straight line. If the deviation from linearity were upwards as $T-T_\infty$ approaches zero, the divergence of timescales would be stronger than VFT, and if the divergence were downwards, it would suggest that the divergence is weaker than VFT or could be going towards Arrhenius-like. It is clear from the figure that the divergence is downwards and the data are fully consistent with conclusions made by Hecksher *et al.* — that is, these data too suggest that the timescales related to the glass transition may not diverge at finite temperatures. Similar findings, though presented differently, have been made for polymers and small-molecule glass-formers[8,9]. However, this too should be taken with a grain of salt as not all investigations[10] agree with these results, and there is evidence to suggest that different processes[7] have different time- and temperature-dependencies near the glass transition — which is yet another confounding and important problem of glass-forming liquids.

To add to this, even the expected connection mentioned above between the Kauzmann temperature T_k and the VFT temperature T_∞ is far from clear. There is important work in the literature that challenges not only this link, but also whether or not T_k itself represents a meaningful or significant thermodynamic signature of the glass transition[11,12]. It is likely, then, that the nature of the glass transition will remain a difficult problem for the foreseeable future. Despite the extremely long timescales necessary to conduct experiments at temperatures below the glass transition, it seems that such could be the only way to fully assess the validity of the conclusions reached by Hecksher *et al.* It may be that other methods of extrapolation to the equilibrium state need to be considered[12] as well. But at the very least, these conclusions do suggest that that the status quo represented by the VFT and WLF equations will need to be reconsidered if we are ever to reach a definitive theory for the glass transition in complex fluids.

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POLARITON CONDENSATES

A feature rather than a bug

Recent work on Bose–Einstein condensation of short-lived 'quasiparticles' in solid-state systems opens up the new field of non-equilibrium condensates.

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When an ensemble of bosons is cooled to low-enough temperatures, a substantial fraction of the particles spontaneously enter a single quantum state. This phenomenon is known as Bose–Einstein condensation (BEC), and the most famous experiments are those involving atomic gases. But the past couple of years has seen a flurry of work on BEC in systems where the condensates consist not of free atoms in a gas, but of so-called quasiparticles in solid-state systems. One class of such quasiparticles is polaritons, which are formed from electronic excitations coupled to photons in a microcavity. A number of BEC-like effects have been observed in this type of system, including a bimodal momentum-space distribution with a narrow peak at zero momentum[1–3], long-range off-diagonal order[2,3], spatial condensation in a macroscopic trap[3], spontaneous symmetry breaking[4], flow without dispersion[5], and a dramatic increase of coherence as measured in first-order and second-order correlation measurements[6].

Two papers in this issue now report canonical features of polariton BEC that further strengthen the connections between the BEC of free atoms and the BEC of electronic quasiparticles in solids (Table 1). On page 706, Konstantinos Lagoudakis and colleagues[7] present evidence for the existence of quantized vortices in a polariton BEC, whereas Shoko Utsunomiya and co-workers[8], writing on page 700, observed a linear Bogoliubov excitation spectrum. Both phenomena are associated with (but not direct tests of) superfluidity in these systems. More importantly, however, they add to a consistent body of work that can build the basis for studying BEC away from thermal equilibrium.

A microcavity polariton is a charge-neutral bosonic quasiparticle in a solid. Don't be hung up on the term 'quasiparticle' — to all intents and purposes they are 'real' particles that move freely as a gas. Polaritons have very light mass, about ten thousand times less than a free electron, they interact weakly with each other, like atoms, and they have a finite lifetime (but their total number is approximately conserved during their lifetime). Polaritons live in a two-dimensional plane, where they can move freely for macroscopic distances, and they can be held in a macroscopic harmonic-potential trap in that plane[3]. Experimental techniques exist that can be used to determine the momentum-space and real-space distribution of the polaritons simultaneously, and there are also methods for looking at long-range coherence and various statistical properties.

Table 1 Types of condensates. Both trapped atoms and excitonic condensates can also be made strongly interacting by changing various experimental parameters.

	Strongly interacting	Weakly interacting
Free atoms	Helium	Trapped atoms
Electronic quasiparticles in solid	Superconductors	Excitonic condensates

At one point, there was debate about whether the polaritons maintain their bosonic character (known as 'strong coupling' between the photon part and the electronic part) at densities high enough to condense, but it is now standard to show that the polaritons remain good bosons in the strong-coupling regime when the above-mentioned effects occur, including the spatial condensation. When the strong coupling breaks down, the system becomes a standard laser. Recent experiments[9,10] demonstrate that polariton BEC and standard lasing can occur as two quite separate transitions at the same place in the same sample, at different densities.

The lifetime of the polaritons in these experiments may seem dauntingly short: a few picoseconds. But the absolute time, of course, is irrelevant; what matters is the ratio of the lifetime to the equilibration time, which is of the order of the particle scattering time. If the lifetime is long compared with the equilibration time, it is proper to treat the system as being in equilibrium[11]. In the case of polaritons, at low density the picosecond lifetime is short compared with the time of equilibration via phonon emission and absorption. As the polariton density is increased, however, polariton–polariton scattering becomes more important, and can become short compared with the lifetime. It never seems to become less than a factor of five or so below the lifetime, however. When the polaritons condense, a new radiative channel of coherent, laser-like photon emission is opened up. Raising the polariton density just increases this coherent emission, and eventually destroys the condensate by an effect known as phase-space filling.

As a result, the momentum distribution measured in the experiments never fits an equilibrium Bose–Einstein distribution. Instead there are three regions of momentum space: a higher-energy 'reservoir' of excitons (which are similar to polaritons, but with much longer lifetime and much heavier mass, on the order of the electron mass); the low-energy polariton states; and a 'bottleneck' region in between. Each of the three regions has a different characteristic temperature. Numerical models[12–14] show that Bose statistics of the particles have an important role in the build-up of the condensate, but the constant inflow of hot polaritons prevents equilibration of the low-energy polaritons with particles in higher energy states.

Is the polariton system therefore uninteresting, because it has incomplete equilibrium? As the classic sales phrase has it, "it's not a bug, it's a feature". Weakly interacting condensates in equilibrium are now thoroughly understood. Much atom-trapping work has turned to non-condensates and fermionic systems. In excitonic and polaritonic condensates, a new knob can be turned, which is the lifetime of the particles. The surprising thing is that despite the incomplete equilibrium, so many of the canonical telltales of condensation can still be observed in polaritonic condensates. But what, exactly, determines the point of breakdown, when we can no longer speak of a condensate because the lifetime is too short? Which properties of a condensate are robust against non-equilibrium perturbations? These questions can be asked very generally in regard to any system of bosons, but polaritons provide a test bed for experimental investigations.

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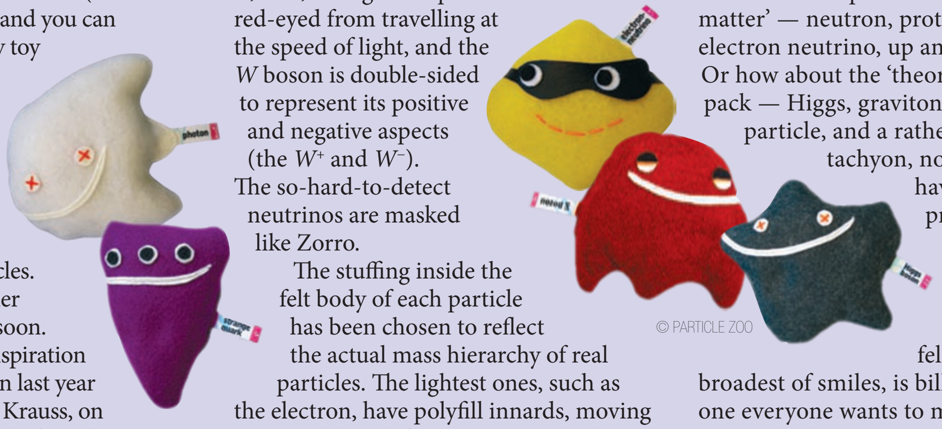
PARTICLE PHYSICS

Going to the zoo

The standard model of particle physics includes a veritable 'zoo' of subatomic particles. Visit the Particle Zoo (at www.particlezoo.net), and you can order your own cuddly toy version of your favourite particle.

Created — and sewn individually — by Julie Peasley, the zoo currently comprises 33 toys of particles and antiparticles. Supersymmetric partner particles are to follow soon.

Peasley cites her inspiration as a public lecture given last year at UCLA by Lawrence Krauss, on "The beginning and end of time". With advice from physicist Derek van Westrum, she devised her toy zoo, in which each of the particles and antiparticles has a distinct, and appropriate, appearance.



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The charm quark, for instance, bears a red rose, and the three-eyed strange quark is, well, strange. The photon is red-eyed from travelling at the speed of light, and the *W* boson is double-sided to represent its positive and negative aspects (the W^+ and W^-). The so-hard-to-detect neutrinos are masked like Zorro.

The stuffing inside the felt body of each particle has been chosen to reflect the actual mass hierarchy of real particles. The lightest ones, such as the electron, have polyfill innards, moving up to poly beads for the muon, which is described on the website as a heavy electron that "lives fast and dies young". Monster particles such as the top quark are stuffed with polished gravel.

Each particle is available individually, or in a series of collections. There's the six-pack of 'everyday matter' — neutron, proton, electron, electron neutrino, up and down quarks. Or how about the 'theoreticals' four-pack — Higgs, graviton, dark-matter particle, and a rather evil-looking tachyon, none of which have yet been proved to exist.

The Higgs boson, rendered in grey wool felt and with the broadest of smiles, is billed as "the one everyone wants to meet". Indeed it is: with the start-up of the Large Hadron Collider now confirmed for 10 September, we could soon be making its acquaintance.

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