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EDITORIAL

80 Years of Plasma

Guest Editors

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Irving Langmuir proposed the term ‘plasma’ in a paper in 1928 (*Proc. Natl Acad. Sci. USA* **14** 627–637) to describe a ‘region containing balanced charges of ions and electrons’. There does not appear to be any record of the thinking behind this proposal, so it is difficult to be definitive. One idea is that since the Greek word ‘plasma’ was used to describe a mouldable fluid, ‘neon’ lighting, with its almost limitless ability to provide colourful shapes, provided the inspiration. Another relates to the prior medical use in relation to blood with its variety of different ‘corpuscles’ and that the essential description of the positive column required one to recognize at least the role of the separate species of electrons, ions and gas atoms. Tonks, when questioned thirty years later, was inclined to the latter idea, but it is unlikely that we shall ever know for certain. (See postscript added December 2008.)

Forty years ago most of the interest in terrestrial plasmas was centred on fusion and the prospect of thus solving the world’s energy problems; the quest continues. However, since then a whole new industry has developed. It emerged in the 1970s as an imaginative way to remove the photoresist layers used in patterning semiconductor wafers. Slowly but steadily, plasma-based ‘dry’ processes began to displace the traditional wet chemistry processes of cleaning, etching and depositing by which the first generation of integrated circuits had been made. Plasma technology offered higher yields while accommodating the complexity of ever-shrinking feature size, driving the microelectronic revolution for almost four decades. Langmuir certainly ushered in an exciting branch of physics when he introduced the term plasma.

We have included as Appendix I a condensed CV for Irving Langmuir to show, amongst other things, the early influences on his subsequent life. An interlude in Paris gave him a taste of the wider world of Europe. His subsequent schooling in the United States led to admission to Columbia University where he studied metallurgical engineering. After graduation, as was common at that time for able students, he was encouraged to go abroad for his doctoral work. He went to Göttingen, which was then one of the leading European universities in science, and studied under Nernst. Returning to the United States he obtained a post as a teaching assistant at the Stevens Institute of Technology, Hoboken, but the atmosphere proved too hierarchical and uncongenial for a scientist who was wanting to spread his wings.

Fortunately the General Electric Company (GEC) recognized his potential; he was recruited in 1909, and remained associated with the GEC for the next 48 years. He quickly established his credentials as a research scientist and was soon given the freedom to pursue his interests wherever they took him, consistent with the overall strategy of the company. His appointment as an Associate Director at the GEC came in the same year that he introduced the term ‘plasma’. Interestingly, while the term gained rapid acceptance in Europe, the associated word ‘sheath’, which Langmuir had already been using for several years, was translated into French, German and Russian and suffered from confusion. That confusion was there in Langmuir’s writings because this ion-rich region sometimes was a region with barely any electrons and sometimes it contained a significant quantity of negative charge. The structure of the plasma–sheath and its elucidation had to await new mathematical techniques and the impact of computers as evidenced by papers in this volume and those quoted therein.

It is clear that Langmuir inspired and benefited from collaboration with co-workers at the GEC, notably Kingdon, Taylor, Mott-Smith, Compton, Jones, Found, Tonks and Blodgett. In several ways he was ahead of his time in his understanding of gas discharges, and a particular example is what has since come to be known as the Bohm criterion. More than once in his plasma papers published in the early 1930s Langmuir stated in words what was needed for a sheath to develop surrounding a plasma, and did so more generally than Bohm did in his subsequent 1949 paper.

Langmuir's life and work, described by Sir Hugh Taylor in the *Biographical Memoirs of Fellows of the Royal Society*, was criticised by Dennis Gabor because it ignored his contribution to plasma physics. Gabor was aware of the Langmuir paradox arising from the knowledge that electron energy distributions when measured by a Langmuir probe are shown to contain high-energy tails. Some of the reason for the *Biographical Memoir* being deficient is undoubtedly the fact that in 1932 Langmuir was awarded the Nobel Prize in chemistry.

The period of Langmuir's life from 1923 to 1932, as evidenced by his published papers, was largely given over to considerations of electrical discharges in gases with thermionic and liquid mercury cathodes. In 1928 he introduced the term 'plasma' essentially to describe the positive column of a low-pressure gas discharge. These papers, though fewer than 50 in number (which we list in Appendix II), created a whole new area of physics, although we know that there was parallel work going on in Europe as evidenced by the two volumes of *Electrische Gasentladungen* by von Engel and Steenbeck, who adopted the term.

The period before 1923 was concerned largely with atomic structure, molecules and crystalline structure, whereas from 1937 onwards attention was directed to proteins leading to the study of Langmuir–Blodgett films, and even later after World War II to atmospheric and oceanic phenomena.

His scientific legacy, named to commemorate his contributions, can be found in (i) the Child–Langmuir Law, (ii) Langmuir probes, (iii) the Langmuir paradox, (iv) Langmuir waves, (v) Langmuir turbulence, (vi) the Langmuir isotherm, (vii) Langmuir–Blodgett films, together with the associated unit of monolayer coverage 'the Langmuir', and (viii) Langmuir circulation of oceanic currents. The purpose of the series of articles collected in this volume, timed to coincide with the 80th anniversary of the establishment of plasma physics as a distinct discipline, looks at the developments in the understanding principally of (i)–(vi) in the above list, over the intervening period.

The first group of articles within this special issue starts with the contribution that Langmuir made during his pre-plasma years to the light bulb and related physical phenomena. Around the same time he conducted a series of elegant studies from which developed the fundamental principles of chemical adsorption and desorption; this work is reviewed in the second article. The topic of the third article is the distinctive character of a 'region containing balanced charges of ions and electrons', especially in the form of non-equilibrium plasma, as a medium in its own right. The next group of articles is concerned with the non-neutral boundary layers between non-equilibrium plasmas and the surfaces adjacent to them. Though the region is continuous, a notional division into quasi-neutral plasma and space-charge sheath continues to stimulate much philosophical debate. The fourth grouping relates to electrical probes and electron kinetics—topics that also owe their origins to the pioneering experimental work of Langmuir. The structure of gas discharge plasmas under a variety of conditions forms the focus of the next group of papers. The final pair of articles is primarily about electrostatic waves in plasmas, and here too Langmuir laid the foundations.

We acknowledge that the idea that there should be some recognition of Langmuir's role in plasmas at this time was suggested by Pierre Barroy, who completed his PhD with us in 2003. We would like to thank all contributors to this Special Issue, many of whom have been led to go back and reassess Langmuir's

work. His collected papers, published by Pergamon Press in 1961, run to some 12 volumes and it is our intention to deposit a set of all 12 volumes in a library so that they may be accessible to future scholars on request. As Appendix II shows, those of interest to modern day plasma physicists are contained in volumes 3, 4 and 5.

Postscript (added December 2008)

Following the October 2008 online publication of our Editorial, we are grateful to Professor Manfred Hellberg of the University of KwaZulu-Natal (Durban, South Africa) for drawing our attention to a letter by H M Mott-Smith, one of Langmuir's co-workers, published in 1971 (*Nature* **233** 219). In this letter Mott-Smith makes clear his recollection that Langmuir was struck by the analogy between 'the way blood plasma carries around red and white corpuscles and germs' and the way that the ' . . . "equilibrium" part of the discharge acted as a sort of sub-stratum carrying particles of special kinds, like high-velocity electrons from thermionic filaments, molecules and ions of gas impurities'. We thus conclude that this now settles the origin of the term.