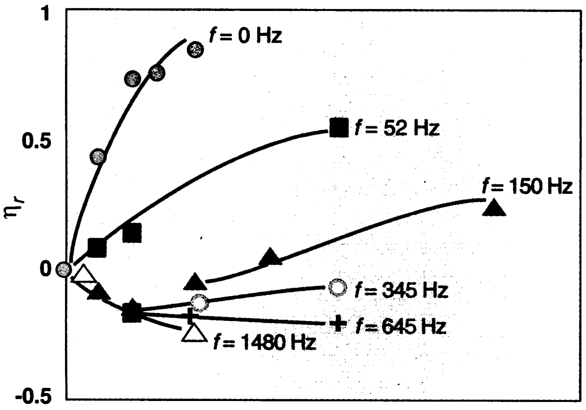

Fig. 2. Experimental reduced viscosity. $\eta_r(B, f) = [\eta(B, f) - \eta(0, 0)]/\eta(0, 0)$ versus magnetic field B for different frequencies f.

0.077 N s m^{-2} in the absence of field and a viscosity increase to 0.220 N s m^{-2} in a field of 0.2 T experiences a viscosity reduction to 0.100 N s m^{-2} at 50 Hz, 0.077 N s m^{-2} at 250 Hz, and 0.058 N s m^{-2} at 700 Hz (Fig. 2).

The alternating, linearly polarized field induces rotational swings of the particles but does not single out any preferred direction of their rotation. Therefore, an averaging over a physically small element of volume results in a spin of zero. Any flow with a vorticity not zero is sufficient to break the degeneracy of the rotation direction and leads to a nonzero macroscopic spin rate of the particles. This transforms a part of the alternating field energy into kinetic energy of the fluid that manifests itself in a reduction of the total viscosity.

Earlier work (*13*) treating asymmetric stress when the product of frequency and relaxation time is less than unity and utilizing a Debye-like relaxation relation predicts viscosity increases in steady applied field that match well with experiment (*14*). A more rigorous magnetization equation derived from a Fokker-Planck equation yields improved predictions when the product exceeds unity.

In a recent study of oscillating field applied to a rotating cylinder of glycerine-based MF, a resonance of the off-axis component of magnetization gives a rather direct and vivid indication of the negative viscosity effect (*15*).

There are applications of MF in areas ranging from tribology to instrumentation to medicine. Virtually every personal computer's hard drive contains MF rotary-shaft seals that prevent contaminants from entering. The seals also are widely used in vacuum to air feedthroughs in the manufacture of single-crystal silicon and subsequent fabrication into integrated circuits. Drive coils in millions of audio speakers are cooled to prevent self-destruction by MF held in place with permanent magnets. Other applications in stages of development include the precision machining of ceramics, high-speed printing, sink-float separation of minerals, inclinometers for directional drilling in oil fields, and means for enhancing signals in medical magnetic resonance imaging (MRI) scans. It is too early to say what new applications, such as tunable dampers, the discovery of negative viscosity may make possible, or whether the phenomenon will remain a laboratory curiosity. Intriguing is the possibility that if the viscosity is driven to zero, spontaneous patterns of flow may develop. In another direction, an interesting analogy exists with suspensions of gravitational dipoles that likewise obey asymmetric stress relations (*16*).

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Ion Channels: Opening the Gate

Much of neuronal action is driven by sodium and potassium ion channels. These cell-membrane proteins respond to voltage changes by opening and letting ions through when the normally negative interior of the cell becomes more positive. The S4 region of the protein, with its charged residues, is thought to sense this voltage change and shift its position in response (*1*), thereby mediating the tiny movement of charge that can be measured as the channel prepares to open—the gating current (*2*).

Because we know little about the three-dimensional structure of ion channels (no crystal structure exists for any eukaryotic channel), our occasional glimpses of how this really happens have been frustratingly indirect. Now two key studies (*3*, *4*) offer a clearer picture of S4 movement in the channel during gating and ameliorate our frustration at not having the crystal structure of an ion channel, at least temporarily.

Yang and co-workers report in the January issue of *Neuron* (*3*) that, for the sodium channel, the S4 region moves a considerable amount of charge across the protein in response to a voltage change. Their trick is to probe the accessibility of introduced cysteine residues to cysteine-modifying agents, revealing that two of the charged residues in S4 and presumably the hydrophobic residues between them move from a position that is accessible from the inside of the cell to one that is accessible from the outside. This large movement of charge completely across the hydrophobic membrane is possible because the charges seem to move through a very short "hole" that contains at most one charged residue of S4 at a time. In a complementary report in *Science* (*4*) Mannuzzu *et al.* describe their success in engineering a fluorophore into the S4 region of the potassium channel; by continually monitoring its accessibility to the extracellular medium, they have been able to follow the movement of these residues of S4 in real time. They find that at least seven S4 amino acids move from a buried position into the extracellular space simultaneously with the gating current. This same group has also shown that potassium channel S4 moves across most of the transmembrane core during gating (*5*).

The identity of S4 as the voltage sensor of these ion channels is more secure now that we have "seen" it move in response to voltage changes in a way consistent with the job of carrying the gating current. Future studies will tell us whether other parts of the protein also contribute and hopefully elucidate the basis of the exquisite voltage sensitivity of these proteins.

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