

Lecture Outline

Chapter 16

Physics, 4th Edition

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Chapter 16

Temperature and Heat

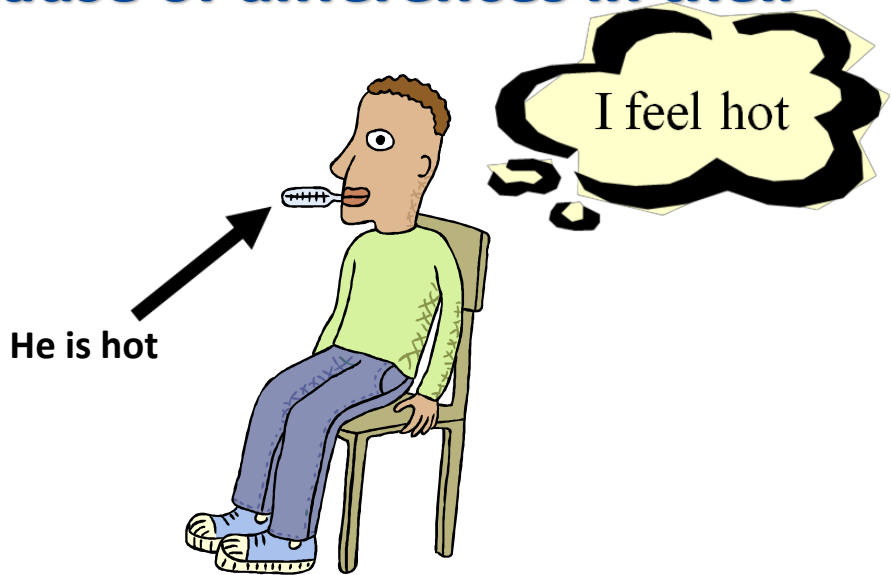


Units of Chapter 16

- Temperature
- Temperature Scales
- Thermal Expansion
- Conduction, Convection, and Radiation

What is Temperature and Heat?

- Temperature is how hot or cold an object feels when we touch it.
- Heat is the exchange of energy between two objects because of differences in their temperatures.



16-1-- Temperature

Definition of heat:

Heat is the energy transferred between objects because of a temperature difference.

Objects are in **thermal contact** if heat can flow between them.

When the **transfer of heat between objects in thermal contact ceases**, they are in **thermal equilibrium**.

16-1-- Temperature

That is, temperature is the only factor that determines whether two objects in thermal contact are in thermal equilibrium or not.

Some important definitions

- * Two objects are in Thermal contact with each other if energy can be exchanged between them.
- Thermal equilibrium *is a situation in which two objects would not exchange energy by heat if they were placed in thermal contact.*

Kelvin = SI unit of temperature

16-2-- Temperature Scales

The Celsius scale:

Water freezes at 0° Celsius.

Water boils at 100° Celsius.

The Fahrenheit scale:

Water freezes at 32° Fahrenheit .

Water boils at 212° Fahrenheit .

16-2-- Temperature Scales

Converting between Celsius and Fahrenheit:

$$T_F = \left(\frac{9}{5} \text{F}^\circ/\text{C}^\circ\right) T_C + 32 \text{ }^\circ\text{F}$$

$$F : \left(\frac{180}{100} \text{C}^\circ\right) + 32^\circ$$

Converting between Fahrenheit and Celsius :

$$T_C = \left(\frac{5}{9} \text{C}^\circ/\text{F}^\circ\right) (T_F - 32 \text{ }^\circ\text{F})$$

$$C : \frac{100}{180} (F^\circ - 32)$$

Example:- 16-1(541)

- On a fine spring day you notice that the temperature is 75°F .
- A) What is the corresponding temperature on the Celsius scale? -
- Sol:- 24°C
- B) If the temperature on the brisk winter morning is -2.0°C , what is the corresponding Fahrenheit temperature
- Sol:- 28°F

$$a) \text{ C}^\circ = \frac{5}{9} (f^\circ - 32)$$

$$\frac{5}{9} (75 - 32) = 23.8^\circ \text{C}$$

$$b) \text{ f}^\circ = \left(\frac{9}{5} \times \text{C}^\circ \right) + 32$$

$$\left(\frac{9}{5} \times -2 \right) + 32 = 28.4^\circ \text{f} \quad \leftarrow \begin{array}{l} \text{degree} \\ \text{before} \end{array}$$

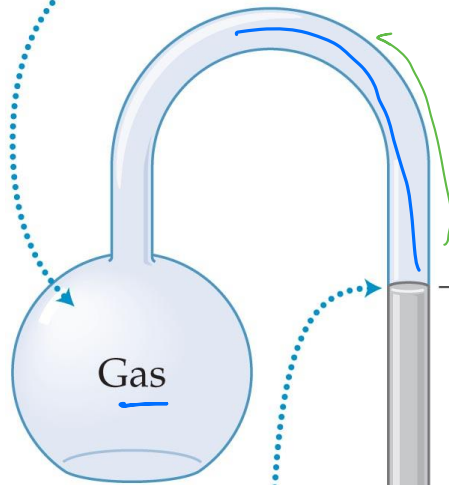
Another Scale...

- Kelvin is another way of measuring temperature.
- Scientists use Kelvin to explain the behaviour of gases.
- “Absolute Zero” is measured in Kelvin – which is the coldest possible temperature
- 0 Kelvin = -273 °C

16-2 Temperature Scales

A constant-volume gas thermometer

The volume of the gas is constant ...



... when mercury is set to the reference level.

$$P = \rho h g + P_{atm}$$



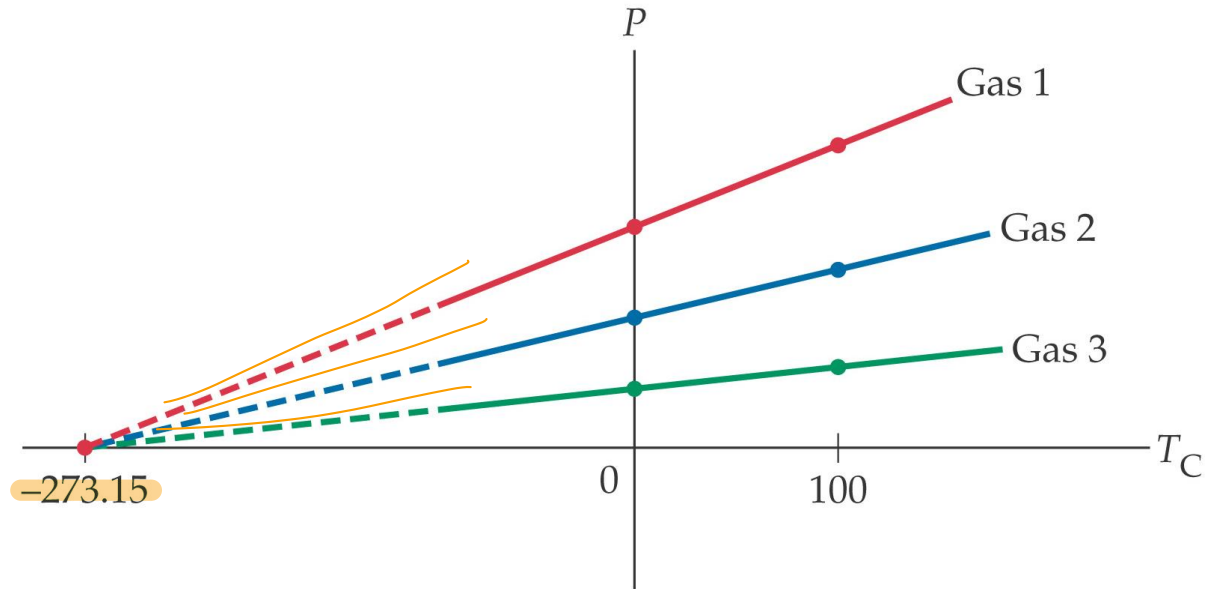
Reference level

Mercury

Freezing point: -39°C

16-2 Temperature Scales

The pressure in a gas is proportional to its temperature. The proportionality constant is different for different gases, but they all reach zero pressure at the same temperature, which we call absolute zero:



16-2-- Temperature Scales

The Kelvin scale is similar to the Celsius scale, except that the Kelvin scale has its zero at absolute zero.

Conversion between a Celsius temperature and a Kelvin temperature:

$$- \quad T = T_C + 273.15$$

$$- \quad f^{\circ} = \left(\frac{9}{5} \times C^{\circ} \right) + 32$$

$$- \quad C^{\circ} = \frac{5}{9} f^{\circ}$$

The three common thermal scales.

K = °C = °F

$$T_K = T_C + 273.15$$

$$T_C = \frac{5}{9}(T_F - 32)$$

$$T_F = \frac{9}{5}T_C + 32$$

Freezing point of water

273.15 K

Kelvin

0°C

Celsius

32°F

Fahrenheit

373.15 K

100°C

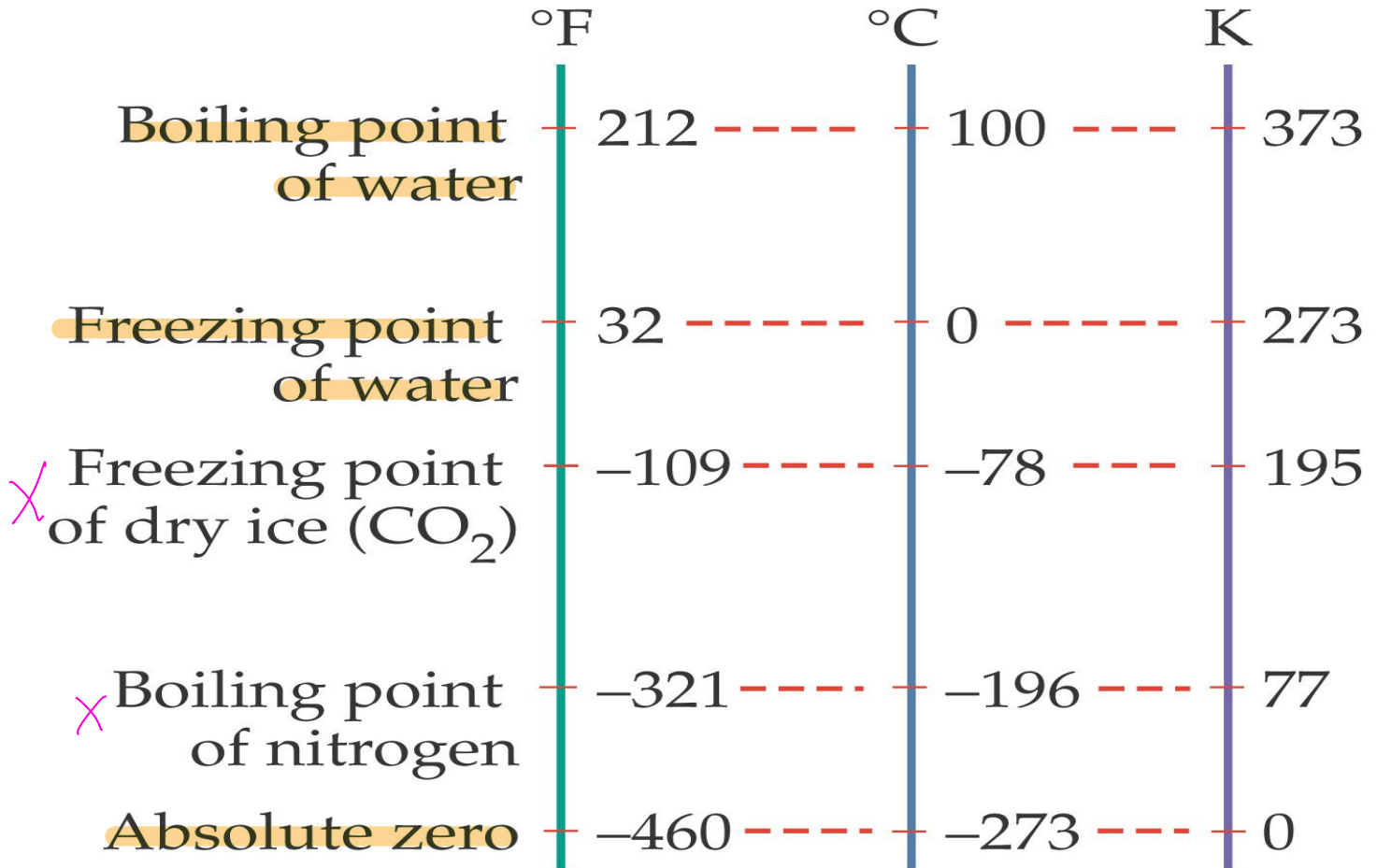
212°F

Boiling point of water at atmospheric pressure

** The SI unit of absolute temperature is the kelvin

16-2 ---Temperature Scales

The three temperature scales compared:



Exercise 16-1(pg 544)

- Convert 55⁰F to K

Answer :T= 286K

$$\begin{aligned}\textcircled{1} \quad C^{\circ} &= \frac{5}{9} (55 - 32) \\ &= 12.7^{\circ}C\end{aligned}$$

$$\begin{aligned}\textcircled{2} \quad K &= 12.7^{\circ} + 273^{\circ} \\ &= 286K\end{aligned}$$

ceptual and numerical parts; **BIO** identifies problems of biological or medical interest. Each problem has two responses: (a) your prediction of a physical outcome, and (b) the best explanation. The letters indicate the level of difficulty.

SECTION 16-2 TEMPERATURE SCALES

1. • **Lowest Temperature on Earth** The official record for the lowest temperature ever recorded on Earth was set at Vostok, Antarctica, on July 21, 1983. The temperature on that day fell to -89.2°C , well below the temperature of dry ice. What is this temperature in degrees Fahrenheit?
2. • More than likely, there is a glowing incandescent lightbulb in your room at this moment. The filament of that bulb, with a temperature of about 4500°F , is almost half as hot as the surface of the Sun. What is this temperature in degrees Celsius?
3. • Normal body temperature for humans is 98.6°F . What is the corresponding temperature in (a) degrees Celsius and (b) kelvins?
4. • What is the temperature 1.0 K on the Fahrenheit scale?
5. • The temperature at the surface of the Sun is about 6000 K . Convert this temperature to the (a) Celsius and (b) Fahrenheit scales.

16-3-- Thermal Expansion

Most substances expand when heated; the change in length or volume is typically proportional to the change in temperature.

The proportionality constant is called the coefficient of linear expansion.

Definition of Coefficient of Linear Expansion, α

$$\Delta L = \alpha L_0 \Delta T$$

$$\text{SI unit for } \alpha: \text{K}^{-1} = (\text{C}^\circ)^{-1}$$

Exercise 16-2(pg-545)

- The Eiffel tower constructed in 1889 by Alexandre Eiffel, is an impressive lattice work structure made of iron. If the tower is 301m high on a 22⁰C day, how much does its height decreases when the temperature cools to 0.0⁰C
- Sol:- -7.9cm
- Iron ($12 \times 10^{-6} \text{ K}^{-1}$)

Length_i: 301 m $L_f = ?$ $\alpha_{\text{iron}} = 12 \times 10^{-6} \text{ K}^{-1}$

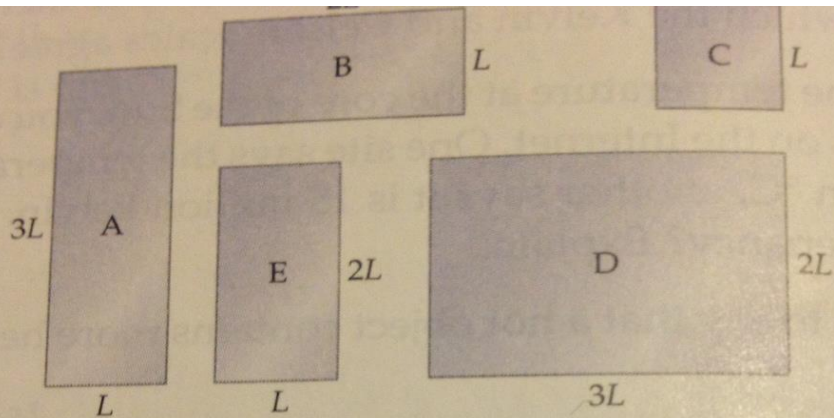
$T_i = 22.0 \text{ C}$ $T_f = 0.000 \text{ C}$

① $\Delta L = \alpha L_i \Delta T$

$$12 \times 10^{-6} \times 301 \times (0 - 22) = -0.079 \text{ m}$$

② $\Delta L = L_f - L_i \rightarrow L_f = \Delta L + L_i$

$$= (-0.079) + (301) = 300.92$$



▲ **FIGURE 16-13** Problems 15 and 16

16. • **CE** Referring to Problem 15, rank the metal plates in order of increasing expansion in area. Indicate ties where appropriate.
17. • **Longest Suspension Bridge** The world's longest suspension bridge is the Akashi Kaikyo Bridge in Japan. The bridge is 3910 m long and is constructed of steel. How much longer is the bridge on a warm summer day ($30.0\text{ }^{\circ}\text{C}$) than on a cold winter day ($-5.00\text{ }^{\circ}\text{C}$)?

$$\textcircled{17} \quad L_i = 3910 \text{ m} \quad , \quad T_f = 30.0 \text{ c} \quad , \quad T_i = -5.00 \text{ c} \quad , \quad \alpha = 12 \times 10^{-6}$$

$$\textcircled{1} \quad \Delta L = \alpha L_i \Delta T$$

$$= 12 \times 10^{-6} \times (3910) \times (30 - (-5))$$

$$= 1.64 \text{ m}$$

$$\textcircled{2} \quad \Delta L = L_f - L_i \quad \rightarrow \quad L_f = \Delta L + L_i$$

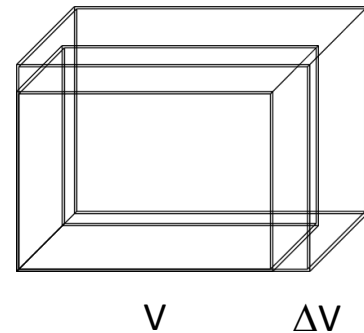
$$1.64 + 3910 = 3911.64 \text{ m}$$

Thermal expansion

- is the tendency of matter to change in length (or volume) in response to a change in temperature.

increase \rightarrow expand, decrease \rightarrow shrink

- This effect is limited in size, and only occurs within limited temperature ranges.



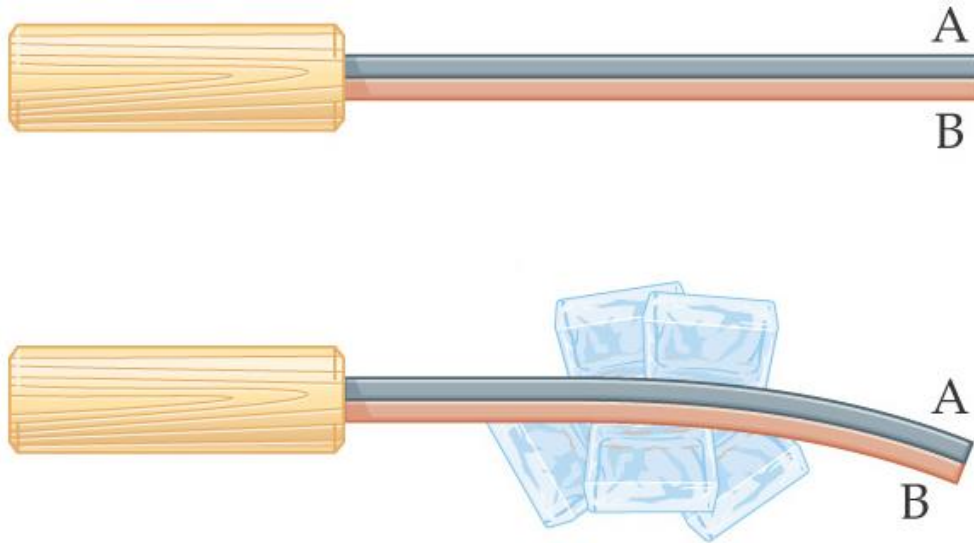
16-3 --Thermal Expansion

Some typical coefficients of thermal expansion:

Substance	Coefficient of linear expansion, $\alpha(K^{-1})$
Lead	29×10^{-6}
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Iron (steel)	12×10^{-6}
Concrete	12×10^{-6}
Window glass	11×10^{-6}
Pyrex glass	3.3×10^{-6}
Quartz	0.50×10^{-6}

16-3 --Thermal Expansion

A bimetallic strip consists of two metals of different coefficients of thermal expansion, A and B in the figure. It will bend when heated or cooled.



16-3-- Thermal Expansion

The change in volume of a solid is also derived from the linear expansion:

$$V = L^3 \quad \text{Solid:} \quad \Delta V \approx 3\alpha V \Delta T$$

For liquids and gases, only the coefficient of volume expansion is defined:

Definition of Coefficient of Volume Expansion, β

$$\Delta V = \beta V \Delta T$$

$$\text{SI unit for } \beta: \text{K}^{-1} = (\text{C}^\circ)^{-1} \quad \frac{1}{\text{C}^\circ}, \frac{1}{\text{K}}$$

Volume = $V = L^3$

Thermal expansion:

Solids: $\Delta V \approx 3\alpha V \Delta T$

Liquids & gases: $\Delta V = \beta V \Delta T$

16-3 --Thermal Expansion

Some typical coefficients of volume expansion:

Substance	Coefficient of volume expansion, $\beta(K^{-1})$
Ether	1.51×10^{-3}
Carbon tetrachloride	1.18×10^{-3}
Alcohol	1.01×10^{-3}
Gasoline	0.95×10^{-3}
Olive oil	0.68×10^{-3}
Water	0.21×10^{-3}
Mercury	0.18×10^{-3}

16-3-- Thermal Expansion

The change in volume of a solid is also derived from the linear expansion:

$$\Delta V \approx 3\alpha V \Delta T$$

For liquids and gases, only the coefficient of volume expansion is defined:

Definition of Coefficient of Volume Expansion, β

$$\Delta V = \beta V \Delta T$$

$$\text{SI unit for } \beta: \text{K}^{-1} = (\text{C}^\circ)^{-1}$$

Example: 3

A copper flask with a volume of 150 cm^3 is filled to the brim with olive oil. If the temperature of the system is increased from 6°C to 31°C , how much oil spills from the flask?

$$[\beta_{\text{oil}} = 0.68 \times 10^{-3} \text{ K}^{-1} ; \alpha_{\text{copper}} = 17 \times 10^{-6} \text{ K}^{-1}]$$

Answer: 2.4 cm^3

$$V_i = 150 \text{ cm}^3 \quad T_i = 6 \text{ C} ,$$

$$V_f = ? \quad T_f = 31$$

$$\begin{aligned} \textcircled{1} \Delta V_{\text{cup}} &= 3\alpha V \Delta T \\ &= 3 \times (17 \times 10^{-6}) \times (150) \times (31-6) \\ &= 0.19 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \textcircled{2} \Delta V_{\text{oil}} &= \beta V \Delta T \\ &= 0.68 \times 10^{-6} \times (150) \times (31-6) \\ &= 2.55 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \textcircled{3} \Delta_{\text{spill from flask}} &= 2.55 - 0.19 \\ &= 2.36 \text{ cm}^3 \end{aligned}$$

Topic : Transferring Energy

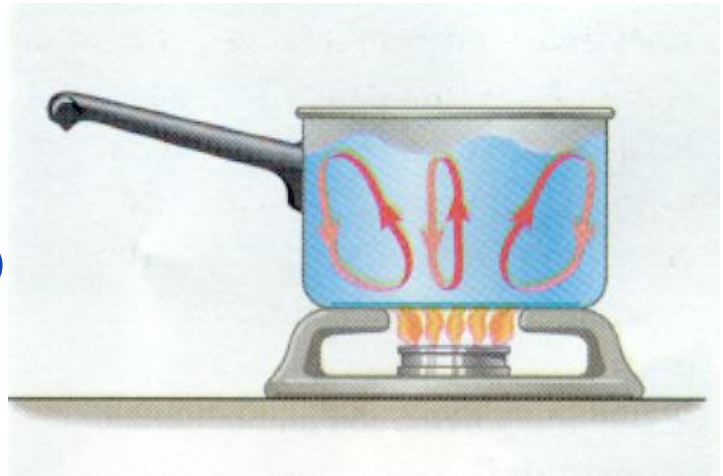
- There are 3 main ways to transfer energy

- 1) Radiation

- 2) Conduction

- 3) Convection

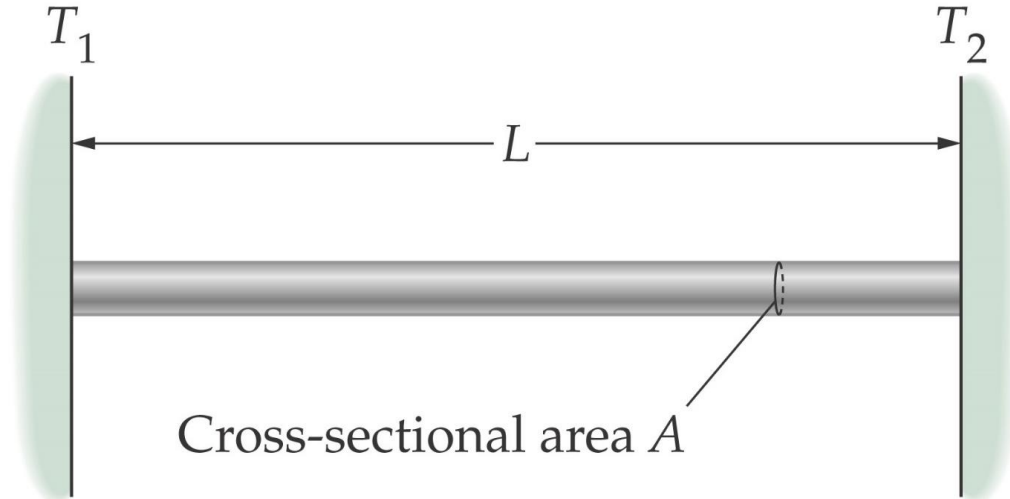
Liquides &
gases



16-6 Conduction, Convection, and Radiation

Conduction, convection, and radiation are three ways that heat can be exchanged.

Conduction is the flow of heat directly through a **physical material**.



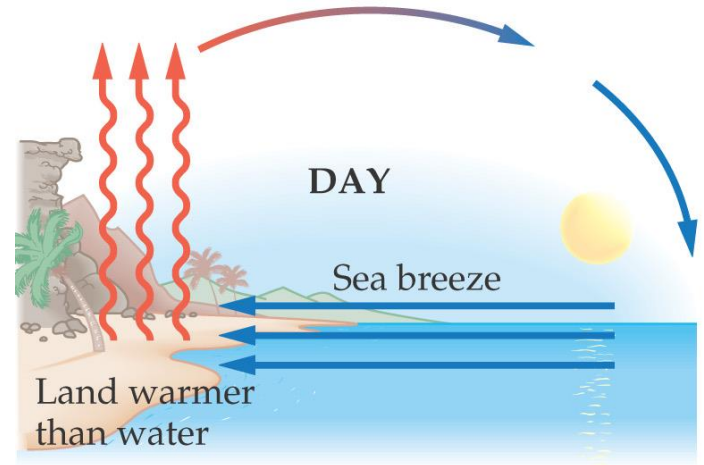
Conduction: The transfer of heat on molecular/atomic level from one substance to another by direct contact. Denser substances are better conductors; the transfer is always from warmer to colder substances. Medium necessary eg metals are good conductors. Insulators are those which do not conduct heat eg wood, glass, ceramic, rubber .

Convection: Convection is the mass movement of molecules within fluids (i.e. liquids, gases). It cannot take place in solids. Needs a medium

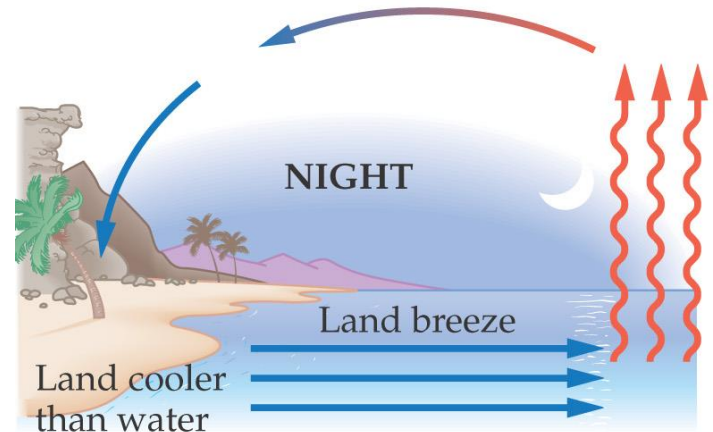
Radiation: energy that is radiated or transmitted in the form of rays or waves or particles. It is the heat transfer by electromagnetic waves or photons. It does not need a propagating medium. The energy transferred by radiation moves at the speed of light eg light, IR etc.

16-6 --Conduction, Convection, and Radiation

Convection is the flow of fluid due to a difference in temperatures, such as warm air rising. The fluid “carries” the heat with it as it moves.



(a)

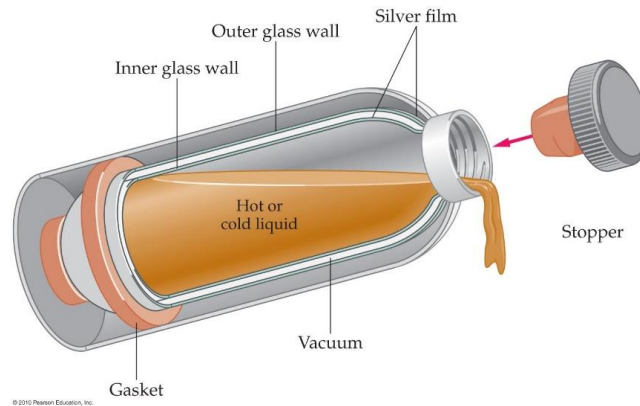


(b)

16-6-- Conduction, Convection, and Radiation

All objects give off energy in the form of radiation, as electromagnetic waves – infrared, visible light, ultraviolet – which, unlike conduction and convection, can transport heat through a vacuum.

Objects that are hot enough will glow – first red, then yellow, white, and blue. Objects at body temperature radiate in the infrared, and can be seen with night vision binoculars.



Summary of Chapter 16

- Heat is the energy transferred between objects due to a temperature difference.
- Objects are in thermal contact if heat can flow between them.
- Objects that are in thermal contact without any flow of heat are in thermal equilibrium.
- Thermodynamics is the study of physical processes that involve heat.

Summary of Chapter 16

- Temperature determines whether two objects will be in thermal equilibrium.
- Celsius scale: water freezes at 0°C , boils at 100°C
- Fahrenheit: water freezes at 32°F , boils at 212°F
- The lowest attainable temperature is absolute zero.
- Kelvin: absolute zero is 0 K ; water freezes at 273.15 K and boils at 373.15 K

Summary of Chapter 16

- Temperature scale conversions:

$$T_F = \frac{9}{5}T_C + 32$$

$$T_C = \frac{5}{9}(T_F - 32)$$

$$T = T_C + 273.15$$

- Most substances expand when heated.

- Linear expansion:

$$\Delta L = \alpha L_0 \Delta T$$

- Volume expansion:

$$\Delta V = \beta V \Delta T$$

Summary of Chapter 16

- Conduction: heat exchange from one part of a material to a cooler part, with no bulk motion of the material.
- Convection is heat exchange due to the bulk motion of an unevenly heated fluid.
- Radiation is heat exchange due to electromagnetic radiation.

Summary of Chapter 16

- Heat is a form of energy:

$$1 \text{ cal} = 4.186 \text{ J}$$

- Energy is conserved in heat flow.