SEEING WITH He ATOMS

2 He 4.0026

Creating the Beam

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 waves	$v = f\lambda$	Magnification	$\frac{H_{image}}{H_{object}}$	Ray Diagrams	
A Level Physics	Electromagnetic waves	$v = f\lambda$	Magnification	$m = \frac{v}{u}$	Lens maker's equation	$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Introduction & context

The source of helium atoms that produces the helium atom beam source is approximately $100\ \mu m$ across. A source this broad would only allow us to image details of a similar size. To improve the resolution of the instrument, the principles of geometric optics and the pinhole camera can be applied.

Reminder on beam formation

The beam for the helium microscope is formed from the expansion of helium gas into a vacuum chamber. A skimmer then selects the narrow beam of particles that are travelling in straight lines, at high speed in the forward direction. The result is that we obtain a source of helium that is typically about $100\ \mu m$ across (about the width of a human hair). If we were to scan this beam across the sample the image that we would produce would have a resolution of about $100\ \mu m$.

Related Concepts

Ray Diagrams

Related Questions

Multi-coloured Pinhole

A pinhole that is much smaller than the source is placed in the path of the source beam.

Pinhole optics

The pinhole currently about $1\ \mu m$ in diameter. Such a pinhole produces two effects, it only allows a narrow beam of atoms through (those that travel approximately parallel to each other) and gives a demagnified image of the source (reduces its width) at the sample.

When the pinhole is large, many atoms pass through the pinhole and reach the sample, which would give a bright image but with low resolution. When the pinhole is small the beam that is directed at the sample has a much reduced width (illustrated as a radius r in this diagram), giving a higher resolution image but many fewer particles pass through making the image darker.

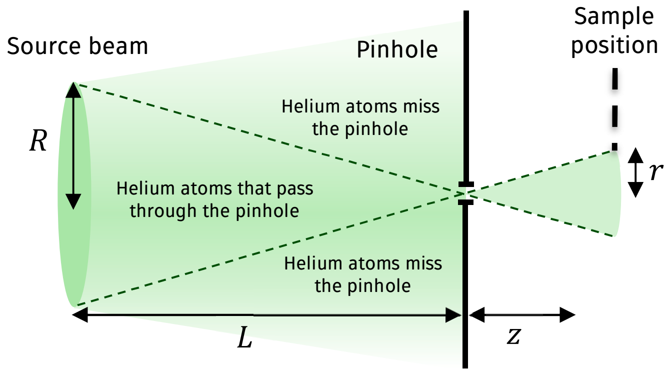
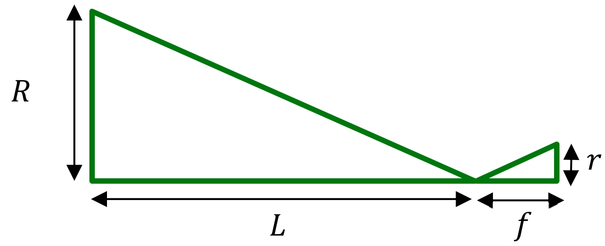


Diagram showing how the atom beam source is demagnified using a pinhole.

By adjusting the size and position of the source, and the size of the pinhole, the number of atoms that reach the sample can be optimised so that the image does not appear grainy (noisy). This graininess can be seen when taking ordinary photographs, if there is little light when the photograph is taken, too few light particles (photons) reach the camera and the image appears grainy.

The size of the demagnified beam depends on how far away the source is from the pinhole and how far away the pinhole is from the sample geometry and similar triangles.



$$\frac{r}{R} = \frac{f}{L}$$

Therefore

$$r = \frac{Rf}{L}$$

In the Cambridge SHeM,

$$L = 200\ \text{mm},\ R = 50\ \mu\text{m},\ f = 2\ \text{mm}$$

which gives a demagnified beam of radius $r = 0.5\ \mu\text{m}$. By moving the source further away (increasing L), the beam can be made narrower but the number of atoms in the beam goes down.

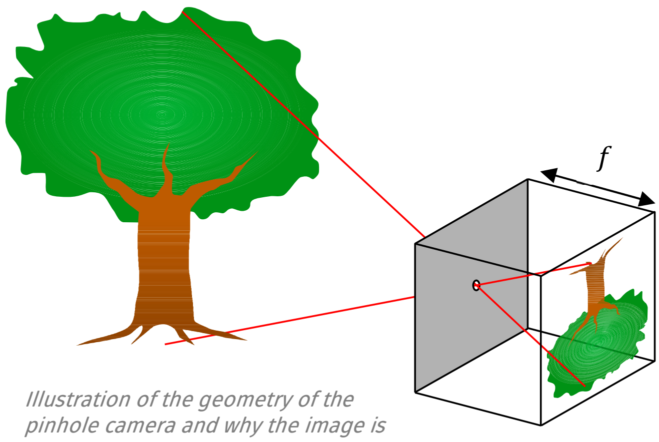


Illustration of the geometry of the pinhole camera and why the image is inverted Credit: From Wikimedia Commons

Pinhole camera

The pinhole for demagnification in the SHeM operates in a similar way to a pinhole camera. By using a short distance between the pinhole camera and the screen, large objects can be imaged onto small screens. Along with this leaflet you will find everything you need to make your own pinhole camera. Once you have made your pinhole camera you can experiment with how your image is affected when you change the distance from the pinhole to the object (source) that you are looking at. You can also investigate what happens to the image as you make the pinhole larger.

When designing a pinhole camera, many of the decisions that you have to make are similar to those decisions that we need to make for the SHeM pinhole. If the pinhole is too small, the image is sharp but will be dark unless the object is brightly lit (need lots of light particles - photons in the same way that we need lots of helium atoms to make a clear image). If the pinhole is too large then plenty of light from the object reaches the screen but the object is now blurred and there is little contrast between the background light level and what you want to see.

The optimal pinhole diameter for a pinhole camera can be calculated using the formula

$$d = 2\sqrt{f\lambda}$$

where d is the diameter of the pinhole, f is the focal length of the camera (which is equal to the distance from the pinhole to the screen) and λ is the wavelength of light. So, if we use a camera that is a $20\ \text{cm}$ cube, with visible light ($\lambda = 500\ \text{nm}$), then the size of the pinhole that we should use is approximately $0.6\ \text{mm}$.

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Related Concepts

GCSE Book Section 48 – Convex Lenses

Related Questions

GCSE Book Section 48 – Q1
Out of the Shadows
Compound Microscope

Conclusion

Helium is difficult to manipulate because it is neutral and unreactive and so we are unable to use conventional techniques such as lenses to focus beams of helium atoms. However, it is possible to use simpler historical methods, very similar to those used in pinhole cameras, to produce a helium beam fit for purpose.