John William Strutt (Lord Rayleigh)

Born: 12 Nov 1842 in Langford Grove (near Maldon), Essex, England
Died: 30 June 1919 in Terling Place, Witham, Essex, England

John William Strutt's father was the second Baron Rayleigh of Terling Place, Witham, in the county of Essex. Certainly it was a family with little previous interest in science for they were mostly landowners with interests in the countryside. One exception was Robert Boyle, who was a distant relation. Let us say at the beginning of this article that we shall refer to Strutt as Rayleigh throughout this article although he did not succeed to the title until he was 30 years old.

As a boy Rayleigh suffered from poor health and his schooling at both Eton and Harrow was disrupted. He had to leave both schools after a short period due to health problems. Four years spent at the Reverend Warner's boarding school prepared Rayleigh for university and at this stage he did begin to show signs of mathematical ability. During these four years he had a private tutor but overall he showed little sign of being anything other than an average child of average ability.

He entered Trinity College, Cambridge, in October 1861 where he took the mathematical Tripos. His coach at Cambridge was Edward Routh who, in addition to being the most famous of the Cambridge coaches at that time (perhaps of all time), was himself a very fine applied mathematician making important contributions to dynamics. There is no doubt that the grounding in mathematical techniques which Rayleigh had from Routh was an important factor in his outstanding scientific career. It was more than just the mathematics which he learnt that was important to him, for in addition he learnt from Routh how to come up with the most appropriate mathematical methods to tackle each problem.

There was another important influence on Rayleigh during his undergraduate years at Cambridge, namely that of Stokes who was the Lucasian professor of mathematics at the time. Stokes inspired Rayleigh with his lectures which combined theory and practice in a novel way with many physical experiments being carried out during the lectures. Students did not have the opportunity to undertake physics experiments themselves, so seeing Stokes perform experiments in his course on light was Rayleigh's only exposure to the experimental side of science. Rayleigh himself later spoke of how important a role Stokes had played in his development as a scientist. However Stokes does not appear to have directly encouraged Rayleigh to undertake a scientific career.

If Rayleigh had been an average school pupil he was far from an average student. He was awarded an astronomy scholarship in 1864, then in the Tripos examinations of 1865 he was Senior Wrangler (the top First Class student) and in the same year he was the first Smith's prizeman. One has to understand that Rayleigh was now faced with a difficult decision. For someone in his position, knowing that he would succeed to a title and become the third Baron Rayleigh, taking up a scientific career was not really acceptable, and certainly various members of his family felt exactly that way. By this time, however, Rayleigh was determined to devote his life to science so he was certain in his own mind that his social obligations must not stand in his way.

His first paper was inspired by reading Maxwell's 1865 paper on electromagnetic theory. It was through reading widely the current scientific literature that Rayleigh tried to work out which were the important problems on which he should undertake research. The other scientist whose works he studied deeply was Helmholtz, in particular reading Helmholtz' 1860 results on the acoustic resonator. In 1866 Rayleigh was elected a Fellow of Trinity College, Cambridge, and he was poised to make his mark in science.

The usual course of action for young British men of social standing at this time was to take a European tour - the grand tour as it was called. Rayleigh, surprisingly, made a very different, and for that time unusual, tour for he set out on a trip to the United States. One advantage of Rayleigh's privileged social position was that he did not need an academic post to earn his living. Rather when he returned from the United States he purchased equipment for undertaking scientific experiments and set it up on the family estate at Terling. He did experiments on the galvanometer and presented his results to the British Association meeting in Norwich in 1868.

Rayleigh's theory of scattering, published in 1871, was the first correct explanation of why the sky is blue. In the same year he married Evelyn Balfour, the sister of Arthur James Balfour who was to be a leading member of the Conservative Party for 50 years and Prime Minister of Britain 30 years later. Rayleigh had been a student at Cambridge with Arthur James Balfour and through him had met Evelyn. Shortly after their marriage Rayleigh had an attack of rheumatic fever which nearly brought his scientific activities to a premature end. He was advised to travel to Egypt and indeed he did just this with his wife. They sailed down the Nile during the last months of 1872 and early 1873, returning to England in the spring of 1873.

It was a trip during which Rayleigh recovered his health but it was also a very profitable trip from a scientific point of view. Rather remarkably he began writing a major text *The Theory of Sound* while on the trip. It was five years after beginning this great classic before it appeared in print. The first volume, on the mechanics of a vibrating medium which produces sound, was published in 1877, while the second volume on acoustic wave propagation was published the following year.

Shortly after returning from his trip down the Nile, Rayleigh's father died and Strutt, as he had been up to that time, succeeded to the title becoming the third Baron Rayleigh. He continued working at Terling where he now took up residence. The laboratory which he had set up there was one where he made impressive discoveries but one should not think that this was because the rich Rayleigh was able to have better equipment than anyone else. On the contrary he obtained impressive experimental results with cheap equipment. Rayleigh was always one to economise and make do with unsophisticated equipment. Also he was not as well off as might have been expected, for the 1870s were a time of economic problems for farming in England and as a consequence his income was far less than might otherwise have been the case.

From 1879 to 1884 Rayleigh was the second Cavendish professor of experimental physics at Cambridge. The laboratory had been opened five years earlier and Maxwell had been the first Cavendish professor. On the academic side Rayleigh was an obvious choice to succeed to Maxwell's chair, yet in other times he might have been content to work at Terling. The agricultural depression however swung the balance making the income from the post look attractive. There was no suggestion, however, that Rayleigh was just there for the money. On the contrary he took his duties very seriously making very substantial improvements to the teaching of physics at Cambridge. Heathcote, in [7], writes:-

To him fell the task of organising the laboratory as a centre of instruction and research, a task which he accomplished with outstanding success.

We mentioned above the lack of experimental physics when Rayleigh himself was an undergraduate and, although changes were being made, still a great deal was required to be done. With the same energy with which he approached everything, Rayleigh developed laboratory courses in heat, electricity and magnetism, properties of matter, optics, and acoustics.

One of the important pieces of experimental work he carried during his time as Cavendish professor was a standardisation of the ohm. Maxwell and Chrystal had carried out experiments in Cambridge earlier and the apparatus was still available for Rayleigh. However the old equipment did not prove good enough to allow Rayleigh to obtain the accuracy he required and so he had new apparatus built. In his Presidential Address to the British Association in Montreal in 1884 he explained the results. He introduced the topic by saying:-

During the last few years much interest has been felt in the reduction to an absolute standard of measurements of electromotive force, current, resistance, etc. and to this end many laborious investigations have been undertaken. The subject is one which has engaged a good deal of my own attention ...

Then in 1884 he resigned his Chair at Cambridge to return to his research on his own estate at Terling. His financial position had improved and what he loved was scientific research, without the time-consuming responsibilities of a university post. There were many colleagues who tried to get him to reconsider his action and continue to hold the chair but Rayleigh knew exactly what he wanted from life. It was not a solitary scientific existence for him in Terling since he made frequent visits to London where he had duties to perform for many learned and scientific societies. Let us look briefly at some of his activities in this area.

Rayleigh had been elected as a Fellow of the Royal Societyin 1873. He received the Royal Medal from the Society in 1882, and became secretary of the Society in 1885, being awarded the Society's Copley Medal in 1899. He gave the Society's Bakerian Lecture in 1902 and he was elected President of the Society in 1905, holding the position until 1908. Rayleigh served as President of the London Mathematical Society in 1876-78 and he was awarded the Society's De Morgan Medal in 1890. He also had connections with the Royal Institution, becoming professor of natural philosophy there in 1887. He became chancellor of Cambridge University in 1908.

Other activities which deserve mention involve the work he put in helping towards establishing the National Physical Laboratory which was set up at Teddington in Middlesex in 1900. He was appointed scientific advisor to Trinity House, the association of English seamen, in 1896. Connected with the political scene through his wife, he was much involved in advisory roles such as serving on a committee on aeronautics.

Clearly this level of activity meant that he did not lack contact with fellow scientists, and he also corresponded with many of the leading scientists. We should now turn to examine briefly some of the scientific work which he undertook. First, however, we note that [7] contains a complete list of Rayleigh's publications and remarkably there are 446 items in the list. They cover an incredible range of topics in applied mathematics and physics. Among the publications devoted to mathematics, rather than to its applications, are papers on Bessel functions, the relationship between Laplace functions and Bessel functions, and Legendre functions. In addition to the more usual topics of applied mathematics and physics which we say a little on below, he wrote on more unusual topics such as *Insects and the colour of flowers* (1874), *On the irregular flight of a tennis ball* (1877), *The soaring of birds* (1883), *The sailing flight of the albatross* (1889), and *The problem of the Whispering Gallery* (1910).

We have mentioned above his work on electromagnetic phenomena, his major treatise on sound, the determination of the ohm, and his important paper of scattering of light which explained why the sky is blue. In addition [7]:-

... he applied the wave theory of light to the mathematical investigation of the resolving power of prisms and diffraction gratings; thus he showed that the resolving power of a grating is determined by the total number of lines in the grating multiplied by the order of the spectrum, and not by the closeness of the lines. ... In 1887 *he published a paper in which he suggested the method of reproducing colours by photography later adopted in principle by Lippmann.*

Rayleigh is perhaps most famous for his discovery the inert gas argon in 1895, work which earned him a Nobel Prize in 1904. In his address on the occasion of receiving the Nobel Prize Rayleigh explained how he made his famous discovery (see for example [7]):-

The subject of the densities of gases has engaged a large part of my attention for over 20 *years. ... Turning my attention to nitrogen, I made a series of determinations ... Air bubbled through liquid ammonia is passed through a tube containing copper at a red heat where the oxygen of the air is consumed by the hydrogen of the ammonia, the excess of the ammonia being subsequently removed with sulphuric acid. ... Having obtained a* *series of concordant observations on gas thus prepared I was at first disposed to consider the work on nitrogen as finished. ... Afterwards, however, ... I fell back upon the more orthodox procedure according to which, ammonia being dispensed with, air passes directly over red hot copper. Again a good agreement with itself resulted, but to my surprise and disgust the densities of the two methods differed by a thousandth part - a difference small in itself but entirely beyond experimental errors. ... It is a good rule in experimental work to seek to magnify a discrepancy when it first appears rather than to follow the natural instinct to trying to get quit of it. What was the difference between the two kinds of nitrogen? The one was wholly derived from air; the other partially, to the extent of about one-fifth part, from ammonia. The most promising course for magnifying the discrepancy appeared to be the substitution of oxygen for air in the ammonia method so that all the nitrogen should in that case be derived from ammonia. Success was at once attained, the nitrogen from the ammonia being now* $^1/_{200}$ *part lighter than that from air. ... Among the explanations which suggested themselves are the presence of a gas heavier than nitrogen in air ...*

Rayleigh of course was correct and succeeded, with considerable difficulty, in isolating the gas. Since it refused to make chemical combinations it was called argon from the Greek word for inactive.

In 1879 Rayleigh wrote a paper on travelling waves, this theory has now developed into the theory of solitons. The preface of [4] explains why Rayleigh-wave theory, introduced by him in 1885 in a paper in the *Proceedings of the London Mathematical Society,* has proved so important:-

There is no respect for mere age in science or technology. Yet the centenary of the discovery, by the third Lord Rayleigh, that elastic waves can be guided by a surface, is memorable for the contradictions which it encompasses: Rayleigh's assessment of his classic 1885 *paper as a rather minor mathematical development with a potential value only in seismology on the one hand; on the other the rediscovery of the subject in a totally different field - that of electronic signal processing - which has led to its explosive growth over the last twenty years.*

In fact in his paper 1885 paper *On waves propagated along the plane surface of an elastic solid* Rayleigh writes:-

It is proposed to investigate the behaviour of waves upon the plane surface of an infinite homogeneous isotropic elastic solid, their character being such that the disturbance is confined to a superficial region, of thickness comparable with the wavelength. .... It is not improbable that the surface waves here investigated play an important part in earthquakes, and in the collision of elastic solids. Diverging in two dimensions only, they must acquire at a great distance from the source a continually increasing preponderance.

Rott [12] looks at Rayleigh's contributions to hydrodynamics, in particular to hydrodynamic similarity:-

[*There were*] *two domains in fluid mechanics in which Lord Rayleigh made explicit use of hydrodynamic similarity: the theory of aerodynamic drag and the treatment of the Aeolian tones.* [*There was a*] *great impact of Rayleigh's ideas on the development of hydrodynamic similarity theory and applications during his lifetime and beyond.*

Of course Rayleigh received many honours for his scientific work. In 1902, at the coronation of King Edward VII, he received the Order of Merit. In addition to the Nobel Prize he received thirteen honorary degrees, five government awards, and honorary membership of five learned societies world-wide.

Rayleigh was a modest and generous man. He donated the proceeds of his Nobel Prize to the University of Cambridge to build an extension to the Cavendish laboratories. On receiving the Order of Merit in 1902 he said:-

... the only merit of which I personally am conscious was that of having pleased myself by my studies, and any results that may be due to my researches were owing to the fact that it has been a pleasure for me to become a physicist.

There is another side to Rayleigh's interests which are mentioned in [3], namely his interest in psychical research. He was president of the Society for Psychical Research and in his address to this Society [3]:-

... he recalled some experiments in hyptonic suggestion in which he took part at Cambridge in the sixties of last century, and which convinced him of the possibility of influencing unwilling minds by suggestion. Later he became interested in the doings of Home and other so-called mediums, and though he pronounced the results on the whole to be disappointing, he found some of the incidents difficult to explain.

We end this brief biography of Rayleigh by quoting from his Presidential Address to the British Association in Montreal in 1884:-

Without encroaching upon grounds appertaining to the theologian and the philosopher, the domain of natural sciences is surely broad enough to satisfy the wildest ambition of its devotees. In other departments of human life and interest, true progress is rather an article of faith than a rational belief; but in science a retrograde movements is, from the nature of the case, almost impossible. Increasing knowledge brings with it increasing power, and great as are the triumphs of the present century, we may well believe that they are but a foretaste of what discovery and invention have yet in store for mankind. ... The work may be hard, and the discipline severe; but the interest never fails, and great is the privilege of achievement.

Article by: *J J O'Connor* and *E F Robertson*