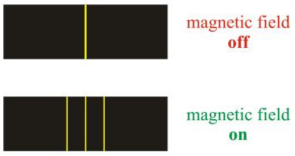
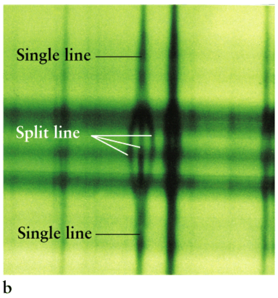
Sun – Part 20 - Solar magnetic field 2 – Zeeman effect



The Zeeman effect



The effect in a solar spectral line

Pieter Zeeman

This is a means of measuring a magnetic field from a distance, one that is particularly useful in astronomy where such measurements for stars have to be made indirectly. Use of the Zeeman effect is particularly important in relation to the Sun's magnetic field because of the central role played by the solar magnetic field in solar activity eg solar flares, coronal mass ejections, which can, potentially, pose a serious hazard to many aspects of human life.

The Zeeman effect is the splitting of a spectral line into several components due to the presence of a static magnetic field. Normally, atoms in a star's atmosphere will absorb a certain frequency of energy in the electromagnetic spectrum. However, when the atoms are within a magnetic field, these lines become split into multiple, closely spaced lines. For example, under normal conditions, an atomic spectral line of 400nm would be single. However, in a strong magnetic field, because of the Zeeman effect, the line would be split to yield a more energetic line and a less energetic line, in addition to the original line. The distance between the splits is a function of the magnetic field, so this effect can be used to measure the magnetic fields of the Sun and other stars. The energy also becomes polarised, with an orientation depending on the orientation of the magnetic field. Thus, strength and direction of a star's magnetic field can be determined by study of Zeeman effect lines.

The effect is named after the Dutch physicist Pieter Zeeman. While a doctoral student, he worked as assistant to theoretical physicist Hendrik Lorentz. (Lorentz is famous for the Lorentz transformation, a set of equations relating position and time of an event a seen by one observer to the time and position of the same event seen by a second observer who is moving at a constant velocity relative to the first – equations fundamental to the precepts of Einstein's later theory special relativity). In 1896, Zeeman disobeyed the orders of his thesis superior and used laboratory equipment to measure the splitting of spectral lines by a strong magnetic field. He was fired, but vindicated later, as he had discovered what is known as the Zeeman effect.

Lorentz heard about Zeeman's observations and explained them in relation to the laws of classical physics and his theory of electromagnetism. Zeeman's discovery confirmed Lorentz's prediction about the polarisation of light emitted in the presence of a magnetic field. It made clear that the oscillating particles that, according to Lorentz, were the source of light emission, were negatively charged, and a thousandfold lighter than the hydrogen atom (these particles were later shown to be electrons, but these had not been discovered yet).

Because of his discovery, Zeeman was reinstated and appointed a lecturer in physics in 1897, continuing to study the Zeeman effect and magneto-optics during his career. In

1902, he won the Nobel prize in physics for his discovery of the Zeeman effect jointly with his mentor Lorentz.

Quantum physics was also needed to fully explain the Zeeman effect. According to quantum theory, all spectral lines arise from transitions of electrons between different allowed energy levels within the atom, the frequency of the spectral line being proportional to the energy difference between the initial and final levels. Because of its intrinsic spin, the electron has a magnetic field associated with it. When an external magnetic field is applied, the electron's magnetic field may assume only certain alignments. Slight differences in energy are associated with these different orientations, so that what was once a single energy level becomes three or more.

Practical applications based on the Zeeman effect include spectral analysis and measurement of magnetic field strength. Since the separation of the components of the spectral line is proportional to the field strength, the Zeeman effect is particularly useful where the magnetic field cannot be measured by more direct methods eg in astronomy.

There is a theory that the magnetic sense of birds which assumes that a protein in the retina is changed due to the Zeeman effect, enabling them to 'see' Earth's magnetic field lines.

Sources: Ridpath, I (Ed) (2012) Oxford dictionary of astronomy 2nd ed rev, www.en.wikipedia.org, www.infoplease.com, www.physlink.com