Extensions of the Farnsworth fusor

What we are doing in my lab currently does bear quite a bit of similarity to the original Farnsworth fusor, and it seems to be confusing many. We certainly owe the man and a few who came after a serious debt, intellectually. But they never truly succeeded, no one really has yet, although some, including my team, have done far better than the originators have.

Or maybe not, in some sense. Going back through history, papers, private communications, it seems many fusor builders report hard-to-repeat huge Q factors (defined as power out divided by power in). Since they are hard to replicate even in the same lab, they have been dismissed as "outliers" or "equipment errors".

That same attitude would mean that if a modern biologist was brought Fleming's famous contaminated petri dish, some lab assistant would be in trouble, and we'd *also* not have penicillin. Luckily, Fleming was the sort of guy who paid attention to "outliers" and "equipment failures" - and also luckily, it turned out to be rather easy to reproduce in his case. Not as much so in a fusor, but philosophically speaking, it seems the same attitude would serve well in fusion research, and it's largely absent in other investigators. With ever better data acquisition, storage, and analysis, I've been able to "catch these in the act" a number of times, and now the challenge is simply to understand and reproduce them, as there is no longer any possible doubt that they do happen – bursts of Q many orders of magnitude higher than "normal" such that on an autoscale plot, the Q of regular fusion operation shows as "zero" by comparison to "thousands and higher" when these events occur. This seems worth the chase, the game is clearly worth the candle.

This document will describe what we've done differently here, and what we intend to do that's even more different.

Our setup is a bit unconventional. We are running our main fusor grid, designed to be a very good electrostatic lens (unlike all others we know of) inside a 6" cylindrical side-arm in a much larger tank. Early on, we found that going to reduced gas pressure improved Q, but had power supply and other limits that prevented the fusor from "lighting off" at the lower pressures with the gas pressures we wanted to explore. We therefore developed various ion sources to allow us to go ever lower in gas pressure (another way of looking at that is "longer mean free path" over which a particle can travel without an accidental wasteful collision). While most of those worked at some level, what we've been doing of late, and which is a "little odd" is simply using another fusor grid (this one not so precise) out in the main body of the larger tank, to take advantage of Paschen's law, which shows that breakdown is a function of p times d – or in other words (counter-intuitively for many), below a certain gas pressure, electricity would prefer to take the longest path, not the shortest one. The reason is obvious in hindsight – if an electron can't get up to ionization energy of the gas before it is slowed down by collision with a gas particle in the extant E field, you get no ionization, and therefore, no discharge. (put wikipedia link here for Paschen's law – nah anyone worth his salt will just type it into a search box and do their own homework)

Somewhere along the way, we also noticed that our extra grid could not only act as a switch for power draw and discharge on the main grid, but that we had created something that also had a moderately linear gain region, and amplifier, not just a switch. Tiny changes in the input to the “ion source” grid could control large power in the main one. In fact, we'd built a rather complex triode. In fact, it would even go into parasitic oscillations under a variety of conditions, as any amateur radio operator who has built a linear amplifier knows, these parasitics are usually NOT at a desirable frequency. In our setup, the frequency is very high – MHz, which is much faster than would sync with transit times of the various ion species we have in the fields we might reasonably have. The real resonance is beyond actual numeric computation ability at this point, we've asked the simulation software guys and they tell us this and refuse to take our money (and guys, thanks for being honest about that).

Further, we noticed that this happened most often at the edge of stability (the small more or less linear range of power gain between the grids), and while onsets were occurring. The steady state turned out, after quite a lot of data acquisition and analysis, to be the absolutely worst case for Q!

This happened a lot, with these crazy-high-good Q measurements, and I'm convinced that this is what others have reported the entire time, but dismissed. We did not do anything special here – it just “went off” into the mode, presumably tuned by the parasitic capacity, inductance, resistance in the circuits, and the transit times of the various species involved. Remember, this is a complex mix of electrons, D, D_2, (and those two can be neutral, positively charged or negatively charged via charge exchanges). That's a lot of “stuff”, and it seems to have emergent behavior – it's quite difficult to do the math here in practice. Who would have imagined such a simple equation in complex numbers, like $Z = Z^2 + C$, would ever have such a complex set of results as the Mandelbrot set, for example? The basic particle in field equations are about as simple as that, with the same idea – iteration – the last output of the system is the next input, except that we have attraction, repulsion, an imposed field, the field generated by the particles themselves, and various spring-mass systems going on, where the spring if the particle's charge and the *true field it see*s (not what we think we imposed, which is affected by the particles in it), while mass is simply its mass.

Further, armchair theorists have hugely misled the fusion community, without experimental data to back up what they say. They claim recirculation through the grid for example. Well, we don't see it here, and we've looked. Yes, a spring-mass system can have oscillations, but not gain – it always has losses, and with a DC input, there's no way to make up for those. Further, via charge-exchange (and other things) what we mostly see here is “once through and out”. Not only have we looked for the field fluctuations with the finest gear money can buy – and not found them – we HAVE seen rather large increases in fusion when the tank inner walls were implanted with fuel atoms. No guessing here, careful measurements that lead to facts are preferred. I often feel like the theorists think they know ecology of an anthill because they've studied just one ant. It's not that simple, guys.

Most fusors are build spherical, there's an emotional attraction to that shape, but we don't do it that way for a variety of reasons. Due to our realization that any shape electrode you put in a tank and put voltage on creates not only a field, but a non-uniform one that acts like an optical element for charged particles, we decided to design our “lens” with malice-aforethought to be a good one. Any book on electrostatic lensing will not show example that look the least bit like all of the spherical grids I've ever seen – and I will note that in 3d space, you cannot tessellate a sphere with uniform circles or anything else that would produce a good point focus. Even a bucky-ball kind of shape or level of complexity would be far too crude to produce the desired “compression ratio” we are looking for here. And with practical materials, you simply can't make even a bucky-ball without making it so opaque it's super-lossy, or simply won't hold up its own weight.

Cylindrical lenses don't have this issue (other than at the ends) and are easy to design and build to generate a line focus. So that's what we do here, and are still making incremental improvements. While we're not even to optical levels of precision, the simpler math would indicate we should (and should be able to) go to levels far more precise – on the order of the wave-function size (At FWHM) of the particles we want to focus would be nice! We are not even within a few orders of magnitude of that at present, so this is one of a few windows for what seems like a very reasonable way to improve.

Of course, at any real density, space charge effects will likely defocus our great lens – something that was worked out long ago by vacuum tube designers – the thing that causes a CRT to lose focus if the brightness is turned up too far. The particles of like charge do repel each other, else we'd not have to force them together in the first place! The one acknowledgment of the fusion community of the space charge issue seems to be when they think they can use it to create a "virtual electrode" that, using electrons, will draw in far heavier ions to collide there.

I hate having to remind people who pretend to be smarter than I that attraction and repulsion are bi-directional, and it's the lighter one that moves the most! That's a pretty huge sin of omission in understanding and only one of them that are widely considered to be "facts". Anything like a close look into basic physics of course demolishes all such silly arguments. That's just not how it works!

So, it seems we want to go for fairly low power density, short focal lengths to reduce the bad effects of space charge causing "blooming", and a few other things, like getting actual instead of fictional recirculation of the ions that we had to put in energy to ionize in the first place, that is, if we want Q rather than just a "star in a jar". We might be able to tolerate very much higher densities if they were "bunched" since by the time the particles "see" one another's fields, they are already "on course for collision" having come from a very diffuse state (2.2 e-2 millibar, or molecular flow) into a much more compressed state at focus – our "compression ratio" if you will let me use that term. We have experimentally witnessed the actual transition from molecular to viscous flow here, many times, but haven't quantified the actual "compression ratio" thus far (it's not trivial to measure with what we have). It is, however visually obvious, particularly if you can then direct that flow through something that would only turn it if it had a very short mean-free-path, as in "high pressure".
To coin a phrase, "nevertheless, it moves".

There are some other considerations here. Pauli's exclusion principle (never proven wrong or even a hint of that) says that identical quantum states are excluded (geometrically if I understand correctly) from happening. And D's have spin of =/- 1. Trying to make two fuse that have identical spin would violate this principle, yet to the extent the forces we currently use bring them together, they tend to also align spin in the worst way for fusion – it's only by accident that a collision or something of that nature flips a spin and allows for fusion at all! When we do have them spun correctly we get D+D->He, but sadly, it won't stay that way – this releases about 16 electron mega-volts worth of binding energy, so the resulting He breaks up unless we have a 3 body collision; theres not enough binding energy even in He, which has quite a lot, to hold it together at that energy. A photon can't carry off the extra because photons themselves have spin and there are conservation laws in operation here that prevent cheating on that. Which no one observes being broken, so for now I feel fairly safe standing on the shoulders of the giants of physics past.

I am only one experimenter working in one moderately well-equipped lab, and I can therefore only try so much per run, or do so many runs in a period of time. Theory (and math) has let us down in numerous ways, so it seem the experimental approach is the way to go here. I'm sure some eyebrows will go up over that statement about math. OK, where's my feedforward solution to the very “simple” 3 body gravitational problem? No perturbation and division into tiny time slices allowed, and tell me where Jupiter in a simplified solar system is in say, 100 years or more. I dare ya. Yet that's exactly the sort of math we need to solve this problem without sort of trying everything that may make sense! Has math become merely the princess of science? I'd submit that we're verging on “chambermaid” at this time, for the important questions. I wish I was wrong, but I don't think I am. Even recursive systems (Julia, Mandelbrot) aren't well defined without just trying something, and even though that's well known, Wolfram comes along claiming he invented it (see his book) – years after the real pioneers. Blind leading the blind in ignorance of history, as far as I can tell.

I'm not claiming to have invented the plasma triode – that seems to have been done by Phillips back in the 50's or so, not the guy 2 years ago who re-invented it and claimed all sorts of interesting applications in what used to be cool – plasma TVs. This was a PhD with no knowledge of things that have happened since my own birth – seems you can get a nice piece of paper without knowing too much these days. Or maybe I should soften that blow by calling it “not enough” these days to actually make a real advance, instead of adding a decimal point to something, or finding something that was already lying there.

But here we have a very interesting use for it. Like any active device with power gain, not only can it sustain oscillations, it can do so at more than one frequency at a time, in several distinct modes, from super-regeneration to reflex oscillations. And here we have a situation where those properties could be extremely useful. We might find that having the electrons bouncing back and forth at one fast frequency, yet controlled by bigger external fields than they alone generate might actually act as a useful virtual electrode for deuterium ions going a lot slower, but oscillating in space themselves. And have this drive them both! Of course, if that turns out to be impractical, we can always just drive this thing like the triode it is, with whatever arbitrary waveform we can generate - a little harder, takes an arb wave-function generator, but we have one of those too.

So, since I have to prioritize or dither endlessly, the next try is going to be taking advantage of this active device to see if we can't pull off something pretty elegant – using its own gain to drive particles around, flip spins, and make a nice transition from the lowest energy state (ions evenly spread throughout the tank) to a lower entropy state – ions of the correct spin all striking at the focus.

This seems to require no actually-new science, or violate any of the “laws”. Yet it would result in fusion Q numbers extremely larger than have been experienced so far – even in those “outliers”.

It's worth a shot, so that's what I'm doing next.