although the individual particles are fixed to their neighbors, they can still wiggle around a little. It is as if the particles are attached to each other by little springs, which allow them to bounce around a little without moving away from each other.[2] Because of the strong bonds between neighboring atoms, a solid retains its shape regardless of what kind of container it is placed in (it doesn't flow like a liquid).

### *Measuring the Size of a Molecule*

It might seem as if molecules are too small to be investigated, let alone have any importance in our day to day lives. We will soon see that thinking of substances as composed of atoms and molecules allows us to develop a very powerful theory for heat and temperature. And while it is true that molecules cannot be seen directly, it is possible to design experiments that do reveal information about lone molecules. In fact, using only a drop of soap, some water, and some pepper you can determine the approximate size of a single soap molecule!

## Activity 2.1.1 Estimating the Size of a Molecules

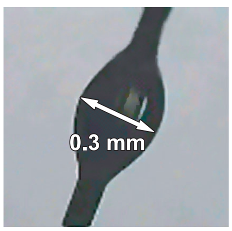



**Figure C-6:** A human hair with a small drop of liquid soap on it as seen under a microscope.

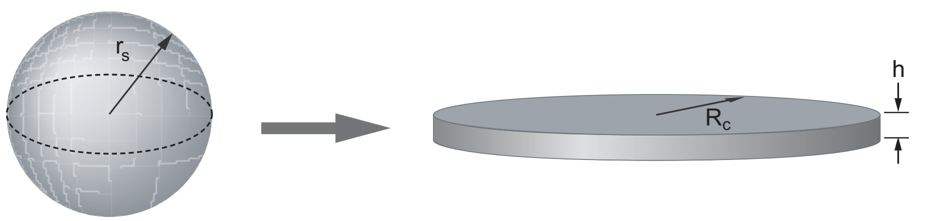
a) Take a small cup of water and gently sprinkle some pepper on the surface. Next, pull a hair out of your head and lightly dip one end in some liquid soap. You should end up with a small bead of soap on the end of the hair. Your bead of soap should look like a tiny sphere with a diameter about twice the width of your hair (see Figure C-6). Now poke this end of the hair into the center of the cup of water and describe what you observe.

b) What do you think happened to the drop of soap?

[2] In fact, the bonds between atoms in a molecule also behave like little springs.

c) You should have seen that an approximately circular area has been "cleared" of pepper. Estimate the radius of this circle and calculate the area in square millimeters. Recall that the area of a circle is $A = \pi R_c^2$, where $R_c$ is the radius of the circle. If you measure the radius in millimeters, your area will be in square millimeters.

d) So what happened in this experiment? The small bead of soap that we began with spread out into a thin pancake when it hit the surface of the water. That is what pushed all the pepper out of the way. Basically, the soap tried to make itself as thin as possible. Clearly, the pancake of soap cannot be thinner than one molecular layer (although there's no guarantee that it isn't more than one molecule thick). Thus, in order to estimate the size of a soap molecule, we need to equate the volume of soap that we started with (the small sphere) to the volume of soap that we ended with (the thin pancake). This is shown schematically below. **Note:** It might help to visualize this using modeling clay. Roll some clay into a ball. This is like the soap droplet on the hair. Then squash the ball with your hand until it is a thin pancake. Notice that the shape of the clay has changed dramatically, but the amount (volume) of clay has remained the same.




Small sphere of soap with volume $V = \frac{4}{3}\pi r_s^3$

Thin Pancake of soap with volume $V = \pi R_c^2 h = A\,h$

Estimate the volume of soap that was initially on the hair. (Remember that this is an estimate. You don't have to know the *exact* size of the sphere of soap, just the *approximate* size). **Hint:** The width of a human hair is about 0.1 mm.

We'll use the picture in Figure C-6, and later check ourselves with a picture.

e) Now equate this volume to the volume of a small pancake, whose area $A$, you estimated in part c), and solve for the height $h$, of the pancake This is your estimate for the smallest thickness that a single soap molecule can have.

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Keep in mind that the size of the molecule you just calculated is only an *estimate* for the size of a soap molecule. In fact, since it is possible that the thin layer of soap is more than one molecule thick, all we can say for sure is that the size of a soap molecule can be *no larger* than the value you calculated in the last activity. However, this estimate should make it clear that the size of a soap molecule is many thousands of times smaller than the width of a human hair. Furthermore, since soap molecules are composed of many atoms, the size of an atom is smaller still.

### *Seeing Molecular Motion*

Because the small size of atoms and molecules prohibits us from seeing them individually, we can't just look at them to understand how they behave. However, because molecular motion is important in understanding much of what is to come, we will attempt to give you some direct evidence for the motion of molecules. The following activity re-creates an observation that was first made in 1827 by the English botanist Robert Brown. Brown was looking through a microscope at pollen grains and other small inanimate objects suspended in water and was surprised to see them moving. This is now referred to as *Brownian motion*.