Big Bang, Black Holes, No Math

ASTR/PHYS 109

Dr. David Toback

Lecture 18
Was due Today - L18

- Reading:
  - (BBBHN Unit 2)
- Pre-Lecture Reading Questions:
  - Let us know if you were misgraded on any submissions
- End-of-Chapter Quizzes:
  - Chapter 8, parts 8a and 8b,
  - Late penalties for Chapter 7 assessed
- Papers
  - Paper 1:
    - Text: Was due Wednesday
      - Both Peerceptiv and TurnItIn on eCampus. Late penalties assessed
    - Reviews: Due tonight, Monday, Feb 26th at 11:59PM
    - Back-Evaluations: Due Wednesday, Feb 28th at 11:59PM
    - Will allow revisions of the text after back-evaluations and re-grades are done
  - Paper 2:
    - Text due Wednesday, March 7th
      - Draft for Feedback (if desired) due Friday March 2nd at 11:59PM
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 Temperature and will eventually come into 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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5. What we can, and can't, learn from a system in Thermal Equilibrium
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.
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
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
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
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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
Prep for Next Time – L18

- **Reading:**
  - BBBHNM Unit 3: Due Wednesday 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:**
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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