INTERNATIONAL PHYSICISTS' TOURNAMENT

Problem list for the XIXth edition of the International Physicists' Tournament

There is no uniquely favored understanding of a problem's conditions and it is up to each team to interpret the conditions in a way that is both interesting from a physical perspective and coherent with the problem statement. It is assumed that every phenomenon will be studied with the aim of proposing and validating a model that explains the phenomenon and its dependence on the most relevant parameters. All experiments should comply with local safety regulations and care should be exercised when dealing with dangerous equipment and substances. Whenever an experiment is not possible due to safety concerns or budget constraints the teams are encouraged to perform an analogue experiment if possible. Teams are solely responsible for any damage or injuries incurred while working (or thinking) on the problems.

1. The magnetic hourglass

Consider an hourglass containing a mixture of normal and ferromagnetic grains. Investigate how an external magnetic field affects the flow rate. What properties of the field (amplitude, gradient, time-variation etc.) can be inferred from observing the granular flow?

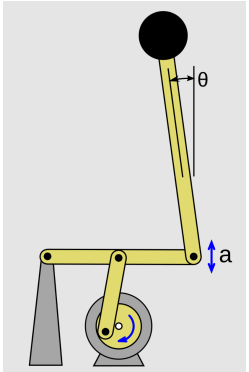
2. Shaken soda syndrome

A shaken can of a carbonated beverage rolls down an inclined plane more slowly than an identical, unshaken one. Explain the phenomenon and investigate its dependence on the relevant parameters. Can this method be used to determine the precise gas content of your soda?

3. Singing light

Construct a speaker by exploiting the photoacoustic effect shown in the video, and characterize its response (sensitivity, sound pressure level and fidelity). What design choices determine the properties and quality of the emitted sound? Is it possible to suppress specific frequencies (e.g. low/high pass filter) by choosing appropriate excitation media? https://www.youtube.com/watch?v=K4LKiJKNsZc

4. Extended Kapitza pendulum



A pendulum whose pivot oscillates vertically can be stabilized in its inverted position. The stability criteria and effective potential for a single pendulum under sinusoidal driving are well established. Investigate how the system behaves when the periodic driving is replaced or supplemented by random noise, and determine how stability depends on the noise spectrum. Extend this study to periodic and noise-driven multi-stage pendulums (e.g., double or triple). Does the system exhibit any collective behavior that has no counterpart in the single-pendulum case?
Kapitza Pendulum: https://www.youtube.com/watch?v=GgYABmG_bto
Double Pendulum: https://www.youtube.com/watch?v=gDnbn0Wz_tg

5. Frustrated klustering

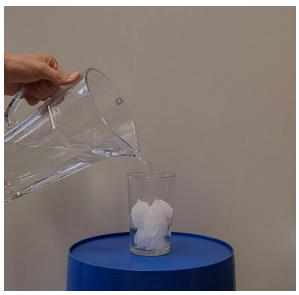
In the game *Kluster*, players place magnets one at a time on a surface without letting any two snap together. Within a fixed area, investigate the stable configurations of N upward-polarized and M downward-polarized magnets. Determine the maximum density for which a stable configuration exists, and how this compares to the maximum density reachable by placing magnets one at a time while keeping every intermediate configuration stable. Investigate how the densities and the impact of perturbations depend on the ratio $N : M$. Does granting the magnets in-plane rotational freedom affect this stability?

6. Aerodynamic juggler

A light ball can be suspended on a vertical air stream. A second ball in the same air stream may float in the downstream of the first ball. Investigate the conditions for the phenomenon to be stable in the multi-ball regime. How many balls can be added to the air stream without destabilizing the system? Does tilting the air stream or using non-spherical balls affect the solution?

7. Electromagnetic pendulums
Hanging magnets normally allow coupled motion with minimal friction and no collisions, but a metal plate in the vicinity can both dampen and excite the system depending on its relative motion. Investigate the dynamics of one or more magnetic pendulums near a driven, conductive plate. Identify relevant regimes of motion and resonances, and study if chaotic motion is possible.
https://www.youtube.com/watch?v=gMzsTfDnvLw&t=65s

8. Macroscopic quasiparticles
A 1D array of coupled spring-mass oscillators can be used to demonstrate lattice vibrations. Measure the dispersion relation of these vibrations. How does the system's behavior change if the masses are replaced by magnets? How do the dispersion relations depend on the magnets' strength and arrangement along the chain? Can one define and measure an analogous "magneto-elastic coupling" constant? Hint: the less friction, the better!
https://www.youtube.com/watch?v=M4WQs_U1nmU



9. Ice ice cubey
Pouring water down on ice cubes can sometimes create a peculiar cracking sound. Why and when do ice cubes crack? How does the sound depend on the ice and water temperatures? What shape of ice produces the loudest cracks?

10. Fluttering soap film
When a uniform stream of air is directed at a soap film held in a rigid frame, the film first bulges into a stable, curved shape, then vibrates once the airflow velocity exceeds a critical threshold. Determine the film's equilibrium shape as a function of the airflow velocity, and investigate the conditions under which this shape becomes unstable. Study the dependence of the critical velocity on relevant parameters. To what extent does this instability follow the scaling seen in the flutter of elastic membranes and flags in a flow?

11. Bristle-bot swarm
A *Bristle-bot* is a simple toy made by attaching a vibrating motor to a small brush, causing it to move erratically across the surface. When placing a swarm of Bristle-bots into a confined space, they can start exhibiting collective behavior. Can the swarm's motion solve a maze quicker than a single bot? Investigate the efficiency of the maze-solving swarm as a function of bot number, shape, and settings, as well as maze design.
https://www.youtube.com/watch?v=jkoXs5HrUjU - A single bristle bot in a maze.

12. Bottled bits
Consider a closed container filled with liquid with two small holes, one on top and one on the bottom. The container will stop leaking when the top hole is covered. Using two top holes, find a way to use this system as a NAND gate. Investigate how the reaction time of its switching process depends on the properties of the liquid and the container. Minimize this time. Extend this setup to build more complex logic gates or circuits, and determine their minimum reaction times.

13. Spiraling paper
If one pushes a stick on the top of a stack of paper and starts spinning the stick, the sheets in the stack start twisting around one another, forming a spiral (link to video). How does the shape of the spiral depend on the relevant parameters of the system? How does the shape of the spiral change with time?

14. Acoustic camera
A bat locates its prey using only two microphones (its ears). Suppose a bunch of grapes is illuminated by a single, fixed point source of sound placed 1 meter away, and an array of microphones records the reflected sound. The fruits and the sound source are stationary. How does the resolution of features in the bunch of grapes depend on the number of microphones?

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15. Causio-e-pepe



When pecorino cheese is stirred into hot water, it can either form a smooth, glossy sauce or collapse into a stringy, separated mass: the "cacio-e-pepe catastrophe." Recent work has shown that adding starch shifts the boundary between these two outcomes in temperature-composition space. Build a predictive model for when and how fast this transition occurs for an arbitrary cheese of your choice, and test it experimentally. Does the pathway by which the sauce is heated and stirred matter as much as its final temperature and composition? Can the model predict the stabilizing starch fraction for a different cheese?

16. Ink boat

A drop of common ballpoint-pen ink applied to a porous carrier can propel it across a water surface, as in the video, thanks to the slow release of the ink. Investigate the impact of system properties (porosity, shape, wetted area, ink type, etc.) on the release rate and maximize the carrier's velocity. How does the residual ink pattern on the water surface impact the carrier's dynamics?
https://www.youtube.com/watch?v=gNoWqvIC4Ks

17. Cloudy, with a chance of rain



A "cloud" can be created in a jar by pouring in hot water and cooling the air with an ice-topped lid like in the video. Replicate the setup and make a cloud in a jar! Can the thickness of the cloud be controlled? Can the cloud droplets be grown large enough to fall as visible "rain" rather than staying suspended as fog? What about "snow"?
https://www.youtube.com/shorts/0EmEcWKUoJ0
Be careful when working with freezing temperatures!

Many thanks to all the people who took part in the proposition and selection of the problems!

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