Chapter T1

- Introduction to Statistical Mechanics
  - This topic does not have the “strangeness” that quantum mechanics had…but it does have some very interesting aspects.
  - Statistical Mechanics describes the behavior of *macroscopic* objects
    - Newtonian Mechanics:
      -
      -
      -
    - EM were dealing with the fields setup by charged objects both stationary and moving.
    - Quantum:
      - Definitely dealing with microscopic objects and treating them as point-like.
  - Consider gas molecules in a balloon.
    - How do we understand the pressure on the balloon walls?
      -
        -
    - This is where statistical mechanics saves us. We can determine the macroscopic properties **without** worrying about the individual objects in the problem.
      - Works when ___________________!
  - We need to define a new set of variables that are useful for systems of many particles
    - Temperature, Pressure, Volume, N_{states}, Entropy, etc
    - Note: It makes little sense to define these for a single object…these are truly properties of the “full system”.

Irreversible Processes

- The fundamental idea that this unit is structured around is the concept that certain processes are not reversibe.
  - The common example is to think about making a movie of some physical process, then think about watching the moving in reverse.
  - Certain actions, if you saw them in reverse, would not strike you as strange.
    - Two fundamental particles colliding (billiard balls)

      Forward Reverse

    - An electron absorbing a photon and making a transition to a higher energy level.

      Forward Reverse

    - A ball being thrown in the air and then caught.
  - One of the reasons that these would not strike you as strange is that these involve ***reversible processes.*** Basic Newtonian Mechanics and Quantum Mechanics are *time symmetric*
    - These theories don't have a "forward arrow" in time.
    - Exception: QM, CP Violation…intense interest now.

Irreversible Process

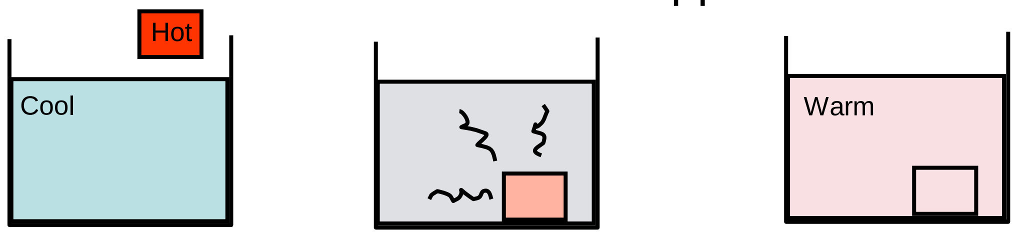
- There are many processes that would strike you as being very strange if the movie was played in reverse:
  - A rock being throw into a pond:
  - A block sliding on the table with friction bringing it to a stop.
  - Milk being spilled onto the floor
- If you saw these things you would say:
  - “That’s not right!”
  - “That would never happen!”
  - “That can’t happen!”
- Why Not?
  - These DO NOT violate energy conservation!
  - Newtonian Mechanics does not prohibit any of these things from happening in reverse. (At least obviously)
  - Neither does quantum mechanics. (At least obviously)
- Answering this question is the main focus of Unit T.

Irreversible Processes

- As a final comment regarding irreversible processes before diving into the detailed study let me make a few final comments:
    - On the microscopic scale, atoms and molecules interact in a way that is reversible.
        - e.g. elastic collisions.
    - The irreversibility seems to be a phenomena of **macroscopic** objects.
    - However, assuming that the action of the whole should some how be the sum of the action of the parts, this seems like a contradiction.
- One of the first scientists to study these irreversible processes was Ludwig Boltzmann in the mid 1800's.
    - He showed how macroscopic quantities such as temperature, entropy etc. could be related to the microscopic motion of atoms (reversible processes).
        - This showed that this contradiction was__________
        - He was criticized by much of the scientific community of the time. Eventually he became so depressed from all the "bad press" that he committed suicide.
        - A few years after taking his life, experiments were conducted that showed his approach was correct.
        - For his efforts and intelligence today we have a fundamental constant called the "Boltzmann Constant".

Model Process

- In order to study all the development of quantities and concepts regarding irreversible processes we want to develop a *model process*, that is a simple processes that we can come back to as an example.
- **Model Process:** A hot block is dropped into cool water.



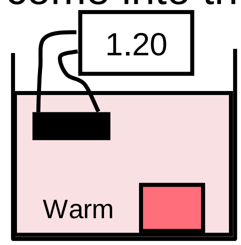
- What happens as time progresses:
  -
  -
- As Moore points out this simple process raises several questions that we would like to answer:
  - **What is temperature?**
    - What does it mean for something to be **hot** or **cold.**
    - Is temperature related to thermal energy?
  - **What is heat?**
    - Is it related to temperature or thermal energy?
    - Why does it seem to "flow" from hot objects to cold ones?
  - **What is thermal equilibrium?**
    - Why does heat start flowing, then stop?
  - **Why is this process irreversible?**

Temperature

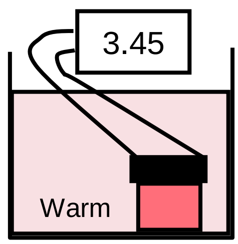
- Let's start by trying to define temperature.
  - Certainly, we all have experience with things that feel "hot" and "cold".
  - We can tell if one object is considerably hotter or colder than another
    - Although sometimes we can be "fooled".
  - Temperature is a way of **quantifying** in a reproducible fashion this concept of "hot" and "cold"
- First, let's define a way to tell if one object is hotter than another.
  - not by how much…just whether object A is hotter than object B)
  - To do this we can develop a "Thermoscope" (not a thermometer…we are not there yet.)
  - A thermoscope relies two important facts:
    -
      - e.g. a metal's resistance to electrical current will usually decrease as the metal gets colder.
    -
  - A good thermoscope:
    -
    -
    -
  - So let's construct our first thermoscope from a metal bar and we connect an ohm meter across the end of the bar.

Thermoscope

- Now we can use the thermoscope on our model processes.
  - First, we put the thermoscope in the water and wait for the resistance on the ohm meter to settle down…this is waiting for our thermoscope to come into thermal equilibrium with the water.
    - Value: 1.20 ohms



  - Now, we put the thermoscope on the hot block (and wait)
    - Value: 3.45 ohms



  - After the block and the water have been together for some time, if we put the thermoscope in the water we get
    - Value: 1.70 ohms (in water)
    - Value: 1.70 ohms (on block)
- The values of the resistance are *related* to the "temperature"…but not the temperature, but we can still state:
- **Zeroth Law of Thermodynamics:**

  A well-defined quantity called temperature exists such that two objects in thermal contact will be in thermal equilibrium if and only if both have the same temperature

Thermometers

- As we have just discussed, the thermoscope we have just constructed does not read *temperature.* We must come up with a definition for temperature.
  - Later we will get a mathematical definition
- The key feature is to define a *standard thermoscope* to which all other thermoscopes are calibratated.
- Standard Thermoscope:
- So the physical quantity that we are measuring here is the pressure of the gas in the cylinder when the gas has a fixed volume.
- We can changes this into a quantitative measurement of temperature by definition a constant of proportionality, C
- Normally, "C" is define by some reference point of some easily producible physical situation:
  - Freezing point and boiling point of water. (Celsius)
  - Modern: Triple point of water (pressure and temperature where, ice, water, and water vapor coexist.)
    - Defined to be 273.15 K (Kelvin)

Thermometers and Temperature

- One good reason that the standard thermoscope was chosen as a constant-volume gas thermoscope is that most gases behave the same under these conditions, especially if the density of the gas is low. So the *technical definition for temperature (when defined in this way):*

- Notice that we get a “zero-point” or “absolute” zero when the pressure goes to zero. Since the pressure can never be negative we cannot have a temperature below 0 K.
- Of course we have two other temperature scales that you probably have experienced.
  - Celsius:

$$T = \left(1\,\tfrac{K}{^\circ C}\right)T_{^\circ C} + 273.15\,\mathrm{K}$$

$$T_{^\circ C} = \left(1\,\tfrac{^\circ C}{K}\right)T - 273.15\,^\circ\mathrm{C}$$

  - Fahrenheit:

$$T_{[F]} = \left(\tfrac{9\,^\circ F}{5\,^\circ C}\right)T_{[C]} + 32\,^\circ\mathrm{F}$$

$$T_{[C]} = \left(\tfrac{5\,^\circ C}{9\,^\circ F}\right)\left(T_{[F]} - 32\,^\circ\mathrm{F}\right)$$

$$T = \left(\tfrac{5\,K}{9\,^\circ F}\right)\left(T_{[F]} - 32\,^\circ\mathrm{F}\right) + 273.15\,\mathrm{K}$$

- We will use Kelvin the vast majority of the time.

Temperature and Thermal Energy

- We want to make one final connection between temperature and thermal energy. We learned this in Unit C.
- If we convert a certain amount of kinetic energy into *thermal (internal) energy,* the temperature of the object rises. The empirical observed change has the following form:

$$dU = mc\,dT \qquad c \equiv \frac{1}{m}\frac{dU}{dT}$$

- Where
  - U = thermal energy
  - M = mass of object
  - c = objects **specific heat**
- This equation is only valid over regions where the specific heat is constant. (e.g. stay away from phase change.)
- If we consider a block sliding along a table, we can still maintain the concept of energy conservation if we assume that the kinetic energy has been stored *inside* the object as internal energy.
  - But how is this energy stored?
  - Why is the temperature linked to thermal energy?
- A Stryrofoam cup, a wood block, and a aluminum cylinder have been sitting on the table. If we touch each one, will they all feel the same temperature? Are they?