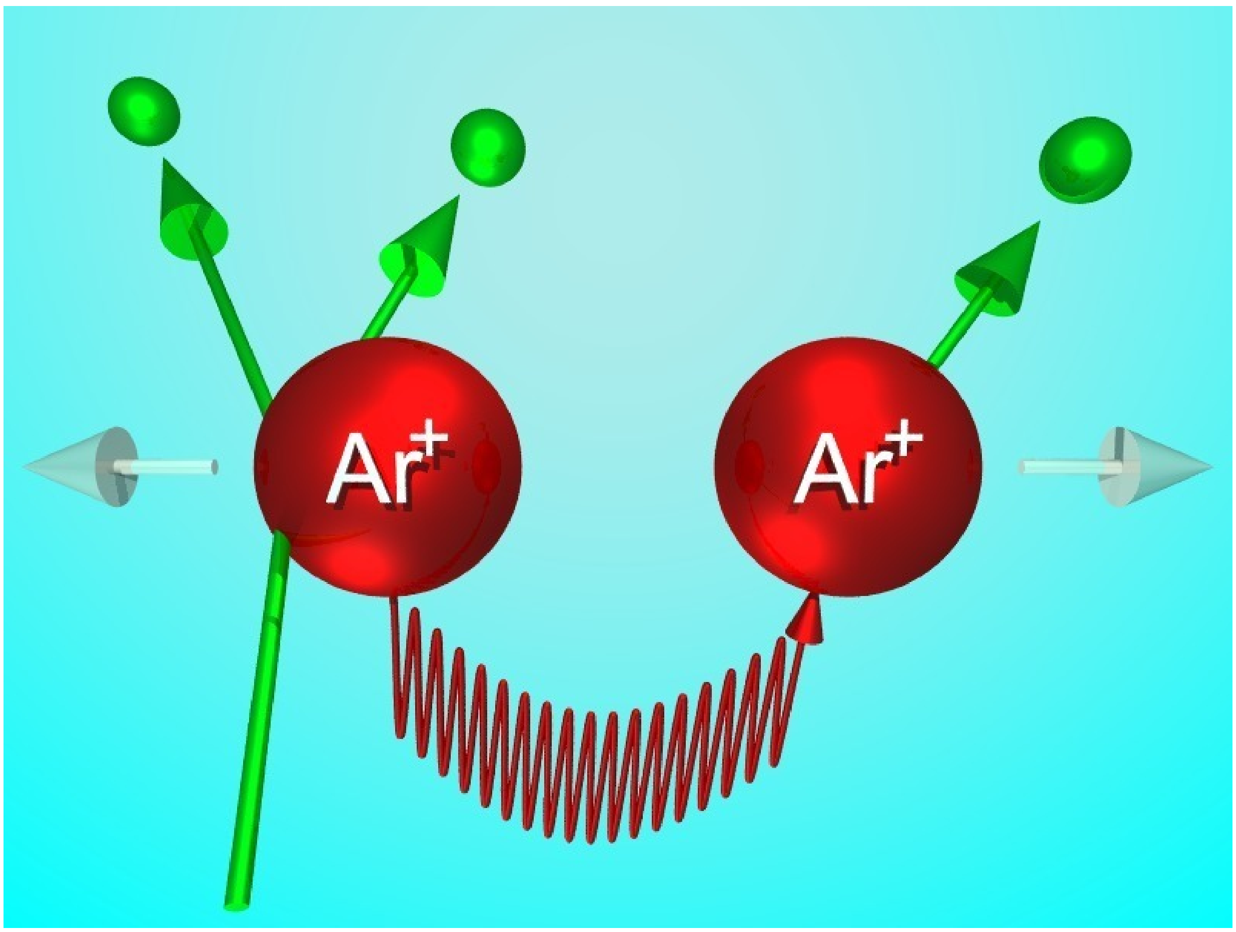
Detailed insight into radiation damage caused by slow electrons

March 31 2016



Protocol of a decay process: When an electron collides with an argon atom in a two-atom molecule (left), it knocks out a secondary electron and is deflected from its orbit as a result. The argon atom absorbs energy and transmits it to the other atom (red zigzag line). This atom is also ionized and the two argon ions repel each other. Two additional slow electrons arise in the process. The harmful impact of electron radiation, as arises in the case of radioactive beta decay, is multiplied in this way. Credit: Alexander Dorn/MPI for Nuclear Physics

Scientists can only offer a partial explanation of how radioactivity damages biological cells. The current research focuses on the effect of so-called secondary particles. When radiation penetrates the body, it knocks out electrons from the biological molecules. These collide with other biomolecules and damage them. The genetic molecule DNA is also affected by this process, which can result in cancer in extreme cases. However, radiation and the associated secondary particles are also used in the targeted destruction of cancer cells.

For a long time, researchers ignored slow electrons among these secondary particles because they do not have sufficient energy to ionize a molecule. However, since it became known that the slow electrons can nonetheless cause effective damage to DNA molecules, physicists have been carrying out more intensive research on the emergence of such secondary electrons. Researchers from the Max Planck Institute for Nuclear Physics in Heidelberg and their colleagues from the University of Innsbruck have studied a process for the first time in which an initially fast electron strikes a molecule and three secondary electrons arise. The volume of free electrons is tripled as a result. Because many of these electrons move slowly, the particle reactions that have now been observed could play an important role in the emergence of radiation damage.

The physicists in Heidelberg and Innsbruck headed by Xueguang Ren studied how secondary electrons form using a simple model system consisting of two weakly bound argon atoms. They fired electrons at what is called an argon dimer.

The argon dimer is veritably ripped apart by the collision with an electron. The electrically charged fragments – negative electrons and positive atomic cores – burst apart in the explosion-like process. Using a specially constructed reaction microscope, the Heidelberg-based scientists succeeded for the first time in measuring not only the energy of the flying ions, which is already possible with the current state of the art, but also that of the electrons, which are far more difficult to channel onto the detector due to their higher energy levels. Using the measured energies of all of the particles involved, the physicists were able to identify the reaction mechanisms in their model system and study the reactions in detail for the first time.

Two disintegration processes can be differentiated from each other

Similar to a billiard ball, the electron transfers part of its energy to its direct collision partner – one of the two argon atoms – and is deflected from its original path (oder: trajectory) in the process. The reaction partner loses an electron and becomes ionized as a result. At the same time, it is energetically excited, in other words it stores some of the energy. It then transmits this energy to the second argon atom which is then ionized too. Due to their positive charge, the two argon ions repel each other and distance themselves from each other. Thus, a total of five particles fly apart in an explosion-like process: the incoming (oder: projectile) electron, two argon ions and the two electrons released from the argon dimer. The entire process is referred to as interatomic Coulombic decay (ICD).

The research team in Heidelberg succeeded in differentiating the ICD from a second process, the radiative charge transfer (RCT). With the RCT, the first argon atom is doubly ionized, meaning it loses two electrons. It then receives one electron from the second argon atom which is also ionized as a result. The outcome is the same: the two ions and three electrons disperse from each other. However, the energy in the two reaction variants is distributed differently between the five particles.

The scientists in Heidelberg made an interesting discovery in relation to the ICD: the more energy the irradiated electron gives off to the argon atom, the more slowly the energy is transmitted to the neighbouring atom.

The number of harmful electrons is multiplied

The researchers established this in the following way: The argon dimer vibrates, so that the atoms move away from each other periodically and then move closer again. With slow energy transmission, due to the vibration, the distance between the atoms can change while the energy flows. With fast transfer, in contrast, the distance remains the same during the energy transfer, as there is no vibration during the short period.

The distance between the two argon atoms at the time of the reaction can be reconstructed from the energy of the dispersing argon ions. If this deviates from the equilibrium distance of the neutral argon dimer, a slow ICD has taken place; otherwise, it was a fast one.

The physicists in Heidelberg and Innsbruck carry out basic research focused on the study of the reaction mechanisms. Nonetheless, as team member Alexander Dorn notes, the new methodology is also of relevance for radiation biology. "Processes like the one we have studied multiply the number of relatively slow electrons that can cause biological damage," he reports. What's more: "In previous studies of a similar type, x-rays were guided onto model systems," he explains. "We have now examined irradiation with electrons." This is very close to reality, as radioactive rays on their path through the body release such electrons which would then collide with biologically active molecules.

More information: Xueguang Ren et al. Direct evidence of two interatomic relaxation mechanisms in argon dimers ionized by electron impact, *Nature Communications* (2016). DOI: 10.1038/ncomms11093

Provided by Max Planck Society