Today you can play with two different experimental systems and some Python simulations. One setup is just a bare subwoofer capable of knotting and bouncing ball experiments, qualitative fluid pattern formation or crystallization, and other exploratory fun. The second system has a modified subwoofer that can be used for more varied and controlled experiments.

1. Introduction

The least expensive experiment in the University of Toronto Advanced Physics Lab has one of the largest phase spaces for student exploration. We originally set out to just develop an experiment to study the unknotting and entropy of chains, but soon realized even more fun is possible with a subwoofer, an amplifier, and a frequency generator. In addition to the physics of chains, which are models for polymers, DNA, and other interesting biomolecules, versions of the system can be used to observe nonlinear waves in liquids and particulates, to study chaotic bouncing balls, and to try to create experimental models of fluids and crystallization.
The pictures and information in this poster are just examples of what can be done.
Information on our current Knots and Faraday Waves experiments (and a copy of this poster) can be found at [http://www.physics.utoronto.ca/~dbailey/bfy](http://www.physics.utoronto.ca/~dbailey/bfy).

This is an active area of research, so students can find lots of inspiration. Our original experiment was motivated by:


Here are just a few example research references:


## 2. Typical APPARATUS

### Basic

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Frequency Loudspeaker (subwoofer)</td>
<td>$200</td>
</tr>
<tr>
<td>Frequency Generator</td>
<td>$225</td>
</tr>
<tr>
<td>Audio Amplifier</td>
<td>$105</td>
</tr>
<tr>
<td>Chains</td>
<td>~$1/ft</td>
</tr>
<tr>
<td>Stopwatch</td>
<td>~$15</td>
</tr>
</tbody>
</table>

### Optional

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>homemade</td>
<td></td>
</tr>
<tr>
<td>Oscilloscope</td>
<td>$935</td>
<td></td>
</tr>
<tr>
<td>Computer with audio/video webcam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-speed camera</td>
<td>$115</td>
<td></td>
</tr>
<tr>
<td>Small spheres</td>
<td>$6-19/100</td>
<td></td>
</tr>
<tr>
<td>Adjustable (leveling), weighted base</td>
<td>homemade</td>
<td></td>
</tr>
<tr>
<td>Subwoofer modifications to attach specialized bases or containers</td>
<td>homemade</td>
<td></td>
</tr>
<tr>
<td>Specialized containers and bases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluids (e.g. water, oils, rice, bronze micro beads)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Plus cables, scale, ruler, calipers, sponges, plastic, ...
3. Subwoofer Modifications

Bare subwoofer speaker

Subwoofer speaker with foam and aluminum mounting plate glued on

Subwoofer with base, low container, aluminum plate, and plastic shield.

Bottom of attachable plate
4. Knots

Can study affects of frequency, amplitude, number of knots, bead density or size, radius of gyration, spontaneous spiral formation, knotted chain pairs, crossing point dynamics, chains in water, models, …

Unknotting

Python Unknotting Simulations

Experimental Knotting probability (from unknotted start)

Cumulative Probability for Knot Formation vs time for Chains of lengths 77, 102, 128, and 152 beads.
5. Liquids and Crystals

Faraday (and other) waves

- Oil
- Cornstarch & Water
- Soapy Water
- Cornstarch & Water

Crystallization by “cooling”

6. Granular Pattern Formation

Square Container (0.14-0.18 micron Bronze Beads)

- Top view
- Rotated
- Domains

Cylindrical Containers

- Squares
- Stripes
- Basmati Rice (for comparison)

Phase Diagram for 8 Layer 0.33mm Sample in Circular Container

- Dimensionless Acceleration
- Frequency (Hz)
7. Acknowledgements
Many people have contributed to the development of these experiments. S. Morris provided the original idea and much expert help, J. Harlow implemented our first shaker experiment, and recent work has been driven by N. Krasnopolskaia. Our skilled Undergraduate Learning Services staff R. Smidrovskis, L. Avramidis, T. Sato, P. Scolieri, and P. Hurley have been essential at all stages. An incomplete list of the many enthusiastic students have contributed through both lab courses and research projects includes Y. Bai, S. Chen, A. Esser, H. Fu, R. Gu, C. Holmes, A. Hui, J. McGibbon, M. Nitzan, T. Rvachov, S. Sata, S. Sathananthan, D. Shaul, C. Wang, Z. Wang, W. Zhao.