- Extension activity 1 - measuring the width of a strand of hair
  - Rosalind Franklin discovered the double helix structure of DNA in 1953 using X-ray crystallography.
  - You can reproduce her experiment by shining a laser beam through an extra spring, and observing the diffraction pattern on a far wall.
  - You can stand the spring up on the table, and the person holding the laser should keep their hand as steady as possible. You may play with the orientation of the spring to see how the diffraction pattern changes (the lights in the room may need to be dimmed to best observe the pattern, see Figure 5).
  - You can use a similar technique with a laser pointer to measure the width of your own hair!
  - Like the spacing between atoms, a human hair is too small to measure its width using a ruler, but you can measure it by performing a diffraction experiment, just like how scientists use X-ray diffraction to study the atomic structure of crystals
  - You can learn how to perform the experiment by reading this activity guide

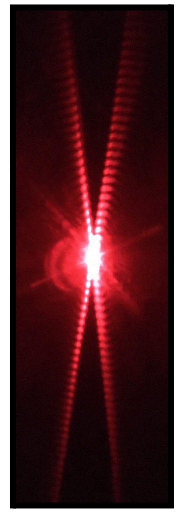

Figure 5. Helix Diffraction pattern

- Extension activity 2 - simulating realistic X-ray diffraction experiments
  - Students may use an online interactive simulator to see how X-ray crystallography experiments are performed, and what more realistic X-ray diffraction patterns actually look like for a variety of real crystal structures. Students should be encouraged to make connections between the simulation and the experiments they were performing.
  - The simulator can be used by visiting: https://ehaber64.github.io/

- Extension activity 3 - creating pure Lissajous figures
  - The sound waves created in the activity were not pure waves with single frequencies, but superpositions (the sum) of waves with many frequencies.
  - Pure waves will create stable Lissajous figures. Since these are sound waves of a single frequency (or pitch), one easy way to generate them is to connect a bluetooth speaker to your computer or phone, and use a free tone generator.

- If you place the speaker so that its cone (where the music comes out) is right up against the ping-pong balls in your crystal model, the pure sound wave it's producing will cause the balls to vibrate with a single frequency (in each direction). The louder you make the speaker, the easier it will be to excite the balls and see the Lissajous patterns.
- Someone can then shine the laser on the mirror attached to one of the balls to observe the patterns (it's important for this person to hold the laser as steady as they can!).
- Try many different frequencies and see the different shapes you can make (one suggestion is to go from around 20 to 100 Hz in steps of 5 Hz (or less)). Do all tones create the same shapes? Do some tones not create any shapes at all? For any musicians in the class, how can this behavior be explained?

- Extension activity 4 - electrons and superconductivity
  - Electrons are the particles that make up electricity and are a key component of atoms. Like photons, electrons have both particle and wave-like behavior, and one of the most important applications of electrons is superconductivity.
  - Superconductivity allows electricity to be sent through wires without any energy being lost, and it arises from the quantum (or wave-like) nature of electrons. There is a huge interest in finding a way to engineer a superconductor that works at room-temperature, because such a discovery would revolutionize everything that uses electricity.
  - If you'd like to learn more about electrons and superconductivity with your crystal model check out this activity guide
- Drawing: a crystal puzzle
  - Using a ruler, markers/pens/pencils, and scissors, draw at least ten puzzle pieces in the shapes of the four types of lattices shown in Figure 6 on a piece of paper. Once you are done, cut out your puzzle pieces.
  - Once you have your pieces, see how many different crystals you can create using only these four lattice shapes.
  - The puzzle piece shapes you are using are called Bravais lattices, and if you were to put any crystal in the world in an X-ray crystallography machine you would see that the atoms are arranged in the exact same pattern as one of the Bravais lattices!

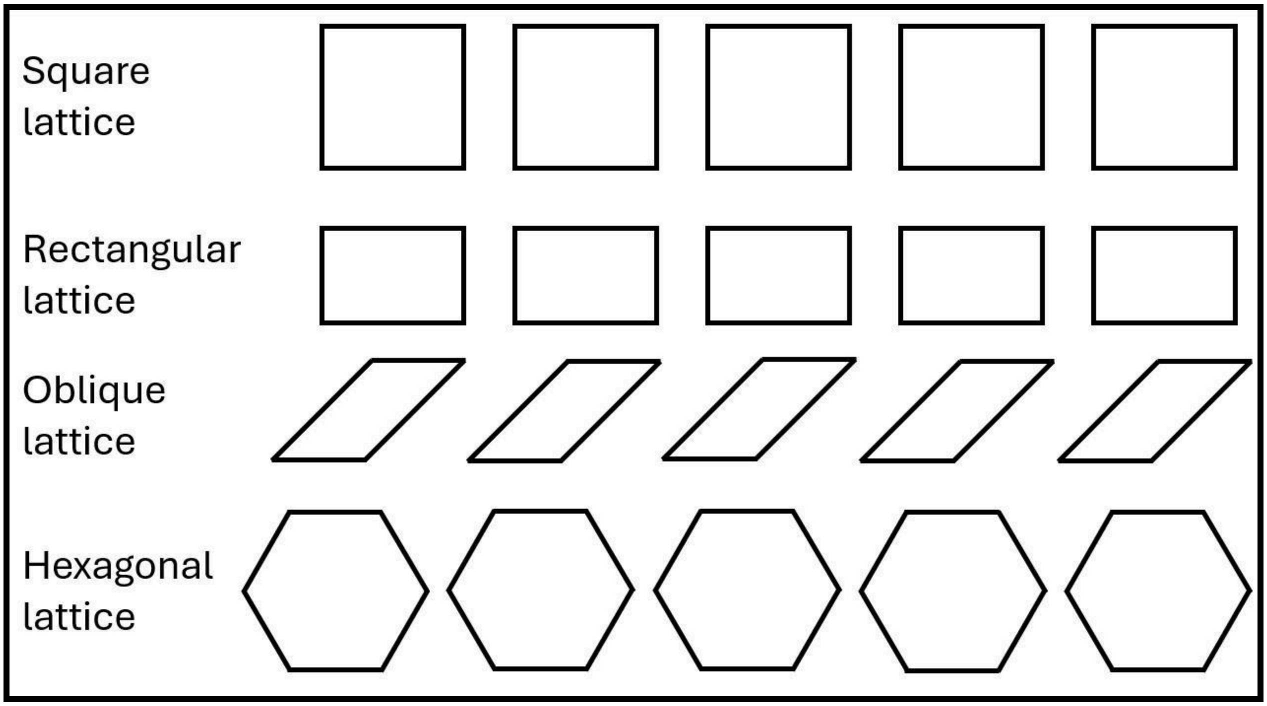

Figure 6. Crystal lattice puzzle pieces.