

Name: _____

The Hydrogen Atom – Student Guide

Background Material

Carefully read the background pages entitled Energy Levels, Light, and Transitions and answer the following questions to check your understanding.

Question 1: Complete the following table which compares how the Bohr Model and the Quantum model represent the Hydrogen atom. In some cases they both describe things in the same way and in some cases they do not.

| Concept | Bohr Model | Quantum Model |
|--|---|---|
| Nucleus | positively charged proton at the center | positively charged proton at the center |
| Electrons | | negatively charged cloud |
| Orbital | | |
| Location of electron in the first orbital | always located at the Bohr radius | |
| Energy of the Energy Levels | | $E = -E_0/n^2$ |

Question 2: Complete the following table which relates the parameters of two different photons by circling the appropriate relationship. The first row is completed for you: “A red photon has a larger wavelength, smaller frequency, smaller energy, and the same velocity through space as a blue photon”.

Photon A

| Photon A | Wavelength | Frequency | Energy | Velocity (in space) | Photon B |
|-----------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|------------------|
| Red | larger the same smaller | larger the same smaller | larger the same smaller | larger the same smaller | Blue |
| Green | larger the same smaller | larger the same smaller | larger the same smaller | larger the same smaller | Orange |
| InfraRed | larger the same smaller | larger the same smaller | larger the same smaller | larger the same smaller | Visual |
| Visual | larger the same smaller | larger the same smaller | larger the same smaller | larger the same smaller | Microwave |
| X-rays | larger the same smaller | larger the same smaller | larger the same smaller | larger the same smaller | Gamma-ray |

(Hint: the speed of *all* photons is the same.)

Question 3: Scientists often say “A is proportional to B” if B increases when A increases. They also “A is inversely proportional to C” if C decreases when A increases. Inspect the table above for evidence of such relationships and use these terms to describe the relationships between wavelength, frequency, energy, and velocity. _____

Hydrogen Atom Simulator – Introduction

The Hydrogen Atom Simulator allows one to view the interaction of an idealized Hydrogen atom with photons of various wavelengths. This atom is far from the influence of neighboring atoms and is not moving. The simulator consists of four panels. Below gives a brief overview of the basics of the simulator.

- The panel in the upper left shows the Bohr Model: the proton, electron, and the first six orbitals with the correct relative spacing.
 - The electron can absorb photons and jump higher energy levels where it will remain for a short time before emitting a photon(s) and drop to lower energy level (with known probabilities fixed by quantum mechanics).
 - The electron can also be ionized. The simulator will a short time later absorb an electron.
 - For convenience you can drag the electron between levels. Once it is released it will behave “physically” once again as if it had gotten to that present level without being dragged.
- The upper right panel labeled “energy level diagram” shows the energy levels vertically with correct relative spacing.
- The “Photon Selection” panel (bottom left) allows one to “shoot” photons at the Hydrogen atom. The slider allows the user to pick a photon of a particular energy/wavelength/frequency.
 - Note how energy and frequency are directly proportional and energy and wavelength are inversely proportional.
 - On the slider are some of the energies which correspond to levels in the Lyman, Balmer, and Paschen series.
 - Clicking on the label will shoot a photon of that energy.
 - If the photon is in visual band, its true color is shown. Photons of longer wavelengths are shown as red and shorter wavelengths as violet.
- The “Event Log” in the lower right lists all the photons that the atom has encountered as well as all the electron transitions.
 - The log can be cleared by either using the button or manually dragging the electron to a particular energy level.

Hydrogen Atom Simulator – Exercises

For any particular level of the Hydrogen atom one can think of the photons that interact with it as being in three groups:

| Increasing Energy → | | |
|--|--|--|
| Range 1 | Range 2 | Range 3 |
| None of the photons have enough energy to affect the atom. | Some of the photons have the right energy to make the electrons to jump to a higher energy level (i.e. excite them). | All the photons have enough energy to ionize the atom. |

Note that the ranges are different for each energy level. Below is an example of the ranges for an electron in the ground state of a Hydrogen atom.

| Ground State electron of H | | |
|--|--|---|
| Range 1 | Range 2 | Range 3 |
| 0eV to 10.2 eV (10.2 eV needed to excite electron to 1 st orbital) | 10.2 to 13.6 (some will excite, some won't) | >13.6 eV (anything greater than this will ionize the electron) |

When the simulator first loads, the electron is in the ground state and the slider is at 271 nm.

- Fire a 271 nm photon. This photon is in range 1.
- Gradually increase the slider to find a photon which is between range 1 and range 2 (for a ground state electron). This should be the Lyman- α line (which is the energy difference between the ground state and the second orbital).
- Increase the energy a bit more from the Lyman- α line and click “fire photon”. Note that nothing happens. This is a range 2 photon but it doesn't have the “right energy”.
- Increase the energy more until photons of range 3 are reached. In the simulator this will be just above the L_{ϵ} line.
 - Technically there are photons which would excite to the 7th, 8th, 9th, etc. energy levels, but these are very close together and those lines not shown on the simulator.
 - The L_{ϵ} line has an energy of -13.22 eV and is in range two. The ionization energy for an electron in the ground state is 13.6 eV and so that is the correct range 3 boundary.

Question 4: Which photon energies will excite the Hydrogen atom when its electron is in the ground state? (Hint: there are 5 named on the simulator, though there are more.)

Question 5: Starting from the ground state, press the L_{α} button twice in succession (that is, press it a second time before the electron decays). What happens to the electron?

Question 6: Complete the energy range values for the 1st excited state (i.e. the second orbital) of Hydrogen. Use the simulator to fill out ranges 2 and range 3. The electron can be placed in the 1st orbital by manually dragging the electron or firing a L_{α} photon once when the electron is in the ground state. Note also that the electron will deexcite with time and so it may need to be placed in the 1st orbital repeatedly.

| 1st Excited State Electron in H | | |
|--|----------------|----------------|
| Range 1 | Range 2 | Range 3 |
| 0 to 1.9 eV (anything less than this energy will fail to excite the atom) | | |

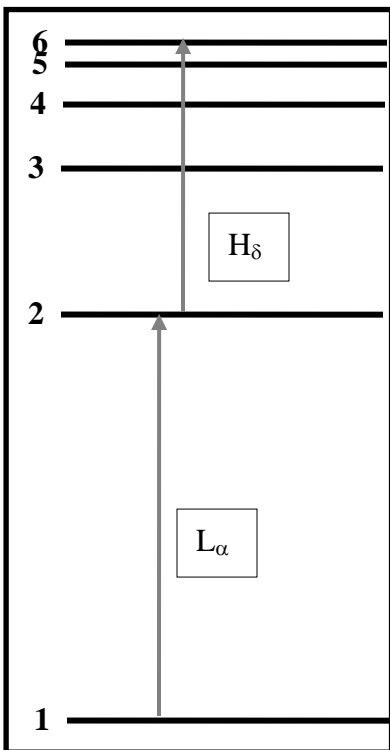
Question 7: What is the necessary condition for Balmer Line photons (H_{α} , etc) to be absorbed by the Hydrogen atom? _____

Question 8: Complete the energy range values for the 3rd orbital (2nd excited state) of Hydrogen. The electron can be placed in the 3rd orbital by manually dragging the electron or firing an L_β photon once when the electron is in the ground state. Note also that the electron will deexcite with time and so it may need to be placed in the 2nd orbital repeatedly.

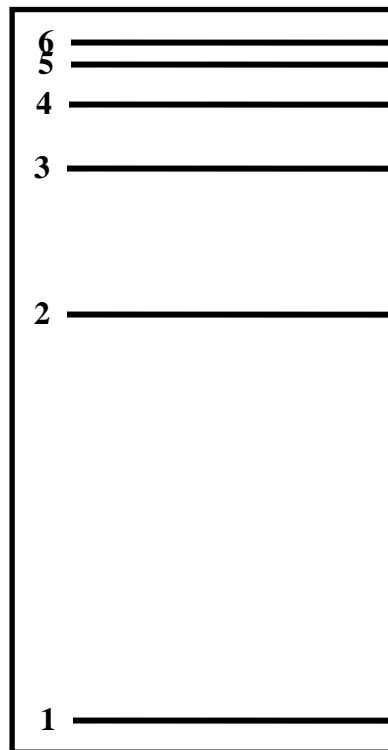
| 3 rd Electron Orbital in H | | |
|---------------------------------------|----------------|---|
| Range 1 | Range 2 | Range 3 |
| | | >1.5 eV (anything more than this will ionize the atom) |

Question 9: Starting from the ground state, press two and only two buttons to achieve the 6th orbital in two different ways. One of the ways has been given. Illustrate your transitions with arrows on the energy level diagrams provided and *label the arrow with the button pressed*.

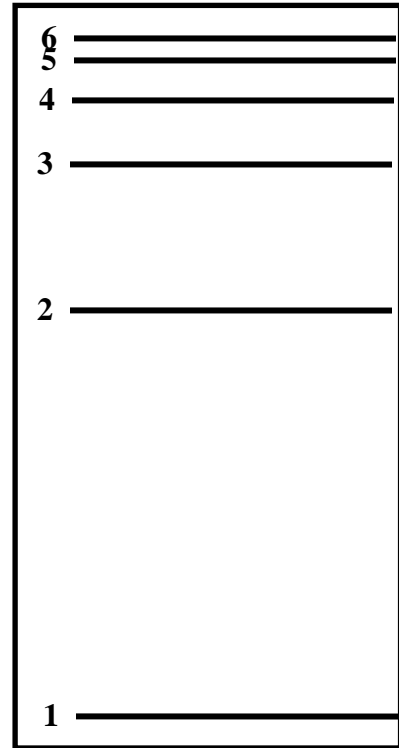
a) Method 1:



b) Method 2:



Question 10: Press three buttons to bring the electron from the ground state to the 4th orbital. Illustrate the transitions as arrows on the energy level diagrams provided and *label the arrow with the button pressed*.



Question 11: How does the energy of a photon emitted when the electron moves from the 3rd orbital to the 2nd orbital compare to the energy of a photon absorbed when the electron moves from the 2nd orbital to the 3rd orbital? _____

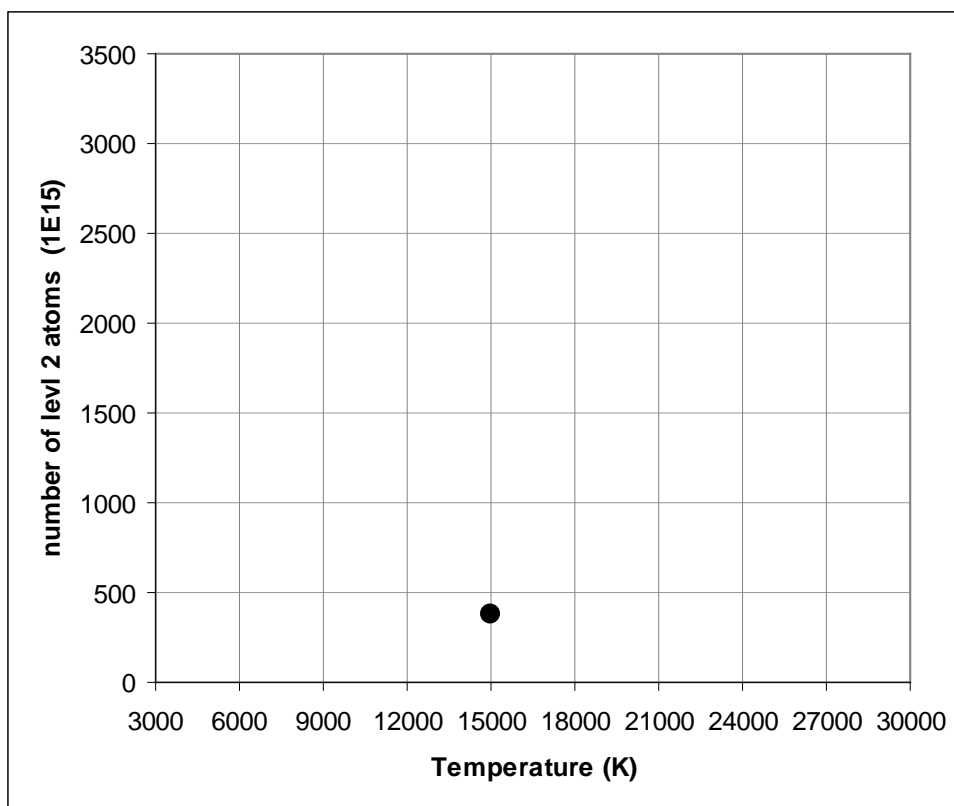
Question 12: Compare the amount of energy needed for the following 3 transitions. Explain why these values occur.

- L α : Level 1 to Level 2 _____
- H α : Level 2 to Level 3 _____
- P α : Level 3 to Level 4 _____

Thermal Distribution

Read through the Level Abundances page. Use the “Thermal Distribution Simulator” to make a plot of the number of atoms with electrons in the 2nd orbital. There should be at least 8 points on your plot. Note also that the y-axis is in terms of 10^{15} particles. Thus the point for 15,000 K, which has 3.82×10^{17} particles in the 2nd orbital, will read as 382 on the graph.

- Plot at least 8 points on the graph. More points near “interesting” features is highly recommended.
- Fit (draw) a curve to the plotted points. It should be a smooth curve.



We can use this plot to motivate some of the concepts needed to understand stellar spectra. The light seen from a star is typically an absorption spectrum. The light produced by the surface of the star – the photosphere – is a continuous spectrum meaning that all wavelengths of light are present. However, certain wavelengths of light are redirected (absorbed and re-emitted in random directions) in the cooler low-density layers above the surface (the chromosphere) of a star. This occurs because electrons in Hydrogen (and other atoms) absorb light as they jump to higher orbitals and then re-emit the light as they drop back down. Thus, we see absorption spectra from stars – rainbows with dark gaps known as spectral lines – because a lot of the light is missing at particular wavelengths.

Question 13: Consider the strength of the H_{β} absorption line in the spectra of stars of various surface temperatures. This is the amount of light that is missing from the spectra because Hydrogen electrons have absorbed the photons and jumped from level 2 to level 4. How do you think the strength of H_{β} absorption varies with stellar surface temperature?
