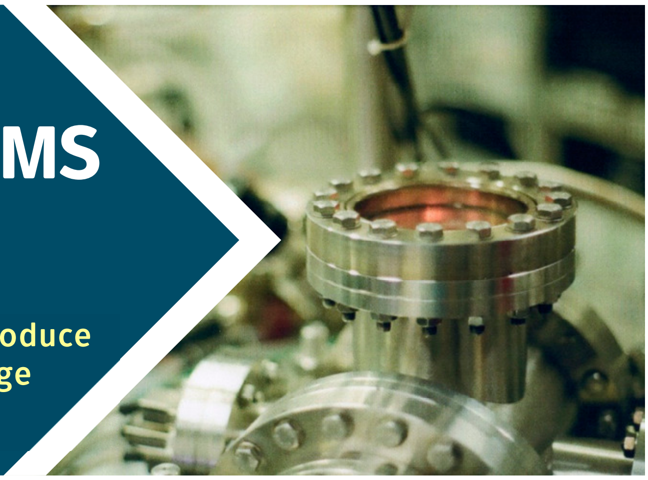
SEEING WITH He ATOMS

2 He 4.0026

Beam Source



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	Kinetic Energy	$\frac{1}{2}mv^2$	Pressure	$P = \frac{F}{A}$	Density of Materials	$\rho = \frac{m}{V}$
A Level Physics	Ideal Gas Law	$PV = Nk_BT$	Internal Energy	$\frac{3k_BT}{2}$	Kinetic Theory of Gases	$\frac{1}{2}m\overline{v^2} = \frac{3}{2}k_BT$

Introduction & context

In a scanning helium microscope (SHeM), a beam of helium atoms is directed onto a sample. The beam is formed by a nozzle in the vacuum chamber. This nozzle releases helium into the chamber at high pressure so the pressure difference between the source and the vacuum chamber causes the gas to accelerate out into the chamber, expanding into the volume. The pressure in the vacuum chamber (0.0000001 atm) is low enough that there are no gas particle collisions and the atoms travel in straight lines.

In the expansion, the lack of collisions means that they travel in straight lines in the forward direction.

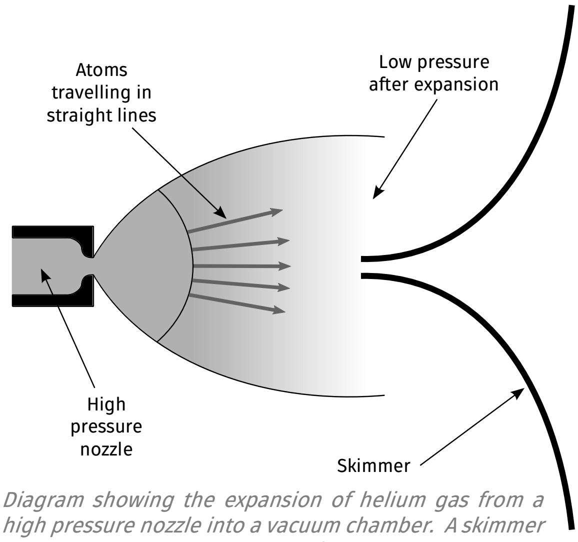


Diagram showing the expansion of helium gas from a high pressure nozzle into a vacuum chamber. A skimmer is used to select the centre line of helium atoms to create the atom beam source.

Gas particle collisions

In a gas, particles are far apart and free moving but will still collide with each other. For example, in air particles typically move by about 100 nm before colliding with another particle. These gas particle collisions cause it to act like a fluid and introduce effects such as turbulence.

Therefore, if a beam of atoms were created at atmospheric pressure it would quickly dissipate due to collisions with other particles.

Related Questions

GCSE Book Section 60 – Q8
An Indecisive Gas
Brownian Motion

Thermal convection plume rising from an ordinary candle in still air. Image from Wikipedia user Gary Settles.

Beam formation

To reduce the background particles that will attenuate the atom beam, the entire experiment (source, sample and detector) is performed in a vacuum chamber. The beam of atoms is created in a chamber that has a pressure about $^1/_{100,000}$ of atmospheric pressure. For comparison, the pressure in a vacuum cleaner is only about $^1/_5$ of atmospheric pressure. In fact, other parts of the experiment are held at even lower pressures, with pressures as low as $^1/_{10^{14}}$ of atmospheric pressure.

Related Questions
Atmospheric Pressure

Once the atoms are travelling in straight lines, the centre part of the expansion is selected with a skimmer so that the beam only contains atoms moving in a forward direction. Therefore, a beam of atoms can then be created without any scattering while it travels to the sample.

Particle theory of gases

The particle theory of matter is a model that says that all matter is made up of particles, which behave differently depending on what state the matter is in. **Solids** are made up of particles that are tightly bound together. **Liquids** contain particles that are still bound closely together, but can now move past each other allowing the liquid to flow. A **gas** contains particles that are far apart and essentially free moving.

The source of helium atoms in our experiment is a gas, contained in a high pressure cylinder. The gaseous helium atoms enter the vacuum chamber through a nozzle. The nozzle is at room temperature. According to the kinetic theory of gases we can calculate how the speed of the helium atoms depends on this nozzle temperature.

We can relate the average velocity of a gas particle $(\overline{v^2})$ to the temperature of the gas using the **kinetic theory of gases**. In this model, N gas particles, each of mass m, collide with the walls of a cubic container volume V, exerting a pressure P, given by

$$P = \frac{F}{A} = \frac{Nm\overline{v^2}}{3V}$$

The ideal gas law relates PV to the temperature of the gas such that

$$PV = Nk_BT$$

Combining these two results, we can relate the average kinetic energy per particle to the temperature of the gas.

Related Concepts
GCSE Book Section 17
Ideal Gases

Related Questions
Essential Pre-University Physics G2.7
Gaseous Ideals
Molar Heat Capacities

$$\frac{1}{2}m\overline{v^2} = \frac{3}{2}k_BT$$

Since the gas particles can move in three perpendicular directions (x, y, z), we see that in this model each direction contributes $\frac{1}{2}k_BT$ to the average kinetic energy of the atoms. This is a simplified model and the way that the gas expands through the nozzle contributes an additional k_BT to the energy of the atoms. The average velocity of the helium gas atoms in the SHeM is given by

$$\frac{1}{2}m\overline{v^2} = \frac{5}{2}k_BT, \qquad v_{rms} = \sqrt{\frac{5k_BT}{m}}$$

The temperature of the nozzle is $293\ \mathrm{K}$, $k_B = 1.38 \times 10^{-23}\ \mathrm{J\,K^{-1}}$, and $m = 4.00 \times 1.66 \times 10^{-27}\ \mathrm{kg}$. This means that the average speed of the helium atoms is $v_{rms} \approx 1740\ \mathrm{m\,s^{-1}}$.