its actual size, real-world numbers would be even higher—at least 10,000 and often even more, says Lande.

"What Lande has done is partition out the quasi-neutral mutations—the only ones potentially useful for evolution—from all new mutations. The resulting mutational input is lower than expected, so you need a much bigger population," explains geneticist Philip Hedrick of Arizona State University in Tempe.

That conclusion is further buttressed by studies in which Lande and his Oregon colleague Michael Lynch, who was working independently on similar questions, explored another genetic danger faced by small populations: an extinction spiral Lynch has christened "mutational meltdown." In this process, mildly deleterious mutations—whose effects are too small for them to be purged by natural selection—accumulate and become fixed in small populations. Their cumulative impact eventually leads to extinction.

In papers in this month's issue of *American Naturalist* and in press at *Evolution*, Lynch and colleagues John Conery, also at Oregon, and Reinhard Bürger of the University of Vienna use genetic models, computer simulations, and empirical data on mutation frequency to calculate that on time scales of 100 generations, effective populations smaller than 100 individuals are at risk. Lande, using a different genetic model, gets even higher numbers, estimating that an effective population of 1000 is needed to avoid mutational meltdown.

Although their estimates aren't identical, Lynch and Lande agree that when the effects of both genetic perils are considered, the old numbers need to be revised upward, to effective populations on the order of thousands rather than hundreds. Actual populations would be even higher. "The main point is that 500 is too low," says Lynch, who says that a "genetically safe" real-world population would be about 10,000.

All these new estimates are much larger than the populations of most endangered species. On average, only about 1000 individuals remain when an animal species makes the endangered list—and only about 120 individuals of plants—according to a 1993 study by the Environmental Defense Fund. The somber implication for those trying to save endangered species: They're going to need a much bigger ark.

–Elizabeth Culotta

PHYSICS

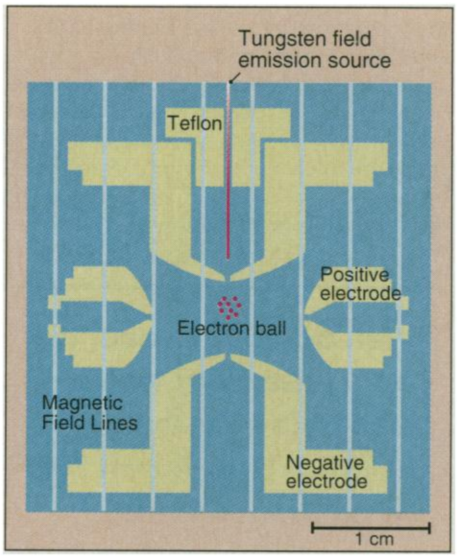
Electron Ball Probes 'House of Mirrors'

All theories strive for accuracy, but none succeeds more spectacularly than quantum electrodynamics. QED's predictions of how particles behave in electric and magnetic fields have held up to within a few parts per billion in some of its most demanding tests, which scrutinize the behavior of a single electron in an electromagnetic trap. Success has made experimentalists greedy for still more accuracy, however. They want to see whether tiny discrepancies between QED's predictions and their measurements result from flaws in the theory or in the experiments—and that means accounting for tiny perturbations introduced by the traps themselves. In an upcoming issue of *Physical Review Letters*, a group at the University of Washington reports a way to do just that, by first creating a superelectron that magnifies those perturbations, then scaling the perturbations down to a single electron.

The group's recipe for a superelectron is simple: Just confine a thousand electrons in the region of the trap ordinarily occupied by one. As a result, all of the electron's properties are multiplied, including one that has been the bane of experimenters: the tendency of the negatively charged electron to induce "image charges" in nearby conductors, which in turn subtly influence the electron's behavior. These image charges, says Richard Mittleman, one of the experimenters, cause a trap to behave like a "house of mirrors." They confuse the search for the slight deviations from QED that might point to a better theory, or perhaps suggest that the electron is not an indivisible particle.

But Mittleman and Washington colleagues Hans Dehmelt and Sander Kim found that an electron ball can amplify the house-of-mirrors effect. As a result, says Dan Dubin of the University of California, San Diego (UCSD), "you see the effect directly instead of having to evaluate it [theoretically]." And that should open the door to more accurate tests of QED with single electrons.

To create the electron ball, the team fired a beam of electrons into a standard electromagnetic trap, a device that can confine electrons along magnetic field lines capped with negatively charged end plates. The energetic beam knocked clouds of slower electrons from residual gas atoms in the trap.



Electrons by the kilo. A ball of 1000 electrons probes the effects of "image charges" on measurements in an optical trap.

These electrons eventually condensed into a ball less than 200 microns across.

Electrons caught in such a trap orbit the magnetic field lines at a rate known as the cyclotron frequency. For a single trapped electron, the ratio of this cyclotron frequency to the rate at which each electron's direction of "spin" precesses, or wobbles, gives a measure of the electron's intrinsic charge and magnetism and how it interacts with the fleeting "virtual" particles that populate free space, according to QED. That's where the house-of-mirrors effect comes in. For the comparison with theory, "you want to measure the properties of an isolated electron in empty space," says Dehmelt, but the image charges cause an unpredictable slowing or speeding up of the cyclotron motion.

Because a 1000-electron ball has the same charge-to-mass ratio as a single electron, its cyclotron frequency—in this case, 164 billion hertz—should also be the same, except for a stronger contribution from image charges. To tease out those effects, the team went on to trap smaller balls, containing hundreds fewer electrons. They saw the frequency increase by about 5 hertz for each electron removed. The increase implies that the image effect, at the same magnetic field strength, should slow a single electron by 5 hertz.

"It's a very nice experiment," says UCSD's Dubin, and it should help remove the largest remaining uncertainty in the single-electron tests. Others, such as Gerald Gabrielse of Harvard University, who has performed related measurements, want to see more data before they're convinced. "It would be nice to show that the [shift] is different at different magnetic field strengths," as theory predicts, he says.

The Washington team plans to go even further than Gabrielse suggests. Taking their cue from another theoretical prediction, they hope to find the precise field strengths at which "the whole frequency shift disappears," says Dehmelt. Then, by running single-electron tests of QED at those field strengths, Dehmelt hopes to feed yet another order of magnitude to the most ravenous obsession with accuracy in physics.

–James Glanz