Nuclear Fusion

John Fleming

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The energy sources we currently rely on today are less than ideal. Carbon based fuel is the most accessible and consumable fuel but in the environmental cost is perhaps the greatest of the fuel sources, contributing about 2 parts per million of carbon dioxide in the atmosphere every year (Wikipedia, Carbon dioxide in Earth's atmosphere). With dwindling supplies of easily accessible fossil fuels, more environmentally costly methods are being used to obtain them such as: deep sea oil drilling and oil sand processing for oil, and mountaintop removal for coal. Nuclear fission is a compact and powerful source of energy, but potentially dangerous in catastrophic circumstances, as the recent events in Japan have shown. Alternative sources of energy such as hydroelectric, geothermal, wind, tidal, etc. are excellent supplements but are not likely to fully supply energy to a growing modern economy. For the best source of renewable and clean energy we need only look to the stars. Nuclear fusion, the energy that has shaped the surface of the earth since its inception, and ultimately brought life to our planet is perhaps our best bet for energy in the future as fossil fuels reserves dwindle to nothing. Nuclear fusion, however, has some significant engineering obstacles to overcome, and some bad press to make up for as result of some fishy claims from cold fusion proponents.

Nuclear fusion is the fusion of atoms together into a larger atom and it releases energy when atoms smaller than iron (such as hydrogen) form nuclear bonds in the nuclei of atoms. The nuclear force is such that it only acts over very short range (1 to 3 millionths of a nanometer), thus to form a nuclear bond, the nuclei of the atoms must get very close to one another to form nuclear bonds (Wikipedia, Nuclear Force). The major obstacle to this is a repulsive electric force that acts over a much larger distance. The first obstacle is the electrons which will repel neutral atoms before nuclei even get close. In a plasma state this obstacle is not as significant because the electrons are stripped from the atom. However, protons exert a repulsive force strong enough that enormous amount of energy must be present in the kinetic energy of the nuclei to get them close enough together to be within the range of the nuclear force, and overcome the electrostatic forces of the nuclei. This is called the Coulomb barrier and it is why fusion doesn't occur in the relatively cold temperatures of common experience. In stars the gravitational force acts on the mass of the star to bring the mostly hydrogen gas to a temperature and pressure high enough to force hydrogen atoms to fuse into helium. This releases an enormous amount of energy, so much so that the fused nucleus loses mass in the form of pure energy.

Selecting the right kind of fuel for fusion reactions is important and a DT fuel mix of deuterium and tritium is the usual approach because this fuel "burns" more rapidly at the relatively low temperature of around 100 million Kelvin than any other fuel considered (Fowler, p.10). Also, deuterium, an isotope of hydrogen with one extra neutron is found in abundance in Earth's oceans at 1 part in 6420 (Wikipedia, Deuterium), and tritium (with two neutrons) can be produced artificially. The byproducts of the fusion reaction are a neutron and a helium atom (an alpha particle).

$${}_{1}^{2}D + {}_{1}^{3}T = {}_{2}^{4}He + {}_{0}^{1}n + 17.6MeV \qquad \text{(Niu, p.11)}$$

The extreme gravitational force of the sun can not be simulated on earth. So the major engineering difficulty of fusion research has been heating the plasma fuel to extreme temperatures and containing it. Because of the electrical properties of the plasma DT gas, magnetism can be used to keep the plasma contained within a region. The most widely accepted and currently effective design for containing the plasma using magnetic fields is the tokamak, invented by Russian physicists Igor Tamm and Andrei Sakharov (Wikipedia, Tokamok). The tokomak a chamber shaped like a torus which produces two magnetic fields: a toroidal field travelling through the inside of the torus, and a poloidal field circling around the sides of the tokamak. These fields combine to produce a helical field which contains the plasma within a certain radius as it travels around the tokamak. The toroidal field is produced by superconducting magnets surrounding the tokomak and the poloidal field is produced primarily by the current induced in the plasma. One problem that makes these reactors less efficient and dissipates a lot of energy is the release of radiant energy in the form of x-rays, which a magnetic field has no effect on (Fowler p.20). An international project called International Thermonuclear Experimental Reactor, ITER, is currently in development to produce a tokomak has the capability of a tenfold gain in energy to what's been put in (Wikipedia, ITER).

Another method for obtaining fusion is inertial confinement fusion or ICF. This is accomplished by blasting lasers at a small pellet of a deuterium-tritium gas/solid mixture. The rapid heating of the surface causes the solid outer shell to explode off the pellet, which in turn, causes the inner gas mixture to implode where hopefully it will reach a temperature and pressure high enough to where the gas "ignites", or undergoes nuclear fusion. The exploding surface takes away 90% of the energy from the laser leaving only 10% of the energy in the system to the imploding core, making this a relatively inefficient way of obtaining fusion energy. (Fowler p.138) The most powerful experiment of this design is the National Ignition Facility based in Livermore, California. The energy stored in the capacitors of this machine can hold 422 MJ, but the energy is released in a few billionths of a second making the power around 500 TW. (Wikipedia, National Ignition Facility)

In conclusion, fusion is still very much in the research stage, with no commercially viable fusion plants online yet. However, with research being done right now, on the NIF, and with ITER coming online within the next decade, we may yet see if fusion can become a truly viable source of energy for the world, and if so there is a lot of work to be done.

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