# *The Missing Link:* ZEEMAN EFFECT

**by Greg Grant**

***A century ago, the Dutch physicist, Pieter Zeeman, firmly established the connection between light and magnetism. Physics was in transition, tentatively edging away from Newtonian conviction, yet only leaning towards what would shortly become Planckian uncertainty. The Zeeman Effect was the blank page between both testaments.***

In March 1862, the great Michael Faraday began work on his last experiment, an "...attempt to find the influence of a magnetic field on the light emitted by a source immersed within it."

He set out to observe a change in the position or width of the spectrum of a flame placed in the field of a powerful magnet. He was however, unsuccessful, because the spectroscopes of the day were simply not up to the task. Five years later, the Great Experimenter was dead, convinced to the end that such an effect would be found, for he looked upon the light as being universal in nature.

This had not been Faraday's first attempt to link light and magnetism. As early as September 1822, he had 'tested his expectation that electricity should alter the polarisation of a beam of light, and six years later, he experimented, again unsuccessfully, on the presumed influence of light on electricity.'

In 1845, he tried again, this time successfully – he discovered that a magnetic field affects the polarisation of light in crystals and, concomitantly, put forward the view that light could be waves of electromagnetism. His last experiment could be seen as an attempt to take this discovery further.

## Enter Machinery

At this time, Spectrum Analysis, or the resolution of a beam of light into components that differ in wavelength, depended on prisms, as indeed, most investigations of light had done since Newton's day.

Diffraction gratings were known (the German optician, Joseph von Fraunhofer, had used one in place of a prism in 1820), but they only became practical in 1885, with the invention of the concave diffraction grating. The brainchild of the American research physicist, Henry Rowland, the new grating could be machine-made, the equipment for doing so being yet another of his inventions. The machine was capable of engraving some 20,000 lines to the inch, a development that removed the need for the usual additional components common in spectrometers, such as mirror and lenses. The concave grating gave all the sensitivity needed.

In the following year, Rowland mapped the solar spectrum using his concave grating. The result was the precise wavelengths of some 14,000 lines and his 'Photographic Map of the Normal Solar Spectrum' of 1888 was, in effect, a spectrogram greater than 11m in length! His Solar Spectrum Wavelength table contained tens of thousands of lines and remained the standard work on the subject for some years. Indeed, some of his gratings are still in use.

In 1895, Hendrik Lorentz, the Professor of Physics at Leiden University in the Netherlands, began to consider if the electric charges within the atom itself could oscillate. He thought that if they could, then they could be observed by experiment.

Lorentz was not alone in this view. The British theoretical physicist, Joseph Larmor, had already put forward a similar theory, but shortly abandoned it after calculating that the oscillations (if any) would be too small to measure. Lorentz however, was not so sure, and asked his assistant, Pieter Zeeman, to look into the matter.

## The Link Revealed

The son of a Lutheran minister, the 31 year old Zeeman had studied under both Lorentz and Kamerlingh Onnes. In 1893, he had been awarded his doctorate for his thesis on the Kerr Effect, a dissertation which also won him a gold medal. He took up Lorentz's suggestion "...feeling that if Faraday had thought the experiment worth doing, it might be worth repeating with better, more sensitive apparatus."

Figure 1 illustrates Zeeman's technique. A sodium flame was placed in a powerful magnetic field and observed via a diffraction grating. Zeeman used a Rowland grating with a 10 foot radius and discovered that the sodium's yellow D-lines broadened, then parted into patterns of a few lines each as the field strength increased. He subsequently found that the broadening was a distinct splitting of the lines into as many as 15 components.

In Figure 1a, the light is received in a direction parallel to the field, the Longitudinal or Parallel Effect, viewed through a hole bored in the pole-piece; the lower pair of lines replace the original line when the field is switched on. These lines are circularly polarised in the opposite sense, as shown, and both lines each account for half the energy of the original.

In Figure 1b, the light is received across the field, the Transverse or perpendicular Effect. Here, the original line has been replaced by a triplet and the original energy is now apportioned frictional, namely ¼, ½ and ½, giving equal amounts to polarisation in each direction. This is termed the NORMAL Zeeman Effect and is explained as the speeding up and slowing down of orbital electrons in the field source as a consequence of the applied magnetic field.

The ANOMALOUS Zeeman Effect, on the other hand, is more complex, splitting the lines into several *very* closely spaced ones.

It is termed anomalous because it does not agree with the predictions of classical physics, and is explained by quantum mechanics in terms of electron spin.

In 1896, however, matters were different. To begin with, the electron had yet to be discovered, although its charge had been estimated, and its name introduced, five years earlier by the Irish physicist, George Stoney.

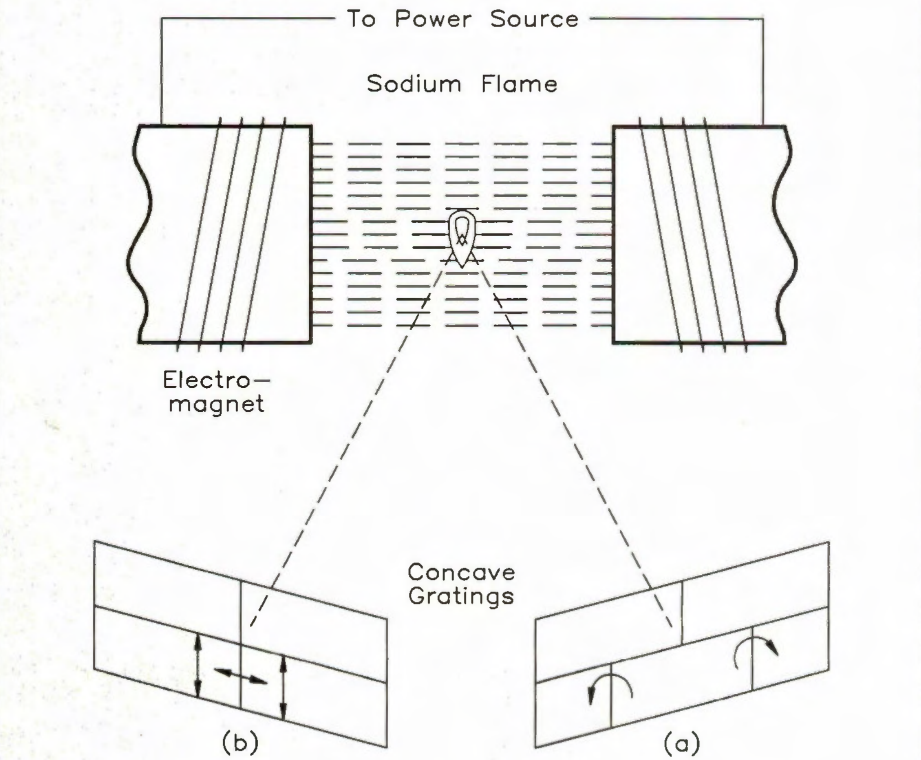


**Figure 1. The Zeeman Effect, illustrating the Longitudinal and the Transverse aspects.**

Furthermore, seven years before Stoney's farseeing prognosis, the Swedish chemist, Svante Arrhenius, suggested that atoms or groups of atoms could carry electric charges. Lorentz favoured Arrhenius's theory and suggested that light resulted from what he termed the motion of charged particles within the atom. He then used Zeeman's discovery, the behaviour of light in a magnetic field, to calculate the mass/charge ratio of such a charged particle. And this, a year before the electron was discovered and some 15 years before the scientific community confirmed that the electron was indeed part of the atom!

In the following year, Zeeman himself demonstrated conclusively that vibrating electrons were the cause of the line splitting, using the blue-green cadmium line.

Later experimenters studying the Zeeman Effect used electric discharge tubes, which emitted a bright-line spectrum between the magnetic poles. Diffraction gratings too, were improved. Manufactured from speculum-metal as well as glass still, they carried a very considerable number of lines, of the order of 1,000/mm.

Later, the Danish physicist, Noels Bohr, in five papers published from 1913 to 1915, proposed that the vibration was, in fact, electrons changing from one discrete energy level to another, each of these levels being split in a magnetic field into substrates of equal energy. In other words, the Zeeman Effect is the result of the outermost atomic electrons interacting with the magnetic field, and what had been a single spectral line without the field, became two or more under its influence, the frequency of spacing between the lines depending on the field strength.

The Zeeman Effect is important in modern science, since it helps physicists to determine the energy levels in atoms and identify them in terms of angular momenta. It is also used in the study of electron paramagnetic resonance.

In astronomy, the Zeeman Effect proved its usefulness as early as 1908, when the American astronomer, George Ellery Hale, discovered magnetic fields in sunspots through observing the splitting of spectral lines.

The Zeeman Effect is still a powerful astronomical tool today, enhancing the study of not only our own sun, but also the magnetic fields of other stars.

The Zeeman Effect was a point between the visualisation of phenomena possible with Newtonian mechanics and the wave of probability likely with Quantum mechanics.

What had begun as a missing link was discovered to be a bridge spanning what was passing and what was yet to be. ELECTRONICS

## Further Reading

*From falling Bodies to Radio Waves*, Emilio Segre, W. H. Freeman & Co., New York, 1984. Page 153.

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*Michael Faraday*, L. Pierce Williams, Chapman & Hall, London, 1965. Page 479.

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