Edward Mills Purcell (1912–1997)

Edward Purcell grew up in a small town in the state of Illinois, USA. The telephone equipment which his father worked with professionally was an early inspiration. His first degree was thus in electrical engineering, from Purdue University in 1933. But it was in this period that he realized his true calling – physics. After a year in Germany – almost mandatory then for a young American interested in physics! – he enrolled in Harvard for a physics degree. His thesis quickly led to working on the Harvard cyclotron, building a feedback system to keep the radio frequency tuned to the right value for maximum acceleration.

The story of how the Manhattan project brought together many of the best physicists to build the atom bomb has been told many times. Not so well-known but equally fascinating is the story of radar, first in Britain and then in the US. The MIT radiation laboratory was charged with developing better and better radar for use against enemy aircraft, which meant going to shorter and shorter wavelengths and detecting progressively weaker signals. This seems to have been a crucial formative period in Purcell's life. His coauthors on the magnetic resonance paper, Torrey and Pound, were both from this lab. I I Rabi, the physicist who won the 1944 Nobel Prize for measuring nuclear magnetic moments by resonance methods in molecular beams, was the head of the lab and a major influence on Purcell. Interestingly, Felix Bloch (see article on p.956 in this issue) was at the nearby Radio Research lab but it appears that the two did not interact much. However, Purcell recollects that Hansen (Bloch's collaborator on NMR) lectured on the then new subject of microwaves in the Radiation laboratory. (See the extensive interview covering this period at https://www.aip.org/history-programs/niels-bohr-library/oral-histories/4835-1)

At the end of the war, Purcell returned to Harvard, but continued working on his part of the famous MIT Radiation laboratory series of books. This was Rabi's initiative which brought all the knowledge gained during the war effort into the public domain and had a major influence on the explosive post-war development of electronics, worldwide. The connection proved helpful in the Nobel Prize winning work of Purcell, Torrey, and Pound – they had to build a cavity and this was possible in the Radiation lab workshop. They were aware of the earlier failed attempt by Gorter in the Netherlands via his paper, available post-war. The key to their success was to understand relaxation (see article by B D N Rao's on p.969 in this issue). Soon after, a young student of Gorter came to work in Purcell's lab, and made a major contribution to the theory of relaxation (the classic Bloembergen, Purcell, Pound paper). Purcell recollects that hiring this research assistant for Harvard was one of the smartest things he ever did – Nicholas Bloembergen went on to become a towering figure in non-linear optics (the study of optical phenomena at high power made possible by the invention of the laser), work recognized by the award of the Nobel Prize in 1981.

Figure 1. Harold Ewen besides the Horn Antenna.

In 1949, Purcell learnt of a proposal by another Dutchman, Van de Hulst to observe the atomic hydrogen gas in our Galaxy at a wavelength of 21 cm [1]. The Dutch group was building an elaborate system to do astronomy with this line, with the help of receivers from the Phillips company, and radar antennae left behind by the Germans. Their effort suffered a major setback when the whole setup caught fire. With his student Ewen, Purcell came up with two crucial innovations – using a horn antenna instead of a dish, and using the concept of switching between signal and a reference to cancel out common disturbances. Both ideas were from the radar days [2]. They were able to detect the signal easily, since it was so strong. Knowing of the Dutch effort, they informed their colleagues, Muller and Oort, who were then able to reproduce the result in six weeks. The two groups published back-to-back in *Nature* [3, 4]. Surely this incident illustrates Purcell's outstanding qualities as a person, not just as a scientist. This horn antenna now occupies a place of pride in the National Radio Astronomy Observatory of the United States. *Figure* 1 shows Ewen standing beside it.

The 21 cm line proved to be absolutely crucial for radio astronomy and our understanding of the Universe. But Purcell did not follow this early discovery. Already, by the early 50's with Smith and Ramsey, he had started the search for an electric dipole moment of elementary particles, parallel to the spin axis. A magnetic moment is easily understood in terms of currents associated with the spin, but an electric dipole moment would violate both mirror symmetry and the symmetry between positive and negative charge. This idea is still being followed today, since it may be one of the most sensitive tests of new physics – carried out at very low energies!

This incomplete account of Purcell's physics brings out the dominant theme of electromagnetism. It is not surprising, therefore, that one of the best undergraduate-level texts in electromagnetism is Purcell's contribution to the '*Berkeley Physics Series*' – volume 2 on electromagnetism. This series originated in a grant from the US National Science Foundation which was a response to the sense of being left behind in science and technology by the early Russian achievements in Space. Purcell is the only non-Berkeley author, and the book is full of extraordinary insights not found in more advanced texts. It is one of the few elementary books which brings in relativity very early so that the electric and magnetic fields are seen as two sides of the same coin. I have not seen elsewhere a discussion of the limitations of the 'electrostatic motor' (a masterly footnote) nor the Lorentz local field calculated elegantly with a cubical cavity! Apparently, the book has done better outside the United States, including in India – its mathematical level was considered too high for first year undergraduates in the US. Interestingly, Purcell did not believe in SI units, and the book used the older cgs Gaussian units, as long as he was alive – a 2013 edition is updated to SI, though he must be turning in his grave.

One very interesting experiment carried out with his research student S J Smith is worth mentioning. They fired an electron beam parallel to a diffraction grating. The time-dependent charges induced in each of the rulings act as coherent sources and optical radiation is produced! This Smith Purcell effect was later exploited in the free electron laser, in which an electron beam radiates coherently as it moves through a periodic magnetic field. The effect also has conceptual connections with Cerenkov radiation.

No article on Purcell will be complete without mentioning one of his most charming pieces of pedagogy – an article in the *American Journal of Physics* entitled "Life at low Reynolds number" [5]. A low Reynolds number refers to situations where viscosity is the dominant force on a body in a liquid. The following extract illustrates his style in this piece, and is meant to attract readers to the whole article.

"It helps to imagine under what conditions a man would be swimming, at say, the same Reynolds number as his own sperm. Well, you put him in a swimming pool that is full of molasses (a very viscous liquid) , and then you forbid him to move any part of his body faster than 1 cm per second. …If under those rules, you are able to move a few metres in a couple of weeks, you may qualify as a low Reynolds number swimmer".

Today, there is a widening gap between pure and applied science. Purcell's words in the interview cited earlier are worth remembering. When asked about his teaching, his reply included the following: "A more recent innovation that I've introduced and tried a few times is a course called "Widely Applied Physics," which was conceived with the idea of introducing physics undergraduates to some other neighboring fields in the hope that some of them might find an interesting direction for their own careers and also I think to indulge my own taste for engineering physics – applied physics of an engineering sort – which has always remained strong. In fact, if I haven't said it before, I'll say now that I really, by intellectual taste, am almost as much of an engineer as a physicist."

Suggested Reading

[1] **Biman Nath, Jan Hendrik Oort – a complete astronomer (1900–1992), *Resonance*, Vol.20, No.10, p.864, 2015.**

[2] **R H Dicke, Cosmology, Mach's principle and relativity, *Resonance*, Vol.16, No.4, pp.372–391, 2011.**

[3] **H I Ewen and E M Purcell, Observation of a line in the galactic radio spectrum: radiation from galactic hydrogen at 1,420 Mc./sec., *Nature*, Vol.168, p.356, 1951.**

[4] **C A Muller and J H Oort, Observation of a line in the galactic radio spectrum: the interstellar hydrogen line at 1,420 Mc./sec, and an estimate of galactic rotation, *Nature*, Vol.168, p.357, 1951.**

[5] **E M Purcell, Life at low Reynolds number, *American Journal of Physics*, Vol.45, pp.3–11, 1977.**

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