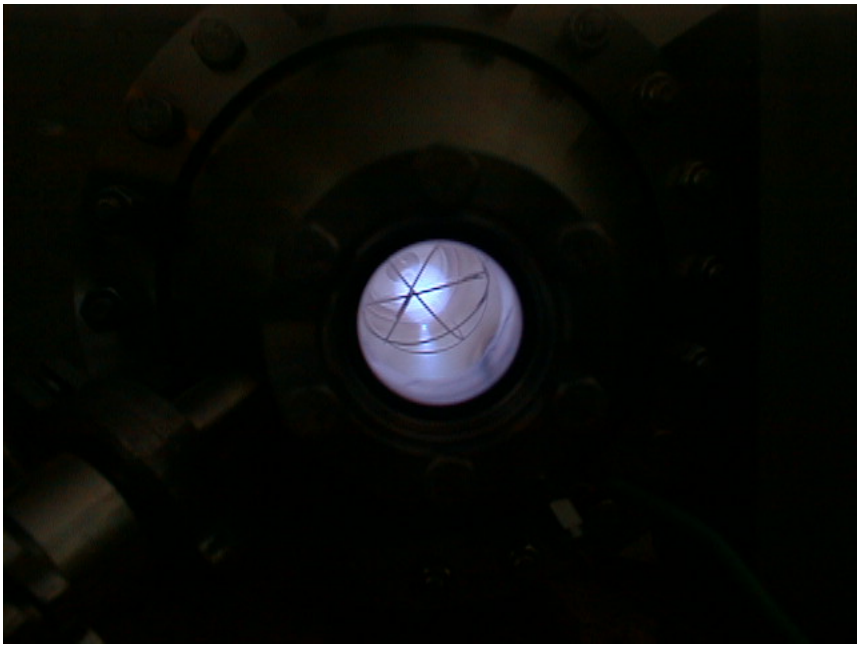

Figure A.2: The first plasma in the fusor

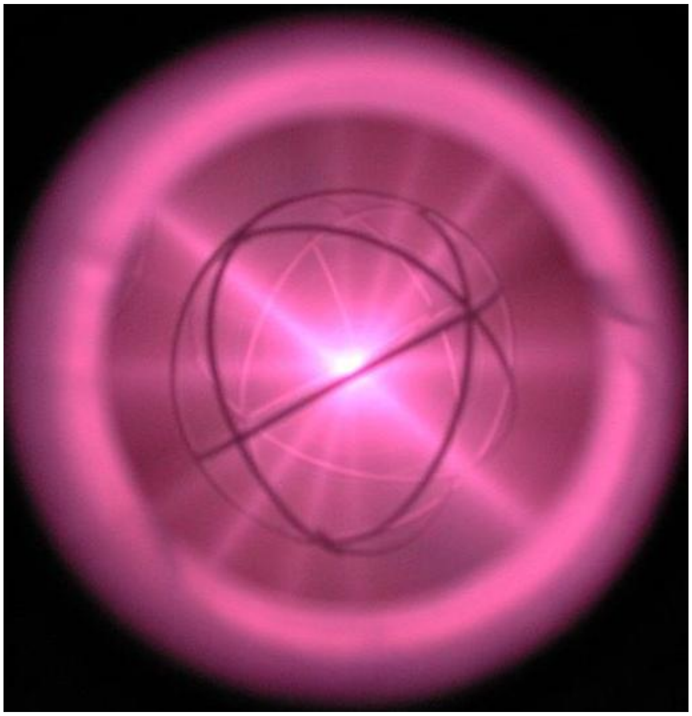

Figure A.3: A fusing, star-mode plasma

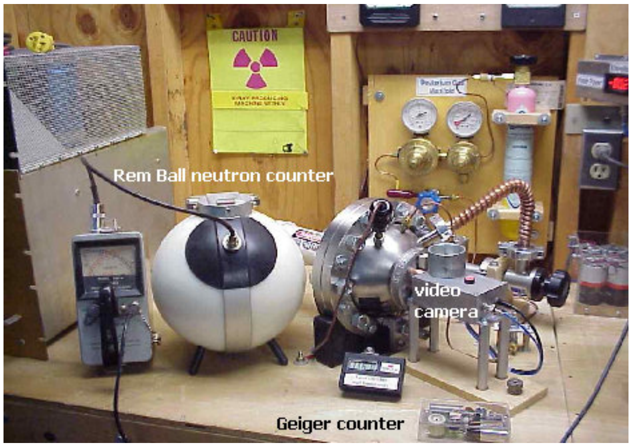

Figure A.4: Richard Hull's fusor setup

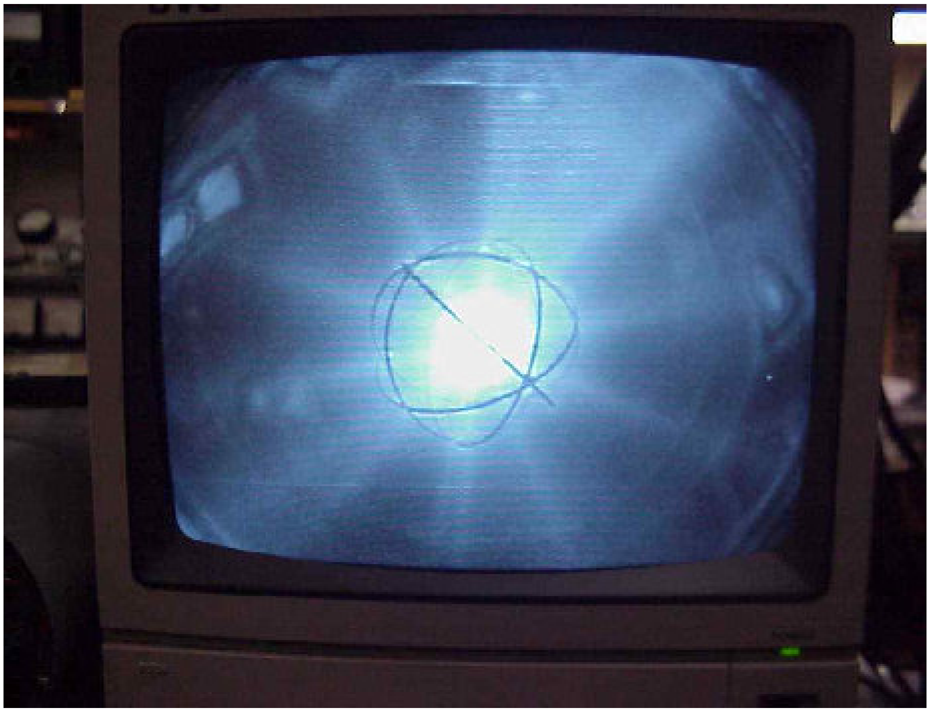

Figure A.5: Richard Hull's fusor in star-mode (possibly fusion) operation

Appendix B

Thanks and Gratitude

There are a whole lot of people I'd like to thank for their help and involvement in my project:

Mr. White for letting me do such a crazy project, then shooting down my construction efforts, but still encouraging me. Also, many thanks for the referral to the next person…

Mrs. Schmidt and the rest of the science department for lending me the vacuum pump and giving general advice.

Dr. Charles Barnes for giving me interesting papers and letting me intrude on his professorial life, as well as introducing me to the actual equations behind the magic.

My parents for trusting in me and trusting that I don't blow up the house (I haven't just yet).

Jim Lux for getting in contact with me and giving me tips and suggestions.

Richard Hull for putting up an awesome web site and videos about the Farnsworth fusor—I wouldn't be doing this presentation without him.

Brian McDermott for being an inspiration as one other high schooler who's built one.

Prof. Paul Bellan for his comments.

The folks in #nnl for proofreading and general jokes about insanity (always keeping insanity spirit!), as well as providing a general relaxing place for suspicious comments.

The fusor discussion board for giving such wonderful insight into the real details of how to work and operate a fusor.

Everybody who doesn't believe me for giving me the incredible strength and endurance to continue this project—I'll prove your thinking wrong!