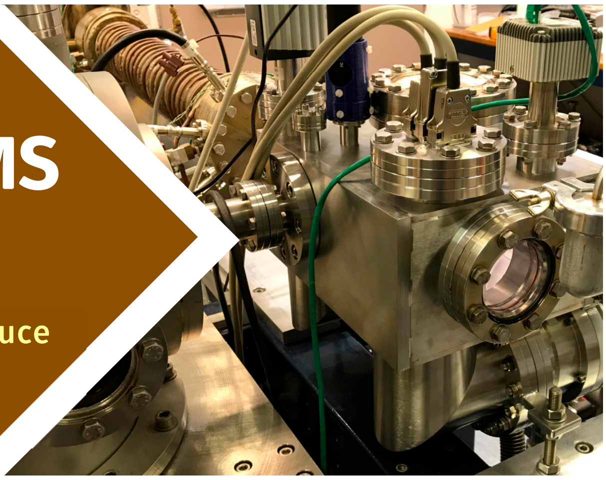
SEEING WITH He ATOMS

Contrast

How do we make sure the helium atom beam will produce an image with enough detail for us to do cutting-edge research on our samples?



Overview: Beam Energy	Stage 1: Beam Source	Stage 2: Creating the Beam	Stage 3: Contrast	Stage 4: Creating an Image

GCSE Physics	Electromagnetic Spectrum	$v = f\lambda$	Law of reflection	$\theta_i = \theta_f$
A Level Physics	Wave particle duality	$p = \frac{h}{\lambda}$		

Introduction & context:

Photograph of a microwave oven
Credit: S. Schulze

When taking an image of an object with a camera, the way that light reflects off the object and reaches the film or CCD is important to give good contrast in the image. A smooth, mirror-like surface will reflect light brightly where the angle of reflection is equal to the angle of incidence.

A rough surface reflects light at a range of angles (known as diffuse reflection). For helium, making a smooth mirror like surface to produce a good contrast image would be incredibly difficult because almost all surfaces appear rough to helium atoms.

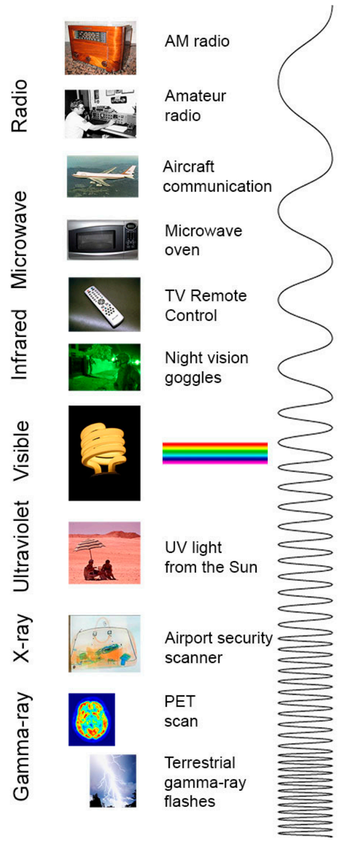
Why is this?

Microwave shielding

We can watch our food cook inside a microwave, but the microwaves cannot escape the oven to harm you, even though both microwaves and visible light are part of the same electromagnetic spectrum. Why can visible light escape but microwaves not? In answering this question, we will also understand why surfaces appear rough to helium, even if they appear shiny and flat when viewed by eye.

The wavelength of visible light is about $500\ \mathrm{nm}$, but the wavelength of a microwave used for cooking is about $120\ \mathrm{mm}$. The shielding in a microwave door has holes that are about $1\ \mathrm{mm}$ in diameter, which means that it appears reflective to a microwave. However, the wavelength of visible light is typically ${}^{1}/_{2000}$ of the hole diameter, so visible light can pass through the holes and we can still see inside the microwave oven and watch our food being cooked!

This analogy helps us to understand that electromagnetic waves of different wavelengths respond differently to material structures (e.g. the holes) **because of the relative size of those structures compared with the wavelength of the light.**



Credit: NASA's Imagine the Universe

Related Concepts

Electromagnetic waves

Related Questions

EM Frequencies

Law of reflection

For a surface to behave as a mirror for visible light it must be reflective and much flatter than $500\ \mathrm{nm}$, whereas a mirror for microwaves only needs to be significantly flatter than $120\ \mathrm{mm}$. By flat, we mean that any surface structures (bumps or dips) must be much smaller than the wavelength of the light.

If a ray of light is incident on a mirror, then the reflected light will follow the law of reflection such that the incoming angle of the ray is equal to the outgoing angle of the ray.

$$\theta_i = \theta_f$$

The reflective surface will obey this law, and behave as a mirror, if the surface is flat compared with the wavelength of the incoming light.

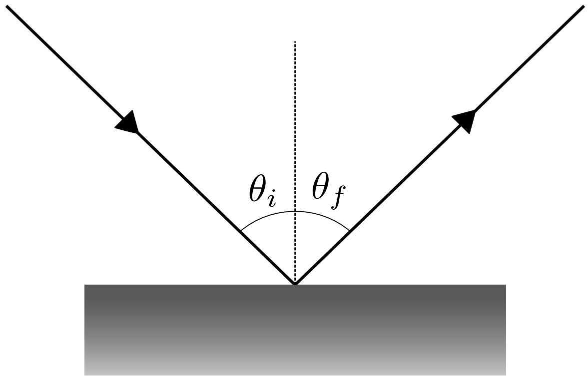


Diagram illustrating the law of reflection, angle of incidence = angle of reflection

Helium scattering

From wave-particle duality we can calculate that the helium beam in the microscope has a wavelength of $0.05\ \mathrm{nm}$, which is $^{1}/_{10,000}$ of the wavelength for visible light. Therefore, most materials look rough to the helium beam, even surfaces that appear shiny to the eye.

For a material to act as a mirror for a helium beam, it would need to be atomically flat ($10^{-10}\ \mathrm{m}$). The samples that we wish to investigate are not this smooth and the helium is scattered diffusely in all directions from their surfaces.

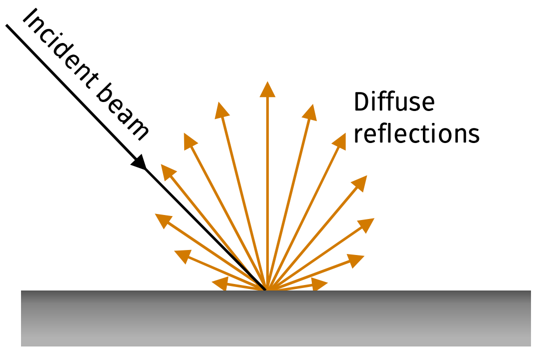
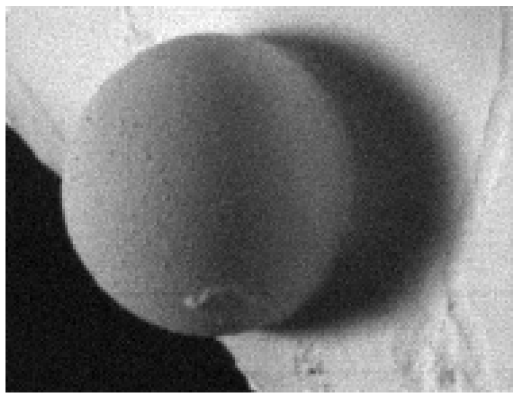


Diagram showing diffuse reflection from "rough" surfaces

However, most of the helium is scattered perpendicular to the surface and the brightest part of an image is where the normal to the surface is pointing towards the detector. For example, in this image of a glass microsphere (~$0.4\ \mathrm{mm}$ diameter) on the edge of an adhesive carbon tape, the left hand side of the sphere is pointing towards the detector.



Scanning helium microscope image of a glass sphere (~$0.4\ \mathrm{mm}$ diameter) with a coating of gold, on the edge of an adhesive carbon tape.
Credit: Cambridge surface physics group

In images produced using the helium microscope, brightness is determined by the number of atoms that reach the detector. The more atoms that are counted by the detector the brighter the pixel in the image. If no atoms reach the detector then the pixel in the image appears dark.

Result – Contrast

Helium beams scatter diffusely from most surfaces due to the wavelength of the beam being so small that most surfaces appear rough. Understanding how helium atoms will scatter from a surface enables us to maximize the contrast in our images. We want to make bright areas of the image as bright as possible and dark areas as dark as possible (i.e. maximize contrast) so that we can identify features in the sample that may help us to understand its structure or physical properties.

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Related Concepts

GCSE Book Section 39 – waves – plane mirrors
Waves
Reflection and Refraction

Related Questions

Essential GCSE Physics 39.1
Light on Surfaces
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Cat's Eye