Was due Today - L14

- Reading:
  - (BBBHNM Unit 2)
- Pre-Lecture Reading Questions:
  - Let us know if you were misgraded on any submissions
- End-of-Chapter Quizzes:
  - Chapter 8 Quiz parts 8a and 8b
- Papers:
  - Paper 1:
    - Back-Evaluations: Were due Tuesday at 11:59PM
    - Let us know if you think you were misgraded
    - You may submit a revised text to TurnItIn
  - Paper 2:
    - Can submit a draft for feedback by Friday at 11:55PM
    - Text: due Tues Oct 16th
      - Both Peerceptiv and TurnItIn
    - Reviews: Due Thursday Oct 8th
    - Back-evaluations: Due Tuesday Oct 23
Where we are...

Topics
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 ← Done
5. Temperature and Thermal Equilibrium ← This Time
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 Sun and the other stars

• The evidence that stars are made of atoms
Other Stuff Out There...

- We don’t just look at the stars...
- We can learn a lot from looking at light in other ways too...

- Talk about this today...
The World in a Jar

As we'll see, in many ways when we look at the stuff in the sky (other than the stars) it looks like we're sitting in a giant jar of stuff, like atoms.

What does it look like to sit inside a jar of atoms?

Why should you care?
Start Simple: Atoms in a Jar

- Since we can see how atoms interact in a jar on Earth we can predict what would happen on Universe sizes
- Next: learn what it’s like to be inside a jar filled with atoms
- Gas (bunch of atoms) is well described by its \textbf{Temperature} and will eventually come into \textbf{Thermal Equilibrium}
  - Describe both these ideas next
Overview of Today’s Material

1. Temperature: Photons and Atoms
2. Thermal Equilibrium
3. Moving in a Gas
4. Different types of Equilibrium
5. What we can, and can’t, learn from a system in Thermal Equilibrium
Temperature

What do we mean when we use the word temperature?
Temperature

How do we typically “think” about Temperature?

• When we’re outside and we “feel” cold, the thermometer reads a small number.

• When we’re outside and we “feel” hot, the thermometer reads a large number.

What is the thermometer measuring?
“Feeling” Cold

- What is hitting you when you are outside?
  1. Photons
  2. Atoms

Can think of temperature as the energy of the particles hitting you.
Temperature of Atoms

Same number, and type, of atoms in both

Low Energy: Cold Gas

High Energy: Hot Gas
Temperature of Atoms and Photons

- Even if a room is completely dark we can still feel warm because atoms hit our skin
  - High energy atoms $\rightarrow$ high temperature
  - Low energy atoms $\rightarrow$ low temperature
- Our skin is a lousy thermometer $\rightarrow$ Feels “cooler” in the shade because we absorb fewer photons
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Thermal Equilibrium

Let's say I'm hanging out in a room and part of the room is hot and part of the room is cold.

Eventually the air mixes and the room has the same temperature everywhere.

Same as putting ice in a cooler full of water. Eventually it will get cold.
What’s really happening?

Look at the atomic level

- You have high energy atoms and low energy atoms
- What happens to high energy atoms when they collide with low energy atoms?
Atomic Perspective

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

• Low energy atom’s perspective: I collide with a high energy atom and “take” some of its energy.
What happens in a room with lots of atoms after lots of collisions?

The higher energy atoms will, over time, become lower energy atoms.

The lower energy atoms will, over time, become higher energy atoms.

Eventually we get lots of medium energy atoms.
Thermal Equilibrium

- Eventually all the atoms will (roughly) have the same energy
  - Said better: The same temperature
  - The temperature stops changing

- We call this *Thermal Equilibrium*
  - It’s called equilibrium because the temperature stops changing
A Visual Example Using Pool Balls

• Think of a perfect pool table (no friction to slow down the balls) with a cue ball and a rack of balls at the other end; all are stationary
  - We then shoot the cue ball at the rack (we break)

• Right after we shoot, but before the cue ball hits the rack, we're NOT in equilibrium
  - One ball is VERY energetic and the others have no kinetic energy
After the Cue Ball Hits the Rack

• After the cue ball strikes the rack, the cue ball has smaller energy and all the other balls have some energy
  - As the balls bounce off each other they will, eventually, all have roughly the same energy
  • Actually more complicated, but it turns out we can predict the distribution of energies
  - Call this Thermal Equilibrium
Pool Table Example

Cue ball after it hits the rack

⇒ All balls have roughly the same energy

Call This THERMAL EQUILIBRIUM
Silly Pool Table Example

NOT THERMAL EQUILIBRIUM
Not all things with the same temperature are in Thermal Equilibrium

• For two areas to be in thermal equilibrium with each other, heat needs to be able to move from one to the other

• If I have two cups of water that are the same temperature, but they aren’t touching, they aren’t in equilibrium with each other
Next consider some things that don’t typically happen to jars in everyday life.
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Moving in a Gas

• What if the jar is moving?
• What if the jar is stationary, and I (as the observer) am moving inside it?

- These are equivalent by relativity
An Observer Inside a Gas in Thermal Equilibrium

What does it look like “in here”?

1. Equal number from all directions
2. Same “temperature” in all directions
What if I, or the Jar, is Moving?

What does it look like “in here”?

1. Equal number from all directions
2. DIFFERENT “temperature” in different directions
I can tell that I am located in a gas in thermal equilibrium if:

1. The temperature is the same in all directions OR
2. The temperature looks as if either me or the gas is moving in a single direction

A gas in Thermal Equilibrium is well described by its Temperature
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Other Types of Equilibrium?

• Different types of gas can mix
• When things stop changing (temperature and other mixing) we say it has come into thermal equilibrium
• Atoms (or particles) can interact and come into thermal equilibrium
First Example: 2 Gases Mixing

- Let’s say I have two different gases with different temperatures on opposite sides of a jar
  - High Mass atoms and Low Mass Atoms
- Before: Not in thermal equilibrium, doesn’t look like equilibrium
  - Different temperatures on each side
  - If I weren’t at the center, it would look different than if I were at the center
- During: The atoms “mix” and come to thermal equilibrium
- After: We’re in thermal equilibrium → equal temperatures everywhere, looks the same in all directions
Two Gases Mixing

Low Mass Atoms High Mass Atoms

http://bigbang.physics.tamu.edu/ Figures/StolenAnimations/ HeatTransferred.avi
Other Examples

- Can have many different types of “mixing” where things eventually come into thermal equilibrium with each other
- Hydrogen and oxygen can mix and turn into water in thermal equilibrium
- At high energies, I can get an electron/photon “soup” in thermal equilibrium
  - How?
Thermal Equilibrium at High Energies/Temperatures

- An electron and an anti-electron can collide and turn into two photons
- Two photons can collide and turn into an electron and an anti-electron
  - If they have enough energy

Big Bang, Black Holes, No Math  Topic 5: Temperature and Equilibrium
Photons and "Electrons"

2 Photons can turn into 2 "Electrons"

2 "Electrons" can turn into 2 Photons
Electrons, positrons, and photons in both production and annihilation
Electron and Photons

• If we have only lots of electrons and positrons, and no photons, they will interact and create photons
  - Number of electrons/positrons falls, and number of photons rises

• If there are only lots of high energy photons, they will interact and create electrons/positrons
  - Number of photons falls, and number of electrons/positrons rises
Always end up the same way

- Eventually, the number of electrons/positrons/photons stops changing
- The energy of the particles stops changing
  - I get an electron/photon “soup” in Thermal Equilibrium
What happens over time?

• If I start with slightly more high energy photons than electrons and positrons, then slightly more of the collisions produce electrons and positrons until things even out.

• Same is true if I start with slightly more electrons/positrons.
Lots of **Types** of Thermal Equilibrium

- It isn’t just electrons and photons
- Given enough time (and things not changing) all places in any room will come to have the same temperature i.e., be in thermal equilibrium
- Depending on what the particles are (electrons, photons, atoms etc.) they can turn into different types of particles and bring the number of objects AND energy into Thermal Equilibrium also
So what???

- Often the details of how it starts don’t matter
- If I know the particles and the energies I can figure out how it will come out in the end
- Things come to be in thermal equilibrium... they stop changing
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What Thermal Equilibrium Can, and Can’t, Tell Us

- Lots of different ways of starting out will come to the same thermal equilibrium
- **So what?** Since this is true we can’t learn a lot about what happened BEFORE it went into equilibrium
  - Single cue ball hit a rack of balls?
  - Two balls hit the rack at the same time?
- Can’t tell the difference looking at much later times...
Different Initial Conditions

Much later in time (after we're in thermal equilibrium) can't tell if the system started in

Funny Way

Usual Way
A Universe in Thermal Equilibrium

• We will see evidence that the Universe appears to have the same temperature everywhere
  - *Was it in Thermal Equilibrium at some point in its history?*

• Tells us a lot about the Universe and how it evolved (and will evolve)

• Can’t tell us about what happened BEFORE it came into Thermal Equilibrium
  - *For example: Was there actually a Big Bang? Something else?*
Lecture on Chapter 9 now complete
The Plan...

Finished:
1. Light and Doppler Shifts
2. Gravity, General Relativity and Dark Matter
3. Atomic Physics and Quantum Mechanics
4. Nuclear Physics and Chemistry
5. Temperature and Thermal Equilibrium

Next time:
• Starting Unit 3
• Using the “Physics We Need” to teach us about the EVIDENCE for the Big Bang
Prep for Next Time – L14

- **Reading:**
  - BBBHNM Unit 3: Due Tuesday before class

- **Pre-Lecture Reading Questions (PLRQ):**
  - Unit 3: Due Tuesday before class

- **End-of-Chapter Quizzes:**
  - If we finished Chapter 9 then end-of-chapter quiz 9 (else just quizzes 8a and 8b)

- **Papers:**
  - **Paper 1:**
    - Back-Evaluations: Due Tuesday at 11:59PM
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Big Bang, Black Holes, No Math — Physics We Need
Full set of Readings So Far

• Required:
  - BBBHNM: Chaps. 1–10

• Recommended:
  - TFTM: Chaps. 1–3
  - BHOT: Chaps. 1–7, 9 and 11 (117–122)
  - SHU: Chaps. 1–3, 4(77–86), 5(95–104), 6, 7 (up-to-page 153)
  - TOE: Chaps. 1 & 2