basalt rocks (see, for example, ref. 11).

So should we rush out to buy this new model? Not yet. With such high compatibility, getting the noble gases out of the mantle at all becomes a significant problem. If we can indeed directly scale $^{40}$Ar concentrations in the convecting mantle to the $^{4}$He flux into the oceans, $^{40}$Ar concentrations in the convecting mantle today would be two to three times higher than the zero-paradox reference value — we would have more $^{40}$Ar in the combined convecting mantle plus atmosphere than the Earth has produced since its formation. Watson and colleagues’ results also point to ultra-slow argon diffusion rates even at mantle temperatures. This would mean that it is very hard for olivine, which is the dominant mineral of the upper mantle, to release its helium or argon at all unless melted. A simple, testable prediction of the model would be that freshly exhumed mantle olivine should contain $^{3}$He and $^{40}$Ar concentrations somewhere between currently accepted average mantle values and the zero-paradox values.

Like many such laboratory studies, the question arises as to how relevant the results truly are to the mantle. Watson et al. exposed the surfaces of their crystals of olivine and enstatite to hot, pressurized argon gas, and deduced high argon compatibility from the high argon concentration at the surface, and very slow diffusion rates from its low penetration into the rest of the crystal. Such surface effects have been observed, in less detail, in other minerals before1. But work on natural glass-olivine samples, theoretical lattice-accommodation models and laboratory experiments2,3, involving crystals grown from a melt containing inert gases, have all resulted in the opposite conclusion — inert-gas incompatibility.

So does the Earth hold its breath? Someone has got it wrong. Let’s hope we don’t have to hold our own breath too long to find out who.

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Our everyday experiences lead us to expect things to seek equilibrium quickly when perturbed from rest. Cold milk poured into hot coffee, for example, soon distributes itself evenly, equalizing the temperature throughout the liquid. This kind of system, which over time samples every state available to it and so can relax to a true equilibrium state, is called ergodic. But unlike the milk-in-coffee example, not all systems that are governed by classical mechanics are ergodic, and it is difficult to push a system that is not naturally ergodic into an ergodic, equilibrium-seeking state. On page 324 of this issue, Hofferberth and colleagues report experiments that seem to indicate that a similar operation is much easier in the quantum world.

In classical statistical mechanics, concepts of ergodicity and thermodynamic irreversibility were originally addressed by Ludwig Boltzmann. His celebrated ‘H-theorem’ of 1872 states that an ideal gas will reach equilibrium starting from an arbitrary initial state. But even in classical mechanics, equilibrium and the equalization of temperature are not guaranteed. One class of many-body systems, described by so-called integrable models, follows very different, non-ergodic dynamics, which does not allow relaxation to true equilibrium. Such systems have an infinite number of conservation laws, which prevents the sampling of the entire phase space, meaning that true equilibrium cannot be attained.

In fact, according to a well-founded hypothesis of classical dynamics, the Kolmogorov–Arnold–Moser (KAM) theorem, a classical system does not even have to be exactly integrable to be non-ergodic; being nearly integrable is enough. For example, coupled nonlinear oscillators in a linear array do not equilibrate (share their energy equally), even though this system is integrable only when the distance between the oscillators tends to zero. Theorists continue to argue whether the KAM theorem has an equivalent in quantum dynamics, but others have set out to address the question experimentally. Their chosen proving-ground is the dynamics of one particular near-integrable quantum system — a condensate of cold atoms caught in a one-dimensional trap.

Just last year, the momentum distribution of a condensate of atoms confined to a one-dimensional tube and then kicked out of equilibrium was measured. It did not re-equilibrate for a very long time — instead, individual atoms passed through each other repeatedly without ever coming to rest. This ‘quantum Newton’s cradle’ was interpreted as a signature of non-ergodic dynamics in a near-integrable system, exactly as seen in the classical case.

Hofferberth et al. investigated a similar system brought out of equilibrium in a different way, and came to precisely the opposite conclusion. They took a single condensate of ultracold rubidium atoms, caught in a one-dimensional magnetic trap, and split it along its length into two identical halves. After holding the atomic clouds separate for a certain time, the

CONDENSED-MATTER PHYSICS

Relaxation after a tight squeeze

Ehud Altman and Eugene Demler

Are the rules that determine relaxation to equilibrium the same in the classical and quantum worlds? Recent experiments supported the idea that they are — but an investigation with ultracold atoms now contradicts that.
Sexual reproduction relies on two cellular processes: meiosis, through which two cellular divisions produce gametes (sperm and egg), and fertilization, whereby male and female gametes fuse to form a zygote. In most organisms, the egg must halt meiosis to prevent embryonic development in the absence of calcium ions (Ca$^{2+}$). Calcium’s double punch is required for meiotic arrest mediated by CSF to ensure the success of embryonic development. It seems that calcium activates apparently opposite molecular signalling pathways to achieve that end.

Calcium’s double punch

Catherine Jessus and Olivier Haccard

Fertilization promotes a calcium surge necessary to ensure the success of embryonic development. It seems that calcium activates apparently opposite molecular signalling pathways to achieve that end.

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