How Do You Slow Molecules to a Standstill? With a Laser!

Did you know that light can push on things? You might not feel the force of the sun's rays on your body, but it is exerting one on you! If you were as small as a single atom, a light beam could provide a force on you large enough to slow you from the speed of a jet plane to a standstill in seconds. More than a century ago, scientists discovered that light exerts a force on matter, called **radiation pressure**. Since then, researchers have worked to harness this feature of light to slow atoms and molecules.

Why would we want to slow atoms and molecules down? At room temperature, air particles are zipping around at nearly 500 meters per second, (more than 1000 miles per hour—faster than a jet plane!). These high velocities make it difficult for scientists to study exactly how the particles interact. If a researcher wants to precisely manipulate particles and observe their interactions more directly, they need to slow them down so that they are hardly moving at all. Easier said than done.

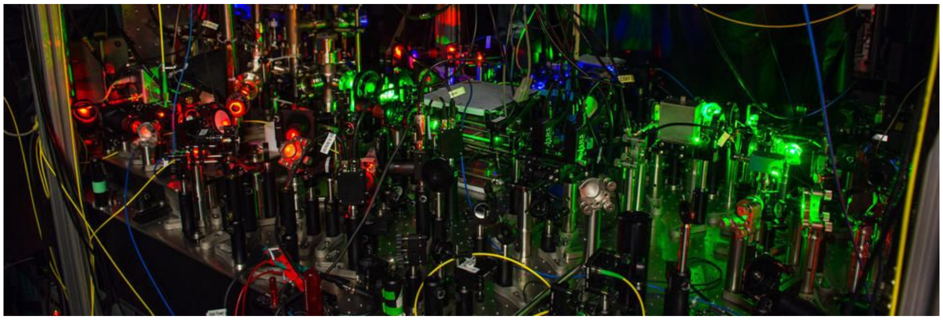

Figure 1. Molecular Slowing Apparatus. The machine used to slow down molecules. *Source:* Harvard Professor John Doyle's [physics group](). Shown here with permission.

One way to slow down molecules is to put them in a box with a cold gas that doesn't react with anything called a **buffer gas**. You can think of this as a very, very cold refrigerator. When the molecules interact with the cold buffer gas, they are slowed to about one tenth of their average room temperature speed (around 50 m/s or 100 mph). But even at this speed, the molecules are moving too fast for scientists to trap and study them. The next step is to open a tiny hole in the buffer gas box, allowing the molecules to stream out, much like what would happen if you poked a tiny hole in a balloon full of water. The molecules now all move in more or less the same direction in what scientists call a **molecular beam**.

Next, the researchers use light (!) to slow down the molecules further. They direct one or more lasers at the molecular beam. The laser light exerts a radiation pressure force in the opposite direction to the molecules' motion, as shown in **Figure 2**. This force slows the molecules down to a near standstill by the time they've moved only a few meters away from the buffer gas box. Next, researchers can trap the molecules and control them using more laser beams. These lasers allow scientists to directly manipulate (move around and control) molecules and study their physical and chemical interactions.

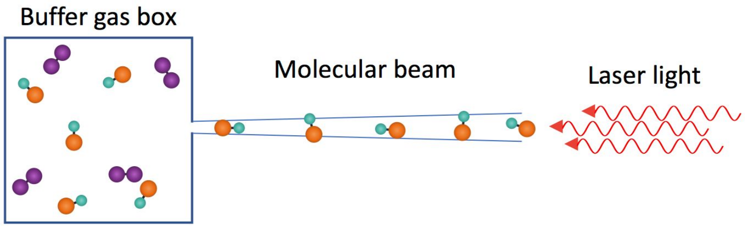

Figure 2. Slowing Molecules With A Laser. Molecules are allowed to escape in a molecular beam, which is hit with a laser to further slow the molecules.

For years, scientists have been able to slow *atoms* with laser radiation pressure, but it's proven much more difficult to slow down *molecules* this way because of their more complex internal structure. In 2012, a group from Yale showed radiation pressure slowing of a beam of strontium fluoride (SrF). Now, researchers are working to slow down and trap more complex compounds, like strontium monohydroxide (SrOH), and even larger compounds containing six or more atoms! These advances open the door to all kinds of new experiments and observations. Soon, scientists may be able to study chemical reactions in highly-controlled environments with molecules as complex as DNA. This research could one day lead to new insights on how molecules combined together on the early Earth to create the first forms of life.

References

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BiteScientist Profiles

Jennifer Schloss is working on her graduate degree in physics at MIT and a researcher at Harvard. She is working to develop a new imaging tool for neuroscience using atomic-scale impurities in diamond crystals, which can sense the tiny magnetic fields produced by firing neurons. Outside the lab, she enjoys rock climbing and experimenting in the kitchen.

Zoe Masters teaches physics and co-facilitates Boston Educators for Equity, a workshop series for teachers from all kinds of schools in the greater Boston area to engage in dialogue and action towards racial equity in our classrooms and community.