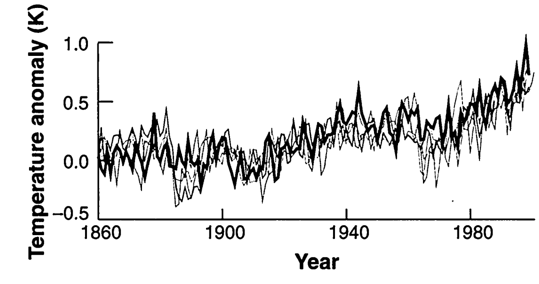
tions to decadal mean observations, Stott *et al.* demonstrate that natural forcing alone is not a plausible explanation for the observed changes in the 20th century and that natural and anthropogenic forcing have both made substantial contributions to the observed change. Together, these forcings explain about 80% of the observed interdecadal variance of global mean temperature.

The result is compelling, but more work is needed. There is still much uncertainty on the mechanism and magnitude of aerosol forcing and on feedback mechanisms involving clouds, the ocean, cryosphere, and the land surface. Historical reconstructions of natural climate forcing also remain uncertain. And the ability of models to simulate the variability of the climate system must be improved. For example, Stott *et al.* point out that their forced simulations do not reproduce the observed trend in the North Atlantic Oscillation (*8*). Also, most models do not accurately simulate the El Niño–Southern Oscillation in the Pacific (*9*).

Nevertheless, this impressive study is a substantial step toward explaining the observed variations of 20th century climate. Stott *et al.*'s approach is far from a diagnostic curve fitting exercise. Rather, a model built on physical principles is used to simulate the climatic response to independent estimates of historical climate forcing. The agreement between observed and simulated decadal-scale temperature variations strongly supports the contention that forcing from anthropogenic activities, moderated by variations in solar and volcanic forcing, has been the main driver of climate change during the past century.



A good match. 20th century global mean surface air temperature departures from the 1880–1920 average. Observations are shown in black; simulations by Stott *et al.* (*5*) are shown in color. The simulations include natural and anthropogenic forcing. Further details in (*5*).

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PERSPECTIVES: PARTICLE PHYSICS

How Strange Is the Proton?

Günther Rosner

Nucleons (protons and neutrons) have been extensively studied over the past 30 or 40 years, but our knowledge of their internal structure is still rather limited. We do not even know exactly what they are made of. Do they consist of only light quarks or do heavy quarks, such as "strange" quarks, contribute as well? The main reason for these difficulties is that the nucleon cannot be taken apart because its constituents, the quarks, are extremely tightly bound. If one tries to remove a quark, it immediately combines with an antiquark in the surrounding vacuum to become a meson (a composite particle containing one quark and one antiquark). The only way to look inside the nucleons is through scattering experiments and the measurement of "form factors" (*1*), which carry information about the spatial distribution of charges, spins and currents within the nucleon. As reported by Hasty *et al.* on page 2117 of this issue (*2*), these measurements are also helping to determine the role of "strange" quarks, originally thought not to play a role in ordinary matter.

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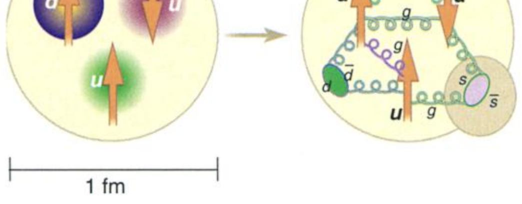
In the 1960s, it became clear that neutrons and protons are not elementary but are composite particles. Symmetry considerations initially led to the simple idea that nucleons consist of three, either up (*u*) or down (*d*), quarks (see the left part of the figure). The quarks are confined within the nucleon, each carrying one-third of its mass of about 939 MeV/c^2. They have spins of $^1/_2$, which combine to give a total spin of $^1/_2$ for the nucleon.

This model was soon found to be too simplistic. Electron scattering experiments in the 1970s showed that the quarks carry only about half of the proton's momentum. The rest is carried by particles called gluons, which are exchanged between the quarks and produce the extremely strong forces that hold the proton together. According to the theory of strong interactions, quantum chromodynamics (QCD), the *u* and *d* quarks still carry a spin of $^1/_2$ but are now pointlike and have masses of only 5 to 10 MeV/c^2. The gluons can temporarily split into quark-antiquark pairs (see the right part of the figure). These "sea-quark" pairs may be formed by *u* or *d* quarks and their respective antiquarks or by the strange quark (*s*) and its antiquark. The strange quark has a mass of around 150 MeV/c^2 and is thus much heavier than the *u* and *d* quarks. It is not yet known to what extent strange quarks determine the nucleon's properties, and this is what Hasty *et al.* and other groups are aiming to resolve.

Two earlier sets of experiments have investigated "strangeness" in the nucleon using lepton or pion beams. (Leptons, such as the electron and the heavier muon, are the lightest elementary particles. Pions are the lightest mesons.) First, analyses of pion-nucleon scattering data in the 1970s (*3*, *4*) indicated that strange quarks might contribute considerably to the nucleon's mass. The strange quark content of the



Artist's view of a proton. **(Left)** In the static quark model, massive constituent *u* and *d* quarks are confined to the proton's volume (the proton has a diameter of about 1 fm = 10^{-15} m). **(Right)** In the QCD picture of the proton, the *u* and *d* quarks are light and pointlike. The proton's volume is filled by gluons (*g*) and quark-antiquark pairs. The figure is based on a template by Frank Maas, University of Mainz.

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proton is now thought to lie between 0 and 32% (*5, 6*) (the uncertainty is mainly caused by inconsistencies in the data and should be reduced by future experiments).

Second, deep inelastic muon scattering experiments at the CERN laboratory in Geneva in the 1980s revealed that only a small fraction of the proton's spin is carried by the quarks. These findings were such a surprise that they gave rise to the so-called spin crisis. The rest of the spin of the proton must be supplied by the gluon spins or by the angular momentum of the quarks and the gluons as they move around within the proton. The experiments further suggested that the polarization of the strange quark-antiquark pairs ($s\bar{s}$) is sizable and contributes considerably to the proton's total spin (*7*). Extensive work at CERN, Stanford (SLAC), and Hamburg (DESY) over the past decade has essentially corroborated the original results (*8*). A quantitative determination of the individual contributions of $s\bar{s}$ pairs, gluons, and angular momentum to the proton's total spin is in sight.

As pointed out by Kaplan and Manohar (*9*) and McKeown (*10*), there is a third way to get hold of the strange quarks in the nucleon. The method uses a unique feature of weak interactions: The weak force violates mirror symmetry, or parity. The mirror image of the experimental setup can simply be achieved by flipping the electron's spin in the beam from the accelerator. Electron scattering on a charged particle involves both electromagnetic and weak forces. Through interference effects, the tiny parity-violating weak part of the interaction is amplified by the much larger electromagnetic part, thus allowing the strange parts of the electric and magnetic form factors, G_{Es} and G_{Ms}, to be determined. Static moments, such as the strange magnetic moment μ_s [now determined in (*2*)], can be obtained from these form factors by extrapolation to zero momentum transfer. The drawback is that the asymmetries resulting from this type of experiment are expected to be very small, about 10^{-5}. Statistical and systematic errors must therefore be kept at or below the parts per million level—a formidable task.

Several collaborations in America and in Germany have taken up the challenge (*11*). Each experiment has a different setup and is therefore sensitive to different combinations of the strange electric and magnetic form factors. Preliminary results have been reported (*12–15*), but the contribution of strange quarks to the magnetic moment of the proton could not be deduced.

By combining new measurements on hydrogen and deuterium, Hasty *et al.* have now determined the strange part of the proton's magnetic moment to amount to (−0.1 ± 5.1)% (*2*). The error margin is still rather large. Nevertheless, the study shows convincingly that the contribution of strange quarks to the magnetic moment is small. It is still an open question whether strange quarks influence other quantities, such as the nucleon's mass or spin, to a larger extent.

With the prospect of new data from ongoing and proposed experiments (*11*) the strange quarks' contributions to the proton's magnetic moment will soon be pinned down and, taking into account new information from pion and deep inelastic lepton scattering, we should know all about strangeness in the proton in the next decade.

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PERSPECTIVES: ECOLOGY

Species-Area Relations in Tropical Forests

Robert M. May and Michael P. H. Stumpf

One of the earliest accomplishments of theoretical ecology was the discovery of a relationship between the number of species (of plants, birds, beetles, or whatever) on a given island and the area of that island (*1*). For example, a 10-fold increase in island area approximately doubles the number of species. This species-area relationship (SAR) is often used by conservation biologists to assess the long-term effects of the fragmentation of tropical forests, or other reductions in habitat area, upon species diversity (*2*). The SAR, as first enunciated by MacArthur and Wilson in their influential book *Theory of Island Biogeography* (*1*) and by others [see (*3*) and references therein], was phenomenological, based on observations.

The islands described by the SAR may be real islands in the ocean, or virtual islands such as hilltops (where the surrounding lowland presents a barrier to many species), lakes, or wooded tracts surrounded by open land. In such island groups, plotting the number of species S in a particular taxonomic category against the area A results in a power-law relation of the form $S = cA^z$ (see the graph, next page). The constant c is characteristic of the taxonomic group, but the exponent z tends usually to lie between 0.2 and 0.3. Such a sweeping generalization inevitably requires qualifications. For example, the linear log S–log A relation tends to fail (the graph curves downward) if the island area is very small; on the other hand, the exponent z tends to have lower values if the islands are very large (particularly on the scale of a continent). But, despite occasional carping, this SAR with a $z \approx {}^1/_4$ applies to such a wide collection of taxa and island groups that a theoretical explanation is called for. Enter Plotkin *et al.* (*3*) with just such a theoretical explanation, reported in their new study of more than 1 million trees from five tropical forests on three different continents.

But Plotkin and colleagues are not the only investigators with a contentious theoretical explanation for SAR. The earliest explanation (*1, 4*) was prompted by the observation that the distribution of numbers of individuals (N) among species (S) is likely to be influenced by the multiplicative interplay of many different ecological factors. This results in a lognormal distribution for the relative abundance of species within a particular area (see the graph, next page). Earlier, Preston (*5*) documented such lognormal distributions; he observed that they were commonly one particular or "canonical" member of this one-dimensionally infinite family, and that for a large number of species they corresponded to the numbers of species and individuals related by $S \approx (\text{constant}) \times N^{0.25}$.

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