The Rotational Period of the Sun
Post-16

Topics covered: solar spectra, Doppler effect formula, error analysis

Teacher's Notes

In this activity students are introduced to the method of error analysis in science and calculate the error in the rotational period of the Sun. They also look at assumptions made in this calculation and the physics involved in measuring this value.

Equipment: calculator

Questions to ask the class before the activity:

What is a spectrum?
Answer: a 'fingerprint' of an object made of light. The spectrum of visible light is composed of the colours of the rainbow.

What are absorption and emission spectra (how do they occur)?
Answer: absorption spectra arise from electrons absorbing photons of light and jumping an energy level or levels; emission spectra occur when electrons fall down to a lower energy level and emit a photon in the process.

What can a spectrum tell us about an object in space?
Answer: the composition of an object such as a star, its temperature, its pressure, the abundance of elements in the star, its motion (velocity).

How can we tell if the Sun is rotating?
Answer: we look at its spectrum from different regions. If the lines are shifted towards the red end (longer wavelengths) relative to a spectrum at rest than that part of the Sun is moving away from us; a blue shift tells us that region of the Sun is approaching us. The extent of the shift tells us the velocity.

Questions to ask the class after the activity:

The Solar Heliospheric Observatory (SOHO) uses different filters to observe the Sun. What colour would the Sun appear through a Hα (6563 Å) filter?
Answer: 6563 Å = 656.3 nm, this is in the **red** part of the optical spectrum.

The emission you looked at came from the eastern and western edges of the Sun. What would you expect to find when measuring the wavelength of hydrogen emission as you move across the equator from limb to limb? What about at the centre of the Sun?
Answer: the extent of the shift would decrease moving inwards from the eastern limb towards the centre where it would be zero and increasing again out to the western limb. The Doppler effect is not seen when the motion is perpendicular to our line of sight i.e. at the centre of the Sun.

Calculating the Rotational Period of the Sun: Answers

Use the following equations to find the rotational velocity of the Sun if the measured wavelength, λ of the Hγ line taken from the eastern (left side) limb of the Sun = 4340.44 ± 0.05 Å and the observed Hγ line on the western edge (right side) = 4340.50 ± 0.05 Å. Which side of the Sun is approaching us?

Balmer Lines	Rest wavelength, λ_0
Hγ	4340.472 ± 0.001 Å
Hβ	4861.350 ± 0.001 Å
Hα	6562.790 ± 0.001 Å

Answer: the wavelength of **Hγ** from the eastern edge of the Sun is blueshifted so this side is approaching us.

Find the error, Δv_{rot} in your calculated velocity, v_{rot} using the equations below:

1

$$\frac{v}{c} = \frac{\lambda - \lambda_0}{\lambda_0} = z$$

$$\left(\frac{\Delta v}{v}\right)^2 = \left(\left(\frac{\Delta \lambda}{\lambda}\right)^2 + \left(\frac{\Delta \lambda_0}{\lambda_0}\right)^2\right)$$

Rotational velocity, v_{rot} = 2211.7 m s^{-1}

Error, Δv_{rot} = 56.4 m s^{-1}

c = 299 792 458 m s^{-1}

2

$$v_{rot} = \frac{2\pi R_S}{T_{rot}}$$

$$\left(\frac{\Delta T}{T}\right)^2 = \left(\frac{\Delta v}{v}\right)^2$$

Time period, T_{rot} = 22.9 days

Error, ΔT_{rot} = 0.6 days   Percentage error = 2.5%

Activity: **The Rotational Period of the Sun**

The Sun, like all of the planets in the Solar System, rotates. The Solar and Heliospheric Observatory, SOHO, a satellite orbiting the Sun 1.5 million km closer than the Earth has captured the rotating Sun, this can be seen here: http://sohowww.nascom.nasa.gov/gallery/Movies/sunspots.html

Below is the visible (flattened) spectrum of the Sun taken by the McMath-Pierce Solar Telescope on Kio Peak in Arizona. The Fraunhofer (absorption) lines can be seen and their relative intensities are shown. The Sun's rotational velocity can be calculated by using its spectrum. Stars like the Sun often show strong hydrogen emission lines such as Hα, Hβ and Hγ (below). By measuring the wavelengths of these solar lines and comparing them to their **rest wavelengths** we can tell whether the part of the Sun we are looking at is redshifted or blueshifted and then we can calculate the velocity of the spinning Sun using the Doppler equation.
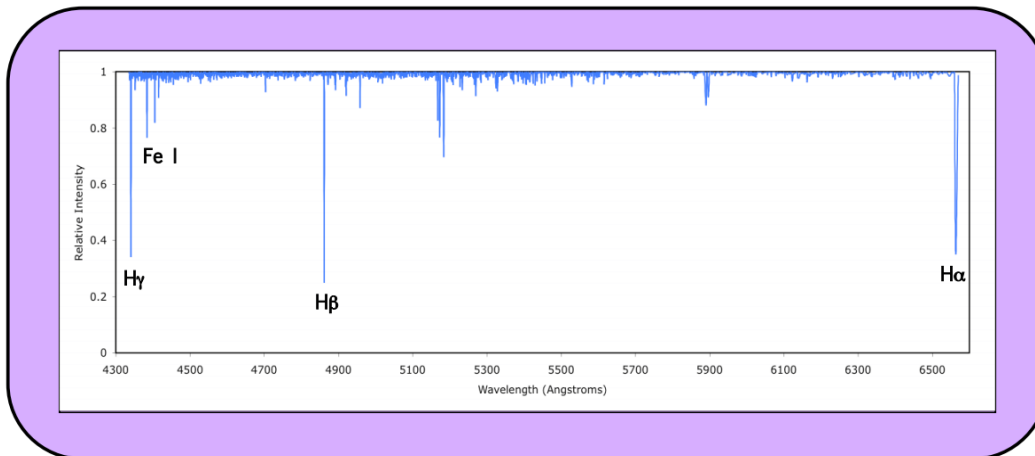
Every measurement has an uncertainty or error associated with it. The rotational speed of the Sun is about **2.2 km s⁻¹**. There are a number of assumptions made in the derivation of this value and sources of error. The measured wavelength of the hydrogen emission line from the Sun will have an uncertainty that is dependent on the precision of the instrument used. For example if the **measured** wavelength is 4340.44 Å, the error, $\Delta\lambda$ = 0.05 Å. There will also be an error in the laboratory wavelength which would be very small but here we will make it a bit bigger: **rest** wavelength of Hγ = 4340.472 Å, error, $\Delta\lambda_0$ = 0.001 Å. We use a value for the speed of light when calculating the velocity from the wavelength, c = 299 792 458 ms⁻¹.

The value calculated above applies to the equatorial region of the Sun; in fact the rotational speed varies with latitude across the Sun, this is termed differential rotation. We have also made significant assumptions when measuring the solar spectral lines. We have ignored other physical effects such as temperature, pressure, elemental abundance, density and surface gravity. These properties affect the width and the height as well as the shape and position of spectral lines.

Calculating the Error in the Period

The quantity we wish to determine is derived from several measured quantities. Errors in measured values can be incorporated into functions to determine the error in the final calculated value. Consider two independent measured quantities X and Y and their errors ΔX and ΔY. The error in the derived quantity, ΔF can be determined as follows:

1) $F = X + Y$ or $F = X - Y$ $\qquad \Delta F^2 = \Delta X^2 + \Delta Y^2$

2) $F = XY$ or $F = X/Y$ $\qquad \left(\dfrac{\Delta F}{F}\right)^2 = \left(\dfrac{\Delta X}{X}\right)^2 + \left(\dfrac{\Delta Y}{Y}\right)^2$

Balmer Lines	Rest wavelength, λ_0
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Use the following equations to find the rotational velocity of the Sun if the measured wavelength, λ of the Hγ line taken from the eastern (left side) limb of the Sun = 4340.44 ± 0.05 Å and the observed Hγ line on the western edge (right side) = 4340.50 ± 0.05 Å.

Which side of the Sun is approaching? Find the error, Δv in your calculated velocity, v using the equations below:

① $\qquad \dfrac{v}{c} = \dfrac{\lambda - \lambda_0}{\lambda_0} = z$ $\qquad\qquad \left(\dfrac{\Delta v}{v}\right)^2 = \left(\left(\dfrac{\Delta \lambda}{\lambda}\right)^2 + \left(\dfrac{\Delta \lambda_0}{\lambda_0}\right)^2\right)$

Rotational velocity, v_{rot} = _____ m s⁻¹

Error, Δv_{rot} = _____ m s⁻¹ $\qquad\qquad$ **c = 299 792 458 m s⁻¹**

② $\qquad v_{rot} = \dfrac{2\pi R_S}{T_{rot}}$ $\qquad\qquad \left(\dfrac{\Delta T}{T}\right)^2 = \left(\dfrac{\Delta v}{v}\right)^2$

Time period, T_{rot} = _____ days

Error, ΔT_{rot} = _____ days $\qquad$ Percentage error = _____