New Phenomenon of Radioactivity

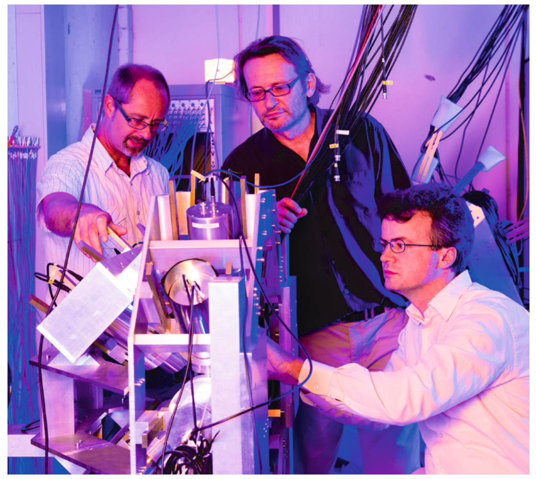

Photo: Katrin Binner

Norbert Pietralla, Thomas Aumann and Heiko Scheit (L to R) measuring gamma rays.

Physicists at the TU Darmstadt have succeeded in observing an extremely rare radioactive decay for the first time ever. The unusual thing about it is that this so-called double gamma decay of an excited nucleus state, which represents a higher order process, takes place although the first order process is not prohibited by the conservation of energy and momentum laws or quantum-mechanical selection rules.

By Christian Meier

EA team led by Associate Professor (PD) Dr. Heiko Scheit and Professors Norbert Pietralla and Thomas Aumann of the Institute for Nuclear Physics (IKP TU Darmstadt) has succeeded in detecting a radioactive phenomenon that is exceptionally difficult to observe. Radioactivity is in some sense similar to giving birth: an atomic nucleus emits a particle or a photon (radiation particle). On extremely rare occasions, a nucleus will produce twins, whereby two identical particles or photons are emitted from the nucleus of the atom at precisely the same time. Previously, this had only been observed in relation to double beta decay in which two electrons (positrons) and two anti-neutrinos (neutrinos) are emitted simultaneously, and double gamma decay, an analogous phenomenon involving high-energy gamma radiation. This process had already been predicted in 1930 by the later Nobel Laureate Maria Göppert-Mayer. Whenever a nucleus emits a photon, it undergoes a quantum jump, losing energy in the process. This energy is carried away by the emitted photon. In rare cases, as Göppert-Mayer predicted, the energy is distributed among two photons emitted simultaneously in the so-called double-photon decay process.

As Scheit explains, processes involving two photons, i.e. not only the decay but also the excitation of an atom, are now routinely observed and applied in the field of atomic physics. Until now, however, nuclear physicists have only succeeded in observing the double-gamma decay in three very special cases, in all of which the single-gamma decay is prohibited by quantum mechanical selection rules. This process has never been observed in cases in which simple gamma decay is allowed.

„Since the 1980s, all attempts to demonstrate double gamma decay in competition with normal single gamma decay have failed," Pietralla explains. There are instruments available that only register photons if they are ‚born' simultaneously, however, because a large number of nuclei in the tested samples decay at the same time, the actual phenomenon of interest, i.e., the emission of twin photons from a single nucleus, has been lost in the crowd, like a real pair of twins in a city of one million souls. In addition, it is possible for a photon to be registered by the first detector and, due to a scattering process at the speed of light, to arrive at the second detector within a few billionths of a second, where it is registered again. That can also mimic the presence of a twin particle.

The research team at the TU Darmstadt managed to solve both of these problems with newly developed gamma radiation detectors, funded by the German Research Foundation (DFG). The special property of these devices is that, not only can they determine the energy of a photon with extreme accuracy, they can also detect time differences of just a few hundred pico seconds (a few ten billionths of a second). Professor Pietralla's collaborator Dr. Christopher Walz and his colleagues constructed a ring of several of these detectors, in the centre of which they placed a substance, which emits gamma rays at a precisely determined energy level.

The detectors were triggered if they registered two photons within a very short timespan of just a few nanoseconds, whose combined energy equalled that of the quantum jump. And sure enough, they actually did succeed in detecting the twin photons using this method. „They come into existence at a rate of about one per million gamma decays," Pietralla reports. Because the time window is shorter than the time it would take a scattered photon to move from one detector to another at the speed of light, the physicists were able to exclude the possibility that their measurements were an artefact of the system set up. With the aid of his colleague Vladimir Ponomarev, Walz has also been able to provide a quantitative explanation for the measured values on the basis of a theoretical model. Incidentally, Christopher Walz was awarded the 2014 Dissertation Prizes of the TU Darmstadt and the European Physical Society for the discovery.

The Autor is a science journalist with a PhD in Physics

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The experimental proof has been published in the scientific journal „Nature":
http://www.nature.com/nature/journal/v526/n7573/full/nature15543.html.

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Cells in Motion

Materials scientist Ljubomira Schmitt and biologist Tobias Meckel are developing a device that can be used to culture cells under induced movements whilst simultaneously allowing them to be observed through a microscope. The technology could improve drug testing and obviate the need for certain experiments on live animals.

Photo: Katrin Binner

Demonstrator with piezo elements and cell culture medium.

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By Uta Neubauer

The cells in our bodies are continuously in motion. Even when we're lying on the sofa, our hearts are pumping blood through our veins, our stomachs are kneading our recent meals through our systems, and our respiration is causing our chests to rise and fall. Whilst the muscle cells in these processes actively move themselves, those in our connective tissues are stretched and contracted passively. As Tobias Meckel, an associate professor in the Department of Biology and Head of Research into Membrane Dynamics, explains: „in this sense the only places where these processes are in abeyance are inside the bones and the brain".

Movement stimuli promote the development of the correct connections both between individual cells and the surrounding tissues, because they transmit important information to the cells about their position and orientation. Movement, whether active or passive, influences the development, growth and behaviour of cells. „If one cultivates undifferentiated heart muscle cells under a specific movement stimulus," Meckel explains, „they'll develop into functioning heart muscle tissue. In the absence of the stimulus, or if it is too strong, then connective tissue is formed." It is, therefore, remarkable that experiments on cells – which are indispensable in fundamental biological research as well as in the cosmetics, food, and pharmaceutical industries – are usually performed on static cell cultures. It is true, as Meckel says, that biologists carrying out experiments on live cells pay meticulous attention to the composition of nutrient solutions, pH values and temperature. In addition, awareness of the fact that 3D cell cultures are better than the commonly used 2D cultures for simulating the processes taking place in our bodies is spreading steadily. Yet, most cell experiments still fail to take account of movement as a parameter. That could be about to change, thanks to an invention by Meckel and his colleague Ljubomira Schmitt. They are developing a device with which three-dimensional cell cultures can be exposed to controlled movement stimuli whilst simultaneously allowing them to be observed through a microscope.

Ljubomira Schmitt is a materials scientist and an expert in piezoelectric ceramics, who studied these materials, which deform in response to an electric voltage, for her doctoral thesis. Her current research activity is also focused in this area, in addition to which, she is studying biology. Two years ago, she attended a lecture by Meckel, concerning an experiment designed to shed light on the adhesion of cells to surfaces. The experimental set-up lacked any kind of dynamics, and Schmitt asked her lecturer how the cells might act in a dynamic system. Thus, the idea was hatched to develop a device with which this could be observed.

A demonstration prototype was constructed in a workshop at the TU Darmstadt based on a design by Meckel and Schmitt. Its core component consists of a cube-shaped silicon scaffold filled with a hydrogel of collagen, the main protein in human connective tissue. Within this hydrogel, the majority of which consists of water in which nutrients are suspended, the cells are able to grow three-dimensionally. A kind of mini trouser pockets on two sides of the cube contain piezo elements, which react to an electric voltage with a reversible deformation, either stretching or contracting, thereby distending or compressing the hydrogel. This distends or squeezes the cells growing in it. „By modifying the current, we can selectively vary the deflection and target any direction within the three-dimensional space," Schmitt explains. And that is not all. Because the system has been integrated into a standardised microtiter plate that fits into standard microscopes, the movement and growth of the cells can be observed in real time during the experiment. „Microscopy is not the issue," Meckel points out. „Using modern high-resolution technologies it is possible to view extremely small cell components and even the positions of individual molecules. But I'll never be able to use single molecule microscopy to analyse a liver or any other organ." That is why it is necessary to modify the research objects to fit the microscope technology and model body tissues as realistically as possible.

Photo: Katrin Binner

Tobias Meckel and Ljubomira Schmitt in the laboratory.

„If one cultivates undifferentiated heart muscle cells under a specific movement stimulus, they'll develop into functioning heart muscle tissue."

The system designed by Meckel and Schmitt can be used for mammalian cells as well as plant cells, micro organisms and other cell types. However, during the development phase, the Darmstadt scientists are initially concentrating on the cultivation of human cells and the demands of academic and industrial pharmaceutical research. Pharmaceutical producers always have to test potential new medical compounds on cell cultures and live animals before they are authorised for testing on human test subjects. Because analyses of 3D cultures are more realistic than traditional cell tests, Meckel and Schmitt's invention could cut costs within the industry, as unsuitable substances could be identified and rejected early on in the testing phase. Moreover, more meaningful and informative cell tests mean fewer experiments on live animals.

Not only have Meckel and Schmitt generated enthusiasm among their colleagues from other specialist disciplines, they also managed to secure funding from the Forum for Interdisciplinary Research (FIF; see infobox). The current plan is to miniaturise the device and optimise it for high throughput. This will be achieved in collaboration with Stefan Breuer, Head of the Semiconductor Workgroup in the Physics Department, and Professor Helmut F. Schlaak, Head of Micro-technology and Electromechanical Systems in the Electrical Engineering and Information Technology Department. In the course of the FIF-funded project, the Darmstadt researchers also want to reduce the production costs of the device, for example, by replacing the relatively expensive piezo elements with more cost-effective micro-actuators.

Meckel and Schmitt have already applied for a patent and now plan - with support from HIGHEST, the business incubator of the TU Darmstadt - to launch a company to which end they are looking for investors. They have discussed the potential of their concept with both small and major pharmaceutical companies and the feedback has been extremely positive. That is hardly surprising, as any device that can help save money and curb animal testing is high on the wish-list of the pharmaceutical producers.

The author is a science journalist and holds a doctorate in chemistry.

Funded interdisciplinarity

The Forum for Interdisciplinary Research (FIF) is a central body at the TU Darmstadt. In addition to organising talks, workshops and other events, the FIF also funds research projects in which scientists from different departments at the TU Darmstadt participate. Between November 2015 and December 2016 the FIF will be funding the project „Cell Cultures in Motion: high-resolution microscopic observations of actuated artificial cellular tissues", which was initiated by Ljubomira Schmitt (Materials and Earth Sciences) and Tobias Meckel (Biology), in collaboration with Prof. Helmut F. Schlaak (Electrical Engineering and Information Technology) and Dr. Stefan Breuer (Physics).

Other FIF-funded projects concern things such as paper houses for disaster victims, micro-hydro-electric units and robots designed to learn human movements such as golf-putting.

For more information about the FIF and all currently sponsored projects, see: www.fif.tu-darmstadt.de.

Ice in the Air

Markus Schremb and Daniel Kintea of the TU Darmstadt are carrying out research into causes of ice formation on aircraft during flight. Their experiments and realistic mathematical models are aimed at the minimization of risk and costs.

By Hildegard Kaulen

When Air France flight 447 crashed over the Atlantic in the night of the 1st of June 2009 en route from Rio de Janeiro to Paris, killing 228 passengers, nobody suspected that the catastrophe had been triggered by ice formation on the speed sensors. The autopilot had switched itself off in response to the ice-over and the flight control had transitioned to an alternative mode. Instead of initiating the standard operational procedure prescribed for this situation, the pilots made one mistake after the other. This led to a wing stall followed by a loss of lift, and the aircraft plunged into the ocean.

„If we can better understand the physics of surface icing and are able to replicate it in realistic mathematical models, then fewer expensive wind tunnel experiments should be required for the certification of new aircraft types."

Ice crystal accretion remains a serious hazard in aviation. For this reason, all new aircraft types need to prove, prior to approval, that they can continue to fly safely even under conditions of in-flight ice accumulation. This involves a complex and laborious certification process requiring expensive flight and wind tunnel testing. „There is only a handful of facilities in the entire world that are equipped for such tests," says Dr. Ilia Roisman of the Institute for Fluid Mechanics and Aerodynamics at the TU Darmstadt, who, together with Dr. Suad Jakirlic is supervising the work of Kintea and Schremb in this specialist field. Professor Dr. Cameron Tropea heads up the institute. „If we can better understand the physics of surface icing and are able to replicate it in realistic mathematical models," Roisman continues, „then the wind tunnel experiments required for the certification of new aircraft types should be less expensive." And this is precisely where the work of Schremb and Kintea comes in. Both of them are carrying out their research in the context of larger projects. Schremb is collaborating on SFB-TRR75, whilst Kintea is involved in the EU's HAIC project.

The scientists are researching two different kinds of ice accretion. Schremb is concerned with wing icing through supercooled water droplets during climbing and descent following take-off off and prior to landing, respectively. Kintea is researching the accumulation of ice in engines and on sensors when flying through ice crystal clouds at cruising altitudes. Without counter-measures, both types of ice accretion would have dramatic consequences for flight safety. Ice build-up on the wings changes the wing profile cross section. The growing ice layer increases the weight of the aircraft, reduces lift and increases drag. Without counter-measures, the aircraft consumes more fuel and may even become uncontrollable. Currently, heating the leading edge of the wings causes the ice layers to melt and fall off. Icing of the engines at high altitude blocks the airflow, which results in a loss of thrust and efficiency and, in the worst case scenario, to engine flame-out.

Airplanes come into contact with supercooled water when flying through low-lying clouds, because supercooled water droplets only exist in the subzero range down to approx. -20oC. Schremb is investigating the hydro- and thermo-dynamic processes at the point of impact and the freezing of supercooled droplets, in order to be able to model these processes. „When the supercooled droplets in the low-lying clouds come into contact with those parts of the aircraft profile directly exposed to oncoming air currents, then a portion freezes to ice immediately," Schremb explains. „Because latent heat is released upon freezing, the precise proportion of the droplet freezes that is necessary to equalize the supercooling," the mechanical engineer adds. „The remaining non-frozen part spreads across the wings in the form of a water film before it

Photo: Katrin Binner

Conducting experiments to increase flight security: Markus Schremb (left) and Daniel Kintea.

also freezes due to the low temperature of the underlying structure." Because the air temperature sinks with increasing altitude, and water only exists in the form of ice below approx. -40oC, ice accretion due to supercooled water droplets can only occur at certain flight altitudes.

Schremb is particularly interested in the crystalline structures formed during the freezing process, the so-called dendrites. He has been able to demonstrate that, whilst the crystallization front consists of a multitude of dendrites, these dendrites do not influence one another. According to Schremb, „a collection of dendrites freezes at precisely the same rate as any single dendrite. That is why it is only necessary to model the solidification front as a whole, rather than every single dendrite. That will significantly simplify the calculations." Schremb has also succeeded in demonstrating that the thermal properties of the surface influence the freezing process, specifically by way of the accretion angle of the solidification front. „If," he concludes, „it proved possible to maximise this angle by means of appropriate measures, then this would minimize the speed at which the surface would ice over. That would represent significant progress."

Daniel Kintea is investigating engine icing at high altitude. This problem can occur either when flying through ice crystal clouds or when flying over storm cells at cruising altitude. In this case, the ice-formation process begins on a warm surface. For many years this problem was not clearly recognized, because it was thought that the ice crystals would bounce off the cold parts of the engine and melt on the warm parts. However, under certain conditions a significant accretion of ice can occur. „That may sound paradoxical," says Kintea, „but even sand will stick to a sloped surface when it is wet." In the case of engine icing, ice crystals are ingested into the warm engines where they melt. The result is a mixture of water and ice, which adheres to the surfaces, just like wet sand. As these adhering particles melt, they further reduce the temperature of the metal until the freezing point is reached. Then the water film freezes on the surface to which the cold ice particles are stuck.

Sensors can also freeze over as a result of this same principle, as was the case with the Air France accident. Until now, pilots have attempted to circumvent ice clouds and storm cells, or else to descend to a warmer layer of air, in which the ice can melt. „We want to create precise models of these ice accretion processes," says Kintea, „in order to do so, we need to know what these ice particles look like in the air, how they behave, what drag they have, and how they melt. One fundamental assumption of previous models has been that these ice particles are spherical, and melt in the same way as a sphere. That is wrong."

To date, Kintea has modelled three processes: the melting of a single ice crystal; the collision, and the behavior of a porous ice layer. As the mechanical engineer explains; „whether ice particles bounce off or stick, depends upon the collision velocity, the surface tension, and the size and density of the ice particles. These four variables are combined in the non-dimensional Weber number. Below a critical Weber number, the particles stick." Kintea has also considered the physical phenomena associated with the melting of porous materials. His mathematical models represent reality far better than previous simplified and idealized models.

The author is a science journalist with a PhD in biology.

The Projects:
The acronym HAIC, under which the EU project is known, stands for „High Altitude Ice Crystals". The project is supported by a consortium of aircraft and engine manufacturers, universities and research institutes, and is aimed at a better understanding of the conditions and root causes under which high-altitude ice-formation occurs. More information is available at: www.haic.eu

Sections of the German Research Foundation (DFG) approved SFB-TRR75 collaborative research centre are located at the TU Darmstadt, the University of Stuttgart and at the German Aerospace Center (DLR) in Lampoldshausen. Its official title is „Drop dynamic Processes under extreme ambient conditions". More information is available at: www.sfbtrr75.de

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D. Kintea, T. Hauk, I. Roisman, C. Tropea: Shape evolution of a melting nonspherical particle, DOI: 10.1103/PhysRevE.92.033012

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Order in Air Vortex

Turbulence makes life difficult for the designers of cars or aircrafts. It cannot be simulated with absolute precision. Martin Oberlack, head of institute of Fluid Dynamics wants an original solution to the problem.

Martin Oberlack, Professor for Computational fluid dynamics

Photo: Katrin Binner

By Christian Meier

Albert Einstein grins impishly from a poster on the wall in Professor Martin Oberlack's office. Perhaps the genius already knew decades ago that his thinking would lend wings to machine construction engineers like Martin Oberlack and help them to solve apparently unsolvable problems involving aerodynamics. Martin Oberlack explains the problem troubling aircraft and car manufacturers using a diagram hanging on the wall in the corridor of the institute of Fluid Dynamics on the Darmstadt Lichtwiese.

It looks like a brightly coloured abstract painting: a 5-metre long strip with smooth, even brush strokes dominating the left edge that become increasingly chaotic as they approach the right. In fact, it's almost as if the artist became less and less controlled as work progressed. But it's not a work of art. „It's a computer simulation of turbulence," says Professor Oberlack, and displays the vortices of air flowing over a flat panel. The vortices increase towards the right, that is as the gap to the panel increases. „That's why Business Class is at the front of an aircraft," he explains. Vortices at the back of the aircraft make that area noisier, adds the machine construction engineer.

Noise isn't the only annoyance caused by turbulence. Vortices also cause air resistance, or drag, which increases fuel consumption. So the shape of a vehicle or aircraft should cause as few air vortices as possible. To establish the best shape, the developers experiment with various different versions in wind tunnels. Computers are also used to help with the design. All this effort, and it's still not quite enough. „Even the most powerful supercomputers in Germany can't simulate turbulence with absolute precision," explains Martin Oberlack. Why not: the less viscous a medium is, the tinier the tiniest vortices are. However, if you want to simulate the occurrence on a computer, it is needed to take vortices of all sizes into account.

Engineers are not interested in every single tiny vortex in the airflow, but in statistical sizes such as the average speed in the air at different distances from the surface, because air resistance can be calculated from this profile. „The tiniest differences in the speed profile matter," he says.

"Even the most powerful supercomputers in Germany can't simulate turbulence with absolute precision."

However, the subtle differences in the statistical values can only be derived from a complete simulation of the chaotic event – just as it takes lots of individual opinions in order for the results of a survey to be precise and reliable. This requires computers with vast memories and unimaginable computing speeds. And even though supercomputers are getting ever-faster and their memories ever-bigger, „It's still going to be about 50 years before they can calculate turbulence with a precision that eliminates the need for expensive experiments in wind tunnels," he adds.

In order to reduce computing time, the developers simplify their mathematical models using empirical assumptions that are based on experiments, but that makes the simulations inaccurate. „To an airline, though, the tiniest differences in kerosene consumption matter," he emphasises. And although there is a huge gap between this requirement for exact results and the precision of the simplified simulations, Martin Oberlack doesn't seem to be losing any sleep over it. That's because the gap defines his playing field. He and his 20-strong team are the only people in the world who are ploughing it with a new method. And they have solutions to offer.

So how did that come about? Professor Oberlack has worked closely with physics since the 1990s, at the renowned Stanford University in the USA. A blackboard in his office is covered in formulas known as differential equations. Most of the books in his office are also on this subject. They describe turbulences mathematically, and they are heavy stuff.

And this is where Einstein comes in. „He realised how important symmetries are in physics," says Martin Oberlack. Symmetry exists when rotations, movements or other operations change nothing in the physical description of the system. A merry-go-round, for instance, looks the same on all sides, and in a spruce mono-culture it is not easy to tell whether you are in spot X or 100 metres east of it.

Symmetries make it much easier to solve complex equations. Oberlack's team uses them to simplify the equations used to describe turbulence so that deriving the statistical values is easier and more precise. This enables the team to produce more exact calculations of average speeds.

All well and good. But isn't turbulence the same as chaos – the absence of symmetry? Oberlack considered this question for a long time before carefully replying. It's a hidden kind of symmetry. A comparison illustrates it more clearly. When you pour milk into a cup of coffee, it creates a random, chaotic pattern. However, if you take photos of lots of these patterns and stack them, then the result is an even milky-coffee brown. The statistical observation turns chaos into symmetry.

There is a similar effect in airflow: The speed of the air fluctuates as it travels just over the surface of a body, such as an aircraft fuselage. However, this fluctuation keeps stopping for short periods of time. These breaks in the chaos are called intermittencies, and appear to be random. However, if their occurrence is evaluated statistically, this reveals regularities in their frequency and duration. In the statistics, the values are often distributed evenly around a mean value, such as the size of a body. Although the distribution of the intermittencies isn't quite that symmetrical, more complex symmetries do exist. „They can be used to determine statistical sizes such as air resistance," explains Martin Oberlack.

Now his team wants to integrate his findings in simulation models in order to make the calculations more precise. Based on preparatory work by Dr. Marta Waclawczyk, a former colleague of Martin Oberlack who is now a researcher at the University of Warsaw, the doctoral candidate Andreas Zieleniewicz is working on them. However, Oberlack has little hope that the optimum designs for vehicle chassis or aircraft fuselages will be spilling forth from the computer any time soon. „So far, our method has only worked on basic systems," he says, including tunnel or pipe flows.

However, the machine constructor with a passion for physics is quick to emphasise that this is all basic research. But the team of scientists is researching further symmetries in the apparent chaos that could make their method more powerful, and therefore of interest for complex industrial applications. Although these symmetries do exist, they are too complex to be fully understood, explains Oberlack. „We have the justified hope that we will come to understand them." The Darmstadt researchers' unfaltering curiosity could soon be used on aircraft.

The author is a science journalist with a PhD in Physics.

Turbulence - a mega challeng:
Turbulence is a wild event that is very difficult to simulate on a computer. This is because it involves vortices of different sizes that all need to be taken into account. The complexity increases as the viscosity of the medium decreases. Stirring honey does not cause the same kind of tiny vortices in the air as occur when it is sliced through by a car or aeroplane. In order to still become master of the chaos, a team of researchers under Professor Martin Oberlack at the TU Darmstadt are seeking order in it. And they'll find it.

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