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4. A Study on Confinement of High Temperature Plasma

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ABSTRACT

During the early stages of research on magnetic confinement fusion, plasma instabilities had to be overcome. It was revealed that macroscopic plasma instabilities had a detrimental effect on plasma confinement. Prior to 1958's Atoms for Peace Meeting, experimental and theoretical research focused mostly on how to suppress or control nuclear weapons. Localized exchange modes and ripping modes were identified during this time period as two distinct types of instabilities. The Comptes rendus hebdomadaires des séances de l'Académie des sciences and French physicists have been actively working in this area for some time. Despite these attempts, it continues to be a focus of inquiry and, perhaps, cause for concern because of the sheer volume of work it created. Many scientists believe that instabilities in magnetic confinement fusion are no longer a significant obstacle because of the advances made. Fusion power generation relies heavily on the capacity to contain extremely hot plasmas.

KEYWORDS:

Plasmas, Confinement, Instabilites.

Introduction:

Since the 1960s, physicists have studied the properties of plasmas in tokamak devices. At the time, the tokamak's doughnut-shaped torus constituted a huge breakthrough in plasma science, allowing for temperature levels and plasma confinement times that had never before been possible. Plasmas are made up of charged particles, such as positive nuclei and negative electrons, that can be formed and restricted by magnetic fields. [1] Plasma particles behave like iron filings when exposed to a magnetic field. Unlike an ordinary solid container, the magnetic field is not changed by heat.

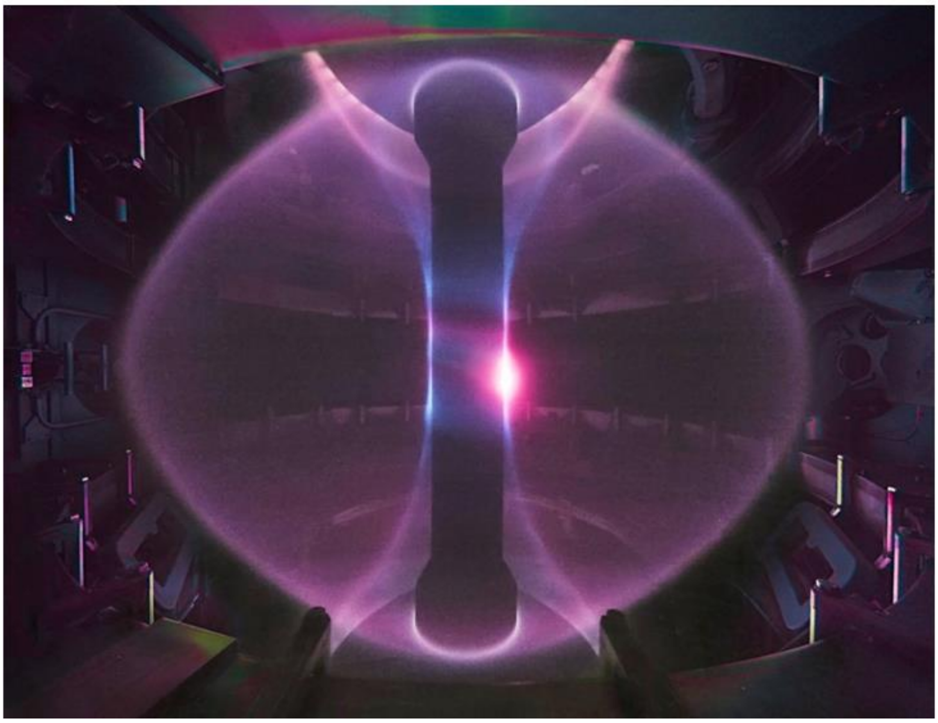

Fig.1: In a tokamak, plasma particles are confined and shaped by magnetic field lines that combine to act like an invisible bottle. Pictured, the spherical tokamak MAST at the Culham Centre for Fusion Energy (UK), where over 30,000 man-made "stars" have been created.

Plasma physics' foundational theories were developed between 1930 and 1950. However, the temperatures of experimentally obtainable plasmas were rarely substantially higher than the first-ionization energy range. Many practical uses of plasma physics were discovered within this "low-temperature" zone, such as illumination, electrical switching, and the study of the ionosphere. [2] The controlled release of fusion energy from heavy hydrogen nuclei appeared in the 1950s as an extremely ambitious new application. The pursuit of this goal resulted in a shift in the relevant plasma temperature from the atomic to the nuclear energy scale, and thus led to the development of contemporary plasma physics.[3]

In the context of thermonuclear fusion, plasma confinement refers to the ability to contain a plasma at the severe conditions required for the fusion process. The gravitational pull of a star keeps these circumstances constant. Strong magnetic fields are used in the laboratory to confine plasma. They may be able to keep fusion-grade plasmas in long-term confinement using this magnetic confinement approach. Imploding matter's inertia can also be used as a means of confinement. Hydrogen bomb detonations and other specialised facilities have proved this inertial confinement approach. The field of inertial confinement is one that's seeing a lot of activity right now. [4] For billionths of a second, high-power lasers or electrical discharges are used in laboratories to compress hydrogen fuel to extremely high densities.

The Department of Energy's Office of Science Fusion Energy Sciences programme is the primary source of funding for magnetic plasma confinement research and development in the United States. With the ITER project, the DOE plays an important role in these endeavours [5]. When ITER is finished, it will be the first experiment to explore power plant-scale confined nuclear fusion plasmas. [5]. It's going to be the largest human-built scientific experiment ever. The Department of Energy's National Nuclear Security Administration is the principal funder of inertial confinement fusion research. [6]

Plasma Confinement Facts:

- It has been proven that magnetically confined plasmas can reach temperatures 10 times hotter than the centre of our sun.
- More than 10 times as much power will be generated as will be fed into the system. NIF is the world's most powerful laser, capable of delivering 2 megajoules of light energy in 16 nanoseconds (the equivalent of 20,000 100-watt light bulbs). [7]

Auxiliary heating systems were successfully developed and implemented on a broad scale beginning in the 1980s, which was another significant advance. High heating power pushed the high pressure plasmas into non-equilibrium states with surprising features, more than an order above the ohmic level. It was a pleasant surprise to see that plasma self-organization in these conditions brought the parameters closer to ignition conditions rather than further away. [8]

High-power external heating systems became available in the 1980s, making helical devices more efficient. Until that point, stellarators were heated ohmically.

Internal rotational transform was applied and the magnetic setting was altered as a result of the unavoidable plasma current. The authors were able to discuss "improvement of energy confinement" in stellarators since the confinement time was longer without ohmic current. [9]

Objectives:

- To observe plasma particles in a tokamak reactor.
- To investigate the confinement of plasma
- To investigate plasma physics in terms of temperature.
- To investigate the Heliotron J's structure

Research Methodology:

Research at the most basic level has been carried out using the internet's wealth of information. Second-hand information is being used to compile the data. The information has been gathered from an external source and synthesised.

The entire research was done with the help of electronic databases, i.e., the computerised database, as the external source of information. The Google Scholars database of published research papers served as a resource for this investigation.

Result and Discussion:

Figure 2 depicts the plasma physics field's complete density-temperature diagram1. A temperature of roughly 1 eV, which is approximately -104 °K, is ideal for ionising hydrogen plasma.

According to this definition, a "ideal classical plasma" has a temperature greater than the Coulomb interaction potential as well as the Fermi energy. The first presupposes that macroscopic electromagnetic fields predominate over interactions among individual particles $n\lambda_D^3$ collectively (or equivalently, the presence of a large number of particles within a Debye sphere). Having a tiny quantum therapeutic impact is ensured by the second requirement. [10]

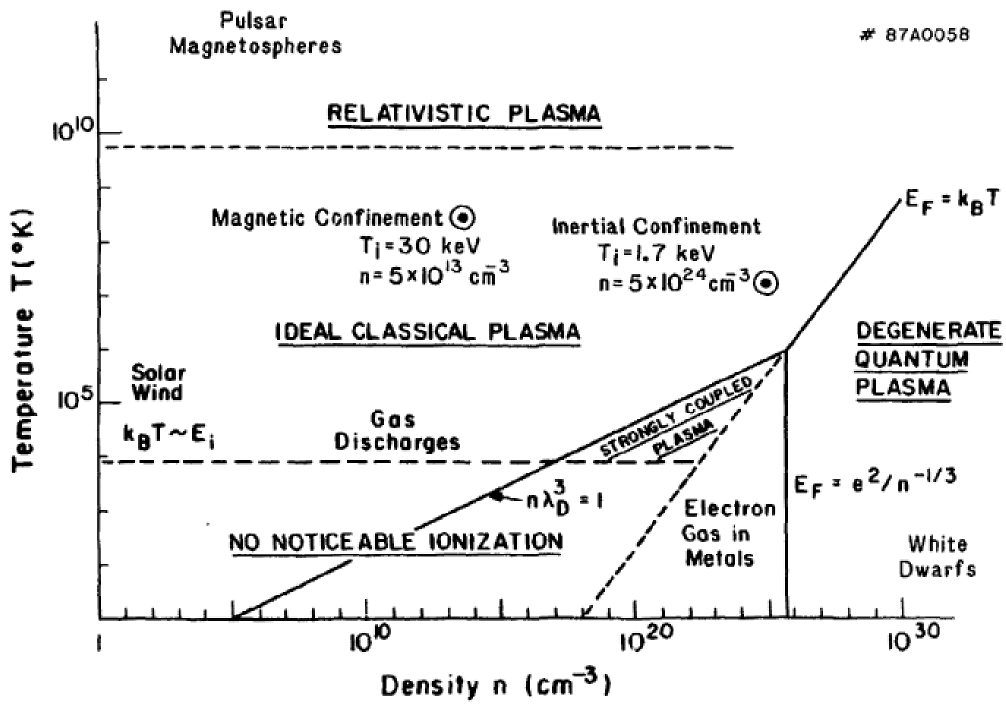

Fig. 2: plasma physics with respect to temperature

Heliotron J, a machine built and housed at Kyoto University, has also been used for plasma studies since 2000. Plasma confinement characteristics in a new range of parameters are being studied thanks to this unique apparatus, which is the only one of its kind on the planet. [11]

Magnetic wells with many layers of magnetic axes are intended to improve the confinement properties of currentless plasma by combining good confinement features with improved MHD stability. [12]

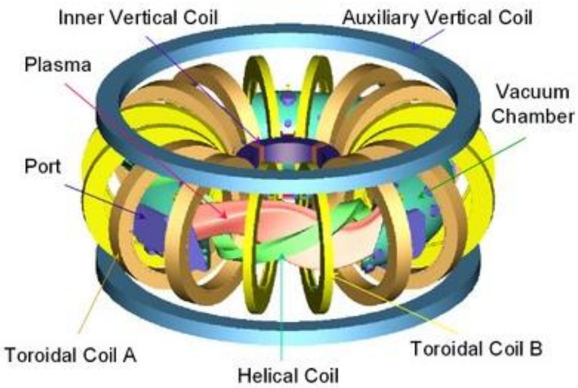

Fig. 3 Structure of Heliotron J

Heliotron J specs: single helical coil, pitch number 4, pole number 1, eight toroidal coils, three pairs of poloidal coils, donut-shaped vacuum chamber of major radius 1.2 m, magnetic field strength 1.5 T within confinement space (about 0.8 m3). It is possible to cultivate new parameter spaces and flexible experimentation in electromagnetic field configuration research by using this coil technology to expand control over the basic magnetic field variables (toroidal, helical, bumpy). [13]

In terms of magnetic-field confinement of plasma, the tokamak design is now the most promising. After achieving high temperatures and densities in the 1970s, the tokamak was conceived in Russia and has since been studied globally. Stellarators and torus-shaped magnetic field arrangements characterise the tokamak setup. [14]

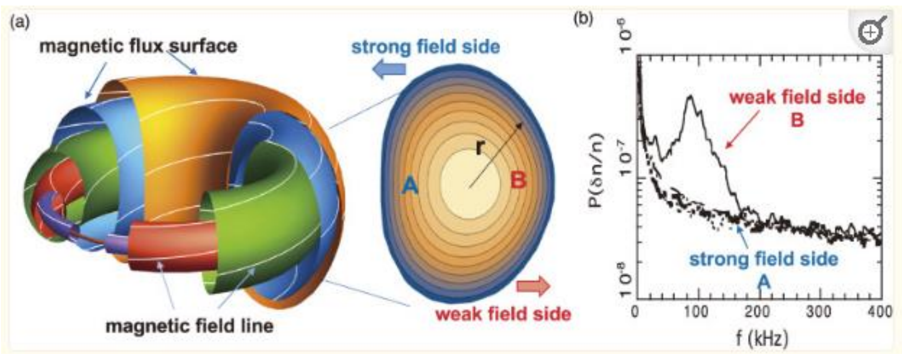

Fig. 4: a shows a schematic representation of a tokamak's magnetic field and plasma cross-section. In order to contain the plasma, magnetic field lines construct a magnetic flux surface, a nested surface. The torus form of the magnetic field results in a higher magnetic field on the inside of the torus, which helps stabilise instabilities. (b) Differences in density fluctuations between the weak and strong field sides. The density fluctuation spectrum on the weak field side is found to be bigger in the frequency range of roughly 100 kHz than on the strong field side. In a tokamak, a heavy ion beam probe is used to quantify density fluctuations.

For example, tokamaks require an internal plasma current to generate a poloidal field essential to confine plasma, while stellarators generate it externally by winding up external coils. The magnetic field lines of torus devices, as depicted in Fig.4(a),4b, produce nested flux surfaces that confine the plasma inside. The effective radial coordinate of the magnetic flux surface can be used to name it. As the effective radial coordinate approaches zero, the temperature and density of torus plasmas decrease. [15]

Conclusion:

The spatial structure of the containing magnetic field has a significant impact on plasma dynamics. By varying the curvature, pitch of the field lines, field intensity (relative to plasma pressure), and spatial symmetry, the experimenter can change critical properties of the magnetic field. The plasma is not fully ionised at low temperatures. In laboratory plasmas and in the early stages of fusion reactors, partial ionisation discharges can be observed. Line radiation, emitted by neutrals and partially ionised ions, has the potential to reduce the (ohmic) heating power by as much as 50%. Power output is directly related to the density of electrons and neutrals. An increase in electron density results in a decrease in neutral density, which is known as the radiation barrier, which is the maximum amount of radiated power that can be generated. It is possible for electron temperatures to rise if a heating power is greater than the radiation barrier.

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