Critical contributions from an unusual physicist

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Critical contributions from an unusual physicist

Eugene Stanley has applied the tools of theoretical physics to the heart and lungs, the search patterns of albatrosses, company growth and much more. **Peter Gywnne** finds out what these diverse topics have in common

His academic qualifications are solely in physics, but H Eugene (Gene) Stanley has always been interested in worlds beyond the narrow confines of his chosen subject. His appointments at Boston University indicate his breadth of interests: he is director of the Center for Polymer Studies, professor of physics and professor of physiology at the medical school.

Equally indicative of the 55-year-old Stanley's scientific breadth is a random selection of his publications. It includes papers on the application of physics principles to the growth of companies, the behaviour of the heartbeat and the lung, metastable water, and the structure of DNA. His team's most recent contribution to *Nature* focuses on the flight patterns of albatrosses.

In pursuing such a broad range of interests, Stanley has followed a muse that goes beyond the accepted boundaries of physics. "I have always been fascinated by discovering new things about the world around me," he says. That interest has helped him to form academic alliances with people working in molecular biology, medicine, economics and other fields distant from physics.

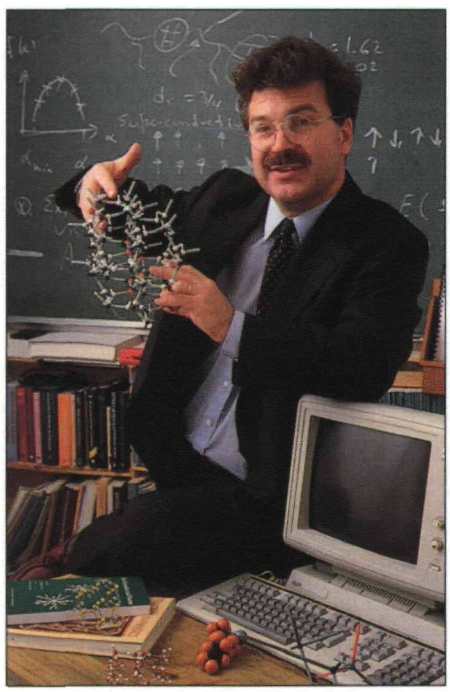
To those alliances he has brought an ability to dream up penetrating ideas. "One of Professor Stanley's widely appreciated talents is coming up with highly original ideas that have opened up new subfields of physics," says Antonio Coniglio of the University of Naples. Stanley has also shown a marked enthusiasm for pushing those ideas to the limit. "To some extent, he's always been at the cutting edge, and to some extent he's pushed the border a little further than others might," says Wolf Prize winner Michael Fisher of the University of Maryland.

Stanley reached his state of academic ubiquity via critical phenomena, the physics subfield that he helped to develop, with Fisher and others, more than two decades ago. The field deals with systems near their critical points. But it is more general than that restriction might indicate, says Stanley, "because it is turning out that a lot of systems are in fact near critical points".

The conceptual framework is scaling – the fact that phenomena look different on different scales. Scaling, Stanley explains, applies to almost any relevant variable. "The key thing about avalanches and stockmarkets," he says, "is that there is no intrinsic scale to the problem" – as opposed to a pendulum, which has an intrinsic scale in the form of its period.

Avalanches, for example, appear to be a totally random, unquantifiable events. But scaling concepts permit scientists to gain some understanding of them. "Even when something is as apparently erratic as an avalanche, one can say something about it. One can make simple models and get a handle on these very complex problems," he asserts.

Stanley has always been more than a blinkered physicist. After receiving his bachelor's degree in physics from Wesleyan University in Connecticut in 1962, he spent a year as a Fulbright fellow at the University of Cologne, studying experimental biophysics with Nobel laureate Max Delbrück. Stanley planned to do his PhD in biophysics, but Delbrück persuaded him that he should concentrate on a foundation subject. So he obtained his PhD in solid-state theory from Harvard University, where he worked under another Nobel laureate, John van Vleck.



Wide-scale interests – Eugene Stanley

During and after his PhD he worked – primarily with Thomas Kaplan – at the Lincoln Laboratory, an institution run by the Massachusetts Institute of Technology that was heavily involved in defence work. The institution gave two important boosts to Stanley's academic career. It introduced him to the emerging subfield of critical phenomena and it helped him to define his working style.

"What happened there really changed how I've run my lab over the last 30 years," he recalls. "There, I really learned how to do science." For example, he had multiple scientific mentors at the Lincoln Lab. Since then, he says, he has tried to ensure that he is never the sole mentor of his students.

By 1969 Stanley was beginning to make a name for himself in critical phenomena and was receiving offers of faculty posts. He chose to move to MIT, where he stayed for the next seven years. During that time, says Fisher, "he attracted a large proportion of the best students". But MIT did not award him tenure.

"There's no single reason why I left MIT," he recalls, "but a lot had to do with responding too much to other peoples' pressures. I tried to learn too much too fast." Adding to his problems were his anti-establishment activities, which included demonstrating against the Vietnam War and in favour of the release of Soviet Jews, and disrupting an American Association for the Advancement of Science meeting – "not a good way to behave if you want tenure at MIT," he muses. According to Fisher, Stanley's departure "was a big mistake by MIT, which Gene has shown since by his work".

He ended up physically, if not spiritually, close to MIT: in the physics department of Boston University, just across Charles River. From there Stanley has run an exemplary programme in scaling and critical phenomena for the past 20 years. "I think the work that has come out of his group has had a lot of impact," says Fereydoon Family of Emory University, a fellow critical phenomena physicist.

The concept of scale invariance is summed up in the Guttenberg–Richter graph. This plots the logarithm of the number of events (such as avalanches, earthquakes and crashes in the stockmarket) against the log of the magnitude of such events. These graphs turn out to be remarkably linear.

Scientifically, Stanley says, such study tells something about the phenomenon. The plots also have practical value in, for example, the insurance and building industries. "We don't predict when an event like an earthquake will happen because it is random. We predict the chance that it will happen," explains Stanley. "There are a zillion problems like this, ranging from the stockmarket to lots of other things that are scale-free phenomena."

Critical phenomena differ from chaos and fractals. Chaos involves systems, almost always deterministic, for which the time evolution depends very sensitively on the initial conditions. Fractals are primarily random rather than deterministic. Critical phenomena are a subset of fractals, in that everything near a critical point is a fractal, but not all fractals are necessarily associated with critical points. However, Stanley points out, "it would be wrong to give the impression that critical phenomena are just a tiny subset of fractals, since the big advances in critical phenomena came 10–20 years before those in fractals".

Stanley's early work applied critical phenomena techniques to percolation, polymers and diffusion. It is in recent years that he has strayed further from conventional physics. In one project, Stanley and cardiologist A L Goldberger have applied scaling concepts to the human heartbeat. Analysis of data collected by Goldberger's team at Harvard Medical School indicates that the healthy human heart beats at a continuously variable rate, with the interval between successive beats changing by as much as 0.1 s. Intriguingly, and counter-intuitively, patients with heart disease show less of this type of variation. "This variability is terribly important in understanding the design of the heart," says Stanley. "The different scaling behaviour in health and disease must relate to the underlying dynamics of the heartbeat."

In a similar fashion, Stanley and Michael Salinger of Boston University's School of Management applied scaling behaviour to the growth of companies. They developed a model in which "the probability of a company's growth depends on its past as well as its present sales accounts." The model applies to companies that manufacture all types of products, suggesting that organizational structure, rather than production-related factors, has more impact on growth.

Family warns that although these most recent studies are quite interesting, they represent a work in progress. "It will take time to see their real significance and their effect in areas like cardiology and the stockmarket. Nevertheless," he adds, "I feel it's the job of a physicist to look at how new findings can be applied to other areas".

Gene Stanley and his colleagues at Boston University are undertaking that task with more intensity than most. As scientists, "we are discoverers of what's out there, like Christopher Columbus," he says. "My guess is that this type of work will emerge as one of the big ideas of science – but it probably won't be appreciated for another 25 years." □

IN BRIEF

Cluster scientists could sue

Scientists working on the ill-fated Cluster mission, which was destroyed when the Ariane 5 rocket exploded in June, have threatened to sue those responsible if they are not provided with a free and safe launch for any replacement. Without a free launch, they argue, any replacement for the mission to study the interaction between the Earth's magnetosphere and the solar wind would be prohibitively expensive. The European Space Agency is responsible for Ariane but handed over execution of the programme to the French *Centre Nationale d'Etudes Spatiales*.

According to ESA's inquiry into the loss of Ariane 5, the failure was due to specification and design errors in the guidance software. "It is clear that negligence occurred in the Ariane programme which led to the destruction of the launcher and of Cluster," says André Balogh of Imperial College, London, principal investigator for the magnetometers on Cluster. A decision on the future – if any – of the Cluster mission will be taken in November. If it is negative, Cluster's space scientists may bring the lawsuit. "We are hoping the agency will do the right thing – which is to recover part of their cornerstone mission," says Balogh.

Norwegian rocket fails

Two Norwegian atmospheric research rockets were destroyed shortly after launch from the northern island of Andøya at the end of July. Developed by the University of Tromsø and private Norwegian companies, the lightweight rockets were expected to revolutionize atmospheric research through their low cost and their high speed. The NOK 150 000 (about £15 000) rockets travel at ten times the speed of traditional rockets.

Apparently, heavy vibrations caused a radio component failure or a cable fracture 2 seconds after launch, when the second rocket had reached a height of 2 km. Scientists from Tromsø's Northern Lights Observatory had expected to receive valuable data from the rockets during the 90 seconds that they should have spent at the edge of the atmosphere.

The Andøya base shot to fame in January 1995 when a rocket launched in the direction of Svalbard triggered a nuclear alert in Russia.

Japan's know-how

Japan has the most inventive scientists, according to figures on the latest international trends in R&D from the Organisation for Economic Co-operation and Development (OECD). The "inventiveness coefficient" – the number of patent applications per 10 000 people – was 26.6 in Japan in 1993, compared with 4.4 in Germany, 3.9 in the US and 3.2 in the UK.

Japan also spends a greater proportion of its Gross Domestic Product on R&D than any other country. It ploughed back 2.90% in 1994, compared with only 2.54% in the US, 2.38% in France, 2.33% in Germany and 2.19% in the UK. However, in absolute terms, the US leads the way. It spent $169.0bn on R&D in 1994, more than Japan ($75.2bn), Germany ($37.4bn), France ($26.5bn) and the UK ($22.6bn).

A different picture emerges, however, when R&D measured at constant prices is considered. In these terms, R&D spending fell by 1.0% in Japan in 1994. There were also falls in Germany (down 1.0%), the US (down 0.5%) and France (down 0.3%). The OECD blamed the general economic downturn for the figures. The UK registered significant growth in 1994 – it spent 3.5% more on R&D at constant prices than the year before. However, the UK still lags behind its competitors in terms of the amount spent on R&D per person. It spent just $387 per head in 1994, compared with $457 in France, $459 in Germany, $601 in Japan and $648 in the US.

Ultraviolet cut-off

After more than 100 000 observations made over 18 years, resulting in 500 doctoral dissertations and 3500 papers in refereed journals, the International Ultraviolet Explorer satellite is to cease operation at the end of this month.

The satellite has a 45 cm ultraviolet telescope for spectroscopic observations in the 115–320 nm waveband. Launched in 1978, its expected lifetime was only three years. Until recently, it was jointly funded by NASA, the European Space Agency (ESA) and the UK Particle Physics and Astronomy Research Council. NASA decided to terminate its funding of the project a year ago, and ESA can no longer afford to make up the difference due to budget pressures on its science programme.

Ex-advisers seek work

A group of scientists and engineers familiar with the US corridors of power has formed a private company to provide advice and assessments on a range of science and technology issues. The Washington Advisory Group will seek clients from private corporations, universities and non-US government agencies. It will assess the quality, organization and effectiveness of R&D, and provide advice on new business opportunities that stem from advances in science and technology.

"In our work we have found that science and technology represents an increasingly bottom line issue," explains Robert White, former president of the National Academy of Engineering and ex-administrator of the National, who is president of the new group. The group's fellows include three former US presidential science advisers – Allan Bromley, Edward David and Frank Press. Also on the books are Robert Frosch, Erich Bloch and Alan Schriesheim. □