Replacing the Bohr atomic model with an accessible picture of how atoms and light interact

Binyomin Abrams, Dan Dill, Emily Allen

Master Lecturer, Department of Chemistry

Associate Director for Natural Sciences, Core Curriculum

abramsb@bu.edu

1 August 2018

25th Biennial Conference on Chemical Education

BOSTON UNIVERSITY

We really didn't understand electrons for a long time

- Skip until the 19th century (Democritus, LaVoisier, Dalton, Thompson)
- 1885: Balmer proposes empirical equation to for H atom visible spectrum
- 1888: Rydberg equation to the H atom atomic line spectra
- 1905: Einstein explains the photoelectric effect
- 1913: Bohr tries to explain electron nature
- 1923: de Broglie hypothesizes wave-nature of electrons (1926 experiment)
- 1926: Schrodinger's wave equation
- 1927: Heisenberg's uncertainty principle

BOSTON UNIVERSITY

Traditional approach to teaching atomic theory

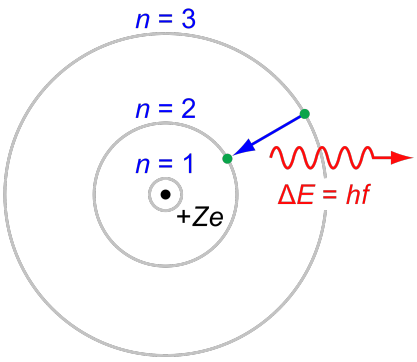
$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \longrightarrow \Delta E = -Rhc\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

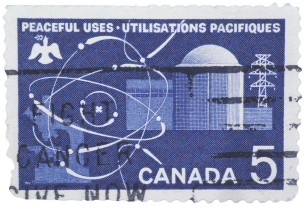
- There is value in history of science, but that is not (necessary) the ***mandate*** of General Chemistry
- Historical approach – we don't do this for ***stoichiometry***!
- Significant concern: teaching this style of atomic theory leads to ***misconceptions*** that are ***persistent***

BOSTON UNIVERSITY

Replacing the Bohr atomic model with an accessible picture of how atoms and light interact

Teaching the Bohr model leads to misconceptions





LOS ANGELES COUNTY SCIENCE FAIR

glasgow science centre

Science

BOSTON UNIVERSITY

Replacing the Bohr atomic model with an accessible picture of how atoms and light interact

Persistent misconceptions are difficult to correct

- Study on use of multiple representations for quantum concepts[1]
  - RQ #1: "What visual representations do students use to successfully explain quantum concepts?"
  - RQ #2: "What visual representations correlate with persistent student misconceptions about nature of atoms and bonding?
  - Students in CH101 General Chemistry 1 at Boston University (*N* = 60)
- Reliance on (and misinterpretation of) the Bohr Model resulted in obstacles to ***future learning***
- ***Misconceptions*** of quantum concepts resulted from reliance on the ***Bohr Model***
- Use of ***multiple presentations*** correlates with student understanding of QC
- We ***didn't teach the Bohr model*** in the course

BOSTON UNIVERSITY

1. B. Abrams, E. Allen, P. Garik ***in preparation***

Replacing the Bohr atomic model with an accessible picture of how atoms and light interact

Persistent misconceptions are difficult to correct

Visual Representations	*Number of Students*		
	Pre	*Post*	*Δ*
Ball and Stick Drawing	2	3	1
Bohr Model	14	4	-10
Box Diagram	2	4	2
Correlation Diagram	0	8	8
Cloud Drawing with Electron Particles (amorphous)	5	3	-2
Cloud Drawing with Electron Particles (spherical)	5	0	-5
Density Graph	0	3	3
Electron Density Isosurface Drawing	0	1	1
Emission Spectrum	0	1	1
Energy Diagram	0	3	3
Geometry Drawing (3D)	0	2	2
Hybridized Orbital Drawing	0	1	1

"So if you were to draw it, it would have like a nucleus and then but the electrons [are] on the outside... There's a big electron cloud where the nucleus is, and there's random electrons inside of it."

"They're just like electrons buzzing around on the outside of the atom. Like I imagine like sort of like a crystal ball, when you shake it and the glitters float around, that's what it feels like."

BOSTON UNIVERSITY

Persistent misconceptions are difficult to correct

Misconceptions that students had in interviews (N = 20) while using Bohr model

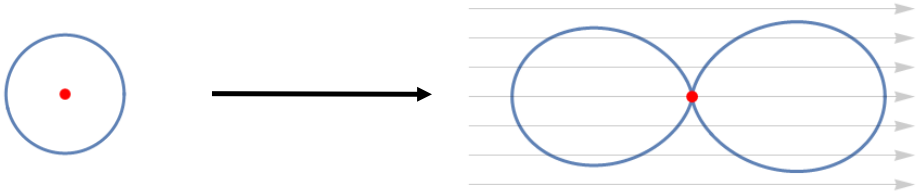
Concepts	*Misconceptions*	*Number of Students*				
		Pre	Post	Pre	Post	Δ
Electron Behavior	Electrons are particles moving in space	15	3	15	6	9 fewer
	Electron spin is a physical movement	1	3			
Atomic Structure	More electrons around the outside of the atom / outer shell	2	0	11	6	5 fewer
	Electrons do not interact	6	1			
	Full outer shells are more stable	11	6			
	Orbitals depict paths on which electrons move	2	0			
	All electrons take the form of a single orbital	0	1			
	Energy determines distances of electrons from the nucleus	7	1			
	Electrons are held by centripetal force	2	0			

BOSTON UNIVERSITY

Replacing the Bohr atomic model with an accessible picture of how atoms and light interact

Replacement? New approach to teaching atomic theory

- Matter experiences light as ***oscillating electric field*** with frequency, ν_{light}
- Light ***tugs on charges in matter*** when $\nu_{\text{matter}} = \nu_{\text{light}}$ (resonance)
- Greenhouse gases absorb IR light because of resonance with natural bond oscillating frequencies
- 1s to 2p: http://quantum.bu.edu/CDF/101/1sTo2pTransition.cdf
- 3d to 2p: http://quantum.bu.edu/CDF/101/2pto3dTransition.cdf

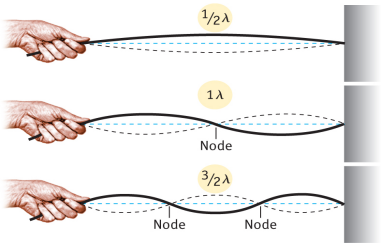


BOSTON UNIVERSITY

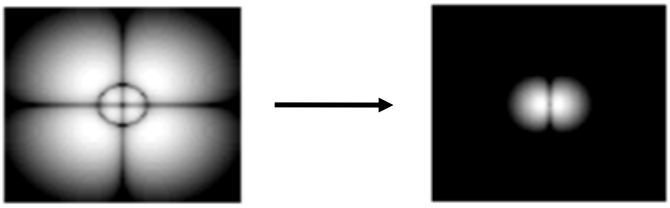
Replacement? New approach to teaching atomic theory

- Spring demo to explain ***standing waves*** ⟶ "***n***" in Rydberg's equation
- All change is associated with a ***change in energy***:

$$\Delta E = E_f - E_i = -R_y\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$



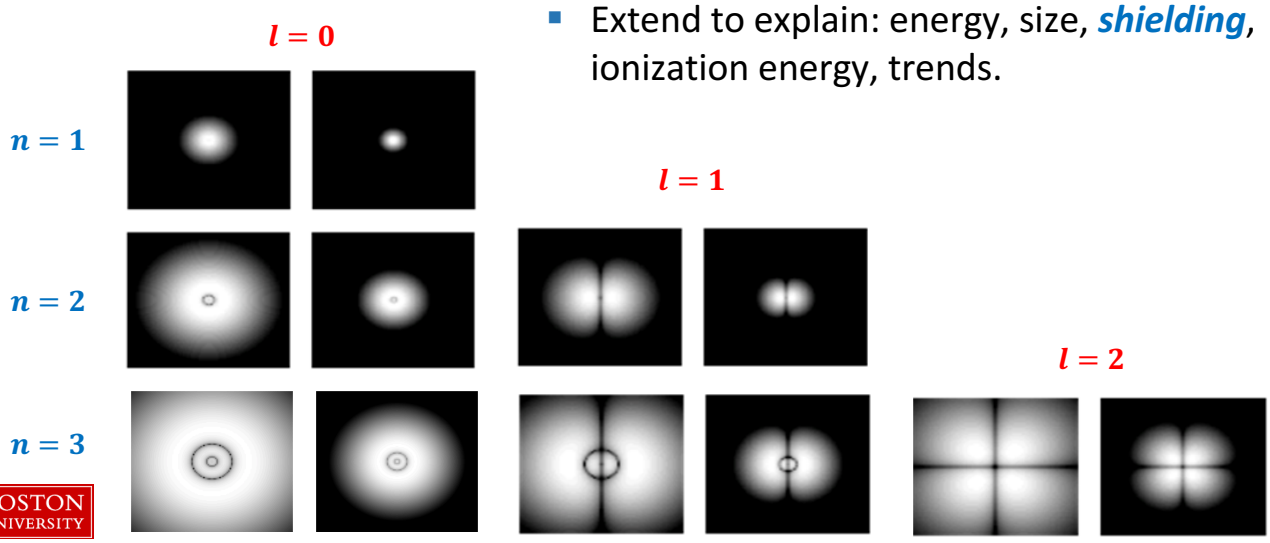
- Light causes electron wave to change from one form to another, and the ***total energy cost*** is $h\nu_{\text{light}}$
- Standing waves in 3D look a little different. It's ok, ***we have pictures***.



BOSTON UNIVERSITY

Use visual representations of electron waves to teach

- Use images to get **quantum numbers *n*, *l***
- Extend to explain: energy, size, ***shielding***, ionization energy, trends.



BOSTON UNIVERSITY

So what now?

- We're fast approaching the ***centennial of de Broglie's work***… it's time to stop teaching the history of atomic theory, and just teach atomic theory
- Developing a ***POGIL-style workbook*** for the waves-only approach
- Professional development opportunities to help ***high school teachers*** adopt this semi-qualitative approach
- Use a similar approach to teach bonding with ***molecular orbital theory***
- Already in use in a ***general education natural science course***

BOSTON UNIVERSITY

Acknowledgments

- Dan Dill, Natalya Bassina, Alex Gogler (Chemistry)
- Emily Allen and Peter Garik (SED)

Details about some of the workbook activities, videos, and more:

people.bu.edu/abramsb/research/

BOSTON UNIVERSITY