

(a) A Laser Emits Light That Has A Frequency Of $4.69 \times 10^{14} \text{ s}^{-1}$. What Is The Energy Of One Photon Of

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Understanding the energy of a photon emitted by a laser is fundamental in fields such as physics, optics, and photonics technology. This article delves into the principles behind photon energy, how it relates to laser light, and provides a comprehensive explanation of calculating the energy of a photon based on its frequency.

Introduction to Photon Energy and Light

Light is a form of electromagnetic radiation that travels through space in the form of oscillating electric and magnetic fields. Photons are the elementary particles of light, carrying quantized amounts of energy. The energy of a single photon depends directly on its frequency, which is the number of oscillations per second.

Fundamental Concepts: Energy and Frequency

What Is a Photon?

A photon is a quantum of electromagnetic energy. Unlike classical particles, photons have zero rest mass and always move at the speed of light in a vacuum. Their energy is directly proportional to their frequency, expressed by the equation:

$$E = h \times f$$

where:

- E is the energy of the photon,
- h is Planck's constant ($6.626 \times 10^{-34} \text{ J}\cdot\text{s}$),
- f is the frequency of the photon.

The Relationship Between Frequency and Energy

Since the energy of a photon depends solely on its frequency, higher frequency photons carry more energy. This relationship is crucial in understanding the behavior of different types of electromagnetic radiation, from radio waves to gamma rays.

Given Data and Problem Statement

The problem states:

- The laser emits light with a frequency of $(f = 4.69 \times 10^{14} \text{ s}^{-1})$.

Our task is to calculate the energy of one photon emitted by this laser.

Calculating the Energy of a Photon

Step-by-Step Calculation

To find the photon energy, we use the formula:

$$E = h \times f$$

Plugging in the known values:

$$E = (6.626 \times 10^{-34} \text{ Js}) \times (4.69 \times 10^{14} \text{ s}^{-1})$$

First, multiply the coefficients:

$$6.626 \times 4.69 \approx 31.07$$

Next, combine the powers of ten:

$$10^{-34} \times 10^{14} = 10^{-20}$$

Thus, the energy becomes:

$$E \approx 31.07 \times 10^{-20} \text{ J}$$

Expressing in standard scientific notation:

$$E \approx 3.11 \times 10^{-19} \text{ J}$$

\]

Final answer:

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\text{The energy of one photon is approximately } 3.11 \times 10^{-19} \text{ J, \text{joules}}

}

\]

Interpreting the Result

The calculated photon energy, roughly (3.11×10^{-19}) joules, is typical for visible light photons. To put this into perspective:

- Visible photons generally have energies ranging from about (1.6×10^{-19}) J (red light) to (3.3×10^{-19}) J (violet light).
- The laser's wavelength corresponding to this frequency can be calculated using:

\[

$$\lambda = \frac{c}{f}$$

\]

where:

- (c) is the speed of light $(3.00 \times 10^8 \text{ m/s})$.

Calculating the wavelength:

\[

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{4.69 \times 10^{14} \text{ s}^{-1}} \\ \approx 639 \text{ nm}$$

\]

This wavelength (~ 639 nm) falls in the orange-red region of the visible spectrum, indicating the laser emits orange-red light.

Applications of Photon Energy Calculations

Understanding photon energy is vital across various technological and scientific applications, including:

- **Laser technology:** Designing lasers with specific wavelengths for precision cutting, medical procedures, or communication.
- **Spectroscopy:** Analyzing material properties based on photon absorption and

emission spectra.

- **Photovoltaics:** Optimizing solar cell materials to efficiently convert specific photon energies into electricity.
- **Quantum computing:** Manipulating qubits that depend on photon energies and wavelengths.

Additional Factors to Consider

While the basic calculation provides the photon energy, real-world applications often involve additional factors:

Photon Flux and Power

- The total power output of a laser depends on the number of photons emitted per second, which relates to photon flux.
- Power (P) can be calculated if the photon flux (N) is known: $P = N \times E$.

Energy Distribution and Linewidth

- Laser emissions have a spectral linewidth, meaning the emitted photons have a small range of energies around the central frequency.
- This affects applications requiring monochromatic light.

Summary

- The frequency of the laser light is $4.69 \times 10^{14} \text{ s}^{-1}$.
- Using Planck's equation ($E = h \times f$), the energy of a single photon is approximately 3.11×10^{-19} joules.
- The wavelength of the emitted light is approximately 639 nanometers, corresponding to orange-red visible light.
- Accurate knowledge of photon energy is essential for the design, application, and understanding of laser systems and other photonic technologies.

Conclusion

Calculating the energy of a photon based on its frequency is a fundamental skill in physics and engineering. For the given laser with a frequency of $4.69 \times 10^{14} \text{ s}^{-1}$, the photon energy is approximately 3.11×10^{-19} joules. This calculation not only enhances our understanding of electromagnetic radiation but also

supports technological advancements in various fields, including communication, medicine, and energy conversion.

By grasping these concepts, scientists and engineers can better manipulate light for innovative applications, ensuring progress in both theoretical and applied sciences.

Frequently Asked Questions

What is the energy of a photon emitted by a laser with a frequency of 4.69×10^{14} Hz?

Using the formula $E = h \times f$, where $h = 6.626 \times 10^{-34}$ Js, the energy is $E = 6.626 \times 10^{-34} \text{ Js} \times 4.69 \times 10^{14} \text{ Hz} \approx 3.11 \times 10^{-19}$ Joules.

How do you calculate the energy of a photon given its frequency?

The energy of a photon is calculated using the equation $E = h \times f$, where h is Planck's constant (6.626×10^{-34} Js) and f is the frequency of the light.

What is the significance of the photon's energy in laser applications?

The photon's energy determines its wavelength and color, which are crucial for applications like communication, medical treatments, and data storage in laser technology.

Can the energy of a photon emitted by the laser be increased by increasing its frequency?

Yes, since the photon's energy is directly proportional to its frequency, increasing the frequency results in higher photon energy.

What is the wavelength of the light emitted by the laser with a frequency of 4.69×10^{14} Hz?

Using the speed of light $c = 3.00 \times 10^8$ m/s, wavelength $\lambda = c / f = 3.00 \times 10^8 \text{ m/s} / 4.69 \times 10^{14} \text{ Hz} \approx 6.40 \times 10^{-7}$ meters (640 nm), which is in the red visible spectrum.

Why is understanding photon energy important in quantum physics?

Photon energy is fundamental in quantum physics because it explains phenomena like the photoelectric effect and the quantization of electromagnetic radiation.

How does the energy of a photon relate to the color of the laser light?

The energy of a photon determines its wavelength and thus its color; higher energy photons correspond to shorter wavelengths (blue/violet), while lower energy photons correspond to longer wavelengths (red).

What is the approximate energy of one photon in electronvolts (eV) for the given laser light?

Converting Joules to eV ($1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$), the photon energy is approximately $(3.11 \times 10^{-19} \text{ J}) / (1.602 \times 10^{-19} \text{ J/eV}) \approx 1.94 \text{ eV}$.

Additional Resources

Understanding the Energy of a Photon Emitted by a Laser with a Frequency of $4.69 \times 10^{14} \text{ s}^{-1}$

When exploring the fascinating world of light and quantum physics, one fundamental concept that often comes into focus is the energy carried by individual photons. Specifically, for a laser emitting light with a frequency of $4.69 \times 10^{14} \text{ s}^{-1}$, calculating the energy of one photon provides insight into the quantum nature of light and the practical applications of laser technology. In this article, we will delve into the principles behind photon energy, walk through the calculation process step-by-step, and explore the significance of these values in scientific and technological contexts.

What Is a Photon and Why Its Energy Matters

Before diving into the calculations, it's crucial to understand what a photon is and why its energy is a key parameter in physics and engineering.

Photons are elementary particles representing the quantum of electromagnetic radiation, including visible light, ultraviolet, infrared, and beyond. Unlike classical waves, photons are discrete packets of energy that obey the principles of quantum mechanics.

Why is photon energy important?

- Determining Light Intensity: The total energy emitted by a light source depends on the number of photons and their individual energies.
- Understanding Interactions: Photon energy influences how light interacts with matter, including absorption, reflection, and transmission.
- Technological Applications: Knowledge of photon energy is essential for designing lasers, photovoltaics, sensors, and communication devices.

Fundamental Relationship: Energy and Frequency

The energy (E) of a single photon is directly proportional to its frequency (ν) , expressed by the fundamental equation:

$$E = h \times \nu$$

Where:

- (E) is the photon's energy, measured in joules (J).
- (h) is Planck's constant, approximately (6.626×10^{-34}) joule-seconds (Js).
- (ν) (ν) is the frequency of the photon, measured in hertz (Hz or s^{-1}).

This relationship is a cornerstone of quantum mechanics and was first proposed by Max Planck to explain blackbody radiation.

Calculating the Energy of One Photon

Given the problem: A laser emits light that has a frequency of $4.69 \times 10^{14} s^{-1}$. What is the energy of one photon?

Let's walk through the calculation.

Step 1: Write down known quantities

- Frequency, $(\nu = 4.69 \times 10^{14}) s^{-1}$
- Planck's constant, $(h = 6.626 \times 10^{-34}) Js$

Step 2: Apply the formula $(E = h \times \nu)$

$$E = (6.626 \times 10^{-34} \text{ Js}) \times (4.69 \times 10^{14} \text{ s}^{-1})$$

Step 3: Multiply the coefficients

$$6.626 \times 4.69 \approx 31.066$$

Step 4: Combine the powers of ten

$$10^{-34} \times 10^{14} = 10^{-20}$$

Step 5: Write the result

$$E \approx 31.066 \times 10^{-20} \text{ J}$$

To express this in a more standard form, convert to scientific notation:

$$E \approx 3.1066 \times 10^{-19} \text{ J}$$

Thus, the energy of one photon emitted by this laser is approximately 3.11×10^{-19} joules.

Interpreting the Result: What Does This Energy Mean?

The calculated photon energy is extremely small, highlighting the quantum nature of light. To put this into perspective:

- Comparison to chemical bonds: The energy of a photon at this frequency ($\sim 4.69 \times 10^{14}$ Hz) is comparable to the energy needed to excite certain molecules or cause electronic transitions within atoms.
- Photon energy in eV: For many practical purposes, it's useful to convert joules to electronvolts (eV), where $1 \text{ eV} \approx 1.602 \times 10^{-19} \text{ J}$.

Let's convert:

$$E_{\text{eV}} = \frac{3.11 \times 10^{-19} \text{ J}}{1.602 \times 10^{-19} \text{ J/eV}} \approx 1.94 \text{ eV}$$

This energy ($\sim 1.94 \text{ eV}$) falls within the visible spectrum, near the red or near-infrared region of light, consistent with typical laser emissions in that wavelength range.

Implications and Applications of Photon Energy Calculations

Understanding the energy of individual photons emitted by lasers informs numerous

scientific and technological domains:

1. Spectroscopy and Material Analysis

Knowing photon energies allows scientists to predict and interpret how light interacts with different materials, aiding in:

- Identifying chemical compositions.
- Studying electronic transitions in atoms and molecules.
- Designing sensors and detectors optimized for specific wavelengths.

2. Laser Manufacturing and Communication

In laser engineering:

- Wavelength selection: Engineers choose lasers emitting photons with energies suited to their application, whether for cutting, medical procedures, or data transmission.
- Power calculations: Determining how many photons are emitted per second helps in calculating the total power output of a laser.

3. Photovoltaic and Energy Conversion Technologies

- Photons with energies above a material's bandgap can generate electron-hole pairs, producing electricity.
- Knowing photon energy helps optimize solar cell materials for maximum efficiency.

4. Quantum Computing and Information

- Quantum bits (qubits) often rely on photon properties.
- Precise control over photon energy is essential for reliable quantum communication.

Additional Considerations and Related Concepts

While this calculation provides a foundational understanding, there are additional factors and related topics worth exploring:

a. Wavelength of the Laser Light

Using the relation:

$$\lambda = \frac{c}{\nu}$$

where:

- c is the speed of light ($\sim 3.00 \times 10^8$ m/s),
- ν is the frequency,

we can find the wavelength:

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{4.69 \times 10^{14} \text{ s}^{-1}} \approx 6.40 \times 10^{-7} \text{ m}$$

or approximately 640 nm, which is within the visible red light spectrum.

b. Energy per Photon vs. Total Power

Total power output depends on the number of photons emitted per second:

$$P = E \times \text{number of photons per second}$$

Knowing E helps in designing laser systems for specific power levels.

Summary and Final Thoughts

Calculating the energy of a photon emitted by a laser with a given frequency is a fundamental exercise in quantum physics, bridging the concepts of wave and particle duality. For a laser emitting light at a frequency of $4.69 \times 10^{14} \text{ s}^{-1}$, each photon carries approximately (3.11×10^{-19}) joules, equivalent to about 1.94 eV. This insight not only enhances our understanding of the quantum properties of light but also informs practical applications across science and technology, from spectroscopy to quantum computing.

By mastering these calculations, scientists and engineers can better manipulate and harness light's quantum properties, paving the way for innovations in communication, energy, and medical fields. The tiny energy of individual photons, when understood and controlled, becomes a powerful tool in advancing modern technology.

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