Lecture 3
Matter and Energy

Reading: Chapter 4

Reminder: 20min Quiz on Thursday from Lecture 1,2,3.

Goals for learning in Chapter 4

- What's energy?
  - Scientific view
  - Conservation of energy
- What's matter?
  - Atoms
  - Phases
- Understanding energy and matter is crucial to understanding the Universe.

Units of Energy

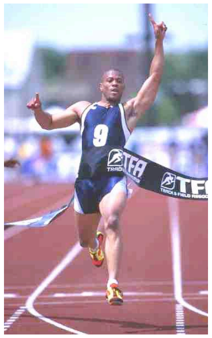
- Perhaps the most familiar units of energy in daily life is *Calories*.
  - A typical male adult uses about 2,500 Calories of enegy each day.
- In science, we use *Joules*.
  - 1 Calorie = 4,184 Joules
- *Watts* are the units of energy (measured in joules) consumed per second.
  - 1 Watt = 1 Joule per second
  - 40-watt light bulbs consume 40 joules per second, or about 1/105 calories per second.
  - Therefore, in order to consume the enegy used by a male each day, you will need to turn on a 40-watt bulb for about 260,000 seconds, or 3 days!

Forms of Energy

- Kinetic Energy : Energy of Motion
- Thermal Energy : Energy of Heat
- Potential Energy : Energy of Force
  - Gravitational
  - Electric
  - Magnetic
- Mass Energy : Energy of Stuff
  - Einstein's formula

Kinetic Energy

- The faster, the heavier… the more energy!
  - Kinetic Energy of a moving object is given by a half of its mass times (velocity of motion)^2
  - $E_{kinetic} = (1/2)\ m\ v^2$
- Maurice Greene: weighs 80kg(=m), runs 100m for 9.79 sec
  - His velocity is calculated as
    v = 100m/(9.79 sec) = 10.2m/sec
  - Now we know his *mass* and *velocity*; thus, his kinetic energy is
    $E_{kinetic}$ = (1/2)*80*(10.2)^2 = 4160 Joules ~ 1 Calorie
  - If he could run twice as faster, then his kinetic energy would be A: 2, B: 4, C: 8 times larger.



Thermal Energy

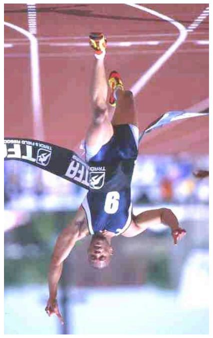
- What's causing heat?
  - A: Thermal energy
- Example: Air
  - The air contains numerous microscopic particles, each having its own mass and velocity and moving randomly -- each has kinetic energy of $E_{kinetic}=(1/2)m\ v^2$
  - The *average* kinetic energy of particles determines temperature of the air.
  - The higher the temperature, the faster the particles move in the air.
- Thermal energy is simply the sum of kinetic energy of all particles. Suppose that there are N particles: $E_{thermal} = N\ E_{kinetic} = (1/2)N\ m\ v^2$

Temperature and Heat

- Temperature measures the *average* kinetic energy. So, if 10 particles had the same kinetic energy E_1, then temperature would also be given by E_1.
- Heat is, on ther other hand, given by **thermal energy**, or the *total* kinetic energy of all particles. Therefore, heat is given by 10E_1 as opposed to E_1.
- Using this fact, the book explains why boiling water could be more dangerous than a cooking oven.

Potential Energy

- When forces act on a substance, it acquires *potential energy*.
- Example: gravitational force acting on a ball (mass m) at height h from the ground.
- $E_{gravity} = m\ g\ h$
  - g is the *gravitational acceleration*.
  - g = 9.8 m/s^2 on Earth
- Maurice Greene (80kg=m) falls from the top of 5-m(=h) high building (oops!)
  - $E_{gravity} = m\ g\ h$ = 80*9.8*5 = 3920 Joules ~ 1 Calorie
  - If he had fallen from 10-m high building (oooops!), then potential energy would be A: 2, B: 4, C: 6 times larger.



Potential --> Kinetic Energy

- As Maurice Greene falls, he acquires speed. The potential energy is converted to the kinetic energy!!
  - When he hits the ground, the potential energy is zero (because height, *h*, is zero).
  - Where did the energy go?
- All the energy was converted into the kinetic energy: Before he fell from the 5-m building, he had about 1 Calorie of potential energy. By the time he hits the ground, he has converted 1 Calorie of potential energy into 1 Calorie of kinetic energy; thus, he hits the ground at velocity of 10m/s, as if he were running 100m at his best time.
  - The conversion and conservation of energy explain many physical phenomena. (The book -- throwing a ball…)

Mass Energy

- You've got enormous energy!
  - $E_{mass} = m\ c^2$
  - c = 300,000,000 meter per second (m/s)
- *Compare it to:*
  - $E_{kinetic}=(1/2)m\ v^2$
  - for Mr. Greene's best speed, $v \sim 10$ m/s
- Since velocity of light is so large, the mass energy is enormous: some 60,000,000 times larger for Mr. Greene.
- A small mass can be a gigantic source of energy.

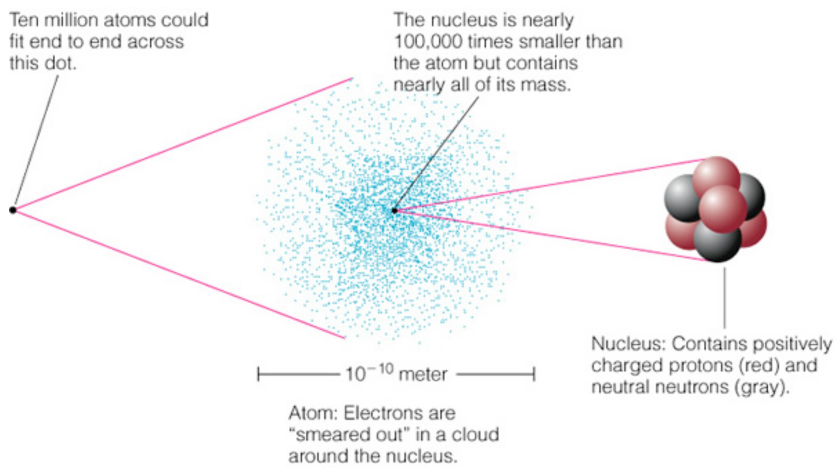
Ultimate source of energy, or Disaster…?

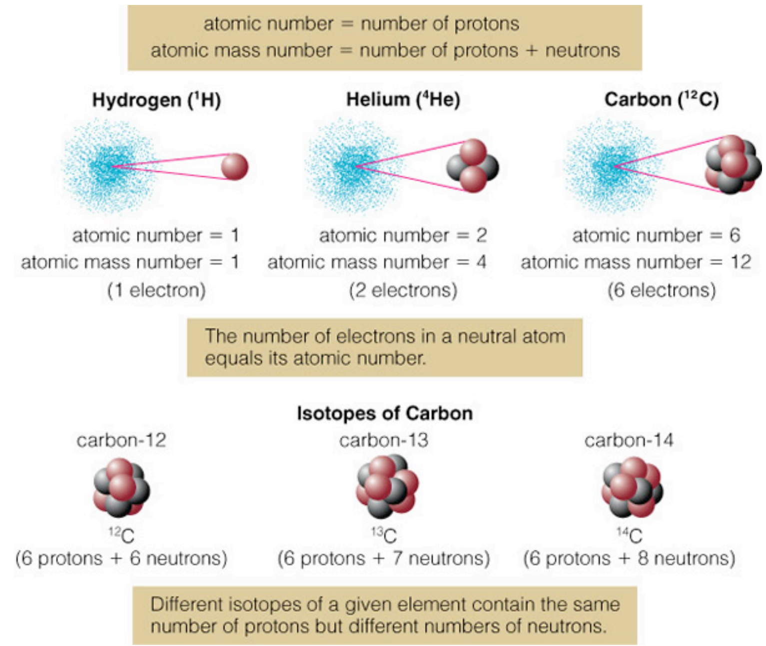
- Applications of the mass energy includes:
  - Nuclear fission ---> Nuclear power plants
  - Nuclear fusion ---> Atomic bombs
- It's Einstein's finding. How do you think he felt about his finding after Hiroshima?
- Stars shine by energy from nuclear fusion. It is $E_{mass} = m\ c^2$ that makes stars shine.

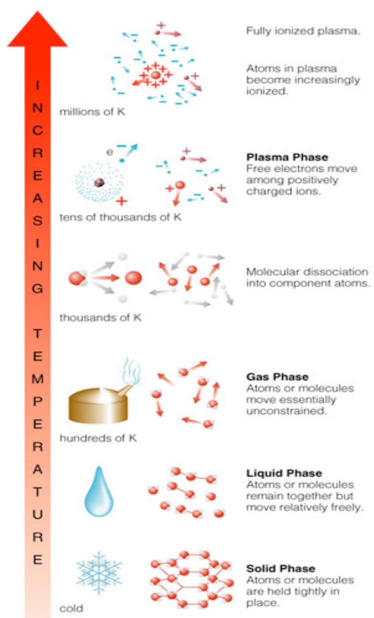
The Material World

- Matter in different *phases*:
  - Solid
  - Liquid
  - Gas
  - Plasma
- Why are there such phases?
  - Atomic structure
  - Thermal energy

Atomic Structure: Protons(+), Neutrons(0), Electrons(-)







- At a *solid phase*, molecules are held tightly together (low thermal energy).
- As temperature is raised, the thermal motion of molecules within a solid becomes more active, partially breaking bond between molecules --> a *liquid state* (medium thermal energy).
- A liquid state becomes a *gas state* for higher temperature (high thermal energy).
- A gas state becomes a *plasma state* for very high temperature. Even atoms are broken up into protons, neutrons and electrons.

Phase transition ain't instantaneous

- Evaporation and Sublimation
  - Atoms and molecules are always trying to free themselves up!
  - Constant escape of molecules from a solid: *sublimation*
  - Constant escape of molecules from a liquid state: *evaporation*

20min Quiz on Thursday

- 11 Multiple-choice Problems
  - you choose the right answer from multiple choices (a) through (d). Problems will be chosen from "*Does It Make Sense?"* at the end of each chapter. Make sure that you know not only "yes" or "no", but also why it is "yes" or "no". (There will be two "yes" and two "no" in multiple choices!)
  - 3 problems from Chapter 1
  - 4 problems from Chapter 2
  - 4 problems from Chapter 4
- 2 Short-answer Problems
  - you answer in short sentences.
  - 1 problem from Chapter 2 on *eclipses.*
  - 1 problem from Chapter 4 on *conservation of energy*.