An experimental apparatus (reaction microscope) for the investigation of electron-atom collisions.

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Atoms under Bombardment

From Electron-Atom Collisions to Tumor Therapy
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Electron-Atom Collisions in Nature, in Applications ...

Reactions which are initiated by microscopic collisions of energetic particles with atoms, the building blocks of matter, are relevant in various areas of our environment, in technical applications and in medicine. E.g., in lightning flashes and in fluorescent tubes atoms are initiated to emit light in collisions with fast electrons. Electrons are negatively charged elementary particles forming the atomic shells. They are responsible for chemical properties of atoms and molecules and carry electrical current in electricity. In medicine they play an important role in tumor therapy where cancer cells are destroyed efficiently by x-rays (radiation therapy) or by fast and energetic ions. In both methods the injected beams produce a large number of free electrons in the tissue. These can destroy very easily the DNA which is the molecule in the cellular nucleus carrying the genetic information.

... and on an Atomic Scale

But what happens on a microscopic scale, when high-energetic, e.g. fast electrons or ions penetrate a gas or tissue? We do research to answer this question by investigating collisions between electrons and single atoms. A decisive reaction channel is collision-induced ionization, in which electrons initially bound in the atom are kicked out by the impact of the projectile electron. This process, however, is up to now not fully understood. Unsolved problems are for example: How fast and in which direction do the ejected electrons escape? How often get two, three or more electrons ejected from the atom? Which role does the atomic nucleus play in this process? Using sophisticated experimental techniques, we try to find answers to these questions.

The Many-Particle Problem

Similar to planets circulating around the sun, the electrons in an atom are moving around the nucleus, where all particles interact with each other through the Coulomb force.

Quantum theory, which has been formulated already in the first half of the last century describes the motions of the atomic building blocks. Even though this theory was confirmed in numerous experiments and, moreover, the force between the electrons and the atomic nucleus is well known, exact solutions of the quantum-mechanical equations may be derived only for the simplest system, the hydrogen atom (consisting of a nucleus and one electron only). As soon as more than two particles are involved either approximations or computer-aided, computationally extensive numerical procedures have to be applied. In order to test the validity of these approximations, a comparison with experimental results is essential.

Dynamics in Collisions

In contrast to the motion of planets, the bound electrons in an atom are not observable directly. Here, a trick has to be used! We bombard single atoms with electrons and select only those events, where one or more electrons are kicked out. The kinetic energies and emission directions of the escaping electrons provide valuable information about their motion just before the collision, a state when they are still bound in the atom. One can learn a lot about the dynamics of these so-called many-particle Coulomb systems by observing this atomic billiard game. The representation of a measured electron angular distribution is shown on the title page.

In recent experiments we studied collisions between electrons and molecules with increasing size. We could observe for the first time how the spatial structure and the alignment of a molecule influence the electron emission pattern. In the collision, the molecule may also disassemble in several fragments. In biological tissue this process plays a decisive role since, e.g., the DNA molecule can be modified or destroyed. We study how the building blocks of DNA behave, if they are hit by electrons. In the above figure the detected fragments of a molecule which initially has a ring structure are sketched. The final reaction products depend on which molecular electron is knocked-out. These experimental results may contribute to a better understanding of the formation of tumors and their destruction by radiation therapy.

A Detector with Atomic Resolution – the „Reaction Microscope“

Single atoms or molecules break up into their constituents – electrons and ions – due to the bombardment with electrons. The goal is to determine the momenta, i.e., the velocities and the flight directions, of all atomic fragments. For this purpose, the negatively charged electrons and the positively charged ions are accelerated in opposite direc-