Experiment: Water in a Blender

- Fill blender with water
- Measure initial temperature
- Blend on high for 5 min.
- Measure temperature again
- Temperature increases: why?

# Energy Conversion Examples

- Potential energy storage in a spring

- Electrical current generating heat in your computer

- Breaking and re-forming chemical bonds

Why Talk About Molecules?

- "If it's good enough for Lord Kelvin, it's good enough for me."

- Kinetic theory in its infancy (Brownian motion, c. 1830)

- Classical thermodynamics doesn't rely on a molecular framework

William Thomson, 1824-1907

J. Willard Gibbs, 1839-1903

Images from Wikipedia.
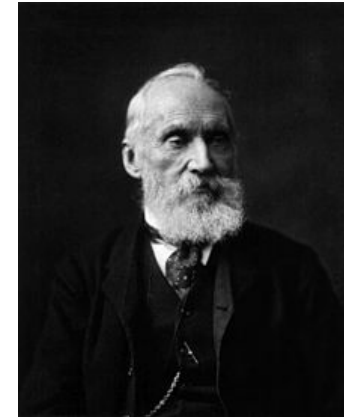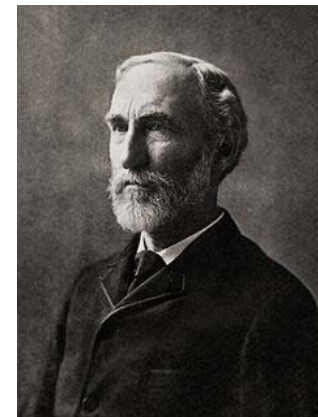
3

Why Talk About Molecules?

- Molecular reasoning makes thermodynamics more intuitive

- Understanding protein and DNA structure is very useful

- Thermodynamics guides our understanding of molecular interactions

William Thomson, 1824-1907

J. Willard Gibbs, 1839-1903

Images from Wikipedia.

4
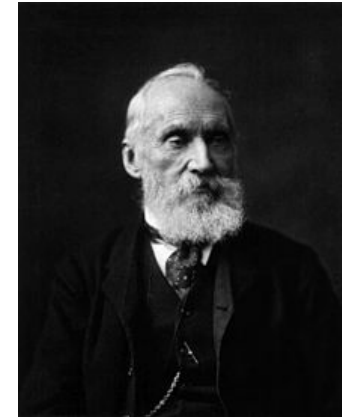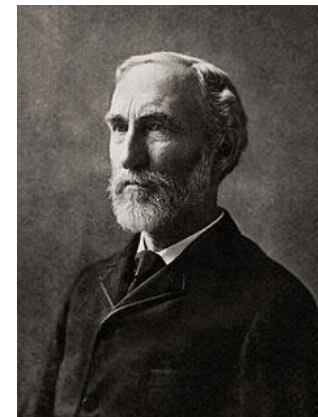
Systems and Surroundings

- **System:** The part of the universe we're interested in

- **Surroundings:** Everything else (generally "local" surroundings, e.g. the lab vs. Jupiter)

- **Boundary:** Geometric surface between system and surroundings

Systems and Surroundings

- **Isolated System:** A system with no mass or energy exchange with surroundings

- **Closed System:** No exchange of mass, but heat exchange possible

- **Open System:** Both heat and mass can exchange

Work Example #1

A piston lifts a 10.0 kg mass from the ground to a height of 10.0 m off the ground. How much work does it do?

Work Example #2

A gas with a pressure P is stored in a cylinder. The top of the cylinder is airtight but can expand against an external pressure P_{ex}. Derive an expression for the work if the gas expands from a volume of V_1 to V_2.

What is the work if P_{ex} is zero?

Properties of the Heat Capacity

- How easy is it to change an object's temperature?

- Orange curve has highest heat capacity: large change in heat → small change in T

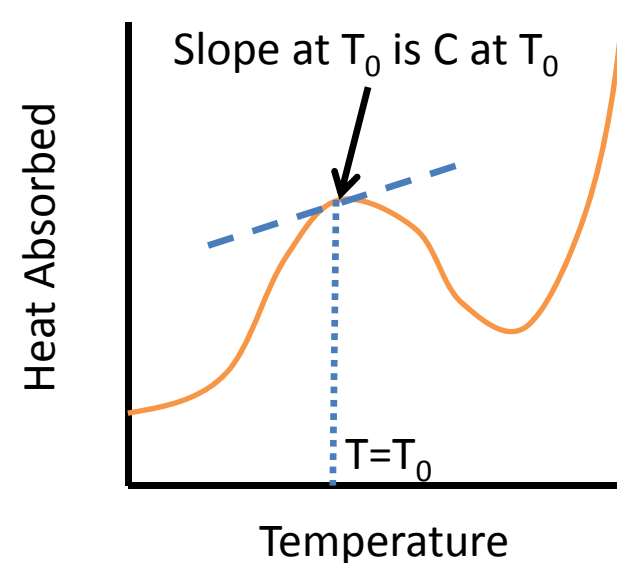- High C is like a buffer, resisting changes in T as q is added

Heat Absorbed
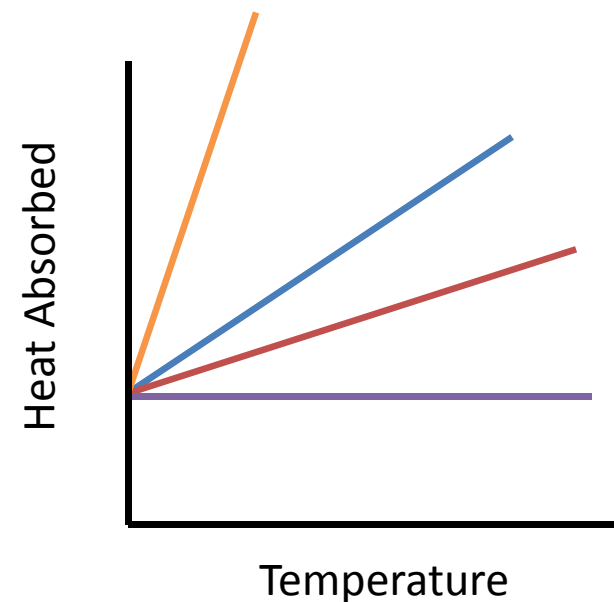
Temperature

Heat Capacity and Calculus

- If we know q(T):

$$C(T) = \lim_{h \to 0} \frac{q(T+h) - q(T)}{h}$$

- C is usually roughly constant for most materials over most temperature ranges

- Integration is possible to determine dq from dT.

$$C = \frac{dq}{dT} \rightarrow \Delta q = \int_{T_1}^{T_2} C \, dT$$

Slope at T_0 is C at T_0

Heat Absorbed

$T = T_0$

Temperature

10

Question

At 25 ^{o}C, which has a higher heat capacity, 100.0 g of water or 500.0 g of water?

Question

At 25 °C, which has a higher heat capacity, 100.0 g of water or 500.0 g of water?

- Normally, C scales with size of system, but C per unit mass (or moles) does not:
    - $\bar{C}_V$, $\bar{C}_P$: Molar heat capacity (J mol^{-1} K^{-1})
    - C_V^*, C_P^* : Specific heat capacity (J mol^{-1} kg)

Intensive vs. Extensive Properties

- **Extensive:** Properties that depend on the system size (they *ex*tend as the system gets bigger). E.g. Volume, Heat Capacity.

- **Intensive:** Properties that do not scale with the size of the system (they are *independent* of system size). E.g. Pressure, Molar Heat Capacity.

Heat Capacity and Materials

- C depends on conditions: i.e. whether volume of system is constant (C_V) or pressure is constant (C_P)

- Volume and pressure changes are small for liquids and solids, so $C_P \approx C_V$. For a gas, $C_P \neq C_V$

- Values given for 1 mol of water

C_P = 38.09 J/K C_V= 38.08 J/K

C_P = 75.33 J/K C_V= 74.53 J/K

C_P = 37.47 J/K C_V = 28.03 J/K

14

The First Law

- Assume a system has an _internal energy_ (E), representing all energies of atoms, bonds, etc.

- Then, any change in E can be calculated as:

Work done by or to system

$$\Delta E_{sys} = \Delta q + \Delta w$$

Heat added to or lost by system

- Note equivalence of heat and work: They can both change E in the same way

The First Law: Consequences

- Since energy is conserved:
$$\Delta E_{sys} + \Delta E_{surroundings} = 0$$

- Work and heat are <u>*not*</u> conserved
  – Calculating real-world changes in heat/work of system/surroundings is not often trivial

- Isolated system: $\Delta E = 0$

What About Internal Energy?

- It is an (extensive) property of the system:
$$E = E(V, T, N_1, N_2, ...)$$

- **ONLY THE AMOUNT OF HEAT AND WORK MATTERS, NOT HOW IT IS GENERATED!!!!**

- Thus, the change in E depends only on the initial and final conditions, not the process, reversibility, etc. (This is really important!)