A Quantum of Energy

Electrons that circle around a positively charged nucleus on stable orbits? When Niels Bohr presents his new model of the atom in 1913, many colleagues shake their heads. Shortly afterward, a successful proof is put forward: **James Franck**, who will later become a department head at the **Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry** in Berlin-Dahlem, and his colleague Gustav Hertz receive the 1925 Nobel Prize in Physics for this work. Initially, though, the two have no idea just what they have discovered here.

TEXT **ELKE MAIER**

April 1940. In Niels Bohr's laboratory in Copenhagen stands 54-year-old chemist George de Hevesy, holding a Nobel Prize medal in his hand. It belongs to Jewish physicist James Franck. To keep it safe from the Nazis, Franck had entrusted it to his friend and colleague Bohr, and he, in turn, had given it to de Hevesy.

Particles on a collision course: James Franck (left) and Gustav Hertz studied collisions between electrons and atoms.

The Germans had now occupied Denmark and were already marching through the streets of the capital. There was no time to lose. De Hevesy pours aqua regia over the prestigious medal and waits until the corrosive mixture of concentrated hydrochloric and nitric acid has dissolved the metal. When the occupying powers turn the laboratory upside down, the beaker with its precious contents stands unnoticed among numerous others.

The gold is later handed over to the Royal Swedish Academy of Sciences, which has a new medal minted from it. On January 31, 1952, James Franck is able to receive the coveted honor for a second time – for an experiment whose significance he and his colleague Gustav Hertz were initially unable to fully appreciate. But first things first.

James Franck is born in Hamburg on August 26, 1882. He is the second child of banker Jacob Franck and his wife Rebecca. James is to receive a classical education at the high school he attends, the Wilhelm Gymnasium. However, he has no appreciation for ancient languages and is thus deemed to "show little promise" as a student. He is much more interested in connections: even at an advanced age, James Franck remembers a eureka moment during his Greek class when he suddenly realized why a grease spot in his exercise book "makes the opaque paper translucent."

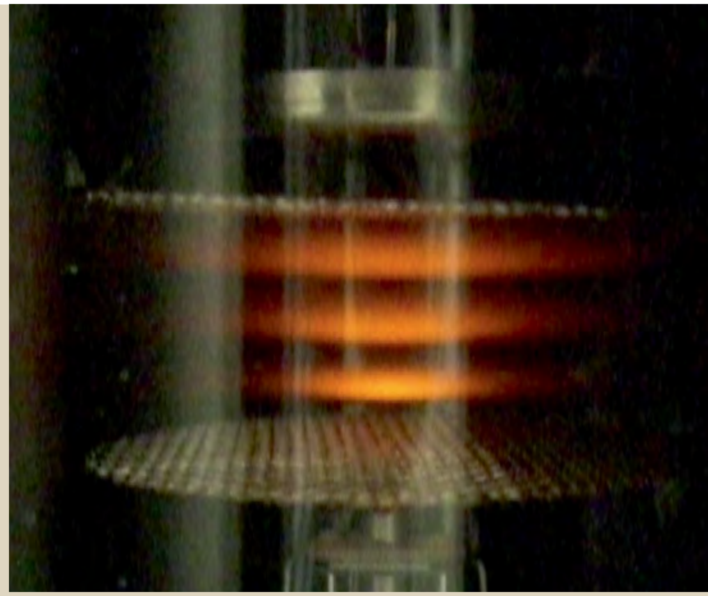
Following high school – where he had to repeat a year – he enrolls at Heidelberg University to study economics and law for his father's sake. Only later does he assert himself and switch to chemistry and then finally to physics. His new place of study, Berlin, is the top choice for this and the center of attraction for the most influential physicists of the time, among them Heinrich Rubens, Emil Warburg and Max Planck, and later also Paul Drude and Albert Einstein. Franck completes his doctorate in 1906 at the Physics Institute of Berlin University on the mobility of ions in gas discharges and becomes a research assistant there.

Also working at the same Institute is Gustav Hertz, who is five years his junior and whose uncle Heinrich Hertz – after whom the unit of frequency is named – had discovered electromagnetic waves, a major key to communications technology. James Franck and Gustav Hertz become friends and launch a joint project to study the interaction between atoms and electrons.

The apparatus consists – in simplified terms – of a glass flask filled with mercury gas. Inside are a negatively charged thermionic cathode and a positive anode, with a voltage applied between them. This causes electrons to be continuously emitted at the cathode and accelerated toward the anode. En route, they collide with the mercury atoms. As soon as the electrons reach the anode, the researchers measure their speed. In this way, they aim to determine how much kinetic energy the electrons have lost through the collisions with the gas atoms.

The scientists observe the following: If a low voltage is applied, the electrons hurtle toward the finish with their speed unchanged. If the electron energy reaches 4.9 electronvolts (eV), the speed of the arriving electrons approaches zero, and in a darkened room, a thin luminescent band appears just in front of the anode. If the voltage is increased further, the electrons speed up again, and the luminescent band moves toward the cathode. At twice the critical value, the speed is suddenly zero, and a second luminescent band is formed, a third one at triple the value – and so on and so forth.

Photos: Wikimedia Commons



Band by band: The gas atoms emit the energy they have received from the electrons in the form of light. In the experiment shown here, mercury gas was replaced with neon, which produces an orange glow.

What was happening here? In their 1914 publication, James Franck and Gustav Hertz write that an energy of 4.9 eV ionizes the mercury atom, or in other words, ejects an electron from its shell – a mistake, as it would turn out. What the two had overlooked in their zeal was that, just a few months prior, Niels Bohr had presented a theoretical model of the structure of the atom that fit their observation perfectly.

In his publication, Bohr describes a kind of miniature planetary system in which electrons circle around a positively charged nucleus on stable orbits. These orbits – so-called shells – have fixed separations from each other. If one now wants to move an electron from one shell to the next (further out), a very specific amount of energy is required that depends on the species of the atom. Niels Bohr, who knew all about "the wonderful experiment of Franck and Hertz," guessed that this amount was precisely 4.9 eV in the case of mercury. He would be proved right about this.

Without knowing it, Franck and Hertz had proved that electrons can be excited only by the right quantum of energy – one of

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» The Nazis didn't yet dare to attack Nobel laureate James Franck, one of the most noble minds among the not always noble nuclear physicists, because he was too well known. The upstanding man resigned in April 1933 to make a point and out of solidarity […]

the key statements of Bohr's theory. If the amount of energy is too low, electron and atom collide without an energy transfer taking place. The electron transfers its energy to the atom only when the critical threshold of 4.9 electronvolts is reached. After such a collision, the electron is initially at rest before being accelerated again by the voltage – and it again passes on the energy it collects in the process upon reaching 4.9 eV. The luminescence is caused by the atom re-emitting the absorbed energy in the form of light.

Only later do the two scientists realize how crucial their experiment was: "It was as if a researcher wanted to explore unknown territory and realized that he already had a complete map of this territory in his hands without knowing it," Franck writes in retrospect. James Franck and Gustav Hertz receive the 1925 Nobel Prize in Physics for their experiment.

In April 1914, Gustav Hertz presents the results at a meeting of the German Physical Society in Berlin. Just over three months later, World War I starts. James Franck enlists. Like Gustav Hertz, he is sent to the front to work under Fritz Haber in gas warfare. Both are later also assigned to the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin-Dahlem. One of their tasks is to test whether gas masks are fit for purpose using themselves as guinea pigs.

Between 1917 and 1921, James Franck works as a department head at the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin under Director Fritz Haber. He then switches to the University of Göttingen as a professor of experimental physics. In 1933, he is supposed to become Director of the Physics Institute at Berlin University, but this never happened.

On January 30, 1933, Adolf Hitler becomes Reich Chancellor, and a few weeks later, the "Law for the Restoration of the Professional Civil Service" comes into force. It states that civil servants of non-Aryan descent are to be retired. Although James Franck, as a former front-line soldier, is exempt, he can't accept the affront. He resigns voluntarily out of protest, but hardly any of his colleagues demonstrate solidarity with him.

In the same year, he and his family leave Germany. Franck spends more than a year as a visiting scientist with Niels Bohr in Copenhagen, takes on a professorship at Johns Hopkins University in Baltimore, then moves to the University of Chicago in 1938. During World War II, he is part of the team there working on the Manhattan Project to develop the atomic bomb. When he learns that the bomb is to be used against Japan even after Nazi Germany has capitulated, he takes a stand. Together with six other scientists, he draws up a memorandum that will go down in history as the Franck Report and speaks out against the use of the atomic bomb in Japan.

In the report, the researchers draw attention to the danger of a nuclear arms race and advocate demonstrating the destructive force of the new weapon in an uninhabited area instead of attacking Japan. Their appeal goes unheeded. On August 6, 1945, the bomb explodes over Hiroshima, and three days later, Nagasaki is hit. Japan capitulates.

After the war, James Franck focuses his research activities on the field of photosynthesis, a process in which solar energy is absorbed and conserved in the form of a chemical bond. The scientist thus remains true to his favorite topic: the energy transfer between atoms and molecules. After the war, Gustav Hertz is obliged to work as a specialist for the Soviet atomic bomb project; on his return in 1955 he takes over the management of the Institute of Physics at Leipzig University. He is the only Nobel laureate to live and work in East Germany. Franck dies at the age of 81 during a visit to Göttingen, and Hertz at the age of 88 in East Berlin.

The Franck-Hertz experiment is now one of the classical experiments in physics. Teachers like to demonstrate it in physics lessons as important support for Bohr's model of the atom and proof of quantum theory.