

at a speed equal to or less than the velocity of light. There were considerable difficulties with doing this sort of experiment, but finally all were solved, and quantum mechanics, once again, turned out to be right².

There still remained a second loophole, based on the statistical nature of previous experiments. The 'detection-efficiency' loophole argues that, in most experiments, only a very small fraction of the particles generated are actually detected. So it is possible that, for each measurement, the statistical sample provided by the detected pairs is biased. For example, in experiments using pairs of photons emitted by atomic cascades², only one pair in every million was used in the measurement. So, to extract a meaningful conclusion from the observed data, it was necessary to assume that a small fraction of data provides a fair statistical sample. This would be similar to allowing one hundred votes to decide a ballot of one hundred million. Not surprisingly, several local realistic models were built to mimic the experimental results, and the detection-efficiency loophole became the Achilles' heel of experimental tests of Bell's inequalities.

It was first thought that improving the detection efficiency in experiments with pairs of entangled photons² would solve this problem. But this proved more difficult than expected and, despite several proposals^{3,4}, no conclusive experiment has been done. Another avenue is to use correlated measurements on pairs of massive particles, with the hope that their quantum states would be easier to detect than those of photons. Theoretical proposals considered pairs of atoms produced through a photodissociation process^{5,6}, or pairs of Rydberg atoms⁷. But such experiments are not easy, and no conclusive test of Bell's inequalities has been carried out in these systems.

In their experiment, Rowe *et al.*¹ manipulate the quantum states of two massive entangled particles — in this case trapped ions. For an efficient measurement, it is necessary to detect and compare the individual quantum states of the two ions, which are separated by only a few micrometres. The authors use a two-step measurement process, which results in four possible outcomes (Fig. 1). Contrary to the photon-correlation experiments, in which many photon pairs are missed, here every ion pair is included in the measurement. Remaining errors are attributed to an incorrect preparation of the initial state (less than 12%), a phase error in the rotations (less than 6%), or a mistake in the identification of the final states (less than 2%). The agreement with quantum mechanics is excellent, making this the first violation of Bell's inequalities with high enough efficiency (80% overall) to close the detection loophole.

What conclusions can be drawn from this experiment? It does not close the locality

loophole, whereas the experiments that do, cited in ref. 2, do not close the efficiency loophole. Closing both loopholes in the same experiment remains a challenge for the future, and would lead to a full, logically consistent rejection of any local realistic hypothesis. Even so, the overall agreement with quantum mechanics seen in all the experimental tests of Bell's inequalities is already outstanding. Moreover, each time a parameter is changed that was considered to be crucial (for example, using time-varying measurements, or increasing the detection efficiency), the experiments show that these changes have no consequence: the results continue to agree with quantum-mechanical predictions. This appears rather compelling evidence to me that quantum mechanics is right, and cannot be reconciled with classical physics.

Finally, Rowe *et al.*'s experiment is a vivid illustration of the high degree of sophistication that has been reached in the

control of 'engineered' quantum systems. The entangled-ion pair was prepared on purpose, and can be observed at will. This opens fascinating possibilities for manipulating the quantum state of entangled many-particle quantum systems. Such systems are the basic elements for achieving long-term goals in quantum information processing, such as building a quantum computer. ■

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Ecology

The rising cost of bushmeat

Peter D. Moore

Some plants depend on specific animal vectors for the dispersal of their seeds. If the vector comes under threat, there are likely to be adverse consequences for the plant.

As human pressure on tropical forests increases, so does the extent of bushmeat hunting — the killing of wild species for food. The adverse effects go beyond the species immediately concerned, and a striking example can be found in a paper by L. F. Pacheco and J. A. Simonetti in *Conservation Biology* (**14**, 1766–1775; 2000).

As might be expected, large-bodied animals — including some primates — are usually the preferred bushmeat prey. Many of these animals have fruits and seeds as a major part of their diet; in turn, the dispersal of the plants concerned may depend on the passage of seeds through the animals' guts, and subsequent deposition elsewhere. Most fruit-eaters are generalists, so if one vector is lost there may be others to take its place. But in fruit consumption, size matters, and the selective loss of all large frugivores could seriously impair dispersal in plants with large fruits. Moreover, some plants are relatively specific in their seed-dispersal vectors, and so are most at risk.

Pacheco and Simonetti have studied one such species, *Inga ingoides* (family Fabaceae), which is one of the common trees in the lowland forests of Bolivia. The seeds

Figure 1 Hunted look: the spider monkey of South America.



of this tree are dispersed almost exclusively by the spider monkey (*Ateles paniscus*; Fig. 1). Three other primate species feed upon the tree's seeds in the study area, but only spider monkeys ingest them intact and act as effective dispersal agents. The monkeys can travel 1 kilometre in a few minutes and have a gut passage time of about 4 hours. So the seeds can be dispersed some distance from the parent plant, ensuring that the genetic structure of the population of *I. ingoides* is well mixed.

The research concentrated on the genetic variability of *I. ingoides* populations, comparing areas where spider monkeys were present with those where they had become locally extinct through bushmeat hunting. After analysing 14 enzyme systems in leaf extracts, the authors found that there was less genetic variation in the seedling populations around parent trees when the monkeys were absent than when they were present. Without the monkeys the seeds simply fall to

the ground around their parents. In other words, the monkeys are responsible for maintaining a thorough genetic mix in the population, and in their absence a series of genetically more uniform patches develops.

In general, trees in the tropical rainforest have high levels of genetic diversity. They are usually out-breeding and have efficient gene flow because of their specialized pollination and seed-dispersal mechanisms. Fragmentation of the forest, whether by physical processes (such as clearance) or by interruption to gene flow (as in the case of vector loss), can lead to the local accumulation of potentially detrimental mutations and an overall loss of fitness. As has so often proved to be the case in ecological studies, when one link is removed from a network, the whole system can start to unravel. ■

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Biochemistry

Single-handed cooperation

Jay S. Siegel

Our bodies use only 'left-handed' amino acids and 'right-handed' sugars. Hints are now emerging on how this handedness evolved and how cooperativity among like-handed molecular components came about.

The sequencing of the human genome provides exciting possibilities to explain the complexities of life. But some more basic questions remain unanswered — such as why the double-helix structure of DNA spirals in a clockwise (right-handed) direction, rather than a left-handed one. On page 797 of this issue¹, Ghadiri *et al.* use a peptide system to demonstrate how 'homochirality', or single-handedness, may have evolved in biological molecules.

Nucleic acids, like nearly all biological molecules, exhibit 'handedness', and only one of the two forms is used in a particular biological process. This gives rise to homochirality, where each molecule is identical. Among sugars, ribose and deoxyribose are not identical; nonetheless, the form of ribose in RNA and the form of deoxyribose in DNA share a common right-handed orientation of their principal functional groups. This common stereochemistry — the three-dimensional shape of the molecule — evokes another concept of homochirality, which relates members of a family of compounds.

The natural amino acids share a common stereochemistry, as they are all left-handed (L-amino acids). This raises the question of whether homochirality within a family of biological molecules is the result of a stereochemical cooperativity (diastereo-

selectivity) among the members within a biopolymer. Indeed, our enzymes and nucleic acids are composed of predominantly L-amino acids and D-sugars — we are unable to use the opposite-handed biopolymers. Why not? Attempts to answer this question by mimicking the creation of a homochiral environment in the laboratory have been unsuccessful until now.

This difference in functional chiral form had tragic consequences in the 1960s when pregnant women were given a sedative (Thalidomide) that was a mixture of the right- and left-handed forms of the drug; one of the two forms, or enantiomers, gave rise to birth defects. That two enantiomers can have such different functions shows that stereochemistry controls whether, and how, molecules recognize one another and 'shake hands'.

The origin of one-handedness in biological molecules is not yet clear². Several explanations have been put forward to explain how homochirality came about, but all are speculative — it is not even known yet whether it arose by chance or by some other means^{3,4}.

Synthetic polymers are simpler than biological systems and provide a model for understanding the origin of homochirality in biomolecules. One proposal stems from observations that polymers made from



100 YEARS AGO

Sensational Newspaper Reports as to Physiological Action of Common Salt. In the interest of the dignity of scientific research I venture to hope you will print the following statement. Some American papers have recently published sensational and absurd reports of physiological theories and experiments whose authorship they attributed to me. These reports, which in America nobody takes seriously, were reprinted and discussed in European papers. I hardly need to state that I am in no way responsible for the journalistic idiosyncrasies of newspaper reporters and that for the publication of my experiments or views I choose scientific journals and not the daily Press. Jacques Loeb
From *Nature* 14 February 1901.

50 YEARS AGO

A recent address on "Freedom in Science" broadcast by Prof. C. A. Coulson made even clearer the need for ensuring that our instruments of government make proper provision for such freedom. Prof. Coulson observed that, since patience, humility, tolerance, fairmindedness, integrity, co-operation and trust are the hallmarks of the scientific tradition, he has been forced to the conclusion that this tradition is ultimately based on, and derives its final sanction from, moral and ethical considerations which lie outside the field of what is popularly called science. A. N. Whitehead maintained that the inner conviction that the world is rational, and the confidence in one another that enables us to dispense with the verification of other people's claims, is a legacy coming to us from "the medieval insistence on the rationality of God". Prof. Coulson accordingly suggests that in a time of crisis like the present, which is marked by the breakdown of personal conviction among ordinary people, it is highly important that... men of science are the custodians of many of the most precious values of our civilization. From this aspect, Prof. Coulson agrees with Prof. Polanyi's view that the suppositions underlying our belief in science "co-extend with the entire spiritual foundations of man, and go to the very root of his social existence". But he discusses a possible danger to the freedom of science which might well arise from intoxication with power and an unmeasured faith in organization. This will have to be guarded against when the Science Centre in London now under consideration is established. From *Nature* 17 February 1951.