Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 12

Physics We Need
Topic 4: Nuclear Physics & Chemistry
Was due Today - L12

- 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:
  - End-of-Chapter Quiz 7a & 7b
- Paper 1:
  - (Stage 2 due Wednesday before class in CPR)
    - Make sure you have submitted to both CPR and turnitin on eCampus
• What is the evidence that Stars are made of Atoms?
• This will be the topic of Paper 2

• In order to understand the evidence, we next talk about Atoms and how they work
• Will be assigned after we finish Chapter 8
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 ←This time
5. Temperature and Thermal Equilibrium
Looking at the Lights in the Sky

What we know about the universe comes from multiple places

So far:
• Learned about the light coming from the sky
• Learned that atoms can produce this light
Questions We're Trying to Answer

• What are stars made of?
• What can we learn from looking at them?
• How do we know? What is the evidence

Today: More about different types of atoms that produce the light

→ A “smoking gun” piece of evidence that the light from the sky is from atoms out there
Outline

• Overview
• What protons and neutrons are made of: Quarks
• How protons and neutrons interact & combine to form a nucleus
• Chemistry
• Spectral lines
  - Light from stars!
• Learning about 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)

- 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
Smaller Building Blocks of Nature

- Atoms are made of a nucleus surrounded by electrons
  - Many types of nuclei
  - Only one kind of electron
- Nuclei are composed of neutrons and protons
  - Neutrons and protons are two different types of nucleons
- Nucleons are made of quarks
Chemistry

• We can put nucleons together in lots of different ways...

• Each different way corresponds to a different type of atom

Knew about the periodic table in the 19th century
Understood it was just combinations of protons and neutrons in the 1920's
Observation: Different Kinds of Atoms

- The kind of atom depends on the number of protons in the nucleus.

- Helium (He), with 2 protons, 2 neutrons and 2 electrons.

  ![Helium 4](image)
What's in a name?

- Need to explain some words
  - Free quarks = A quark not inside another particle (e.g. a proton)
    - This occurs in the early universe only
  - Completely ionized atom = A nucleus
  - Proton = Completely ionized hydrogen atom
  - Neutral atom = Equal number of electrons and protons
Why do nucleons stick together?

• If what holds the atom together is the opposite charge of the protons and the electrons...

   ➔ Why don’t the same sign charges of the protons “blow the nucleus apart?”
What Nucleons are Made Of

- Each nucleon is made of 3 quarks
- Two different types of quark
- Called “up” quarks and “down” quarks
- Each quark has fractional charge

More to say about this later
What holds the quarks together?

- The strong force is so much more powerful than the EM force that it holds the quarks together inside the nucleon.
- The force mediator is the “gluon”:
  - Quarks talk to each other via gluons.
The same strong force keeps the nucleons together.

Essentially the gluons “leak” out of the nucleons and provide the attractive force.
A neutral helium atom is sitting in space when a photon hits it. Depending on the photon energy, the following things can happen:

A. An electron gets knocked out and the atom become ionized
B. A proton gets knocked out and it become a hydrogen atom
C. A quark gets knocked out of the proton

Place the following in order from highest required energy to lowest.

a) A>B>C
b) A>C>B
c) B>A>C
d) C>A>B
e) C>B>A
So what?

• Why do we care about all the different kinds of atoms?
• What does this have to do with Stars and the Big Bang?
• The different mass and charge of each nucleus means that each atom has a different set of energy levels
  - Each one has unique fingerprints!
Different energy levels for each different type of atom

Fingerprinting the different atoms

Hydrogen  Helium  Boron

Can use light of different energies to identify atoms: Different Colors

Big Bang, Black Holes, No Math  Topic 4: Nuclear Physics & Chemistry
Atomic Fingerprints

- Each atom produces a large number of different wavelengths with VERY SPECIFIC values.
- Quantum Mechanics predicts ALL of them.
- If you see all the ones you expect and none you don't, that gives you confidence.
More on Fingerprinting

• Look at light from a light bulb with Hydrogen gas in the way
• Different lines will be absorbed by Helium
• Can now identify a mystery gas!

From the spectrum, we can tell that our mystery gas is Hydrogen
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Using Light From Stars

- Can look at the light from the stars to “see” if they are made of atoms
- Figure out what TYPE of atoms...
- How stars are formed...
- What makes them shine...
What is a Star?

- Our best understanding is that stars are giant balls of (mostly) hydrogen gas
- The hydrogen interacts and produces the light we see
  - Makes them shine...
- What is the evidence for this?
Stars

• What would happen inside a giant ball of hydrogen?
  - Interactions

• What would it look like to us?
  - Light from the interactions
  - Next look at interactions
Proton + Proton
\[ \rightarrow \text{Deuterium} + \text{Anti-Electron} + \text{Neutrino} \]

The Deuterium, neutrino and the Anti-Electron get energy in the reaction.
Proton + Deuterium $\rightarrow$ Helium$_3$ + Photon

Photon can have almost any energy
Creating Stable Helium

$$\text{Helium}_3 + \text{Helium}_3 \rightarrow \text{Helium}_4 + 2 \text{ Protons}$$
Stars

• Nuclear interactions in the center of the star create lots of energy which is eventually emitted as light from the surface of the star
  - Shines white (or yellow)
• This light passes through other atoms of the star
  - Light is “absorbed” by the outer atoms → Spectral lines
• Tells us what the stars are made of
Looking at the Stars

From the spectrum, we can tell the star is made of Hydrogen gas.
Analyzing Absorption Spectra

• Each element produces a specific set of absorption (and emission) lines
• Using this information, we can study the composition of stars

See only spectral lines for known atoms

- Hydrogen 91.0%
- Helium 8.1%
- Carbon, Nitrogen, Oxygen, other elements 0.9%
Remarkable...

• The Sun and stars are mostly made of Helium and Hydrogen
• Our Sun is made of the same stuff as all the other stars!
• The stuff out in the universe is made of the same stuff that is found here on Earth!
Even More Remarkable

If all the stuff “out there” looks the same as the stuff here on Earth then:

- The particles out there (electrons, protons, photons etc.) are the same as they are here

- The **laws of physics** that govern putting together protons, nuclei and atoms are likely to be the same everywhere!

- Provides evidence that it’s been this way for billions of years!
Now that we know what stars are made of and what they are SUPPOSED to look like, can we learn anything else?
Prep For Next Time - L12

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  - If we finished Chapter 8 then End-of-Chapter Quiz parts 8a and 8b (else, just 7a and 7b)
- Papers:
  - Paper 1, Stage 2: Due Wednesday before class in CPR
    - Make sure you have submitted to both CPR and turnitin on eCampus
  - Paper 2, Stage 1: If we finished Chapter 8, it will be due next Wednesday before class
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