

Calculate The Wavelength And Energy Of Light That Has A Frequency Of 1.1×10^{17} Hz

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Understanding the properties of light, such as its wavelength and energy, is fundamental in physics and many scientific applications. When dealing with a specific frequency, like 1.1×10^{17} Hz, it's essential to be able to accurately determine the corresponding wavelength and energy. This article provides a comprehensive guide on how to calculate these properties, offering insights into the underlying physics principles, relevant formulas, and practical examples.

Understanding the Basics of Light's Properties

Before diving into calculations, it's important to grasp what wavelength and energy signify in the context of electromagnetic radiation.

What Is Wavelength?

Wavelength refers to the distance between two successive peaks (or troughs) of a wave. It is typically measured in meters (m), nanometers (nm), or other units of length. Wavelength is inversely related to frequency: as frequency increases, wavelength decreases.

What Is the Energy of Light?

The energy of a photon (the quantum of light) is directly proportional to its frequency. The higher the frequency, the greater the energy carried by each photon. The energy is usually measured in joules (J) or electronvolts (eV).

Key Physics Principles and Formulas

Calculating the wavelength and energy involves fundamental physics equations derived from the properties of electromagnetic waves and quantum theory.

1. Speed of Light Equation

The relationship between wavelength (λ), frequency (f), and the speed of light (c) is expressed as:

- $c = \lambda \times f$

Where:

- c is the speed of light in vacuum ($\sim 3.00 \times 10^8$ meters per second)
- λ is the wavelength in meters
- f is the frequency in hertz (Hz)

2. Energy of a Photon Equation

The photon energy (E) is given by Planck's equation:

- $E = h \times f$

Where:

- h is Planck's constant ($\sim 6.626 \times 10^{-34}$ Joule·seconds)
- f is the frequency in Hz

Alternatively, if the energy is desired in electronvolts (eV), the conversion factor can be used:

- $1 \text{ eV} = 1.602 \times 10^{-19} \text{ Joules}$

Calculating the Wavelength for a Frequency of $1.1 \times 10^{17} \text{ Hz}$

Using the speed of light equation, we can find the wavelength corresponding to the given frequency.

Step-by-Step Calculation

1. Identify known values:

- Frequency (f) = $1.1 \times 10^{17} \text{ Hz}$
- Speed of light (c) = $3.00 \times 10^8 \text{ m/s}$

2. Apply the wavelength formula:

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

3. Substitute the known values:

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{1.1 \times 10^{17} \text{ Hz}}$$

4. Perform the division:

$$\lambda \approx 2.727 \times 10^{-9} \text{ meters}$$

5. Convert to nanometers (1 nm = 10^{-9} m):

$$\lambda \approx 2.727 \text{ nm}$$

Result: The wavelength of light with a frequency of 1.1×10^{17} Hz is approximately 2.73 nanometers.

Calculating the Energy of Light with a Frequency of 1.1×10^{17} Hz

Next, determine the energy associated with photons of this light frequency.

Step-by-Step Calculation

1. Identify known values:

- Frequency (f) = 1.1×10^{17} Hz
- Planck's constant (h) = 6.626×10^{-34} J·s

2. Apply the energy formula:

$$E = h \times f$$

3. Substitute the values:

$$E = 6.626 \times 10^{-34} \text{ J}\cdot\text{s} \times 1.1 \times 10^{17} \text{ Hz}$$

4. Calculate the energy:

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\[
E \approx 7.2886 \times 10^{-17} \text{ Joules}
\]
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5. Convert Joules to electronvolts (optional):

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\[
E_{\text{eV}} = \frac{7.2886 \times 10^{-17} \text{ J}}{1.602 \times 10^{-19} \text{ J/eV}} \approx 455 \text{ eV}
\]
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Result: Each photon of light with this frequency carries approximately 7.29×10^{-17} Joules, or about 455 electronvolts (eV) of energy.

Implications and Applications of These Calculations

Understanding the wavelength and energy of light at specific frequencies has numerous scientific and technological implications.

1. Ultraviolet and X-ray Light

A wavelength of approximately 2.73 nm falls within the X-ray region of the electromagnetic spectrum. This kind of radiation is used in medical imaging, security scanners, and materials science.

2. Photonic Technologies

Knowing the energy per photon allows engineers to design lasers, photodetectors, and other optoelectronic devices optimized for specific wavelengths and energies.

3. Spectroscopy and Material Analysis

Spectroscopic techniques rely on understanding photon energies to analyze atomic and molecular structures.

Additional Factors and Considerations

While the calculations above are straightforward, several factors can influence the practical interpretation.

1. Medium Effects

The calculations assume the light travels in a vacuum. In media like air, water, or biological tissues, the effective wavelength can change due to refractive index variations.

2. Quantum Effects

At high energies, relativistic effects or quantum electrodynamics (QED) phenomena might become significant, especially for photons in the X-ray or gamma-ray regions.

3. Measurement Techniques

Accurate determination of frequency and wavelength requires precise instrumentation such as spectrometers and frequency counters.

Summary

- The wavelength of light with a frequency of 1.1×10^{17} Hz is approximately 2.73 nanometers.
- The energy of each photon at this frequency is roughly 7.29×10^{-17} Joules, or about 455 eV.
- These calculations are based on fundamental physics equations, specifically the relationship between speed, wavelength, and frequency, and Planck's quantum theory.

Conclusion

Calculating the wavelength and energy of light from a given frequency is essential for understanding the properties of electromagnetic radiation across various scientific disciplines. By applying the fundamental formulas – $\lambda = c/f$ and $E = h \times f$ – scientists and engineers can accurately determine key characteristics of light, enabling advancements in fields like spectroscopy, medical imaging, and telecommunications. Mastery of these calculations not only deepens our understanding of the nature of light but also supports the development of innovative technologies leveraging specific wavelengths and energies.

Whether you're a student, researcher, or professional, being adept at these calculations empowers you to interpret and manipulate electromagnetic phenomena effectively.

Frequently Asked Questions

What is the wavelength of light with a frequency of 1.1×10^{17} Hz?

The wavelength can be calculated using the formula $\lambda = c / f$, where $c = 3.0 \times 10^8$ m/s. So, $\lambda = (3.0 \times 10^8) / (1.1 \times 10^{17}) \approx 2.73 \times 10^{-9}$ meters or 2.73 nanometers.

How do you calculate the energy of light given its frequency?

The energy (E) of light is calculated using the equation $E = h \times f$, where $h = 6.626 \times 10^{-34}$ Js. For a frequency of 1.1×10^{17} Hz, $E = 6.626 \times 10^{-34} \times 1.1 \times 10^{17} \approx 7.29 \times 10^{-17}$ Joules.

What is the significance of the wavelength 2.73 nanometers in the electromagnetic spectrum?

A wavelength of approximately 2.73 nanometers falls within the X-ray region of the electromagnetic spectrum, indicating high-energy radiation.

Is the light with a frequency of 1.1×10^{17} Hz visible to the human eye?

No, a wavelength of about 2.73 nanometers corresponds to X-rays, which are not visible to the human eye.

What type of electromagnetic radiation has a frequency of 1.1×10^{17} Hz?

This frequency corresponds to X-ray radiation, which is used in medical imaging and other applications.

How does the energy of this light compare to visible light?

The energy is much higher than that of visible light photons, which have frequencies roughly between 4.3×10^{14} Hz and 7.5×10^{14} Hz, making this X-ray radiation significantly more energetic.

What is the relation between wavelength and energy for light?

Wavelength and energy are inversely related; as wavelength decreases, energy

increases. Shorter wavelengths like X-rays have higher energy photons.

What are some practical applications of light with such high frequency and energy?

High-frequency, high-energy light like X-rays is used in medical imaging, cancer treatment, and materials analysis.

How precise are the calculations of wavelength and energy for electromagnetic radiation?

The calculations are based on fundamental constants and formulas, providing accurate estimates within the assumptions of ideal conditions.

Can we convert the energy of this light into other units?

Yes, the energy can be converted into electronvolts (eV) using the conversion $1 \text{ eV} \approx 1.602 \times 10^{-19} \text{ Joules}$. For this light, $E \approx 7.29 \times 10^{-17} \text{ J}$, which is approximately 455 eV.

Additional Resources

Calculate The Wavelength And Energy Of Light That Has A Frequency Of $1.1 \times 10^{17} \text{ Hz}$

Understanding the fundamental properties of light is essential in physics, especially when exploring its wave-particle duality, applications in technology, and the nature of electromagnetic radiation. In this comprehensive review, we will delve into the process of calculating the wavelength and energy of a specific light wave with a frequency of $1.1 \times 10^{17} \text{ Hz}$, examining the underlying principles, relevant formulas, and broader implications.

Introduction to Electromagnetic Radiation and Light

Electromagnetic radiation encompasses a broad spectrum of waves, from radio waves to gamma rays. Light, visible to human eyes, is just a small segment within this spectrum, characterized by its wave-like properties and quantized particle nature, photons.

- Wave Nature: Light propagates as oscillating electric and magnetic fields

perpendicular to each other and to the direction of travel.

- Particle Nature: Light can be described as discrete packets of energy called photons.

The duality is central to modern physics and underpins many calculations such as the wavelength and energy of specific photons.

Fundamental Concepts and Relevant Constants

Before diving into calculations, it is essential to understand the fundamental constants and formulas involved:

Constants:

Constant	Symbol	Value	Units	Description
Speed of light	c	3.00×10^8	meters per second (m/s)	The universal speed limit for electromagnetic waves in vacuum
Planck's constant	h	6.626×10^{-34}	joule seconds (Js)	Fundamental constant relating energy and frequency
Electronvolt to joules	1 eV	1.602×10^{-19}	joules (J)	Energy unit often used in atomic physics

Key Formulas:

- Wavelength (λ):

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

where:

- λ = wavelength (meters)
- c = speed of light ($\sim 3.00 \times 10^8$ m/s)
- f = frequency (Hz)

- Photon Energy (E):

$$E = h \times f$$

where:

- E = energy (joules)
- h = Planck's constant ($\sim 6.626 \times 10^{-34}$ Js)
- f = frequency (Hz)

Calculating the Wavelength of Light with a Frequency of 1.1×10^{17} Hz

Step 1: Understand the Physical Significance

The wavelength indicates the spatial extent of one complete wave cycle. For electromagnetic radiation in the visible or near-ultraviolet spectrum, wavelengths typically range from about 400 nm (violet) to 700 nm (red). Calculating the wavelength for our given frequency will reveal where it lies within the electromagnetic spectrum.

Step 2: Applying the Wavelength Formula

Given:

$$f = 1.1 \times 10^{17} \text{ Hz}$$

Using:

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

Substituting the known values:

$$\lambda = \frac{3.00 \times 10^8 \text{ m/s}}{1.1 \times 10^{17} \text{ Hz}}$$

Calculate numerator and denominator:

$$\lambda = \frac{3.00 \times 10^8}{1.1 \times 10^{17}}$$

Perform division:

$$\lambda \approx 2.727 \times 10^{-9} \text{ m}$$

Step 3: Converting to Nanometers

Since wavelengths in the electromagnetic spectrum are often expressed in nanometers (nm):

$$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$$

Thus:

$$\lambda \approx 2.727 \text{ nm}$$

Step 4: Interpreting the Result

A wavelength of approximately 2.73 nm indicates this light is in the extreme ultraviolet (EUV) or soft X-ray region, which is absorbed by Earth's atmosphere and requires specialized instrumentation for detection. These wavelengths are relevant in applications like astrophysics, materials science, and medical imaging.

Calculating the Energy of a Photon with the Same Frequency

Step 1: Understanding Photon Energy

Photon energy quantifies the amount of energy carried by a single photon of electromagnetic radiation at a given frequency. This is crucial in quantum mechanics, spectroscopy, and applications like photodetectors.

Step 2: Applying the Energy Formula

Given:

$$f = 1.1 \times 10^{17} \text{ Hz}$$

Using:

$$E = h \times f$$

Substituting known constants:

$$E = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} \times 1.1 \times 10^{17} \text{ Hz}$$

Calculating:

$$E = (6.626 \times 1.1) \times 10^{-34 + 17} \text{ J}$$

$$E \approx 7.2886 \times 10^{-17} \text{ J}$$

Step 3: Expressing Energy in Electronvolts

Since electronvolts (eV) are commonly used for photon energies:

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

Calculating:

$$E \approx \frac{7.2886 \times 10^{-17}}{1.602 \times 10^{-19}} \approx 455 \text{ eV}$$

Step 4: Significance of Photon Energy

An energy of approximately 455 eV places this photon well within the X-ray region. X-ray photons are capable of penetrating tissues and materials, making them invaluable in medical imaging, crystallography, and security scanning.

Broader Context and Implications

The Electromagnetic Spectrum and Wavelengths

The calculated wavelength (~2.73 nm) and energy (~455 eV) position this light in the X-ray region of the electromagnetic spectrum. Understanding this placement is vital for several reasons:

- Medical Imaging: X-rays are used for radiography, computed tomography (CT), and cancer therapy.
- Material Science: X-ray diffraction reveals crystal structures.
- Astronomy: Observing high-energy phenomena like black holes and neutron

stars.

Quantum-Mechanical Perspective

The quantization of electromagnetic radiation means each photon at this energy is a discrete packet, which explains phenomena like the photoelectric effect. The higher the photon energy, the more capable it is of ejecting electrons from atoms, leading to applications in spectroscopy and imaging.

Technological Applications

- X-ray Generators: Devices produce X-rays via accelerating electrons to high energies.
- X-ray Detectors: Convert incident X-ray photons into electrical signals.
- Spectroscopy: Determine material composition based on characteristic absorption and emission lines.

Safety Considerations

Given the high energy (~455 eV), exposure to such radiation requires proper shielding and safety protocols due to its ionizing nature, which can damage living tissues and DNA.

Additional Factors and Considerations

Effect of Medium

While calculations are based on vacuum conditions, in real-world applications, the medium through which light propagates can influence its effective wavelength (through refraction) and absorption.

Relativistic Effects

At extremely high energies, especially in gamma-ray regions, relativistic effects might need to be considered. However, for our current calculations, classical formulas suffice.

Limitations and Assumptions

- The calculations assume the electromagnetic wave propagates in a vacuum.
- The frequency is exact; real sources might have bandwidths.
- The constants are approximations; for ultra-precise work, more exact values are used.

Summary and Conclusion

Calculating the wavelength and energy of light at a given frequency provides rich insight into its physical properties and applications. For a photon with a frequency of 1.1×10^{17} Hz:

- The wavelength is approximately 2.73 nanometers, situating it within the X-ray spectrum.
- The photon energy is around 455 electronvolts, indicating its ionizing potential.

This exercise exemplifies the interconnectedness of wave and particle descriptions of light, demonstrating how fundamental constants and formulas underpin our understanding of electromagnetic phenomena. Such calculations are foundational in fields spanning physics, engineering, medicine, and astronomy, highlighting the importance of precise measurement and comprehension of the properties of electromagnetic radiation.

In conclusion, understanding how to compute both the wavelength and energy of light given its frequency is vital for interpreting the behavior of electromagnetic waves across various scientific and technological domains. These fundamental calculations not only enhance our grasp of physical principles but also enable practical applications that benefit society in numerous ways.

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