Stellarators

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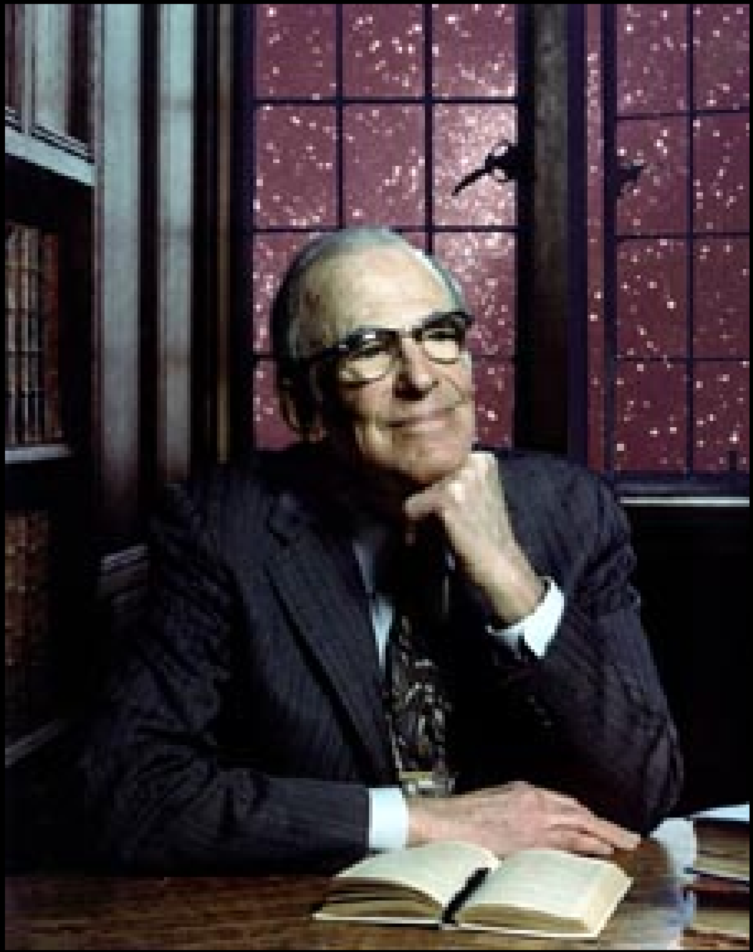
Background image courtesy of Wikipedia.

Overview

- What are stellarators?
- Where did they come from?
- How do they work?
- Why should we care about them?

The Story of the Stellarator

- In 1951, Project Matterhorn came about
- Lyman Spitzer proposes magnetic confinement in a figure eight pattern
- Magnetic confinement for fusion



Courtesy of NASA.

More Historical Facts

- Fusion remained classified until 1958
- First research in the US was done at Princeton
- Sahkarov and Tamm proposed tokamak design in 1950, wasn’t internationally known until 1956

How do stellarators work?

- Goal is to keep ions as close as possible to each other, without getting gas too dense
- As we've seen, need toroidal and poloidal magnetic fields
  - Toroidal field to keep charged particles moving along circular field lines
  - Poloidal field lines to keep particles from drifting

How will we do this?

Some math

$$P_N = \pi a^2 EN$$

$$N = \alpha n_1^2 \rightarrow \alpha = S_1 S_2 \int_0^\infty v\sigma P(v)dv$$

$$nkT = \frac{xH^2}{8\pi} \qquad n_1 = \frac{n}{1+z}$$

$$P_N = \frac{\alpha x^2 a^2 EH^4}{64\pi(1+z)^2 k^2 T^2}$$

For standard D - T conditions

$P_N = 37{,}000$ Watts/cm

Some more math

Lose some energy to radiation of ions

$$P_R = \frac{a^2 E z^3}{(1+z)^2} \frac{e^2 h}{3 m_e^2 c^3} \left(\frac{kT}{2\pi m_e} \right)^{1/2} \frac{x^2 H^4}{\pi^2 k^2 T^2} \approx 510 \text{ Watts/cm}$$

Lost energy due to creating magnetic field

$$P_H = \frac{25}{4\pi} \frac{r_2 + r_1}{r_2 - r_1} \frac{H^2}{\sigma_{con}} = 11{,}000 \text{ Watts/cm uncooled}$$

$$P_H = 2{,}200 \text{ Watts/cm cooled (but not superconducting)}$$

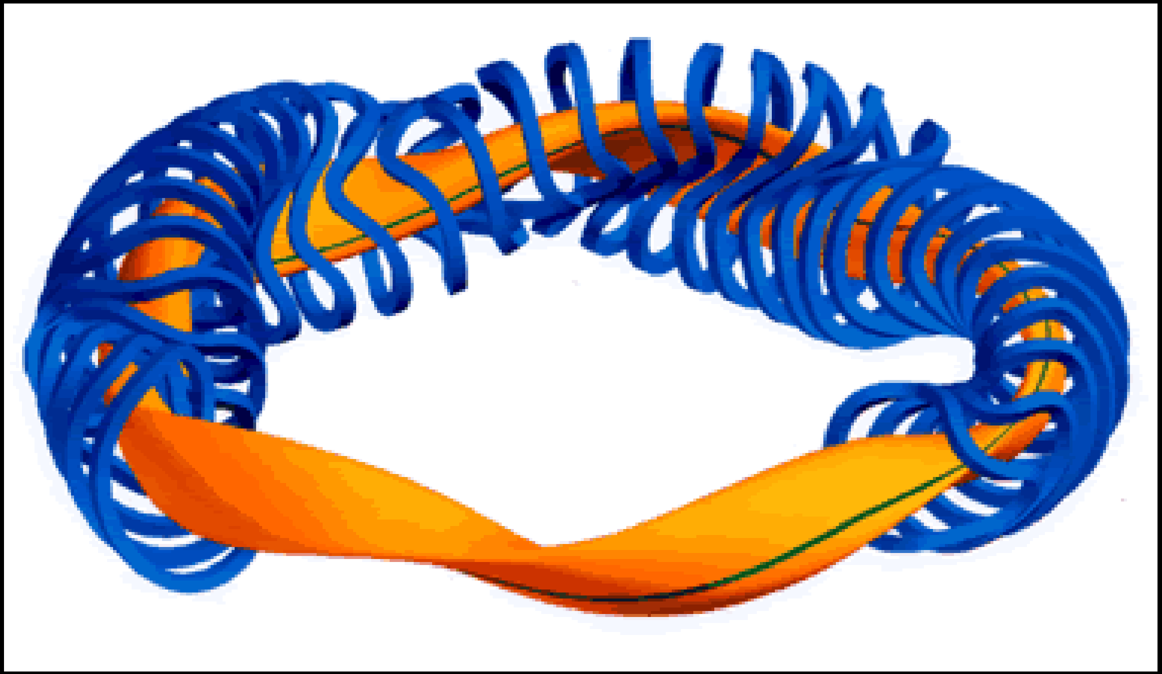
Did we forget something?

- Calculations show we should have net 34,290 Watt/cm power gain
- But what about poloidal field?
- Plasma will crash into wall in our model
- Clearly needs refinement

So what happens now?

- Tokamaks, that's what happens now
- 1956, tokamaks show up
- Federal funding shifts to other areas of fusion, including tokamaks, other forms of torii, and inertial confinemen
- Spitzer's figure eight abandoned

Why are stellarators back?



Courtesy of Wikipedia.

- Problems with inducing plasma current in tokamaks, disruptions
- Computational power increases
- Better understanding of MHD

Experiments through the Ages

- US, Japan, Germany, all continued or developed programs to investigate stelarrators
- Reduced damage from disruptions, continuous operation made this a possibility
- So what’s out there now?

Large Helical Device

Figure removed for copyright reasons.
Photo of LHD in Nagoya, Japan.
See http://tempest.das.ucdavis.edu/pdg/image003.jpg

- Located in Nagoya, Japan
- Turned on in 1998

Info on LHD

- Largest superconducting stellarator in the world
- Major helical radius 3.9m
- Max helical field 6.9T
- Three poloidal coils of varying size, strength

Figure removed for copyright reasons.
Image of poloidal coils.
See image at http://www.lhd.nifs.ac.jp/en/lhd/LHD_info/coil.html

Results at LHD

- T=10keV for electrons
- T=13.5 keV for ions
- 0.36s confinement time
- Plasma duration of 3900 seconds

Figure removed for copyright reasons.
See Reference 1.

Wendelstein 7-X

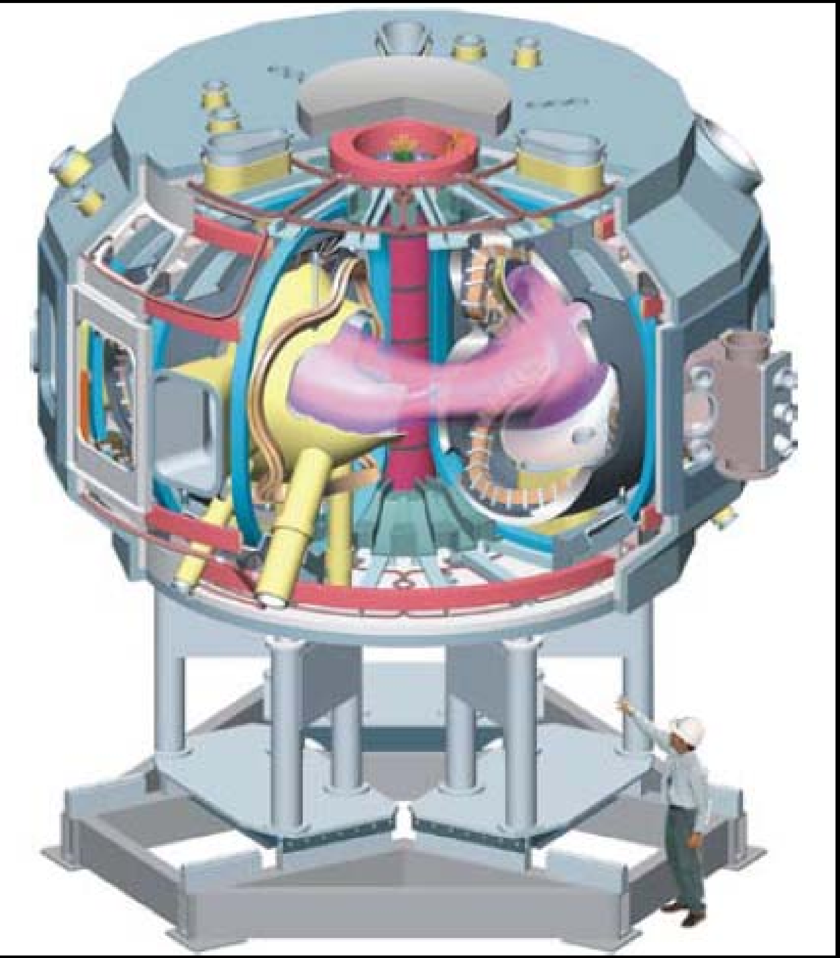
- Located in Garching, Germany
- Currently in construction
- Scheduled to start up in 2011
- Superconducting magnets
- Proof-of-concept experiment

Info on W7-X

- Field of 3T
- Max T=60 million K
- Max radius 5.5m
- Discharge time of about 30 minutes, steady state with RF heating
- 5-30 milligrams of material

National Compact Stellarator Experiment

- Based out of Princeton Plasma Physics Lab (PPPL)
- First plasma in 2009
- Demonstrate feasibility of smaller, compact stellarators



Courtesy of the Princeton Plasma Physics Laboratory.

Some NCSX Facts

- Compact size requires high fields, high densities
- Major radius 1.4m
- 1.2-1.7T field
- Uses 12MW heating

So what's the problem?

- Stellarators are expensive
  - Billions, not millions, of dollars
- Stellarators are not modular
  - Custom design and implementation for each coil makes repair/modification difficult
- Stellarators are still big unknowns
  - Still a lot of unanswered questions: how to remove power, how to control plasmas, how to maximize efficiency

The Future of Stellarators

- Up in the air at this point
  - Success of experiments
  - Success of ITER
  - Advances in technology
- May work in the distant future, but not before we know about ITER
- Still a good source of plasma science

References

- CTIX website, http://ctix.das.ucdavis.edu/default.htm
- PPPL website, http://www.pppl.gov
- LHD website, http://www.lhd.nifs.ac.jp/en/lhd/LHD_info/coil.html
- WX-7 website, http://www.ipp.mpg.de/de/for/index.html