Big Bang, Black Holes, No Math
ASTR/PHYS 109
Dr. David Toback
Lectures 18 & 19

Physics We Need
Topic 5: Temperature and Equilibrium
Was due Today - L19

- Reading:
  - BBBHNM Unit 3: Was due today before class
- Pre-Lecture Reading Questions (PLRQ)
  - Unit 3: Due Friday before class
- End-of-Chapter Quizzes:
  - (Quizzes 8a and 8b)
  - Late penalties for Chapter 7 assessed
- Papers
  - Paper 1:
    - Back-Evaluations: Due tonight, Wednesday, Feb 28th at 11:59PM
    - Will allow revisions of the text after back-evaluations and re-grades are done
  - Paper 2:
    - Draft for Feedback (if desired) due Friday March 2nd at 11:59PM
    - Text due Wednesday, March 7th
    - Reviews: Due Monday after Spring Break, March 19 at 11:59PM
    - Back-evaluations: Due Wednesday after Spring Break, March 19 at 11:59PM
Bottom Line

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**
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
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 \( \Rightarrow \) 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
Photons and “Electrons”

2 Photons can turn into 2 “Electrons”

2 “Electrons” can turn into 2 Photons
Visualize: Electrons and 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
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
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

Big Bang, Black Holes, No Math
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 - L19

• Reading:
  - BBBHNM Unit 3: Was due today before class

• Pre-Lecture Reading Questions (PLRQ)
  - Unit 3: Due Friday before class

• End-of-Chapter Quizzes:
  - If we finished Chapter 9 then end-of-chapter quiz 9 (else just quizzes 8a and 8b)
  - Late penalties for Chapter 7 assessed

• Papers
  - Paper 1:
    • Back-Evaluations: Due tonight, Wednesday, Feb 28th at 11:59PM
    • Will allow revisions of the text after back-evaluations and re-grades are done
  - Paper 2:
    • Draft for Feedback (if desired) due Friday March 2nd at 11:59PM
    • Text due Wednesday, March 7th
    • Reviews: Due Monday after Spring Break, March 19 at 11:59PM
    • Back-evaluations: Due Wednesday after Spring Break, March 19 at 11:59PM
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