Biochemistry Literacy for Kids, Daniel Fried

Lesson 9 outline

Preparation:
Hand out worksheet.
Hand out molecular model kits.

Overview:

“Powerful nucleus” concept
This lesson uses the idea that elements within a certain row of the periodic table can be compared based on the positive charge “power” of their nucleus. We are talking about electronegativity without naming the concept.

Polarized hydrogen model
I created a way of explaining the polarization of hydrogens attached to “powerful” nuclei which shows those hydrogens as distorted, exposing their protons on the far side of the molecule.

Hydrogen bonding
The final step in understanding hydrogen bonding is the realization that the “exposed” protons bonded to N, O, and F will be susceptible to electrostatic attraction from lone pair electrons from other molecules.

Examples of hydrogen bonding
We look at how hydrogen bonding is essential in explaining the structure of water, proteins, and DNA.

Lecture sequence:

“Powerful nucleus” concept
Understanding why some hydrogens can hydrogen bond requires students to realize that some atom nuclei are “more powerful” or have more effective positive charge than others. Of the elements on the second row of the periodic table, fluorine has the most protons (other than neon). Carbon is therefore much “less powerful”.

Polarized hydrogen model
Neutral atoms have an equal number of protons and electrons, so how can one nucleus pull its electrons closer than another? Since the second orbital is the same, despite the number of electrons that populate it, the more protons in the nucleus really does effect the size of the electron orbital cloud. The fact that fluorine has more electrons does not change the kind of orbital cloud it is, so since fluorine has more protons, the cloud will be pulled closer than in carbon. I start the lesson by showing them a more sophisticated way of thinking about the Lewis dot structure drawings by both shrinking the central atom (in N, O, and F) as well as polarizing the attached hydrogen orbitals. They become asymmetrical (polarized) since the powerful nuclei pull those electrons toward themselves as well.

To teach this section, start with carbon and show how the more powerful the nucleus, the more the central atom shrinks, and the more polarized the hydrogen atoms become.

Hydrogen bonding
Next, students begin to think about what happens when these polar molecules approach one another. Since the hydrogens bonded to nitrogen, oxygen, and fluorine have somewhat exposed protons (you can use words like unprotected, vulnerable, etc.) they will “see” or “be seen” by lone pair electrons. Since electrons, even those bound to atoms, have a negative charge, they will be attracted to the polarized hydrogens (really the exposed proton) and form a new kind of bond called a hydrogen bond.

When students begin building, have them use the lone pair pieces that come with the kits. Since hydrogen bonding is so important in biology, I made sure the custom kits from MolyMod came with many of these pieces. Now is a great time to emphasize that the lone pair piece represents two electrons, as do the gray bond pieces—the only difference is that the bond pieces represent shared pairs of electrons.

It is important to emphasize the difference between shared pair electrons and the lone pair electrons involved in hydrogen bonds. Shared pair electrons (covalent bonds) are permanent and can only be broken in chemical reactions. They must obey the octet rule, as well as the 4, 3, 2, 1, 0 rule. Hydrogen bonds however are simply the result of positive-negative attraction. They are not part of the octet rule of the 4, 3, 2, 1 0 rule. Hydrogen bonds are also weaker and tend to be transient, and can be easily be broken. (However some hydrogen bonds, like those that hold cellulose fibers together in wood, can probably remain unbroken for thousands of years.)

I include several diagrams of possible hydrogen bond scenarios and others showing where hydrogen bonds do <u>not</u> form. Hydrocarbons importantly do not generally make hydrogen bonds because their hydrogens are <u>not polarized enough</u> to expose their protons—carbon is not “powerful” enough for that. This is a critical idea in the lesson and is needed when we discuss protein folding in future lessons.

Examples of hydrogen bonding
Students can fill in the drawings on the worksheets and in PyMol to practice finding them. Importantly, hydrogen bonds do not occur “side on”. This is because only the part of a hydrogen farthest from its parent atom has a thin enough electron cloud to expose its proton. The “sides” of polarized hydrogens are actually almost as think as a hydrocarbon, according to my models.

One nice activity is to have students build a hydrogen bonded network of water molecules to build a tiny “snowflake”. They can then melt the structure by adding heat (shaking vibrations). They will notice that the water molecules usually remain intact why only the hydrogen bonds break. You can find many molecular dynamics simulations of melting ice on the molecular level on YouTube as well. Students love the fact that they understand melting to this level of precision. Several of the PyMol structures can be used to find hydrogen bonds. You will be using the measurement wizard for this. To learn more, check out my YouTube channel and watch the “hydrogen bonding” video. The G-quadruplex file in particular is interesting since it is from an NMR experiment and includes several structures. To cycle through all the structures, press space bar. The motion you see are similar to what real molecules experience at ambient temperatures. You can easily see that the hydrogen bonds stabilize the core of the DNA structure while less hydrogen bonded areas of the molecule are much more flexible and variable in their conformations.