Fun With Grains

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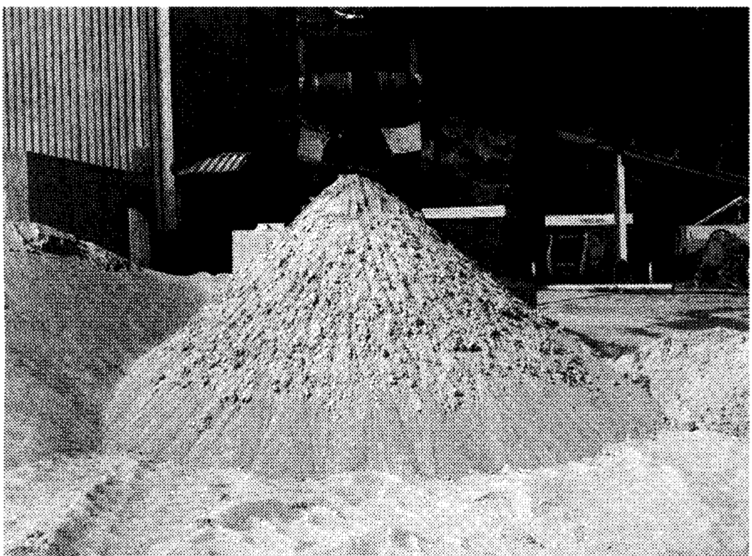
Vasant looked out of his window. There were construction workers' children happily playing with sand, pouring it through sand sifters and watching it flow — a fluid of grains!

Inside the house in the kitchen he loves to experiment with grains — grains of sugar, salt, rice and lentil. When he pours out some lentil from a bottle onto a cooking pan to make dal, he watches it flow — a fluid of lentil grains. When he buys a packet of lentil from a nearby grocery store and cuts a hole in the packet to pour it into a bottle, he sometimes notices the grains getting stuck, clogging the hole and stopping the lentil grains from flowing.

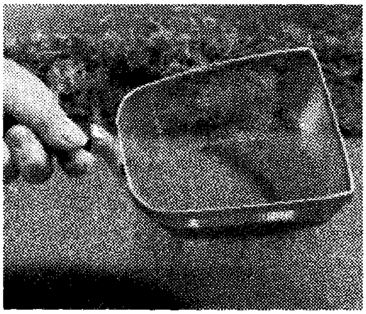
He says to himself: "Interesting! Grains have two facets to them — they behave like liquids when they flow but because of their graininess the grain particles can get stuck when they are poured through small holes of size comparable to the size of the grains!



Vasant's mother Sharda is a physicist who works with granular matter. She finds the system intriguing. Granular fluids can be viewed as scaled up atomic fluids: the grains are like magnified atoms!

Sharda and Vasant have used a kitchen blender to shake up a plate of grains. The shaken grains look like gas. As they pour more and more grains onto the plate they find at a high density it goes into a jammed state. As they were doing the experiment Vasant said to Sharda "Wow, it's fun" — we don't need any microscope. We can see atoms, a gas of atoms, a liquid of atoms and at a high density, a solid of atoms in this magnified world of grains!"

Granular matter is an active area of research. Researchers all around the world are trying to quantify their physical properties, borrowing theoretical tools from their knowledge base in atomic fluids. There are many broad similarities but there are some differences



as well. These are challenges that many researchers are engaged in facing and understanding.

Here at the 'Theorists' Lab' at our Institute my colleague Abhishek Dhar and I have experimentally studied a granular system consisting of a layer of a large number of mustard seeds covering a vertically driven horizontal ground glass plate.

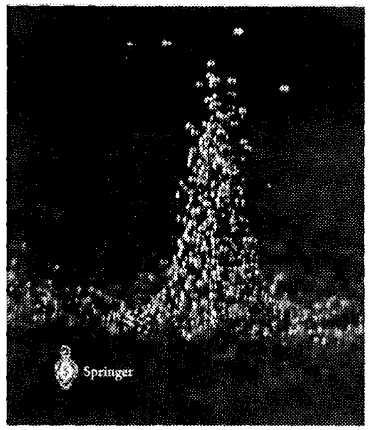
The driving was provided by a speaker attached to a signal generator. The chosen frequency setting was 300 Hz. We carried out the experiment at various densities ; typical values being 400, 600 and 800 particles in an area of 9.5 X 12 sq cm.

We stuck a graph paper on the underside of the ground glass plate, allowed the granular system to be vibrated and manually counted the number of grains in a box area of 8 X8 sq cm (marked out in black ink on the graph paper) every 30 secs by stopping the vibration and counting.

This sequential data as a function of time was converted into a frequency distribution (a histogram) by counting the frequency of occurence of a given number of grains in the marked out box on the graph paper. We got a fair picture of the number density distribution by this simple and crude method.

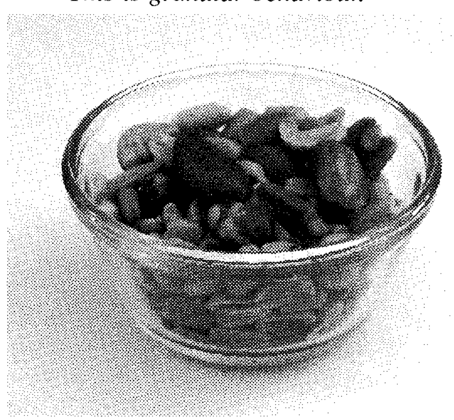
Then we analyzed in greater detail by using the following set up. We captured each visual frame of the vibrated grains using a CCD camera attached to a video system. We could see the movie on a monitor. Each frame was tagged using a timer which kept track of the time of recording. Subsequently we converted the film frames recorded in the videotape into bitmap (bmp) files in the computer and analyzed and plotted our data.

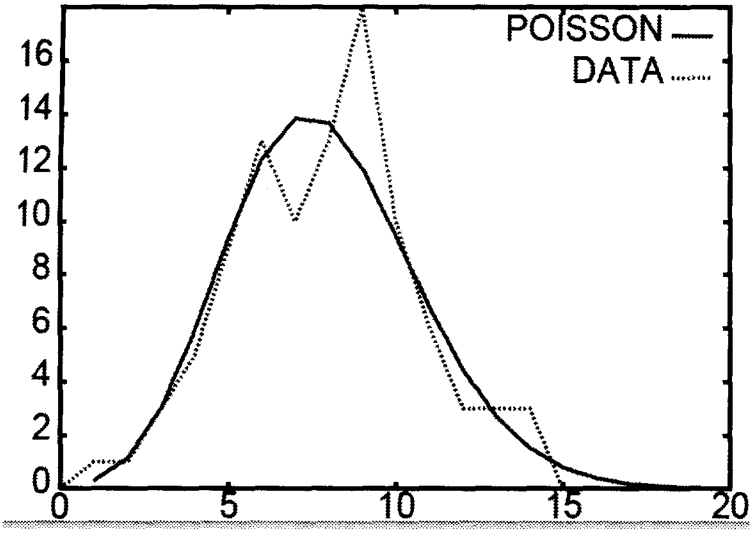
Our low packing fraction data for the number distribution for the grains, fitted well to a Poissonian statistical distribution [See Box], which is expected for a non-interacting gas. (See the figure.) This indicates that at low densities a vibrated granular system has a dilute gas like behavior.



We expect a better agreement with Poissonian statistics in the dilute limit for a larger number of data points. As we probed higher densities we noticed the formation of jammed structures resembling the structure of a glass. One important difference between probing a liquid consisting of smaller sized particles, say, a colloidal glass-forming liquid, and probing glass-like states in

When you shake a bowl of nuts, the bigger ones move to the top. This is granular behaviour.

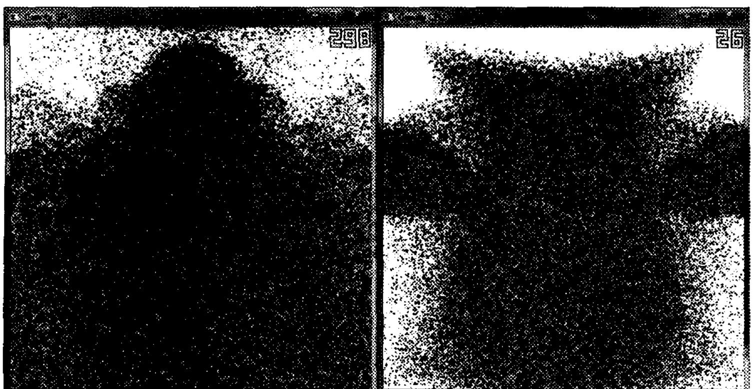




The number distribution of vibrated grains (dashed line) for 400 grains contained in an area of 8 X 8 sq cm compared against a Poissonian distribution (solid line) with the same mean value as the experimentally determined one. This experimental run involved 100 data points..

such vibrated granular systems is that we can study these effects in great detail by directly looking at the system even without the use of a microscope!

I encourage you to try to come up with a simpler version of this experiment where you shake the grains kept on a tray and stop and repeat the experiment to make a histogram of the number of grains in a small patch of the tray. See for yourself what you get for the number distribution at various packing densities.



The Poisson distribution

The Poisson law of large numbers is a discrete probability distribution that captures the probability of a number of events occurring in a fixed period of time if these events occur with a known average rate and independently of the time since the last event. This distribution can also be used for the number of events in other specified intervals such as distance, area or volume.

If the expected number of occurrences in a given interval is λ, then the probability that there are exactly k occurrences (k being a non-negative integer, k = 0, 1, 2, ...) is

$$f(k,\lambda)=\frac{\lambda^k e^{-\lambda}}{k!}$$

where e is the base of the natural logarithm (e = 2.71828...), k is the number of occurrences of an event, the probability of which is given by the function k!, the factorial of k is k!, where k!=1 X 2 X 3.... X (k-3) X (k-2) X (k-1) X k.

λ is a positive real number, equal to the expected number of occurrences during the given interval.