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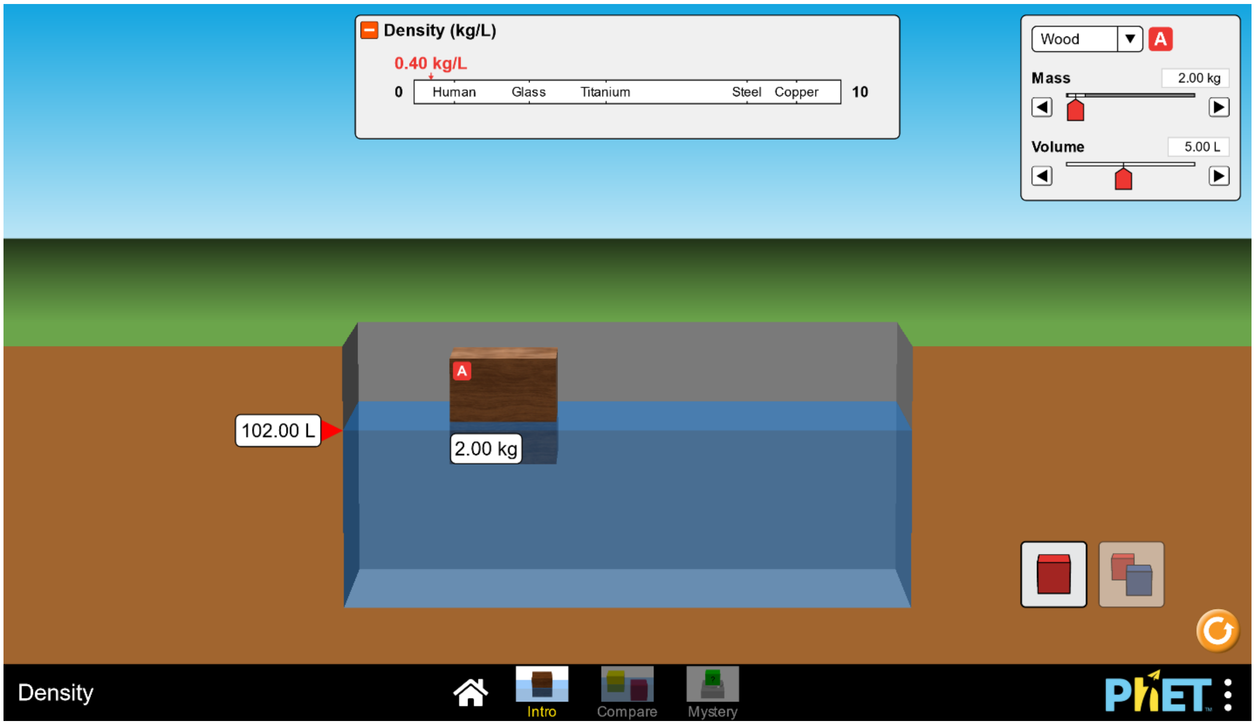
Computational Model Exploration: Density

The model comes from the PhET website, a project maintained by the University of Colorado Boulder which hosts educational simulations. All the models run directly in the web browser. This particular model, as the title suggests, pertains to density. It has three main modes, namely *Intro*, *Compare* and *Mystery*. When the user first opens the model, the user can select one the three modes. After making a selection, the user can use the "home" button to bring them back to the main screen. The user can also navigate between the three modes by clicking their respective buttons at the bottom of the screen. Each of the three modes shares the same two core components: a body of liquid water and blocks. In the *Intro* and *Compare* modes, the properties of these blocks can be manipulated to achieve different effects. The water level cannot be changed in any of the modes; it is set to a standard 100.00 L. A reset button in the bottom right corner allows the user to reset the model to its original state.

What is density?

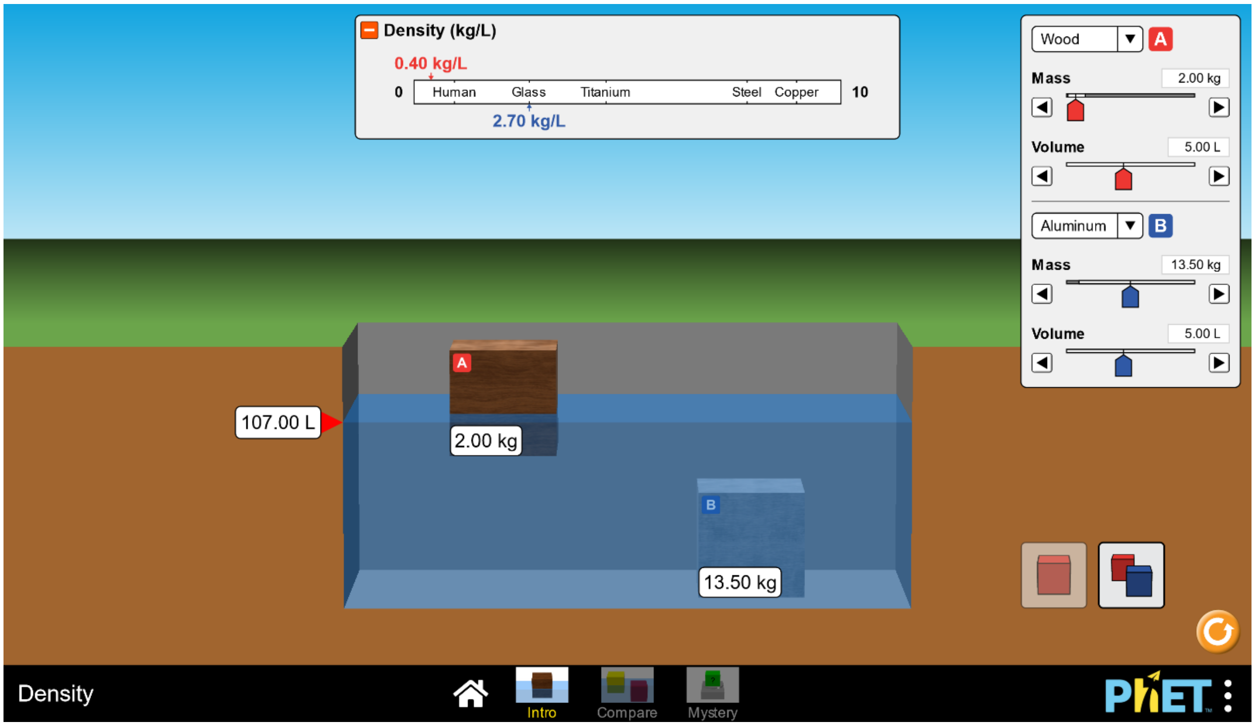
Density is a substance's mass per unit volume. The formula for density is $D = \frac{m}{v}$, where *D*, *m*, and *v* represent the object's density, mass, and volume, respectively (although the letter *D* is used here, the symbol most used for density is the Latin number ρ). The units used most commonly for density are grams per centimeters cubed: g/cm3. The density of an object determines its ability to float or sink on water.

Mode 1: Intro



(Fig 1.1: *Intro* mode on startup)

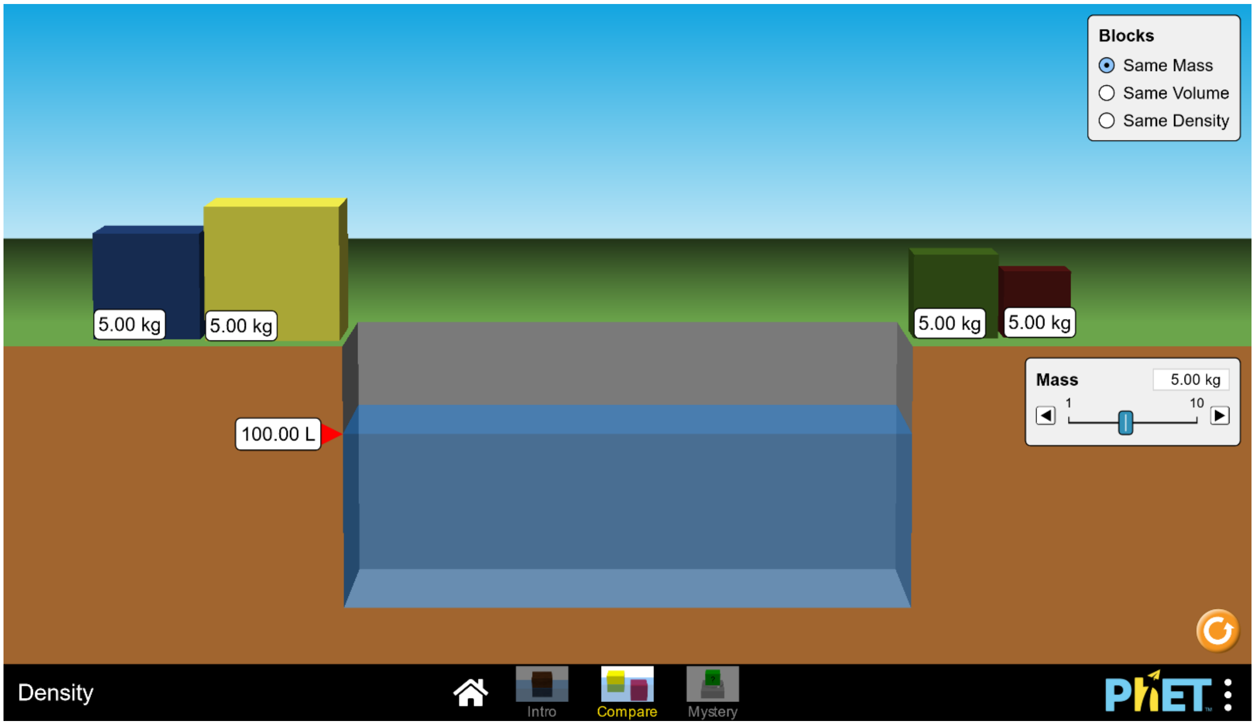
In the *Intro* mode, the model's initial state contains a block of wood with a mass of 2.00 kg. At the top of the model, the density of the block, titled "A," can be observed and is placed on a density scale with other objects—with densities ranging from 0 to 10—for the sake of comparison. This component can be minimized, but it is the only way to view the density of the currently selected object. On the top right, a drop-down menu allows the user to change the material of the block; options include ice, Styrofoam, brick, and more. The mass and volume parameters of the block can be increased or decreased, by using either the slider or the corresponding arrow buttons. These parameters cannot be altered independently: modifying one causes the other to change as well, maintaining the mass-to-volume ratio. In the above image, the density of the wood block is 0.40 kg/L, which allows it to float on the surface of the water which has a density of 1 kg/L. The density can also be calculated by dividing the mass, in this case 2.00 kg, by the volume, 5.00 L. The user can also choose to add another object by clicking on the corresponding button and can manipulate its properties in a similar fashion to the original object, as shown in the image below.



(Fig 1.2: Comparing two different objects)

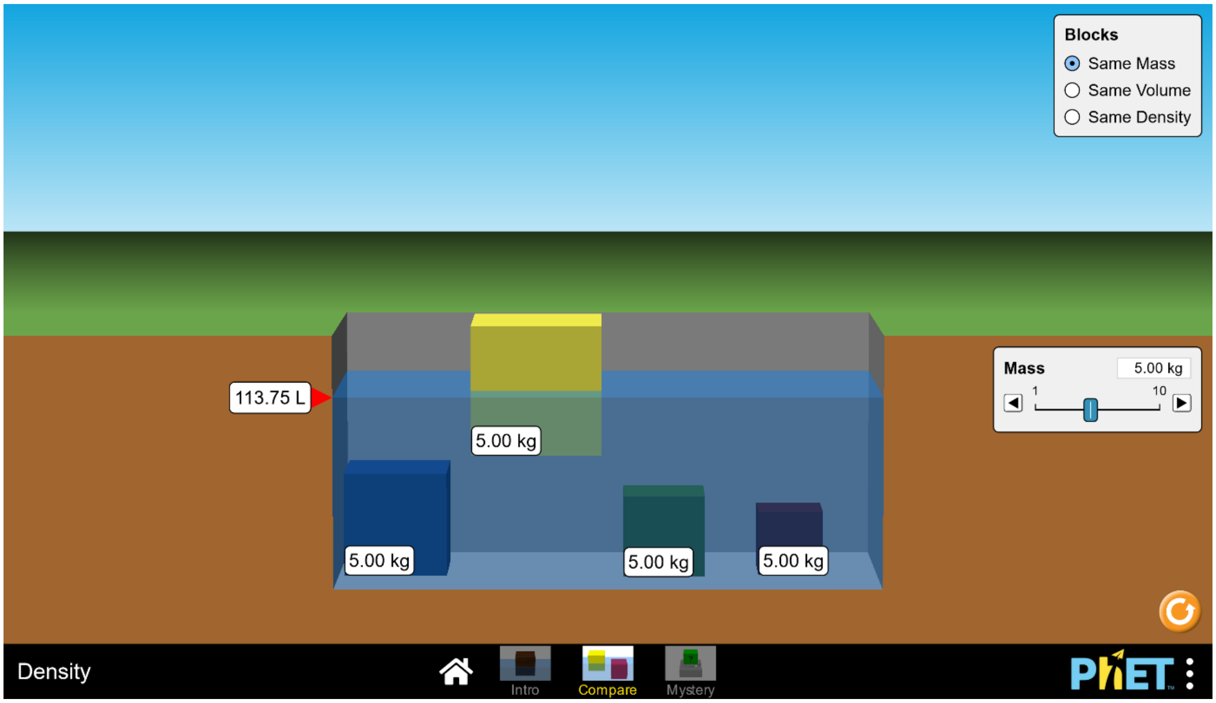
A second indicator appears on the scale, corresponding to the second object. Thus, the user can compare the two objects with ease. In this case, since aluminum is denser than water, with a density of 2.60 kg/L, it sinks below the surface. By referring to the density scale, the user can observe that the density of aluminum is approximately equal to the density of glass.

Mode 2: Compare



(Fig 2.2: *Compare* mode on startup)

The *Compare* mode looks very different from the *Intro* mode; the density scale and other notable components have been removed. Instead, the focus of *Compare* mode is to provide the user a more nuanced understanding of how mass and volume work together to affect density. The initial state sets all the blocks to the same mass, 5.00 kg, but this can be modified by using the slider or the arrow buttons. By placing all the blocks in the water and observing which among them float or sink, the user can reason that among objects with the same mass, objects with higher volumes— "bigger" objects—have lower densities, and objects with lower volumes— "smaller" objects—have higher densities. This could also be explained mathematically: since volume is the denominator of the density equation, a larger volume value would result in a smaller density—dividing by a larger number yields a smaller number—while a lower volume would achieve the opposite effect. This can be observed in the below image, where the larger blocks were able to float on the water while the smaller objects sank.

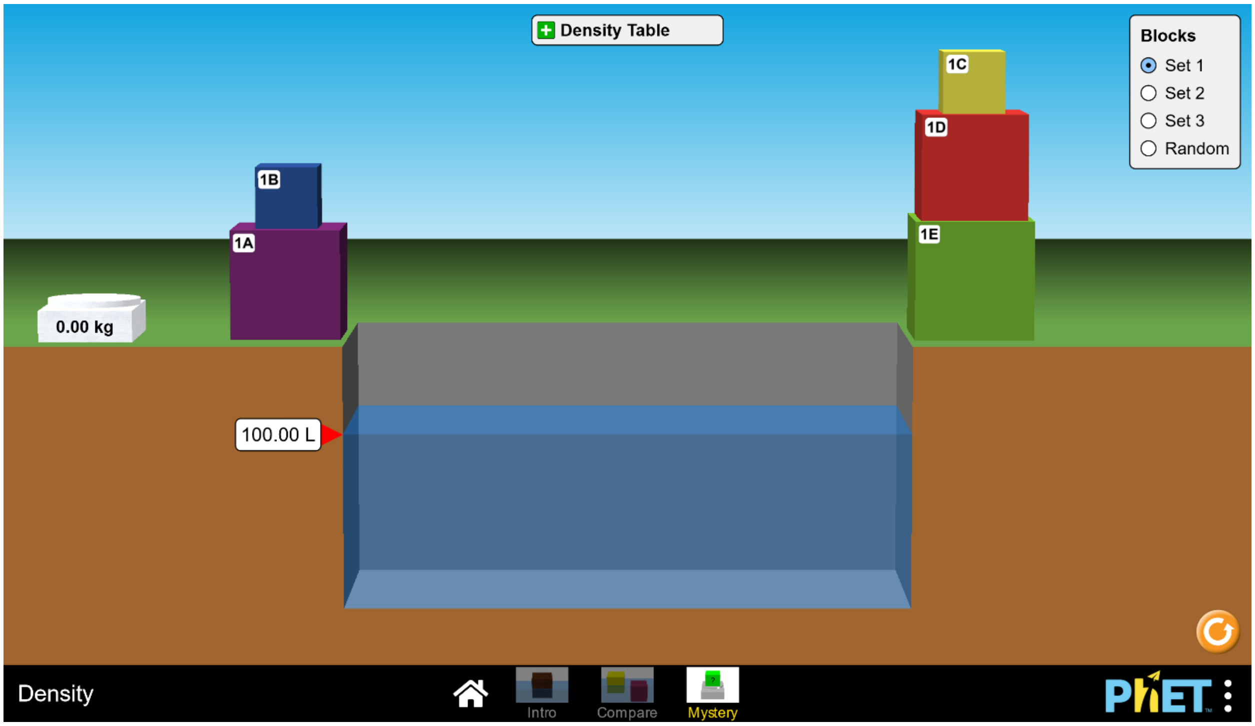


(Fig 2.3: *Compare* mode in action)

Similarly, by clicking on the “Same Volume” setting, the user can observe that among objects of the same size, objects with lower masses have lower densities, while objects with higher masses have higher densities. By clicking on the “Same Density” setting, the user can observe how objects can have the same density while having different masses and volumes. Mathematically, this can be reasoned thusly: so long as the values of the mass and volume are in the same ratio for some number of objects, then they can share the same density. For example, an object with a mass of 2.00 kg and a volume of 4.00 L has the same density as an object with a mass of 7.4 kg and a volume of 14.8 L, since the mass-to-volume ratio is maintained.

Mode 3: Mystery

The layout of this mode looks very different from that of the other modes; none of the blocks’ properties can be changed, and a weighing scale has been placed on the left. The *Mystery* mode presents a challenge for the user: they must calculate the density of each object, using the block mass and volume, and identify it by comparing it with the density table. The mass of the block can be found easily by simply placing the object in question on the scale, which displays the mass of the block in kg, but the methodology the user must use for finding the volume is a little more involved—water displacement.



(Fig 3.1: *Mystery* mode in action)

Water displacement hinges on the principle that, when an object is placed in water, it will displace, or push, the water upwards (or outwards). The amount of water displaced is equal to the volume of the object and can be calculated by subtracting the original volume of the water from the volume of the water after the object was placed. When considering regular objects—such as spheres, cubes, and cones—the volume can be calculated easily by using the corresponding volume formulas. For example, the volume of a cube can be calculated by simply multiplying its length, width, and height together. However, when measuring irregular objects—which are more commonly found in nature—water displacement becomes necessary.

Worked Example:

If we select block "1D," and place it on the scale, the mass comes out to 19.32 kg. The volume after placing the block in the water is 101.00 L, so the volume of the block is: $101.00\ L - 100.00L = 1.00\ L$. Dividing the mass by the volume, $\frac{19.32\ kg}{1.00\ L}$, yields a density of 19.32 kg/L. By referring to the density table, the user can deduce that the object must be made of gold, as it shares the same density.

Limitations

A core limitation of this model is that it assumes a constant temperature. In fact, since temperature is one of the biggest factors that affects density, the temperature should also be reported whenever recording the density of an object. As temperature increases, most materials will expand or increase in volume, resulting in a decrease in density. Likewise, if the temperature decreases, the density will likely increase. For example, the density of solid aluminum is at 931 K 2.542 g/cm^3, while it is 2.640 g/cm^3 at 600 K.[1] Another limitation is that the model only uses water as a source of comparison and does not give the user the ability to explore different options. Liquids can have much higher or lower densities—such as mercury, which has a much density 13.6 times that of water, or gasoline, which has a density nearly 30% less than that of water—which can affect its interactions with objects. Finally, the model only features solid objects, and does not allow the user to observe the properties of density as they pertain to gases or liquids.

Conclusions

So why is density important? In a practical sense, density allows us to determine an object's buoyancy—whether it will float or sink—which is extremely important to consider when designing boats, airplanes, and more. Density is an intensive property, meaning that it does depend on the amount of the substance being examined, so it can also be used to identify unknown substances, as seen in the *Mystery* mode of the model. In a broad sense, density is simply the measure of how tightly or loosely packed a substance is, so it can be applied to other disciplines as well. Examples include soil density (agriculture), population density (geography), bone density (biology), and more.

[1] http://www.knowledgedoor.com/2/elements_handbook/density.html

Works Cited

“Density: The Elements Handbook at Knowledgedoor.” *KnowledgeDoor*, www.knowledgedoor.com/2/elements_handbook/density.html.