

The Biggest Fritos[®] Always Rise to the Top

Commentary:

Not only is the above expression an allegory for life, but it is an observational fact. As any cereal or chip manufacturer can attest, one of the most vexing problems is that the largest corn flakes, salsa chips, etc. are always found on top of the package and the smallest ones at the bottom. Consumers don't like this (unless they are crumb fans) and an industrial challenge is one of making sure that the consumer receives a more or less even mix of sizes when opening the package.

What has this got to do with physics and science? Well, we use the concept of *density* to describe a basic property of solids, liquids, and gases, that affects how they behave. Density is defined as the mass per unit volume, or M/V . We find that this quantity is used when defining the *buoyant force* on an object, pressure at a depth in a fluid (gases are also considered fluids), and it is important in determining how fluids behave when put into motion in the context of **Bernoulli's Principle** or **drag forces**. Density is an absolutely fundamental idea in physics.

The questions we might ask are ones like what **determines** density? Does it have something to do with the size of the atoms? Is it more closely related to how they are put together or fit into a volume? Let's find out!

Inquiry:

Let's start out with the basic concept of density and why things "float".

Materials required: A transparent container and a collection of spherical or nearly spherical object, such as beads and BB's, marbles of at least three sizes, or wooden balls. Piece of cardboard, scissors, and a ruler.

- Gather a collection of spheres, or objects that approximate spheres. This can include a collection of wooden balls, marbles of various sizes, or assorted beads. Place the collection in an appropriately-sized transparent container, such as a beaker, glass, or plastic cup.
- Mix up the balls thoroughly by shaking or stirring. All sizes should be present at all levels, or heights in the container.

- Next, we want to let the balls or beads “settle out” so that the lightest layer stays on top, the next lightest (in order of density) is below it and the heaviest ends up on the bottom. You can do this by gently shaking the container, tapping, or vibrating it (think of what happens to a box of cereal while being transported from the factory to the consumer).
- After some time doing the above, you should see a pattern developing. It may not be perfect but there is a clear pattern. Describe it in your portfolio.
- Which “floated” on the top - the largest spheres or the smallest?
- Now comes the tough part-figuring out why this happened! In terms of DENSITY, describe which layers you think are the most and least dense.
- So, you think the largest spheres are the “least dense” layer. But why? After all, aren’t the biggest ones the heaviest? There seems to be a contradiction here. Can you resolve this dilemma?
- Did it appear that the larger balls “displaced” the smaller ones and, as a result, experience a form of “buoyant force” and float on top of them? (See the exercise on buoyancy for more details and hints)
- If your spheres were made of different materials (glass, plastic, etc.), was there a relationship between the density of the spheres themselves and the “density” of the layer formed by those spheres? Did the heaviest balls “sink”?
- (*This step is optional*) Actually, we are using an analog of density here. Try this. Separate the balls by size. Put an equal mass of large ones and then small ones into a small container so you can observe the volume occupied by each. Alternatively, determine the mass of each collection of spheres and also the volume and divide the mass by the

volume to obtain the actual density. Is there a difference? Explain why you think there is or isn't in your portfolio.

- Actually, there is some subtle and interesting physics going on when you vibrate the mix and cause sizes to separate. Do it again and look closely! In terms of **potential energy**, what do you think is really going on?
- Now, we get to the heart of the matter. Make a rectangular or square tray out of cardboard of an appropriate size so that you can fit a single layer of your spheres into it (you can use ANY size spheres, but the largest ones or marbles are easiest to work with). Rather than spheres, you can also use circular objects, such as pennies (for the two-dimensional case only). I recommend making the tray such that it is about 4 marbles/spheres high and wide. More than that and you will be counting a lot of marbles! Lay the spheres in the tray in neat vertical rows and horizontal columns (just like a checkerboard or tic-tac-toe). Mark the APPROXIMATE centers of the spheres. Record, in addition, the number of spheres you can fit into the tray (hopefully not ALL of them!). Draw a picture in your portfolio and record your data. Also, measure the distance between the CENTERS of the spheres and record that, as well.
- Determine the “density” of your layer above in two dimensions by dividing the total area of the tray by the area of the circles representing all of the spheres (area of a cross section of a single sphere multiplied by number of spheres). This number will be something less than one. Record the value.
- Finally, see if you can increase the “density” by packing the spheres or “pennies” in a different manner. I think you can! When you have decided upon a means of arranging them, mark the centers and repeat the entire step above, finally arriving at a “density”. Is the number (again less than one) GREATER THAN, SMALLER THAN, or the

SAME AS that which you obtained using rows and columns? Show your numbers in your answer.

- The arrangement you have discovered in the above step represents one found in nature called “hexagonal array”. If you connect the dots marking the centers, you should see something that resembles a honeycomb. Each sphere has six “nearest neighbors”. Bees discovered long ago that they could fit the maximum number of cells into the minimum amount of space this way (also makes for a strong structure) Does yours look like this?
- I think we can now understand that, in nature, it is not necessarily the weight or mass of each atom that determines the density of a substance, but how they are packed. The spaces between the spheres represent “empty space” in a crystal lattice or in a liquid or gas. You can determine how much “empty space” there was in two dimensions for each of the arrangements you made by subtracting the total area occupied by spheres from the area of the tray. Did you observe that the LEAST dense had the greatest amount of empty space? If not, explain why you think you observed what you did.
- Now try this and think about it. If you were to add a second layer of spheres to the hexagonal array you made and wanted them to take up as little space as possible, would you put the second layer directly on top of the first or some other way? Explain what you would or did do and your reasoning.
- Nature gives us a fine example of the above. The element Carbon can form graphite (the portion of the pencil you write with) or diamond (in addition to some other structures that look like tubes or soccer balls called “fullerenes” after architect Buckminster Fuller, who designed geodesic domes of that shape). In the case of graphite, the hexagons are place on one top of the other. In the case of diamond, carbon atoms are squeezed in between the lower ones. We know that diamond is harder! Do you think it is more dense, as well?

- Finally, back to our container of spheres in a three-dimensional system. For which spheres was the greatest proportion of volume empty space? For was it the least? Do these findings correlate with the way the spheres arranged themselves (least dense on top and most dense on the bottom)? Add any comments or observations you would like about what happened in this activity.

- Explain, now, in your own words, why the biggest Fritos always rise to the top.