In thermodynamics, we defined heat transfer as the flow of energy across a system boundary due to a temperature difference between the system and its surroundings. It is a boundary phenomenon and is thus completely dependent on how we choose our system boundary. It would be incorrect, therefore, to say that a system contains heat, just as it would be incorrect to say that a system contains work, which is another boundary phenomenon.

Consider, for example, two metal cubes, one hot and the other cold, which are brought into contact with one another. If either block is chosen to be the system we are analyzing, then we would say that heat is transferred from one block to the other. If both blocks are taken to be within the system boundaries, however, no heat transfer occurs! Instead, we would say there was a redistribution of thermal energy within the system. No energy crossed the system boundary.

In thermodynamics, the arbitrary sign convention we used was as follows: Heat flowing from the surroundings into the system was taken to be positive. In heat transfer courses, the sign convention is different. We arbitrarily choose positive directions for our coordinate system, and thermal energy flowing in these directions is taken to be positive.

There are three modes of heat transfer: conduction, convection and radiation. In conduction heat transfer, energy flows through a medium (solid, liquid or gas) by virtue of a temperature gradient within the medium. The rate of heat transferred (Watts or BTU/s) can be calculated using Fourier's law of conduction, which is given by

$$q_x = - kA \frac{dT}{dx},$$

where q_x is the rate of heat transfer by conduction in the positive x direction,
  k is the thermal conductivity (a material property readily found in handbooks) with
  units of BTU/s-ft-R or W/m-K,
  A is the area perpendicular to the x direction through which heat is being conducted,
  $\frac{dT}{dx}$ is the temperature gradient in the x direction.

The negative sign is there to make heat flow positive in the positive x direction, since dT/dx is negative (temperature must fall in the positive x direction).

Convection heat transfer occurs when thermal energy is transported away from or into the system boundary by a moving medium. An example of this is cold water flowing through the hot tubes of a heat exchanger. The energy is first conducted from the tube walls into the colder liquid, and then transported by the bulk motion of the liquid. The rate of heat transferred can be calculated using Newton's law of cooling (the convection equation), which is given by

$$q = hA(T_s - T_\infty),$$

where q is the rate of heat transferred by convection to or from the surface,
  h is the convective heat transfer coefficient with units of $\frac{BTU}{s\ ft^2\ R}$ or $\frac{W}{m^2\ K}$,
  A is the area from which heat is being transferred,
  T_s is the temperature of the surface,
  T_∞ is the free-stream temperature.

The convective heat transfer coefficient h depends on both the properties of the fluid and the nature of the flow (laminar, turbulent, etc.). For simple geometries, h can be calculated analytically, but in most cases it is determined experimentally. Determination of an appropriate value for convective heat transfer coefficient represents the greatest uncertainty in the calculation of heat transfer rates due to convection.

Radiant heat transfer is the transport of energy by electromagnetic radiation. Unlike conduction and convection, radiation heat transfer does not require a medium (for example, the sun heats the earth by radiation which travels through empty space). The Stefan-Boltzmann Law for heat transferred by radiation from a surface is given by

$$q_r = \varepsilon A \sigma T^4,$$

where q_r rate of heat transferred by radiation from the surface (W),
   ε is the emissivity (a dimensionless material property),
   A is the area from which heat is being transferred (m^2),
   σ is the the Stefan-Boltzmann constant($\sigma = 5.67\text{E-}8 \; \dfrac{W}{m^2 K^4}$),
   T is the absolute temperature (K) of the surface.

Other forms of this equation handle the net heat exchange due to radiation between two surfaces at different temperatures. This mode of heat transfer acts in parallel with the other two, but can frequently be neglected.