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Observing the Solar Spectrum at House of Science

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Physical principles

Students and teachers visit House of Science [1] at AlbaNova University Center in Stockholm to make laboratory experiments in astronomy, biotechnology and physics. In April 2005 the World Year of Physics was celebrated with a special Einstein week [2], focusing on activities related to Einstein's work in 1905. One of the laboratory exercises was the observation of the fusion induced radiation from the Sun. In this experiment the emphasis was on the innermost region of the Sun where the temperature reaches about 15 million degrees and where the fusion processes powering the Sun take place. The main process responsible for the energy production in the Sun is the proton-proton chain reactions. In these reactions four hydrogen nuclei are fused into a helium nucleus. The sum of the masses of the four hydrogen nuclei is slightly larger than the mass of the final helium nucleus, and this mass is turned into energy described by Einstein's equation, $E=mc^2$. The mass difference between four protons and one helium nucleus, $4.6\ 10^{-29}$ kg, is transformed into 27 MeV of energy including the annihilation of the two positrons created in the process. Each second about 4 million tonnes of matter is converted into $2\ 10^{39}$ MeV of energy in the Sun, most of it in the form of gamma-rays.

Experimental details

House of Science has six CCD (Charge-Coupled Device) spectrometers AvaSpec-2048 from Azpect Photonics, with which the radiation from the Sun is studied. It is also possible to do solar observations with the spectrometers on cloudy days as the scattered sunlight still gives rise to good spectra. The CCD has an array of 2048 pixels and covers the wavelength range 100–1100 nm. A demonstration CCD spectrometer (Fig.1) is used to describe the different components. The sunlight passes through an optical fibre into the spectrometer where it is further reflected by two mirrors and a grating, splitting up the light into different wavelengths, until it finally falls on the CCD. The CCD pixels are read out and the intensity distribution is displayed. A group of 2-3 students usually work with one spectrometer (Fig.2).

The observed sunlight comes from a thin layer of the solar atmosphere, the photosphere. The thickness of the photosphere is only 400 km which is very thin compared to the 700 000 km radius of the Sun. This is the reason why the solar surface seems so sharp when viewed through a solar filter or projected on a piece of paper. When working with solar observations it must be emphasized that one should never look directly at the Sun without proper solar filters. To do so is to risk serious damage to the eyes. For a safe observation of the Sun and the darker sunspots, a Sunspotter can be used. This is a simple projection solar telescope which is easy to use and can be handled by students of all ages (Fig.3).

Spectrum analysis

Blackbody radiation

To a very good approximation the photosphere of the Sun radiates as a blackbody, ie the radiation spectrum is determined by the temperature. The spectrum of the Sun (Fig. 4.) shows the blackbody continuum superimposed with a number of absorption lines. Using Wien's displacement law

$$\lambda_m T = 2.898 \cdot 10^{-3} \text{ K m},$$

where λ_m is the wavelength at which the Planck curve has its maximum, it is possible to determine the temperature (T) of the photosphere. From their observations the students estimate the value of λ_m either by visual inspection or with the help of the software accompanying the CCD spectrometers. Usually the students find an accurate value of the temperature of around 5800K.

Absorption lines
There are several absorption lines superimposed on the blackbody spectrum. These lines originate from the upper parts of the photosphere. By determining the wavelength for these lines it is possible to identify the elements in the solar atmosphere that are causing them. It is important to go through the energy level diagram of hydrogen (Fig. 5) and how absorption lines arise, particularly the Balmer lines emerging from transitions from the second energy level in the hydrogen atom. The Balmer lines are emitted in the optical region of the spectrum and are detectable with the spectrometer. The students identify them in their observed spectrum and can also identify lines from other elements in the solar atmosphere like calcium, magnesium and iron. The sunlight also passes through the Earth's atmosphere and strong absorption lines from H_2O and O_2 molecules in the Earth's atmosphere can be seen.

Emission lines
As a complement to the solar observations the students study the spectrum from a hydrogen lamp. This spectrum is an emission spectrum containing both hydrogen and oxygen lines. The difference between absorption and emission lines is discussed. The students easily identify at least six components of the Balmer series. By accurately determining the wavelengths of the Balmer lines (quantum numbers n=2 and m=3,4,5..) with the spectrometer software the students are able to calculate Rydberg's constant (R_H) from Bohr's formula:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n^2} - \frac{1}{m^2}\right).$$

This exercise of observing the solar spectrum contains many different aspects of physics in addition to the transformation of mass to energy. The students measure the temperature of the Sun and Rydberg's constant and they learn about absorption and emission lines as imprints of elements in the Sun's and in the Earth's atmospheres. This exercise can be extended to studying environmental aspects by investigating light absorption in the Earth's atmosphere and its composition.

References

1. House of Science, a university laboratory for school, 2004 K.E. Johansson, Physics Education 34, 342.
2. Einstein for schools and the general public, K.E. Johansson, C. Kozma and Ch. Nilsson, to appear in Physics Education.

Figure captions

Fig. 1 Students observing the Sun light with a CCD spectrometer a cloudy winter day.

Fig. 2 The demonstration spectrometer showing schematically the path of the light from the optical fibre to the CCD.

Fig. 3 A Sunspotter used to display and observe the solar surface.

Fig. 4 A solar spectrum registered by the CCD spectrometer shows the blackbody radiation spectrum and a number of absorption lines.

Fig. 5 The energy level diagram of hydrogen.