Tips for Teachers — Models of the Hydrogen Atom

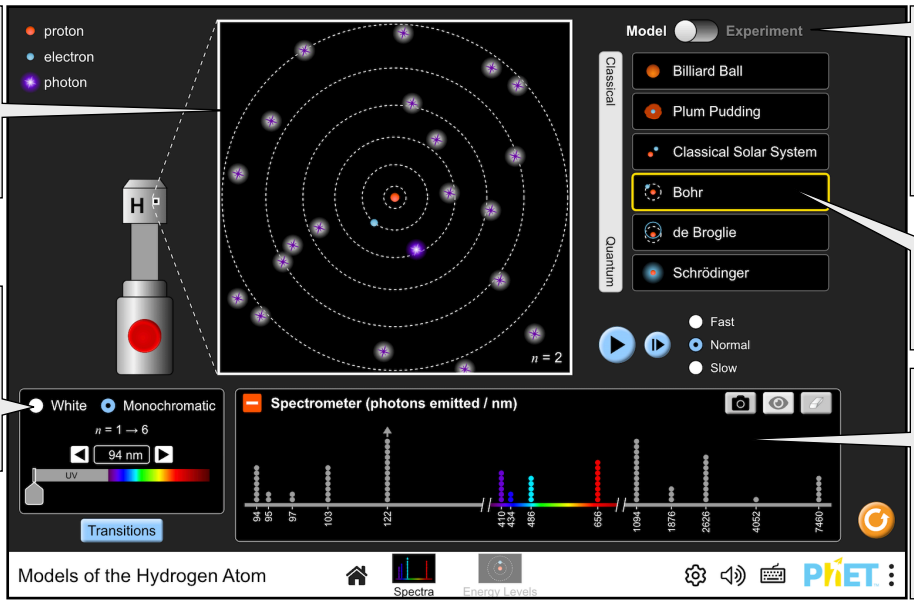
The ***Models of the Hydrogen Atom*** simulation allows students to explore historical models of the hydrogen atom and compare the models to experimental results.

Spectra Screen

Shine light on a sample of hydrogen and observe what happens. Collect spectroscopy data and compare snapshots of different models to the experimental results.

OBSERVE a zoomed-in view of the hydrogen atom

SHINE white or monochromatic light on the hydrogen atom



COMPARE historical models to experimental data

SELECT model to observe

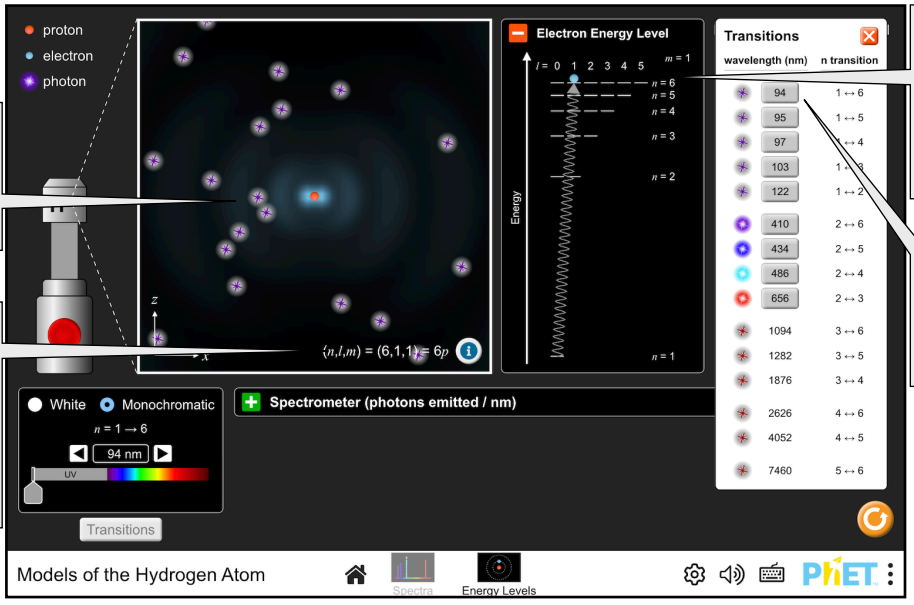
COLLECT spectroscopy data; **TAKE** snapshots to compare

Energy Levels Screen

Explore the relationship between the model representation of electron transitions and the energy level diagram.

SEE the orbital representation of the electron state

OBSERVE the current electron state and quantum numbers



VIEW the electron state in the energy level diagram

SET wavelength to a specific transition

López, Rouinfar, Salpepi April 2025

Customization Options

Query parameters allow for customization of the simulation, and can be added by appending a '`?`' to the sim URL, and separating each query parameter with a '`&`'. The general URL pattern is:
`…html?queryParameter1&queryParameter2&queryParameter3`

For example, in Models of the Hydrogen Atom, if you only want to use the first screen (`screens=1`), and mute the audio by default (`audio=muted`) use:
https://phet.colorado.edu/sims/html/models-of-the-hydrogen-atom/latest/models-of-the-hydrogen-atom_all.html?screens=1&audio=muted

To run this in Spanish (`locale=es`), the URL would become:
https://phet.colorado.edu/sims/html/models-of-the-hydrogen-atom/latest/models-of-the-hydrogen-atom_all.html?screens=1&audio=muted&locale=es

⚙ Indicates this customization can be accessed from the Preferences menu within the simulation.

Query Parameter and Description	Example Links

`screens` - specifies which screens are included in the sim and their order. Each screen should be separated by a comma. For more information, visit the Help Center.	`screens=1`
	
	`screens=2,1`

`initialScreen` - opens the sim directly to the specified screen, bypassing the home screen.	`initialScreen=1`
⚙ `locale` - specify the language of the simulation using ISO 639-1 codes. Available locales can be found on the simulation page on the Translations tab. Note: this only works if the simulation URL ends in "_all.html".	`locale=es` (Spanish) `locale=pt_BR` (Portugues Brazil)
⚙ `colorProfile` - changes simulation colors for easier projection.	`colorProfile=projector`
`audio` - if muted, audio is muted by default. If disabled, all audio is permanently turned off.	`audio=muted` `audio=disabled`
`allowLinks` - when `false`, disables links that take students to an external URL. Default is `true`.	`allowLinks=false`
`supportsPanAndZoom` - when `false`, disables panning and zooming using pinch-to-zoom or browser zoom controls. Default is `true`.	`supportsPanAndZoom=false`

Insights into Student Use

- Encourage students to adjust the sim speed settings when instructionally relevant. Fast mode will reduce the time needed to collect and compare spectroscopy data. The Slow option can be helpful when tracking electron behavior or making sense of the de Broglie and Schrödinger representations. Alternatively, pause the sim and then use the step forward button to incrementally analyze.
- The goal of the 'Experiment' mode is to allow students to collect observational data, as though they were the scientists studying atomic structure. When in this mode, the zoomed-in view of the hydrogen atom and the electron energy level diagram both display a '?'. Students may benefit from scaffolding when using this mode.

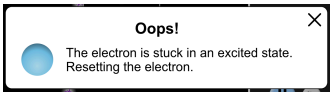
López, Rouinfar, Salpepi April 2025

- When the light source is set to a transition wavelength, the corresponding transition is displayed near the wavelength readout (e.g., $n = 1 \rightarrow 5$). Students may not notice this readout when using the slider to set the wavelength, as the readout only appears at precise wavelengths, which can be difficult to set directly. To facilitate exploration of transition wavelengths, use the Transitions dialog.
- Students may try to excite an electron from the n=2 state using a visible transition wavelength. In the Bohr and de Broglie models, this is nearly impossible to do. The probability of the electron absorbing a photon during its short duration in the excited state is very small.
- Students may not realize that UV photons can have different wavelengths, since they all look the same.

Complex Controls

- The Spectrometer only collects data while it is open.
- In the Schrödinger model, the electron transitions obey the selection rules $\Delta\ell = \pm 1$ and $\Delta m = 0, \pm 1$. Due to these rules, the electron can occasionally get caught in the metastable *2s* (2, 0, 0) state and cannot decay to the *1s* (1, 0, 0) ground state. In white light mode, the light source will automatically emit a visible photon with exactly the right energy to excite it. In monochromatic mode, the electron will remain stuck in this state unless you select a wavelength that can excite it out of this state or use the Excite Electron button. The Excite Electron button will emit an absorbable visible photon without otherwise changing the light source settings.

- When encountering a metastable state in Experiment mode, a warning dialog was displayed. To "reset" the electron, the light source will emit an absorbable visible photon without otherwise changing the light source settings.



Model Simplifications

- We model all wavelengths as integer values to avoid floating-point errors.
- The electron orbits and the spacing between them are distorted so that we can display up to n=6 in the zoomed-in box and the Electron Energy Levels diagram.
- The x-axis of the Spectrometer is not to scale. The UV and IR spectra are compressed to fit all emission wavelengths within the horizontal space available.
- The Experiment mode behaves identically to the Schrödinger model, but the atomic structure and Electron Energy Level diagram are obscured.
- In the Bohr and de Broglie models, transitions between any two levels are equally probable. In the Schrödinger model, the transition probability is based on the overlap between the wave functions, and some transitions are forbidden or highly improbable. Thus, there are fewer spectral lines in the Schrödinger model than in the Bohr or de Broglie models.
- In the Plum Pudding model, we assume the electron can absorb any frequency of light, but always emits light with a frequency equal to its oscillation frequency. (A.P. French and E. F. Taylor, *An Introduction to Quantum Physics* (1978), p. 11.)
- We chose to use common names for the classical models (Billiard Ball, Plum Pudding, Classical Solar System). These correspond to the Dalton, Thomson, and Rutherford models, respectively.
- Both spontaneous and stimulated emission are possible in the simulation, though the latter is rare. Under stimulated emission, the emitted photon will travel in the same direction as the incident photons, while spontaneously emitted photons will travel in a random direction. To help distinguish between the two types of emission, spontaneously emitted photons will always have a minimum deflection of ~20° with respect to the incident photon direction.
- See the Model Documentation for more details.

López, Rouinfar, Salpepi April 2025

Suggestions for Use

Sample Challenge Prompts

- Describe each historical model's differences and limitations.
- Collect spectrometer data and relate it to the energy absorbed and emitted.
- Explain which model most accurately predicts the experimental line spectrum for hydrogen.
- Compare and contrast the appearance of Hydrogen's electron in the three quantum models.
- Summarize the relationship between wavelength, energy, and the distance between energy levels.

See all published activities for Models of the Hydrogen Atom here.
For more tips on using PhET sims with your students, see Tips for Using PhET.

López, Rouinfar, Salpepi April 2025