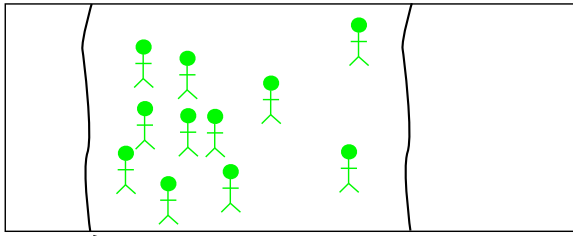


**Students represent individual molecules that move around to represent matter in a sealed container.**

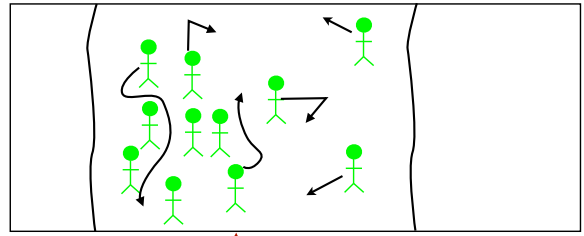
I take my students in a nearby low-traffic hallway that has no classroom doors (to minimize disturbing others).



**masking tape**  
(or caution tape) suspended across the hallway represents edges of container

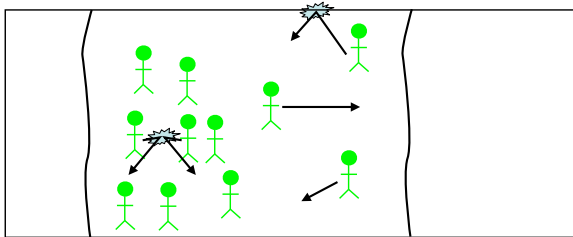
“All molecules in the Universe are moving. So show me your movement.”

Trying to emulate the animation of moving gas molecules bouncing around a container in a socially acceptable way, they typically taking curving paths to avoid other students and/or randomly stop and change direction.



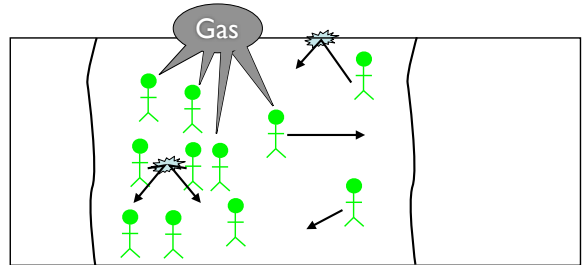
**example of incorrect representation of molecular motion**

“STOP! I see a lot of people walking ‘randomly,’ but when we talk about molecules moving ‘randomly’ in a container, they actually follow some pretty strict rules. They move in perfectly straight lines until they collide with something else. That means if you are heading towards a wall, you keep going until you hit it. Then you turn around and bounce off. If you are heading towards another molecule, you GENTLY bounce off in the opposite direction. So, try that again.”



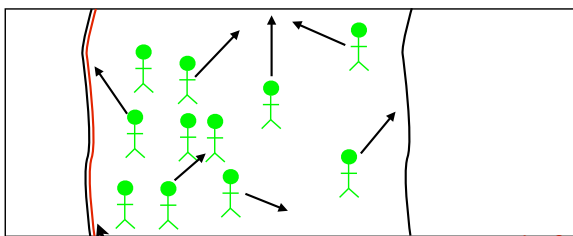
Yes, it's true that one of the molecules needs to slow down after the collision!

“Good! Stop for a moment. Now, there is a lot of space between you. What state of matter does that mean you are representing?”



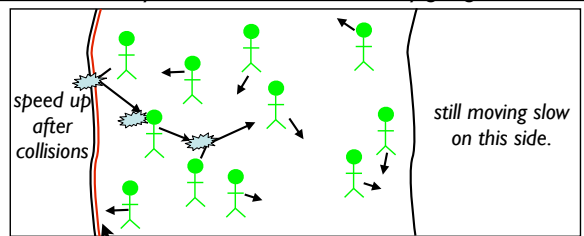
“Now, I'm going to make this wall of our container into an electric heater so that our gas is going to warm up. Ready? Go!”

Students, having memorized that heat = move faster, instantly start to move faster. It's great that they are eager to demonstrate their knowledge, but not quite correct...



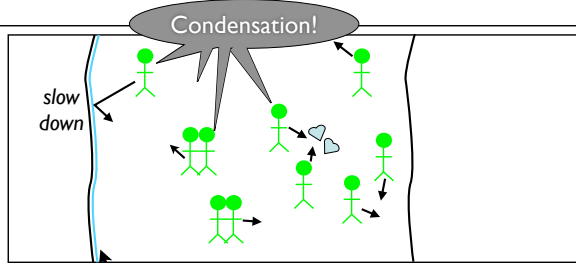
**imaginary space heater**  
*example of students speeding up instantly upon turning on a heater: incorrect!*

“Wait! STOP! You all started going faster instantly. Where did you get that energy from? You should continue along at exactly the same speed you were before. Franco, you were heading towards the heating wall at a nice slow walking pace. What will happen to you when you hit the wall? [bounce off, speed up]. At that moment, only one person in the room should have sped up. But then Franco is going to collide with someone and they will speed up. Then we'll have a chain reaction-like effect where everyone in the room is eventually going faster!”



**imaginary space heater**  
*speed up after collisions*  
*still moving slow on this side.*  
Yes, it's true that one of the molecules needs to slow down after the collision!

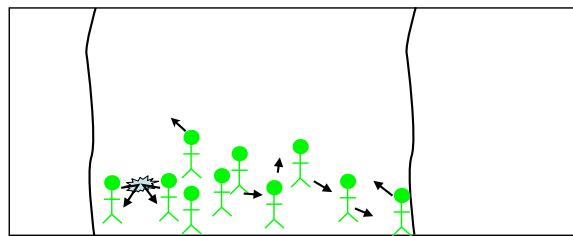
“Great, now, let’s cool you down the same way. Note that we are slowly sending energy into the refrigeration or cooling element, which carries it away. But as you start walking really slow, you notice that you are strangely attracted to other molecules. You didn’t feel the attraction as intensely before because you were all going too fast. What will happen next?”



imaginary cooling element

Yup, so now show me what a liquid looks like.

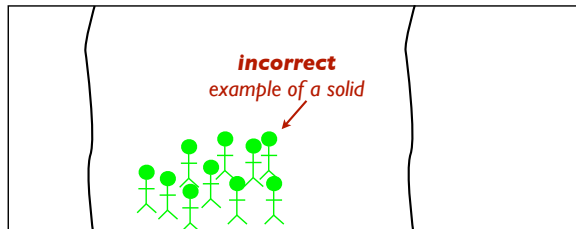
“You should still be moving around following the same rules. You go straight until you hit another molecule in the container or a barrier wall (which is really just another molecule!). But now you are all clustered much closer together, feeling a stronger attraction to one another. You’re at the bottom of the container because the big, slow moving cluster doesn’t have enough energy to overcome gravity.”



Gravity

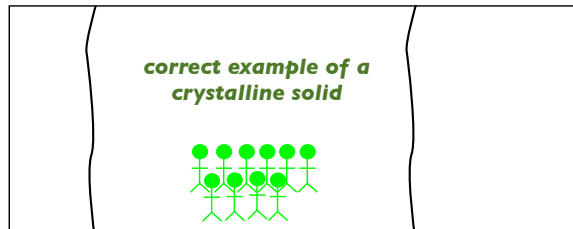
“What will happen if we cool you down further? [Slow down and freeze into a solid]. So show me a solid.”

Students tend to just move closer together and start to wiggle. The majority of naturally occurring solids are crystalline and the atoms arrange themselves in a defined order.



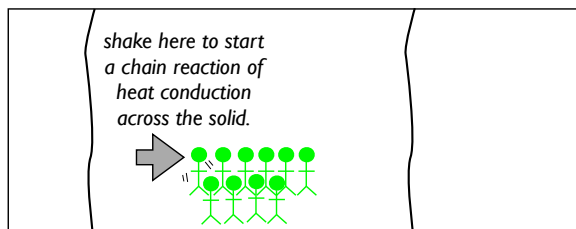
What will happen if we cool you down further? [Slow down and freeze into a solid]. So show me a solid.

Students tend to just move closer together and start to wiggle. This is a good start, but the majority of naturally occurring solids are crystalline and the atoms arrange themselves in a defined structure or order.\*



\*Amorphous solids from everyday life include glass, wax, a lot of polymers that make up plastics and foams. But they are the minority of materials.

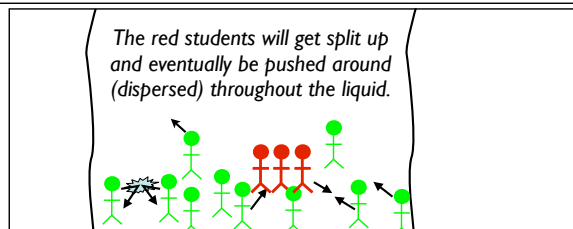
“I see that you are all wiggling or vibrating back and forth. Do you collide and touch? It turns out that molecules in a solid are loosely bonded to their neighbors, and those attractive bonds behave sort of like springs that prevent molecules from getting either too far apart or too close. But they do allow the molecules to interact and transfer energy even when they don’t crash together.\* So show me what would happen to the energy if I heat up this side of our solid [gently shake one student].”



\*Metals bonds are different and can also include some energy transfer by collision between free electrons. This ‘extra’ energy transfer option explains why metals conduct heat so well compared to other materials!

### Kinesthetic Assessment

Melt yourselves back into a liquid. Students wearing red shirts today represent red food coloring. I’m going to start you off as a drop clumped together in our liquid. Show me what will happen to the red dye. Now, show me what would happen if I did the same thing in much warmer water.



\* Or do a paper assessment having students construct a scientific explanation that draws on their kinesthetic experience. Consider this video showing the temperature dependence of diffusion: <http://youtu.be/M30PrZDB8I>