Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lectures 10 & 11
Was Due for Today - L11

- **Reading:**
  - BBBHNM Unit 2 (already due)
- **Pre-Lecture Reading Questions (PLRQ):**
  - Let us know if you were misgraded on any submissions
- **End-of-Chapter Quizzes**
  - (Chapter 6)
- **Paper 1:**
  - Stage 1 was due today, before class, in both CPR and Turnitin on eCampus
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
A Hydrogen Atom

The simplest atom:
*Hydrogen*

One electron and one proton

(Partially wrong)

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
Problem

- Electromagnetism says electrons slow down when they move in circles
  - 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 ($10^{-11}$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 orbit a specific distances from the nucleus
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)

- 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
  - Atomic “fingerprints”
  - The light we see from the stars
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

Two big issues:

1. All particles can be described both as particles AND waves
   - Saw this for photons
   - Turns out to be true for electrons also!

2. In atoms: 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
Energy of Electron Waves

- Small energy electron have large wavelengths
- Small wavelength electrons have large energy
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

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Topic 3: Quantum Mechanics and 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

$E_4 = 16E_1$

$E_3 = 9E_1$

$E_2 = 4E_1$

$E_1$

$E = 0$

Higher Energy and further away from the nucleus

Lower Energy and closer to the nucleus

Permitted Radii

Only these levels are allowed!
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*
Quantum Mechanics and EM

• In General Relativity we found that it is better to describe the “force” of gravity as the curvature of space-time

• How do we “better” describe ElectroMagnetism, especially with Quantum Mechanics?
  - Electric fields

• Answer: In ElectroMagnetism “Force” is essentially all about the “emission” and “absorption” of photons by charged particles like electrons and protons
Quantum Mechanics - Force Carriers

• Think of the force between electrically charged things as being caused by the exchange of “virtual” photons

• The force, or interaction, is “carried” by particles
Example with Two Electrons

- First electron emits a “force-carrying” particle (a photon)
- Causes a recoil of the first electron
  - You shoot a gun and lurch back
- The other electron “catches” it and gets “banged”
  - Your friend gets hit with the bullet and falls backward
- Net result: The two particles move differently, “as if” there were a force between them
1: Two electrons held in place, then let go

2: electron on the right “emits” a photon and “recoils”

3: Photon bangs into the left electron and bumps it

Both now move apart: Same sign charges “repel” each other
A Proton and Electron

1: A proton and an electron hanging out
2: Proton on the right “emits” a photon and “recoils”

3: Photon bangs into the electron
   Doesn’t transfer Momentum
   Transfers information on how to move
   Opposite signs attract

For those of you who know a little bit, this is how “electric fields” work
More Interactions

• Can also get electrons and protons interacting with REAL photons
  - Photons we can see, as opposed to ones that are emitted then absorbed never to be seen outside the interaction
• Real photons can be emitted or absorbed
Electron and Photon Interacting

Electron can “absorb” a photon
→ Electron becomes more energetic

-
Electron Emitting a Photon

Electron can “emit” a photon → Electron becomes less energetic
A Simple way of drawing things: Feynman Diagrams

Electron can “absorb” a photon → becomes more energetic

Electron can “emit” a photon → becomes less energetic

Big Bang, Black Holes, No Math  Topic 3: Quantum Mechanics and Atoms
Feynman Diagram for an Atom

Hydrogen Atom

• A diagram of how the particles “talk” to each other
• These two are attracted
If a photon with the right energy hits an atom and is absorbed, the electron can “jump” to an “excited state.”
If an atom is in an excited state, it’s just a matter of time before it emits a photon with exactly the energy between the two states.
Other ways of drawing the same thing

- An electron can move into a more energetic orbit when it absorbs a real photon with exactly the right energy.
  - The photon is absorbed, and the electron goes into an excited state.
- A high energy atom can "emit" a photon and go into a lower energy state.
A Proton bumps into an atom and excites it

Atom in Lowest Energy State

Atom in a Higher Energy State

Proton

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Physics We Need

Topic 3: Quantum Mechanics and Atoms
An Excited Atom Emits a Photon

Atom in a high Energy State

Atom in the Lowest State

Photon with a specific energy
Absorbing and Emitting a Photon

http://bigbang.physics.tamu.edu/ Figures/ StolenAnimations/ bohr. swf
Lots of Different Energy States
Photons and Atoms

Photons can interact with Atoms in three ways

1. Very low energy photon: Because the electron in the atoms can only have quantized states around the nucleus VERY low energy photons will be ignored, or bump the path of the atom
   - Ignoring is a kind of interaction

2. If an atom encounters a photon with the “right energy” photon it can get “excited” and go into a higher energy state. The photon is absorbed and is gone forever

3. If a REALLY energetic photon comes along it can completely knock an electron out of orbit from a nucleus
Putting it All Together

A cartoon of an atom and a photon

No thanks. Wrong energy.

Aha!

Ahh.

Oops.

Note: The electron being completely out of the atom is a perfectly good “energy state”
Atomic Transitions

- Any photon that hits the atom with the right energy will be absorbed
- Absorbs only special colors
How is this helpful?

• Can look at light from a light bulb → all colors observed

• Look at light from a light bulb with Hydrogen gas in the way
  – Only special colors will be absorbed!

Atomic Fingerprinting
Lecture on Chapter 7 now complete
Outline for Unit 2: Physics We Need

1. Light and Doppler Shifts ← Done
2. Gravity, General Relativity and Dark Matter ← Done
3. Atomic Physics and Quantum Mechanics ← Done
4. Nuclear Physics and Chemistry ← Next
5. Temperature and Thermal Equilibrium
Prep For Next Time - L11

• Reading:
  - BBBHNM Unit 2 (already due)

• Pre-Lecture Reading Questions (PLRQ)
  - Let us know if you were misgraded on any submissions

• End-of-Chapter Quizzes:
  - If we finished Chapter 7 then End-of-Chapter Quiz 7a & 7b (else, just through Chapter 6)

• Papers
  - Paper 1, Stage 2: Due Wednesday March 1st, before class