NUCLEAR FUSION – UNLIMITED GREEN POWER

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Abstract. *The power of stars, driven by nuclear fusion, holds immense potential for addressing our energy needs. Fusion involves small atoms combining into larger ones, releasing substantial energy. This process, occurring in stars like our Sun, powers Earth's weather, and water cycle, and sustains flora and fauna. Fusion's energy source lies in the mass of particles, particularly the binding energy of atoms. Comparing different elements, the fusion of small elements surpasses the energy potential of fission in heavy atoms. Practical fusion processes, like combining deuterium and tritium, yield helium and spare neutrons, releasing substantial energy. Despite technological challenges, researchers aim to replicate star-like conditions on Earth, requiring temperatures exceeding 100 million degrees Celsius. Promising technologies include torus-shaped tokamak reactors. Achieving sustained fusion for net power production remains a crucial milestone. Fusion's advantages include abundant fuel sources like deuterium from seawater, minimal greenhouse gas emissions, and no significant radioactive waste, making it a promising green energy solution. While challenges persist, fusion's potential as a clean and abundant energy source fuels ongoing research, offering a transformative solution for the future.*

Keywords: *nuclear fusion, reactor, deuterium, tritium, helium, neutron.*

Introduction

The dazzling stars that light up the night sky are colossal fusion reactors. Within their fiery hearts, tiny atoms merge into bigger ones, releasing tremendous energy that fuels the universe. This unimaginable power source is exactly what we aim to recreate on Earth. Imagine a world free from energy limitations, a future where a clean and abundant source powers our civilization's progress.

Unlike nuclear fission, which splits atoms, stars rely on fusion, a process where atoms combine. This reaction generates the light we perceive as sunlight, driving our planet's weather patterns, water cycle, and sustaining all life forms. By harnessing this stellar power on Earth, we can eliminate energy scarcity and usher in a new era of human advancement.

1. The Nuclear Fusion Reactor

Nuclear fusion reactors are complex machines designed to replicate the process that powers stars like our warm Sun. They aim to achieve this by heating a gas, called plasma, to incredibly high temperatures (approximately 100 million degrees Celsius). This hot plasma is then confined using powerful magnetic fields, forcing the nuclei of light elements like deuterium and tritium to fuse together. When fusion occurs, a tiny amount of mass is converted into a tremendous amount of energy according to Einstein's equation $E=mc^2$. However, achieving sustained fusion and extracting usable energy remains a significant challenge. Researchers are actively developing two main approaches: tokamaks, shown in Fig. 1., which use the magnetic field generated by the plasma itself, and stellarators, which employ more complex magnetic coil configurations, Fig.2.

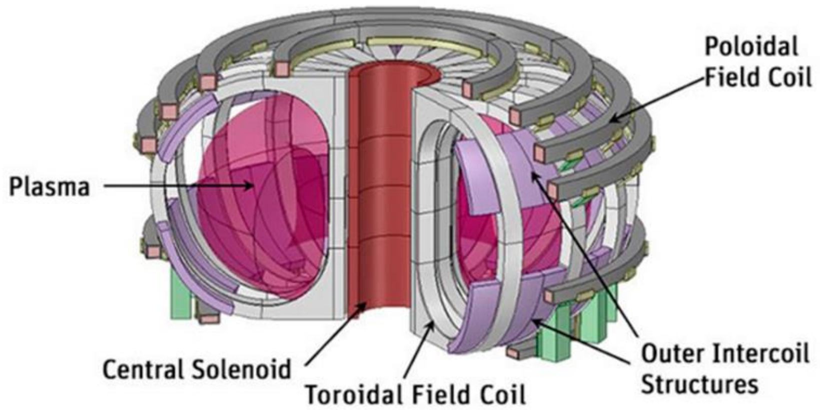

Figure 1. Tokamak [7]

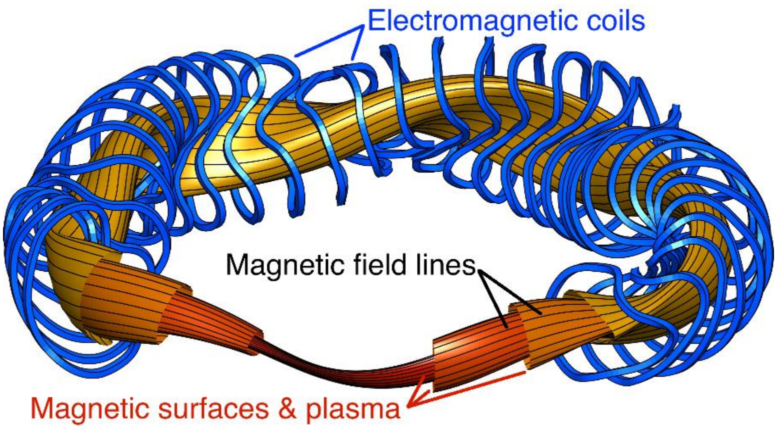

Figure 2. Stellarator [8]

2 International Thermonuclear Experimental Reactor

The International Thermonuclear Experimental Reactor (ITER) aims to harness the power of nuclear fusion to generate energy. At its core is a machine known as a tokamak, shown in Fig.1, a concept conceived by Soviet scientists in the 1950s. A tokamak is a doughnut-shaped structure containing powerful superconducting magnets both internally and externally. The principle involves creating a hot plasma, the fourth state of matter, by combining two isotopes of hydrogen - deuterium (^2_1H) and tritium (^3_1H). This plasma, suspended within the tokamak by the magnets, reaches extreme temperatures where fusion reactions occur, converting hydrogen isotopes into helium and releasing excess energy in the form of heat. This heat, if effectively captured, can be utilized to generate vast quantities of electricity [4].

The ITER reactor is designed to operate for pulses, not continuously. These pulses can last between 400 and 600 seconds. So, ITER wouldn't be "on" for thousands of seconds at a time, but rather cycle through these operational periods.

3. Fusion reaction

Deuterium and tritium fuse to form helium-4 and a neutron releasing energy in the process. Atomic masses of these isotopes and particles are shown in Tab.1. A deuterium nucleus (one proton and one neutron) collides with a tritium nucleus (one proton and two neutrons) at a sufficiently high energy. The nuclei combine to form an excited intermediate nucleus of helium-5 (two protons and three neutrons). The intermediate helium-5 nucleus rapidly decays into helium-4 (two protons and two neutrons) and a free neutron Fig. 3 [1, 2, 6].

The total mass of the reactants (deuterium + tritium) is greater than the total mass of the products (helium-4 + neutron). The difference in mass is converted into energy in the form of gamma radiation and kinetic energy of the neutron and the helium-4 nucleus [1, 6].

Table 1

The atomic masses of reactants and byproducts in fusion reaction [2, 6]

Isotopes of hydrogen and particles	Atomic masses (atomic units)
Deuterium (isotope with 1 proton and 1 neutron)	2.01410 a. u.
Tritium (isotope with 1 proton and 2 neutrons)	3.01605 a. u.
Helium (alpha particle with 2 protons and 2 neutrons)	4.00260 a. u.
Neutron (subatomic particle)	1.00886 a. u.

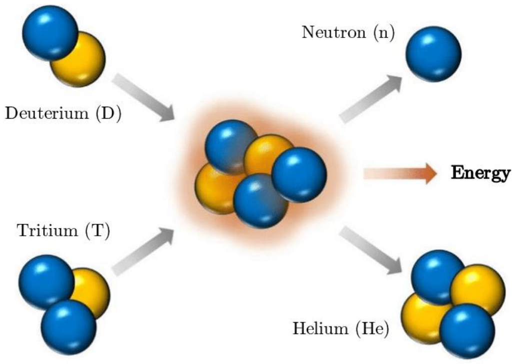

Figure 3. Fusion reaction [6]

4. Benefits and Environmental Impact

Fusion reactors burn a very different fuel compared to traditional power plants(coal, natural gases, uranium and others). The primary fuel for fusion is deuterium, a readily available isotope of hydrogen extracted from seawater. Tritium, another hydrogen isotope, is also needed but can be bred within the reactor itself or obtained from lithium, another widespread element. The fuel sources are abundant and could provide energy for thousands of years. Unlike fossil fuels or uranium used in fission reactors, fusion does not produce greenhouse gases or long-lived radioactive waste. The byproduct of the reaction is helium, an inert gas. This clean burning process makes fusion a highly attractive option for sustainable energy production with minimal environmental impact [3, 5].

5. Challenges

Scientists need to accomplish and maintain fusion for extended periods to produce usable energy. As I said earlier fusion requires temperatures exceeding 100 million degrees Celsius, which is hotter than the Sun's core, and can turn any material we know into a gas. Containing and controlling such hot plasma is extremely difficult. Building and operating fusion reactors is currently very expensive. Moreover, this type of reactor consumes more energy than it produces, because the reactor needs energy to work properly. The economic feasibility of fusion power needs to be established before widespread adoption can occur [5].

Conclusion

While a milestone in temperature is good news for fusion, for net power to be produced, this heat needs to be sustained for long periods. It's a goal well worth pursuing. Compared with the uranium needed for fission, the fuel for fusion is much easier to collect. The hydrogen isotope deuterium can be extracted from seawater using hydrolysis. Tritium is another isotope of hydrogen with two neutrons and one proton. It's much harder to find on Earth, but could still be made by bombarding lithium with neutrons or separated from water in a heavy water-cooled reactor. Either way, the end product of fusion is helium that can cause no damage. No greenhouse gases or radioactive waste are produced, making fusion an appealing choice in green power. Therefore, nuclear fusion reactors aim to unlock a clean and sustainable energy source. By achieving controlled fusion and eventually reaching a net energy gain, these reactors have the potential to revolutionize how we generate power. Theoretical calculations suggest efficiencies of around 30-40%, similar to conventional power plants. Future advancements could potentially push efficiencies higher, possibly exceeding 50%.

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