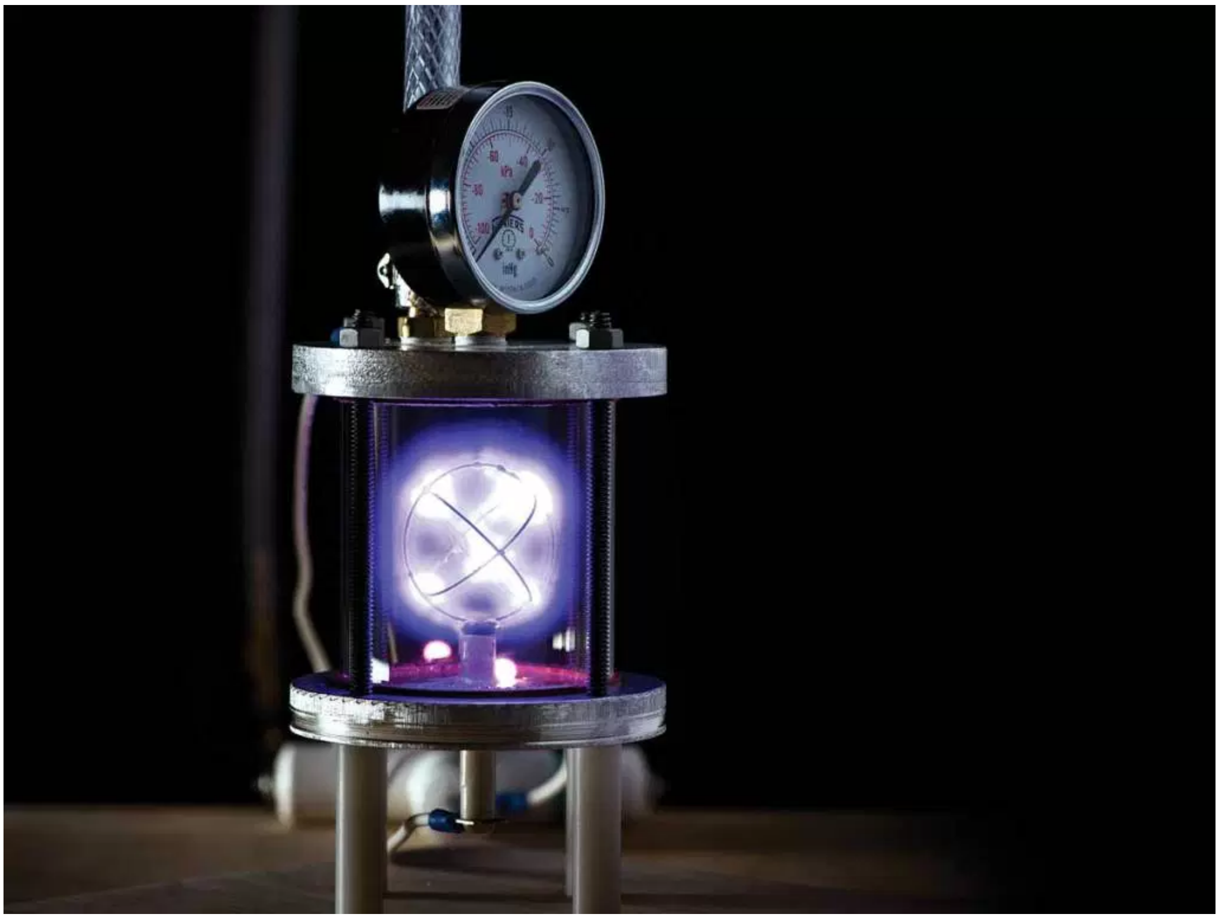
MAKE: PROJECTS

Learn How to Build a Nuclear Fusor

By **Dan Spangler**
Time Required: >16 Hours
Difficulty: Hard



Nuclear fusion is the process of squeezing two atoms together so tightly that their nuclei fuse, creating a heavier atom and releasing a blast of energy. Fusion creates the inferno inside the sun — and the hydrogen bomb — but no one has yet harnessed its enormous power for peaceful uses.

They've tried, however, often with skepticism. In 1989, physicists Martin Fleischmann and Stanley Pons announced they'd achieved "cold fusion" of hydrogen into helium at room temperature, only to face withering scorn when others failed to replicate their results.

Luckily, DIY nuclear engineers can achieve honest-to-goodness “hot fusion” right at home by making a Farnsworth-Hirsch fusion reactor, or fusor for short.

Nuclear Fusor

This mini fusor is a demonstration version — while it generates only insignificant quantities of fusion products, it does show how inertial electrostatic confinement (IEC) reactors use kinetic energy to cause fusion. It’s also a good introduction to high-voltage power supplies and vacuum systems. The skills the project imparts will help you tackle bigger fusors and other projects involving plasma and high-energy physics.

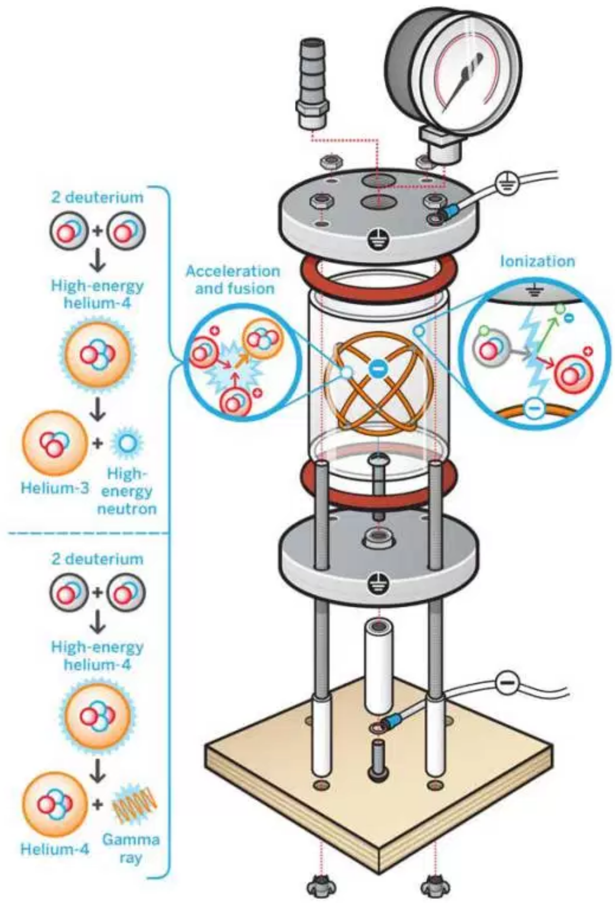
Plus, the fusor just looks totally cool. An eerie purple-blue glow emanates from the reactor, and a really well-made fusor can produce a mesmerizing phenomenon called a “star in a jar.”

Curious? Read on…

Warning

This project uses high voltages at potentially lethal currents. A high-vacuum apparatus may implode if improperly handled. This device may produce ultraviolet and x-ray radiation. Do not attempt to build or operate it unless you are capable of safely using high voltage and vacuum equipment.

How It Works



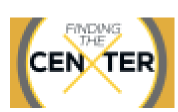
The typical Farnsworth-Hirsch fusor has two concentric electrical grids inside a vacuum chamber: an inner grid charged to a high negative potential, and an outer grid held at ground potential. Our benchtop version has a stainless steel wire inner grid, and uses the aluminum chamber walls as the outer grid.

A variac controls the AC mains voltage input to a neon sign transformer, which steps up standard 110V AC to the 10kV range. A homemade rectifier converts AC to DC power to charge the grid.

A vacuum pump evacuates the chamber to a pressure of about 0.025mm of mercury, clearing the playing field so the few remaining gas molecules can accelerate

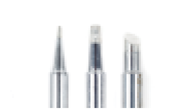
Skills Needed for this Project

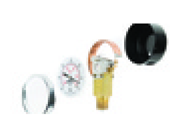

Skill Builder: Files



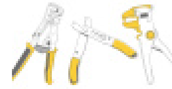
Skill Builder: Find the Center of any Circle


Skill Builder: PVC Pipe Tips for Your Next Project


Skill Builder: Understanding Different Soldering Iron Tips


Skill Builder: Quick Tips for Using Vacuum Gauges

without premature low-energy collisions. A vacuum gauge indicates the pressure inside.


Skill Builder: 4 Wire Strippers You Should be Using

High voltage across the grids causes gas molecules to ionize; that is, they lose an electron and become positively charged. Electrostatic forces then accelerate the ions — mainly O_2^+, N_2^+, Ar^+, and H_2O^+ — toward the high negative charge at the center. Some ions collide; those that miss the first time are arrested by the electric field and re-accelerated toward the center for another go.

Low-power fusors produce a beautiful purple ion plasma "glow discharge" similar to plasma globes and neon signs. In high-power fusors, the inertia of the ion collisions squeezes hydrogen atoms tight enough to fuse, hence the term *inertial confinement*.

High-power fusors typically fuse deuterium (D or ^2H) into helium and tritium. Deuterium is a hydrogen isotope whose nucleus contains a neutron in addition to the usual single proton. It occurs naturally in very low concentrations, primarily as hydrogen deuteride (HD) but also as "heavy water" (D_2O), "semiheavy water" (HDO), and deuterium gas (D_2). Only 1 in 6,000 hydrogen atoms is deuterium. Tritium (a hydrogen atom with two neutrons and one proton) is even rarer.

When two deuterium atoms fuse they create a high-energy helium-4 atom, which stabilizes itself by releasing a proton, a neutron, or a gamma ray. This release leaves behind a tritium atom, helium-3 atom, or helium-4 atom, respectively.

Fusor Nation

The fusor was developed in the 1960s by Philo T. Farnsworth, who also invented television. It's popular with DIY experi-menters because it's easy to build and can reliably produce fusion reactions.

Fusors have yet to produce useful power, but they can be dangerous. They require high voltages and can produce harmful ultraviolet, x-ray, gamma, and free neutron radiation.

IEC reactors are currently being studied at MIT, the University of Wisconsin-Madison, University of Illinois, Los Alamos National Laboratory, and EMC Corporation, among other labs.

PARTS / TOOLS

PARTS

Nylon spacers, unthreaded, 1/2" OD, 2" long, for 1/4" screws (4) McMaster-Carr #94638A29 or 94639A089

Threaded rods, plain steel, 1/4-20 × 7" (4) McMaster-Carr #91565A566

Barbed hose fittings, brass, 3/8" hose ID × 1/4" NPTF male pipe thread (2)

Oil cup cylinder, borosilicate glass, 3" OD × 2-19/32" ID × 3" high McMaster-Carr #1176K27, mcmaster.com

Spade terminals, 1/4" wide, for 16–14 AWG wire (8-11)

PVC pipe fittings, 1/2" nominal, slip fit: end caps (3) and tee (1)

Variable transformer, 110V–140V, 5A aka "Variac"

PVC tubing, flexible braided, 3/8" ID, 2' length Braided reinforcement keeps it from collapsing under high vacuum.

Hose clamps, for 3/8" tubing (2)

AC power cord, 3-wire, 4' (optional)

Mineral oil, 16 fl oz

Diodes, high voltage, 0.1A 20kV (2) Search **hvstuff.com** and buy extra in case you accidentally fry your rectifier.

Male plug with ground prong, (optional)

STEPS

Project Steps

1. Cut the chamber parts.

2. Cut the chamber parts (cont'd).

3. Cut the chamber parts (cont'd).

4. Cut the chamber parts (cont'd).

5. Cut the chamber parts (cont'd).

6. Install the feed-through.

7. Add the vacuum ports.

8. Fabricate the grid.

9. Fabricate the grid (cont'd).

10. Make the base.

11. Assemble the fusor chamber.

12. Assemble the fusor chamber (cont'd).

13. Assemble the fusor chamber (cont'd).

14. Plumb your fusor.

15. Make the high-voltage rectifier.

16. Make the high-voltage rectifier (cont'd).

17. Make the high-voltage rectifier (cont'd).

18. Make the high-voltage rectifier (cont'd).

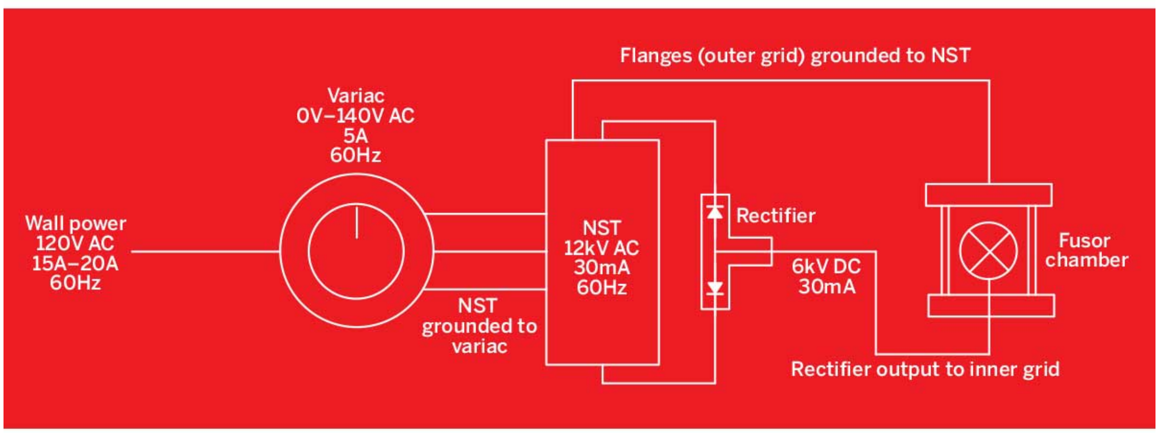
19. Wire the transformer.

20. Wire the fusor.

21. Test the vacuum.

22. Working with high voltage.

Step #22: Working with high voltage.



- Our fusor is a relatively low-power version, with its components grounded to minimize the danger of shock. Still, accidents happen. Here's what you need to know to stay safe.
- Electricians have a saying: Volts hurt, amps kill. Current is more dangerous than voltage — just 10–20 milliamps (mA) of alternating current (AC) can cause muscle contractions that prevent you letting go of the electrified object, and 70mA–100mA can cause heart fibrillation and death.
- Household AC wall power is typically 120 volts at a lethal 15 amps of current. And it alternates at 60Hz frequency, which can also cause fibrillation. It's very

hazardous.
- The variable transformer modulates wall power up to 140V AC at 5A current — lower, but still a real electrocution hazard.
- Next, the neon sign transformer steps up the voltage to a high 12,000V AC and slashes the current to 30mA — unlikely to cause fibrillation but still above the “let-go threshold.”
- Finally, the rectifier converts AC to DC — direct current — at 6,000V, 30mA. That’s half the voltage of the NST output, and falls below the let-go threshold for DC current (about 75mA). But it can still be deadly, as DC causes worse contractions and tissue burns than AC.
- So be sure to wire your fusor correctly, and avoid touching any part of it during operation except the variable transformer knob. And when in doubt, ask an expert before proceeding.

CONCLUSION

Running Your Fusor

Plug the transformer’s power cord into the outlet on your variac, then plug the variac into the wall outlet. Don’t switch the variac on yet.

Turn on the vacuum pump, wait for the gauge to reach 0, then wait another 2–5 minutes to reach deeper vacuum. Leave the pump running. Now switch on the power for the variac and slowly turn the knob, increasing the voltage fed through the transformer.

If everything works, you should see a bright purple discharge inside the chamber, and as you turn up the voltage a defined plasma ball will form inside the grid, with the occasional plasma beam leaching out through one of the grid openings. If you’ve built carefully, you may achieve the coveted “star in a jar”: a glowing plasma ball with fine plasma lines radiating out in all directions through the grid openings.

Congratulations, you have successfully built a demonstration fusion reactor based on the principle of inertial electrostatic confinement!

Never run your fusor for extended periods of time. A minute or two is plenty. Plasma beams escaping from the core may spot-heat the glass and cause it to implode. Make sure that you and everyone nearby wears ANSI-approved safety goggles whenever the cylinder is under vacuum.

Warnings

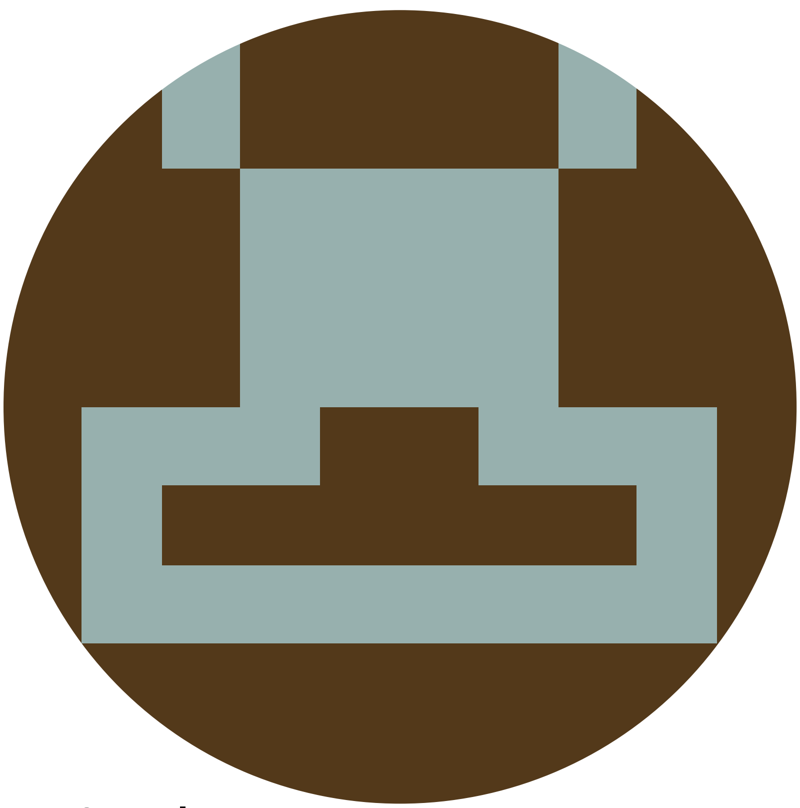
Glass vacuum chambers can implode. Do not operate the vacuum system without safety goggles. Reminder: High voltage and current can injure or kill. Fusors may generate harmful radiation. Do not attempt to build or operate this fusor unless you understand the risks and are capable of safely using high voltage and vacuum equipment. Do not run this device at more than 12kV rectifier input.

Troubleshooting

When you first ignite your reactor, you may see sparks and arcs on the inner grid. As long as these don't persist in one spot, it's fine — just bits of dust and debris burning off, and after a while the sparks will stop. But if arcing persists, you've probably got carbon deposits, which will continue to arc. This can be dangerous, so stop and clean the chamber thoroughly before proceeding.

If the glow discharge is deep purple, the seals are probably leaky; check the gaskets and reapply vacuum grease. With a good vacuum, you should see a bright, almost-blue purple glow.

This project first appeared in MAKE Volume 36, page 90.



Dan Spangler

Dan Spangler is a freelance maker with a passion for fabricating speed, high voltage, and the things that go boom.