Theory of the strong interaction verified

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Supercomputer JUQUEEN. Credit: Forschungszentrum Jülich

The fact that the neutron is slightly more massive than the proton is the reason why atomic nuclei have exactly those properties that make our world and ultimately our existence possible. Eighty years after the discovery of the neutron, a team of physicists from France, Germany, and Hungary headed by Zoltán Fodor, a researcher from Wuppertal, has finally calculated the tiny neutron-proton mass difference. The findings, which have been published in the current edition of *Science*, are considered a milestone by many physicists and confirm the theory of the strong interaction. As one of the most powerful computers in the world, JUQUEEN at Forschungszentrum Jülich was decisive for the simulation.

The existence and stability of atoms relies heavily on the fact that neutrons are slightly more mas-sive than protons. The experimentally determined masses differ by only around 0.14 percent. A slightly smaller or larger value of the mass difference would have led to a dramatically different universe, with too many neutrons, not enough hydrogen, or too few heavier elements. The tiny mass difference is the reason why free neutrons decay on average after around ten minutes, while protons - the unchanging building blocks of matter - remain stable for a practically unlimited period.

In 1972, about 40 years after the discovery of the neutron by Chadwick in 1932, Harald Fritzsch (Germany), Murray Gell-Mann (USA), and Heinrich Leutwyler (Switzerland) presented a consistent theory of particles and forces that form the neutron and the proton known as quantum chromodynamics. Today, we know that protons and neutrons are composed of "up quarks" and "down quarks". The proton is made of one down and two up quarks, while the neutron is composed of one up and two down quarks.

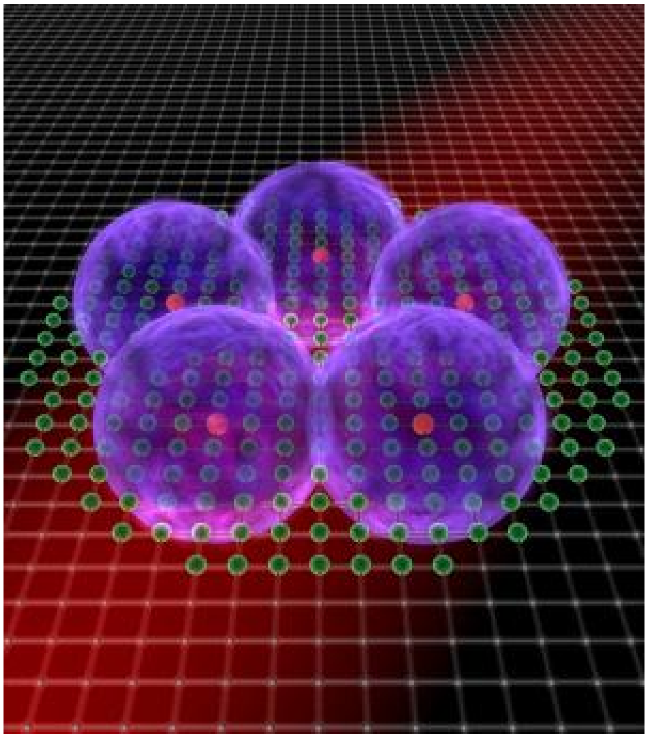

Illustration of a Rydberg quantum crystal. The atoms (green) are regular arranged on an optical lattice. When laser light couples the ground Rydberg states, all but a few excitations (red) are suppressed due to the strong Rydberg state interactions. These excitations are strongly correlated (illustrated in the blue spheres) and arrange themselves to form Rydberg crystal. Credit: Immanuel Bloch

Simulations on supercomputers over the last few years confirmed that most of the mass of the proton and neutron results from the energy carried by their quark constituents in accordance with Einstein's formula E=mc2. However, a small contribution from the electromagnetic field surrounding the electrically charged proton should make it about 0.1 percent more massive than the neutral neutron. The fact that the neutron mass is measured to be larger is evidently due to the different masses of the quarks, as Fodor and his team have now shown in extremely complex simulations.

For the calculations, the team developed a new class of simulation techniques combining the laws of quantum chromodynamics with those of quantum electrodynamics in order to precisely deter-mine the effects of electromagnetic interactions. By controlling all error sources, the scientists suc-cessfully demonstrated how finely tuned the forces of nature are.

Professor Kurt Binder is Chairman of the Scientific Council of the John von Neumann Institute for Computing (NIC) and member of the German Gauss Centre for Supercomputing. Both organizations allocate computation time on JUQUEEN to users in a competitive process. "Only using world-class computers, such as those available to the science community at Forschungszentrum Jülich, was it possible to achieve this milestone in computer simulation," says Binder. JUQUEEN was supported in the process by its "colleagues" operated by the French science organizations CNRS and GENCI as well as by the computing centres in Garching (LRZ) and Stuttgart (HLRS).

The results of this work by Fodor's team of physicists from Bergische Universität Wuppertal, Centre de Physique Théorique de Marseille, Eötvös University Budapest, and Forschungszentrum Jülich open the door to a new generation of simulations that will be used to determine the properties of quarks, gluons, and nuclear particles. According to Professor Kálmán Szabó from Forschungszentrum Jülich, "In future, we will be able to test the standard model of elementary particle physics with a tenfold increase in precision, which could possibly enable us to identify effects that would help us to uncover new physics beyond the standard model."

More information: Ab initio calculation of the neutron-proton mass difference, www.sciencemag.org/lookup/doi/ … 1126/science.1257050

Provided by Forschungszentrum Juelich