Phys 111: Lecture 26

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The 26th Day: "Cryonis Rune Transfer Complete"

Homework Wk #13 Due Today

Today's Topics

1. Specific Heat
2. Heat Transfer Methods
3. Applications

Motivation

Why is aluminum or tin foil used when cooking with an oven or bbq?

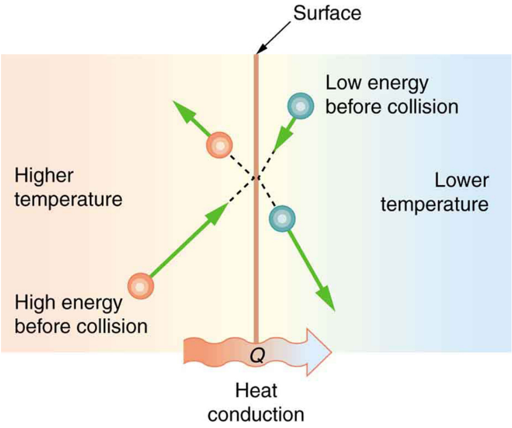

Figure: 26.1 Collision model of heat transfer[1]

[1] OPSTX College Physics Figure 14.14

Specific Heat Capacity

Specific Heat Capacity (c) is a measure of how much heat (Q) is required to change the temperature (ΔT) of an object of a given amount of mass (m).

$$c = \frac{\left(\frac{Q}{\Delta T}\right)}{m}$$

We simply write the fraction as

$$c = \frac{Q}{m\Delta T}$$

Specific Heat Capacity Continued

Often, the discussion is focused on how much heat is required to change the temperature of a given material sample:

$$Q = mc\Delta T$$

Alternatively, how much heat must have been added or subtracted for a recorded temperature change.

Units:

$$\frac{J}{^\circ C \cdot kg} \qquad or \qquad \frac{cal}{^\circ C \cdot g}$$

Exercise #1

C&J 12.44 Blood can carry excess energy from the interior to the surface of the body, where the energy is dispersed in a number of ways. While a person is exercising, $0.6\ kg$ of blood flows to the body's surface and releases $2000\ J$ of energy. The blood arriving at the surface has the temperature of the body's interior, $37.0°C$. Assuming that blood has the same specific heat capacity as water, determine the temperature of the blood that leaves the surface and returns to the interior.

Exercise #1 Translation

C&J 12.1 Calculate the approximate temperature of the blood at the body's surface (T_f) by approximating the specific heat capacity of blood to be the same as water ($4,186\ J/(^\circ C \cdot kg)$) for a blood mass of $0.6\ kg$ and an initial temperature of $T_o = 37^\circ C$ for a heat loss of $2000\ J$.

$$Q = mc\Delta T$$

$$\Delta T = \frac{Q}{mc}$$

Exercise #1 Answer

C&J 12.1 $c = 4186\ J/(^\circ C \cdot kg)$, $m = 0.6\ kg$, $T_o = 37^\circ C$

$$T_f - T_o = \frac{Q}{mc}$$

$$T_f = \frac{Q}{mc} + T_o$$

$$T_f = \left[\frac{-2000}{(0.6)(4186)} + 37.0\right]{}^\circ C$$

$$T_f = 36.2^\circ C$$

Exercise #2

C&J 12.49 At a fabrication plant, a hot metal forging has a mass of $m_1 = 75\ kg$ and a specific heat capacity of $c_1 = 430\ J/(^\circ C \cdot kg)$. To harden it, the forging is immersed in $m_2 = 710\ kg$ of oil that has a temperature of $T_{2o} = 32^\circ C$ and a specific heat capacity of $c_2 = 2700\ J/(^\circ C \cdot kg)$. The final temperature of the oil and forging at thermal equilibrium is $T_f = 47^\circ C$. Assuming that heat flows only between the forging and the oil, determine the initial temperature T_{1o} of the forging.

Exercise #2 Translation

C&J 12.5 The heat transfer between the forging and the oil is equal in magnitude so we can use the specific heat capacity relationship to heat to calculate an initial temperature of the forging given all of the other quantities.

Given: $m_1 = 75\ kg$, $m_2 = 710\ kg$, $T_{2o} = 32°C$, $c_1 = 430\ J/(°C \cdot kg)$, $c_2 = 2700\ J/(°C \cdot kg)$, and $T_f = 47°C$ for both objects.

Strategy: Calculate T_{1o} because all of the other information is known for $Q_1 = Q_2$.

$$Q_1 = Q_2$$

$$m_1 c_1 |\Delta T_1| = m_2 c_2 |\Delta T_2|$$

Exercise #2 Answer

$$m_1 c_1 |\Delta T_1| = m_2 c_2 |\Delta T_2|$$

$$|\Delta T_1| = \frac{m_2 c_2}{m_1 c_1} |\Delta T_2|$$

In this situation the metal forging cooled down so

$$T_f + |\Delta T_1| = T_{1o}$$

$$T_{1o} = T_f + \frac{m_2 c_2}{m_1 c_1} |T_f - T_{2o}|$$

$$T_{1o} = 47^\circ C + \frac{(710)(2700)}{(75)(430)} (47 - 32)^\circ C$$

$$T_{1o} \approx 939^\circ C$$

Calorimetry is the science or act of measuring changes in a body for the purpose of deriving the heat transfer associated with said changes.

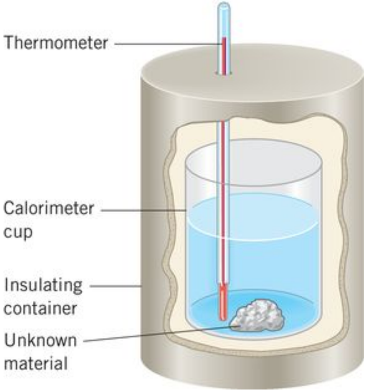

Figure: 26.2 Descriptive diagram of a calorimeter[2]

[2] C&J Figure 12.24

Mechanical Equivalent to Heat

James Prescott Joule (1818 - 1889) helped establish the mechanical equivalent of heat. The equivalence often used today is

$$1.000\ cal = 4.186\ J$$

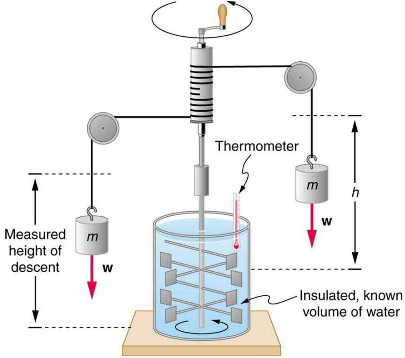

Figure: 26.3 One of Joule's famous experiments[3]

[3] OPSTX College Physics Figure 14.03

Heat Added, But Zero Temp Change???

You might be thinking: "Seems like we gotcha Ross! How do you explain this?"

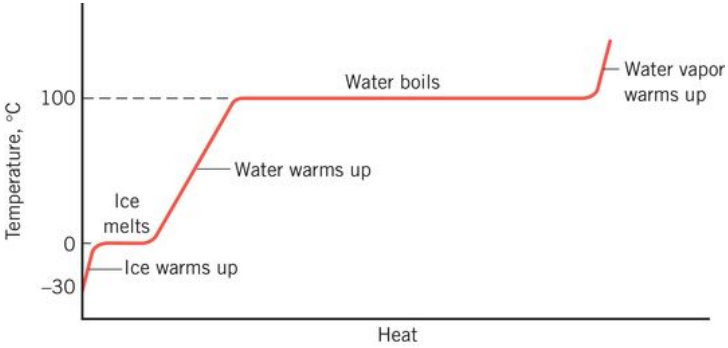

Figure: 26.3 Ideal graph for phase change data[3]

[3] C&J Figure 12.27

Latent Heat

Latent Heat (L) is the heat required per kilogram to change the phase of a substance:

$$Q = mL$$

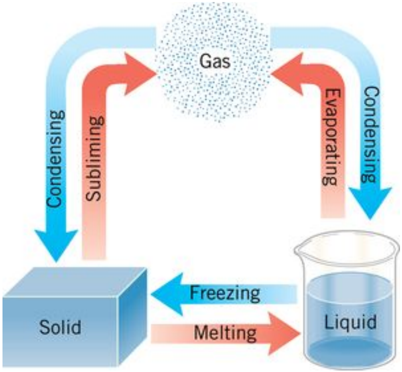

Figure: 26.4 Visualization to summarize general types of phase change[4]

[4] C&J Figure 12.26

Sublimation Application

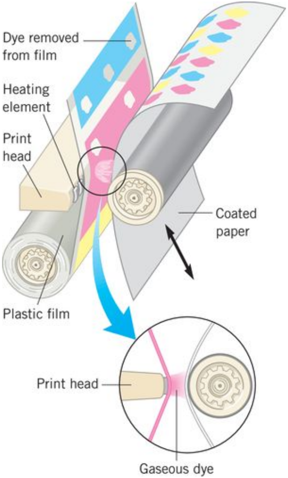

Figure: 26.5 A dye-sublimation printer not to scale[5]

[5] C&J Figure 12.29

Exercise #3

C&J 12.57 How much heat must be added to $0.45\ kg$ of aluminum to change it from a solid at $130°C$ to a liquid at $660°C$ (its melting point)? The latent heat of fusion for aluminum is $4.0 \times 10^5\ J/kg$ and the specific heat capacity of aluminum is $9.00 \times 10^2\ J/(°C \cdot kg)$.

Exercise #3 Translation

Calculate the total heat required to melt aluminum by calculating the heat for two distinct processes:

1. heating the solid to the melting point
2. melting all of the aluminum sample.

$$Q_{tot} = Q_1 + Q_2$$

$$Q_{tot} = mc\Delta T_1 + mL$$

Exercise #3 Answers

C&J 12.57 How much heat must be added to $0.45\ kg$ of aluminum to change it from a solid at $130°C$ to a liquid at $660°C$ (its melting point)? The latent heat of fusion for aluminum is $4.0 \times 10^5\ J/kg$ and the specific heat capacity of aluminum is $9.00 \times 10^2\ J/(°C \cdot kg)$.

$$Q_{tot} = mc\Delta T_1 + mL$$

$$Q_{tot} = m\Big(c\Delta T + L\Big)$$

$$Q_{tot} = \Big(0.45\Big)\Big[(9.00 \times 10^2)(660 - 130) + 4.0 \times 10^5\Big]J$$

$$Q_{tot} \approx 395\ kJ$$

Heat Facts Summary

Specific Heat Capacity determines how much heat is needed for temperature changes:

$$Q = mc\Delta T$$

Latent Heat is a measure of how much heat is needed to finish a phase change:

$$Q = mL$$

Heat Transfer Methods/Types

Heat Transfer is categorized into three types: Conduction, Convection, and Radiation.

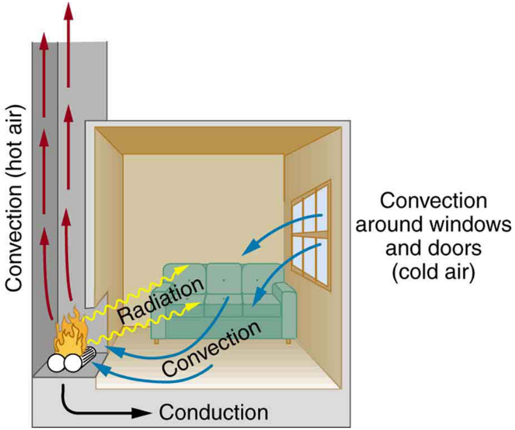

Figure: 26.6 Modeling heat transfer from a fireplace[6]

[6] OPSTX Figure 14.12

Conduction

Conduction is the process whereby heat is transferred directly through a material, with little to no contributions from bulk motion of the material.

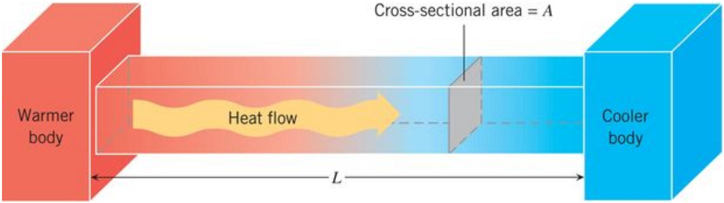

Figure: 26.7 Modeling heat conduction in a solid beam[7]

[7] C&J Figure 13.7

Conduction Application/Consideration

I would like everyone to think about a scenario where it would be desirable to increase the number of channels which increases the area over which conduction occurs.

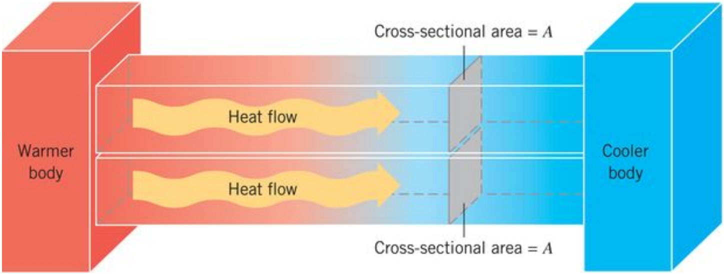

Figure: 26.8 Modeling heat conduction in two solid beams[8]

[8] C&J Figure 13.8

Motivation

Aluminum and tin have a specific heat capacity and thermal conductivity that aren't too high or too low when compared to other metals.

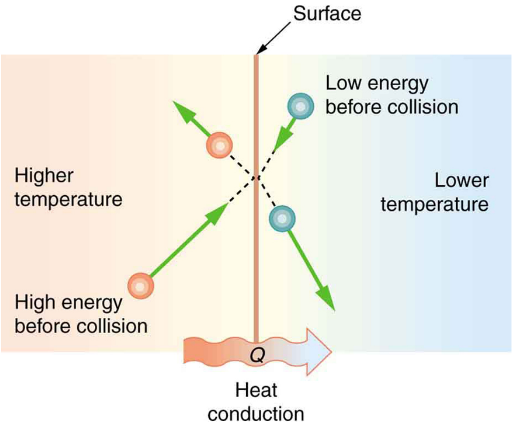

Figure: 26.1 Collision model of heat transfer[1]

[1] OPSTX College Physics Figure 14.14

Convection

Convection is the process in which heat is carried from place to place by the bulk movement of a fluid.

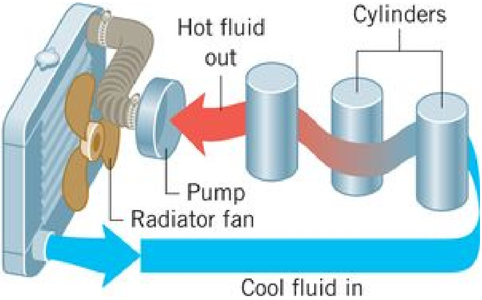

Figure: 26.9 Visualzing forced convection in an automobile radiator[9]

[9] C&J Figure 13.6

Convection Application

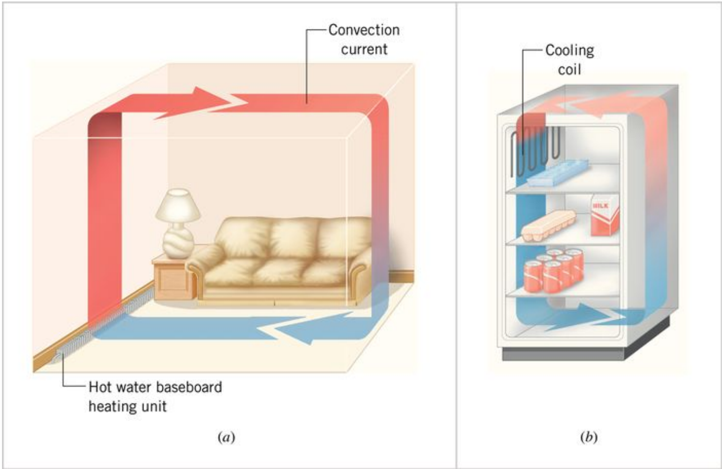

Figure: 26.10 Modeling heat conduction at home[10]

[10] C&J Figure 13.3

Radiation

Radiation is the process in which energy is transferred by means of electromagnetic waves. Visual light, infrared, UV, xray, microwaves, radio, ...

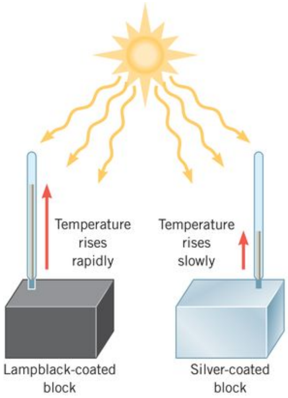

Figure: 26.11 Radiant heating of an object with two different coatings[11]

[11] C&J Figure 13.14

Perfect Radiation from "Black Bodies"

A **black body radiator** is an object that absorbs and emits all types of electromagnetic radiation perfectly.

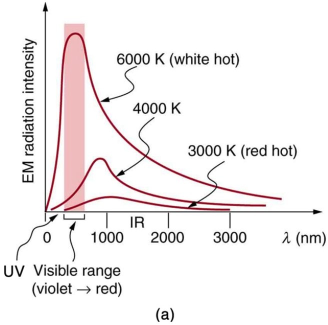

Figure: 26.12 Radiant heating of an object with two different coatings[12]

[12] C&J Figure 14.24

Quantifying Heat Transfer by Method

Conduction: Thermal Conductivity (k)

$$Q = \frac{kA\Delta Tt}{L}$$

$$P_{ow} = \frac{kA\Delta T}{L}$$

Radiation: Perfect Transfer

$$Q = \sigma T^4 At$$

$$P_{ow} = \sigma T^4 A$$

Exercise #4

C&J 13.3 A person's body is covered with $1.6\ m^2$ of wool clothing. The thickness of the wool is $2.0 \times 10^{-3}\ m$. The temperature at the outside surface of the wool is $11°C$, and the skin temperature is $36°C$. How much heat per second does the person lose due to conduction? $(k_{wool} = 0.040\ J/(°C \cdot s \cdot m))$

$$P_{ow} = \frac{Q}{t} = \frac{kA\Delta T}{L}$$

Exercise #4 Answers

$$\frac{Q}{t} = \frac{kA\Delta T}{L}$$

$$\frac{Q}{t} = \frac{(0.040)(1.6)(36-11)}{(2,0 \times 10^{-3})}\ \frac{J}{s}$$

$$\frac{Q}{t} = \frac{1.6}{2.0} \times 10^{-3}\ W$$

$$\frac{Q}{t} = 0.80\ mW$$

Transfer Methods Summary

Conduction is the process whereby heat is transferred directly through a material, with little to no contributions from bulk motion of the material.

Convection is the process in which heat is carried from place to place by the bulk movement of a fluid. Little to no motion, then little to no heat transfer by convection.

Radiation is the process in which energy is transferred by means of electromagnetic waves. Works without mechanical contact!