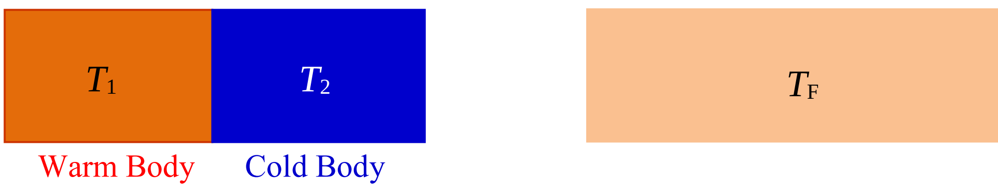
ASME231 Atmospheric Thermodynamics NC A&T State U
Department of Physics Dr. Yuh-Lang Lin
http://mesolab.org ylin@ncat.edu

Lecture 6 Heat

(Ch. 3 First Law of Thermodynamics
(3.2a Heat)

Consider the following system:

Initial State (T_1, T_2) Final State (T_F)



$T_1 > T_2$ $T_1 > T_F > T_2$

The energy which exchanged from the warm body to the cold body is called heat.

The amount of heat loss by the warm body is proportional to the temperature difference between the initial and the final states of that body:

$$-\Delta Q = C_1(T_F - T_1) \tag{3.5}$$

Similarly, the amount of heat gained by the cold body is proportional to T_F-T_2,

$$\Delta Q = C_2(T_F - T_2) \tag{3.6}$$

where C_1 and C_2 are called heat capacities of the two these bodies.

The amount of heat gained by the cold body must be the same as the amount of heat lost by the warm body. Adding (3.5) and (3.6) gives

$$C_1(T_F - T_1) + C_2(T_F - T_2) = 0 \tag{3.7}$$

From Eq. (3.5), we have

$$C_1 = \frac{-\Delta Q}{(T_F - T_1)} = \frac{-\Delta Q}{-(T_1 - T_F)} = \frac{\Delta Q}{\Delta T_1}$$

where $\Delta T_1 = T_1 - T_F$. Thus, C_1 is the heat loss by body 1 (warm body) lost per degree K.

Similarly, C_2 can be derived from Eq. (3.6),

$$C_2 = \frac{\Delta Q}{(T_F - T_2)} = \frac{\Delta Q}{\Delta T_2}$$

where $\Delta T_2 = T_F - T_2$. Thus, C_2 is the heat gained by body 2 (cold body) gained per degree K.
Clearly, as ΔT_1 and ΔT_2 approach 0, T_1, T_2 and T_F approach to the same value. In other words, we have

$$C_1 = \lim_{\Delta T_1 \to 0} \frac{\Delta Q}{\Delta T_1} = \lim_{\Delta T_2 \to 0} \frac{\Delta Q}{\Delta T_2} = C_2 = \left.\frac{dQ}{dT}\right|_{T=T_F}$$

Thus, we can define the heat capacity at temperature T as,

$$C = \frac{dQ}{dT} \tag{3.8}$$

Divide (3.8) by mass m, we get the expression for specific heat capacity,

$$c = \frac{dq}{dT} \tag{3.9}$$

where $q=Q/m$, $c=C/m$. The unit for the specific heat is $J\,K^{-1}\,kg^{-1}$.

If the transformation process from T_1 to T_F is isobaric, the specific
heat is called the specific heat at constant pressure:

$$c_p = \left(\frac{dq}{dT}\right)\bigg|_p .$$

Similarly, if the transformation process is isosteric, the specific heat is called the specific heat at constant volume:

$$c_v = \left(\frac{dq}{dT}\right)\bigg|_v .$$

For example,

For water vapor, $c_v = 1463\ J\,kg^{-1}\,K^{-1}$, $c_p = 1952\ J\,kg^{-1}\,K^{-1}$.
For dry air, $c_v = 717\ J\,kg^{-1}\,K^{-1}$, $c_p = 1004\ J\,kg^{-1}\,K^{-1}$.

Note that:
(a) In general $c_p > c_v$.

This may be explained by considering the piston-cylinder system. The amount of heat needed to heat the air in the cylinder with a constant pressure (c_p) is larger than that with a constant pressure (c_v) because part of the heat is used to do work of expansion on the environment.

(b) c_p and c_v are temperature dependent

Strictly speaking, an exact value of c_p or c_v only applies to the condition of a certain temperature. However, for gas (e.g., air and water vapor), the difference for different temperatures is small. Thus, normally we just use the constant values as shown above.

(c) Heat has a unit of *Joule* (*Nm* or kgm^2s^{-2})

It is the same as work and energy. Sometimes heat is measured by calorie, which is defined as the quantity of heat needed to raise the temperature of 1 gram of pure water from 14.5 ^oC to 15.5 ^oC. The relation between J and calorie is 1 calorie = 4.186 J.