A water tank 11.5 m in diameter and 13.5 m tall is supported with its base 8.75 m above the ground as shown. The water level is 10.6 m deep. A very small hole is formed at the base of the vertical wall of the tank, and water is squirting out of this hole horizontally. When this water hits the ground, how far has it traveled horizontally from the hole, assuming no air resistance? ($\rho_{H_2O} = 1.00 \text{g/cm}^3$)

\[ v = \sqrt{2gh} = \sqrt{2(9.8)(10.6)} \]

\[ x = v_x t \]

\[ y = \frac{1}{2} gt^2 \]

\[ t = \sqrt{\frac{2(8.75)}{9.8}} \]

a) Impossible to determine.

b) About 19 m

c) About 10 m

d) About 41 m
When a block of volume $1.00 \times 10^{-3} \text{ m}^3$ is hung from a spring scale as shown (Figure A), the scale reads 10.0 N. When the same block is then placed in an unknown liquid, it floats with $2/3$ of its volume submerged as shown in Figure B. What is the density of the unknown liquid?

a) About $3.03 \times 10^3 \text{ kg/m}^3$

b) About $4.62 \times 10^3 \text{ kg/m}^3$

c) About $6.16 \times 10^3 \text{ kg/m}^3$

d) About $8.01 \times 10^3 \text{ kg/m}^3$

e) About $1.57 \times 10^4 \text{ kg/m}^3$
Lecture

• Temperature and Heat
• Thermal Expansion
• Absolute temperature (Kelvin)
• Specific Heat and Calorimetry
• Latent Heat
• Simple Harmonic Motion
On a microscopic scale, the arrangements of molecules in solids (a), liquids (b), and gases (c) are quite different.
Temperature and Thermometers

• Temperature is a measure of how hot or cold something is.

• Most materials expand when heated.
Temperature and Thermometers

Thermometers are instruments designed to measure temperature.

In order to do this, they take advantage of some property of matter that changes with temperature.
Common thermometers used today include the liquid-in-glass type and the bimetallic strip.
Temperature and Thermometers

Temperature is generally measured using either the Fahrenheit or the Celsius scale.

The freezing point of water is 0°C, or 32°F; the boiling point of water is 100°C, or 212°F.
Thermal Equilibrium and the Zeroth Law of Thermodynamics

Two objects placed in thermal contact will eventually come to the same temperature. When they do, we say they are in thermal equilibrium.

The zeroth law of thermodynamics says that:
if two objects are each in equilibrium with a third object, they are also in thermal equilibrium with each other.
Linear expansion occurs when an object is heated.

\[ \ell = \ell_0 (1 + \alpha \Delta T) \]

Here, \( \alpha \) is the coefficient of linear expansion.
A segment of steel railroad track has a length of 30.000 m when the temperature is 0.00000 °C. What is its length when the temperature is 40.000° C? The linear expansion coefficient of steel is: \( \alpha_{\text{steel}} = 11.000 \times 10^{-6} / ^\circ C \)

a) 30.0132 m  
b) 0.0132 m  
c) 29.9868 m  
d) 31.0021 m  
e) 0.0021 m
Example: Linear Expansion

A segment of steel railroad track has a length of 30.000 m when the temperature is 0.00000 °C. What is its length when the temperature is 40.000°C? The linear expansion coefficient of steel is:

$$\alpha_{\text{steel}} = 11.000 \times 10^{-6} / ^\circ C$$

$$\ell = \ell_0 (1 + \alpha \Delta T) \Rightarrow \Delta \ell = \ell_0 \alpha \Delta T$$

$$\Delta \ell = 30.000 m \cdot (11 \times 10^{-6} / K) \cdot 40 K = 0.0132 m$$

$$\ell = 30.000 m + 0.0132 m = 30.0132 m$$
A segment of steel railroad track has a length of 30.000 m when the temperature is 0.00000 °C. What is its length when the temperature is 40.000° C? The linear expansion coefficient of steel is: \( \alpha_{steel} = 11.000 \times 10^{-6} / ^\circ C \)

- a) 30.0132 m
- b) 0.0132 m
- c) 29.9868 m
- d) 31.0021 m
- e) 0.0021 m
Thermal Expansion

Volume expansion is similar, except that it is relevant for liquids and gases as well as solids:

$$\Delta V = \beta V_0 \Delta T$$

Here, $\beta$ is the coefficient of volume expansion.
Thermal Expansion ($\text{H}_2\text{O}$)

Water behaves differently from most other solids

- Its minimum volume occurs when its temperature is 4°C.
- As it cools further, it expands.
Notes on Thermal Expansion

A material may be fixed at its ends and therefore be unable to expand when the temperature changes.

It will then experience large compressive or tensile stress—thermal stress—when its temperature changes.

What is the force required to keep the material from expanding?

The Young’s modulus of a material is given:

$$Y = \frac{F \ell_0}{A \Delta \ell}$$
Notes on Thermal Expansion

The force required to keep the material from expanding is given by:

\[ F = \frac{\Delta \ell}{\ell_0} AY \]

\[ F = \alpha AY \Delta T \]
Absolute Temperature

• The concept of absolute zero allows us to define a third temperature scale—the absolute, or Kelvin, scale.

• This scale starts with 0 K at absolute zero, but otherwise is the same as the Celsius scale \( \Delta T_C = \Delta T_K \).

• Therefore, the freezing point of water is 273.15 K, and the boiling point is 373.15 K \( (\Delta T = 100^\circ C = 100K) \).
**Definition of heat:**

Heat is the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings.
Internal Energy

The sum total of all the energy of all the molecules in a substance is its internal (or thermal) energy.

• **Temperature**: measures molecules’ average kinetic energy

• **Internal energy**: total energy of all molecules

• **Heat**: transfer of energy due to difference in temperature
**Example**

A student eats a dinner rated at 2,000 Calories. He wishes to do an equivalent amount of work in the gymnasium by lifting a 50.0-kg barbell. How many times must he raise the barbell to expend this much energy? Assume that he raises the barbell 2.00 m each time he lifts it and that he regains no energy when he lowers the barbell.

\[ W_T = Nmgh = 2000 \text{ cal} \]

\[ N = \# \text{ of times} \]

\[ 2000 \text{ cal} \left( \frac{4.186 \text{ J}}{1 \text{ cal}} \right) = N (50 \text{ kg}) (9.8 \text{ m/s}^2) (2 \text{ m}) \]

\[ N = \frac{2000 \cdot 4.186 \text{ J}}{50 \text{ kg} \cdot 9.8 \text{ m/s}^2 \cdot 2} = 8543 \text{ times} \]
Specific Heat

The amount of heat \((Q)\) required to change the temperature of a material is proportional to the mass and to the temperature change:

\[
Q = mc \Delta T
\]

The specific heat, \(c\), is characteristic of the material.
Note on Specific Heat

• Specific heats of gases are more complicated.

• Generally measured at constant pressure \((c_p)\) or constant volume \((c_v)\).
Calorimetry

Closed system: no mass enters or leaves, but energy may be exchanged

Open system: mass may transfer as well

Isolated system: closed system where no energy in any form is transferred

For an isolated system:
Energy out of one part = energy into another part

\[ Q_{\text{Hot}} + Q_{\text{Cold}} = 0 \]  

heat lost = heat gained  (Conservation of Energy)
Calorimetry

The instrument to the left is a calorimeter, which makes quantitative measurements of heat exchange.

A sample is heated to a well-measured high temperature, plunged into the water, and the equilibrium temperature measured. This gives the specific heat of the sample.
Calorimetry

• Another type of calorimeter is called a bomb calorimeter; it measures the thermal energy released when a substance burns.

• This is the way the caloric content of foods is measured.
Problem Solving: Calorimetry

1. Is the system isolated? Are all significant sources of energy transfer known or calculable?

2. Apply conservation of energy.

3. If no phase changes occur, the heat transferred will depend on the mass, specific heat, and temperature change.

4. If there are, or may be, phase changes, terms that depend on the mass and the latent heat may also be present. Determine or estimate what phase the final system will be in.

5. Make sure that each term is in the right place and that all the temperature changes are positive.

6. There is only one final temperature when the system reaches equilibrium.
Example

A 0.050 kg block of metal is heated to 200.0°C and then dropped into a beaker containing 0.400 kg of water initially at 20.0°C. If the final equilibrium temperature of the system (water and metal) is 22.4°C, what is the specific heat of the metal? \((Q = mc\Delta t)\)

**Conservation of Energy** \(Q_{\text{cold}} = -Q_{\text{hot}}\)

\[
m_w c_w (T_f - T_w) = -m_x c_x (T_f - T_x)
\]

\[
c_x = \frac{c_w m_w (T_f - T_w)}{m_x (T_f - T_x)} = \frac{(4186 \text{ J/kg \cdot °C})(0.4 \text{ kg})(2.4 \text{ °C})}{-(0.05 \text{ kg})(-177.6 \text{ °C})}
\]

\[
c_x = 452.5 \text{ J/kg \cdot °C}
\]
A block of wood floats in a container of water as shown on the right. On the Moon, how would the same block of wood float in the container of water?
Latent Heat

• There are situations in which the transfer of energy does not result in a change in temperature.

• The physical characteristics of the substance change from one form to another, i.e. a phase change.

• Latent ("hidden") Heat, L, is the Energy required for a material to change phase, even though its temperature is not changing.
Latent Heat

The value of $L$ for a substance depends on the nature of the phase change, as well as properties of the substance.

**Heat of fusion, $L_F$:** heat required to change 1.0 kg of material from solid to liquid

**Heat of vaporization, $L_V$:** heat required to change 1.0 kg of material from liquid to vapor
Latent Heat

The total heat required for a phase change depends on the total mass and the latent heat:

\[ Q = mL \]
Part A. On this portion of the curve, the temperature of the ice changes from $-30.0{}^\circ$C to $0.0{}^\circ$C. Because the specific heat of ice is $2090 \text{ J/kg} \cdot {}^\circ\text{C}$, we can calculate the amount of energy added

$$Q = m_i c_i \Delta T = (1.00 \times 10^{-3} \text{ kg})(2090 \text{ J/kg} \cdot {}^\circ\text{C})(30.0{}^\circ\text{C}) = 62.7 \text{ J}$$
Part B. When the temperature of the ice reaches 0.0°C, the ice–water mixture remains at this temperature—even though energy is being added—until all the ice melts. The energy required to melt 1.00 g of ice at 0.0°C is,

\[ Q = m_i L_f = (1.00 \times 10^{-3} \text{ kg}) (3.33 \times 10^5 \text{ J/kg}) = 333 \text{ J} \]
The latent heat of vaporization is relevant for evaporation as well as boiling. The heat of vaporization of water rises slightly as the temperature decreases.

On a molecular level, the heat added during a change of state does not go to increasing the kinetic energy of individual molecules, but rather to break the close bonds between them so the next phase can occur.
Example

What mass of steam initially at 130°C is needed to warm 200 g of water in a 100-g glass container from 20.0°C to 50.0°C?

The steam loses energy in three stages:
1. Steam is cooled to 100°C
2. Steam is converted to water (no temperature change).
3. Water (from steam) at 100°C is cooled to 50°C

\[ Q_1 = m_s c_s \Delta T = m_s \left( \frac{2.01 \times 10^5 \text{J/kg}}{\text{°C}} \right) (-30 \text{°C}) \]

\[ Q_2 = -m_s L_v = -m_s \left( \frac{2.26 \times 10^6 \text{J/kg}}{\text{°C}} \right) \]

\[ Q_3 = m_c w \Delta T = m_s \left( \frac{4.18 \times 10^3 \text{J/kg°C}}{\text{°C}} \right) (-50 \text{°C}) \]

\[ Q_{\text{hot}} = Q_1 + Q_2 + Q_3 \]
Example

What mass of steam initially at 130°C is needed to warm 200 g of water in a 100-g glass container from 20.0°C to 50.0°C?

\[ Q_{\text{cold}} = (0.200 \text{kg})(5.119 \times 10^5 \text{J/kg°C})(30°C) \]
\[ + (0.100 \text{kg})(4.18 \text{ J/g°C})(30°C) \]

\[ Q_{\text{cold}} = -Q_{\text{hot}} \]
\[ 2.77 \times 10^4 \text{ J} = m_s(2.53 \times 10^6 \text{ J/kg}) \]

\[ \Rightarrow m_s = 1.1 \times 10^{-2} \text{ kg} \]
A mass oscillates on a horizontal spring with period $T = 2.0$ s. What is the frequency?

a) Impossible to determine.

b) 0.50 Hz

c) 1.0 Hz

d) 2.0 Hz

e) 4.0 Hz

$$f = \frac{1}{T}$$
Periodic Motion

The motion of an object is called periodic if:

- It vibrates or oscillates back and forth over the same path
- Each cycle takes the same amount of time
Simple Harmonic Motion: Spring Oscillations

- There is a point where the spring is neither stretched nor compressed; this is the equilibrium position.
- We measure displacement from that (equilibrium) point (i.e. \( x = 0 \) on the figure).
- Recall the force exerted by the spring depends on the displacement: \( \vec{F} = -k\vec{x} \)
Spring Oscillations

- **Displacement** is measured from the equilibrium point
- **Amplitude** (A) is the maximum displacement
- **Period** is the time required to complete one cycle
- **Frequency** is the number of cycles completed per second
Simple Harmonic Oscillator

Any vibrating system where the restoring force is proportional to the negative of the displacement is in simple harmonic motion (SHM) and is often called a simple harmonic oscillator.