wraps, and the altered conformation seems to cause genes to turn on or off. But that takes place on the scale of minutes, not seconds. And no one has yet identified a molecular trigger for the unwrapping. "The million dollar question," says Wigge, "is whether the release or uptake of Ca^{2+} from pectin also signals gene expression."

Di Giacomo, Daraio, and Maresca are more interested in the practicality of their new material. Although inexpensive, scalable in size, and exceedingly sensitive, cyberwood is tricky to calibrate in devices—a thermal camera, for example—because of the natural complexity of plants. Porosity, surface charge, and pH all influence the transport of ions within a cell wall. To work around the difficulty, the researchers plan to build devices from only extracted pectin and nanoparticles.

Mark Wilson

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The neutron and proton weigh in, theoretically

By adding electromagnetic effects to quantum chromodynamics calculations, theorists have achieved a leap in accuracy.

The mass difference between the neutron and proton—about 0.14%—is known experimentally with an impressive precision of 4 parts in 10 million. But calculating that difference from scratch via quantum chromodynamics (QCD), the theory of the strong force, is another matter altogether.

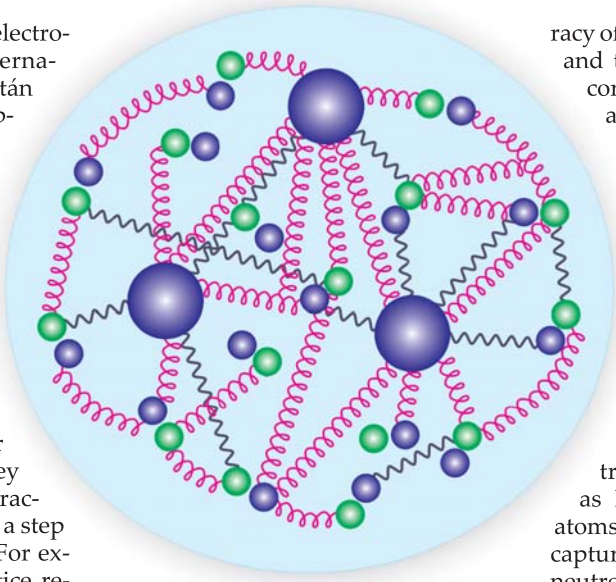
The simplest description of neutrons and protons posits them as bound states of three "valence" quarks (up, up, down for protons and up, down, down for neutrons). Analogous to the way photons mediate the electromagnetic force between charged electrons, gluons mediate the strong force between quarks, which carry color charge. (See the article by Frank Wilczek, PHYSICS TODAY, August 2000, page 22.) But unlike neutral photons, gluons also carry color charge and therefore interact with each other. One consequence is that perturbation theory, so successful for quantum electrodynamics (QED), fails spectacularly for QCD at the GeV energy characteristic of neutrons and protons.

In lattice QCD, spacetime is discretized into a four-dimensional lattice with quarks at each lattice site. Gluon interactions connect only quarks on neighboring sites, which makes the problem tractable for numerical calculations. (See the article by Carleton DeTar and Steven Gottlieb, PHYSICS TODAY, February 2004, page 45.) But a closer look inside a neutron or proton, whose complexity is indicated by the figure, reveals a roiling sea of virtual quark–antiquark pairs and gluons, which can give even modern supercomputers indigestion. To complicate matters, those sea quarks and antiquarks, like the valence quarks, also interact electromagnetically.

Theorists have dealt with the resulting computational difficulties by resorting to such approximations as including only two or three of the six types of quarks, assigning equal mass to the up and down quarks, or ignoring electromagnetic effects. Now an international collaboration led by Zoltán Fodor at the University of Wuppertal in Germany has calculated the neutron and proton masses with a precision of 0.03%, and thus has made the most accurate theoretical determination of their difference to date.[1]

In simulations that produced a combined 60 terabytes of data, the researchers used four types of quarks: up, down, strange, and charm, each with a different mass. Crucially, after a series of QCD-only runs, they turned on electromagnetic interactions in the quark–antiquark sea, a step that was easier said than done. For example, the finite-sized QCD lattice requires imposing boundary conditions on the long-range electromagnetic interactions. The team had to figure out how to control the large artifacts that can crop up when applying those boundary conditions. "The theoretical approach, the algorithmic steps, which were developed for the strong interaction, had to be reworked," says Fodor. In all, the group combined 41 independent simulations to reach the final result.

The new calculation wasn't just a computational feat. The results revealed in detail a competition between electromagnetic effects and the mass difference between the up and down quarks. That the up quark is lighter than the down quark increases the neutron's mass relative to the proton's, whereas the QED contribution does the opposite.



The neutron and proton, in addition to having three valence quarks (larger balls), are filled with a virtual sea of gluons (red springs) and quark (purple)–antiquark (green) pairs. The quarks and antiquarks also interact electromagnetically by exchanging photons (gray wavy lines).

"For the first time, all effects have been included and controlled to the first nonvanishing order in the fine structure constant," says Thomas Blum of the University of Connecticut. Important next steps, he says, are to improve the accuracy of the calculated light quark masses and to apply similar electromagnetic corrections to other phenomena such as the decay of kaons, which pair strange quarks or antiquarks with up or down antiquarks or quarks. Observations of kaon decay in 1964 led particle physicists to discover a fundamental symmetry-breaking process called charge–parity violation.

Fodor and his collaborators think their findings also have important implications for cosmology. "Imagine that the electromagnetic coupling was twice as large," he explains. "Hydrogen atoms would collapse through electron capture." In the other direction, if the neutron–proton mass difference were much larger than it is, faster neutron beta decay would have left the universe with far fewer neutrons at the end of Big Bang nucleosynthesis. Stellar fusion of hydrogen and the production of heavy elements would be more difficult.

Robert Jaffe of MIT agrees. "How finely tuned do the parameters of the standard model have to be for complex structures like human observers to form?" he asks. "Only lattice quantum field theory can explore questions like this."

Sung Chang

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Remarkable gravitational lensing by the galaxy cluster Abell 3827

The distorted image of a background galaxy may be a record of frictional dark-matter interactions.

Most of the matter in the universe, according to the standard cosmological model, is invisible stuff whose nature is unknown. Dark matter interacts gravitationally but as far as we know is not subject to the electromagnetic or any other interaction. Gravity is enough, however, to ensure that a spherical halo of dark matter surrounds a galaxy's shining stars. Evidence for dark matter has accumulated from several sources; they include the anisotropy of the cosmic microwave background, galaxy-rotation data, and the gravitational lensing of light from galaxies by unseen masses.

In 2006 a pair of colliding galaxy clusters, together called the bullet cluster, provided a spectacular confirmation of dark matter. The two clusters had passed through each other 100 million years ago, and an analysis of how the bullet cluster distorted the images of background galaxies established that its intergalactic gas lagged behind its dark-matter halos. The proffered explanation was that gas–gas interactions dragged the conventional material while the halos traveled unimpeded. Indeed, observations of the bullet cluster enabled researchers to set an upper limit on how strongly dark matter can interact with itself (see PHYSICS TODAY, November 2006, page 21).

Now a team of astrophysicists led by Durham University's Richard Massey has spotted a galaxy in the Abell 3827 cluster that appears to be *leading* its halo as both are attracted toward the cluster center.[1] Massey and colleagues suggest that the offset may result from frictional interactions between the halo and the dark matter of the cluster core.

Finding halo

The four galaxies in Abell 3827 shown in the figure lie within a few kiloparsecs of each other (a parsec is a bit more than 3 light-years). Partially surrounding them is an arc that manifests the severe distortion of a background galaxy by the gravity of Abell 3827; additional lensing can be seen in the area of the galaxy labeled N1. With the help of spectroscopic measurements obtained by the Very Large Telescope in Chile, Massey and colleagues associated each