Slow electrons to combat cancer

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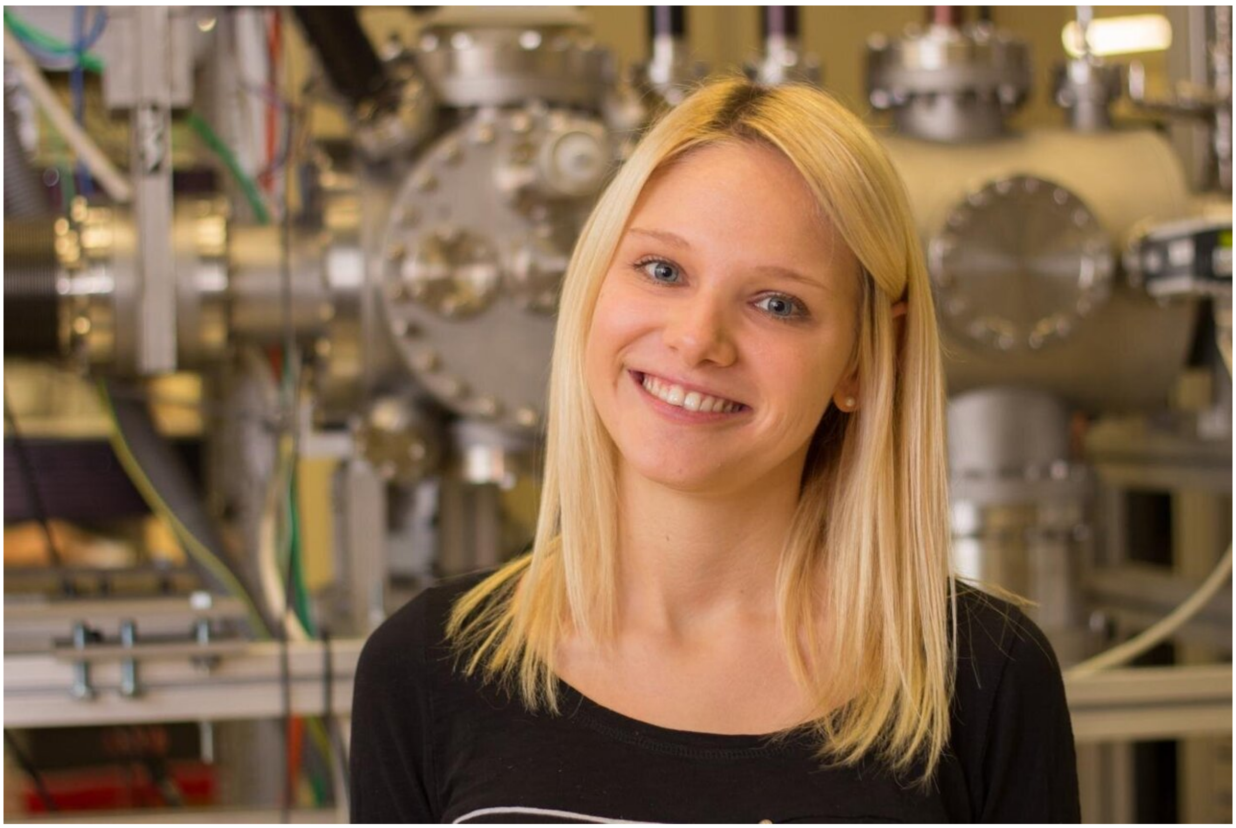

Janine Schestka. Credit: TU Wien

Ion beams are often used today in cancer treatment: this involves electrically charged atoms being fired at the tumour to destroy cancer cells. Although, it's not actually the ions themselves that cause the decisive damage. When ions penetrate through solid material, they can share part of their energy with many individual electrons, which then continue to move at relatively low speed—and it is precisely these electrons that then destroy the DNA of the cancer cells.

This mechanism is complex and not yet fully understood. Researchers at TU Wien have now been able to demonstrate that a previously little-observed effect actually plays a pivotal role in this context: owing to a process called interatomic Coulombic decay, an ion can pass on additional energy to surrounding atoms. This frees a huge number of electrons, with precisely the right amount of energy to cause optimal damage to the DNA of the cancer cells. In order to understand and further improve the particular effectiveness of ion therapy, this mechanism absolutely has to be taken into account. The results were recently published in the specialist publication *Journal of Physical Chemistry Letters*.

One fast particle—or lots of slow ones

When a charged particle penetrates a material at great speed—such as human tissue—it leaves a giant atomic mess in its wake: "This can trigger a whole cascade of effects," says Janine Schwestka, lead author of the recent publication, who is currently working on her dissertation in the team led by Prof. Friedrich Aumayr and Dr. Richard Wilhelm. When the ion moves through other atoms, these and other particles can become ionised, fast electrons fly around and then collide with other particles. Ultimately, a fast, charged ion can trigger a particle shower of hundreds of electrons each with much lower energy.

In everyday life, we are used to fast objects having more dramatic effects than slower ones—a football kicked with full force causes much more damage in a china shop than one that is gently rolled in. At an atomic level, however, this does not apply: "The likelihood of a slow electron destroying a DNA strand is much greater. Conversely, an extremely fast electron normally just flies right past the DNA molecule without leaving a trace," explains Janine Schwestka.

From one electron shell to another

The team from TU Wien recently took a closer look at an extremely special effect—namely, interatomic Coulombic decay. "The ion's electrons can assume different states. Depending on how much energy they have, they can be located in one of the inner shells, close to the nucleus, or in an outer shell," says Janine Schwestka. Not all possible electron spaces are occupied. If an electron shell in the medium energy range is free, an electron can then cross over to there from a shell with higher energy. This releases energy, which can then be passed to the material via interatomic Coulombic decay: "The ion transfers this energy to several atoms in the direct vicinity at the same time. One electron is detached from each of these atoms but because the energy is divided among several atoms we are talking about lots of really slow electrons," explains Schwestka.

Xenon and graphene

With the help of an ingenious experimental setup, it has now been possible to prove the efficacy of this process. Multiply charged xenon ions are shot at a graphene layer. Electrons from the outer xenon shells switch to a position in another shell with less energy, causing electrons to be detached from numerous carbon atoms in the graphene layer, which are then recorded by a detector, so as to measure their energy. "In fact, in this way, we were able to show that interatomic Coulombic decay plays a vital role in generating a large number of free electrons in the material," says Prof. Friedrich Aumayr.

In order to correctly describe the interaction of ion beams with solid materials or organic tissues, this effect absolutely must be taken into account. This is important, on one hand, for optimising ion beam therapies for treating cancer, but also for other important areas, such as protecting the health of space station crews, where you are exposed to constant particle bombardment from cosmic radiation.

More information: Janine Schwestka et al, Charge-Exchange-Driven Low-Energy Electron Splash Induced by Heavy Ion Impact on Condensed Matter, *The Journal of Physical Chemistry Letters* (2019). DOI: 10.1021/acs.jpclett.9b01774

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