

Fusion

FUNCTION: Fusion is the process by which two or more atomic nuclei combine to form a single nucleus with a mass less than the sum of the individual masses. This process releases energy, as described by Einstein's famous equation, $E=mc^2$. Fusion is the primary energy source for stars, including our Sun, and is the basis of hydrogen bombs. It is also the subject of ongoing research, with the goal of developing a clean, sustainable source of energy for the future.

Fusion

Physics of a Fundamental Energy Source

ENERGY SOURCES & CONVERSIONS

(AN OVERVIEW OF ENERGY CONVERSION PROCESSES)

Energy can take on many forms, and various processes convert one form into another. This table shows the primary energy sources and the processes that convert them into usable energy.

Source	Conversion	Usable Energy
Chemical	$\text{Fuel} \rightarrow \text{Heat} \rightarrow \text{Electricity}$	~30-40%
Geothermal	$\text{Heat} \rightarrow \text{Steam} \rightarrow \text{Electricity}$	~10-20%
Nuclear	$\text{Fission} \rightarrow \text{Heat} \rightarrow \text{Steam} \rightarrow \text{Electricity}$	~30-40%
Solar	$\text{Sun} \rightarrow \text{Photovoltaic} \rightarrow \text{Electricity}$	~15-20%

Physical Parameters of Energy-Releasing Reactions

Reaction Type	Chemical	Fusion	Fission
Sample Reaction	$\text{C} + \text{O}_2 \rightarrow \text{CO}_2$	$\text{D} + \text{T} \rightarrow \text{He} + \text{n}$	$\text{U} + \text{n} \rightarrow \text{Ba} + \text{Kr} + \text{n}$
Typical Inputs (to Power Plant)	Coal and Air	D_2O (2L, 10%) and T_2O (10%, 10%)	Uranium and Lithium
Typical Temp. (K)	1000	10000	100,000,000
Energy Released per kg Fuel (kJ/kg)	1.5×10^7	2.5×10^{11}	1.5×10^8

HOW FUSION REACTIONS WORK

NUCLEAR PHYSICS OF FUSION

Fusion reactions release energy by combining light nuclei to form heavier ones.

Plotting Energy per Nucleon as a Function of Nucleon Mass



Nuclear Reaction Energy: $E = \Delta E = \Delta(m_1 c^2 + m_2 c^2) = \Delta E_{\text{binding}}$

For example, $E = 17.6 \text{ MeV}$ is the energy released per reaction, m_1 is the initial mass of the reactants, m_2 is the final mass of the products. The conversion factor is $1 \text{ u} = 931.5 \text{ MeV}/c^2$, where 1 u is the atomic mass unit, or $1.66 \times 10^{-27} \text{ kg}$.

Detailed Nuclear Masses

(The values are in atomic mass units)

Label	Species	Mass (u)
^1H	Hydrogen	1.007825
^2H	Deuterium	2.014102
^3H	Tritium	3.016049
^4He	Helium	4.002603
^6Li	Lithium	6.015122
^{12}C	Carbon	12.000000
^{16}O	Oxygen	15.994915
^{238}U	Uranium	238.02891

Note: $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ is the atomic mass unit.

Fusion Rate Coefficients



Plasma Fusion Reaction Rate Density: $R = n_1 n_2 \langle \sigma v \rangle$

n_1, n_2 = Number of reacting species (ions/m³), $\langle \sigma v \rangle$ = Rate Coefficient (m³/s), which is a function of temperature and the masses of the reacting species.

To make

CHALLENGE: To make fusion reactions occur, the nuclei must be heated to very high temperatures, typically above 100 million K. At these temperatures, the nuclei are ionized, forming a plasma. The plasma must be held together by magnetic fields or other means to prevent it from cooling and escaping. This is a major challenge in fusion research, as it requires the development of advanced materials and techniques to contain the plasma.

PLASMAS - THE 4th STATE OF MATTER

CHARACTERISTICS OF TYPICAL PLASMAS

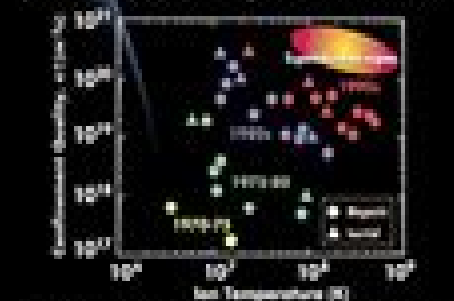
Plasma is a state of matter consisting of ionized gases. It is the most common state of matter in the universe, but it is rarely found on Earth. Plasmas are characterized by their high temperature, low density, and collective behavior. They are used in a variety of applications, including fusion energy, space exploration, and industrial processes.



ACHIEVING FUSION CONDITIONS

EXPERIMENTAL RESULTS IN FUSION RESEARCH

The world's most powerful fusion experiments have been conducted at the Joint European Torus (JET) and the National Ignition Facility (NIF). These experiments have achieved record-breaking results in terms of energy output and plasma temperature. However, there are still many challenges to be overcome before fusion energy can be used as a practical power source.



These results are currently limited by the experimental facilities available. The development of new experimental facilities, such as the International Thermonuclear Experimental Reactor (ITER), will allow for more extensive and precise measurements of fusion conditions.

CHALLENGE 1: How to Create a Plasma That is Hotter Than the Sun's Core

One of the most significant challenges in fusion research is creating a plasma that is hot enough to sustain fusion reactions. The temperature of the plasma must be maintained at a level that is significantly higher than the temperature of the surrounding environment.

There are several methods for heating a plasma, including ohmic heating, neutral beam heating, and radio-frequency heating. Each method has its own advantages and disadvantages, and the choice of method depends on the specific requirements of the experiment. The goal is to create a plasma that is hot enough to sustain fusion reactions for a long enough time to produce a net gain in energy.

Fusion Plasma Physics

**Y P Huo, Chuan Sheng Liu, Friedrich
Wagner**



Fusion Plasma Physics:

Plasma Physics and Fusion Energy Jeffrey P. Freidberg, 2008-07-10 There has been an increase in interest worldwide in fusion research over the last decade and a half due to the recognition that a large number of new environmentally attractive sustainable energy sources will be needed to meet ever increasing demand for electrical energy Based on a series of course notes from graduate courses in plasma physics and fusion energy at MIT the text begins with an overview of world energy needs current methods of energy generation and the potential role that fusion may play in the future It covers energy issues such as the production of fusion power power balance the design of a simple fusion reactor and the basic plasma physics issues faced by the developers of fusion power This book is suitable for graduate students and researchers working in applied physics and nuclear engineering A large number of problems accumulated over two decades of teaching are included to aid understanding

Plasma Physics for Nuclear Fusion Kenrō Miyamoto, 1989 The original English language edition of this work appeared in 1979 Since then researchers around the world have made slow but steady progress toward the realization of sustained controlled nuclear fusion This new edition has been updated to review the important contributions of the past decade The final chapter Confinement of High Temperature Plasmas has been rewritten entirely to include the recent results of confinement in several types of devices and advances the understanding of wave heating Miyamoto's approach is unique in encompassing Western Soviet and Japanese research in the fusion field The book's 16 chapters are grouped into four major subject areas Chapters in the first part develop the fundamentals of plasma physics and present the conditions of nuclear fusion reactions those in the next two parts provide a magnetohydrodynamic description of plasmas and explain wave phenomena and instabilities by means of a kinetic model Concluding chapters take up the problems of heating diagnostics and confinement Specific topics include the Lawson condition Boltzmann and Vlasov equations plasma equilibrium magnetohydrodynamic instabilities waves in cold and hot plasmas microinstabilities fast neutral beam injection and wave heating and diagnostics using microwaves lasers and energy analyzers Plasma confinement in tokamaks and stellarators multipole fields mirrors and cusps as well as inertial confinement are reviewed Kenro Miyamoto is Professor of Physics at the University of Tokyo

Introduction to Plasma Physics and Controlled Fusion Francis F. Chen, 2013-03-09 TO THE SECOND EDITION In the nine years since this book was first written rapid progress has been made scientifically in nuclear fusion space physics and nonlinear plasma theory At the same time the energy shortage on the one hand and the exploration of Jupiter and Saturn on the other have increased the national awareness of the important applications of plasma physics to energy production and to the understanding of our space environment In magnetic confinement fusion this period has seen the attainment of a Lawson number nTE of 2×10^21 cm³ sec in the Alcator tokamaks at MIT neutral beam heating of the PLT tokamak at Princeton to 6.5 keV increase of average to 3% 5% in tokamaks at Oak Ridge and General Atomic and the stabilization of mirror confined plasmas at Livermore together with injection of ion current to near field reversal conditions in

the 2XII device Invention of the tandem mirror has given magnetic confinement a new and exciting dimension New ideas have emerged such as the compact torus surface field devices and the E T mirror torus hybrid and some old ideas such as the stellarator and the reversed field pinch have been revived Radiofrequency heating has become a new star with its promise of dc current drive Perhaps most importantly great progress has been made in the understanding of the MHD behavior of toroidal plasmas tearing modes magnetic VII VIII islands and disruptions Fusion Plasma Physics Weston M.

Stacey, 2005-10-28 Nuclear fusion has the potential to become the most important energy source of the new century But still many problems as e g the confinement of the plasma are not yet solved Thus they are subject to intense research which drives a rapid evolution of this field of nuclear physics and generates the need for an up to date textbook for graduate students This state of the art textbook assembles the material for a modern course and is aimed at graduate and advanced undergraduate students It both introduces the fundamental principles and theories of fusion plasma physics and presents the most recent topics from various sources in a systematic and concise way Each chapter is rounded off with a set of exercises

Introduction to Plasma Physics and Controlled Fusion Francis Chen, 2015-12-17 This complete introduction to plasma physics and controlled fusion by one of the pioneering scientists in this expanding field offers both a simple and intuitive discussion of the basic concepts of this subject and an insight into the challenging problems of current research In a wholly lucid manner the work covers single particle motions fluid equations for plasmas wave motions diffusion and resistivity Landau damping plasma instabilities and nonlinear problems For students this outstanding text offers a painless introduction to this important field for teachers a large collection of problems and for researchers a concise review of the fundamentals as well as original treatments of a number of topics never before explained so clearly This revised edition contains new material on kinetic effects including Bernstein waves and the plasma dispersion function and on nonlinear wave equations and solitons For the third edition updates were made throughout each existing chapter and two new chapters were added Ch 9 on Special Plasmas and Ch 10 on Plasma Applications including Atmospheric Plasmas *Plasma Physics for Controlled Fusion* Kenro Miyamoto, 2016-05-12 This new edition presents the essential theoretical and analytical methods needed to understand the recent fusion research of tokamak and alternate approaches The author describes magnetohydrodynamic and kinetic theories of cold and hot plasmas in detail The book covers new important topics for fusion studies such as plasma transport by drift turbulence which depend on the magnetic configuration and zonal flows These are universal phenomena of microturbulence They can modify the onset criterion for turbulent transport instabilities driven by energetic particles as well as alpha particle generation and typical plasma models for computer simulation The fusion research of tokamaks with various new versions of H modes are explained The design concept of ITER the international tokamak experimental reactor is described for inductively driven operations as well as steady state operations using non inductive drives Alternative approaches of reversed field pinch and its relaxation process stellarator including quasi symmetric

system open end system of tandem mirror and inertial confinement are also explained Newly added and updated topics in this second edition include zonal flows various versions of H modes and steady state operations of tokamak the design concept of ITER the relaxation process of RFP quasi symmetric stellarator and tandem mirror The book addresses graduate students and researchers in the field of controlled fusion **Plasma Physics for Nuclear Fusion** Kenro Miyamoto,1976

Magnetically Confined Fusion Plasma Physics Linjin Zheng,2019-02-06 This book describes the ideal magnetohydrodynamic theory for magnetically conned fusion plasmas Advanced topics are presented in attempting to fill the gap between the up to date research developments and plasma physics textbooks Nevertheless they are self contained and trackable with the mathematical treatments detailed and underlying physics explained Both analytical theories and numerical schemes are given Besides the current research developments in this field the future prospects are also discussed Nowadays it is believed that if the ideal MHD theory predicts major instabilities none of the magnetic confinements of fusion plasmas can survive The author has also written the book Advanced Tokamak Stability Theory In view of its importance the MHD theory is further systematically elaborated in this book The conventional ideal MHD framework is reviewed together with the newly developed multi parallel fluid MHD theory The MHD equilibrium theory and code are described with the non letter X separatrix feature pointed out The continuum modes quasi modes phase mixing and Alfven resonance heating are analysed The analytical theories for MHD stability in tokamak configurations are systematically presented such as the interchange peeling ballooning toroidal Alfven modes and kink type of modes The global stability computations are also addressed including resistive wall modes error field amplifications and Alfven modes etc Nuclear Fusion And Plasma Physics - Proceedings Of The International Summer School Y P Huo,Chuan Sheng Liu,Friedrich Wagner,1995-08-31 The lectures given in the Summer School covered most of the important topics in controlled nuclear fusion and high temperature plasma physics The topics are as follows tokamak research stellarator physics transport and confinement of high temperature plasma plasma wall interaction and edge plasma physics heating and current drive diagnostics and general plasma theory Introduction to Plasma Physics and Controlled Fusion Francis F. Chen,1985 **Comments on Plasma Physics and Controlled Fusion**,1987 Fusion Reactor Design Takashi Okazaki,2021-11-04 Fusion Reactor Design Provides a detailed overview of fusion reactor design written by an international leader in the field Nuclear fusion generating four times as much energy from the same mass of fuel as nuclear fission is regarded by its proponents as a viable eco friendly alternative to gas fired coal fired and conventional power plants Although the physics of nuclear fusion is essentially understood the construction of prototype reactors currently presents significant technical challenges Fusion Reactor Design Plasma Physics Fuel Cycle System Operation and Maintenance provides a systematic reader friendly introduction to the characteristics components and critical systems of fusion reactors Focusing on the experimental Tokamak reactor this up to date resource covers relevant plasma physics necessary technology analysis methods and the other aspects of fusion reactors In depth chapters include derivations

of key formulas figures highlighting physical and structural characteristics of fusion reactors illustrative numerical calculations practical design examples and more Designed to help researchers and engineers understand and overcome the technological difficulties in making fusion power a reality this volume Provides in depth knowledge on controlled thermonuclear fusion and its large scale application in both current fusion reactors and future test reactors Covers plasma analysis plasma equilibrium and stability and plasma transport and confinement and safety considerations Explains each component of fusion reactors including divertors superconducting coils plasma heating and current drive systems and vacuum vessels Discusses safety aspects of fusion reactors as well as computational approaches to safety aspects of fusion reactors Fusion Reactor Design Plasma Physics Fuel Cycle System Operation and Maintenance is required reading for undergraduate and graduate students studying plasma physics and fusion reactor technology and an important reference for nuclear physicists nuclear reactor manufacturers and power engineers involved in fusion reactor research and advanced technology development

Introduction to Plasma Physics and Controlled Fusion Francis F. Chen,1990 **Plasma Physics and Controlled Nuclear Fusion** Kenro Miyamoto,2005-10-20 *Fusion* Hans Wilhelmsson,1999-12-01 Journeying through fusion in the universe *Fusion A Voyage Through the Plasma Universe* discusses all aspects of fusion and how they relate to our universe It also studies the attempts to produce fusion energy on Earth The book addresses a wide range of topics from stars galaxies comets pulsars black holes and quasars to the auroras lightning and fluorescent tubes Interestingly the author explores how artists and authors like Vincent van Gogh Leonardo da Vinci and Hannes Alfvén have been fascinated by cosmic phenomena that rely on fusion and plasmas He discusses motions in plasma such as flames waves and whirls similar to those that occur in water The book also examines several other branches of science where parallels can be found with fusion plasmas including ecological systems that provide only very short term weather forecasts and the dramatic changes in the world economy with its explosive tendencies and sometimes catastrophic results It briefly shows how these nonlinear phenomena are at the heart of modern fusion plasma theory *Plasma Physics and Fusion Plasma Electrodynamics* Abraham Bers,2016 Plasma is a ubiquitous state of matter at high temperatures The electrodynamics of plasmas encompasses many applications from understanding plasmas in space and the stars to their use in processing semiconductors This textbook at the early graduate level covers basic plasma physics and illustrates its use in many current applications *Nuclear Fusion* Edward Morse,2018-10-15 The pursuit of nuclear fusion as an energy source requires a broad knowledge of several disciplines These include plasma physics atomic physics electromagnetics materials science computational modeling superconducting magnet technology accelerators lasers and health physics Nuclear Fusion distills and combines these disparate subjects to create a concise and coherent foundation to both fusion science and technology It examines all aspects of physics and technology underlying the major magnetic and inertial confinement approaches to developing nuclear fusion energy It further chronicles latest developments in the field and reflects the multi faceted nature of

fusion research preparing advanced undergraduate and graduate students in physics and engineering to launch into successful and diverse fusion related research Nuclear Fusion reflects Dr Morse s research in both magnetic and inertial confinement fusion working with the world s top laboratories and embodies his extensive thirty five year career in teaching three courses in fusion plasma physics and fusion technology at University of California Berkeley **An Indispensable Truth** Francis Chen,2011-04-11 Recent books have raised the public consciousness about the dangers of global warming and climate change This book is intended to convey the message that there is a solution The solution is the rapid development of hydrogen fusion energy This energy source is inexhaustible and although achieving fusion energy is difficult the progress made in the past two decades has been remarkable The physics issues are now understood well enough that serious engineering can begin The book starts with a summary of climate change and energy sources trying to give a concise clear impartial picture of the facts separate from conjecture and sensationalism Controlled fusion the difficult problems and ingenious solutions is then explained using many new concepts The bottom line what has yet to be done how long it will take and how much it will cost may surprise you Francis F Chen s career in plasma has extended over five decades His textbook Introduction to Plasma Physics has been used worldwide continuously since 1974 He is the only physicist who has published significantly in both experiment and theory and on both magnetic fusion and laser fusion As an outdoorsman and runner he is deeply concerned about the environment Currently he enjoys bird photography and is a member of the Audubon Society

Plasma Physics and Nuclear Fusion Research Richard D. Gill,2013-09-03 Plasma Physics and Nuclear Fusion Research covers the theoretical and experimental aspects of plasma physics and nuclear fusion The book starts by providing an overview and survey of plasma physics the theory of the electrodynamics of deformable media and magnetohydrodynamics and the particle orbit theory The text also describes the plasma waves the kinetic theory the transport theory and the MHD stability theory Advanced theories such as microinstabilities plasma turbulence anomalous transport theory and nonlinear laser plasma interaction theory are also considered The book further tackles the pinch and tokamak confinement devices the stellarator confinement devices the mirror devices and the next generation tokamaks The text also encompasses the fusion reactor studies heating and diagnostics Physicists and people involved in the study of plasma physics and nuclear fusion will find the book invaluable **Magnetic Fusion Energy** George Neilson,2016-06-02 Magnetic Fusion Energy From Experiments to Power Plants is a timely exploration of the field giving readers an understanding of the experiments that brought us to the threshold of the ITER era as well as the physics and technology research needed to take us beyond ITER to commercial fusion power plants With the start of ITER construction the world s magnetic fusion energy MFE enterprise has begun a new era The ITER scientific and technical S T basis is the result of research on many fusion plasma physics experiments over a period of decades Besides ITER the scope of fusion research must be broadened to create the S T basis for practical fusion power plants systems that will continuously convert the energy

released from a burning plasma to usable electricity operating for years with only occasional interruptions for scheduled maintenance Provides researchers in academia and industry with an authoritative overview of the significant fusion energy experiments Considers the pathway towards future development of magnetic fusion energy power plants Contains experts contributions from editors and others who are well known in the field

Reviewing **Fusion Plasma Physics**: Unlocking the Spellbinding Force of Linguistics

In a fast-paced world fueled by information and interconnectivity, the spellbinding force of linguistics has acquired newfound prominence. Its capacity to evoke emotions, stimulate contemplation, and stimulate metamorphosis is truly astonishing. Within the pages of "**Fusion Plasma Physics**," an enthralling opus penned by a highly acclaimed wordsmith, readers set about an immersive expedition to unravel the intricate significance of language and its indelible imprint on our lives. Throughout this assessment, we shall delve in to the book is central motifs, appraise its distinctive narrative style, and gauge its overarching influence on the minds of its readers.

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