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Quanta at Large: 101 Things to Do with Schrödinger's Cat
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What's a reef doing in a place like this?

Within an hour after discovering the fossilized remains of a coral reef in the Wallowa Mountains in Oregon, two paleontologists decided that the reef could just as well have been in the Austrian and German Alps. The rock forms and fossils entombed in the Oregon reef were nearly identical to the reef formations in the European mountain chain. "As far as we're able to determine now, almost everything [in the Oregon reef] including the algae has counterparts over in the Alps," says George D. Stanley Jr. at the University of Montana in Missoula.

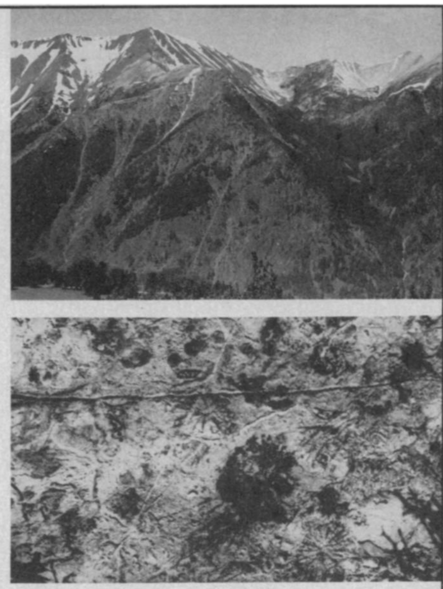
Now Stanley and Baba Senowbari-Daryan of Erlangen University in West Germany are faced with the problem of how the Oregon reef — the first known coral reef of Triassic age (about 220 million years old) found in North America — came to be.

Roxanne Jumer

One theory of how corals and other sea life might have arrived in North America: All aboard the "island boats" become inhabitants of suspect terrains.

While the reef is in North America today, it's unlikely that it originated there, in part because the magnetic signature of the underlying volcanic rocks indicates that they formed at a much more southerly latitude. Sections of the Wallowa Mountains are thought to be parts of "suspect" or "displaced" terrains — the 100 or so chunks of crust that have been grafted onto western North America in the last 200 million years as a result of plate tectonics. Over the last decade scientists have come to realize that when continents break up and crustal plates collide, the process is far from neat; slivers of continents and pieces of oceanic crust — from volcanic islands to ocean ridges — become plastered onto other continents, making a mosaic of lands that are alien to their surroundings.

One of Stanley's theories is that the Oregon reef originally formed much closer to the Alpine reefs. The Alpine reefs are thought to have grown along the banks of a dead-end seaway called the Tethys — which extended from the present east coast of Japan across Asia and into the Alps region — before it closed up to form the Alps. The coral reef now in Oregon might once have capped volcanic islands that formed close to Tethys in an ancestral ocean of the Pacific. But in the course of 220 million years the islands, anchored to the spreading seafloor, moved eastward toward the North American continent, eventually merging into it, according to the theory. Stanley also suspects that by the time they reached North America, the coral reefs had been drowned and killed.



Stanley

Stanley

One of the 20 coral species found in Wallowa Mountains, Oregon (top) — all identical to species found in the Alps.

Another possibility, says Stanley, is that the mobile larvae of the corals, sponges and other reef organisms moved across the ancestral Pacific by "island hopping," swimming from island to island along a chain of islands. A report of the researchers' findings will appear in an upcoming issue of PALAIOS, a new journal of the Society of Economic Paleontologists and Mineralogists. — *S. Weisburd*

Quanta at large: 101 things to do with Schrödinger's cat

Is a zebra a white animal with black stripes or a black animal with white stripes? Either-or? Neither-nor? Both-and? Sometimes-one-sometimes-the-other? This question might be an illustration (analogy, metaphor?) of what a macroscopic superposition of states could be.

Superposition of states used to be confined to the microscopic world of quantum mechanics. In the microcosm, objects have a characteristic duality of nature, a mysterious union of opposites for which Niels Bohr adopted the word "complementarity." As long as it was safely quarantined where we couldn't really see it, we weren't really afraid of it. Now it is breaking loose into the macroscopic world of our ordinary perceptions, and physicists are concerned for the future of classical physics and for our ordinary ideas of what's what.

"Do we really think there's a possibility of seeing quantum mechanical effects on a macroscopic scale?" asked Anthony J. Leggett of the University of Illinois at Urbana-Champaign during the recent conference on New Techniques and Ideas in Quantum Measurement Theory, held in New York City under the sponsorship of the New York Academy of Sciences. "Can you see a pure quantum state in a macroscopic system?" asked Sean Washburn of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y.

The questions are rhetorical. Leggett and Washburn told how to do it. Claudia Tesche, also of the IBM Watson Research Center, described a "system to undergo macroscopic quantum oscillations." Helmut Rauch of the Atomic Institute of the Austrian Universities in Vienna declared that experiments involving wavelike interference effects of neutrons are testing quantum mechanical properties on a macroscopic scale. Leggett's opening remark could sum up the discussion: "The quantum measurement paradox [in which these questions of superposition and duality play a prominent role] is no longer a matter of 'theology.' It has become an experimental subject."

With recent improvements in experimental techniques, physicists are beginning to do experiments that for 50 or 60 years they could only dream about (SN: 1/11/86, p. 28; 2/1/86, p. 70). These thought experiments, or "gedankenexperiments," as physicists tend to call them, were originally devised to illustrate principles or make a point in an argument, not with the expectation that anyone could actually carry them out. In the words of Anton Zeilinger of the Atomic Institute of the Austrian Universities, physicists are now learning "how to ungedanken gedankenexperiments."

This could prove something of a shock to physics and philosophy. For decades there has been a great gulf fixed between the microcosm, where the ambiguities and uncertainties of quantum mechanics prevail, and the macrocosm, where common sense and the classical physics derived from our bodily senses dominate. A school of physicists usually named for

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Albert Einstein and Louis de Broglie has contended that the mysterious dualities and superpositions of quantum mechanics are appearances derived from too little knowledge. If we can gain deeper knowledge of the situation, we will see how to resolve the difficulties, and the unambiguous certainties characteristic of classical physics (or some suitable modification of them) will be seen to apply to the microcosm. Macroscopic experimentation with quantum effects seems likely to test some of these expectations.

The other main current of opinion, historically led by Niels Bohr, tends to believe that the dualities, uncertainties and superpositions of quantum physics are fundamental to nature. *If* that is true and *if* they should be shown to rule the macroscopic world, some interesting and perhaps spooky changes in our way of perceiving the universe would result.

A zebra is not really a superposition of states, but it can be a kind of both-and, sometimes-this-sometimes-that perception. Macroscopic objects are usually one-thing-or-the-other, either-or kinds of beings. A hand is either a left or a right hand. A superposition of states that makes it both at once is something we can hardly imagine let alone describe in words, but we could have to face such situations.

In recent years nature has provided physicists with several phenomena in which macroscopic quantities seem to be quantized or in which macroscopic phenomena are driven by quantized effects. These include certain aspects of superconductivity and superfluidity and the more recently discovered quantized Hall effect. To prove that quantum effects are really operating on a macroscopic scale, experimenters have to suppress or get around the things that make classical physics classical: heat (dissipation) and noise, and environmental connections generally.

Quantum effects have a numerical precision. Changes come in integral multiples of a basic amount (a quantum) characteristic of the system or the situation. Unless they see such quantum multiples and a hierarchy of energy states separated by these quantum jumps, experimenters cannot say they have really seen quantized phenomena. In the macroscopic world, classical nature tends to intervene with environmental effects, heat and noise, that destroy the sharpness (in technical terms, the coherence) of these quantized states and changes.

Experimenters are now learning to suppress these environmental effects. Washburn cites experiments he and Richard A. Webb of the IBM Watson Research Center have done with SQUID circuitry. A SQUID (Superconducting Quantum Interference Device) is a ring of superconducting material interrupted by a thin piece of insulating material. The insulating material makes a tunneling junction, or Josephson junction, and it imposes a hierarchy of quantized states on the relation between current and voltage in these circuits.

The electrons that form the current in the circuit exist in a series of quantized levels that form a kind of cascade from the higher amounts of current the circuit can sustain to the lower ones. To get out of any particular level and cascade to the next level below, the electrons must surmount or pass through an energy barrier. That is, each of these energy states is metastable: The electrons need to get a little energy—from the effects of heating, perhaps—to get out of one state and enable themselves to slide down to the next level below.

Quantum mechanics gives the electrons another out. Instead of getting heated until they have enough energy to surmount the barrier, they can tunnel through it. That is, they never have enough energy to get over the barrier in a classical way, but they get through it nevertheless. From the classical physics point of view this looks like magic, but it is well known to happen on the microscopic level. It arises from the wavelike nature of electrons and so is a direct expression of the duality of quantum physics.

On the macroscopic level the environment intervenes with all its connections to the system and all the possibilities of change they offer to average the quantum states and smear everything out. (On the microscopic level, inside an atom, for instance, there are far fewer environmental connections to do this sort of smearing out.) Washburn says he and Webb have been able to get around these difficulties, and in a series of experiments that manipulated the voltage, current and capacitances of a series of SQUIDs and played up-and-down games with the energy barriers, they have shown that macroscopic quantum tunneling occurs.

Tesche intends to play another kind of game with these energy barriers. Physicists imagine that in each of the quantum states the electrons exist in the bottom of a kind of energy well, known as a potential well. Tesche plans to slosh these wells back and forth. By linking SQUID circuits together she intends to set up an oscillation that will alternately raise and lower the barriers that prevent the electrons from getting out of the wells. Such an oscillation would be an oscillation between quantum states in a macroscopic system, a macroscopic demonstration of a superposition of states. She hopes to do it within a year.

This realizes in very different form a famous thought experiment of Erwin Schrödinger, in which a cat is alternately killed and resurrected by a quantum oscillation.

The wave-particle dualities of quantum physics also drive macroscopic effects in the neutron interference experiments. Starting more than 10 years ago, these experiments have demonstrated more and more wavelike behaviors of neutrons. In neutron interference a beam of neutrons is split in two, sent over different paths and then recombined. In the recombination the experiments show all the effects of adding and subtracting waves of different (or the same) phases.

Now these experiments have reached the point where they can operate with only one neutron in the apparatus. "Only one neutron at a time," says Rauch. "The next neutron is not yet born. It is still in a uranium nucleus in the reactor fuel." As Zeilinger of Vienna describes it, with one neutron in an apparatus 10 meters long they will be able to do analogs to all the experiments that in the 19th century proved the wave nature of light — single slit, double slit, sharp edge, etc. — *and hope to see what the single neutron does.*

The single neutron interferes with itself. It behaves as if it were a wave splitting in two and following separate paths. Yet it is only one neutron. Which path did the single neutron follow? The followers of Bohr (generally known as the Copenhagen school) would say that duality and complementarity make it impossible to talk about a neutron moving in space and time as a billiard ball or a planet does. All we can say is that something we call a neutron entered one end of the apparatus, and at the other end a characteristic interference pattern appeared. The Einsteinian school would say that even though the neutron behaves like a wave it is nevertheless a particle, and it has to take one route or the other. Eventually physics should be able to find out which one.

A way experimenters are planning to find out is to put magnetic coils called spin flippers on the paths. A spin flipper will reverse the spin of a passing neutron by taking a small quantum of energy from it. Neutron spins are quantized, so this is itself a quantum effect on a macroscopic object. It also could identify the path taken by a neutron. Furthermore, manipulating the spins of neutrons in flight should permit the experimenters to study the effects of such changes on quantum coherence and the production of superpositions of neutron spin states in the macroscopic apparatus.

As this kind of experimentation proceeds, physicists hope to learn more about the mysteries of quantum physics. They may also find that those mysteries apply to our familiar macroscopic world. We could then find ourselves in the situation where the left hand can know what the right is doing in ways that it couldn't under classical physics, but at the cost of not knowing whether it is really a right or a left hand. *—D. E. Thomsen*