Even though alkalinization of the cell interior might not serve as a direct signal for mitosis and cell division, in some cells it is linked to increased DNA synthesis, which is a prerequisite for division. Human lymphocytes, for example, are stored in the spleen in an inactive state until they are stimulated to divide by encountering an antigen. They can also be activated artificially in the laboratory by exposing them to mitogenic materials such as concanavalin A or a lipopolysaccharide isolated from bacteria. According to Gerson, the *p*H of lymphocytes stimulated in this way increases transiently by about 0.2 unit a few hours after the mitogen treatment. It then returns to normal, only to rise again between 12 and 48 hours after stimulation and again return to normal in an additional 24 hours.

The first increase corresponds in time with the first step of lymphocyte activation, which involves production of a growth factor that stimulates a subset of the population to divide. The second peak occurs at about the same time that lymphocytes begin copying their DNA as they prepare for mitosis. "We are left wondering," Gerson says, "if these are independent effects or whether one causes the other. And, if so, which is the cause and which is the effect."

Toward a Proof of Quark Confinement

A key theorem of mathematical physics—as yet unproved—states that quarks are permanently bound inside the particles of ordinary matter, that no amount of force can ever break one free. Recently, however, Stephen L. Adler of the Institute for Advanced Study in Princeton has taken an important step toward that proof. His work is published in the 15 June *Physical Review D.*

Current conventional wisdom holds that nuclear forces are best described by quantum chromodynamics (QCD), which tells how quarks interact with a group of eight photo-like particles called gluons. Simple heuristic arguments indicate that quarks governed by QCD would behave as if they were connected by springs: their mutual attraction, nearly zero in the close confines of a proton or neutron, would grow larger and larger if one tried to escape; they would be trapped, rather like marbles inside an unbreakable rubber bag. In fact, a phenomenological model postulating just such a bag was developed a decade ago by physicists at the Massachusetts Institute of Technology, and proved very successful in explaining the properties of the known nuclear particles. Unfortunately, the complexity of the mathematics has made a rigorous proof of the QCD force law impossible.

Adler does not claim to have a complete proof either. "But I do claim to have found the right mechanism," he says. Internal consistency checks lead him to believe that the approximations used in his derivation are "robust," in the sense that the exact solution to the QCD equations will differ from his solution only in the details, not in the overall structure. Moreover, he believes it may well be possible to do away with the approximations and establish a rigorous proof of quark confinement. His work has drawn a good deal of favorable comment from fellow theorists, most recently at a meeting in Baltimore.*

Adler begins by treating the QCD equations in strict parallel with the "mean field" approximation of quantum electrodynamics, the theory of electrons and photons. The approximation assumes that electrons are heavy and slow-moving, and furthermore, that quantum fluctuations in the electromagnetic field are unimportant. The field can safely be replaced with its average, or "mean" value and calculated according to the standard nonquantum field equations. The method is quite accurate in the tame environs of systems such as the hydrogen atom. And since the confining force only takes hold when the quarks are far apart and slow-moving, says Adler, the method should also be valid in the case of quark confinement.

He finds that the whole procedure can indeed be applied to QCD but that there are two crucial differences. First, QCD implies that the gluon fields within a real nuclear particle would average out to zero; to extract a useful mean field theory one has to average the product of the field with certain matrices representing the internal states of the quarks. (In technical terms, the expectation values of the gauge potentials are zero in a color singlet state; the expectation values of the product of the gauge potentials with the color charge matrices are not.) Second, in QCD, quantum fluctuations in the gluon field *are* important, largely because of mutual interactions among the gluons. Fortunately, well-established "renormalization group" methods can be used to approximate these effects. Building on earlier work by Heinz Pagels of Rockefeller University, Elestherios Tomboulis of Princeton University, and G. K. Savvidy of the Soviet Union, Adler derives a set of differential equations for the gluon field that resembles the equations of electrostatics in a continuous medium—except that the "medium" is not water or air, but empty space, and the "dielectric constant" of this medium is a nonlinear function of the gluon field strength.

Adler is currently developing computer codes to solve these equations in the relatively simple case of a quark bound to an antiquark inside a meson. Two other groups are working on deriving the corresponding equations for three quarks bound inside a proton or neutron. Once the field equations are solved it will be a simple matter to compute (within the approximations) the binding energy of the quarks as a function of their separation, and thence to find the force between them.

But some things can already be learned just from the form of the equations. For example, the "dielectric constant" of empty space is such that the gluon field is confined and compressed, rather like a bubble under water. Quark and antiquark move freely within the bubble when they are close together; as they are separated, however, the bubble stretches out in a thin tube between them. It is easy to show that the potential energy then grows linearly with the separation and that the quarks cannot escape. Such behavior has long been expected. But Adler is the first to derive a confining potential from the basic QCD equations (albeit with approximations) without having to impose it artificially.—M. MITCHELL WALDROP

*The Fifth Johns Hopkins Workshop on Current Problems in Particle Theory, 25 to 27 May 1981.

0036-8075/81/0814-0746$01.00/0