er 4B appear to project to separate higher visual areas (*5, 6*), knowing which visual signals they carry may help to distinguish the different streams of information transmitted through visual areas of mammalian cerebral cortex (particularly those areas that mediate motion perception) (*7, 8*). For example, the pathway emanating from layer 4B is thought to be dominated by the M system and therefore is essentially insensitive to color information. Can P signals be detected emanating from layer 4B in experiments in vivo? If so, what perceptual relevance might they have? Also, not all cells in layer 4B are directionally selective; are these cells primarily stellate or pyramidal in morphology? What are the visual response properties of these cells? Do they too project to visual motion areas such as MT? Yabuta *et al.*'s data make an important contribution to our understanding of how differences among the various parallel pathways emanating from V1 might acquire their unique functional characteristics.

Why might the cerebral cortex segregate relays of visual information in this way? Perhaps there is a need to isolate particular projection pathways leaving V1 from the influence of feedback inputs (from higher cortical areas back to V1). Pyramidal cells can be distinguished from stellate cells because they have access through their apical dendrites to feedback projections from higher cortical areas, which terminate in the upper cortical layers. It may be that some visual computations use feedback from downstream cortical areas, whereas others do not. Cells in layer 4B retain some of the characteristics of their inputs, but they are more selective for the spatial frequency, direction of motion, and orientation of the stimulus. This clearly indicates that they perform further computations on incoming information. The Yabuta *et al.* findings suggest that some aspects of visual motion are analyzed solely in a feedforward ("bottom-up") manner, whereas others make use of feedback ("top-down") signals. Different motion perception pathways could consist of a color-blind motion channel versus one multiplexed with chromatic information, or of channels concerned with motion at different spatial scales or speeds. The suggestion of selective access to feedback is complicated by the fact that certain feedback pathways to V1 (from areas V3 and MT) terminate broadly within layer 4B itself, but these pathways might specifically target different groups of neurons.

Are projection pathways distinguished this way elsewhere in the cerebral cortex? Because a variety of systems in the brain consist of multiple parallel subsystems, the visual cortex is a valuable model, reminding us that anatomy and physiology do indeed have something to do with one another.

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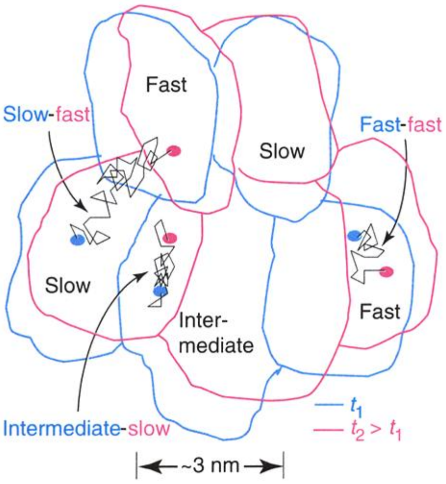
PERSPECTIVES: PHYSICAL CHEMISTRY

Single Molecules Rock and Roll Near the Glass Transition

M. D. Ediger and J. L. Skinner

The motion of molecules in liquids and solids is traditionally measured by spectroscopy and by the scattering of particles or radiation. Such experiments usually average over a very large number of molecules. Recently, researchers have developed techniques for measuring the dynamics of individual molecules in condensed systems (*1–3*). Single-molecule experiments can provide a wealth of new information in cases where different molecules exhibit different dynamics (*4, 5*). An impressive example is reported on page 255 of this issue by Deschenes and Vanden Bout (*6*), who have measured the rotation of individual dye molecules in a polymer film a few degrees above the glass transition temperature T_g (the temperature below which the polymer becomes an amorphous solid). They find that different molecules rotate with very different rates. This may have important implications for our understanding of the glass transition, which has been a notoriously difficult challenge.

Glasses are important as structural and optical materials and are also used for drug delivery applications and biological tissue preservation. If crystallization can be avoided while a liquid is cooled, the molecules in the liquid move more and more slowly. Eventually, motion is frozen (at least on the time scale of human perception) and an amorphous (noncrystalline) solid is formed. Although glasses have been used as practical materials for millennia, there is no agreement about what causes the slowdown of molecular motion responsible for the glass transition. One clue comes from contrasting the motion in a high-temperature liquid with that in a material near T_g. In the past 10 years, ensemble experiments (which involve large numbers of molecules) have been interpreted to indicate that dynamics near the glass transition are spatially heterogeneous (*7–9*): Dynamics in one region of the sample may be orders of magnitude faster than in another region only a few nanometers away, even though the material may contain only a single type of molecule and exist in a single thermodynamic phase. Regions of different dynamics do not remain fixed in space but rather evolve on very long time scales (perhaps as long as weeks or more). If this view is correct, then individual molecules will have different rates of motion at different places in the material, and the rate of mo-



Dynamics of individual molecules near T_g. Regions of different dynamics at two different times (t_1 and t_2) showing possible trajectories of individual molecules in such a heterogeneous environment. Each trajectory is labeled to indicate how the reorientation of this molecule would be observed to change with time. Spatial aspects of this figure are inferred from other measurements (*12*).

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tion of any one molecule will change substantially with time.

The experiments of Deschenes and Vanden Bout (*6*) are a dramatic confirmation of spatially heterogeneous dynamics near the glass transition. Using an optical microscope, they isolated the fluorescence of individual dye molecules in a polymer film a few degrees above T_g. Fluorescence was detected simultaneously for two different polarizations, allowing the orientation of the dye molecule's transition dipole to be measured in real time. Individual dye molecules were observed to reorient hundreds of times before they stopped fluorescing (because of photochemistry). Deschenes and Vanden Bout report that the rate of reorientation of individual molecules differed by more than a factor of 10 and that, for a given molecule, the rate can change substantially with time. For example, one molecule reoriented more than 100 times with a given rate and then suddenly changed to a different reorientation rate. Presumably, the dynamics of a particular molecule can change either because its environment evolves or because it moves from one region to another (see the figure on the previous page).

The concept of dynamic heterogeneity can be quantified in the following manner. Assuming that the system is ergodic (that is, a single molecule explores all possible configurations and environments given an infinite amount of time), if one could measure the orientation of a single molecule for long enough, its time-correlation function would be identical to that from the ensemble average over all molecules. Over a finite time window, a time-correlation function can still be defined from a single-molecule trajectory if in this finite time the molecule has reoriented many times. Using this procedure, Deschenes and Vanden Bout observe that the time-correlation functions of different molecules are different, showing that on the time scale of thousands of seconds, the dynamics are heterogeneous. This heterogeneity may arise from slight variations in density, local packing, or the local energy landscape.

It would be of great interest to see how the distribution of time-correlation functions (obtained from a large number of single-molecule experiments) depends on the time window and the temperature of the system. This information, which cannot be obtained from ensemble experiments, is ideal for discriminating among models of dynamic heterogeneity. In particular, it will be interesting to see if the time-correlation functions become exponential as the time window decreases (the results of Deschenes and Vanden Bout suggest that they do) and, if so, to obtain information on the lifetimes of regions of different mobility, a matter of considerable importance and controversy (*10*).

The single-molecule rotation experiments of Deschenes and Vanden Bout reveal, in a way that no ensemble measurement can, the intricate details of the molecular motions responsible for the glass transition—motions that correspond to atomic displacements of only a few angstroms. They demonstrate clearly the importance of heterogeneous dynamics near T_g. Future experiments on single molecules and mesoscale systems (*11*) will likely provide a comprehensive picture of this heterogeneity, which according to at least some models is fundamentally connected to the slow dynamics that cause the glass transition.

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PERSPECTIVES: SUN-CLIMATE CONNECTIONS

Earth's Response to a Variable Sun

Judith Lean and David Rind

"Since we are the children of the Sun, and our bodies a product of its rays … it is a worthy problem to learn how things earthly depend on this material ruler of our days." Thus wrote Samuel Pierpont Langley in *The New Astronomy* in 1898. But the "worthy problem" of how solar variability may affect processes on Earth remains unresolved after more than a century, despite the fact that it is of particular importance today because of its implications for global climate change. Even a modest influence of solar variability on Earth's climate alters the assessment of anthropogenic effects and their likely future impacts.

Recent investigations of Earth's surface, upper ocean, and lower tropospheric temperatures and the sun's irradiance suggest that there is indeed a discernable influence of solar variability on global climate. This follows a decade in which connections between solar variability and climate were alternately pronounced and dismissed (*1–3*). But how solar variability is translated into climatic changes on Earth remains to be fully explained.

Solar irradiance varies slightly over an 11-year cycle. This cycle of the sun's magnetic activity alters its energy output, as well as the occurrence of sunspots, flares, and coronal mass ejections. Sunspots (see the dark regions on the solar disk in the first figure, next page) have been used to track fluctuations in the strength of the sun's 11-year activity cycle for more than 300 years. Variations that are approximately in phase with this solar cycle have now been detected in satellite records of global temperatures in the lower troposphere as monitored by the Microwave Sounding Unit (MSU) since 1978 (*4*), in upper ocean temperatures since 1955 (*5*), and in surface temperatures, primarily from thermometer records during the past century (*6*). In recent decades, these 11-year temperature cycles had peak-to-peak amplitudes of 0.06° to 0.1°C. They coincided with directly observed total solar irradiance changes ΔI of 1.1 W m^{-2} (0.08%) (*7*), which resulted in a climate forcing ΔF of 0.2 W m^{-2}, where $\Delta F = 0.7\Delta I/4$. For comparison, net climate forcing by anthropogenic sources is currently about 0.35 W m^{-2} per decade (*8*). The solar cycle signal becomes increasingly apparent in the upper troposphere and stratosphere, where it persists in four decades of global temperature records with amplitudes that increase from 0.3°C at an altitude of 6 km to 0.9°C at 20 km (*9*).

Decadal-scale climate oscillations by themselves do not prove a solar connection. Such variations have been linked to other phenomena, particularly ocean circulation (*10*, *11*). But confidence in the reality of the sun-climate connection has grown as quantitative relations are established between increasingly long and precise databases of global temperature and

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