Big Bang, Black Holes, No Math

ASTR/PHYS 109

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Lectures 11 & 12
The Training Wheels are now off

- I’m happy to help, but you are expected to know what to do for all assignments
- If you have done the work diligently, you should be able to concentrate on just the science from here on out
Was Due for Today - L12

- Reading:
  - (Unit 2)
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  - (Chapter 6)
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    - (Reviews & Back-evaluations)
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Big Bang, Black Holes, No Math  Topic 3: Quantum Mechanics and Atoms
So Far

Topics
1. Light and Doppler Shifts ← Done
2. Gravity, General Relativity and Dark Matter ← Done
3. Atomic Physics and Quantum Mechanics ← Now
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium
Overview of the story

• Big things are made from LOTS of small things
• Small things: The Fundamental Building Blocks of Nature
  - What is the “stuff” in atoms
• ElectroMagnetism (electric charge)
  - What holds electrons and protons together
• Quantum Mechanics
  - Why atoms form the way they do
  - Electron in orbits
  - Atoms absorbing and emitting photons (light)

• The Strong Force
  - Keeps protons and neutrons together
  - Different types of nuclei → different types of atoms
  - Different atoms → Different light...
  • Nuclear Physics and Chemistry Different TYPES of Atoms
• Studying the Stars using their light
  - Spectral lines of the atoms
  - Atomic “fingerprints”
  - The light we see from the stars
A Hydrogen Atom

The simplest atom: 
*Hydrogen*

One **electron** and one **proton**

*Partially wrong*

![Diagram of a hydrogen atom](image)

- Positively charged proton: $\sim 10^{-10}$ m
- Negatively charged electron: $\sim 10^{-15}$ m

Figure not to scale
Is the world this simple?

- This is a nice simple model
- Why does the electron stay in “orbit”?
- Simple (partially wrong) answer: There is a “Force” that keeps it in orbit just like Gravity keeps the Earth orbiting the Sun
Why the simple answer can’t be the whole story

- Electromagnetism says electrons emit energy/slow down when they move in circles (are accelerate by the EM Force)
  - Kinda like friction
- Observe this for electrons moving in big circles
- Should be true for electrons in small circles (atoms) also
  - Spiral down until they hit the nucleus and we’d have nothing: No atoms!
  - Calculations show it would take ~10 picoseconds \((10^{-11}\text{s})\)
  - (This is one of the reasons people in the late 1800’s thought electrons orbiting protons was WRONG!)
Another Problem

• Stars can be in orbit any distance from the center of the galaxy
  - Depends only on their speed
• Electrons should, depending on their speed, be able to orbit almost anywhere near the nucleus (like a planet or a comet)
• Don't observe this... Electrons only observed to orbit at specific distances from a nucleus
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- Different TYPES of Atoms
  - The Strong Force
  - Keeping protons and neutrons together (atomic nuclei)
  - Nuclear Physics and Chemistry
  - Different atoms → Different light...
- Studying the Stars using their light
  - Spectral lines of the atoms
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Quantum Mechanics

• **How do we explain these weird features that we observe about Atoms?**

• **Quantum Mechanics!**

• **LOTS we COULD say about QM, but since we could spend years on this we'll focus only on the most important points you need**
Quantum Mechanics

• All particles are both particles AND waves
  - Saw this for photons
  - Turns out to be true for electrons also!
Energy of Electron Waves

- Small energy electrons have large wavelengths.
- Small wavelength electrons have large energy.
Quantized Numbers

• This has big implications for electrons in atoms

• The electron “wave” has to go all the way around an exact number of wavelengths
  - Whole (Integer) number of wavelengths

http://bigbang.physics.tamu.edu/Animations/SignWave_atom.gif
Only Orbits with Specific Wavelengths Work

- The electron “wave” has to go all the way around
- Can have one peak/trough, two peaks/troughs, three peaks/troughs etc...
  - A quantized number
  - The Quantum in Quantum Mechanics
Only certain wavelengths work?

- If only certain wavelengths work, only certain energies are allowed.
- This means electrons can ONLY be in one of the available energy states, and at certain distances from the nucleus.
  - Keep atoms from collapsing! (Good!)
  - “Quantizes” the interactions with light i.e. only some energy photons interact with atoms.
Only Orbits with Specific Wavelengths Work

- **Lower Energy** and closer to the nucleus

- **Higher Energy** and further away from the nucleus
Energy and Distance from The Nucleus

Energy and Distance from The Nucleus

\[ E_4 = 16E_1 \]
\[ E_3 = 9E_1 \]
\[ E_2 = 4E_1 \]
\[ E_1 \]
\[ E = 0 \]

Higher Energy and further away from the nucleus

Lower Energy and closer to the nucleus

Only these levels are allowed!
Next:
How we “SEE” atoms
How Photons Interact with an Atom

• To understand better how photons interact with the stuff in an atom, “how we’ll SEE atoms”, we need to say a bit more about Energy and about Quantum Mechanics

• Lots of different ways they can interact… start with the simple interactions
Simple: Photon-Atom Collision

- **Before**: Start with a high energy photon and a low energy atom
- **After**: Lower energy photon, higher energy atom (like two billiard balls colliding)
- Same TOTAL energy before and after collision
  - Conservation of Energy
Clicker Question

After a collision with a stationary atom, the energy of a photon is

a) Higher
b) Lower
c) Same
Clicker Question

After a collision with a stationary atom, the **speed** of a photon is

a) Higher
b) Lower
c) Same
Clicker Question

After a collision with a stationary atom, the wavelength of a photon is

a) Longer  
b) Shorter  
c) Same
Atom-Photon Perspective

• Photon’s perspective: *I collide with a low energy atom and “transfer” some of my energy*

• Atom’s perspective: *A high energy photon collides with me and I “take” some of its energy*
Next:

Collisions, Quantum Mechanics and Electromagnetism
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