Developing and evaluating research-based classroom materials to help students understand concepts of spectroscopy[1]

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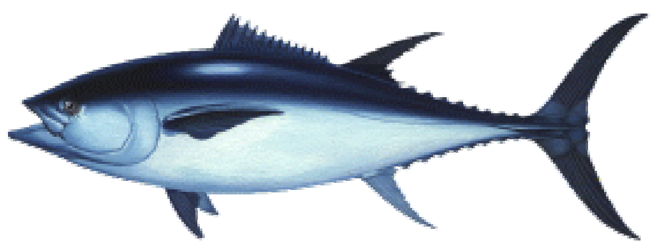
Why Spectroscopy?

- Real world application of Quantum Theory
  - elements present in stars, our atmosphere, other unknowns
- Students forced to reason from laboratory evidence to underlying theory



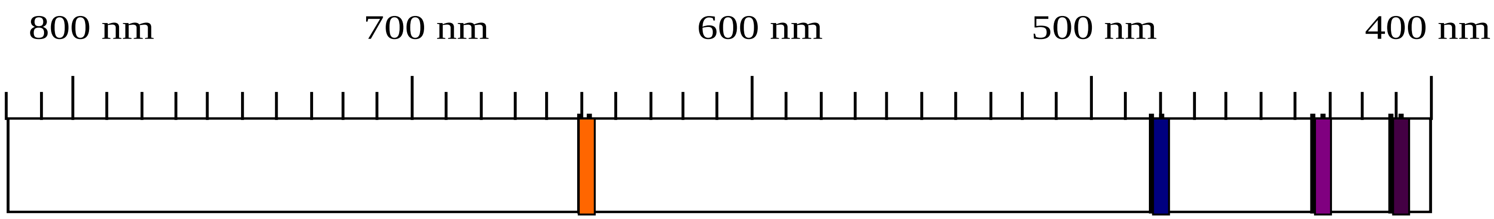
Context for Instruction

- Two one-semester Modern Physics courses
- 12 juniors and seniors
- Mostly Electrical Engineering students
- three 50 min. lectures a week
- First semester taught traditionally
- Second semester taught using modified methods illuminated in last talk

Pre-Instruction Evaluation

Given to students in the modified course

1. Below is a part of a spectrum produced from a sample of gas. Describe the structure of the energy levels of the atom that produces such a spectrum.

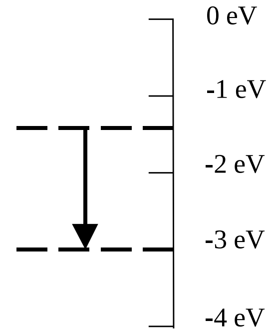


Most students (7/12) stated that spectral lines

- **are evidence for the quantization of energy levels**
- **are the energy levels themselves**

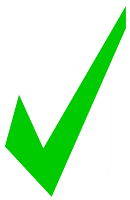
Pre-Instruction Evaluation

2. What aspect of an atom does this diagram represent? What would be the physical evidence that would show such a representation describes an atom? Explain.



Most students (10/12) knew that

- **the diagram showed an electron dropping to a lower energy level**
- **when an electron drops in energy a photon (or a flash of light) is given off**

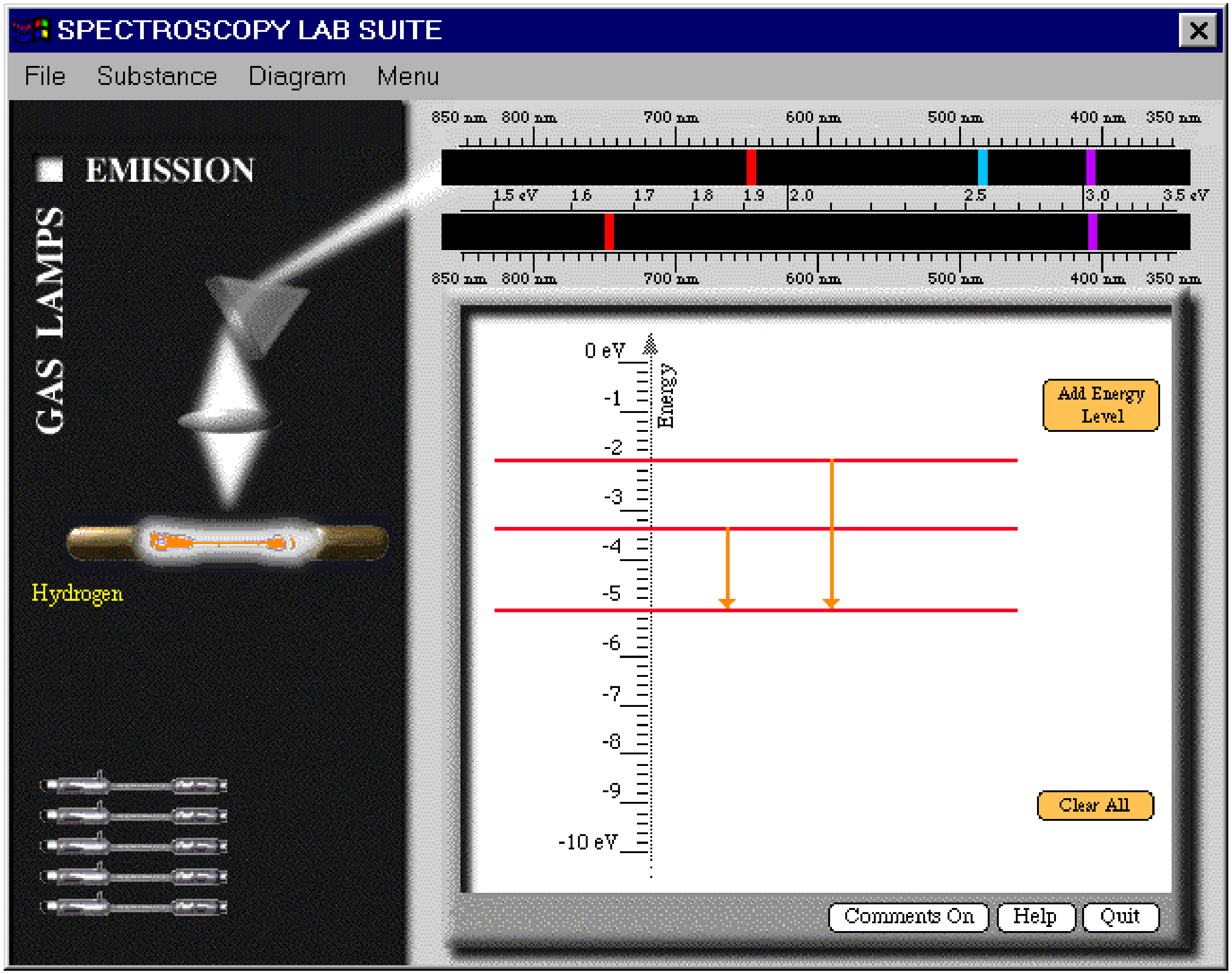


Students are able to produce the result given the theory but unable to produce the theory given the result.

Tutorial

- Students discover the results of a classical model of the Hydrogen atom, which contradicts spectral evidence
- The quantum model is developed, and spectral lines are related to energy level transitions.
- Students develop their own energy level diagrams that emit the correct spectrum
- Homework on absorption spectra

Spectroscopy Lab Suite



Developed by the Physics Education group at Kansas State University

Post-Instruction Evaluation

Multiple choice question given in modified class

The frequency of spectral lines seen when an electric current is passed through dilute pure Neon gas is:

(a) equal to the frequency of oscillation of one electron in the atom.

(b) equal to the frequency of oscillation of all the electrons in one particular normal mode of oscillation of the atom.

(c) associated with the energy difference between two particular discrete states of the atom.

(d) associated with the frequency of oscillation of one electron in a single particular discrete state of the atom.

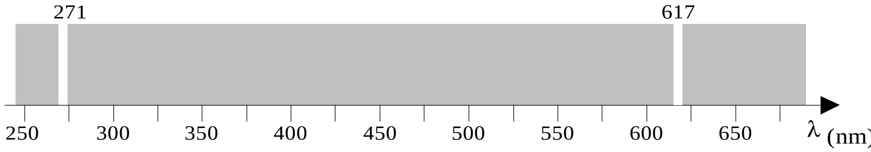
(e) none of the above.

All students answered (c).

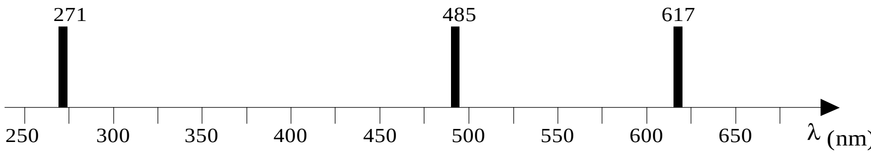
Post-Instruction Evaluation

Given to both classes

Observations of an interstellar gas give an absorption spectrum, a part of which is shown below. The gas is cold, such that when not excited, all electrons are in the ground state.



Astronomers suspect the gas to be a type of helium, but they aren’t sure. When they excite a sample of helium in a spectrometer in the laboratory, they observe an emission spectrum, part of which is shown below.



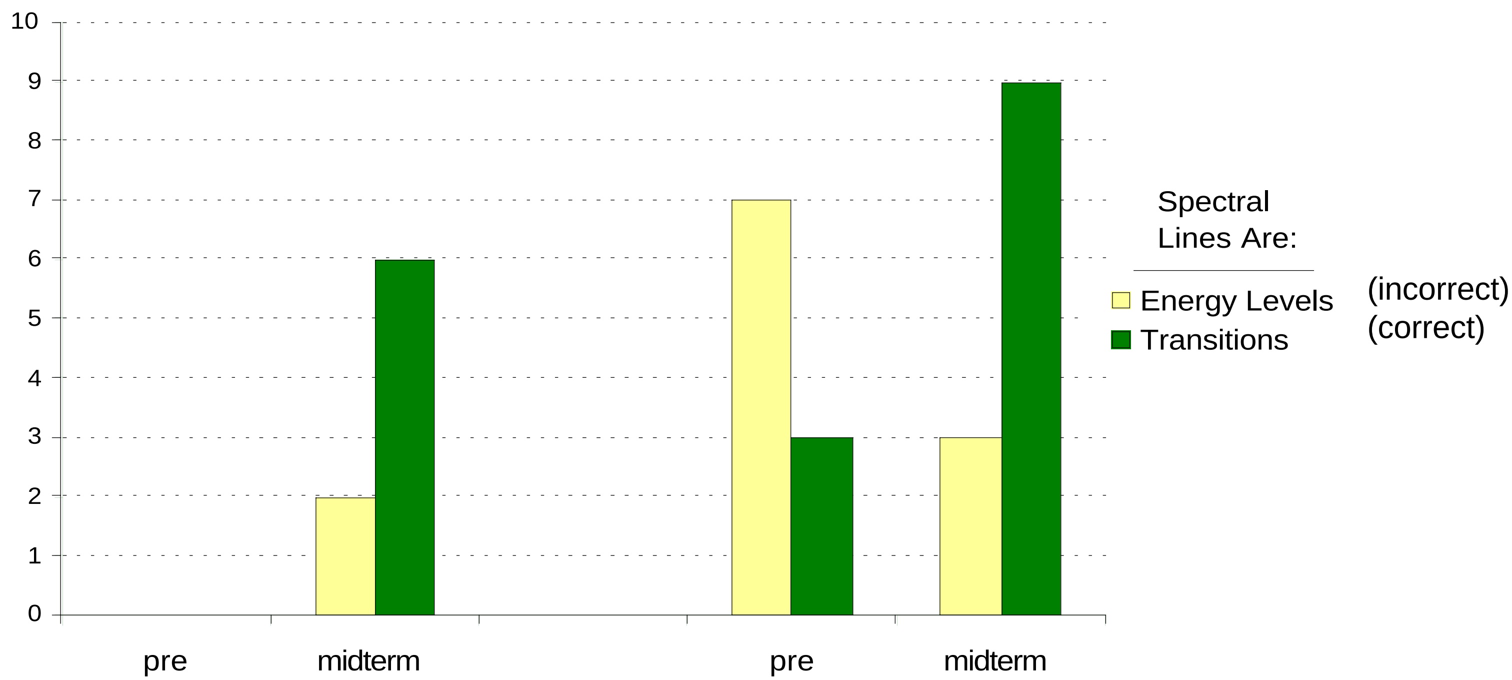
1. From their observations, could the astronomers conclude that the two gases have the same atomic energy levels?

2. The astronomers believe that these are the same gases. How could they account for the additional line in the emission spectrum?

Post-Instruction Results

Tested whether students thought of spectral lines as energy levels or as transitions

- Students in the modified course (n=12) performed similarly to students in the traditional course (n=12)

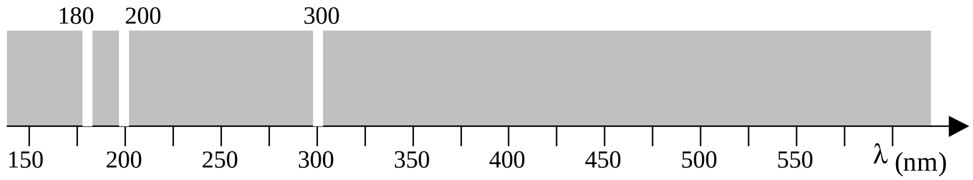


Post-Instruction Evaluation

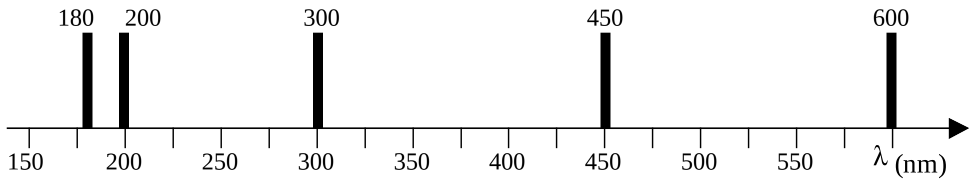
Given to students in the modified class

Consider two gases of N non-interacting atoms.

I. Consider the first gas. It is at its lowest possible temperature.
A uniform light (i.e. equally intense in all frequencies) shines upon the gas. The following spectrum is observed:



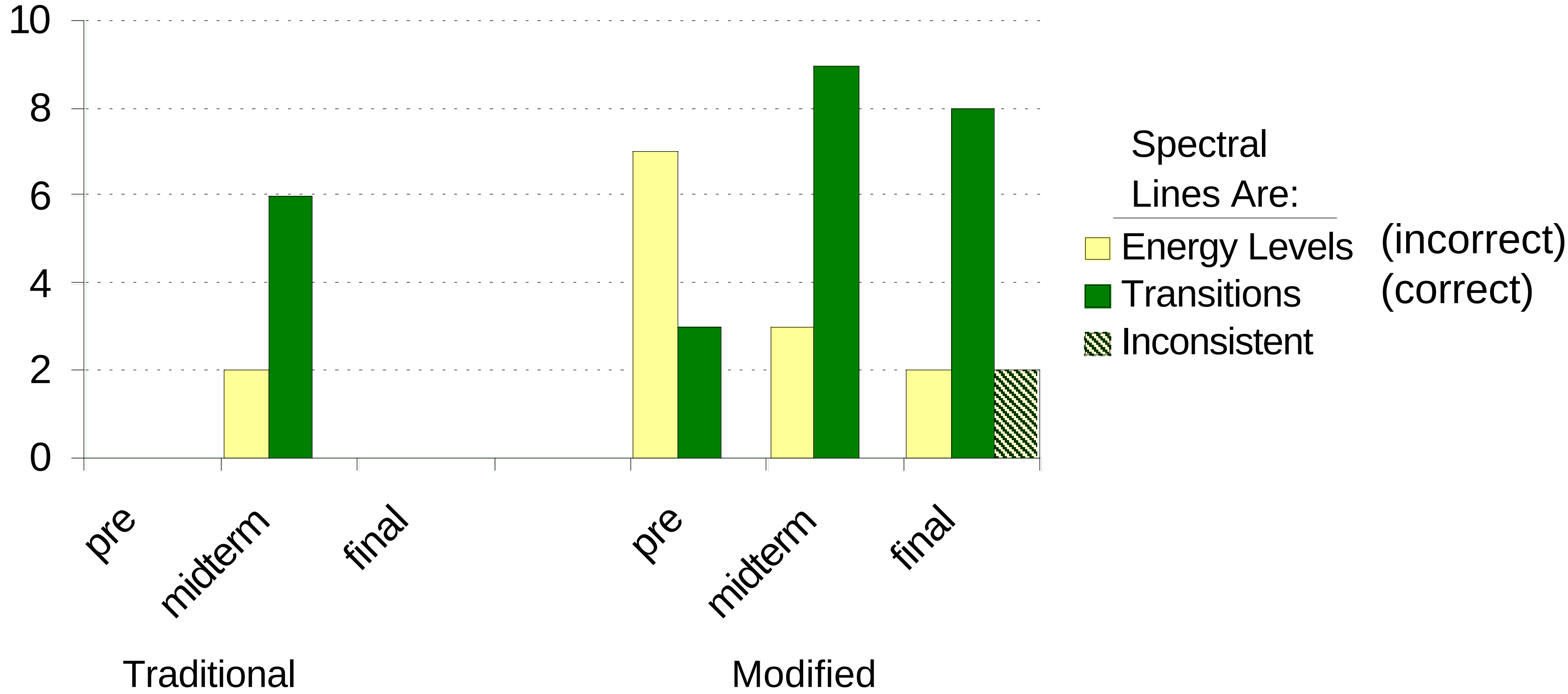
II. Consider the second gas at its lowest possible temperature. When a current is run through this gas of atoms, the following spectrum is observed:



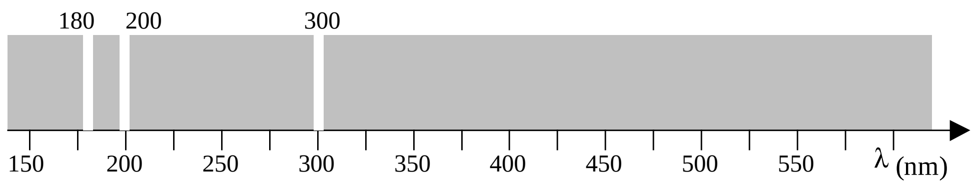
1. Can you conclude that the two gases are the same?

2. Consider that the spectrum region is expanded to reach from 0 nm to 1000 nm. Would you expect to find additional lines in the figure?

Post-Instruction Results



Student 1: Inconsistent Responses



Q: What is the highest energy line measuring?

A: "The highest energy line corresponds to the highest absorbed energy. Energy is absorbed when electrons [move to higher] energy states..."

Q: Discuss the differences between the emission spectrum and the absorption spectrum:

A: "One will correspond to the energy lost when electrons drop in energy level and the other to when electrons gain in energy level."

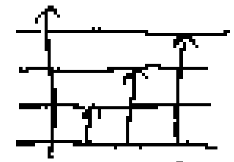
Q: Describe the structure of the energy levels of the atom that produces such a spectrum.

A: "There is a large gap between the first and second energy levels (λ=300 and λ=200 lines) but a smaller gap between the second and third energy levels (λ=200 and λ=180)"

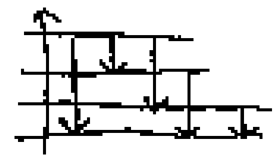
Student 2: Inconsistent Responses

Q: Discuss the differences between the emission spectrum and the absorption spectrum:

A: “Emission spectrum always has more lines than absorption because absorption can only have jumps from the ground state up where emission can jump from any level down.”



absorbtion



emission

Q: What is the highest energy line measuring?

A: “The highest energy line... measures the energy of the photon absorbed by the gas. The electrons have stationary states and at these frequencies electrons can absorb that energy and jump to higher states.”

Q: Would you expect to find additional spectral lines outside of the range shown?

A: “I would expect to find lines above the 600 nm mark. Since it is at the lowest possible temp. 180 nm refers to the ground state, lowest possible energy. ... When λ=180 nm this seems to be the ground state so each E level will require a photon of higher energy to make it jump to another level.”

Conclusion

- Students should be able to produce the result given the theory as well as produce the theory given the result.
- Students should develop consistent mental models and check for self-consistency