PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Introduction to The approach to ignited plasma. A Discussion Meeting held at the Royal Society on 15 and 16 July 1998

D. C. Robinson

Phil. Trans. R. Soc. Lond. A 1999 **357**, 373-375
doi: 10.1098/rsta.1999.0332

THE ROYAL SOCIETY

Introduction

By D. C. Robinson

UKAEA, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, UK

The last time high-temperature plasma physics and its relation to fusion research was considered at a Royal Society Discussion Meeting was in 1980 (Pease & Gibson 1981). Since then, the quest for the realization of the production of energy from the fusion of light nuclei has advanced considerably, as has the understanding of high-temperature plasmas in magnetic and electric fields and their relationship to terrestrial and extraterrestrial phenomena. The recent production of significant amounts of fusion power (16 MW) and fusion energy (21 MJ) in deuterium–tritium plasmas on JET with conditions close to energy breakeven, and the transient production of plasmas with solid densities, using high-power lasers and at high temperatures using pulsed magnetic fields, indicate that it is timely to consider how close the world programme has come to producing burning or ignited plasmas. The first indications have already been seen on JET with the α-particles from the fusion reactions heating the core electrons by some 2 keV and core fusion power exceeding the externally applied heating power (i.e. a factor of *ca.* 3 away from the core igniting).

High-temperature plasma physics and fusion research has been conducted for 50 years, and it is instructive to ask why has it taken so long to reach this point. The 1950s has been termed the 'age of ignorance' (R. S. Pease) with the construction of a range of facilities all aimed at producing high-temperature plasma and fusion reactions. Sadly, some of the early results were misinterpreted, poor diagnostics and modest development in theoretical understanding of the complex phenomena in plasmas leading to misplaced optimism. The 1960s saw an 'age of enlightenment', with carefully designed experiments to test specific aspects of theory, with some success, and the first sustained high-temperature plasmas (1 keV). The 1970s was the 'age of construction', with the recognition that by scaling to larger size, power-plant-relevant conditions could be produced in the laboratory, typified by the start of construction of JET. There were also new ideas with the recognition that an alternative route for fusion was possible using high-power lasers to produce high densities for short times: 'inertial confinement'. The 1980s was the 'age of fusion-relevant results'; with the production of temperatures of more than 10 keV, beyond those needed to ignite a plasma. The 1990s is the 'age of fusion energy', with first production of fusion energy at the MJ level, the demonstration of α-particle heating (figure 1) and plans for next-step devices to produce burning/ignited plasmas.

The first paper at this meeting, by Dr Sheffield, considers the future energy scene, the increasing world population and its aspirations for safe, environmentally friendly power production. The second, by Dr Bickerton, is on the history of the approach to ignition, with the fusion triple product having increased by three orders of magnitude since the last meeting in 1980, the gap to that ultimately required for power production (a factor of five) closing rapidly. This process has seen considerable advances in our understanding which are displayed in the papers by Dr Keilhacker and Dr Hawryluk on results from deuterium–tritium plasmas in Europe and the USA, respectively. Alpha-particle physics is a key to the future of such plasmas and this has emerged

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

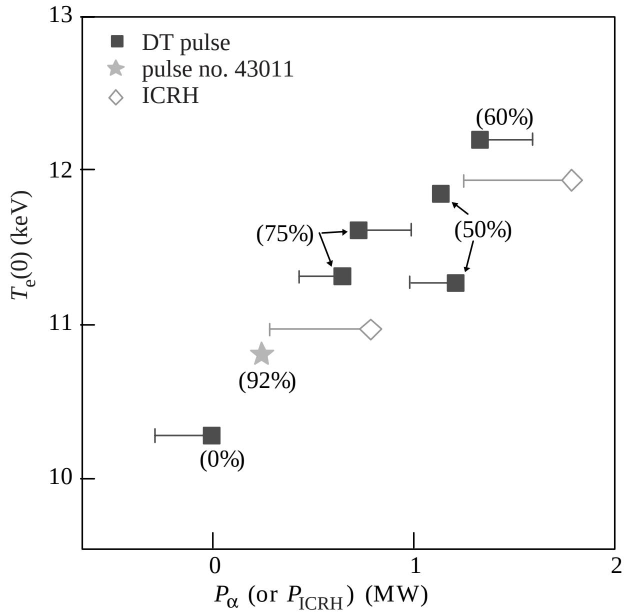

Figure 1. Alpha-particle heating in the JET D–T experiments (Thomas *et al.* 1998).

as a new science, which is reviewed by Dr Zweben, covering the latest results on the retention of α-particle energy in plasmas and a variety of phenomena which can arise (with wider relevance than fusion research). The world focus for the future in magnetic confinement is the quadripartite international project ITER. The final design report has just been completed and the next paper by its director, Dr Aymar, describes the physics and technology state of the project after six years of design.

In magnetic confinement, there are other approaches than the tokamak, i.e. concept improvements or alternatives that add to our understanding of high-temperature plasmas and may prove ultimately more attractive as fusion power plants, much as has occurred in fission. The paper by Dr Robinson reviews these alternatives, which include the inherently steady-state stellarators, the relatively new spherical tokamak with its potential to provide a more compact ignited plasma, and the dense Z pinch, which, given recent results, could be attractive as a driver in an inertial fusion system than as a magnetic fusion system in its own right.

Inertial confinement has made significant progress with the development of high power lasers, and the paper by Dr Kilkenny reviews the progress and understanding and the status of the National Ignition Facility in the US. This is followed by Professor Willi's paper on the fast ignitor shows how the prospects for producing an ignited plasma by this approach can be improved, possibly on an earlier timescale. For reasons of the efficiency of the power source, ion beams are considered to be attractive for power production by inertial fusion and the physics and technology of this are reviewed by Dr Bangerter.

Not only is it essential to establish the physics needed to achieve ignition, but it is necessary to develop the right engineering and technology if the full benefits of fusion power are to be realized in an economic and environmentally friendly way. Materials issues are the key to this, and are covered by Professor Ehrlich. The final paper, by

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Professor Najmabadi, addresses the present position on a range of studies of fusion power plants with an indication of the physics and technology advances needed in ignited plasmas to produce power plants that will satisfy the aspirations of future generations for a clean, limitless form of baseload electrical power at reasonable cost.

The next step needs to be one that demonstrates the scientific and technological feasibility of fusion energy for peaceful purposes by producing a burning plasma and integrating the physics and technology required for a power plant.

References

Pease, R. S. & Gibson, A. F. 1981 *High temperature plasma physics and its applications. Phil. Trans. R. Soc. Lond.* A **300**, 473–692.

Thomas, P. R. (and 22 others) 1998 Observation of alpha heating in JET DT plasmas. *Phys. Rev. Lett.* **80**, 5548.

MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES
THE ROYAL SOCIETY A
PHILOSOPHICAL TRANSACTIONS OF