Nuclear Fusion: A Holy Grail of Clean Energy

Lou-Chuang Lee
Institute of Earth Sciences, Academia Sinica, Taipei

Energy is what runs the modern world. Fossil fuel is the most common source in our daily life. However, the greenhouse effect due to carbon emission and the limited reserve of fossil fuel drives humans to find alternative sources of energy. The discovery of nuclear fission can be traced back to early 1900s. In nuclear fission, a heavy nucleus is splitting into two or more lighter nuclei and emit neutrons and energy. After the disasters in Three Mile Island, Chernobyl and Fukushima, there are more and more people protesting against nuclear fission power plants.

In nuclear fusion, two nuclei collide at a very high speed to form new nucleus (nuclei). The by-products are much less hazardous to even hazard-free. In conventional fusion reactors, a thermal plasma with temperature of tens to hundreds of keV is confined by strong magnetic fields in a complicated helical configuration. The super-thermal plasma inside the strong magnetic field could lead to intensive plasma instabilities and cause difficulties for sustaining the plasma confinement. Examples of such machines are tokamaks. The largest tokamak in the world so far is built by several countries under the megaproject of International Thermonuclear Experimental Reactor (ITER). In the past 60 years, many efforts have been devoted into this study, but so far break-even power gain has never been reached.

In this talk, I will present a new approach to achieve clean proton-boron fusion,

$$^{1}p + {}^{11}B \longrightarrow 3\,{}^{4}He + 8.68\,MeV,$$

where no neutron is produced. This approach has resulted in the first-ever observed break-even power gain in fusion. In this new method, weakly ionized hydrogen gas (the density ratio of charged protons to neutral hydrogens is only $10^{-4} - 10^{-6}$) in a cylindrical device is driven by Lorentz force to obtain high-speed rotation, leading to a strong centrifugal acceleration. Particles are compressed toward outer boundary of the cylindrical device by the centrifugal force, and a high-density layer of neutrals is formed. Such a high density of neutrals and borons can effectively increase reaction rate of fusion and suppress plasma instabilities. Meanwhile, a large number of free electrons are produced by a low work-function target (LaB_6), providing high electric fields to lower the Coulomb barrier between two nuclei and hence also increase the cross-section of fusion reaction. The time duration of operation in this design so far has reached from several seconds to one hour. A net energy gain is observed through recordings of temperature changes in the coolant and chamber components, and the ratio of output to input power can reach 6 to 10. This new approach can generate clean and safe energy from nuclear fusion to replace fossil fuels, leading to deep decarbonization. It can provide a long-term solution to the energy and global warming problems.