Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 10
Was Due for Today - L10

- Reading:
  - (BBBHN Unit 2)

- Pre-Lecture Reading Questions:
  - Let us know if you were misgraded on any submissions
  - Unit 2 Revision (if desired): Was due today before class

- End-of-Chapter Quizzes
  - Chapter 6

- Papers
  - Paper 1: Due Tuesday Oct 2nd at 11:59PM
    - Must be submitted to both Peerceptiv and TurnItIn on eCampus
    - Can submit a draft for feedback on eCampus if you like before Friday Sept 28th at 11:59PM
    - Will do our best for late submissions
Paper 1

• Abbreviated description: What is the evidence for Dark Matter?
  - More detail on Peerceptiv, you REALLY need to read ALL the instructions
• Explain it to someone who isn’t taking the class (no jargon)
• Follow the required Format:
  - Introduction paragraph
    • Lawyers opening arguments at a Trial
  - ~1 paragraph per piece of evidence/talking point
    • The case at a Trial
  - Conclusion paragraph that ties it together
    • Lawyers closing arguments at a Trial
• Help:
  - Example of good paper

http://people.physics.tamu.edu/toback/109/WritingAssignments/samplepaper.shtml

Holes, No Math  Topic 3: Quantum Mechanics and Atoms
Big Bang, Black Holes, No Math Topic 3: Quantum Mechanics and Atoms
Reminders about Papers

Re-read pages 48-52 of the Course Organization Document

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
Where We Are Going Next

In Chapter 3 we learned a little about how the stuff of the Universe is put together

• Big things are made from LOTS of small things

• Small things: The Fundamental Building Blocks of Nature
  -What is the “stuff” in atoms?
Most of the light we see from space comes from stars.

What are stars made of?

- Stars are lots of atoms interacting
- The ways they interact creates light we can see
- Can study the distant stars by looking at the light from them
- Can study atoms here on Earth. Are they the same?
How do Atoms work?

• ElectroMagnetism (electric charge)
  - What holds electrons and protons together
• Quantum Mechanics
  - The way atoms form and do the funny things they do
  - Electrons in orbits
  - Atoms absorbing and emitting photons (light)
Different Types of Atoms

- **The Strong Force**
  - Keeps protons and neutrons together in the atomic nucleus
  - Different types of nuclei
    - different types of atoms
  - Different atoms → Different light...

- **Nuclear Physics and Chemistry**

- **Studying the Stars using their light**
  - Spectral lines of the atoms
  - Atomic “fingerprint”
  - The light we see from the stars
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
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The Fundamental Building Blocks

Our best understanding:

The very BIG stuff is made up of LOTS of very small stuff

Need to understand:

1. What are the fundamental building blocks of nature

2. How it’s all held together

3. How they “create” the light we see
Early Evidence for the Atomic Model
(before we knew it was electrons orbiting a nucleus)

Shoot atoms at a “target”

Theory:

1?

Bag stuffed with cotton

2?

Bag stuffed with cotton and a few small rocks

Experiment (1910’s):

The experiment gives results like #2!

The positive charge in an atom and most of its mass is concentrated in a tiny, very dense center: The Nucleus

Big Bang, Black Holes, No Math

Physics We Need

Topic 3: Quantum Mechanics and Atoms
The Building Blocks of Nature

In the 19-teens and 20's experiments determined:

- Atoms are made of a nucleus surrounded by electrons
  - Many types of nuclei
  - Only one kind of electron
Nuclear Physics

Many years later (using many of the same methods):

• Nucleus is composed of neutrons and protons
• Number of protons and neutrons in the nucleus determines the atom type
  - Explains the periodic table
The Fundamental Building Blocks of Atoms

- Electrons
- Neutrons
- Protons

- Neutrons and Protons are really made of quarks
  - Discovered in the 1970’s
  - We’ll talk more about this in the next chapter

Talked about this in Chapter 3
More in Chapter 8

Big Bang, Black Holes, No Math  Topic 3: Quantum Mechanics and Atoms
Putting Them Together

How do we put these fundamental building blocks together to form atoms?
Overview of the story

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• Quantum Mechanics
  - Why atoms form the way they do
  - Electron in orbits
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• The Strong Force
  - Keeping protons and neutrons together
  - Different kinds of nuclei
• Nuclear Physics and Chemistry → different atoms
• Spectral lines of the atoms
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ElectroMagnetism

- You probably already know that protons and electrons have "electric" charges
- Positive charge and negative charge attract each other
- Call this ElectroMagnetism
You probably never thought about it this way but in many ways the way things with electric charge attract is very similar to gravity.
Gravity vs. ElectroMagnetism

**Gravity**
- Every object in the universe attracts every other object in the universe
- The bigger the mass, the bigger the attraction
- The further the distance between the objects, the smaller the attraction

**ElectroMagnetism**
- Every charged object in the universe "attracts" every other charged object in the universe
- The bigger the charge, the bigger the attraction
- The further the distance between the objects, the smaller the attraction

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**Physics 201**

**Physics 202**

**Physics 208**

**Physics 218**
What's different?

• **Gravity:**
  - All objects attract no matter what
  - (As far as we know...)

• **ElectroMagnetism:**
  - Ignores neutral particles

Opposite charges attract each other
Like charges repel each other
Other Differences

- ElectroMagnetism is **MUCH** stronger than gravity

- If I have two electrons, the electric force between them is so powerful that it is \(10^{42}\) times stronger than gravity

- Can “ignore” gravity inside atoms
Aside

• **ElectroMagnetism** is *MUCH* weaker than the **Strong Force**

• For two quarks inside a proton, the **Strong Force** is ~100 times stronger than the **EM force**
  
  - Can almost “ignore” **Electromagnetism** inside protons
Atomic Physics

How do we make up atoms?

1. Start by describing a simple (partially wrong) atomic model
   - Positive Nucleus attracts the negatively charged electrons and keeps them in “orbit”

2. Then move to the weird world of Quantum Mechanics
A Hydrogen Atom

The simplest atom: Hydrogen

One electron and one proton

(Partially wrong)
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

Big Bang, Black Holes, No Math Topic 3: Quantum Mechanics or
Why the simple answer can’t be the whole story

- 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
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- Quantum Mechanics
  - Why atoms form the way they do
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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
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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 electron 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
Prep For Next Time - L10

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

- **Papers**
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Full set of Readings So Far

- **Required:**
  - BBBHNM: Chap 1-9

- **Recommended:**
  - BHOT: Chap. 1-6, 9 and 11 (117-122)
  - SHU: Chap. 1-3, 6 and 7 (up-to page 153)
  - TOE: Chap. 1