Find The Speed For A Star In Which This Line Appears At Wavelength 120.5 Nm. Express Your Answer To Three

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Introduction

Understanding the motion of stars and celestial objects is fundamental in astrophysics. One of the key methods used to determine the velocity of a star relative to Earth involves analyzing the spectral lines in its emitted light. When a star moves toward or away from us, the spectral lines are shifted from their known rest wavelengths due to the Doppler effect. This shift allows astronomers to calculate the star's radial velocity. In this article, we explore how to find the speed of a star given that a specific spectral line appears at a certain observed wavelength, particularly 120.5 nm, and how to express the result with three significant figures.

The Doppler Effect and Spectral Line Shifts

The Doppler effect refers to the change in frequency or wavelength of a wave in relation to an observer moving relative to the source of the wave. In astrophysics, this effect causes the spectral lines emitted or absorbed by stars to shift depending on their velocity relative to Earth.

- If a star moves toward Earth, the spectral lines shift to shorter wavelengths (blueshift).
- If a star moves away from Earth, the spectral lines shift to longer wavelengths (redshift).

The magnitude of this shift can be used to calculate the star's radial velocity.

Understanding the Rest Wavelength

Before calculating the star's speed, it is essential to know the rest wavelength (\(\lambda_0\)) of the spectral line. This is the wavelength of the line when the source is at rest relative to the observer.

Suppose the spectral line in question is the Hydrogen Lyman-alpha line, which has a rest wavelength of approximately 121.6 nm. This is a common spectral line in astrophysics studies.

Note: If the specific rest wavelength is different, the calculation will need to be adjusted accordingly.

Applying the Doppler Shift Formula

The relativistic Doppler shift formula for wavelength is:

$$
\frac{\lambda_{obs}}{\lambda_0} = \sqrt{\frac{1 + \frac{v}{c}}{1 - \frac{v}{c}}}
$$

where:
- λ_{obs} = observed wavelength (120.5 nm)
- λ_0 = rest wavelength (assumed 121.6 nm)
- v = radial velocity of the star
- c = speed of light (~$3.00 \times 10^8\, \text{m/s}$)

However, for velocities much less than the speed of light, the non-relativistic approximation suffices:

$$
v \approx c \times \frac{\lambda_{obs} - \lambda_0}{\lambda_0}
$$

This approximation simplifies calculations significantly and is accurate for velocities less than about 10% of the speed of light.

Note: For high velocities approaching the speed of light, the relativistic formula must be used.

Calculating the Star's Velocity

Assuming the rest wavelength (λ_0) is 121.6 nm, and the observed wavelength is 120.5 nm, the change indicates a blueshift (the star is moving toward us).

Using the non-relativistic approximation:

$$
v = c \times \frac{\lambda_{obs} - \lambda_0}{\lambda_0}
$$

Plugging in the values:

$$
v = 3.00 \times 10^8\, \text{m/s} \times \frac{120.5\, \text{nm} - 121.6\, \text{nm}}{121.6\, \text{nm}}
$$

$$
v = 3.00 \times 10^8\, \text{m/s} \times \frac{-1.1\, \text{nm}}{121.6\, \text{nm}}
$$

$$
v = 3.00 \times 10^8\, \text{m/s} \times (-0.00904)
$$

$$
v \approx -2.71 \times 10^6\, \text{m/s}
$$

The negative sign indicates the star is moving toward us.

Final answer to three significant figures:

$$
\boxed{
v \approx -2.71 \times 10^6\, \text{m/s}
}
$$

Converting to Kilometers per Second

Often, astrophysicists prefer expressing velocities in km/s:

$$
v \approx -2,710\, \text{km/s}
$$

Note: The negative sign signifies approach, but when reporting speed, the magnitude is often considered:

$$
\boxed{
\text{Speed} \approx 2710\, \text{km/s}
}
$$

Considerations and Limitations

While the above calculation provides a good estimate, several factors can influence the accuracy:

- Rest Wavelength Accuracy: The precise rest wavelength of the spectral line must be known. Variations in the line's rest wavelength can alter the velocity calculation.
- Relativistic Effects: For velocities approaching a significant fraction of the speed of light, the relativistic formula should be used.
- Measurement Errors: Spectroscopic measurements have inherent uncertainties, which should be considered for precise calculations.
- Interstellar Medium: Absorption and scattering can affect spectral line observations.

Relativistic Correction (If Necessary)

If the star's velocity is a significant fraction of c, the relativistic Doppler shift formula should be employed:

$$
v = c \times \frac{\left(\frac{\lambda_{obs}}{\lambda_0}\right)^2 - 1}{\left(\frac{\lambda_{obs}}{\lambda_0}\right)^2 + 1}
$$

Using the same values:

$$
\frac{\lambda_{obs}}{\lambda_0} = \frac{120.5}{121.6} \approx 0.9918
$$

Then,

$$
v = 3.00 \times 10^8\, \text{m/s} \times \frac{(0.9918)^2 - 1}{(0.9918)^2 + 1}
$$

$$
v = 3.00 \times 10^8\, \text{m/s} \times \frac{0.9836 - 1}{0.9836 + 1}
$$

$$
v = 3.00 \times 10^8\, \text{m/s} \times \frac{-0.0164}{1.9836}

\]

\[
v \approx 3.00 \times 10^8\, \text{m/s} \times (-0.00828)
\]

\[
v \approx -2.48 \times 10^6\, \text{m/s}
\]

which is close to the non-relativistic estimate, confirming that for this case, the simpler approximation is adequate.

Summary

- To find the star's velocity, use the spectral line's observed wavelength and its rest wavelength.
- The Doppler effect allows calculating the velocity via simple formulas, with relativistic corrections as needed.
- The calculated velocity indicates the star is approaching us at approximately 2710 km/s.
- The negative sign indicates direction, but the magnitude (speed) is 2710 km/s.

Conclusion

Determining the speed of a star from spectral line shifts is a cornerstone technique in astrophysics, revealing the dynamic motions of celestial bodies. Given the observed wavelength of 120.5 nm for a specific spectral line (assuming a rest wavelength of 121.6 nm), the star is approaching Earth at approximately 2710 km/s, accurate to three significant figures. This information not only provides insights into the star's motion but also contributes to our broader understanding of galaxy dynamics, star formation, and the expansion of the universe.

Frequently Asked Questions

How do you calculate the speed of a star when a spectral line appears at a specific wavelength?

You can use the Doppler effect formula: v = c (λ_observed - λ_rest) / λ_rest, where c is the speed of light, λ_observed is the observed wavelength, and λ_rest is the rest wavelength.

What is the significance of the wavelength 120.5 nm in determining a star's speed?

The wavelength 120.5 nm represents the observed spectral line; comparing it to the known rest wavelength allows us to determine the star's velocity via Doppler shift.

What is the rest wavelength of the spectral line if it appears at 120.5 nm in the star's spectrum?

The rest wavelength is the known wavelength of the spectral line when the source is at rest; it must be provided or known from spectral data to calculate the star's speed accurately.

How do I express the star's speed to three significant figures?

After calculating the velocity using the Doppler formula, round the result to three significant figures for the final answer.

What is the value of the speed of light used in these calculations?

The standard value of the speed of light, c, is approximately 299,792 km/s.

What are common sources of error when calculating star velocity from spectral lines?

Errors can arise from inaccurate wavelength measurements, assumptions about the rest wavelength, instrumental limitations, and not accounting for other effects like gravitational redshift.

Can the Doppler effect be used to determine the speed of stars moving away or towards Earth?

Yes, the Doppler effect causes spectral lines to shift towards the red or blue end of the spectrum, indicating whether the star is receding or approaching.

If the observed wavelength is greater than the rest wavelength, what does that imply about the star's motion?

It implies the star is moving away from us (redshift), and the calculated velocity will be positive indicating recession.

Additional Resources

Find The Speed For A Star In Which This Line Appears At Wavelength 120.5 Nm: An In-Depth Investigative Analysis

The quest to determine the velocity of celestial bodies has long fascinated astronomers and physicists alike. Among the myriad techniques employed, spectroscopic analysis stands out as a cornerstone method, enabling scientists to probe the motion of stars through their emitted or absorbed light. A particularly intriguing case involves identifying the speed of a star based on the observed wavelength of a specific spectral line. This article delves into the scientific process behind determining the star's velocity when a spectral line appears at 120.5 nanometers (nm), exploring the underlying physics, calculations, potential implications, and broader context.

Understanding Spectral Lines and Their Significance in Stellar Motion

Spectral lines are the fingerprints of elements present in stars. They arise when electrons transition between energy levels within atoms or ions, absorbing or emitting photons at characteristic wavelengths. These lines, when observed from Earth, provide critical clues about the star's composition, temperature, and motion relative to the observer.

Key Concepts in Spectroscopy:

- Rest Wavelength (λ_0): The wavelength of a spectral line emitted or absorbed by an element at rest, i.e., with no relative motion.
- Observed Wavelength (λ): The wavelength measured by an observer, which can be shifted due to the Doppler effect if the source is moving.
- Doppler Effect: The change in observed wavelength caused by the relative motion between the source and observer. When a star moves toward us, spectral lines shift toward shorter wavelengths (blueshift); when it moves away, lines shift toward longer wavelengths (redshift).

Significance: By measuring the shift in spectral lines, astronomers can determine the radial velocity of the star, which is vital for understanding stellar dynamics, galactic motion, and cosmological models.

The Context of the Spectral Line at 120.5 Nm

The specific spectral line at 120.5 nm falls within the ultraviolet (UV) region, which is often associated with highly energetic transitions in ions such as hydrogen, helium, or heavier elements like carbon and nitrogen. Such lines are crucial in astrophysics for probing hot, young stars, active galactic nuclei, and interstellar matter.

Why UV Lines Matter:

- High Energy Transitions: UV lines often originate from highly excited states, providing insights into extreme astrophysical environments.
- Diagnostic Power: The position and strength of UV lines help determine physical conditions such as temperature, density, and motion.

Implication of Shift: If the line is observed at 120.5 nm instead of its known rest wavelength, the shift can be used to infer the star's velocity along the line of sight.

Calculating the Star's Radial Velocity from Spectral Shift

To find the star's speed, we employ the Doppler shift formula for non-relativistic velocities:

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

Where:

- v: Radial velocity of the star (positive if receding, negative if approaching).
- c: Speed of light (~299,792 km/s).
- λ: Observed wavelength (120.5 nm).
- λ_0: Rest (or laboratory) wavelength of the spectral line.

Key Step: Determine the rest wavelength λ_0. Since the problem states "Find the speed for a star in which this line appears at 120.5 nm," and the wavelength is given as 120.5 nm, the missing piece is the rest wavelength λ_0. Typically, for a specific spectral line, the rest wavelength is known from laboratory measurements.

Identifying the Rest Wavelength (λ_0)

Given the nature of the problem, it is likely based on a specific known spectral line, perhaps from the hydrogen Lyman-alpha transition, which occurs at approximately 121.6 nm. Alternatively, the line might be from a different ion with a known rest wavelength.

Assuming the spectral line is the hydrogen Lyman-alpha at 121.6 nm, the calculation proceeds as:

$$
\lambda_0 = 121.6\, \mathrm{nm}
$$

Note: If the problem specifies a different line, substitute the appropriate λ_0.

Step-by-Step Calculation of the Star's Velocity

Given:

- Observed wavelength $\lambda = 120.5\, \mathrm{nm}$
- Rest wavelength $\lambda_0 = 121.6\, \mathrm{nm}$
- Speed of light $c = 299,792\, \mathrm{km/s}$

The Doppler shift formula for velocity:

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

Plugging in values:

$$
v = 299,792 \times \frac{120.5 - 121.6}{121.6}
$$

$$
v = 299,792 \times \frac{-1.1}{121.6}
$$

$$

$$
v = 299,792 \times (-0.009045)
$$

$$
v \approx -2,709\, \mathrm{km/s}
$$

Interpretation:

- The negative sign indicates the star is approaching us.
- The star's radial velocity is approximately 2,709 km/s toward Earth.

Considering Alternative Rest Wavelengths

Suppose the spectral line in question is from a different element or ion, with a different known rest wavelength. The calculation process remains similar:

1. Identify the correct λ_0.
2. Use the observed $\lambda = 120.5\, \mathrm{nm}$.
3. Apply the Doppler formula to find the velocity.

Example:

If the line is from C III at 117.5 nm, then:

$$
v = 299,792 \times \frac{120.5 - 117.5}{117.5} \approx 299,792 \times 0.02553 \approx 7,652\, \mathrm{km/s}
$$

which would indicate the star is receding at approximately 7,652 km/s.

Relativistic Corrections and Their Relevance

For velocities approaching a significant fraction of the speed of light, relativistic Doppler formulas are necessary:

$$
\frac{\lambda}{\lambda_0} = \sqrt{\frac{1 + v/c}{1 - v/c}}
$$

However, in the current case, with a velocity on the order of a few thousand km/s, the classical approximation is sufficiently accurate.

Broader Implications and Significance of the Measurement

Determining the star's velocity provides insights into various astrophysical phenomena:

- Galactic Dynamics: Understanding stellar motions within galaxies helps map gravitational potentials and dark matter distributions.
- Star Formation and Evolution: High velocities may indicate past interactions, supernova kicks, or binary system dynamics.
- Cosmological Context: Stars with extreme velocities can be hypervelocity stars, ejected from galactic centers or interactions with black holes.

Furthermore, measuring spectral line shifts in UV wavelengths requires sophisticated instrumentation, such as space-based telescopes equipped with UV spectrometers, due to Earth's atmospheric absorption.

Conclusion and Summary

The process of finding the star's speed based on the spectral line appearance at 120.5 nm hinges on precise identification of the rest wavelength and accurate spectroscopic measurements. Given a typical rest wavelength—such as the hydrogen Lyman-alpha line at 121.6 nm—the calculated radial velocity indicates the star is approaching Earth at approximately 2,709 km/s.

This analysis exemplifies how spectroscopic techniques serve as powerful tools in astrophysics, allowing scientists to unravel the motions of celestial objects across vast cosmic distances. As observational technology advances, the capacity to measure such velocities with greater precision will continue to enrich our understanding of the universe's dynamic fabric.

In essence, by carefully analyzing spectral shifts, astronomers can determine stellar velocities with remarkable accuracy, revealing the intricate dance of stars within our galaxy and beyond.

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