Comment on "Giant Plasticity of a Quantum Crystal"

In their Letter, Haziot *et al.* [1] report a novel phenomenon of giant plasticity for hcp ^{4}He quantum crystals. They assert that ^{4}He exhibits mechanical properties not found in classical plasticity theory. Specifically, they examine high-quality crystals as a function of temperature T and applied strain $\epsilon_{\rm app}$, where the shear modulus $\mu = \tau_{\rm app}/\epsilon_{\rm app}$ reaches a plateau and dissipation $1/Q$ becomes close to zero; both quantities are reported to be independent of applied stress $\tau_{\rm app}$ and strain $\epsilon_{\rm app}$, implying a reversible dissipation process and suggesting dislocation motion by quantum tunneling. At lower T, an increase in μ and $1/Q$ is found, which is argued to be caused by ^{3}He atoms binding to dislocations, thus pinning them and stiffening the solid.

In this Comment, we show that these signatures can be explained with a classical model of thermally activated dislocation glide without the need to invoke quantum tunneling or dissipationless motion. Recently, we proposed a dislocation glide model in solid ^{4}He containing the dissipation contribution in the presence of other dislocations with qualitatively similar behavior [2].

In Fig. 1(a), we plot our results for both effective shear modulus $\mu = \tau_{\rm app}/\epsilon_{\rm app}$ and the work hardening rate (WHR) $d\tau_{\rm app}/d\epsilon_{\rm app}$ at low (2.65×10^{-8}) and high strain (1.0×10^{-7}). The yield strain at 20 mK is 2.72×10^{-8}. In Fig. 1(b), we show the corresponding dissipated plastic energy density dW_p/dt, which is proportional to $1/Q$ in periodic shear-strain measurements. Notably, μ and WHR exhibit the key features observed in Ref. [1]; namely, they decrease at high T. In addition, our model describes the corresponding dissipation at low strain [see Fig. 1(b)], which drops at high T, whereas the dissipation remains small and independent of T at high strain. This low dissipation arises due to the low Peierls stress that permits dislocations to glide freely. However, even in the dislocation freely glide regime, the plastic flow is viscous with finite dissipation. In Fig. 1(c), we plot $\tau_{\rm app}$ vs $\epsilon_{\rm app}$ at 20 mK to demonstrate that $\tau_{\rm app}/\epsilon_{\rm app}$ is nearly independent of $\epsilon_{\rm app}$ above the yield point, just as is reported in Ref. [1], which implies a reversible process. Clearly, the presented results contradict the conclusion of Ref. [1], namely, that motion in the giant plasticity regime is dissipationless. Note that recent torsional oscillator studies no longer show evidence for motion without friction or supersolidity [3].

Additional concerns exist with the interpretation of the results of Ref. [1]: (a) anisotropy in the dislocation glide does not prove any kind of quantum effect but can arise classically in perfect crystals with specific glide planes and directions of high atomic density. (b) Reversible plastic flow can exist in clean systems with no cross glide [4] or in ac driven systems [5,6]. (c) The low-T dissipation peak is not sufficient evidence for the process of ^{3}He atoms binding to dislocations as T is lowered, as our model results show in Fig. 1(b) for a scenario without ^{3}He atoms.

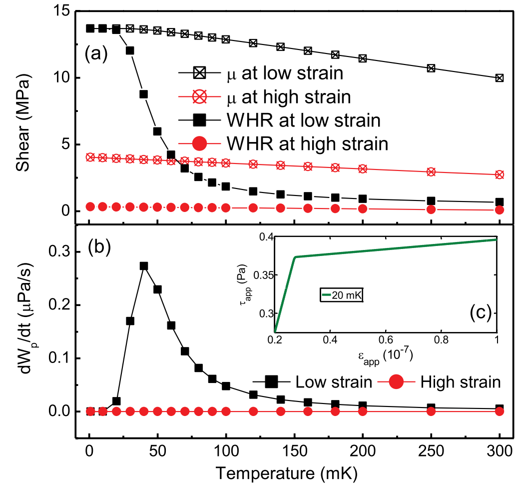

FIG. 1 (color online). (a) Shear modulus and WHR of solid ^{4}He, (b) dissipated plastic energy density, and (c) stress-strain curve at 20 mK. The model parameters of Ref. [7] were used.

In summary, the results in Ref. [1] can be explained with a classical model of dislocation glide and without requiring quantum tunneling or dissipationless motion of dislocations or other exotic processes.

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