Linking quantum physics and classical chaos

The equations expressing Newton's laws of motion provide a remarkably successful means for describing the movements of objects ranging from stars and planets to baseballs and dust particles. In the last 10 years, researchers have come to realize that even very simple physical systems governed by these equations can exhibit complicated, unpredictable behavior, now termed chaos.

The situation is somewhat different in the microscopic world of atoms. There, Newton's laws no longer hold sway, and the laws of quantum mechanics, as expressed in the Schrödinger equation, govern the behavior of atoms and electrons. Unlike planets in orbit around a star, electrons can't follow orbits drawn as well-defined curves in space, and they gain and lose energy only in well-defined quantities. In this realm, chaos as seen in classical systems appears absent.

To help answer the question of what happens to chaotic patterns of particle behavior when moving from the classical to the quantum world, several groups of researchers have now formulated mathematical models that attempt to bridge the gap between these two realms. Da Hsuan Feng of Drexel University in Philadelphia and his colleagues describe one such model in the Sept. 15 PHYSICAL REVIEW A. Their theory demonstrates that the introduction of quantum effects can wipe out the chaos seen in classical physics, the researchers say.

Feng and his collaborators approached the problem of reconciling the different mathematical formulations of quantum and classical mechanics by searching for a "deeper" mathematical structure underlying both theories. They discovered a geometric intermediary that seems to encompass key aspects of both classical and quantum mechanics, supplying a framework within which to study systematically the way classical behavior emerges from quantum dynamics.

The resulting equations provide a classical-like picture of a physical system that would normally require a quantum description. By changing the value of a specific parameter in the equations, the researchers can show how the gradual introduction of quantum effects suppresses chaotic behavior. Eventually, that parameter reaches a value at which quantum physics takes over completely and chaos disappears.

"For me, this opens up some questions about the foundations of quantum mechanics," Feng says. "Quantum mechanics has been so successful that we sometimes forget its connection to the macroscopic world. I think this whole question [of the correspondence between the classical and quantum worlds] is beginning to come back to haunt us."

Ronald F. Fox of the Georgia Institute of Technology in Atlanta and his colleagues have taken a different tack. They looked at the behavior of a special, hypothetical physical system that could be treated either as a purely classical problem — in which case it would display chaos — or as a quantum problem. By comparing how the system's quantum version varies depending on whether the corresponding classical version shows chaotic behavior, the researchers hoped to identify characteristics of the quantum system that could be tied to chaotic behavior in the classical system.

"We found that there is such a property," Fox says.

In a quantum system, the Heisenberg uncertainty principle determines how precisely two variables — such as position and momentum — can be defined simultaneously. At the same time, a given variable has a certain probability distribution representing the range of values it may have. When the corresponding classical system is chaotic, Fox and his collaborators find that this probability distribution, initially as narrow as the uncertainty principle allows, becomes extremely broad, growing exponentially as the system evolves.

"For a classical object, one normally thinks of these quantum fluctuations [expressed by the probability distribution] as very, very small and ignorable," Fox says. "We argue that when the dynamics is chaotic, these quantum fluctuations grow very large."

Because of their mathematical complexity, many theoretical problems remain unsolved at both the classical and quantum levels. "Understanding the mathematics of classical nonlinear dynamics is very, very hard," says Roderick V. Jensen of Yale University in New Haven, Conn. "What seems clear is that understanding the classical physics better will allow us to understand the quantum mechanics better."

Meanwhile, experimentalists keep uncovering surprises in the behavior of electrons and atoms under extreme conditions. "Lots of new physical phenomena have been exposed," Jensen says. "In some cases, the quantum behavior can look very much like classical chaos. In other cases, quantum systems have behavior that is completely different from classical chaos but which nevertheless reflects some aspects of the underlying classical mechanics."

Jensen adds, "As a theorist, I am continually amazed at how imaginative nature is compared to the combined efforts of all the theorists actively working in this field." *— I. Peterson*

Fish hint at temperate biodiversity threat

Most groups arguing a need to preserve biodiversity focus on measures to save tropical forests, home to an estimated half the world's plant and animal species. But a new survey of fish in California suggests that the rate and proportion of species declines in temperate aquatic ecosystems matches or exceeds those in the tropics.

Concern about downward trends in California's fish populations prompted Peter B. Moyle and Jack E. Williams of the University of California, Davis, to initiate a statewide analysis of fish diversity. Their findings, published in the just-released September CONSERVATION BIOLOGY, indicate that fish native to California are "in a general state of decline." Most of the decline results from the introduction of "weedy" (non-native) fish species and from massive water-development projects that dam, straighten or divert waterways to serve human needs, they report.

Of 113 native fish species, Moyle and Williams found that seven (6 percent) have become extinct — most since 1960. Another 14 species (12 percent) are officially listed as endangered or threatened with extinction; seven warrant immediate addition to that list; 19 (17 percent) may need listing soon; and 25 (22 percent) show serious population declines. Although 41 of the species (36 percent) "are holding their own without special management," the researchers note that "even abundant species can have unexpected and precipitous changes in status."

The delta smelt offers a case in point. Only a decade ago, it was one of the most abundant fish swimming in the Sacramento-San Joaquin estuary. Last year, wildlife officers requested that it receive protection as an endangered species.

The California survey portrays the plight of fish throughout the western United States and perhaps beyond, says Williams, who has since moved to Washington, D.C., where he manages the Bureau of Land Management's fisheries program. W.L. Minckley, an ichthyologist at Arizona State University in Tempe, goes further. Because California spans such a range of ecosystems — from deserts to neorainforests — the new study probably portrays the status of fish throughout the lower 48 states, he says.

Native fish species serve as a barometer of the health of aquatic communities and are now signaling a "very broad" threat, Williams says. He recommends immediately undertaking national surveys to identify intact fish communities, since habitat protection is most cost-effective when native communities are still largely intact. The U.S. Senate is considering a bill to acquire and protect a range of such habitats. *— J. Raloff*