

# X Rays With A Wavelength Of 0.12 Nm Undergo First-order Diffraction From A Crystal At 68° Angle Of Incidence.

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## Understanding X Rays and Their Wavelengths

X rays are a form of electromagnetic radiation with wavelengths much shorter than visible light, typically ranging from about 0.01 nm to 10 nm. Their high energy and short wavelength make them invaluable in fields such as medical imaging, material analysis, and crystallography. In this context, we focus on X rays with a wavelength of 0.12 nanometers (nm), which is well within the range used for probing atomic structures in crystals.

## Basics of X-ray Diffraction

X-ray diffraction (XRD) is a technique used to investigate the internal structure of crystalline materials. When X rays encounter a crystal lattice, they are scattered by the atoms within the crystal. Under specific conditions, these scattered waves interfere constructively, producing diffraction peaks that can be analyzed to determine the crystal's structure.

## Bragg's Law: The Foundation of X-ray Diffraction

The fundamental equation governing X-ray diffraction is Bragg's Law, expressed as:

$$n\lambda = 2d \sin \theta$$

where:

- $n$  is the order of diffraction (an integer),
- $\lambda$  is the wavelength of incident X rays,
- $d$  is the spacing between crystal planes,
- $\theta$  is the angle of incidence (or diffraction angle).

This law states that constructive interference occurs when the path difference between rays reflected from successive crystal planes is an integer multiple of the wavelength.

## First-Order Diffraction of X Rays at 68° Incidence

In our scenario, X rays with a wavelength of 0.12 nm undergo first-order diffraction ( $n=1$ ) from a crystal at an incidence angle of 68°. To understand the implications, we analyze the specific parameters involved.

# Calculating the Interplanar Spacing ( d )

Using Bragg's Law:

$$d = \frac{n \lambda}{2 \sin \theta}$$

Substituting the known values:

$$d = \frac{1 \times 0.12 \text{ nm}}{2 \times \sin 68^\circ}$$

Calculating (  $\sin 68^\circ$  ):

$$\sin 68^\circ \approx 0.9272$$

Therefore:

$$d = \frac{0.12 \text{ nm}}{2 \times 0.9272} = \frac{0.12 \text{ nm}}{1.8544} \approx 0.0647 \text{ nm}$$

This interplanar spacing indicates the crystal planes responsible for the observed diffraction.

## Implications for Crystal Structure

The calculated interplanar spacing (~0.0647 nm) suggests that the crystal structure has closely spaced planes, typical of many crystalline materials such as metals or complex minerals. This information can be used to identify the material or analyze its lattice parameters.

## Relevance of the Diffraction Angle and Wavelength

The specific angle of  $68^\circ$  is critical because it ensures that the incident X rays satisfy Bragg's Law for the given wavelength and interplanar spacing. Variations in either parameter would alter the diffraction conditions, affecting the intensity and position of diffraction peaks.

## Understanding the Significance of First-Order Diffraction

First-order diffraction (  $n=1$  ) is the simplest form of constructive interference, corresponding to the primary diffraction peak. Higher-order diffractions (  $n=2, 3, \dots$  ) occur at different angles and can provide additional information about the crystal structure.

# Practical Applications of Such Diffraction Phenomena

X-ray diffraction at specific wavelengths and angles is instrumental in various scientific and industrial contexts:

- Material Characterization: Determining crystal structures, lattice parameters, and identifying unknown materials.
- Quality Control: Ensuring the purity and structural integrity of crystalline substances.
- Research in Solid-State Physics: Investigating atomic arrangements and defects.
- Pharmaceuticals: Analyzing the crystallinity of drug compounds.

## Advantages of Using 0.12 nm Wavelength X Rays

- Suitable for probing atomic-scale structures due to their short wavelength.
- Capable of resolving small interplanar spacings ( $\sim 0.05$  nm to 0.2 nm).
- Compatible with common crystal lattice parameters.

## Factors Affecting X-ray Diffraction Outcomes

Several factors influence the diffraction pattern observed during XRD:

- Crystal Quality: Defects or imperfections can broaden diffraction peaks.
- Wavelength Stability: Precise wavelength control ensures accurate measurements.
- Incidence Angle Precision: Accurate setting of the angle ( $68^\circ$  in this case) is vital.
- Detector Sensitivity: Proper detection equipment captures diffraction intensities effectively.

## Optimizing Experimental Conditions

To achieve precise diffraction data, experimental setups often include:

- High-quality monochromatic X-ray sources.
- Goniometers for precise angle adjustments.
- Sensitive detectors and data acquisition systems.
- Proper sample preparation to ensure crystallinity.

## Conclusion

The phenomenon of X rays with a wavelength of 0.12 nm undergoing first-order diffraction from a crystal at a  $68^\circ$  angle of incidence exemplifies the core principles of X-ray crystallography. By applying Bragg's Law, scientists can derive interplanar spacings and gain insights into the crystal's atomic structure. This process is fundamental in materials science, chemistry, physics, and biology, enabling the detailed analysis of crystalline substances and advancing various technological applications. Understanding and controlling parameters such as wavelength, incidence angle, and crystal quality are essential for obtaining accurate and meaningful diffraction data.

## Frequently Asked Questions

### **What is the significance of the 0.12 nm wavelength in the context of X-ray diffraction experiments?**

A wavelength of 0.12 nm falls within the typical range used to probe atomic and molecular structures in crystals, allowing for detailed analysis of crystal lattice spacings through diffraction patterns.

### **How does the angle of incidence (68°) influence the diffraction pattern observed in X-ray crystallography?**

The incidence angle affects the Bragg diffraction condition, determining which lattice planes produce constructive interference, and thus influences the position and intensity of diffraction peaks in the pattern.

### **What is the significance of first-order diffraction in analyzing crystal structures?**

First-order diffraction corresponds to the primary constructive interference ( $n=1$ ), providing essential information about the spacing between crystal planes and serving as the basis for determining lattice parameters.

### **How can Bragg's law be applied to calculate the interplanar spacing for the given X-ray wavelength and diffraction angle?**

Bragg's law,  $n\lambda = 2d \sin\theta$ , can be used with  $n=1$ ,  $\lambda=0.12$  nm, and  $\theta=68^\circ$ , to calculate the interplanar spacing  $d$  as  $d = \lambda / (2 \sin\theta)$ , which helps identify crystal lattice parameters.

### **What are the typical applications of X-ray diffraction using 0.12 nm wavelength in material science?**

Such X-ray wavelengths are commonly used to analyze crystal structures, determine lattice parameters, identify phases, and study defects in materials at the atomic scale.

### **Why is understanding the diffraction of X-rays at specific wavelengths and angles important in scientific research?**

It allows scientists to accurately determine atomic arrangements in materials, facilitate the development of new materials, and improve understanding of crystal properties and behaviors.

## Additional Resources

X Rays With A Wavelength Of 0.12 Nm Undergo First-order Diffraction From A Crystal At 68° Angle

Of Incidence

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When exploring the fascinating realm of X-ray crystallography and diffraction, understanding the fundamental principles that govern the interaction of X-ray photons with crystalline structures is essential. The specific scenario of X-rays with a wavelength of 0.12 nanometers (nm) undergoing first-order diffraction at a  $68^\circ$  angle of incidence offers a compelling case study into the core concepts of Bragg diffraction, crystal lattice interactions, and the practical implications for material characterization. This article delves deep into this phenomenon, providing an expert analysis suitable for researchers, students, and professionals involved in X-ray diffraction techniques.

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## Understanding the Fundamentals: X-ray Diffraction and Bragg's Law

X-ray diffraction (XRD) is a powerful analytical technique used to determine the atomic and molecular structure of crystalline materials. When X-rays encounter a crystal, they are scattered by the electrons surrounding the atoms. Constructive interference of these scattered waves results in detectable diffraction peaks, which are directly related to the crystal's internal periodic structure.

Bragg's Law is the cornerstone of understanding diffraction phenomena in crystals:

$$n\lambda = 2d \sin \theta$$

Where:

- $n$  is the order of diffraction (an integer),
- $\lambda$  is the wavelength of the incident X-ray,
- $d$  is the interplanar spacing within the crystal,
- $\theta$  is the angle of incidence (Bragg angle).

This relation indicates that constructive interference (diffraction peaks) occurs when the path difference between X-rays reflected from successive crystal planes equals an integer multiple of the wavelength.

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## Analyzing the Given Scenario

The scenario specifies:

- Wavelength ( $\lambda$ ): 0.12 nm
- Order of diffraction ( $n$ ): 1 (first-order diffraction)
- Incidence angle ( $\theta$ ):  $68^\circ$

The primary goal is to determine the interplanar spacing ( $d$ ), assess the feasibility of this

diffraction, and understand the implications of such conditions.

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## Calculating the Interplanar Spacing $(d)$

Applying Bragg's Law for  $(n=1)$ :

$$d = \frac{\lambda}{2 \sin \theta}$$

Substituting the known values:

$$d = \frac{0.12 \text{ nm}}{2 \sin(68^\circ)}$$

Calculating  $(\sin(68^\circ))$ :

$$\sin(68^\circ) \approx 0.9272$$

Therefore:

$$d = \frac{0.12 \text{ nm}}{2 \times 0.9272} = \frac{0.12 \text{ nm}}{1.8544} \approx 0.0647 \text{ nm}$$

Result: The interplanar spacing  $(d)$  is approximately 0.0647 nm.

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## Implications of the Calculated $(d)$

This interplanar spacing is characteristic of very closely packed crystal lattices, typically found in high-density materials such as metals or certain complex minerals. For context:

- Typical interplanar spacings in common crystalline materials:
- Metals like copper: about 0.208 nm
- Silicon (diamond cubic): approximately 0.313 nm
- Graphite: around 0.335 nm

Given the calculated  $(d)$ , the crystal involved must possess very compact atomic arrangements or specific high-index planes with such small interplanar distances.

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## Feasibility of the Diffraction at 68° Incidence

The high angle of 68° suggests that the X-ray is incident relatively obliquely upon the crystal planes, close to a grazing incidence. Several factors influence whether such diffraction is physically feasible:

### Crystal Structure and Plane Orientation

- High-angle diffraction generally corresponds to reflections from planes with small  $d$  values.
- The derived  $d$  aligns with tightly packed planes, which are often observed in metals and dense crystalline structures.

### Intensity Considerations

- First-order diffraction at high angles can produce strong peaks if the crystal is well-ordered.
- The intensity depends on factors such as atomic form factors, thermal vibrations, and crystal quality.

### Geometrical Constraints

- At 68°, the incident beam is entering at a high angle, which can impact the experimental setup.
- Ensuring precise alignment is critical to observe clear diffraction peaks.

### Practical Limitations

- For X-rays with a wavelength of 0.12 nm, the maximum diffraction angle for a given  $d$  is constrained by the relation:

$$\sin \theta \leq 1$$

- Rearranged to find maximum  $d$ :

$$d \geq \frac{\lambda}{2}$$

- Since  $(\lambda = 0.12, \text{nm})$ , the maximum  $d$  for which diffraction can occur at any angle is 0.06 nm at  $(\theta = 90^\circ)$ . Our calculated  $d$  is slightly above this, implying that such diffraction at 68° is near the upper limit, but still physically plausible considering experimental tolerances.

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# Practical Applications and Significance

Understanding such diffraction conditions is fundamental in multiple scientific domains:

## Material Characterization

- Precise measurements of  $d$  provide insights into the crystal lattice parameters.
- Detecting high-angle diffraction peaks helps identify specific crystallographic planes and disorders.

## Crystallography and Structural Analysis

- The ability to observe first-order diffraction at high angles aids in detailed structure determination, especially in complex or dense crystals.
- It assists in confirming phase purity and detecting lattice distortions.

## Medical Imaging and Material Testing

- Knowledge of diffraction patterns guides the development of X-ray-based imaging techniques, including crystallography in pharmaceuticals and non-destructive testing of materials.

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# Limitations and Challenges

While the theoretical calculations support the feasibility, practical challenges include:

- Instrumental Resolution: High-angle diffraction peaks require detectors with high angular resolution.
- Sample Quality: Crystals must be of high perfection to produce sharp diffraction peaks.
- Absorption Effects: At high angles, X-ray absorption within the crystal can diminish signal strength.
- Alignment Precision: Accurate control over the incident angle is crucial for observing the predicted diffraction.

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# Conclusion: Expert Perspective

The analysis of X-rays with a wavelength of 0.12 nm undergoing first-order diffraction at a  $68^\circ$  incidence angle reveals a plausible and insightful scenario within the realm of X-ray crystallography. The derived interplanar spacing of approximately 0.0647 nm indicates interaction with densely packed crystal planes, typical of closely bonded metallic or high-density crystalline structures.

This phenomenon underscores the importance of precise experimental setup, high-quality crystalline samples, and advanced detection systems to observe and interpret diffraction patterns at such high angles. The understanding gained from this scenario not only reinforces core principles like Bragg's

Law but also highlights the delicate balance between theoretical calculations and practical implementation in material science and structural analysis.

In sum, this case exemplifies how fundamental physics translates into real-world applications, enabling scientists to unravel the atomic architecture of materials with remarkable detail and accuracy.

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