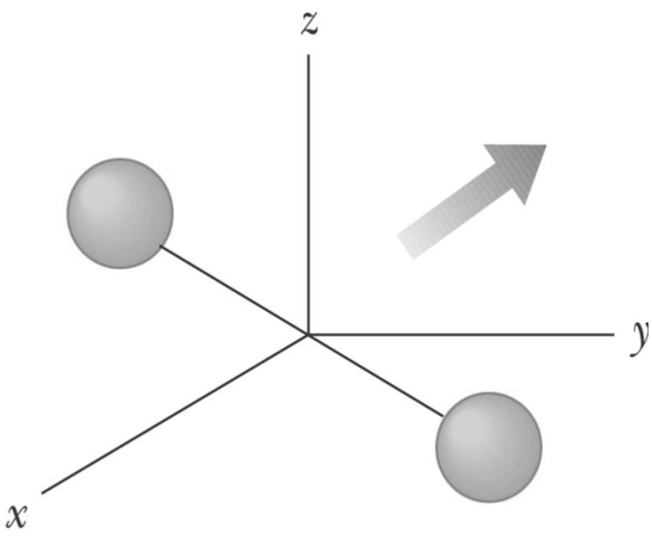
Internal energy

Internal Energy

- **Internal energy** is all the energy of a system that is associated with its microscopic components
  - These components are its atoms and molecules
  - The system is viewed from a reference frame at rest with respect to the center of mass of the system

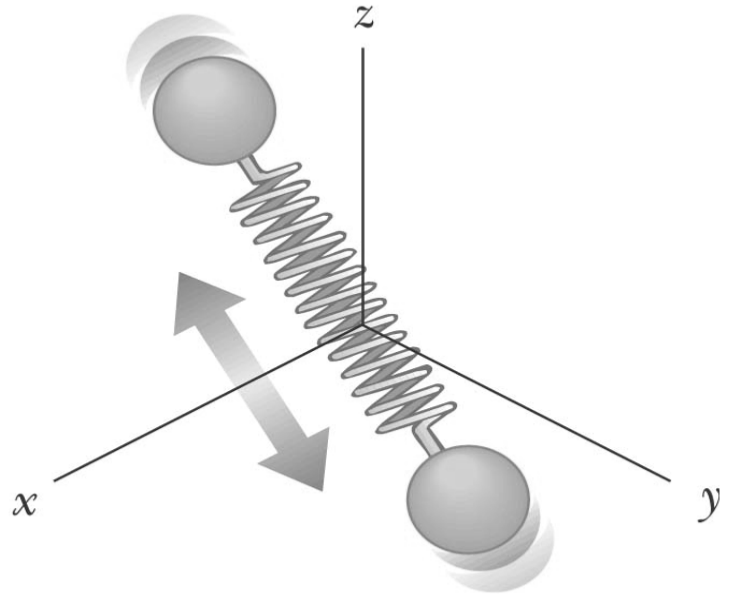
Internal Energy and Other Energies

- The kinetic energy due to its motion through space is **not** included
- Internal energy does include kinetic energies due to:
  - Random **translational** motion
  - **Rotational** motion
  - **Vibrational** motion
- Internal energy also includes **potential energy** between molecules



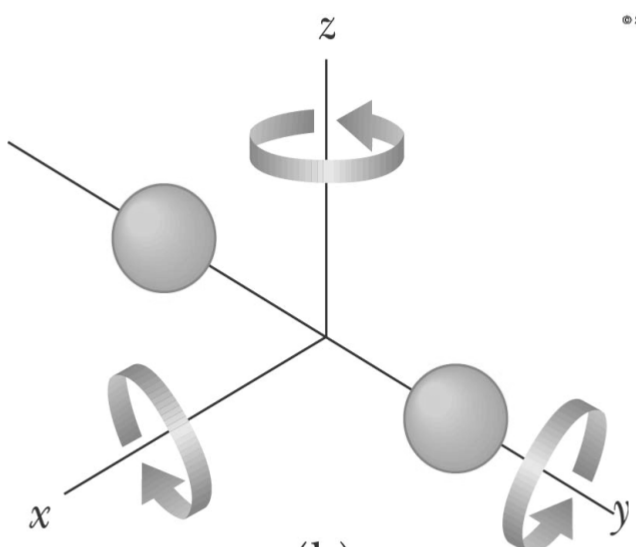
(a)

Translation



(c)

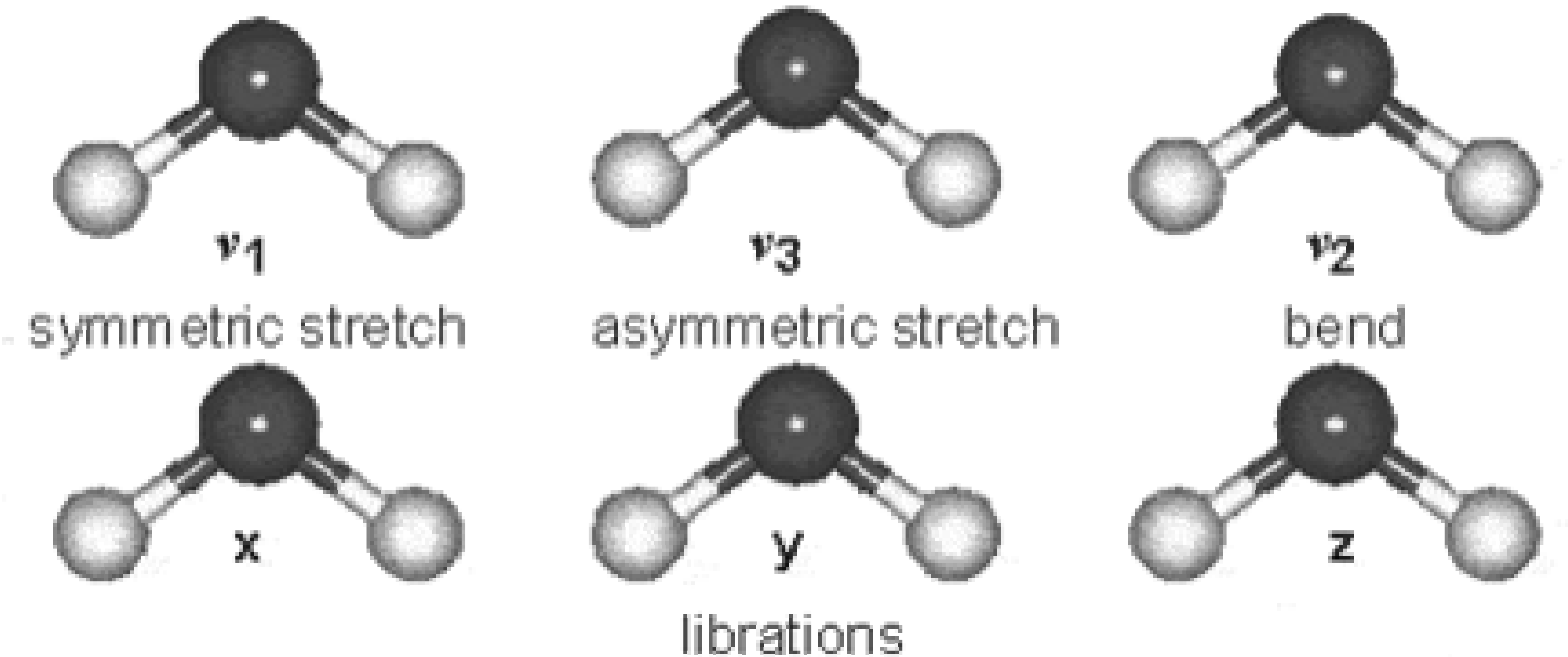
Vibration



(b)

Rotation

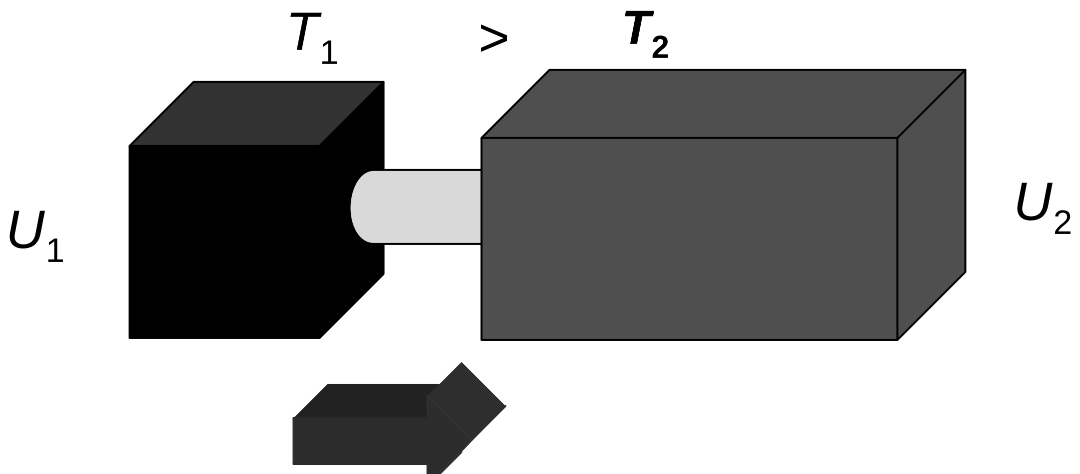
Water vibrations and rotations



http://www.lsbu.ac.uk/water/vibrat.html

Heat

- **Heat** is defined as the transfer of energy across the boundary of a system due to a temperature difference between the system and its surroundings
- The term *heat* will also be used to represent the ***amount* of energy** transferred by this method



Changing Internal Energy

- Both heat and work can change the internal energy of a system
- The internal energy can be changed even when no energy is transferred by heat, but just by work or other processes:
  - Example, compressing gas with a piston
  - Energy is transferred by work
  - Temperature of electrical conductors can be increased by passing electric current through them.

Such processes are called ***adiabatic***. In neither case does contact with a hotter or colder body play a significant role.

Units of Heat

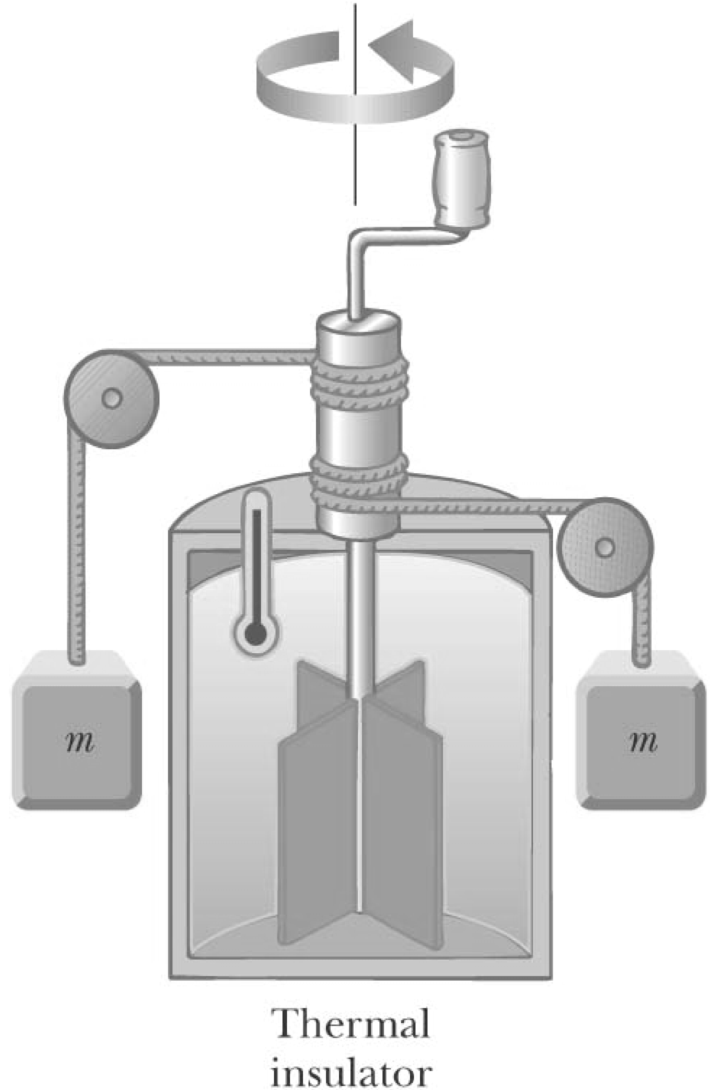
- Historically, the **calorie** was the unit used for heat
  - One **calorie** is the amount of **energy** transfer necessary **to raise** the temperature of **1 g of water**

    from **14.5^{o}C to 15.5^{o}C**
    - The “Calorie” used for food is actually

      1 kilocalorie

Mechanical Equivalent of Heat

- Joule established the equivalence between mechanical energy and internal energy
- His experimental setup is shown at right
- The loss in potential energy associated with the blocks equals the work done by the paddle wheel on the water



Mechanical Equivalent of Heat

- Joule found that it took approximately 4.18 J of mechanical energy to raise the temperature of water by 1.0 ^{o}C
- Later, more precise, measurements determined the amount of mechanical energy needed to raise the temperature of water from 14.5^{o}C to 15.5^{o}C
- **1 cal = 4.186 J**
  - This is known as the **mechanical equivalent of heat**

Heat Capacity

- The **heat capacity**, C, of a particular sample is defined as the amount of energy needed to raise the temperature of that sample by 1.0 ^oC
- If energy *Q* produces a change of temperature of ΔT, then

$$\boldsymbol{Q = C \, \Delta T}$$

Specific Heat

- **Specific heat**, c, is the heat capacity per **unit mass**
- If energy *Q* transfers to a sample of a substance of mass *m* and the temperature changes by ΔT, then the specific heat is

$$c \equiv \frac{Q}{m\,\Delta T}$$

Specific Heat

- The specific heat is essentially a measure of how insensitive a substance is to the addition of energy
  - The greater the substance's specific heat, the more energy that must be added to cause a particular temperature change
- The equation is often written in terms of *Q* :

$$Q = m\,c\,\Delta T$$

Some Specific Heat Values

Substance	Specific heat c J/kg · °C	Specific heat c cal/g · °C
Elemental solids		
Aluminum	900	0.215
Beryllium	1 830	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Gold	129	0.030 8
Iron	448	0.107
Lead	128	0.030 5
Silicon	703	0.168
Silver	234	0.056

More Specific Heat Values

	Specific heat c	
Substance	**J/kg · °C**	**cal/g · °C**
Other solids		
Brass	380	0.092
Glass	837	0.200
Ice (−5°C)	2 090	0.50
Marble	860	0.21
Wood	1 700	0.41
Liquids		
Alcohol (ethyl)	2 400	0.58
Mercury	140	0.033
Water (15°C)	4 186	1.00
Gas		
Steam (100°C)	2 010	0.48

Sign Conventions

- If the temperature increases:
  - *Q* and ΔT are positive
  - Energy transfers into the system
- If the temperature decreases:
  - *Q* and ΔT are negative
  - Energy transfers out of the system

Specific Heat Varies With Temperature

- The specific heat varies with temperature
- The corrected equation is: $Q = m\int_{T_i}^{T_f} c\,dT$
- However, if the temperature intervals are not too large, the variation can be ignored and *c* can be treated as a constant
  - There is only about a 1% variation between 0^{o} and 100^{o}C

If heating is carried out under conditions of arbitrarily changing pressure and volume, ***c*** is found to be **different for each different “path”** or sequence of states.

Hence, it is apparent that specific heat becomes a uniquely definable property only if the path of the heating process is uniquely specified.

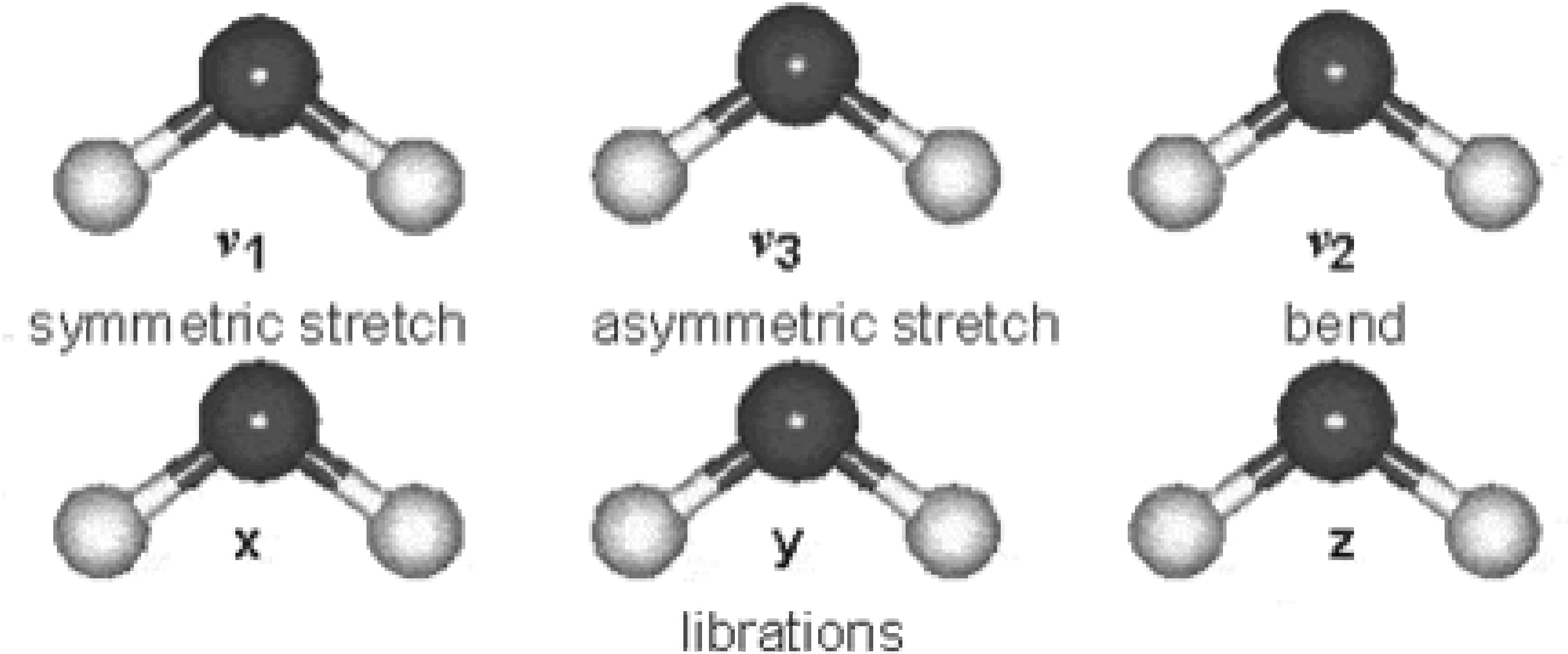
The method of mixtures is usually used under conditions of **constant** atmospheric **pressure**, and the specific heat so determined is denoted by the symbol c_P, “**specific heat at constant pressure**,” and this is really what we have been talking about up to this point.

Another readily defined path is the **constant volume** process. Specific heats so determined are labeled c_V.

Specific Heat of Water

- Water has the highest specific heat of common materials
- This is responsible for many weather phenomena
  - Moderate temperatures near large bodies of water
  - Global wind systems
  - Land and sea breezes

Water vibrations and rotations



http://www.lsbu.ac.uk/water/vibrat.html

Calorimetry

- One technique for measuring specific heat involves heating a material, adding it to a sample of water, and recording the final temperature
- This technique is known as **calorimetry**
  - A calorimeter is a device in which this energy transfer takes place

Calorimetry

- The system of the sample and the water is isolated
- Conservation of energy requires that the amount of energy that leaves the sample equals the amount of energy that enters the water
  - **Conservation of Energy** gives a mathematical expression of this:

$$Q_{\mathrm{cold}} = -Q_{\mathrm{hot}}$$

Calorimetry

- The negative sign in the equation is critical for consistency with the established sign convention
- Since each $Q = mc\Delta T$, c_{sample} can be found by:

$$c_s = \frac{m_w c_w \left(T_f - T_w\right)}{m_s \left(T_s - T_f\right)}$$

  – Technically, the mass of the container should be included, but if $m_w >> m_{\text{container}}$ it can be neglected

Calorimetry, Example

- An ingot of metal is heated and then dropped into a beaker of water. The equilibrium temperature is measured

$$c_s = \frac{m_w c_w \left(T_f - T_w\right)}{m_s \left(T_s - T_f\right)}$$

$$= \frac{(0.400\,\text{kg})(4186\,\text{J/kg}\cdot{}^\circ\text{C})(22.4^\circ\text{C} - 20.0^\circ\text{C})}{(0.0500\,\text{kg})(200.0^\circ C - 22.4^\circ C)}$$

$$= 453\ \text{J/kg}\cdot{}^\circ\text{C}$$