ESCI 241 – Meteorology
Lesson 2 – Thermodynamics

References: ***Meteorology Today*****, Ahrens**

Reading: MT – Chapter 2

ENERGY

- **Energy is *the capacity to do work*.**
- **Two main types of energy**
  - ***Potential energy* – stored energy**
    - **Example: In a gravitational field, $PE = mgh$.**
  - ***Kinetic energy* – energy of motion**
    - $KE = \frac{1}{2}mv^2$
- **Other types of energy**
  - ***Thermal energy* – total of the kinetic energy of all the molecules in a substance**
  - ***Internal energy (U)* – the sum of thermal energy and any potential energy due to the forces between the molecules of a substance.**
    - **Note that for an ideal gas, since there are no intermolecular forces, there is no potential energy between molecules. Therefore, *for an ideal gas, internal energy and thermal energy are identical!***
- **Energy is conserved**
  - **Energy can be converted from one form to another, but it cannot be created nor destroyed.**

TEMPERATURE

- **Temperature is related to the average kinetic energy of the molecules of a substance, $T \propto KE$.**
- **Hot objects have faster moving molecules. Cold objects have slower moving molecules**
- **Heat is energy that is in the process of being transferred from one object to another due to temperature differences.**

TEMPERATURE SCALES

- **Temperature scales are rather arbitrary. Meteorologists use three different scales.**
- **Fahrenheit (°F)**
  - **Zero point was determined by the lowest temperature that could be achieved with a mixture of ice, water, and salt.**
  - **100° point was determined by the rectal temperature of a cow (Callen, 1985).**
  - **Water freezes at 32°F, and boils at 212°F.**
- **Celsius (°C)**
  - **Zero point determined by freezing point of water**
  - **100° point corresponds to boiling point of water.**
  - **Conversion from Celsius to Fahrenheit**

$$F = \frac{9}{5}C + 32$$

- **Kelvin (K)**
  - **Referred to as the *absolute* temperature scale**
  - **Zero point determined by the lowest temperature to which any matter can be cooled (*entropy, not energy, is zero*).**
  - **Degree interval is same as in Celsius**
  - **Conversion from Kelvin to Celsius**

$$C = K - 273.15$$

FIRST LAW OF THERMODYNAMICS

- **Energy is conserved.**
- **The internal energy (*U*) of an air parcel can be changed by either heating the parcel (*Q*) the parcel, or by doing work (*W*).**

$$\Delta U = Q + W$$

  - **Positive work implies work being done *on* the air parcel, whereas negative work implies work being done *by* the air parcel.**
- **An expanding air parcel does work on its environment. Therefore, *an expanding air parcel will lose internal energy, and cool*.**

- **Conversely, a shrinking air parcel has work done on it by the environment. Therefore, *a shrinking air parcel will gain internal energy, and warm*.**

SENSIBLE HEAT AND HEAT CAPACITY

- **Sensible heat results in a change of temperature.**
- **The amount of heat required to raise the temperature of an object by 1°C is called the *heat capacity, C*.**
  - ***Heat capacity depends on both the amount and type* of the substance**
  - **Units of heat capacity are J-K^{-1}**
- **The heat capacity will depend on whether the pressure or volume changes during the heating.**
  - **If pressure is held constant, then the heat capacity is denoted as *Cp*.**
  - **If volume is held constant, then the heat capacity is denoted as *Cv*.**
- **Heat capacity per unit mass is called the *specific heat***

$$c_v = C_v / m$$
$$c_p = C_p / m$$

  - **Units of specific heat are J-kg^{-1}-K**

PHASE CHANGES AND LATENT HEAT

- **The amount of heat required to change the phase of a unit mass of a substance is called the *latent heat*.**
  - **The amount of latent heat depends on the substance and the process. The processes are:**
    - ***Melting* – solid to liquid, absorbs heat**
    - ***Freezing* – liquid to solid, releases heat**
    - ***Evaporation* – liquid to vapor, absorbs heat**
    - ***Condensation* – vapor to liquid, releases heat**
    - ***Sublimation* – solid to vapor, absorbs heat**
    - ***Deposition* – vapor to solid, releases heat**
- **Latent heating is an important heat source and sink for the atmosphere.**

HEAT TRANSFER

- **Heat can be moved or transported in one of three ways**
  - ***Conduction* – Transfer of heat through physical contact**
  - ***Convection* – Transfer of heat through movement of fluid**
    - **In Meteorology, the term convection is used solely for vertical transport by a fluid. Horizontal transport is referred to as *advection*.**
  - ***Radiation* – Transfer of heat through electromagnetic waves**

EXERCISES

1. The specific heat of water at constant pressure is 1 cal-g^{-1}-°C^{-1}.

a. What is the heat capacity at constant pressure of 2 kg of water?

b. How much energy must be added to 2 kg of water to increase the temperature by 3°C?

2. How much heat is released by the condensation of 3 kg of water vapor? (The latent heat of vaporization is 600 cal-kg^{-1}.)

3. A 3 kg block of aluminum has a heat capacity (constant pressure) of 2691 J-K^{-1}. A 0.5 kg block of beryllium has a heat capacity (constant pressure) of 912 J-K^{-1}. Which one has a higher specific heat at constant pressure?

4. A 1.5-kg parcel of dry air is at a temperature of 15°C and a pressure of 1013 mb.

a. How many moles of air are in the parcel? (The molecular weight of air is 28.96 g/mol)

b. What is the volume of the parcel?

c. If 50 KJ of heat are added to the parcel while its volume is held constant, what is the new temperature of the parcel? (The specific heat of air at constant volume is 717 J-kg^{-1}-K^{-1}).

d. If 50 KJ of heat are added to the parcel while its pressure is held constant, what is the new temperature of the parcel? (The specific heat of air at constant pressure is 1005 J-kg^{-1}-K^{-1}).