Transforming a traditional hands-on activity into an inquiry activity to foster more in-depth understanding of the concept of density

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Abstract

Traditional methods used to teach the concept of density that employ solid objects of different masses and volumes can be supplemented by inquiry activities in which students vary the mass to volume ratio of the same object to test ideas about density and flotation. A simple substance, Blu-Tack, is an ideal material to use in this case. The activity introduced in this paper not only allows students to explore the effect of air on the density and flotation of an object, but also stimulates them to relate a macroscopic property such as density to the microscopic structure of matter.

Introduction

A common hands-on activity allowing junior secondary students to inquire into the concept of density makes use of a density kit that contains blocks of equal or different sizes made of different kinds of materials (an example of such a kit is shown in Figure 1). The density of each material can be determined by measuring its mass and volume. Students are expected to grasp the concept that the density of an object is a constant, regardless of its size. The blocks are placed in water to determine whether they float or sink. Their densities are then compared with that of water, thus helping students to deduce the relationship between density and flotation and to dispel common misconceptions about flotation. However, one limitation of this type of “density kit” is that it allows only limited opportunities for students to test ideas about flotation other than the effect of the nature and size of the object, and does not lead students to explore the explanations behind these additional phenomena.

This paper introduces an alternative density activity that draws on students’ everyday life experiences with flotation. It leads students to explore the relationship between flotation and density by engaging them in both hands-on and minds-on activities. This activity could also help students to develop a deeper understanding of how a macroscopic property of matter such as density can be explained in terms of its microscopic structure.

Most young students believe that objects that contain air will float. Students might have developed this conception while playing with toy floats in the bath or when using floats while swimming. This can be used as a convenient point of departure to guide students to explore why things float and to lead in to developing the concept of density.

The teacher can begin by posing this question to students: do objects that contain air float in water? To test students' predictions, the teacher can show students how to make a small "dumpling" with a piece of Blu-Tack by trapping air inside it (Fig. 2). The dumpling can easily be made by using a plastic rod or a chopstick to mould the Blu-Tack into a thin layer before folding it up to trap air inside it. Blu-Tack is a kind of synthetic polymer. Using Blu-Tack offers certain advantages: it is flexible, is not sticky, can be molded into different shapes, is impervious to water, and will not dissolve in water like ordinary plasticine. Our experience shows that most students fail to make a Blu-Tack dumpling that floats in water at their first attempt because the mass to volume ratio is often too large in comparison with that of water. At this juncture, the teacher could prompt students to think more deeply by asking further probing questions as circumstances warrant: why doesn't your Blu-Tack dumpling float, even though it has air inside it? Does the amount of air inside the Blu-Tack dumpling matter? Suppose that after a few more trials, students come up with the idea that having more air inside the dumpling will help it to float: the teacher could then ask students to hypothesize why this is so. What variables associated with the Blu-Tack dumpling will change when more air is trapped inside it? The teacher could challenge students further by asking them to predict the least amount of air the dumpling needs to contain to make it float in water. The teacher could then let students explore the variables (mass and volume) that determine whether or not the dumpling floats. The following activity comprising three parts is designed to guide students as they explore this topic.

The activity

Part 1:

What variables determine whether a Blu-Tack dumpling floats in water?

- Cut a Blu-Tack strip into a few pieces of the same length so that the mass of each strip is more or less the same;
- Mould the Blu-Tack strips into dumplings with progressively greater amounts of air trapped inside them. This means that each piece of Blu-Tack has to be made increasingly thin and large in area;
- Measure the mass of each dumpling with an electronic balance;
- Measure the volume of each dumpling.

Students are encouraged to devise a method of their own to measure the volume of their dumplings. One suggested way of doing this is as follows:

1. Fill a 250 cm^3 measuring cylinder with water up to any measure on the scale that is easy to read, e.g. the 250 cm^3 mark;
2. Immerse the dumpling in the water;
3. If the dumpling sinks, use a dropper to remove water until the level returns to the original mark;
4. Transfer the water into a 10 cm^3 measuring cylinder. Record the volume of the water, which will be the same as the volume of the dumpling (Fig. 3). (The 10 cm^3 measuring cylinder is used instead of the 250 cm^3 cylinder to minimize the percentage error made in measuring the volume of water due to inaccurate reading of the meniscus);
5. If the dumpling floats in the water, first tie the dumpling to a weight with a very fine piece of cotton thread. Slowly lower the dumpling and the weight into the water with the free end of the thread resting on the mouth of the measuring cylinder and measure the water volume as shown in steps 3 and 4. This measurement will give the volume of the dumpling and the weight (Volume 1);
6. Repeat step 5 to measure the volume of the weight only. Record the volume of the weight (Volume 2);
7. Calculate the volume of the dumpling (Volume 1 – Volume 2).

After measuring the volume of the dumpling, blot it dry with a piece of tissue paper and reweigh it to make sure the dumpling has not absorbed any water. Students should repeat the above procedure with several dumplings of different sizes. After completing the experiment, ask them to find the mass to volume ratio for each dumpling.

The teacher can pool the data recorded by all the groups to obtain a more accurate pattern. Students are then asked to infer from the data the condition that determines whether or not the dumpling floats: the mass to volume ratio of the dumpling must be less than or equal to one. The teacher can further introduce the concept of density and how the density of an object relative to that of a liquid determines whether the object will float or sink in that liquid.

Part 2:

To further extend the conclusion drawn from Part 1, the teacher could lead students to test whether an object will float in a liquid as long as its density is lower than that of the liquid. Another liquid can be used; for example, glycerin, which is denser than water (density of glycerin = 1.23). Students can test the same dumplings they used in Part 1 with glycerin instead of water and check whether the results are consistent with their predictions. Because glycerin is miscible with water, a range of glycerin solutions could be prepared by diluting it with water in different proportions to make the activity more interesting. Students can check the final density of any glycerin-water mixture by calculating its mass to volume ratio.

Part 3:
To further consolidate students' understanding of density and add more excitement to the lesson, students could be asked to make a column with liquids of different densities and predict where in the liquid column a dumpling of known density will stay, either within a particular liquid or at the interface between two liquids. Alternatively, they could make use of the column to estimate the density of a dumpling of unknown density based on where it floats or sinks in the column. A three-layered column comprising glycerin at the bottom, water in the middle, and cooking oil at the top (Fig. 4) can be prepared for this purpose.

Precautions:
The dumpling has to be rigid enough to withstand water pressure when submerged in water to measure its volume in case it becomes deformed or collapses, thereby reducing its volume. In addition, the Blu-Tack should not be molded into too thin a layer to avoid leakage, which will result in an influx of water. The chief source of error is inaccurate measurement, such as inaccurate reading of the meniscus in the measuring cylinder or imprudent use of the displacement bottle.

Beyond the "macroscopic": relating density to the microscopic structure of matter

Enthusiastic teachers could go further by using this activity to explain that density is determined not only by the mass to volume ratio of the object at the macroscopic level, but also by the microscopic properties of the material. This activity can foster in students an understanding that the air inside an object can lower its density and that the mass of the material together with the volume of air inside it largely determine its overall density and whether the object will float or sink in water. Based on this understanding, students could be led to explore why objects made of a particular kind of material such as wood or wax float, while others made of different materials such as iron and copper sink. Is it because wood and wax contain air, which makes them float in water? Wood is a simpler material to start with because it contains a large number of empty vessels. Students could observe the cross-sections of these tiny empty xylem vessels under a light microscope to appreciate their effect in lowering the density of wood (Fig. 5), although the vessels in heartwood are often blocked by deposits such as tannins. Foam is another material that could be used to illustrate the effect of air because air is added to the polymer to make it less dense when foam is produced.

For materials such as wax that float in water but are seemingly non–porous, the teacher could challenge students to hypothesize what makes them floats in water. With some prompting, the teacher could help students to realize that the answer lies in the nature of the atoms and the atomic arrangement within the material. Although there are spaces between the atoms, they are so as to be invisible, even under the microscope. Figure 6 shows different types of atomic arrangements in materials. The density of a material is determined by both the mass of the atoms and the packing efficiency, that is, how closely the atoms are packed within a unit volume. Wax is chiefly made of alkanes. Its low density relative to that of water is presumably related to the relatively small mass of hydrogen atoms that constitute the bulk of alkanes. However, in many cases, it is the packing efficiency that matters. For example, different forms of carbon differ markedly in their density. Diamond, a tetrahedrally bonded giant lattice, has a density of 3.515 g/cm^3 (Pierson, 1993, p.248). Graphite has a layered structure in which the atoms are arranged hexagonally into separate sheets some distance from each other, resulting in a less closely packed structure than that seen in diamond. The density of graphite is 2.26 g/cm^3 (Pierson, 1993, p.51). Fullerene (C-60) has a hollow structure that makes it highly porous and hence has a density (1.65 g/cm^3 (Krätschmer et al., 1990) that is much lower than that of the other forms of carbon. Another example is ice, in which water molecules move toward a hexagonal arrangement with large empty spaces between them, making the density of ice lower than that of water (Mortimer and Machado, 2000). The atomic mass and packing efficiency of a material can be used to establish its density to a high degree of accuracy. For example, based on its face-center-cubic crystal structure, the theoretical density of copper is 8.89 g/cm^3, a figure that agrees quite well with its actual density of 8.94 g/cm^3 (Callister 2007, Chapter 3).

In this activity, trapping air inside the Blu-Tack dumpling can be seen as a way of manipulating the packing efficiency of the Blu-Tack by introducing large spaces between the atoms of which it is composed. Although the density of Blu-Tack is 1.8 g/cm^3 (Bostik, 2008), it can be made to float in water by dramatically increasing the air space inside the dumpling. Because the material used (Blu-Tack) remains the same, the variation in density is a reflection of the amount of “empty space” introduced rather than of the different mass of the atoms, as may be the case when different materials in the “density kit” are compared with each other. Hence, one of the additional benefits of this activity is that it can be used to demonstrate that the amount of space inside a material is an important determinant of its density. It could be further explained to students that air has a very low density in comparison with liquids and solids because its molecules are so loosely packed as to make it invisible. Air can be considered a kind of ‘material’ with an extremely low packing efficiency. Thus, anything containing a lot of air is likely to have a density that is low enough to allow it to float in water.

Conclusion

Density is often studied as a macroscopic property of matter. Students usually learn about the concept of density through a phenomenological approach in which the volume and mass of a certain material are measured and the conclusion reached is that the mass to volume ratio is a constant. Most of the teaching about density does not go further to relate the concept of density to the microscopic properties of matter. Most students therefore gain the impression that density is a standalone (ad hoc) property of matter and has no deeper meaning. Only a small proportion of students – those who carry on studying the physics of materials or engineering – will understand that the packing of atoms at the microscopic level is an important factor determining density. As shown above, theoretical calculations of density based on the crystalline structures of materials are very close to their actual density.

The introductory science curriculum often emphasizes the connection between macroscopic properties such as thermal and electrical conductivity with atoms and electrons. There is no reason to ignore the connection between density and atomic arrangement. While the topic of crystalline structure may be too advanced for an introductory physics course, the concept of packing efficiency is useful in understanding density at the atomic level.

The activity described above could be used as an extension to traditional activities to consolidate and enrich students’ understanding of the concept of density. It could be used to engage students in applying scientific reasoning not only to test hypotheses, collect evidence, and identify patterns from data, but also to construct knowledge and explanations by linking the macroscopic properties of matter to its microscopic structure. Arguably, this kind of linkage is a fundamental building block enabling students to understand more advanced topics like material science and nanotechnology, which are concerned with changing the macroscopic properties of materials by manipulating their microscopic structures.

References

Bostik Limited (2008). Safety Data Sheet for Bostik Blu-Tack (www.farnell.com/datasheets/455847.pdf).

Callister, W. D. (2007), Materials Science and Engineering: An Introduction. 7th edition. New York, N.Y.: John Wiley & Sons.

Krätschmer, W., Lamb, L. D., Fostiropoulos, K., & Huffman, D. R., (1990). Solid C60: a New Form of Carbon. Nature, 347(6291), 354–358.

Mortimer, E. F., & Machado, A. H. (2000). Anomalies and Conflicts in Classroom Discourse. Science Education, 84, 429-444.

Pierson, H. O. (1993). Handbook of Carbon, Graphite, Diamond and Fullerenes: Properties, Processing, and Applications. Park Ridge, N.J.: Noyes Publications.

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