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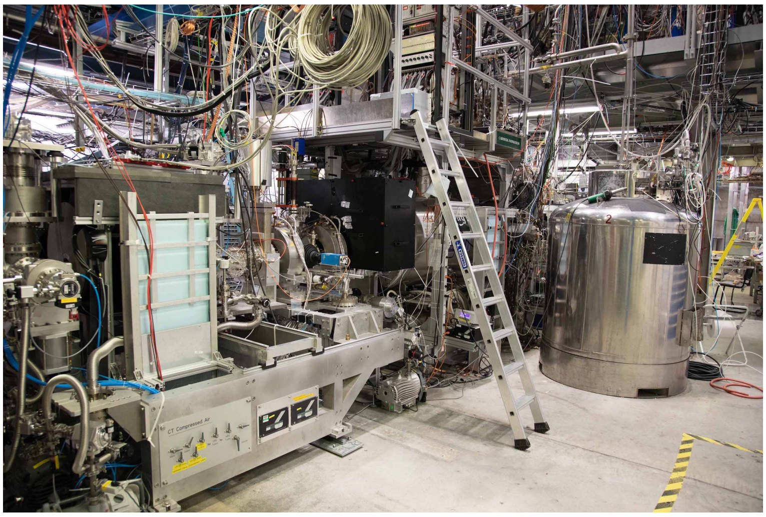
HOW ANTIMATTER FALLS DOWN



The ALPHA experiment scientific collaboration at CERN, whose members include INFN (the Italian Institute for Nuclear Physics), managed to make the first direct observation of the effects of gravity on the motion of antihydrogen atoms during the 2022 data run. The results were published in the journal *Nature* on 28 September. This is the first measurement of gravitational interaction between matter and antimatter, in this case antihydrogen atoms, in the Earth's gravitational field. The value obtained is compatible, within the limits of experimental error, with the predictions of general relativity.

“Although the gravitational interaction between matter and antimatter has been the subject of theoretical speculations since the discovery of the latter in 1928, it is the first time that an experiment has proven sensitive to the effects of gravity on antimatter atoms, in particular antihydrogen”, **Germano Bonomi**, professor at the University of Brescia, associated with INFN and member of the ALPHA Collaboration, points out. “The Antimatter Factory community at CERN has been working on this measurement for almost two decades and so, as ALPHA Collaboration, we are very happy to have finally succeeded”, Bonomi concludes.

In the experimental apparatus used for the measurement, called ALPHA-g, once the antihydrogen atoms are created, they are trapped, thanks to a magnetic field, in a vertical trap between two barriers that respectively determine the lower and upper barriers of magnetic potential. The experimental strategy is based on balancing the gravitational force with the magnetic one and is conceptually simple: trap and accumulate antihydrogen atoms in the desired region, before releasing them slowly, lowering the upper and lower magnetic potentials of the vertical trap, and then trying to measure any influence of gravity on their movement when they escape and are annihilated on the apparatus walls. The effect of gravity is shown as a difference between the number of annihilation events and the antiatoms that escape through the upper or lower part of the trap. Considering the statistical and systematic errors, mainly deriving from the precision with which the magnetic fields were measured at the reels and the uncertainties relating to the simulation of the dynamics of the antiatoms in the magnetic trap used as a comparison, a downwards gravitational acceleration of 0.75 ± 0.13 (stat. + syst.) was estimated, ± 0.16 (simulation) of the value of g.

“It was exciting to participate in this research, and in a laboratory like CERN where you find the best scientists in the world”, **Marta Urioni**, PhD student of the University of Brescia and member of the ALPHA Collaboration, observes. “I was able to contribute both to the experimental phase of data collection, and to that of the analysis, by extraction, of the result that, within the limits of experimental error, is in line with that expected by General Relativity”, Urioni concludes.

There are theoretical scenarios that predict a violation, though very small, of the gravitational acceleration between matter and antimatter. Since these scenarios exist, after having determined the sign and approximate quantity of the acceleration, the next years will be dedicated to improving the experimental measurement.

"The level of precision is not yet great enough to say something new about gravity in relation to what we already know", explains **Simone Stracka**, INFN researcher in Pisa and member of the ALPHA Collaboration. "In the future, the challenge will be to verify, with greater precision, the theoretical predictions. In addition to our ALPHA Collaboration, other experiments at CERN, like AEgIS and GBAR, are also advancing this type of research and so we expect more progress soon", Stracka concludes.

The theory

Every body falls towards the centre of the Earth, irrespective of its mass and composition, with the same acceleration (g ~ 9.81 m/s^2). Introduced for the first time by Galileo and Newton, this concept was verified over the centuries with a very high degree of precision. In 1915, Einstein adopted this concept as one of the fundamental principles of general relativity. It is the so-called weak equivalence principle. In another form, it can be expressed by stating that gravitational mass and inertial mass have exactly the same value. In other words, the motion of a body inside a lift pulled upwards with an acceleration equal to g and far from any celestial body is indistinguishable from that of a body subject to the Earth's gravitational field. This implies that the gravitational force, unlike, for example, the electrical one, is only attractive. But what happens when you consider antimatter?

Antimatter was theorised by Dirac in 1928, 13 years after the general theory of relativity, and was discovered in cosmic rays a few years later. In the following decades, we found out that, for every known particle (like, for example, the electron and proton present in the hydrogen atom), there exists, in nature, an "anti" particle, with the same mass but with opposite charges (and other quantum numbers). At the end of last century and at the start of our own, in an experimental complex called the "Antimatter factory" at CERN consisting of a system of particle decelerators (AD and ELENA), scientists managed to create the first antihydrogen atoms (composed of an antiproton and a positron, i.e., an antielectron), and, subsequently, to trap them to study their properties.

The experiment

The experiment was repeated many times, setting different magnetic field values between the upper and lower barrier, with differences of nominal multiples of 4.53x10^{-4} T. Considering that the barriers are 25.6 cm apart, , a difference in magnetic fields equal to this value determines the same gravity effect on the antiatoms present in the trap. The various configurations were, thus, indicated with multiple numbers of g. For example, if the magnetic field of the upper barrier is less than that of the lower barrier by a value of 4.53x10^{-4} T, this experiment is classified as a measurement with a bias of -1 g. By slowly lowering, over 20 seconds, the upper and lower barriers and keeping the bias constant, the annihilations of the antiatoms that slowly escape from the electromagnetic trap are reconstructed thanks to a vertex detector. Overall, approximately 2,000 events were used during a data run that lasted a month. The effect of the difference in magnetic field between the upper and lower barrier is clearly visible in the distributions of the vertical coordinate of the annihilations for the different biases. Qualitatively, the number of annihilations of antiatoms that exit downwards is equal to that of annihilations upwards for the configuration with a bias of -1 g. When, instead, the barriers, while being lowered, are kept at the same level, more annihilations are noted downwards than upwards. In short, you clearly see that the antihydrogen atoms tend to fall downwards in Earth’s gravitational field.