Non-obvious controls:

- In **Experiment** mode, a single Hydrogen atom is hidden behind the black box. In **Prediction** mode, the atom is visible. Students should be able to discover that only the predictions of the **Schrodinger** model match the results of an experiment.
- Select **Transitions** in the **Help** menu to show the wavelengths needed for transitions in the **Bohr**, **deBroglie**, and **Schrodinger** models. If **Light** is set to **Monochromatic**, the wavelength slider flashes white when it is over a wavelength that could excite the electron from the ground state.
- Use the camera icon () to take a snapshot of the **Spectrometer** so that you can compare the patterns for different models.
- Set the slider at the bottom to **fast** to build up the Spectrometer pattern quickly.
- You can **Pause** the sim and then use **Step** to incrementally analyze.
- If you are doing a lecture demonstration, set your screen resolution to 1024x768 so the simulation will fill the screen and be seen easily.

Important modeling notes / simplifications:

- These atoms are not to scale!
- In the **Schrodinger** model, transitions obey the selection rules $\Delta \ell = \pm 1$, $\Delta m = 0, \pm 1$. Because of these selection rules, the state 2,0,0 is a metastable state from which the electron cannot spontaneously emit a photon. If **Light** is set to **White**, whenever the electron falls into this state, the gun will soon emit a photon of exactly the right energy to excite it. If **Light** is set to **Monochromatic**, the electron will remain stuck in this state unless you select a wavelength that can excite it out of this state.
- In the **Plum Pudding** model, we assume the electron can absorb any frequency of light, but always emits light with frequency equal to its oscillation frequency.[1]

Insights into student use / thinking:

- Students may not realize that UV photons can have different wavelengths, since they all look the same.
- If **Light** is set to **Monochromatic**, students may not realize that they need to move the slider into the **UV** region to excite the atoms.
- Students many have trouble identifying the red goo in the **Plum Pudding** model as positive charge. In interviews, we see that some students describe the **Plum Pudding** model as a cloud of negative charged filled with little specks of positive charge, rather than the other way around. The word "cloud" suggests that they are mixing up the **Plum Pudding** model with the **Schrodinger** model, in which the electrons are often described as a cloud of negative charge. These students initially thought that the electron in the simulation was a proton, but were eventually able to identify it correctly by using the legend or by comparing it to the electrons in other models.

Suggestions for sim use (NOT an exhaustive list!):

- While the PhET sims may be used in many different types of activities, we believe that they are best used when integrated into activities which use a ***guided inquiry***

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[1] A.P. French and E. F. Taylor, *An Introduction to Quantum Physics* (1978), p. 11.

approach to learning. For guidelines on creating effective guided inquiry activities, see: http://phet.colorado.edu/activities/guidelines.pdf

- For activities and lesson plans written by the PhET team and other teachers, see: http://phet.colorado.edu/activities
- Ask students to determine which model most closely matches the experimental observations.
- Ask students to explain the reasons that people believed in each model, as well as the reasons they discarded each model in favor of a new model. This sim can be used in conjunction with the *Rutherford Scattering* sim, which illustrates the reasons for moving from the plum pudding model to the solar system model.