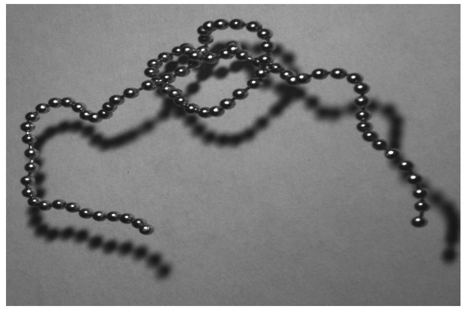

Granular Chains

E. Ben-Naim, Z. A. Daya, and R. E. Ecke

*Theoretical Division, Center for Nonlinear Studies, Condensed Matter & Thermal Physics Group,
Los Alamos National Laboratory, Los Alamos, NM 87545*

Granular chains are made of hollow steel balls connected by thin metal rods. They can be purchased at your neighborhood hardware store. Add a shaker and a little bit of imagination and you have a rich laboratory for polymer physics [1], nonequilibrium statistical mechanics [2], nonlinear dynamics [3, 4], and biological physics [5]. The attached video and the brief summaries below highlight a series of our recent experiments in vibrated granular chains.

Like a tie on a shoestring, a knot in a granular chain comes undone upon vibration. The time it takes for the knot to untie grows quadratically with the number of balls in the chain, indicative of a diffusive motion. Moreover, the shape of the distribution of opening times is universal, as it is independent of the length of the chain. The statistics of the unraveling times are governed by the number of crossing points. For example, a simple trefoil knot has three crossing points (top figure). The diffusive motion of the crossing points governs the knot dynamics [1].

The chains can be easily made into rings and by controlling the vibration strength, it is possible to control the chain topology. For example, a gently vibrated figure-8 remains forever in that configuration (bottom left figure). We observed that as the figure-8 explores various configurations, it is much more likely for one of the two loops to be small while the other is large. This is the first observation of the entropic tightening phenomenon that is expected from the equilibrium statistical mechanics of macromolecules. Although the chain is not in equilibrium, being driven in an athermal fashion, the structure of the configuration phase space overwhelmingly favors the small-loop large-loop state [2].

We also observed that in a narrow range of driving parameters, a linear chain spontaneously coils into a stable spiral (bottom right figure). In this state the chain undergoes a slow rotation, keeping itself wound while the core of the spiral undergoes a ratcheting motion. Shaking excites vibrational motion with dominant transverse oscillations. Small asymmetries between the two ends of the chain are responsible for this behavior: the spiral is stable only when one of the two end balls is its the core [3] .

[1] E. Ben-Naim, Z.A. Daya, P. Vorobieff, and R.E. Ecke, Phys. Rev. Lett., **86**, 1414 (2001).
[2] M.B. Hastings, Z.A. Daya, E. Ben-Naim, and R.E. Ecke, Phys. Rev. E., **66**, 025102(R) (2002).
[3] R. E. Ecke, Z. A. Daya, M. K. Rivera, and E. Ben-Naim, MRS Symposium Proceedings **759**, 129 (2003).
[4] A. Belmonte, M. J. Shelley, S. T. Eldakar, and C. H. Wiggins, Phys. Rev. Lett. **87**, 114301 (2001).
[5] J. S. Olafsen and B. Bammes, Chaos **14**, S9 (2004).