Thermodynamics
General
Lecture 2

Heat, thermal heat, heat capacity, sensible heat, and latent heat
(Read pages 526-538 in Physics for Scientists and Engineers (Third Edition) by Serway)

I. Historical background
A. Heat was thought to be an invisible weightless fluid called a "caloric" that was produced when a substance was burned and which could be transmitted by conduction from one body to another. Some thought that the caloric was explained by matter being repeatedly subdivided: matter's capacity for retaining caloric grew smaller and the caloric was released. However, it was found that the so called caloric could be produced even when matter was not being sub-divided. Said another way, there seemed to be an inexhaustible supply of caloric as long as mechanical work was done. The idea of conservation was lost. Mechanical energy seemed not to be conserved (as it was understood) and the caloric was not conserved as it was continually being created.
B. Today, we have one not two conservation principles: the conservation of energy. Mechanical energy can be continually transformed into heat. Heat is considered as just one of the forms of energy.

II. Review of Energy and Work
A. Energy is any quantity of dimensions M L^2/T^2. There are various forms of energy including kinetic energy, gravitational potential energy, internal energy, heat, work, radiant energy, enthalpy, Gibbs, Helmholtz, etc. For our purposes we might same that energy is a quantity that permits work to be done or heat to flow (which, admittedly is a dangerous statement as heat and work are forms of energy).
B. The work done by a system is product of the force applied and the resultant displacement (eg. W = F cosθ * l, where W is work, F is force and l is displacement.
   a. Draw a diagram
   b. Work is only done on the surface of a system. More later.
C. Kinetic energy (KE)
   1. Kinetic energy is the energy of motion in a body.
   2. KE = 1/2 mV^2
      a. m is mass, and V is velocity
   3. A description of work without explicitly showing acceleration for a body moving a frictionless surface
      a. a = (V_f + V_i) / (t_f + t_i)
      b. If t_i = 0 then V_f = V_i + a t_f
      c. With constant acceleration V = 1/2 (V_f + V_i) and l = V t
      d. l = 1/2 (V_f + V_i) t
      e. Substituting t from V_f = V_i + at_f into l = 1/2 (V_f + V_i) t_f
      f. l = (V_f + V_i) (V_f - V_i) / (2a)
      g. l = (V_f^2 - V_i^2) / (2a)
h. So $V_f^2 = V_i^2 + 2a\,l$

i. With $F = ma$ and $V_f^2 = V_i^2 + 2a\,l$

j. $W = ma\,\frac{(V_f^2 - V_i^2)}{2a} = \frac{1}{2}mV_f^2 - \frac{1}{2}mV_i^2$

k. Neither $F$ nor $l$ appears in the expression for work. Only mass and initial and final velocities are used. The only work done is that to increase the speed of the object.

l. When a body is caused to move along a frictionless surface and no work is done except to increase the body's speed the work done is equal to the change in KE.

m. The kinetic energy is arbitrary to a reference (e.g., relative to earth's velocity through space and rotational velocity).

D. Potential energy (PE)
1. Potential energy is the energy of position. Gravitational potential energy is given by $PE = mgz$, where $z=0$ is the reference level.
   a. weight $(w)$ is given by $mg$
   b. There is also potential energy owing to electrical, magnetic, etc. properties.

2. A description of work without explicitly showing lifting a body through a frictionless environment.
   a. $W = mg\,(z_f - z_i)$
   b. $W = \,w\,(z_f - z_i)$
   c. The only work done is that to raise the center of gravity or the change in gravitational potential energy.
   d. The potential energy is arbitrary to a reference (e.g., a reference height).

III. Heat and thermal energy.

A. Heat ($Q$)
1. Heat is not a thermodynamic property.
   a. Just as it is wrong to speak of work in a body it is wrong to speak of heat in a body.

2. Heat is intangible. The quantity of heat involved in a process is measured by some change in a process.

3. Heat is involved with bringing about thermal equilibrium as work is involved with bringing about mechanical equilibrium. ($Q\rightarrow TE$ and $W\rightarrow ME$)

4. Heat is the flow of energy - a non-mechanical energy transfer of energy - brought about by a temperature difference between two bodies.
   a. When flow of energy ceases thermal equilibrium is reached.
   b. Heat is an energy transfer owing to temperature differences only
   c. Heat results from the flow of energy from a warmer system to a cooler system. (Heat appears only during a change of state.)
   d. Heat flows through boundaries.
   e. Heat only appears at boundaries of a system.
   f. Heat is positive if a system is cooled (heat flows from a warm system to a cooler environment). Heat is negative if a system warms (heat flows from a warm environment to the cooler system).

5. Heat is path dependent. The amount of heat depends on the different incremental changes to a system.
6. To distinguish between heat and temperature, consider equally heating two containers, one with more water than the other. The container with less water would have a higher temperature (if boiling did not occur in either container). Thus, while equal amounts of heat were applied to the two containers, the temperature change in each was different.

7. The SI unit of heat is the Joule. (1J is 1kg m^2 s^-2)

B. Internal energy (U)

1. It is important to remember that energy can be transferred when there is no heat flow. The text uses the example of rubbing two objects together. Their internal energy (U) increases owing to mechanical work done. Kinetic energy is transformed into internal energy contained in the objects. The changes in internal energy are measured by changes in temperature.

2. From an atomic view, internal energy of a body is the sum of kinetic energy (mean speed) and potential energy (configuration) of its molecules and atoms (translation, rotation, vibration). (Valid at low pressures.)

3. A method is defined of measuring changes in U, not in U itself. There is no standard reference for U.
   a. An unambiguous volume can be defined for a substance but not for internal energy.
   b. Only changes in U with reference to a transition from one to another configuration of a system are considered.

4. The internal energy is given as the heat absorbed minus the work done.
   a. \( \Delta U = \Delta Q - \Delta W \)
   b. The U is a NOT path dependent. U only depends on initial and final states. \( \Delta U \) is an exact differential.
      i. definitions of an exact differential:
         • A linear differential expression containing two variables of the form of \( dL(x,y) = M(x,y)dx + N(x,y)dy \)
           is an exact differential if there exists a function \( f(x,y) \) so that \( df(x,y) = dL(x,y) \).
         • If \( dL \) is an exact differential, the line integral (integral over a path), \( \int L(x,y) \), depends only on initial and final states and not on the path between them.
         • If \( dL \) is an exact differential, the line integral over a closed path is zero: \( \int L(x,y) = 0 \)
         • In thermodynamics, if a function \( dJ \) is exact, \( J \) is a thermodynamic property!
   c. An example of when work is an exact differential is an adiabatic process; heat is an exact differential for an isovolumetric process

5. As an example of misuse of the word heat energy, we hear that internal energy is the heat energy of a body. However, could you tell whether a sample of hot air was heated by compression or heat flow from another body? The answer is no!

C. Mechanical equivalent of heat.

1. As hinted at above, when the friction is present in a mechanical system, some of the mechanical energy is lost (not conserved). This energy loss does not disappear but is transformed into thermal energy.
   a. One of Joule's Experiment.
      i. potential energy used to heat water.
   b. 1 calorie = 4.186 J
c. One-Kilogram calorie is the quantity of heat that must be supplied to one kg of water to raise its temperature 1 deg C (between 14.5 and 15.5 deg C).

D. Introduction to Heat Capacity and Specific Heat
1. Heat capacity (C) is the heat change per temperature change.
2. Specific heat (c) is heat capacity / mass
   a. $c = C/m$ where $m$ is mass
3. Molar heat capacity is
   a. $c = C/n$ where $n$ is the number of moles
   b. Heavier molecules should be expected to have larger specific heats for ideal gases.
4. The heat capacity of a substance depends on how the substance is heated. More on this later (e.g., at constant pressure or constant volume)
5. At constant volume, as heat is acquired, heat capacity C is
   a. $dQ = C \, dT$
   b. $dQ = dU$ (definition of internal energy)
   c. $C = dQ/dT = dU/dT$

E. Sensible heat
1. Sensible heat describes the transfer of energy that causes changes in temperature in system.
   a. At the ocean-air interface, sensible heat is the transfer of energy that directly warms or cools the ocean or air through conduction, convection, etc.

F. Latent heat
1. There are instances when heat flow does not result in the change in the temperature of a system even though there is a temperature difference between the system and its environment.
   a. This type of heat flow occurs when there is a change in the phase of substance or loosely the molecular organization of a substance. (Explain the following in terms of amount of work required for molecular rearrangement.)
      i. vapor to liquid (evaporation/condensation)
      ii. vapor to solid (deposition/sublimation)
      iii. liquid to solid (freezing/melting)
   b. Phase changes involve a change in the internal energy of a substance. The energy required for the phase change is called the heat of transformation or latent (hidden) heat.
   c. Computation of net heat to convert 1g of ice (solid) at -30°C to steam (vapor) at 120°C. $ci = 2090 \text{ J/(kg°C)}$ and $cw = 4190 \text{ J/(kg°C)}$ and $cv = 2010 \text{ J/(kg°C)}$ (approximate)
      i. change temperature of ice from -30°C to 0°C
         $Q = m \, ci \, dT = 1.0 \times 10^{-3} \text{ kg} \times 2090 \text{ J/(kg°C)} \times 30°\text{C}$
         $= 62.7 \text{ J}$
      ii. melt ice at 0°C
         $Q = m \, Lf = 1.0 \times 10^{-3} \text{ kg} \times 3.33 \times 10^5 \text{ J/(kg)}$
         $= 333 \text{ J}$
      iii. change temperature of liquid from 0°C to 100°C
         $Q = m \, cw \, dT = 1.0 \times 10^{-3} \text{ kg} \times 4190 \text{ J/(kg°C)} \times 100°\text{C}$
         $= 419 \text{ J}$
iv. change liquid to vapor at 100°C
   \[ Q = m \cdot L_v = 1.e^{-3}\text{kg} \cdot 2.26e^6 \text{J/(kg)} \]
   \[ = 2260\text{J} \]

v. change temperature of vapor from 100°C to 120°C
   \[ Q = m \cdot c_v \cdot dT = 1.e^{-3}\text{kg} \cdot 2010 \text{J/(kg°C)} \cdot 20\text{°C} \]
   \[ = 40.2\text{J} \]

vi. Total heat input is 3110 J.

vii. Latent heat input is 2593 J.