Electron Diffraction Tube

Introduction

The electron diffraction tube consists of an electron gun that accelerates electrons towards a graphite foil. In contrast to the cathode ray tube and the fine beam tube a much higher voltage is used, why the wave behaviour of the particles outcrop: the electrons are diffracted at the inner structure of the graphite.

Functional principle

- The source of the electron beam is the electron gun, which produces a stream of electrons through thermionic emission at the heated cathode and focuses it into a thin beam by the control grid (or "Wehnelt cylinder").
- A strong electric field (10 kV!) between cathode and anode accelerates the electrons, before they leave the electron gun through the spaces of the anode-grid.
- Afterwards the accelerated electrons hit a thin graphite foil. The electrons are diffracted there so they fly towards the screen in different directions.
- When electrons strike the fluorescent screen, light is emitted so that the diffraction picture gets visible.
- The whole configuration is placed in a vacuum tube to avoid collisions between electrons and gas molecules of the air, which would attenuate the beam.

Electron Diffraction Tube
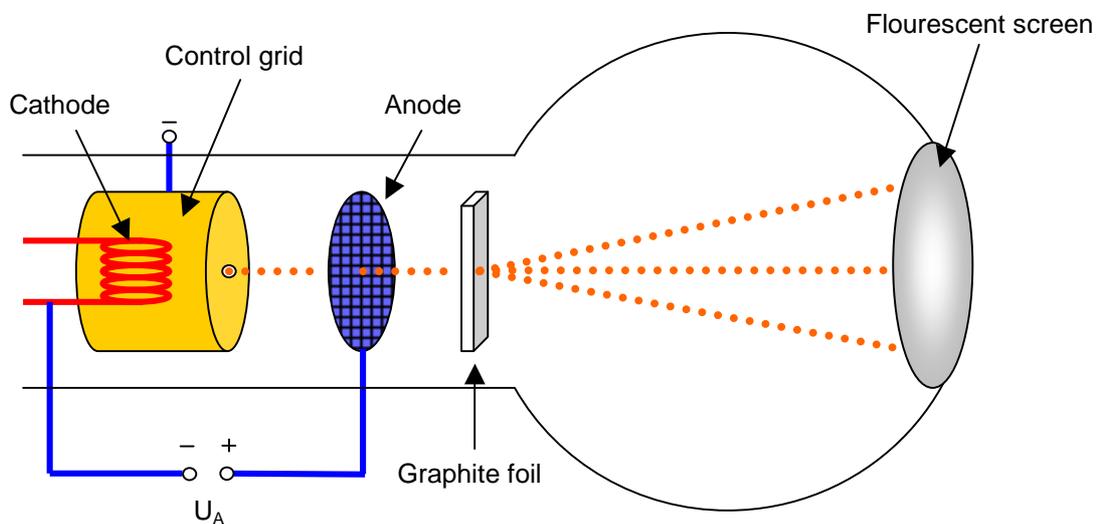
Setup

Equipment	Assembling the experiment
1 Electron diffraction tube 1 DC power supply 1 High voltage supply unit (0..10kV) Cables	1. Connect the sockets of the electron diffraction tube to the power supply as shown in the circuit diagram below. 2. Connect the high voltage to the anode G3 through a 10 MΩ protective resistor (the resistor can be cancelled if the high voltage power supply unit includes a current leveller like the one at teachers lab).

Electron Diffraction Tube
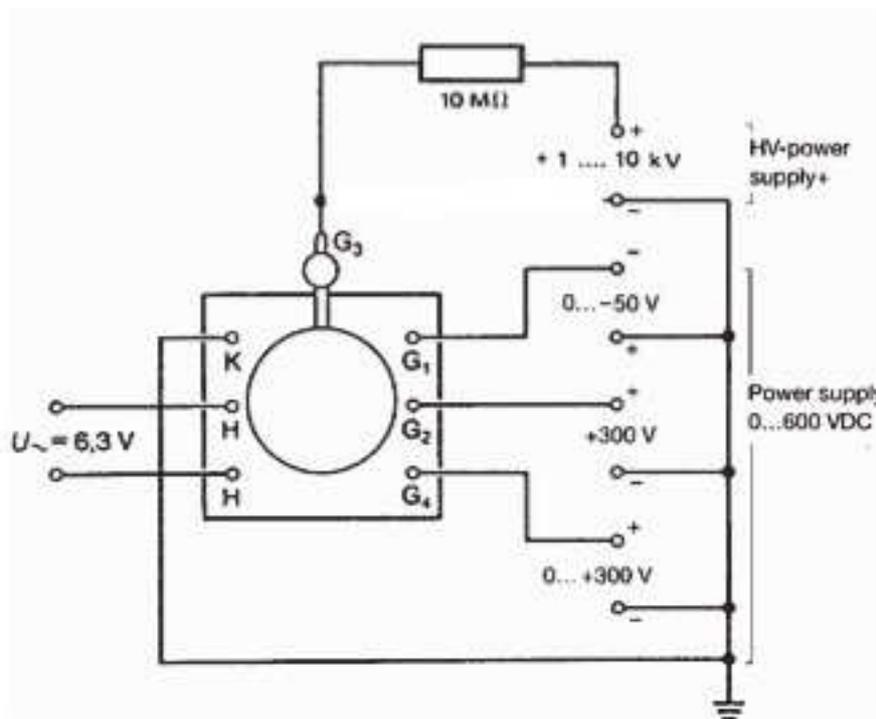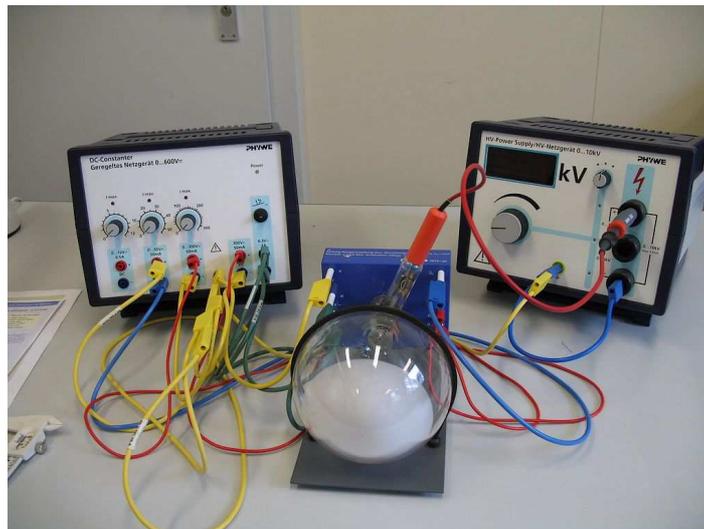
Experimental procedure

1. Set the voltage of G1 to -50 V using the second knob on the dc power supply (or whatever value the beam is bright enough).
2. Set the voltage of G4 to about 0 V using the third knob on the dc power supply (or whatever value that make the beam is sharp enough).
3. Slowly increase the high voltage supply until the ring structure appears on the fluorescent layer on the electron diffraction tube. The visibility of high order rings depends on the light intensity in the laboratory and the contrast of the ring system which can be influenced by the voltages applied to G1 and G4. Rings should appear when the voltage is about 4 kV.
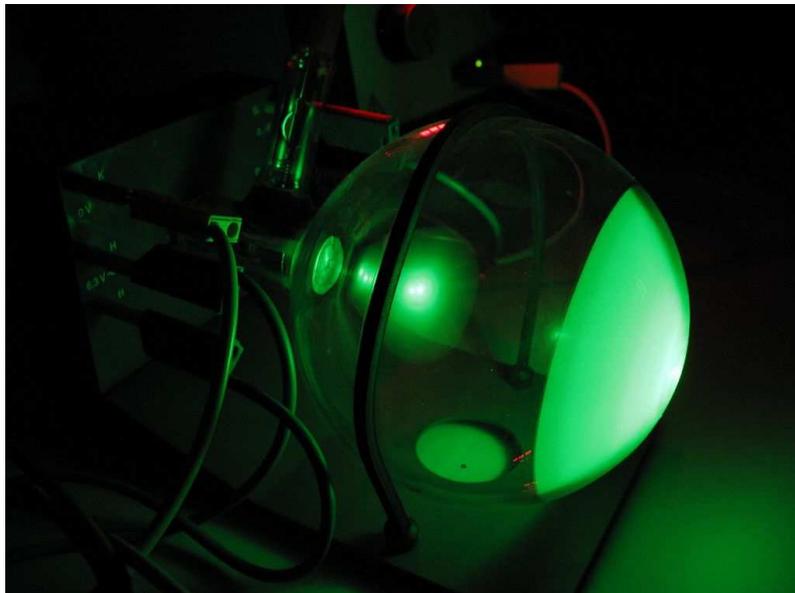
Safety precautions

- Don't touch fine beam tube and cables during operation, high voltages of 10 kV are used in this experiment!
- Do not exert mechanical force on the tube, danger of implosions!
- The bright spot just in the center of the screen can damage the fluorescent layer of the tube. To avoid this reduce the light intensity after each reading as soon as possible.

Electron Diffraction Tube

Wave behaviour of the electron

Tasks:

1. Build up the experimental setup (see "setup") and observe the diffraction picture on the screen!
2. Measure the radii r of the first and the second ring und work out the wavelength of the electrons!

   Information:

   - The optical retardation between light reflected at neighbouring planes (distance: d) of the carbon atoms is $\delta = 2 \cdot d \cdot \sin\theta$ (see draft). Constructive interference occurs if the optical retardation is a multiple of the wavelength λ, that's why for maxima (brightly rings at the screen) it is $n \cdot \lambda = 2 \cdot d \cdot \sin\theta$.

   - The diffraction angle θ can be calculated by the radius r of the maxima and the distance D=127mm between screen and graphite foil through geometrical reasons (for further information, see PHYWE 25113-00) with:

   $$\theta = \frac{1}{4}\arcsin\frac{2r}{D}$$

   - The distance between the two relevant planes of the carbon atoms is d_1=213 pm and d_2=123 pm.
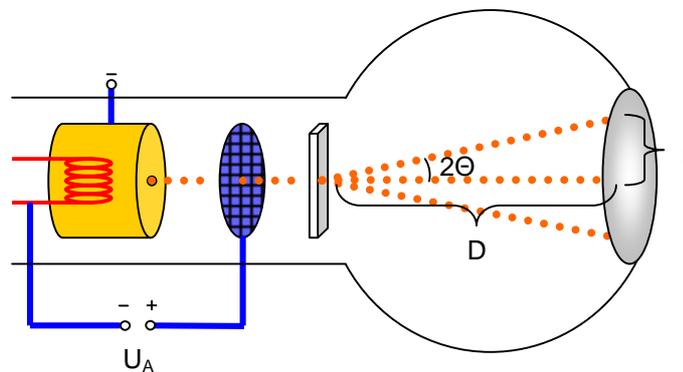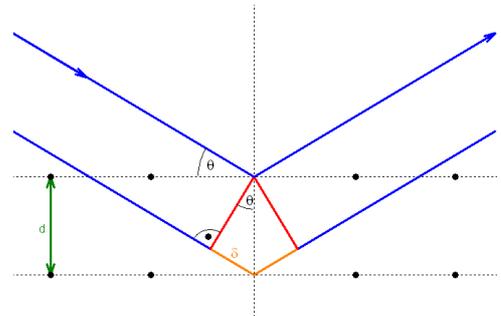
3. Compare your result to the wavelength that is given by deBroglie equation $\lambda = {}^h/_p$!

Electron Diffraction Tube

Results:

1. Electrons behaving like particles would not case a diffraction picture when passing matter like the graphite foil. Since a diffraction picture gets visible, there is diffraction – electrons behave like waves.
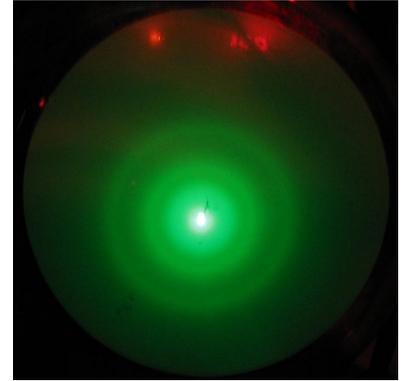
> After Einstein introduced the duality of wave and particle behaviour of light first in 1905, deBroglie proposed 1924 that not only light has both wave and particle behaviour: matter, so far seen as consisting of particles, should behave like waves as well, which can be verified with this experiment in the electron diffraction tube

2. Measuring the radii r_1 und r_2 and working out the corresponding wavelengths we have a wavelength of $\lambda = 12$ pm at 10 kV acceleration voltage.

3. DeBroglie posited the formula $\lambda = {}^h\!/_p$ for the wavelength of matter. The impulse p of the electrons in the electron diffraction tube depends on the acceleration voltage U:

$$E_{kin} = \frac{1}{2} m \cdot v^2 = e \cdot U \quad \Rightarrow \quad \frac{p^2}{m} = 2 \cdot e \cdot U \quad \Rightarrow \quad p = \sqrt{2 \cdot e \cdot m \cdot U}$$

With deBroglie equation we have for U=10 kV:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2 \cdot e \cdot m \cdot U}} = 12,29 \, pm$$

This is almost the same as the experimental result from (2.), whereby deBroglie's hypothesis of „matter waves " and his formula to compute their wavelength are confirmed experimentally.

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Scattering experiments

Tasks:

1. Operate the electron diffraction tube with an acceleration voltage of U_A=8 kV. Measure the radii of the first and the second ring and work out the spacing of the lattice planes d_1 and d_2 inside the graphite by using the deBroglie wavelength of the electrons (which supposed to be known in this case)!

   Information: use Bragg equation $n \cdot \lambda = 2 \cdot d \cdot \sin\theta$ and $\theta = \frac{1}{4}\arcsin\frac{2r}{D}$, D=127mm.

2. Adjust an acceleration voltage of U_A=300 V. What can be observed?

Results:

1. Solving Bragg equation to d, we get: $d = \frac{n \cdot \lambda}{2 \cdot \sin\theta}$

   Since diffraction angle θ can be worked out of the radius r using $\theta = \frac{1}{4}\arcsin\frac{2r}{D}$ and deBroglie

   wavelength of 8 kV electrons is $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2 \cdot e \cdot m \cdot U}} = 13{,}7\,pm$, we can calculate the distance d

   between the lattice planes of the graphite foil (manufacturer information: d_1=213 pm und d_2=123 pm).

   In this task we succeeded to find out something about the inner structure of matter (namely the distance between the planes of the carbon atoms) by firing it with fast small particles, in this case electrons. This procedure is one of the basic principles used in particle physics experiments. Such scattering experiments resulted in the discovery of the atomic nucleus (Rutherford 1908) and the quark structure of hadrons (Friedman, Kendall, Taylor 1962).
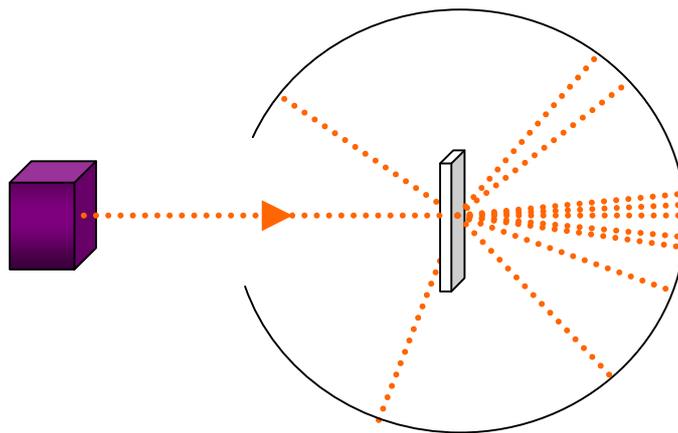
2. At low energy there is no diffraction image on the screen. The reason is that deBroglie wavelength of with 300 V accelerated particles is only $\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2 \cdot e \cdot m \cdot U}} = 70,83\,pm$ which is too much to analyse the distance between the lattice planes of graphite that is d_1=213 pm and d_2=123 pm.

> To analyse the inner structure of matter, the bullet particles have to be as small as possible compared to the analysed structure. Light with a wavelength of λ=500 nm e.g. is not appropriate to analyse the planes of a graphite foil whose distance is only d = 213pm. That's why light-optical microscopes are not useful to analyse the planes of graphite because the wavelength is much bigger than the structure. The deBroglie wavelength of 10 kV electrons is about 12 pm (see above) so they allow the study of the inner structure of graphite.
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> In summary bullet particles for scattering experiments have to be very small to get a good resolution. Since deBroglie wavelength $\lambda = {}^h/_p$ is inversely proportional to the impulse p, scattering experiments need strong particle accelerators. This is the reason why the electron diffraction tube needs a high voltage of at least 10 kV.

Well-known scattering experiments

Year	Experiment	Bullet particles	Cognitions
1908	Rutherford	α-particles	Discovery of the atomic nucleus
1956	Hofstadter	Electrons	Size of a proton
1962	Friedman, Kendall, Taylor	Electrons	Proof of the existence of quarks
1992	HERA	Electrons, muons, neutrinos	Structure of protons

Electron

Proton
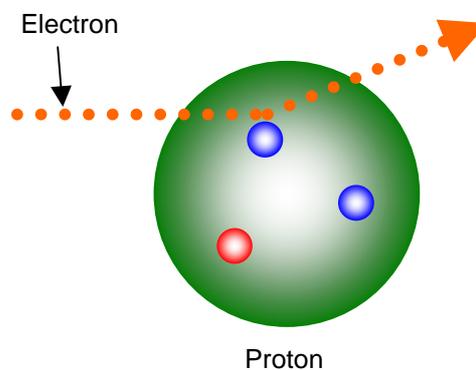
Scattering experiment to prove the existence of quarks