Bohr model of the atom

Announcements:

Look for new Homework assignment by end of day

- Fourth Homework Set was due today
- Comments about storm victims
- Learning Assistants
- Still have a few midterms – see if you haven't picked it up

Niels Bohr 1885 – 1965

Why are atoms found predominantly in the ground state?
Answer: Depends on the temperature!

2013 Flood Assistance

- Let me know if you are struggling as a result of last month's inundation.
- Campus has provided help with hotel and campus meal tickets
- Check out website www.colorado.edu/2013flood/

Learning Assistants (LAs)

- Work with instructors in Physics 1110, 1120 or 1240 and 1020 – next semester.
- Learn about teaching, better learn the material.
- Pays $10/hr * 10hr/wk *15wks/course = $1500/course
- An informational meeting, followed by an on-line application form – factors are GPA, interest in being a teacher, enthusiasm, some evidence of social skills.
- Top applicants are given an interview. About 2 applicants for each position. About 15-20 positions available.
- Many of top students have served as LAs

http://laprogram.colorado.edu

Want to be an LA?

Come to the **LA Info Session** to learn more about becoming a *Learning Assistant*.

When: **Monday, October 7, 2013, at 5:30 p.m.**

Where: Center for Community (C4C) Abrams Room

Refreshments will be served, while they last.

Applications for Spring 2014 available October 7 – 21

Goto: https://laprogram.colorado.edu/applications

Get more information from faculty and LAs in these departments:

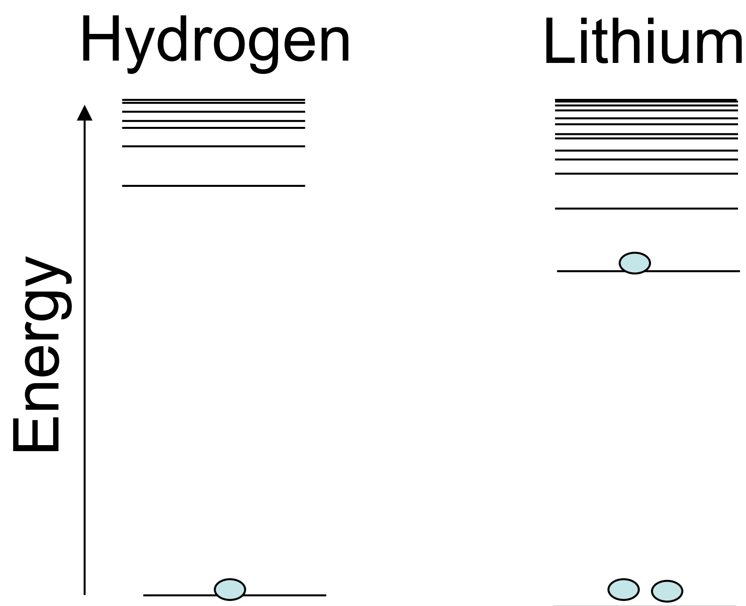
Applied Math	Math	Education
MCDBiology	ATOC	Chemistry
EBIO	Astronomy	Physics

Learning Assistant (LA) Model
UNIVERSITY OF COLORADO **BOULDER**

htt

Summary of atomic energy levels

1) Electrons in atoms only found in specific energy levels.
2) Different set of energy levels for different atoms.
3) 1 photon emitted per electron jump *down* between energy levels. Photon color determined by energy difference.
4) Electron spends very little time (10^{-8} s) in excited state before hopping back down to lowest unfilled level.
5) An electron not stuck in an atom is *free*; can have any energy.



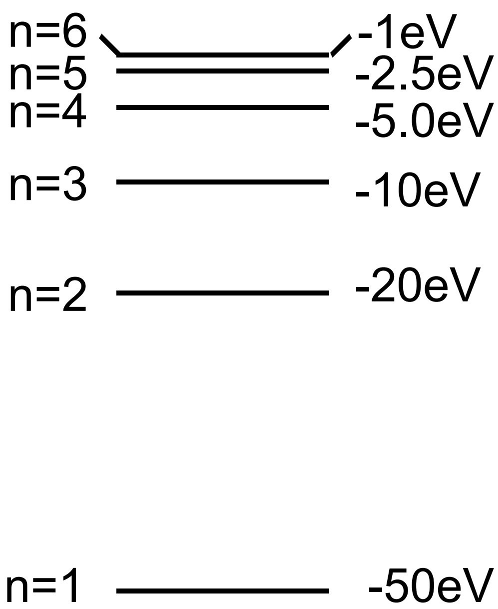
Electron energy levels in 2 different atoms …

Levels have different spacing.

Atoms with more than one electron … lower levels filled.

Clicker question 1 | Set frequency to DA

A partial energy level spectrum of element X is shown below.



Of the transitions listed, which one produces the shortest wavelength photon?

A. 4 → 3 5 eV photon

B. 6 → 2 19 eV photon

C. 6 → 5 1.5 eV photon

D. 2 → 1 30 eV photon

E. 4 → 1 45 eV photon

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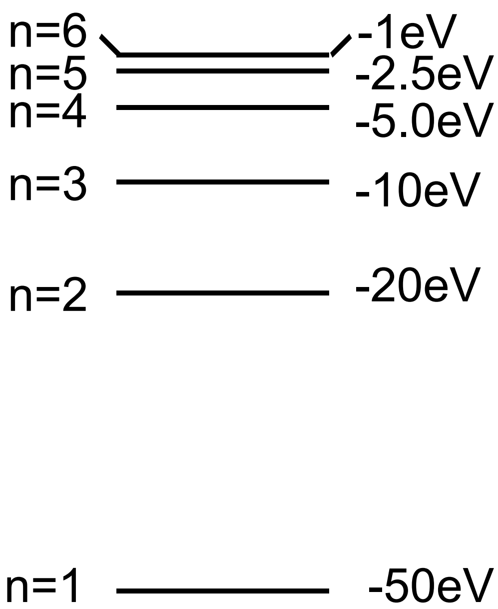

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The energy of the photon emitted is equal to the energy difference of the levels involved in the transition.

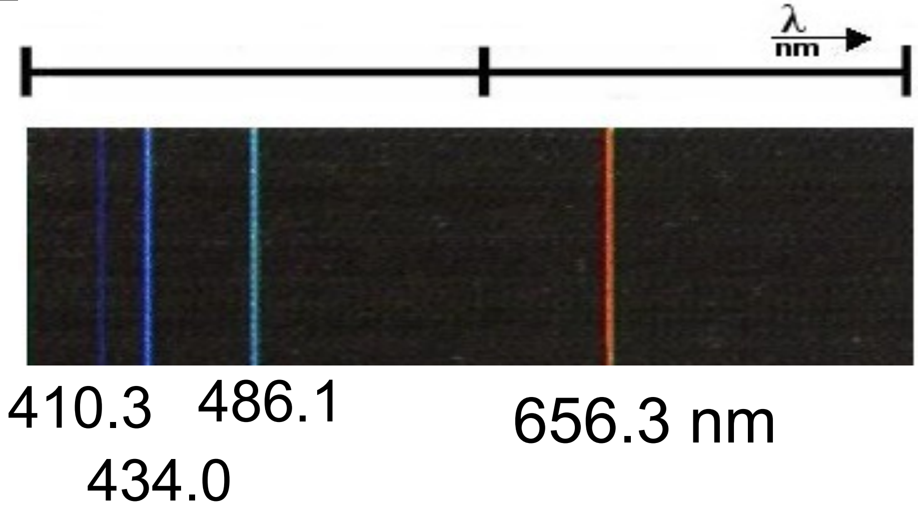
$$|\Delta E| = E_\gamma = hf = \frac{hc}{\lambda}$$

Clicker question 2 | Set frequency to DA

In 1885, Balmer noticed the Hydrogen wavelengths followed a pattern:

$$\lambda = \frac{91.18\,\text{nm}}{\frac{1}{2^2} - \frac{1}{n^2}}$$

where n = 3,4,5,6, …



As n gets larger, what happens to wavelengths of emitted light?

A. gets larger and larger without limit
B. gets larger and larger, but approaches a limit
C. gets smaller and smaller without limit
D. get smaller and smaller, but approaches a limit

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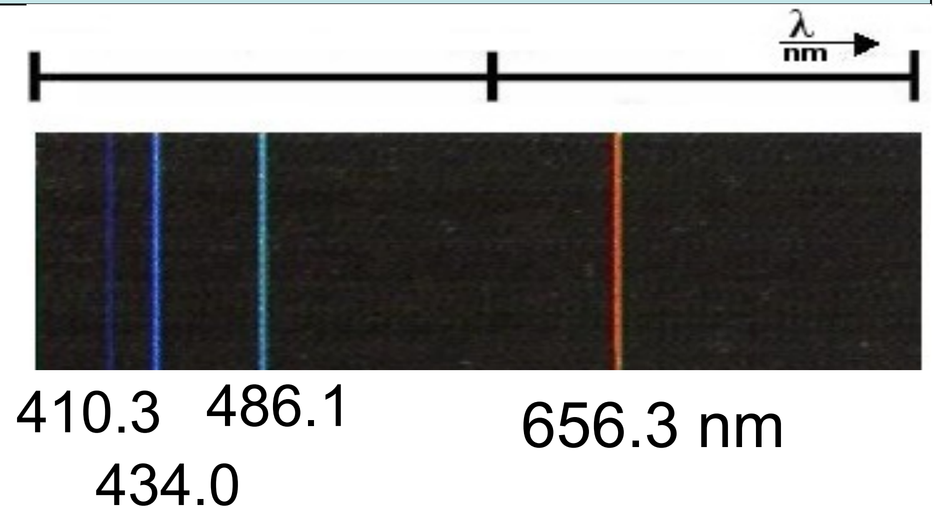

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Balmer series

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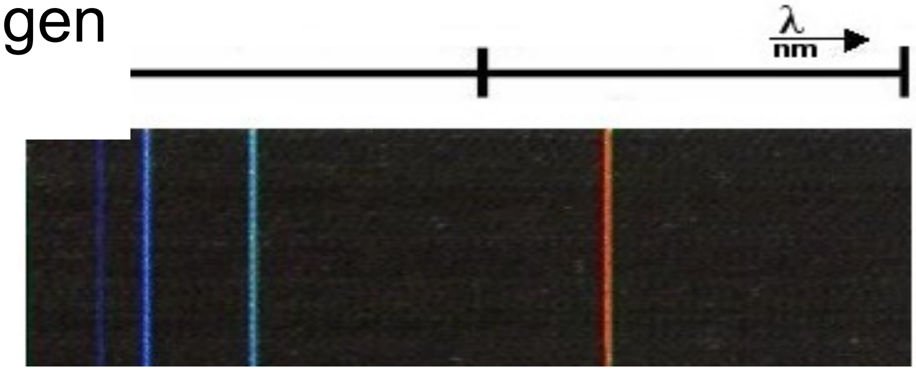


So this gets smaller $\lambda = \frac{91.18\,\text{nm}}{\frac{1}{2^2} - \frac{1}{n^2}}$ where n = 3,4,5,6, ….

$\frac{1}{n^2}$ gets smaller as n increases

$\frac{1}{2^2} - \frac{1}{n^2}$ gets larger as n increases, but no larger than 1/4

Balmer predicted additional spectral lines which were quickly discovered.

$$\lambda_{\text{limit}} = 4 \cdot 91.18\text{nm} = 364.7\text{nm}$$

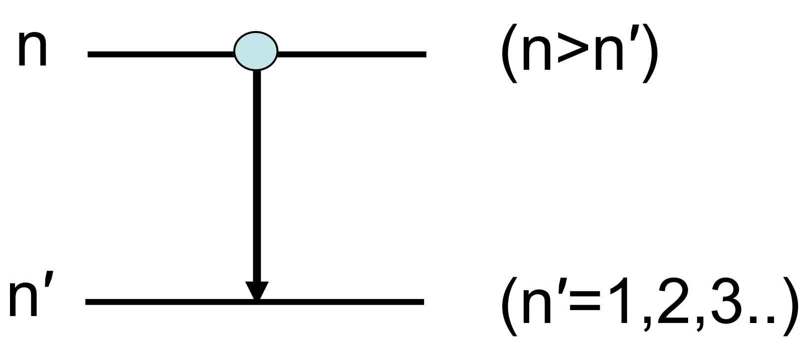
Hydrogen atom - Balmer series

Generalizing the formula correctly predicts more hydrogen lines.

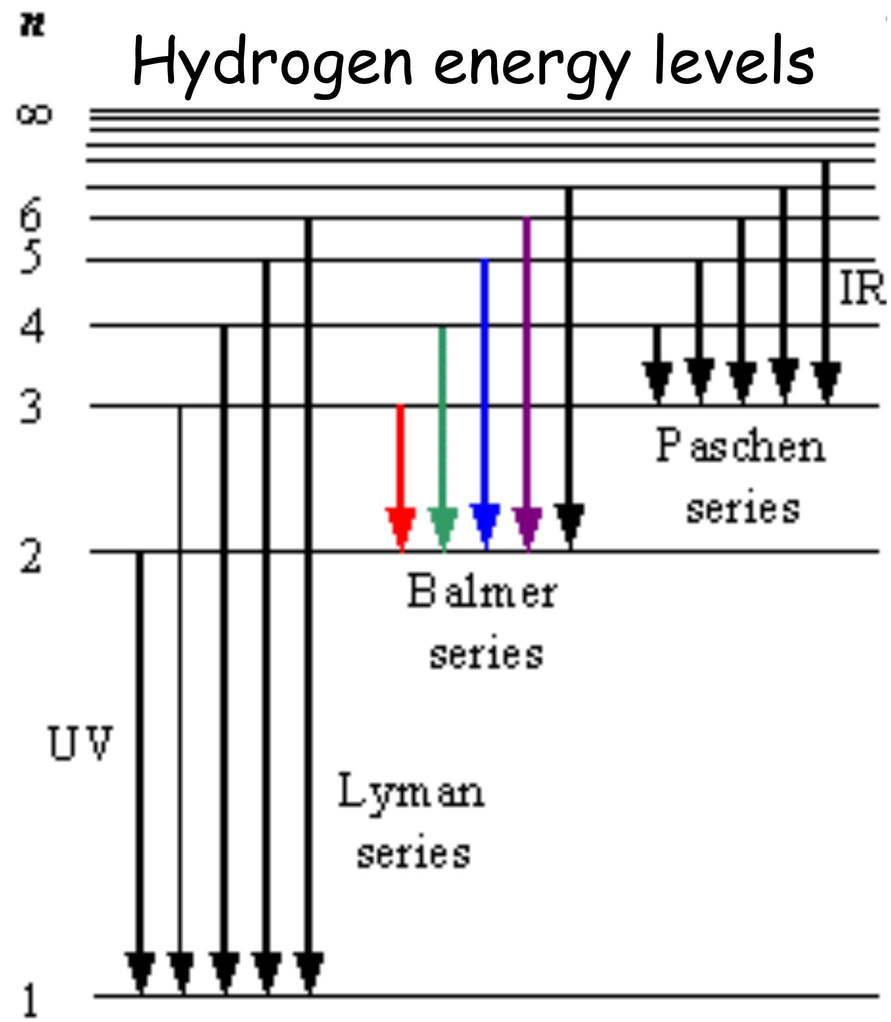
Balmer's general formula

$$\lambda = \frac{91.18\,\text{nm}}{\frac{1}{2^2} - \frac{1}{n^2}}$$

Predicts λ of n→n′ transition:



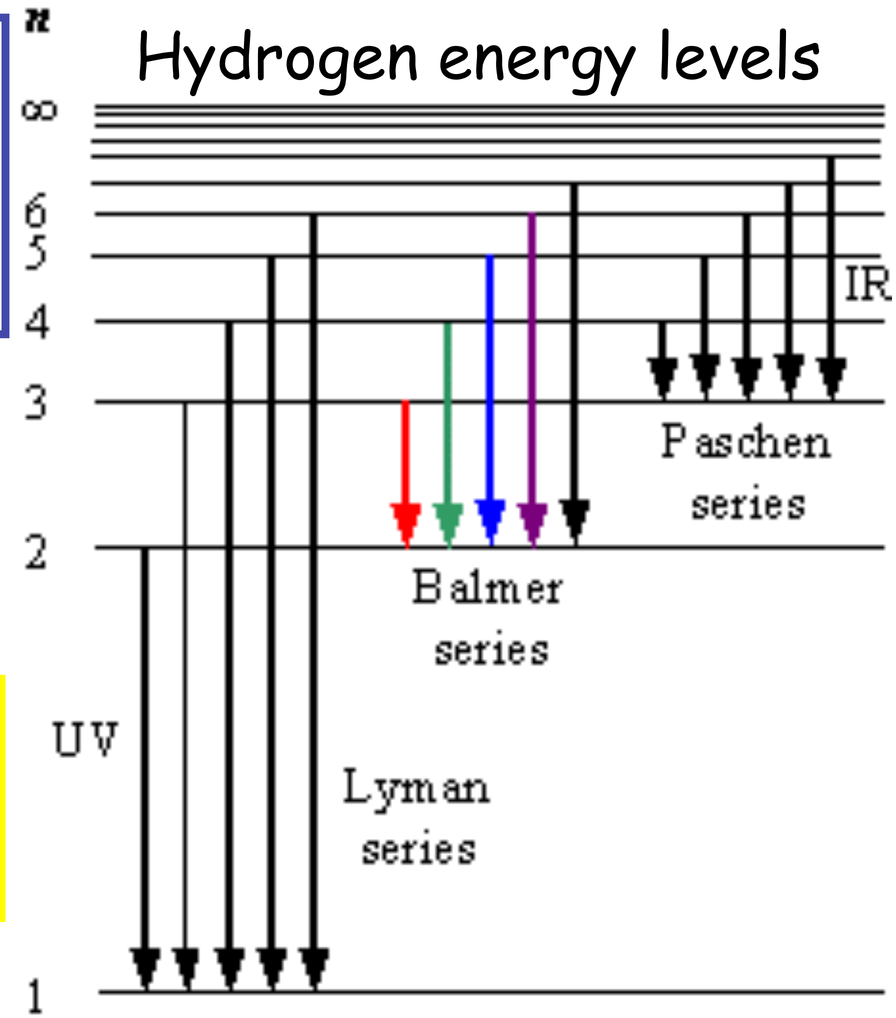
Hydrogen energy levels



Hydrogen atom - Balmer series

$$\lambda = \frac{91.18\,\text{nm}}{\frac{1}{n'^2} - \frac{1}{n^2}}$$

where
n′ = 1,2,3…
and n > n′



Balmer had a formula but no idea where it came from or how to apply it to other atoms.

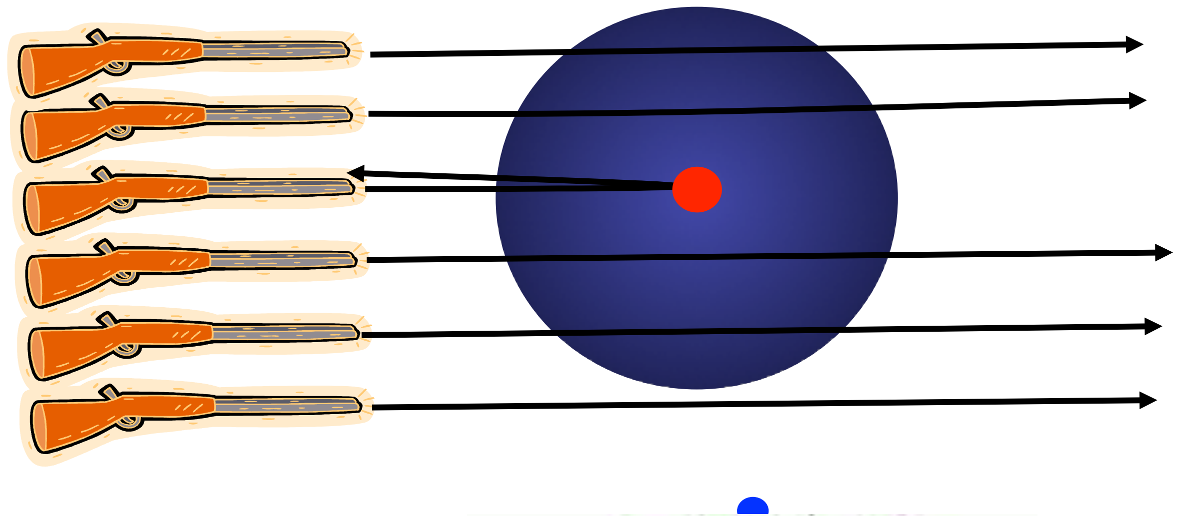
Physics strives for not just a description but for understanding and predictive power.

Note: we often write this formula as: $\frac{1}{\lambda} = R\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$

where R is the Rydberg constant: $R = 0.0110\ \text{nm}^{-1}$

Rutherford Solar System Model of the Atom

After discovering the nucleus, Rutherford proposed the solar system model.



Electrons circle the nucleus like planets circling the sun.

Big problem: electrons should radiate energy, spiraling into the nucleus

Elapsed time: ~10^{-11} seconds

Incidentally, planets radiate gravitational radiation and are spiraling into the sun.

For the earth, it will take 10^{22} years so the sun will be long gone.

Clicker Question 3 | Set frequency to AD

Please answer this question on your own.
No discussion until after.

In the Bohr model for hydrogen, quantized energy levels for the electrons arise…

A. because Bohr already knew the level are quantized and he put in the values by hand.
B. as a natural consequence of classical mechanics and quantized charge.
C. from an assumption of quantized electron position.
D. from an assumption of quantized photon energy.
E. from an assumption of quantized angular momentum.

The Bohr model is the next step toward understanding the atom.

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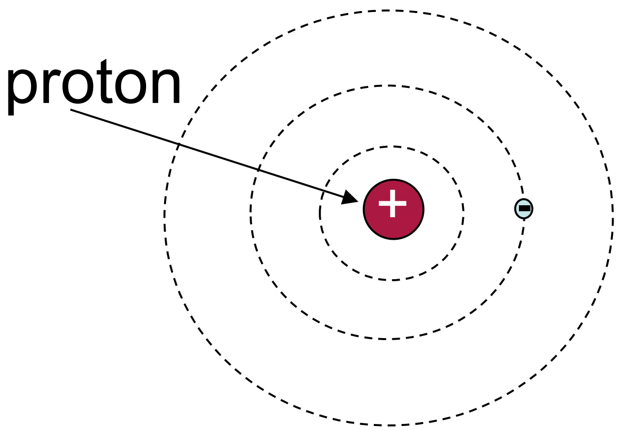
Bohr model

Bohr model background:

1. $1/\lambda = R\,(1/n'^2 - 1/n^2)$ – from Balmer
2. Gravity $-Gm_1m_2/r^2$ force between planets and sun gives orbits. Coulomb $-ke^2/r^2$ force between electron and proton could be expected to give orbits as well.
3. Classical EM says electron going in circle should radiate energy, and spiral in (accelerating charge radiates).

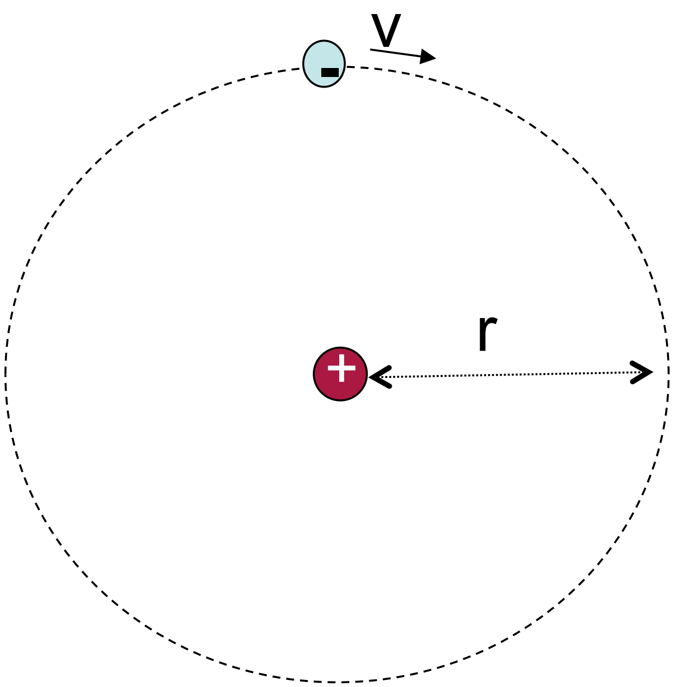


Bohr's additional postulate:

Electrons orbit at particular radii which have particular energies.

But WHY?!

Clicker question 4	Set frequency to AD



If the electron orbits the proton at a constant speed, the magnitude of the net force on the electron is…

A. mv

B. mv^2/r

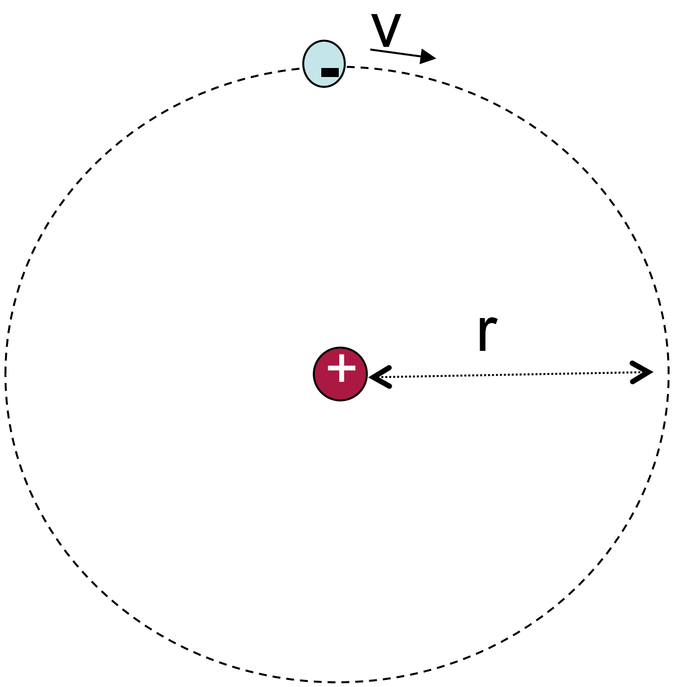
C. v^2/r^2

D. mvr

E. $\frac{1}{2}mv^2$

$$F_C = \frac{kq_1q_2}{r^2}$$

Clicker question 4 | Set frequency to AD



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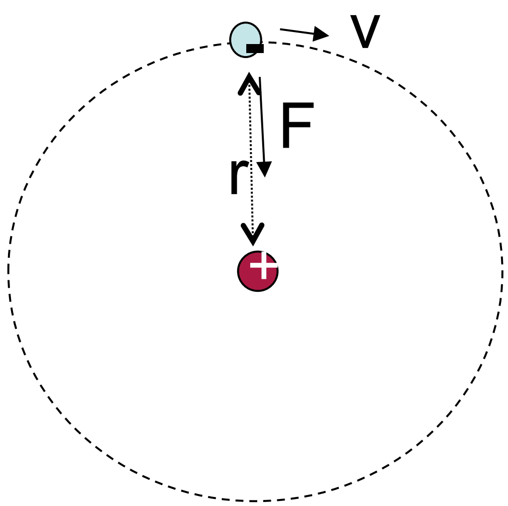
E. $\frac{1}{2}mv^2$

This force comes from the Coulomb force:
$$F_C = \frac{kq_1q_2}{r^2}$$

Setting the net force (from Coulomb) equal to the mass times acceleration (mv^2/r) for circular motion gives us:
$$\frac{mv^2}{r} = \frac{ke^2}{r^2}$$

which we can also write as: $$mv^2 = \frac{ke^2}{r}$$

What does this say about total energy?

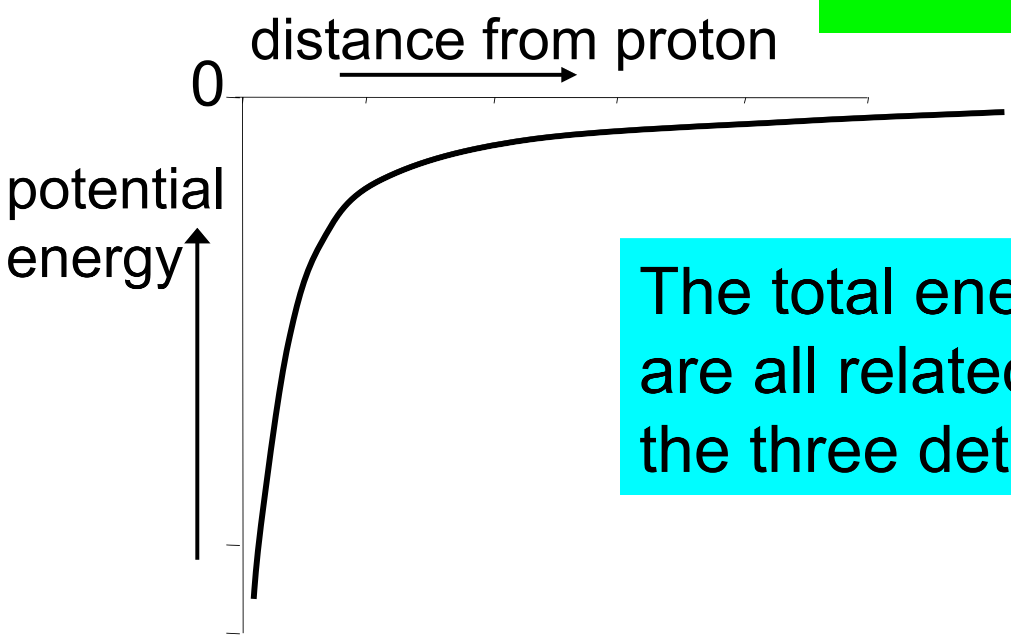


We now put together three pieces:

1. $mv^2 = ke^2/r$ (just derived)
2. electrostatic potential energy is $U = -ke^2/r$
3. nonrelativistic kinetic energy is $K = ½mv^2$

This means $K = -½U$ and the total energy is

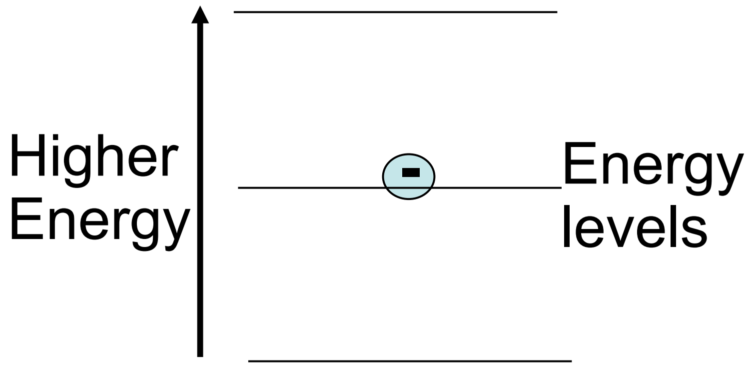
$$E = U + K = U - \tfrac{1}{2}U = \tfrac{1}{2}U = -\frac{1}{2}\frac{ke^2}{r}$$

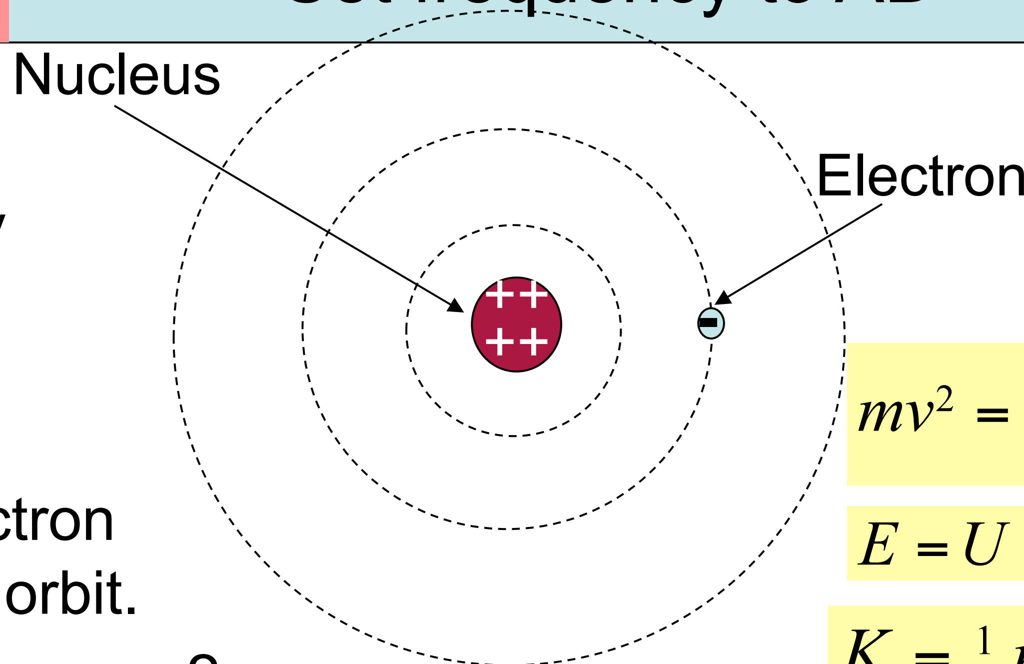


The total energy, radius, and velocity are all related. Knowing just one of the three determines the other two!

Clicker question 5

Set frequency to AD





$$mv^2 = \frac{ke^2}{r}$$

$$E = U + K$$

$$K = \tfrac{1}{2} mv^2$$

$$U = -\frac{ke^2}{r}$$

$$E = -\frac{1}{2}\frac{ke^2}{r}$$

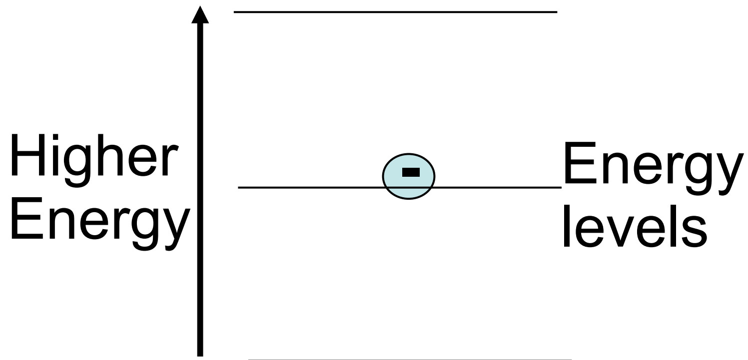
A force is applied to the electron bringing it to a larger radius orbit.

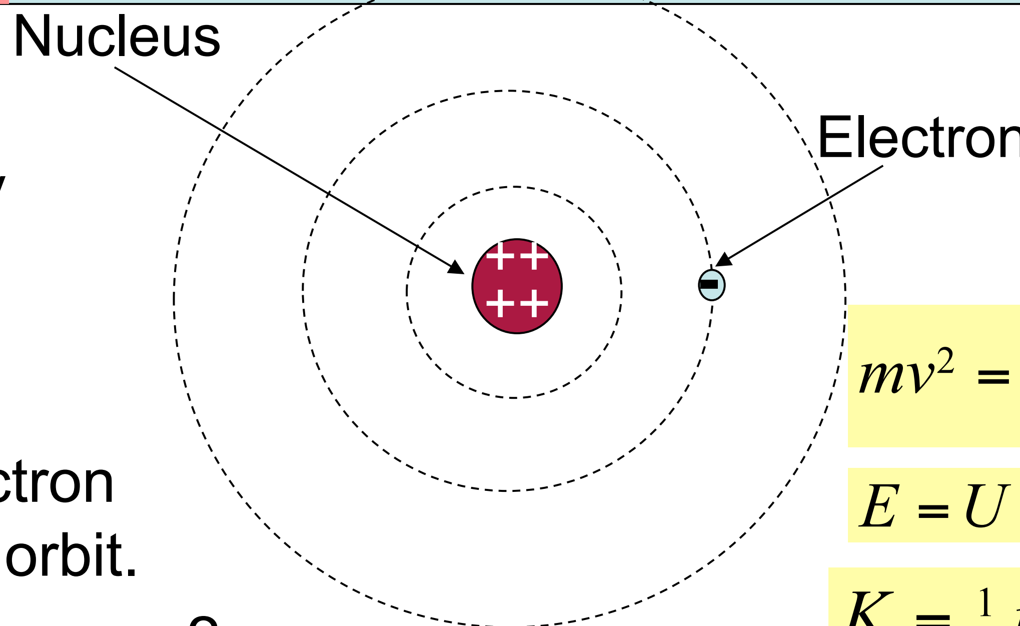
What can we say about the energy?

A. Total, potential, and kinetic energy increase
B. Total, potential, and kinetic energy decrease
C. Total and potential energy decrease, kinetic energy increases
D. Total and potential energy increase, kinetic energy decreases
E. Some other combination

Clicker question 5

Set frequency to AD





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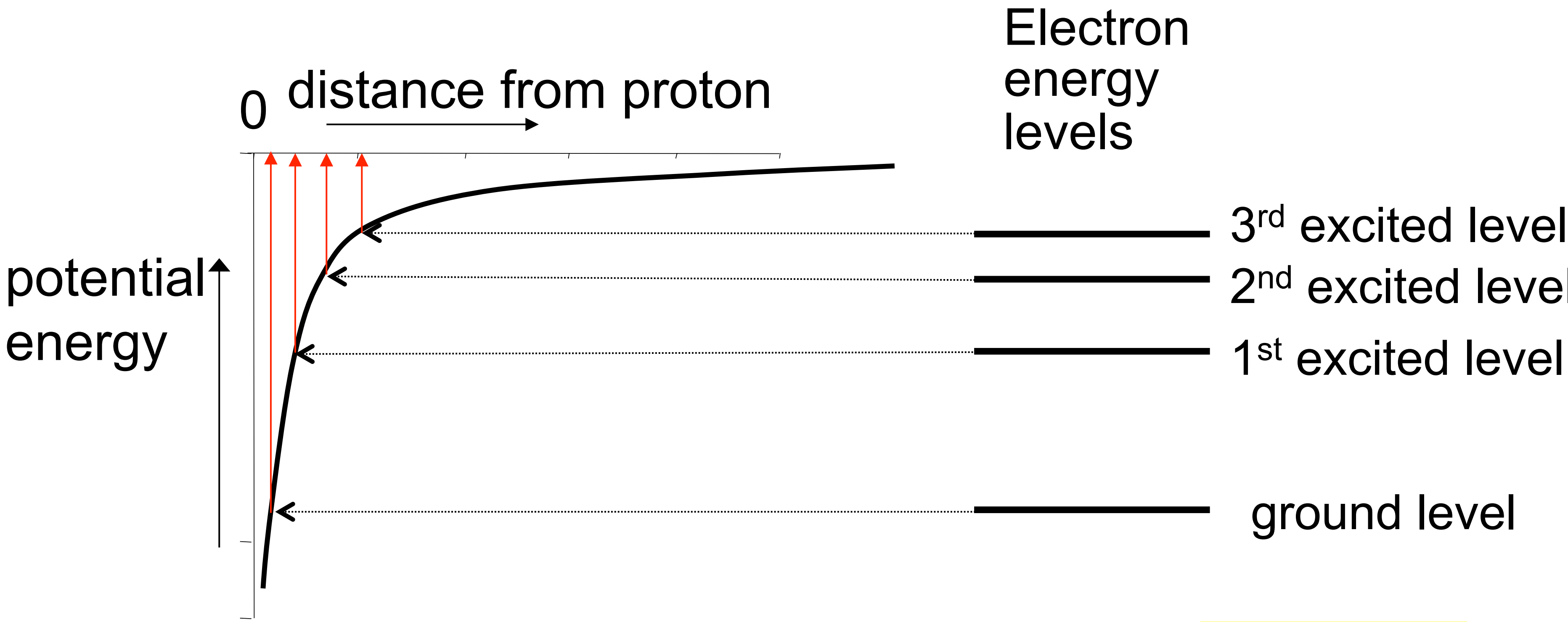
Increasing *r* increases potential and total (less negative) but lowers kinetic (smaller *v*).

Bohr model energy levels

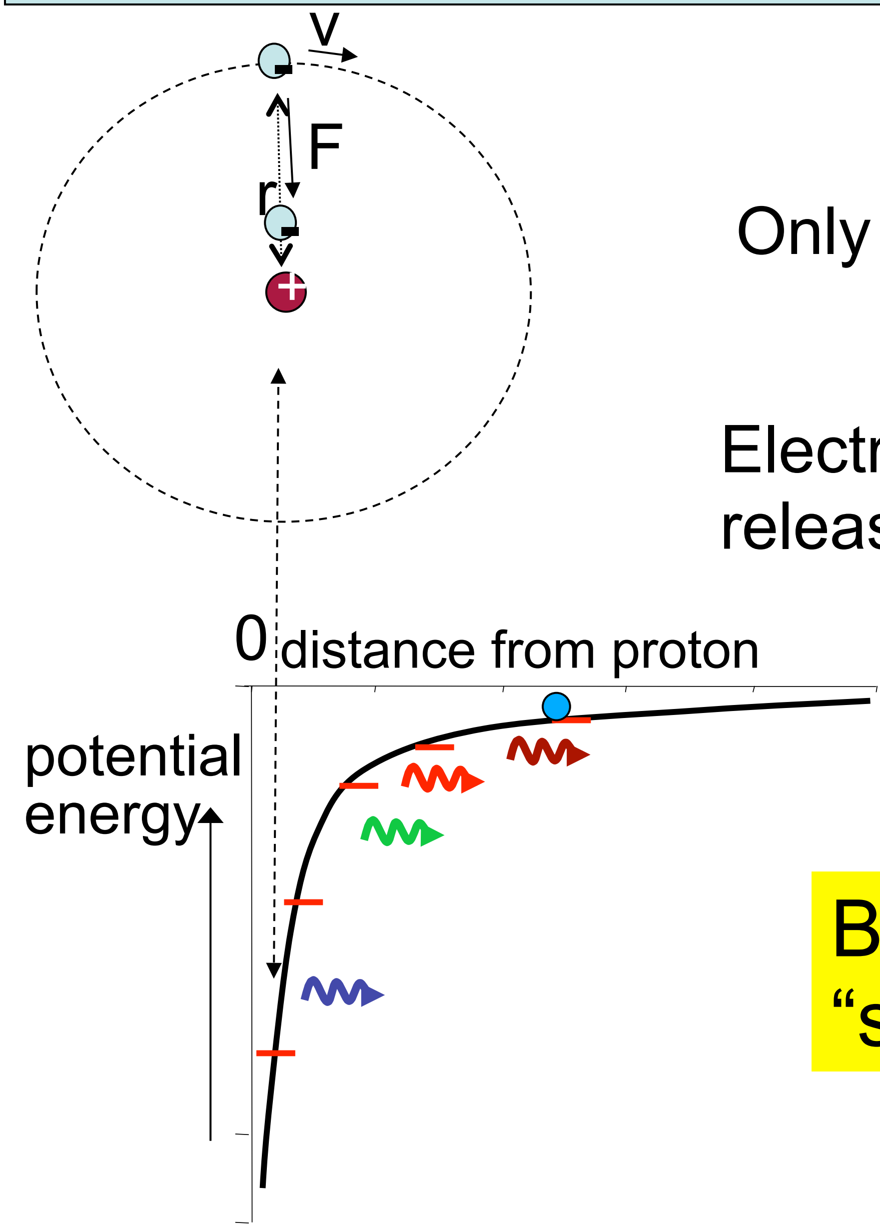


$$E = -\frac{1}{2}\frac{ke^2}{r}$$

In the Bohr model, each energy level corresponds to a certain radius and velocity.

$$mv^2 = \frac{ke^2}{r}$$

Bohr model energy levels



Only certain energy levels exist.

Electron can hop down energy levels, releasing a photon on each hop.

But what determines these "special" energies?

Why are only certain energy levels allowed?

Bohr supposed that electrons could only be in certain energy levels but then he needed to justify this in some way.

Bohr postulated that angular momentum was quantized

Remember angular momentum is $\vec{L} = \vec{r} \times \vec{p}$

For electron at radius *r* the angular momentum is $L = m_e v r$

Quantizing, Bohr found: $L = m_e v r = n\hbar$ where $\hbar = h/2\pi$

Quantizing angular momentum leads to a quantization of radius: $r_n = n^2 a_B$

$$a_B = \frac{\hbar^2}{m_e k e^2} = 0.053\,\text{nm}$$

is the Bohr radius

Quantizing radius leads to a quantization of energy:

$$E_n = -\frac{ke^2}{2a_B}\frac{1}{n^2} = -13.6\,\text{eV}/n^2$$

A little algebra

$mvr = n\hbar = nh/2\pi$, $n = 1, 2, 3, \ldots..$

From last page, $ke^2 = mrv^2 = mrn^2\hbar^2/m^2r^2 = n^2\hbar^2/mr$

So

$r = n^2\hbar^2/m\,ke^2$, $n = 1, 2, 3, \ldots.$

$r = .053$ nm for $n = 1$

And

$v = ke^2/n\hbar$, $n = 1, 2, 3, \ldots.$

$v = 2.2 \times 10^6$ m/s

Justifies using classical mechanics, but large Z

$E = -K = -mv^2/2 = -mk^2e^4/2n^2\hbar^2$, $n = 1, 2, 3, \ldots.$