such buffering. The statistical method of power analysis is appropriate and well understood, but rarely used. In this analysis, the consequences of making errors of two types (type I and type II) when testing the null hypothesis of no effect are clearly determined and stated. If the conclusion is that there is an effect when in fact none exists, a type I error results. However, if the null hypothesis is not rejected when in fact an impact does exist, a type II error results (1).

Consider a proposal to restrict trawling from some areas in the Gulf of Maine to protect benthic habitat. If the proposal is accepted and fishing is restricted, when in fact it has no serious impact, it would be a type I error; however, if the proposal is rejected and trawling results in habitat destruction, a type II error is made. Current management focuses on reducing the type I error because this kind of error results in catching fewer than the maximum number of fish and is therefore highly visible to politicians and the fishing industry; management virtually ignores the type II error, principally because the deleterious effects are not immediately obvious. But ignoring the type II error results in failure to recognize and avoid serious long-term damage such as the collapse of the fisheries or environmental destruction. Scientific advice should be explicit about both types of errors, and most importantly, it must articulate the consequences to the ecosystem of making each type of error. The environmental consequences from type II error are much more serious because of the great time lags in the recovery of ecosystems or animal populations. Type I errors usually result only in short-term economic costs.

Proper management that weights both types of error has proven difficult because those profiting from the public resources are not required to prove that their actions cause no damage. The only mechanism available to society to protect these resources is somehow to prove actual or potential serious impact. This is virtually impossible for many reasons. Those defending the profiteering can argue endlessly over the accuracy of statistics that are virtually impossible to verify without an observer on each fishing boat or exorbitantly expensive sampling programs to generate independent data. Implementation of restrictions may be delayed by creating imaginative alternative explanations for the ecological damage and demanding that these be negated before restricting exploitation. Finally, even when presented with excellent data, regulators can simply assert that the data are inadequate and ignore serious environmental impacts. Resource management officials face strong economic barriers to risk-averse strategies. These policies cannot be expected to be implemented until the burden of proof is placed on exploiters of public marine resources to prove that they do not cause damage rather than simply assuming this to be the case until demonstrated otherwise. Similar commercial use of land resources requires extensive environmental impact studies and is carefully regulated. Continued monitoring is required, and all data are readily accessible to the public. Our marine resources need the same careful protection and stewardship.

In other contexts, particularly those involving human health and safety, we routinely place the burden of proof that the intervention will not cause damage on those hoping to exploit public resources. This need to protect against the serious type II errors is obvious for the Nuclear Regulatory Agency, which demands an extremely high margin of safety for the building and operation of nuclear power plants, for example. The Food and Drug Administration too demands a large margin of safety before approving the use of drugs in humans. Extensive testing to demonstrate the safety of new pesticide products is required before they can go to market, and air pollution regulations are expressly written to include an adequate margin of safety to protect human health. If society's environmental needs are to be protected so that future generations can also enjoy, learn, and profit from marine ecosystems, this legal burden of proof must be applied to our marine resources so that those hoping to exploit them must demonstrate no ecologically significant long-term changes. If the public hopes to preserve our marine environment, they must act quickly to change the relevant regulations and reverse the burden of proof.

References

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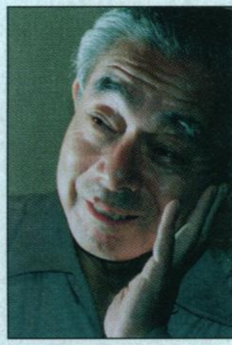
RETROSPECTIVE

Kenichi Fukui (1918–1998)

Kimihiko Hirao

Kenichi Fukui, director of the Institute of Fundamental Chemistry in Kyoto, Japan, passed away on 9 January 1998. Fukui was awarded a Nobel Prize in Chemistry (1) in 1981, jointly with Roald Hoffmann, for their independently developed theories concerning the course of chemical reactions. Fukui conceived the theory of frontier orbitals, which are the outermost orbitals in a molecule, similar to valence orbitals in atoms. In the early 1950s, he proposed that HOMO (the highest occupied molecular orbital) and LUMO (the lowest unoccupied molecular orbital) play a dominat role in reactions, and he called these the frontier orbitals. Fukui discovered that the symmetry of the frontier orbital itself governs chemical reactions, finding that chemical reactions involved neither a square of the frontier orbital, nor an electron density. Based on a solid quantum-mechanical foundation, Fukui was able to naturally incorporate the idea of orbital and orbital phase into his theory. At that time, chemists had tried in vain to solve the challenge of chemical reactions. Once awakened by this insight, chemists around the world were able to explain and predict the course of organic reactions, as if solving a jigsaw puzzle. His theory is now a permanent part of chemistry. The Woodward-Hoffmann rules (2) came about as a result of collaborative work between a genius of organic chemistry and an excellent theoretical chemist. Fukui's background and expertise encompassed both these fields, and his huge commitment to science is self-evident. However, it must be remembered that he was interested in a great number of pursuits, including leisure activities such as walking and reading. Moreover, he had a passion for nature and was deeply concerned about environmental issues. Fukui will be greatly missed; for so many years, scientists have relied on his knowledge and sound reasoning.



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1. For more on Fukui and the 1981 Nobel Prize, see http://www.nobel.se/ lureates/chemistry-1981.html.
2. The Woodward-Hoffmann rules state that a reaction is forbidden if the symmetry of the orbitals is not conserved during the reaction.

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