Chapter 2

Energy and the First Law of Thermodynamics Continued-3

Modes of Heat Transfer

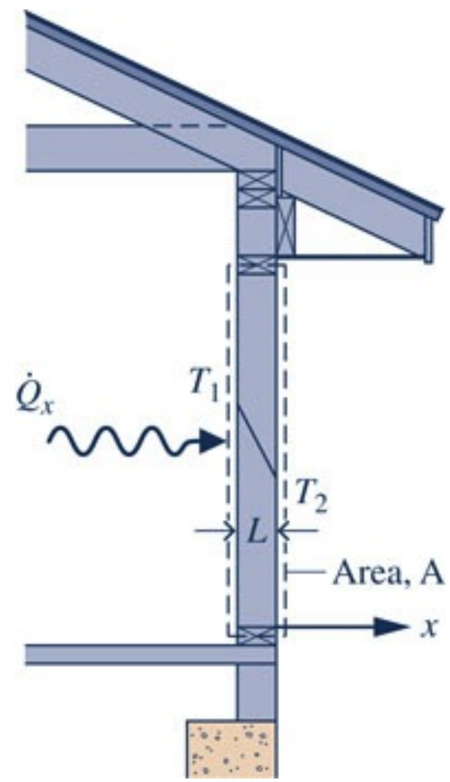
- For any particular application, energy transfer by heat can occur by one or more of three modes:
  - conduction
  - radiation
  - convection

Conduction

►Conduction is the transfer of energy from more energetic particles of a substance to less energetic adjacent particles due to interactions between them.

►The time rate of energy transfer by conduction is quantified by *Fourier's law*.

►An application of Fourier's law to a plane wall at steady state is shown at right.



Conduction

► By **Fourier's law**, the rate of heat transfer across any plane normal to the x direction, $\dot{Q}_x$, is proportional to the wall area, A, and the temperature gradient in the x direction, dT/dx,

$$\dot{Q}_x = -\kappa A \frac{dT}{dx}$$

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$$\dot{Q}_x = -\kappa \mathrm{A} \frac{dT}{dx} \qquad \textbf{(Eq. 2.31)}$$

where

► κ is a proportionality constant, a property of the wall material called the **thermal conductivity**.

► The **minus sign** is a consequence of energy transfer in the direction of decreasing temperature.

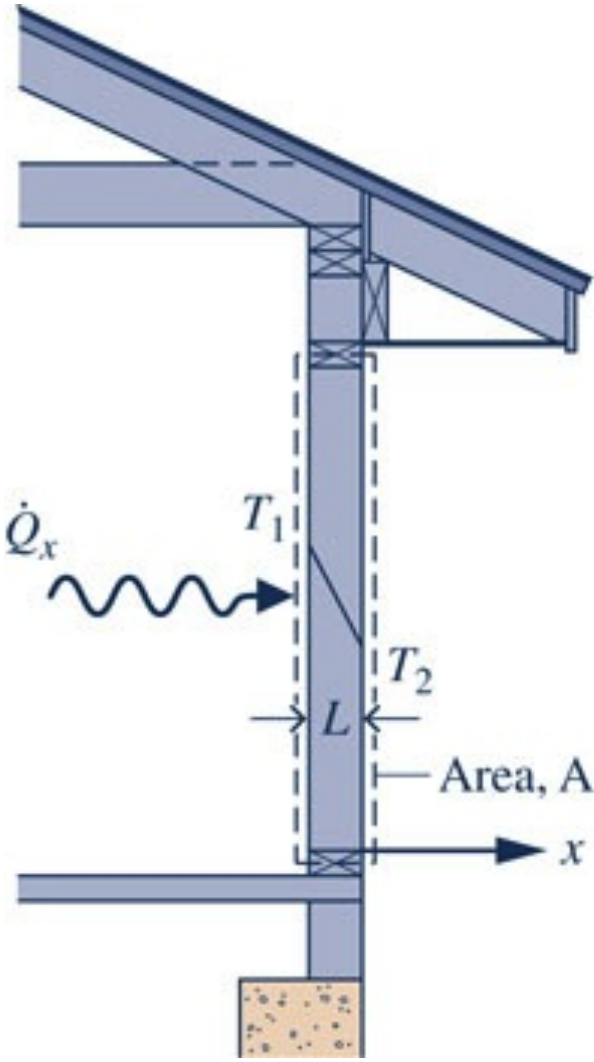
► In this case, temperature varies linearly with x, and thus

$$\frac{dT}{dx} = \frac{T_2 - T_1}{L}$$

and **Eq. 2.31** gives

$$\dot{Q}_x = -\kappa \mathrm{A}\left[\frac{T_2 - T_1}{L}\right]$$

Conduction



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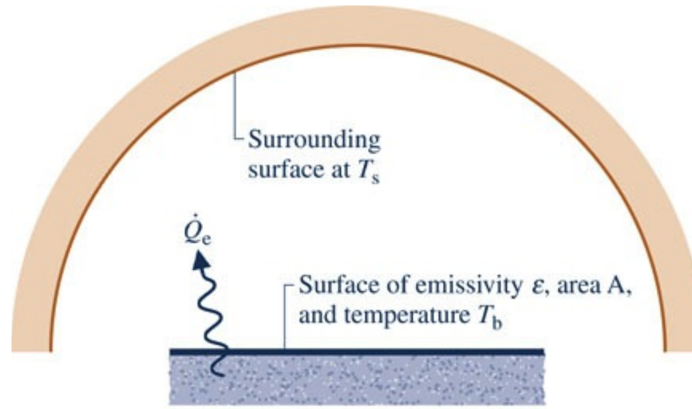
Thermal Radiation

- Thermal radiation is energy transported by electromagnetic waves (or photons). Unlike conduction, thermal radiation requires no intervening medium and can take place in a vacuum.
- The time rate of energy transfer by radiation is quantified by expressions developed from the *Stefan-Boltzman law*.

Thermal Radiation

►An application involving net radiation exchange between a surface at temperature T_b and a much larger surface at T_s (< T_b) is shown at right.



►Net energy is transferred in the direction of the arrow and quantified by

$$\dot{Q}_e = \varepsilon \sigma A [T_b^4 - T_s^4] \qquad \textbf{(Eq. 2.33)}$$

where

►**A** is the **area** of the smaller surface,

►ε is a property of the surface called its **emissivity**,

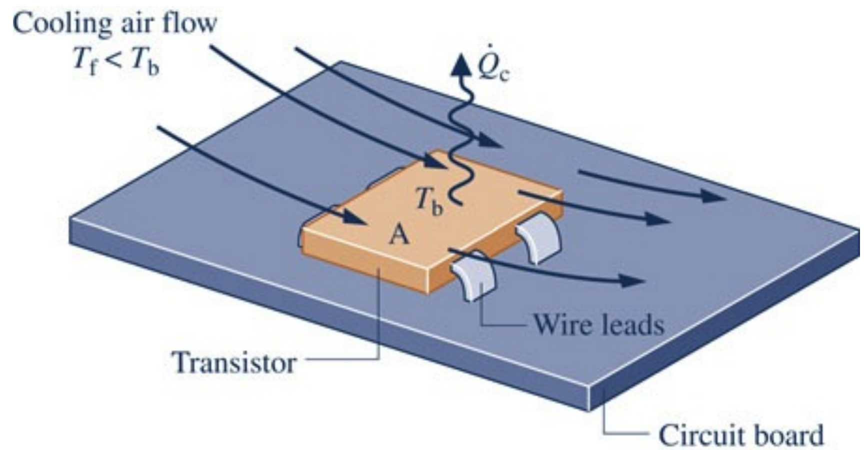
►σ is the **Stefan-Boltzman constant**.

Convection

- Convection is energy transfer between a solid surface and an adjacent gas or liquid by the combined effects of conduction and bulk flow within the gas or liquid.
- The rate of energy transfer by convection is quantified by *Newton's law of cooling*.

Convection

►An application involving energy transfer by convection from a transistor to air passing over it is shown at right.



►Energy is transferred in the direction of the arrow and quantified by

$$\dot{Q}_c = hA[T_b - T_f]$$ **(Eq. 2.34)**

where

►**A** is the **area** of the transistor's surface and

►***h*** is an empirical parameter called the **convection heat transfer coefficient**.