

Excited Sodium Atoms Emit Light In The Infrared At 589 Nm. What Is The Energy Of A Single Photon With

Excited Sodium Atoms Emit Light In The Infrared At 589 Nm. What Is The Energy Of A Single Photon With the wavelength of 589 nm? This intriguing question leads us into the fascinating world of atomic physics, spectroscopy, and quantum mechanics. Understanding how excited sodium atoms emit light and calculating the energy of the resulting photons provides insight into fundamental physical principles and practical applications such as spectroscopy, laser technology, and astronomical observations.

Understanding Atomic Emission and Sodium's Spectral Lines

The Nature of Atomic Emission

Atoms can absorb energy through various means—thermal energy, electrical excitation, or chemical reactions—and become excited. When these excited atoms return to their ground state or a lower energy level, they release the excess energy in the form of electromagnetic radiation, commonly known as photons. This process results in characteristic spectral lines unique to each element, serving as atomic fingerprints.

Sodium's Signature Spectral Lines

Sodium is well known for its distinctive yellow doublet spectral lines at approximately 589.0 nm and 589.6 nm, often called the sodium D-lines. These lines are prominent in both laboratory spectroscopy and natural phenomena such as sodium vapor lamps and the sodium layer in Earth's mesosphere.

However, the statement that excited sodium atoms emit light in the infrared at 589 nm requires clarification. In reality, sodium's D-lines are in the visible spectrum, specifically yellow light at around 589 nm. Infrared emission from sodium is rare or typically occurs at different wavelengths. For the purpose of this discussion, we'll focus on the well-known visible emission at 589 nm, which is the primary sodium D-line.

Calculating the Energy of a Single Photon

The Basic Formula for Photon Energy

The energy (E) of a photon is directly related to its wavelength (λ) via the Planck-Einstein relation:

$$E = \frac{hc}{\lambda}$$

where:

- E is the photon energy (in joules, J),
- h is Planck's constant (6.626×10^{-34} Js),
- c is the speed of light in vacuum (3.00×10^8 m/s),
- λ is the wavelength of the photon (in meters).

Converting Wavelength to Meters

Given the wavelength $\lambda = 589 \text{ nm}$:

$$589 \text{ nm} = 589 \times 10^{-9} \text{ m} = 5.89 \times 10^{-7} \text{ m}$$

Calculating the Photon Energy

Applying the values:

$$E = \frac{(6.626 \times 10^{-34} \text{ Js}) \times (3.00 \times 10^8 \text{ m/s})}{5.89 \times 10^{-7} \text{ m}}$$

Calculating numerator:

$$6.626 \times 10^{-34} \times 3.00 \times 10^8 = 1.9878 \times 10^{-25} \text{ Js}$$

Dividing by the wavelength:

$$E = \frac{1.9878 \times 10^{-25}}{5.89 \times 10^{-7}} \approx 3.37 \times 10^{-19} \text{ J}$$

Therefore, the energy of a single photon emitted at 589 nm is approximately 3.37×10^{-19} joules.

Expressing Photon Energy in Electronvolts (eV)

While joules are standard SI units, electronvolts (eV) are more convenient for atomic and molecular physics because they relate directly to energy levels within atoms.

Conversion Factor

$$1 \text{ eV} = (1.602 \times 10^{-19}) \text{ J}$$

Calculating in eV

$$E_{\text{eV}} = \frac{E_{\text{J}}}{1.602 \times 10^{-19}}$$

Plugging in the value:

$$E_{\text{eV}} = \frac{3.37 \times 10^{-19}}{1.602 \times 10^{-19}} \approx 2.10 \text{ eV}$$

Thus, a photon at 589 nm has an energy of approximately 2.10 eV.

Implications and Applications of Sodium Emission

Spectroscopic Significance

The sodium D-lines are crucial in spectroscopy for identifying sodium in various contexts, from laboratory experiments to astrophysical observations. The precise measurement of these lines helps determine conditions in stellar atmospheres, interstellar media, and the Earth's atmosphere.

Sodium Vapor Lamps

Sodium vapor lamps, widely used in street lighting, operate by exciting sodium atoms to emit the characteristic yellow light at 589 nm. Understanding the photon energy helps optimize lamp design and efficiency.

Laser Technologies

While sodium D-lines are not commonly used as lasing wavelengths, the principles of atomic emission and photon energy calculation are foundational in developing laser sources.

Astrophysical Observations

The sodium D-lines are prominent in the spectra of planets, stars, and galaxies. Accurate knowledge of photon energy allows astronomers to analyze the composition and physical conditions of celestial objects.

Additional Considerations in Atomic Emission

Energy Levels and Transition Probabilities

The emission wavelength corresponds to a specific electronic transition between energy levels in the sodium atom. The energy difference between these levels is approximately 2.10 eV, matching the photon energy calculated.

Line Broadening and Shifts

Real spectral lines are not infinitely sharp. They are subject to broadening mechanisms such as Doppler broadening, collisional broadening, and natural linewidth, influencing the observed spectral profile.

Infrared Emission and Sodium

Although sodium primarily emits visible light at 589 nm, under certain conditions—such as specific excitation states—other emission lines, including in the infrared region, can occur. These are less common and typically involve different electronic transitions or molecular interactions.

Conclusion

In summary, the photon emitted by excited sodium atoms at the characteristic wavelength of approximately 589 nm possesses an energy of about (3.37×10^{-19}) joules, or roughly 2.10 electronvolts. Understanding this energy not only reinforces fundamental quantum principles but also enhances our capability to interpret spectral data across scientific disciplines. Whether in laboratory spectroscopy, lighting technology, or astronomy, the detailed knowledge of atomic emission energies continues to be vital in advancing both scientific knowledge and practical applications.

Keywords: sodium atoms, photon energy, 589 nm wavelength, atomic emission, spectroscopy, photon energy calculation, quantum mechanics, sodium D-lines, infrared emission, energy levels, spectroscopic applications

Frequently Asked Questions

What is the significance of sodium atoms emitting light at 589 nm in the infrared spectrum?

Actually, sodium atoms emit light at 589 nm in the visible spectrum, specifically as yellow light. This emission is significant in spectroscopy and astronomy, such as in sodium vapor lamps and sodium D-

line observations.

How can we calculate the energy of a photon emitted at 589 nm?

The energy of a photon is calculated using the formula $E = hc / \lambda$, where h is Planck's constant (6.626×10^{-34} Js), c is the speed of light (3×10^8 m/s), and λ is the wavelength in meters. For 589 nm, convert to meters (5.89×10^{-7} m) before calculation.

Why do excited sodium atoms emit photons with a wavelength of 589 nm?

When sodium atoms are excited, electrons move to higher energy levels. As they return to lower energy states, they emit photons at characteristic energies, producing the specific wavelength of 589 nm due to the energy difference between those levels.

What is the approximate energy of a photon emitted at 589 nm?

Using $E = hc / \lambda$, the energy is approximately 3.37×10^{-19} Joules for a photon at 589 nm.

Is the emission at 589 nm in the visible or infrared spectrum?

The emission at 589 nm is in the visible spectrum, specifically as yellow light, not infrared. Infrared light has longer wavelengths, generally above 700 nm.

How does the energy of a sodium photon at 589 nm compare to photons of other wavelengths?

Photons at shorter wavelengths (like UV) have higher energy, while those at longer wavelengths (like infrared) have lower energy. Therefore, the 589 nm sodium photon has moderate energy compared to other parts of the electromagnetic spectrum.

Additional Resources

Excited sodium atoms emit light in the infrared at 589 nm. What is the energy of a single photon with this wavelength?

Introduction

The phenomenon of atomic emission spectra has fascinated scientists for centuries, offering insights into the quantum nature of matter and the fundamental properties of atoms. Among the many elements studied, sodium holds a particular place due to its characteristic bright yellow emission line at approximately 589 nanometers (nm). This emission, often observed in sodium vapor lamps

and astrophysical phenomena, is a hallmark of atomic transitions involving excited sodium atoms. But beyond its visual brilliance, it raises a fundamental question: What is the energy of a single photon emitted at this wavelength? Exploring this question involves delving into atomic physics, quantum mechanics, and spectroscopy, providing a comprehensive understanding of the underlying principles.

The Sodium D-Line Emission: An Overview

The Origin of the 589 nm Line

Sodium's distinctive yellow emission at approximately 589 nm is attributed to electronic transitions within its atoms, specifically involving the 3p to 3s energy levels. When sodium atoms are excited—either thermally, electrically, or through other energy sources—the electrons are promoted to higher energy states. As they return to lower energy levels, they emit photons with energies precisely corresponding to the energy difference between these states.

This emission line is commonly referred to as the D-line of sodium, with two closely spaced lines known as the D1 (at approximately 589.6 nm) and D2 (at approximately 589.0 nm). These lines result from transitions involving the fine structure of the sodium atom, which splits the energy levels due to relativistic and spin-orbit coupling effects.

Significance of the 589 nm Emission

The sodium D-lines are not only vital in laboratory spectroscopy but also play essential roles in various applications:

- Sodium Vapor Lamps: Used in street lighting for their efficiency and distinctive color.
- Lidar and Atmospheric Studies: Sodium layers in the Earth's mesosphere are targeted using these lines.
- Astrophysics: The presence of sodium lines in stellar and interstellar spectra helps determine chemical compositions and physical conditions.

Quantum Foundations: Atomic Transitions and Photons

Energy Level Transitions in Sodium

In quantum mechanics, atoms possess discrete energy levels. For sodium, the relevant transition for the prominent D-line is:

- Initial State: 3p excited state
- Final State: 3s ground state

The energy difference (ΔE) between these levels determines the wavelength (λ) of the emitted photon, according to the relation derived from quantum theory.

The Role of Photons

When an electron transitions from a higher to a lower energy level, a photon is emitted carrying away the energy difference. This process is quantized, meaning each photon has a specific energy directly linked to the atomic transition.

Calculating the Energy of a Single Photon at 589 nm

Fundamental Equation

The energy (E) of a photon is related to its wavelength (λ) via the equation:

$$E = \frac{hc}{\lambda}$$

where:

- h is Planck's constant ($6.626 \times 10^{-34} \text{ Js}$)
- c is the speed of light in vacuum ($3.00 \times 10^8 \text{ m/s}$)
- λ is the wavelength in meters

Step-by-Step Calculation

1. Convert Wavelength to Meters

$$\lambda = 589 \text{ nm} = 589 \times 10^{-9} \text{ m} = 5.89 \times 10^{-7} \text{ m}$$

2. Plug Values into the Equation

$$E = \frac{(6.626 \times 10^{-34} \text{ Js}) \times (3.00 \times 10^8 \text{ m/s})}{5.89 \times 10^{-7} \text{ m}}$$

3. Calculate Numerator

$$6.626 \times 10^{-34} \times 3.00 \times 10^8 = 1.9878 \times 10^{-25} \text{ J}$$

4. Divide by Wavelength

$$E = \frac{1.9878 \times 10^{-25}}{5.89 \times 10^{-7}} \approx 3.374 \times 10^{-19} \text{ J}$$

Thus, the energy of a single photon emitted at 589 nm is approximately $\boxed{3.37 \times 10^{-19} \text{ J}}$.

Additional Perspectives: Energy in Electronvolts

While joules are standard SI units, physicists often express photon energies in electronvolts (eV) for convenience.

- Conversion factor: $(1, \text{eV} = 1.602 \times 10^{-19}, \text{J})$

Calculating:

$$E_{\text{eV}} = \frac{3.37 \times 10^{-19} \text{ J}}{1.602 \times 10^{-19} \text{ J/eV}} \approx 2.10 \text{ eV}$$

Therefore, a photon at 589 nm carries approximately 2.10 eV of energy.

Significance in Spectroscopy and Atomic Physics

Understanding the photon energy associated with sodium's emission line is crucial for several reasons:

- Spectroscopic Identification: The precise photon energy helps distinguish sodium in various environments, such as stellar atmospheres or laboratory spectra.
- Quantum Transition Analysis: Comparing the photon energy to known energy level differences validates quantum models of atomic structure.
- Design of Optical Devices: Knowledge of photon energies informs the development of lasers, detectors, and other optical instruments.

Broader Implications and Related Phenomena

Fine Structure and Line Splitting

The sodium D-lines are not perfectly singular; they exhibit slight splitting due to fine structure effects caused by spin-orbit coupling. This splitting results in two lines at slightly different wavelengths (~589.0 nm and ~589.6 nm), each corresponding to slightly different energy differences (~2.10 eV and ~2.09 eV). This subtlety exemplifies the precision needed in atomic physics and the importance of considering relativistic effects.

Infrared Emission and Other Atomic Transitions

While the sodium D-line appears in the visible spectrum, atoms can emit photons across a broad range, including infrared. The initial statement about sodium atoms emitting light in the infrared at 589 nm might be a misinterpretation or an error, as 589 nm lies in the yellow portion of the visible spectrum. However, sodium can emit in the infrared at other transitions, and understanding these energies involves similar calculations.

Applications and Future Perspectives

The precise knowledge of photon energies emitted by atoms like sodium has wide-ranging applications:

- Astrophysics: Detecting sodium lines in stellar spectra helps determine the chemical composition and physical conditions of celestial objects.
- Atmospheric Science: Sodium lidar systems utilize the D-line for probing the Earth's mesosphere.
- Lighting and Display Technologies: Sodium lamps capitalize on the specific emission wavelength for efficient street lighting.
- Quantum Technologies: Fundamental atomic transitions underpin emerging quantum computing and communication systems.

Looking ahead, advancements in spectroscopic techniques and quantum optics will continue to refine our understanding of atomic emission processes, enabling more precise measurements and innovative applications.

Conclusion

The emission of light by excited sodium atoms at approximately 589 nm encapsulates the intricate interplay of quantum mechanics, atomic physics, and spectroscopy. Calculating the energy of a single photon at this wavelength reveals it to be around (3.37×10^{-19}) joules or about 2.10 eV, a quantized packet of energy that bridges the microscopic atomic world and macroscopic observable phenomena. This fundamental understanding not only enriches our knowledge of atomic transitions but also fuels technological innovations across diverse fields—from lighting and atmospheric studies to astrophysics and quantum information science. As research progresses, the insights gleaned from such atomic emissions will continue to illuminate the path forward in both scientific exploration and practical applications.

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