

PERSPECTIVES

been passing mention of this only in one experiment so far (6).] Fourth, at least one biochemical substrate must be found that affects reconsolidation selectively while not affecting consolidation of the original memory. This is essential, otherwise reconsolidation could be confused with new additional learning (5).

Lee *et al.* (1) have now carried out the last two sets of experiments successfully. They found that intrahippocampal administration of a Zif268 antisense oligodeoxynucleotide (ODN), when given at the time of the first of three memory retention tests, hindered retrieval for the two remaining sessions. Furthermore, they observed that this treatment did not affect consolidation of the original memory. In contrast, an antisense ODN for brain-derived neurotrophic factor (BDNF) selectively blocked consolidation but not reconsolidation. The investigators conclude that there is a double dissociation between consolidation and reconsolidation, and between BDNF and Zif268. Memory consolidation requires BDNF but not Zif268, whereas reconsolidation recruits Zif268 but not BDNF.

There are two other major forms of memory loss besides Pavlovian extinction: Freudian repression and amnesia. The

mechanisms of Pavlovian extinction involve the activation of enzymatic pathways, gene expression, and protein synthesis in the hippocampus and amygdala (7, 8). The mechanism of memory repression consists of the inhibition of hippocampal activity through the influence of prefrontal neurons at the time of memory retrieval (12). Amnesia is widely believed to result from real neuronal or synaptic loss that can be either morphological or functional. The passage of time is often accompanied by some degree of forgetting, even in the absence of brain disease, so doubtless research into the retrieval of remote memories will continue to thrive.

The hippocampus and several other cortical areas, including the anterior cingulate cortex, are necessary for the retrieval of memories associated with contextual fear conditioning (4). In their study, Frankland and co-workers (2) show that the anterior cingulate cortex is particularly crucial for retrieval of remote fear memory. They demonstrate that retrieval of remote fear memory in mice is accompanied by an increase in Zif268 and the product of another activity-dependent gene (*c-fos*) in the anterior cingulate cortex and other brain areas. This increase is not seen in animals with transient blockade of the nucleus accumbens or in mu-

tant α -CaMKII mice in which the remote memory of contextual fear is impaired.

It would be useful to investigate whether the phenomena described by Lee *et al.* (1) and Frankland *et al.* (2) also are observed in tasks other than those involving contextual fear conditioning in a restricted environment. Such findings would reconsolidate the results discussed here and would ensure their future as a remote memory that can be readily retrieved.

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PHYSICS

Colloids as Big Atoms

Wilson Poon

Colloid science is important for applications ranging from drugs to dairy products. Less well known is that it can also illuminate basic physics questions, because in certain crucial respects, colloids behave as “big atoms.” The report on page 847 of this issue by Aarts *et al.* (1) beautifully illustrates this approach, which was pioneered by Einstein. In particular, the results show that phenomena at the interface between a liquid and a vapor can be studied with a colloidal model.

Beginning with his doctoral thesis, Einstein showed that the incessant, random jiggling of colloidal particles known as Brownian movement was the visible manifestation of the “graininess”—the molecular nature—of the surrounding liquid. One consequence is that the density of particles as a function of height in a dilute suspension in sedimentation equilibrium is given by an equation that depends on the particle’s buoyant mass, the gravitational accelera-

tion, Boltzmann’s constant, and the absolute temperature. It turns out that this equation also expresses the distribution of gas molecules in a constant-temperature atmosphere in gravity, where it is known as the barometric distribution. In other words, colloids made up of relatively large particles can behave in the same way as much smaller counterparts in the molecular world; for some purposes, colloids behave as “big atoms.” Jean-Baptiste Perrin’s experimental verification of the “colloidal barometric distribution” contributed toward his 1926 physics Nobel Prize and the widespread acceptance of the reality of molecules.

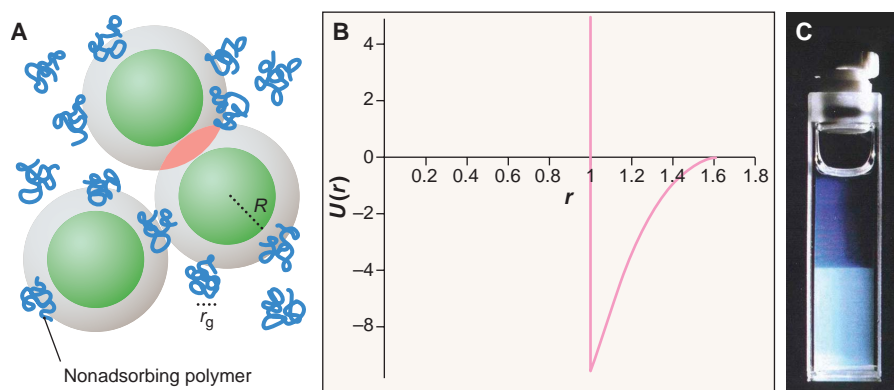
Today, the study of colloids is throwing new light on fundamental problems of condensed matter physics, from the kinetics of crystallization (2) to the nature of glassy states [(3, 4); see (5) for a review]. In their work, Aarts *et al.* (1) use colloids to study the vapor-liquid interface. At conditions far from the critical point (the temperature and pressure beyond which vapor and liquid do not exist separately), such interfaces are macroscopically flat. Microscopically, however, thermal energy excites ripples in the

interface. These capillary waves (which, like capillary rise, are governed by the surface tension) are important in diverse fields such as oceanography (where wind-excited capillary ripples amplify to giant waves) and the rupture of polymer films (which is bad for coatings). After a century of study, these ripples still hold surprises. Thus, recent x-ray scattering from capillary waves in organic liquids (6) shows that as we move down to molecular length scales, the surface tension first decreases and then increases again; the decrease is probably caused by the long-range nature of the dispersion (that is, van der Waals) forces between the molecules.

Vapor-liquid coexistence reflects a tug of war between intermolecular attraction and repulsion. Aarts *et al.* used inert polymers to induce attraction between hard-sphere colloids of diameter $d \approx 140$ nm. Polymer coils are excluded from the region between the surfaces of two nearby particles, creating an unbalanced osmotic pressure pushing them together—the particles effectively attract each other (see the figure, A). The range and strength of this so-called depletion attraction is directly proportional to the size and the concentration of the inert polymers, respectively (see the figure, B).

The study of such colloid-polymer mixtures has yielded many new insights [see (7) for a review]. In particular, it has been

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Colloidal coexistence. A schematic illustration of the origin of the polymer-induced depletion attraction between hard spheres. (A) The centers of mass of the polymer coils with radius of gyration (r_g) (blue) are excluded from a thin shell (white) surrounding each particle of radius R (green). There is no polymer in the lens-shaped region (red) between two nearby particles, leading to a net osmotic force pushing them together. (B) The depletion potential, $U(r)$, for a polymer that is $\sim 60\%$ the size of the colloids (with diameter $2R$ set to unity). (C) A colloid-polymer mixture showing coexisting colloidal liquid (lower) and colloidal vapor (upper) phases. Note the macroscopically sharp interface. Aarts *et al.* (1) obtained images of the interface in a similar system at near-single-particle resolution.

verified that attraction is necessary but not sufficient for vapor-liquid coexistence. An attraction of long enough range is needed—something like a quarter of the size of the particles or larger. Thus, by adding sufficiently large polymers to a suspension (Aarts *et al.* used polymers that were 60% the size of their particles), it is possible to create colloidal vapor-liquid coexistence—thermodynamically stable phases of dilute and dense disordered arrangements of diffusing particles, separated by an interface (see the figure, C).

The colloidal vapor-liquid interface has many of the properties one expects from its molecular analog. For example, Wijting *et al.* have demonstrated that the colloidal interface shows a curved meniscus next to a wall as a result of capillary rise (8). Now Aarts *et al.* have studied the capillary waves at this interface. To understand why their work is feasible and beautiful, we need to know that the surface tension scales as the inverse square of the particle diameter, d . Thus, colloids, with $d \approx 10$ nm to $1 \mu\text{m}$, give very low values of surface tension indeed, from micronewtons per meter down to nanonewtons per meter (compare this with the surface tension of water at 70 mN/m). This made the task of Wijting *et al.* (8) rather difficult because capillary rise is proportional to surface tension. On the other hand, the low surface tensions in colloid-polymer mixtures mean that the capillary wave amplitude and velocity have values of ~ 0.1 to $1 \mu\text{m}$ and ~ 1 to $10 \mu\text{m/s}$, respectively, in the system of Aarts *et al.* This made it possible for them to catch capillary waves “in the act” by real-time imaging using fluorescent particles and a confocal microscope.

Their observations confirmed various

features expected of classical capillary waves, including a dramatic increase in amplitude near the critical point [see the bottom part of figure 1 in (1)] and certain predictions for the interfacial roughness and dynamics. The full power of this approach, however, emerges with the observation by Aarts *et al.* of capillary waves roughening up the surface of droplets, leading to their coalescence [figure 3C of (1)]. That capillary waves have this role has

ECOLOGY

Domains of Diversity

Stuart L. Pimm and James H. Brown

Leaving an English winter, Charles Darwin was soon writing gushing prose to his family about Brazil’s biodiversity (1). He expected such variety because for centuries naturalists had returned from the tropics with unusual and colorful specimens. Yet, even today, pointed disagreements persist about why the tropics have more species than other latitudes. The many hypotheses (2–4) reflect three deeply different approaches. Two date back to the time of Wallace (2): One stresses ecological processes, such as a location’s temperature and rainfall, the other historical factors, such as whether a region was covered in ice during recent glaciations. The third approach is a newcomer that explains species

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long been suspected; their small amplitudes and fast speeds in molecular systems, however, have hampered experimentation.

The longer term significance of the work of Aarts *et al.* lies in the possibilities it opens up. An optical microscope can resolve submicrometer features. By using somewhat larger particles, one could image capillary waves down to the single-particle level. In this case, the depletion attraction has strictly finite range, so we may expect that the decrease in surface tension with length scale observed in molecular systems (6) will not occur in the colloidal system. On the other hand, Wijting *et al.* have found evidence for wetting transitions in a similar system (8); high-resolution imaging should be a powerful technique for investigating these transitions in the future. In any case, Aarts *et al.* have demonstrated again the continued fecundity of Einstein’s and Perrin’s approach to “colloids as (big) atoms.”

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richness as a simple, statistical consequence of the observation that some species have large geographical ranges, whereas others have small ranges. This explanation echoes a classic debate about the patterns of communities (5, 6). (By “pattern,” ecologists mean such features as how many species a community houses, or how similar those species are morphologically.) Proponents and critics of all three approaches have recently exchanged salvos (7–9).

Most species live in the tropics and, in particular, within moist forests (see the figure). Why do warm, wet places generate diversity? “There are more niches,” goes one argument, “as demonstrated by their being more species to fill them,” goes its circular conclusion. Warm, wet places are proposed to be more productive and to support more individuals, which in turn permit more species to coexist (10). Unfortunately, tropical richness increases much faster than ex-