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Plasma Physics Group

UK Plasma Physics News – Summer 2020.

Welcome to the UK IOP Plasma Physics Group (PPG) e-newsletter. If you have items for inclusion in future newsletters e.g. any meeting announcements or reports, research achievements, new appointments, facilities, projects, buildings etc. please contact: ken.mcclements@ukaea.uk.

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COMMITTEE NEWS

There have been two committee meetings since the last newsletter. Further details of committee activity and actions are available on the Group website.

RECENT MEETINGS

17th UK Technological Plasma Workshop 2019

The 17th Technological Plasma Workshop (TPW'19) was held in Coventry alongside the Vacuum Symposium at the Vacuum Expo at the Ricoh Arena, on the 9th and 10th of October 2019.

47th IOP Plasma Physics Conference

Unfortunately, due to COVID-19, the 47th IOP Plasma Physics conference, which was due to be held at the IOP HQ in London during April 2020 has had to be postponed until 6th-9th April 2021. Any abstracts submitted and accepted for this year will be carried over to next year for those who would still like to attend and present. The new website address for the postponed Plasma Physics Conference is http://plasma2021.iopconfs.org/home, which also has a photo collage of 'Plasma Physics celebrates 100 years of the IOP' originally planned to be shown at this year's conference.

FORTHCOMING MEETINGS

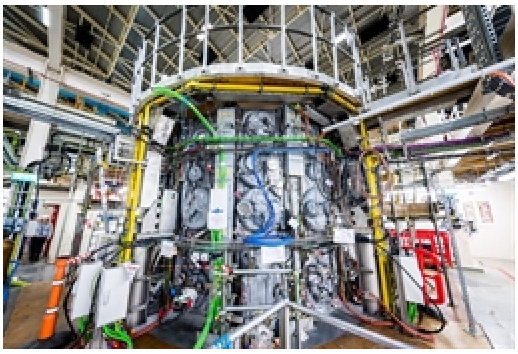
TPW-2020: a decision on whether to defer this to 2021 will be taken later in the year.

47th IOP Plasma Physics Conference: 6-9th April 2021 at IOP, 37 Caledonian Road, London, UK. Abstract submission deadline: 18 December 2020; early registration deadline: 26 February 2021; registration deadline: 26 March 2021.

COMMUNITY NEWS

UKAEA

MAST-U team hit key milestone on way to first full campaign



A key stage in the commissioning of MAST Upgrade was reached in March 2020 with the first magnetic field produced inside the machine.

Prior to any campaign starting, all the power supplies have to be commissioned and coils connected. Although several of the power supplies had been tested with a dummy load (known as *off-coil commissioning*), this was the first time the power supplies were connected to the magnets inside the machine (*on coil commissioning*).

In order for engineers to connect electrical current to the machine, MAST-U had to pass a process known as the High Voltage Inspection, which is in itself an important step on the way to first plasma.

On coil commissioning allows engineers to measure the level of current with a range of independent diagnostics including Rogowski coils (for measuring the current). Although the commissioning has only been carried out to date with one pair of coils (P4), it will soon be followed by the suite of MAST-U coils (24 in total).

Adam Kenny, power supplies engineer at UKAEA, said: "The MAST-U power supplies team were very pleased to see the first current on-coil. It is exciting to see all our hard work in preparing the new and existing power supplies, such as SFPS (P4), for first plasma beginning to be seen.

"It is also good to see the MAST-U system coming together to achieve this milestone."

Ioannis Katramados, MAST-U on-coil responsible officer, said: "It was a long wait but great that we finally got there. Getting current on a coil was both a very exciting moment and somewhat of a relief as well."

New JET science focuses on balancing the issues of divertor heat load and plasma confinement

A vital discovery regarding the best way to force the extreme heat load away from JET's exhaust system while maintaining high plasma confinement has been discovered in the first part of the scientific campaign.

The role of a tokamak's exhaust system – also known as its 'divertor' region – is to remove both the extreme heat and impurity particles from the plasma.

One of the problems with scaling up JET to a reactor size machine is that the divertor components in ITER, the international fusion project in France, will not be able to take extreme levels of exhausted heat as it will damage the divertor. This is why the importance of the experiments carried out on JET at the start of this campaign cannot be underestimated.

Scientists working on JET can spread the heat load across different tiles by moving the strike point, spreading the heat, but in ITER, the heat load will be much higher than in JET and the strike point cannot be moved. Therefore, in order not to melt the divertor, the power has to be radiated before reaching divertor tiles.

One solution to this problem is to use a gas as an impurity (often nitrogen) to cool down the plasma by radiating the heat over a wider surface area within the divertor region. But nitrogen can break down into additional compounds - leading to tritiated ammonia - and this is not compatible with JET's processing systems. The alternative is to use neon, but previously the level of heating power available on JET has meant that this hasn't been able to achieve the same effects as nitrogen without affecting the plasma confinement.

However, with the neutral beam heating power now reaching 30MW and additional neon being injected into the plasma, the effects are just as good – something hugely positive for ITER.

JET Taskforce Leader Alexander Huber explained how this process – known as impurity gas seeding – works: "The ITER divertor is not able to withstand high heat flux and so ITER has asked us to find out if neon can do the same as nitrogen in terms of both the exhaust and the confinement", he said.

"We needed to develop a scenario in which the heat is spread out and not sent to the divertor immediately.

"We have had success doing this with nitrogen because it radiates mostly in the divertor area.

"This is what we want - we don't want heat radiation in main chamber because it can reduce performance in plasma – and so from this point of view, nitrogen is perfect. There is only one problem with it and that is that nitrogen is chemically active. Nitrogen can act to form ammonia and we don't want tritiated ammonia in DT."

Carine Giroud, who coordinated the experiment together with Sebastijan Brezinsek and with a strong involvement from ITER, explained that 'H-mode' or 'high confinement plasma' is achieved by the formation of an insulating barrier in the edge region of the plasma known as a 'pedestal'. This pedestal – which acts like the wall of a thermos bottle – separates the very hot plasma core from a cooler layer of plasma and away from material surfaces. It was important for these experiments because as long as the impurity radiates in the divertor region, it will have limited impact on the plasma's confinement.

The higher this pedestal is, the more fusion power is generated, as it lifts the core plasma temperature to very high temperatures where it can be magnetically confined. Carine said the key success point – which had not been realised before - was the discovery that neon could be used to radiate and improve the pedestal – this in turn reduces the power load and improves plasma confinement.

"This is significant for us as it wasn't something we achieved in a previous experiment" she said. "We had 25MW of neutral beam power which allowed us to put in more neon, and it was both these elements which led to the improvement.

"We did not yet achieve a partial reduction of power to $5MWm^{-2}$ in relation to the divertor tile at the outer strike point (a target acceptable for ITER), but we did see that the temperature of the divertor tile didn't increase significantly during the time where the radiation from the neon was applied. This was something we could do this with nitrogen in 2014 but not with neon – but now we can.

"With the impurity, we have a reduction of power load to the divertor, and an improved pedestal – something which influences good plasma confinement. We are in a win-win scenario."

Obituary: John Wesson

Dr John Wesson, theoretical physicist, was born on September 4, 1931. He died on January 4, 2020 aged 88.

John Wesson was born in Leicester on 4th September 1931. Although he was to go on to establish himself as a leading fusion plasma physicist, he had to overcome some adversity in his early life. His father, Claude Wesson, was a framework knitter in the hosiery industry and his mother, Laura, had also been a factory worker. On his mother's side his great- grandfather, Robert Bindley, was a well-known activist on behalf of hosiery workers, and represented them at a Commission set up by Parliament to investigate their conditions of employment. He was seven when the Second World War started, and narrowly escaped a German bomb attack the following year. He had been to a shop along the road in which he lived. When he had been home for a few minutes, the part of the road where he had been was struck by a string of eight bombs, killing six people, two of whom he knew.

However, he showed early promise, 'jumping' a year in primary school and taking the eleven-plus at the age of ten, receiving a scholarship to the Wyggeston Grammar School (as had his brother and sister, Alf and Alma). However, he was expected to leave school as soon as was legally possible and indeed left at age fifteen. It was quite common then for working class children who passed the eleven-plus not to go to grammar school because their parents wanted to have them earn a wage as soon as possible.

A job was found for him in a (in his own words, 'dreadful') foundry, but the day before he was due to start, he refused to go, indicating his stubbornness and desire to succeed in life. Instead, he then went to work on the production line in a factory making transformers. His plight was recognised by a friend of the family who arranged for him to become an apprentice draughtsman at the lamp factory of Associated Electrical Industries (AEI). After a year it was decided that he should become a Student Design Engineer and would study in preparation to take an engineering degree. However, when the time came to start the degree, he decided to go to University College, Leicester to take a physics degree. He was already engaged to his future wife, Olive, on entering university, and they were married after a further year.

On obtaining his degree he was awarded a research scholarship and embarked on a PhD. He was given the project of measuring charge exchange collision rates between hydrogen ions and diatomic molecules. He became convinced that the method prescribed by his supervisor was inaccurate and, although he failed to convince him, he insisted on using a design of his own. After a year he was appointed to a teaching post.

Having completed his PhD, he joined the AEI Research Laboratory in 1957 as a member of the team which, under the guidance of Sir George Thomson, was working on what was then secret research aimed at obtaining useful energy from the fusion of hydrogen isotopes in high temperature plasmas (returning to AEI was merely a coincidence). Shortly after he joined, the team detected neutrons from fusion reactions, and this was reported on the front pages of the national press. But it was then found that the reactions did not result from a high temperature of the plasma, and the research programme had to be rethought. Initially, Wesson was employed as an experimental physicist, studying the problem of finding materials which were compatible with the high temperature plasma, but he started to fit theoretical analyses of the results into his work. This led the team leader, Alan Ware, to ask him to turn his attention entirely to the theoretical problems presented by plasma physics. Some of Wesson's work caught the interest of Sir George Thomson, who invited him to stay with him in Cambridge for a couple of days.

In 1963 AEI ran into financial difficulties and decided to close the laboratory. Fortunately, this coincided with the setting up of a UK national fusion laboratory in 1962, the Culham Laboratory in Oxfordshire, when the national effort on fusion research was concentrated there. Although he had no theoretical training, he was offered a post in the Theory Division. By then he was 31, his daughter, Karen, was three and his son, David, was born that year.

His contributions in his early years at Culham covered a range of topics. These included a publication on the ‘Heat flow through a plasma sheath’ (with G Hobbs in 1967) which provided a model of the sheath that has become a basic element in the design of ion thrusters for rocket propulsion - this is his most cited paper. In that year he also published (with Fred Haas) papers on the ‘Instability of the theta pinch’ and in 1970 on the ‘Dynamic stabilisation of plasma’. He began a productive partnership with Alan Sykes, carrying out a number of non-linear numerical simulations of plasma instabilities. The first of these was a simulation on the ‘Theory of Ion-sound Instability’ in 1973, leading to an interpretation of its non-linear saturation.

In the 1970s he turned his attention to clarifying the theory of the magnetohydrodynamic (MHD) stability of tokamaks – the most promising type of fusion device. These macroscopic instabilities have a profound effect on the tokamak’s behaviour and an understanding is crucial to optimising the performance of these devices. With Alan Sykes, he produced a seminal numerical study on the ‘Simulation of sawtooth relaxation in tokamaks’, a ubiquitous phenomenon that has challenged explanation. Although not concerning tokamaks, they also produced in 1976, a ‘Simulation of field reversal in the z-pinch’, another striking experimentally observed phenomenon. Wesson published a widely acclaimed ‘Review of tokamak stability’ in 1978, drawing together a substantial body of his theoretical and numerical work on the stability of various MHD instabilities in tokamaks. In 1979, he was awarded a DSc by London University for his body of work in theoretical plasma physics.

When the Joint European Torus (JET) project was proposed he participated in the preparatory studies, and when the JET tokamak was constructed, he joined the JET team, and had responsibility for the program of stability experiments. During this period, he produced in 1985, again working with Alan Sykes, an ‘Analytic calculation of the tokamak beta limit’, important for the economics of fusion power. In the same year he provided a novel interpretation of the sawtooth in terms of ‘The quasi-interchange instability’, while in 1989 he published, with others, a ‘Summary of the behaviour of disruptions in JET’. The following year he proposed ‘The importance of electron inertia in the sawtooth instability’ as an explanation of the surprisingly rapid crash of the core plasma observed during this instability. In retirement he continued his interest in theoretical plasma physics problems, publishing in 2015 a paper on ‘Landau damping’ that avoided the normal complex analysis invoked to explain the phenomenon.

In total he published more than 100 articles in journals, those mentioned above being a small subset.

Most of Wesson’s career was spent at the Culham and JET laboratories. He also spent periods at MIT, Los Alamos, the Italian National Laboratory of Frascati, the Australian National University at Canberra and the Max Planck Institute at Munich.

Throughout his life, Wesson showed a wide-ranging intellectual curiosity. In the late 1960s he spent some time studying economics and inaugurated the mathematical theory of optimal taxation in a paper entitled “On the distribution of personal incomes”. This paper showed that it is possible to devise a taxation system under which the total benefit of society is maximised by each individual maximising their own benefit. He believed in communicating physics in a clear, uncluttered fashion, as evidenced by his own scientific presentations. In 1985 he published a textbook, “Tokamaks”, which clearly exhibited this feature. This book, with its subsequent three further editions, became the standard textbook on the subject. On retirement he was asked to write a book describing the scientific progress achieved on JET – “The Science of JET”.

During his time in the Culham Theory Division, his lively mind was also evident in the range of group activities he organised: a regular football game; a running competition; surveys, such as ranking 'unlikely events' in order of their possibility and which newspaper provided most news per penny; and sophisticated sweepstakes on the outcomes of the World Cup football competitions.

Always a keen follower of Leicester City Football Club, he wrote a book on "The Science of Soccer" with several translations, even carrying out practical experiments in support of it. In retirement he became an enthusiastic golf player, leading him to publish a book on "The Science of Golf", even proposing an improved handicapping system.

Unfortunately, he suffered from ill health in later life. In 1996 he had a tumour removed from his head that left him deaf in his right ear. He was then diagnosed with cancer in 2007. He did not allow these conditions to prevent him pursuing his many interests with enthusiasm.

Obituary: Jan Hugill

Former UKAEA and University of Manchester Institute of Science and Technology (UMIST) plasma physicist Professor Jan Hugill died in March 2020. Following a PhD in astronomy at Cambridge, Jan was for many years a leading tokamak experimentalist at Culham, rising to leadership of the DITE programme and department. He in turn handed over his department manager role to William Morris when he decided, towards the end of his career, to move to UMIST where he was a professor and head of plasma physics. As well as at Culham and in the UK, Jan was very well known in the international fusion community, not least for the "Hugill diagram" of tokamak operating space. He participated in many annual conferences of the PPG, and was one of the first judges of the Culham Thesis Prize when it was introduced by the group in 2001.

EuPRAXIA

European consortium publishes conceptual design of a plasma-based accelerator facility

A new design for an ultra-compact, powerful electron accelerator facility has been produced by the European consortium EuPRAXIA.

The EuPRAXIA design study has shown that plasma acceleration provides a viable alternative to established accelerator technologies.

The accelerator designed by EuPRAXIA will use lasers or electron beams to propel electrons forward on a plasma wave. The result will be a much smaller, more affordable accelerator that uses accelerating gradients up to 1,000 times higher than those that can be achieved with radio frequency technology.

The results could enable the installation of future accelerators in university campuses, hospitals and factories, as well as opening up opportunities for new applications.

EuPRAXIA Coordinator Dr Ralph Assmann from DESY in Germany explains: "*EuPRAXIA has involved, amongst others, the international laser community and industry to build links and bridges with accelerator science. The proposed EuPRAXIA infrastructure aims at the construction of an innovative electron accelerator using laser- and electron-beam-driven plasma wakefield acceleration that offers a significant reduction in size and possible savings in cost over current state-of-the-art RF-based accelerators. Our Conceptual Design Report presents a fascinating concept for a next-generation facility.*"

The design of EuPRAXIA includes a facility for pilot users so that researchers can explore the full potential of plasma accelerators. The foreseen electron energy range of 1-5 GeV and its performance goals will enable versatile applications in various domains, e.g. as a compact free-electron laser

(FEL), compact sources for positron generation, table-top test beams for particle detectors, as well as deeply penetrating X-ray and gamma-ray sources for material testing.

The EuPRAXIA design is the work of leading scientists from 16 laboratories and universities from five European countries, with a further 25 partner institutes globally. It has been coordinated by DESY and funded by the EU's Horizon 2020 programme.

Over the last four years, the scientists have evaluated nine different scenarios for creating high-quality beams using plasma acceleration. In the end, several highly performing accelerator designs have been found as an optimal way forward and will be integrated into multiple beamlines using laser- and electron-beam-driven plasma wakefield acceleration.

Once a factor-3 reduction in facility size has been demonstrated by EuPRAXIA, a miniaturization process towards even more compact designs will be pursued. A reduction factor of 10 and even 20 for the accelerator itself seems feasible at high beam energy.

The UK has an international lead in wakefield acceleration research and has led three of the eight EU-funded work packages of EuPRAXIA. The EuPRAXIA report concludes: "*Given the UK's world-leading expertise in developing high-repetition-rate, high-quality plasma-accelerator technology and applications, we propose that the UK build prototypes, develop all the beamlines, and play a major role in their delivery.*"

Moreover, the UK's Plasma Wakefield Accelerator Steering Committee (PWASC) recommended, in its Roadmap for Plasma Wakefield Accelerator Research 2019-2040 that "*The UK should aim to play a key role, and support the pan-European EuPRAXIA initiative for a European Plasma Research Accelerator with eXcellence In Applications.*"

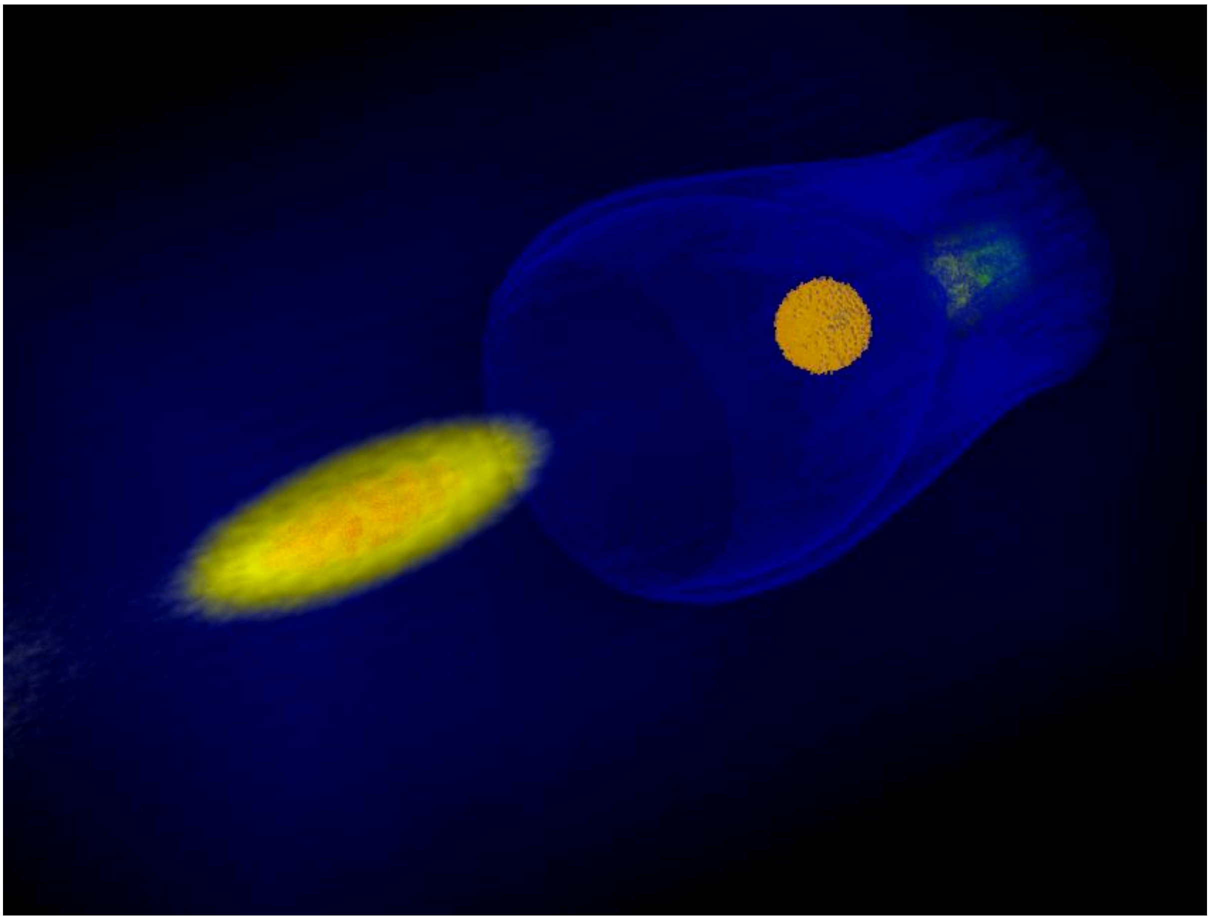
Professor Carsten P Welsch, EuPRAXIA's Communication Lead and Head of Physics at The University of Liverpool, says: "*EuPRAXIA is a game-changer with the potential to offer accelerators for everyone, everywhere. It can make existing applications more accessible and affordable, so that future accelerators could be installed in university campuses, hospitals, and factories and offer the opportunity for new applications that we can currently only dream about.*"

Professor Dino Jaroszynski, of the University of Strathclyde's Department of Physics and the director of the Scottish Centre for the Application of Plasma-based Accelerators (SCAPA) said: "*Development of these next-generation and ultra-compact accelerators is extremely important in that they will eventually take their place alongside 'conventional' accelerators that are at least 1000 times larger.*"

The UK partners in EuPRAXIA are: Imperial College London, Queen's University Belfast, STFC, University of Liverpool, University of Manchester, University of Oxford, University of Strathclyde, and University of York.

More information about EuPRAXIA and the Conceptual Design Report can be found on the project website: http://www.eupraxia-project.eu.

Rendering of the two-stage, very low energy spread plasma accelerator developed for the EuPRAXIA facility. The open tubes show the paths of the laser pulses (red lines) that drive the plasma wakefields in the vacuum chambers.



Simulation of a plasma wakefield with ALaDyn PIC code. Credit A. Marocchino, INFN-LNF

PRIZES AND AWARDS

Rutherford Prize for the Communication of Plasma Physics 2020 (sponsored by STFC)

This was not awarded this year due to no entries being received and is currently being reviewed by the STFC.

Culham Thesis Plasma Physics Prize 2020

Ben Chapman from the UKAEA is this year's Culham thesis prize winner for his PhD on 'Ion cyclotron emission from energetic ion populations in fusion plasmas' completed at the University of Warwick. He has received £500 and will have the opportunity to present his work at the postponed IOP Plasma Physics conference in 2021. Congratulations Ben.