Physicists “flip the D” in tokamak, get unexpectedly good result

Enlarge / “Small” isn’t necessarily all that small when it comes to tokamaks like the DIII-D.

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In the world of fusion physics, two letters say it all: ‘L’ and ‘H’. All the cool kids play with the H-mode, which is hot and fiery and is our best prospect for achieving useable fusion energy. The L-mode, which is neither hot nor fiery, has been largely abandoned. But by changing the shape of the L-mode, researchers have been able to get unexpectedly high pressures. High enough for fusion? Maybe.

To understand what all that means, we need a quick refresher on what a tokamak is.

We’ve covered fusion physics before, but in short, a tokamak reactor uses a series of twisted magnetic fields to confine a fluid of charged particles (called a plasma) in a donut shape. The temperature and pressure of the plasma is the key to fusion; once it’s hot enough, the positively charged nuclei will collide to fuse, releasing gloriously large amounts of energy.

The problem with plasmas and magnetic bottles like tokamaks is that the motion of the plasma needs to *create* parts of the

magnetic field that confines it. Researchers discovered that this dynamic led to two different types of bottles. One bottle confined the plasma tightly and was called the H-mode. The other, called the L-mode, didn’t confine the plasma very tightly.

High-strung H-mode, stoner L-mode

The H-mode is highly unstable, with something called an “edge localized mode” giving physicists sleepless nights. This mode is the product of fluctuations that, as the name suggests, start at the edge of the plasma and can grow rapidly. Once they get large enough, they can, in the words of physicists, transport a large number of particles into the reactor wall. This is a long way of saying that the reactor will be converted into a slowly cooling puddle of slag.

The L-mode does not confine plasma very tightly. As a result, the temperature never gets very high, and fusion is unlikely to ever happen. Worse, the L-mode leaks badly—a constant stream of particles leave the plasma and hit the wall. On the plus side, none of this happens suddenly; the L-mode’s instabilities seem easier to deal with, meaning that interest in it has never quite died away.

One of the reasons that the L-mode wasn’t very good may lie in its overall geometry. Neither the L nor the H-modes are donut-shaped. Sure, they both form a ring, but a cross-section of the ring would show two ‘D’ shapes that are mirror images of each other. The flat part of the Ds are located on the inner side of the ring.

In a set of experiments conducted at DIII-D, an old tokamak in San Diego, researchers reversed the orientation of the D shape. In this configuration, the flat side of the D is on the outside of the ring. Since the vessel shape and power handling are all designed around the standard D-shape, this limited the amount of power that researchers could put into the plasma.

Plasma under pressure

Nevertheless, the researchers gritted their teeth and did it anyway. The results were a bit surprising. Despite heating the plasma well beyond where the H-mode normally appears, it failed to materialize. Instead, the plasma stayed in the L-mode. At the same time, the pressure ramped up to reach values equivalent to those required in a fusion reactor. The energy stored in the plasma was also much higher than expected based on the normal H-mode—both very promising signs.

Now, we should be careful here. In practice, DIII-D can never reach the right temperature or pressure for fusion, because it's not big enough. However, fusion researchers know how the temperature and pressure scale between differently sized machines. That allows the researchers to state (with good confidence) what the temperature and pressure would be in any other tokamak and thus what the implications of these results are for fusion.

The researchers also looked for indications of various instabilities and found many promising signs. For instance, the fluctuations in the electron density (one of the warning signs for an instability) were lower compared to the H-mode with the traditional D shape. Even better, a closer examination showed that most of the energy in the fluctuations was at lower frequencies (compared to the H-mode), meaning that any instability would grow more slowly.

Rebuild a tokamak?

The next step is to ramp up the power even more. That may be difficult, though, because of the design choices that have been made at most tokamak facilities. It will almost certainly take some physical modifications to the vessels themselves before we can test this approach in them. And as the researchers state, there is no certainty that the H-mode won't

reappear once the temperature gets up.

Even if the H-mode does return, there are some more advantages to reversing the D. The reverse-D shape requires that the diverters—the plasma is vented onto blocks of material called a diverter—are located at the outer wall of the torus. This means that the surface area of the diverter can be increased and that the material that the diverter is made from is more likely to survive. That in itself may be worth the price.

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