two growth regimes. Furthermore, when the availability of external nitrogen is interrupted, phycoerythrin is mobilized in high-nitrogen grown cells and growth rate is maintained. Since the difference in the phycoerythrin content of nitrogen-replete and nitrogen-limited cells is considerable, it was not part of our original argument that only energetically uncoupled phycoerythrin is mobilized during nitrogen starvation. Rather, we see the accumulation of uncoupled phycoerythrin as one part of a reserve which continues to meet the nitrogen demands of the cell during short-term periods of reduced nitrogen availability (4).

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Magnetically Oriented Solutions

The report "X-ray diffraction from magnetically oriented solutions of macromolecular assemblies" by Glucksman et al. (1) does not acknowledge that the virus solutions investigated are liquid crystal phases (2–4). The field-induced orientation reported would not be possible were it not for the preexisting high degree of orientational ordering of the virus particles indigenous to such phases.

The liquid crystallinity of the Pf1 solutions examined by Glucksman et al. is evident from figure 2 of their report; the virus solution external to the field is birefringent. This spontaneous birefringence is a direct consequence of long-range orientational ordering of the particles that extends over macroscopic distances in liquid crystals. It is

usually expressed with an order parameter, S, an average over the restricted, rotational diffusion of the rods within a uniform (macroscopic) domain. In typical liquid crystals, values of S are in the range of 0.3 to 0.9. This high intrinsic order accounts for the spontaneous birefringence of liquid crystals even in the absence of external constraints (shear, surface effects, applied magnetic or electric fields, and so forth), where the local nematic director (optic axis of a domain) assumes random orientations throughout a bulk sample.

It has been recognized for a long time that random liquid crystal textures may be readily transformed into uniform textures [a "single (liquid) crystal"] by exposing them to modest magnetic fields [$H \leq 0.2$ tesla (5)]; the feasibility of magnetic alignment in macromolecular liquid crystals despite their higher viscosities was reported two decades ago (6). The phenomenon derives from the interaction of the field with the bulk diamagnetic anisotropy of the ordered fluid, $\Delta\chi$ (7), and not with the anisotropy of an individual particle, $\Delta\chi°$, as implied. The magnetic potential energy for typical macromolecular assemblies, $\Delta\chi°H^2$, is small relative to ambient thermal energy. Even high-strength fields ($H \cong 10$ T) induce small orientational biasing of the Brownian motion of isolated particles suspended in isotropic, dilute solutions, that is, the classical Cotton-Moutton effect, where, dependent on the magnitude of $\Delta\chi°$, S is observed to be 10^{-6} to 10^{-5} for organic molecules (8), and is typically $< 10^{-2}$ for macromolecular assemblies (4).

While the magnet design proposed by Glucksman et al. ($H < 2$ T) can facilitate diffraction experiments, the large degree of orientational order required to carry out high-resolution structural analysis ($S > 0.5$) will limit its use to studies of liquid crystal phases. Generally speaking, for biological macromolecules or macromolecular assemblies, the prerequisites for liquid crystallinity will in turn limit consideration to solutions (with $\phi > \phi^*$) of those species having anisometric shapes. Particles with large aspect ratios (prolate or oblate) are required for lyotropic liquid crystal formation.

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7. $\Delta\chi = N\Delta\chi°S$ where N is a significant enhancement factor corresponding to the number of particles reacting collectively as a consequence of their belonging to the same macroscopic domain. (The anisotropy and the orientation of the solvent are assumed to be negligible.)
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Response: We agree with most of the points raised by Samulski and appreciate his detailed discussion of the importance of long-range orientational ordering as a prerequisite for obtaining highly oriented phases. As we discuss in the last paragraph of our report, particles with anisotropic shapes may orient better because the orientations of adjacent particles are not independent of one another. In fact this may be required for formation of highly oriented specimens. Exposing a liquid crystalline texture to a modest magnetic field does not universally result in the formation of highly oriented specimens, as Samulski suggests. This depends on the properties of the macromolecular assembly of interest. The orientation of a liquid crystalline domain depends on its bulk diamagnetic anisotropy, but the bulk anisotropy depends, in turn, on the anisotropy of individual particles and the orientational correlation among particles in the domain. Our interest here is in the properties of the individual particles and the generation of high-quality diffraction data. Samulski's interest appears to be in the bulk behavior of liquid crystalline textures. His point of view supplements our work, and his comments are appreciated.

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