connecting the two choices — one marble can just roll over to the other one. The condensate wavefunction can thus 'unwind' in the complex plane and the soliton can vanish.

A topological defect can only form where at least three regions of different $<\Psi>$ meet on a line, and only if the angle of $<\Psi>$ changes by a non-zero multiple of 2π as one goes around that circle — the marble makes a non-zero number of round trips around the Mexican hat. Such round-trip paths cannot be contracted to a point without crossing zero, and so this line defect is topologically stable. The only possible value for the condensate wavefunction on the line is therefore zero, again the normal state, and the defect is topologically stable. This is the case for the proposed cosmic strings in the Universe, as well as for vortices in superfluids and superconductors.

The observation of solitons on quench-cooling is already a surprising finding, and the longevity of the created defects — surviving for over a second — is counter to common expectation. Solitons in fully three-dimensional BECs as prepared by Lamporesi *et al.* are expected to 'snake' and bend, and eventually decay into vortex rings and lines[9,10]. It was widely believed that BECs would have to be strongly confined into a quasi-one-dimensional tube to prevent snaking. However, both the present experiment and another recent experiment on a strongly interacting fermionic superfluid[11] are performed in a fully 3D setting, yet solitons are found to be stable. A partial solution to the riddle is probably an enhanced stability of solitons due to interactions in the gas that decrease the decay rate of the snake modes. In addition, at sufficiently low temperature there are simply not enough excitations available to trigger snaking. If the lifetime of solitons is thus much longer than the total time it takes to cool through the phase transition and establish local order, a large number of such non-topological defects will be seen. This was recently predicted[8] and has now been observed in the laboratory[7].

The experiment by Lamporesi *et al.* represents a beautiful demonstration of the Kibble-Zurek mechanism, and shows that long-lived non-topological defects emerge as the phase transition is crossed. The characteristic scaling for the number of solitons versus cooling rate could allow the extraction of the critical exponents of interacting condensates and strongly interacting fermionic superfluids — whose non-equilibrium properties are largely unknown. Their study is therefore an exquisite example of how careful laboratory experiments with ultracold gases can improve our understanding of Nature in the much broader context of condensed matter physics, particle physics and cosmology. ❐

Martin W. Zwierlein is at the Massachusetts Institute of Technology, the MIT-Harvard Center for Ultracold Atoms and the Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA.
e-mail: zwierlein@mit.edu

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ELECTROCHEMISTRY

Discrete answer

For almost a century, deviations of Ohm's law have been known to occur in electrolyte solutions. Now, lattice-model simulations of these systems are providing valuable insight into the microscopic mechanisms involved.

Erik Luijten

For many of us, Ohm's law was one of our first encounters with the theory of electricity. Governing the fundamentals of electrical circuitry in numerous applications, it states that the electrical current through a material is linearly proportional to the applied voltage. However, in the 1920s Max Wien noticed deviations from this relationship in a wide variety of electrolyte solutions when high electric fields are applied[1]. These deviations are not always small: for certain classes of electrolytes the conductivity can increase several times when the field strength is increased. Within a few years of this discovery, Lars Onsager, one of the giants of statistical mechanics and later a Nobel laureate in chemistry, presented a comprehensive theoretical description that matched the data well[2]. Now, as they explain in *Nature Materials*, Vojtech Kaiser and colleagues have used Monte Carlo simulations to show that this theory also describes the so-called Wien effect when the electrolyte is modelled as a lattice[3] — making it possible to study how the change in conductivity arises on a microscopic level.

Wien performed his original measurements[1] on so-called strong electrolytes, in which all salt molecules have dissociated into positive and negative ions. Each ion is surrounded by an oppositely charged 'cloud' of other ions. In an electric field, the ion and its cloud are moving in opposite directions, slowing each other down and suppressing conductivity. When the electric field is so high that the cloud cannot relax quickly enough, this effect diminishes. However, Wien[4] (and to some extent Gyemant[5] before him) observed a far stronger increase in conductivity for weak electrolytes, in which the salt is only partly dissociated. This phenomenon, now known as the second Wien effect, has a different underlying mechanism, namely the field-dependent dissociation of bound pairs of oppositely charged ions: as the field strength increases, the number of mobile charge carriers in the material grows.

The magnitude of the second Wien effect depends on the type of electrolyte, and various parameters come into play, including temperature, salt concentration and dielectric constant of the solvent. Onsager, who had been interested in electrolytes since the very beginning of his scientific career[6], derived a beautiful theoretical description of the field-dependent electrolyte dissociation in which all parameters appear in the form of a single ratio between two length scales:

the Bjerrum length, the separation at which the Coulomb interaction between two ions equals their thermal energy; and the field length, the distance over which the electrical energy of a single ion varies by the thermal energy[2]. Even though Onsager's work is very widely cited and, as Kaiser *et al.* point out[3], of direct relevance to a striking variety of phenomena that range from the role of electric fields in biological systems[7] to the dissociation of charge carriers in photoexcitation[8], it seems not to have been probed using numerical simulations.

This lack of numerical verification is surprising not so much because of the need to test Onsager's theory more carefully (it has long been known to describe the experimental data remarkably well), but rather because discrete simulations offer insights complementary to both theory and experiment. Without requiring the mean-field type approximations often invoked in theoretical treatments, these simulations yield both macroscopic observables (such as the conductivity of the system) and the behaviour of individual charge carriers that is typically not accessible experimentally. Several factors conspire to make this problem computationally demanding, accounting for the dearth of simulation studies so far: one must deal with a system of charge carriers and ion pairs at low concentration (which requires large-volume systems to ensure an appreciable number of particles), all strongly coupled by long-range interactions. This vexing situation is remarkably similar to what has long plagued the study of various other fundamental questions in electrolytes, in particular the nature of their critical point[9], a long-standing question that was ultimately resolved[10] by using techniques comparable to those used by Kaiser and colleagues.

One strategy adopted to accelerate the calculations is the use of a lattice model, in which the ions are located at discrete sites. Despite this significant simplification, the numerical results for a range of properties extracted from the simulations — including the number of bound pairs and the ionic conductivity as a function of the applied electric field — are described remarkably precisely by Onsager's theory. This not only reinforces the validity of the latter, but also instils confidence that coarse-grained models go a long way towards reproducing subtle phenomena. The true strength of these models is then the microscopic information that they provide, a point illustrated through the positive–negative pair correlation function, which exhibits an asymmetry along the electric field that could not have been deduced from conductivity measurements alone.

Kaiser and colleagues have performed their study in a skilful manner, cleverly exploiting existing theoretical insights to derive maximum gain from the coarse-grained model. Nevertheless, the real merit of their work lies at least as much in reinvigorating some of the phenomena that were investigated and explained so carefully in the very early days of electrochemistry. It reminds us of the exceptional insight of its pioneers, whose near-legendary names are now indelibly connected to the fundamentals of this fascinating and practically important field. ❐

Erik Luijten is in the Department of Materials Science and Engineering and the Department of Engineering Sciences and Applied Mathematics, Northwestern University, Evanston, Illinois 60208, USA.
e-mail: luijten@northwestern.edu

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QUANTUM GASES

Relaxation dynamics

The current understanding of the relaxation dynamics in quantum many-body systems is still incomplete, but an ultracold atom experiment brings new insights by confirming the local emergence and propagation of thermal correlations.

Marc Cheneau

It is usually assumed that, if left alone, a piece of matter will sooner or later reach a state of equilibrium. From the viewpoint of classical physics, equilibration occurs because the microstate of the system uniformly explores the phase space over time — this is the long-established concept of ergodicity. But in quantum mechanics things are different, the reason being that quantum dynamics constrains the microstate to evolve along a periodic orbit in the Hilbert space, which is the quantum equivalent of the classical phase space. In the absence of classical ergodicity, what mechanism can then lead to the equilibration of an isolated quantum system?

This 50-year-old question has been the subject of renewed interest in the past few years[1], with notable input from the field of quantum information theory. According to a recent conjecture[2,3], the relaxation dynamics is driven by the propagation of elementary excitations that travel across the system like acoustic waves along a pinched cord. By connecting the distant parts of the system to each other, the excitations provide the necessary mixing that leads to equilibration. Writing in *Nature Physics*, Tim Langen and colleagues[4] report direct experimental evidence for this remarkably elegant scenario.

Establishing a generic framework to describe the relaxation dynamics of quantum systems is such a vast task that the only viable strategy for theorists has so far been to focus on simple systems and to ask simple questions. A typical example is to consider a spin chain that is initially polarized by a very large magnetic field, and to investigate how the correlations between distant spins evolve once the field has been suddenly switched off. The role of experimentalists is then to perform the corresponding measurements on real, more complicated systems, in the spirit of the celebrated quantum simulation approach[5].