The secret world of amateur fusion

Nuclear fusion is not just the preserve of professional physicists. It is also pursued by a small but growing band of amateur "fusioneers", whose work might, one day, lead to a new source of energy. **Edwin Cartlidge** reports

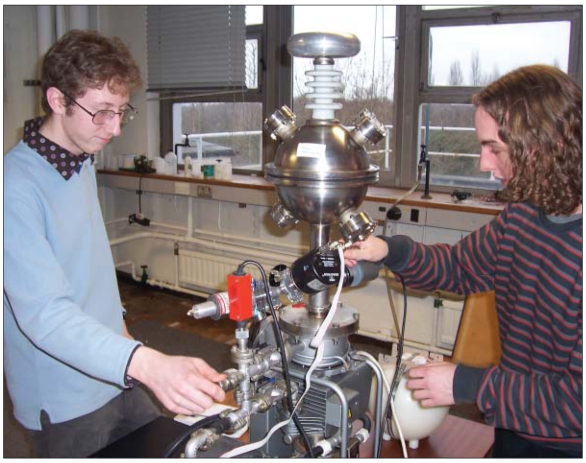
The idea of harnessing the process that powers the Sun has been a dream of scientists for decades – and it is easy to see why. Generating energy by fusing light nuclei together would produce little radioactive waste and no greenhouse gases. There is an almost limitless supply of fuel in seawater and there would be no danger of nuclear meltdown. But actually making a practical fusion-energy source is a huge technical challenge, and massively expensive.

The International Thermonuclear Experimental Reactor (ITER) has been designed to show for the first time that fusion reactions can produce substantially more energy than they consume, and is due to switch on in about 2016. But this device, which is being built in the south of France and is being developed by thousands of scientists across the globe, is an enormous undertaking. Weighing some 20 000 tonnes, it will cost about €10bn in total. And even then it is not guaranteed to work.

Contrast this with the device that sits on a bench in the corner of a quiet laboratory at Cambridge University. Like the reactors built by professional scientists, this machine can be used to create fusion reactions – tens of thousands of deuterium–deuterium reactions per second. But this device, known as a "fusor", cost about £3000 and was put together by two secondary-school students in the garage of one of their parents' houses in Torquay. One, Henry Hallam, is now a second-year engineering undergraduate at Cambridge and the other, Fergus Noble, will start a natural-sciences degree later this year.

Much of the equipment used by Hallam and Noble to make their device was scavenged from various sources. The transformer needed for the high-voltage power supply, for example, was taken from a 1920s X-ray machine, and the neutron counter was bought on the eBay website. Only the vacuum pump was bought from a specialist company, while the steel ball, inside which the fusion reactions take place, was manufactured by a local machine shop to the pair's own design.

Hallam and Noble are two of about 20 amateurs who, over the past 10 years, have generated nuclear reactions inside fusors. It is highly unlikely that the machines built by these self-styled "fusioneers" will ever produce more energy than they consume. Indeed, the motivation for many of the enthusiasts is as much about the satisfaction of building an unusual device that works – or as Hallam puts it, "to be able to control one of the fundamental forces of nature" – as it is about creating a new energy source. But there are those who believe that a variation on the fusor could one day be used to produce useful amounts of energy, and do so far more cheaply than conventional reactors.



Edwin Cartlidge

Fusion enthusiasts Henry Hallam (left) and Fergus Noble built their fusor in a garage.

Fusioneers can be divided into three groups: "scroungers", "Plasma Club" members and "Neutron Club" members

The power of fusors

The basic reason that fusion has proved so difficult to carry out on Earth is because of the huge amount of energy needed to force two positively charged nuclei together. In the deuterium–tritium reactions that will take place inside ITER each nucleus will have to have an energy of at least 4 keV in order to fuse. But because the nuclei in ITER exist as ions in a plasma that is in thermal equilibrium – in other words the energies of the particles follow a Maxwell–Boltzmann distribution – the plasma must be heated to temperatures of tens of millions of Kelvin in order that a significant number of the ions possess the required energy. Furthermore, the plasma must be kept away from the walls of the reactor if it is not to lose heat, which means holding it in place with enormous and very costly magnets.

In the 1950s engineer Philo Farnsworth thought he could overcome these problems by adapting technology from earlier work he had carried out in the development of television. In essence, he proposed imparting individual ions with the energy needed to fuse by accelerating them inside a vacuum tube and then allowing them to recirculate via electrostatic forces acting between a hollow inner electrode system and the fusion reactors' chamber wall. This is an approach he called "inertial electrostatic confinement" (IEC). The voltage needed for this can be as low as 10–20 kV, a level typically found inside televisions.

Unfortunately Farnsworth's fusor has never been made into a practical energy source. His original model, in which ions were injected into a cylinder using small accelerators, was upgraded in the 1960s by a colleague of his – Robert Hirsch – and it is this model that is still used by fusioneers today. It consists of two concentric spherical steel grids – with the outer acting as positive electrode and the inner a negative electrode – contained within an outer steel sphere filled with a dilute fuel gas. The outer electrode ionizes the gas, with the ions then drawn towards the inner electrode and into the central reaction area where they fuse, producing neutrons and energy. There does, however, appear to be a fundamental limit to the amount of energy that such a device can produce. This is because not all of the accelerated ions fuse – some pass through the target area completely while others either do not have the energy to fuse or hit the inner electrode and generate waste heat.

Despite these problems, Hirsch's fusor has been commercialized as a neutron source – providing a smaller, cheaper alternative to nuclear reactors and particle accelerators. It has also been the reactor of choice for enthusiasts. These fusioneers, most of whom live in the US, communicate with one another via their own website, fusor.net, and can be divided into three groups, according to Richard Hull, the first amateur to generate fusion reactions. "Scroungers", as they are affectionately known, are those looking for components to build their own machines. Members of what Hull calls the "Plasma Club" are those who have built a fusor and are putting it through its paces using air or other gases, while those in the "Neutron Club" have actually created fusion reactions in their fusor.

According to Hull, interest in fusors is growing rapidly. This interest is boosted by periodic success stories in the media, such as that of 17-year-old Thiago Olson, who was reported by the *Detroit Free Press* last November as having achieved fusion in the basement of his parents' home. "Most new visitors to the website move on after a while, but there is always a small cadre that sticks around, of which one or two may actually assemble hardware," Hull adds.

Adam Szendrey

Bright spark
This photograph of the core of a fusor was taken by fusioneer Adam Szendrey.

Future energy

While amateurs are busy in their basements and garages building their own IEC devices, there are also a handful of professional scientists carrying out research in this area. One of them is physicist Robert Bussard, who helped found the US fusion programme in the 1970s. At the end of 2005 Bussard's company, EMC2, obtained promising results from a variant on the Farnsworth–Hirsch fusor. He says that this machine, which creates a negative potential well for fusion reactions using electrons trapped in quasi-spherical magnetic fields rather than using a grid electrode, produced deuterium–deuterium fusion reactions at over 100 000 times the rate achieved by Hirsch's machine when using the same voltage.

Bussard believes that a larger version of the device could generate useful energy, and that this reactor could be made within four to six years at a cost of between \$150m and \$200m. Unfortunately, however, the US Navy cut Bussard's grant, which forced his lab to shut down a week after achieving its results. "We are probably the only people on the planet who know how to make a real net-power clean-fusion system, and we are out of support!" he wrote on the fusor.net site.

Bussard's work has, however, drawn enthusiastic support from others working on fusors. University of Illinois engineer George Miley, who is developing a cylindrical fusor as a neutron source for detecting explosive or nuclear materials, believes that Bussard's proposal has real potential. He also points out that his former graduate student Hyung Jin Kim, now at Fermilab, has carried out promising theoretical research of his own on scaling up fusors.

Others, however, are more sceptical. Karl Lackner from the Max Planck Institute for Plasma Physics in Garching, Germany, says that Bussard's concept is similar to the "mirror" fusion devices developed in the 1970s that suffered because electrons were lost at the cusps of their magnetic fields (i.e. where the field was not spherical). For Lackner, there is nothing in Bussard's proposal that would suggest his device can overcome this problem. "Using phrases like 'quasi-spherical' magnetic fields sounds beautiful to a layman but is about as misleading as calling a sieve a 'quasi-bucket'," he adds. Even fusor enthusiast Hull is not convinced. He believes that Bussard must carry out more tests if his idea is to have any credibility, and that IEC, like any other form of fusion, is "miles from the goalpost".

But whether or not IEC could ever be used as the basis for a practical energy source, fusors do provide a useful way of teaching young people about physics. Engineer John Hendron, for example, points out that in 2001 his then 15-year-old daughter and her friend built a fusor at their school, Coleraine High, in Northern Ireland. "If others see that two teenage girls can do this, then maybe they might try doing something similar themselves," he says.