First Law of Thermodynamics: The first law of thermodynamics is another name for the law of conservation of energy for a system. If a heat flows into a system from the surroundings, the system gains internal energy as the random kinetic energy of its particles increases. Likewise, a system will also gain energy if an outside agent does work on the system through the application of forces. The figure below shows an isolated (insulated) system in which the energy stays constant.

**Isolated System**

The next figure shows a system that has energy flowing in from the surroundings.

**System gaining energy**

The first law of thermodynamics predicts the change in internal energy ($\Delta E_{\text{int}}$) of a system as follows:

$$\Delta U_{\text{system}} = Q_{\text{in}} - W_{\text{by the system}}$$

or

$$\Delta U = Q - W$$
Summary:

+Q  heat transfer into system
-Q  heat transfer out of system
+W  Work done by the system
-W  Work done on the system

Surroundings

\[ \Delta U = Q - W \]

System losing energy

Example: 5 Joules of work is done in stirring a beaker of warm water. During this time, 15 Joules of heat transfers from the poorly insulated container. By how much did the internal energy of the container/water system change?

**Thermal processes:** Ideal gasses may do work through changes in pressure, volume, and/or temperature. Thermodynamic processes of ideal gasses are represented on a pressure-volume (p-V) diagram. By knowing both the pressure and volume at any point on the graph, the state of the gas is completely specified. Three common thermal processes for gasses are isobaric, isochoric, and isothermal processes.
An **isobaric process** is one that occurs at constant pressure. For example, a heated gas in a container may expand to lift a piston that applies a constant pressure. In the process of lifting the piston, work is done by the gas in increasing its volume. This is represented as follows on a p-V diagram:

```
  P
  |
  |
V_f----------V_i
```

The area of the shaded region represents the energy transferred from the gas to the gravitational energy stored in the lifted cylinder. In general,

\[ W = \text{Area under P-V graph} \]

Example: A gas expands from an initial volume of 0.40 m³ to a final volume of 0.8 m³ as the pressure increases linearly from 100kPa to 250KPa. Find the work done by the gas.

An **isochoric process** is one that occurs at constant volume. For example, a heated gas in a closed container has no room to expand and its pressure must rise. Even though the gas exerts more and more force on the walls, the walls do not move and the gas does *no work on the container*. This process is represented on the following p-V diagram:

```
P
  |
P_f----------------P_i
  |
V
```

Example: A gas is held at constant volume as the pressure increases from 100kPa to 250KPa. Find the work done by the gas.
An isothermal process is one that occurs at constant temperature. The pressure and volume of the gas must both change in order for the temperature to remain constant. For example, the following p-V diagram represents an ideal gas expanding isothermically:

![p-V diagram](image)

Notice how the pressure decreases and the volume increases. The area of the shaded region represents the energy transferred from the gas to its surroundings during the expansion.

The internal energy of a gas depends on temperature and the amount of moles. Since the temperature of the gas remains the same in isothermal processes, the internal energy of the gas must remain constant.

To find the work done during an isothermic expansion as the volume changes from $V_1$ to $V_2$:

$$W = \int_{V_1}^{V_2} p \, dV = \int_{V_1}^{V_2} \frac{nRT}{V} \, dV = nRT \left( \frac{V_2}{V_1} \right)$$

When $T$ is constant, $\frac{V_2}{V_1} = \frac{P_1}{P_2}$

$$\therefore W = nRT \left( \ln \frac{P_1}{P_2} \right)$$

Questions:

1) Consider the p-V graph to the right and answer the following questions:
   1) Which line demonstrates an ideal gas heated isochorically?
   2) Which line demonstrates isothermal compression of an ideal gas?
   3) Which line demonstrates isobaric expansion of an ideal gas?
**Adiabatic Processes:** If a system is well insulated, no transfer of heat will occur between it and its environment. This means that $Q = 0$, and the first law of thermodynamics shows that

$$\Delta U = -W$$

If work is done by the system (positive $W$) its internal energy decreases. Conversely, if work is done on the system (negative $W$) its internal energy will increase. For gases, the internal energy is related to the temperature: a higher internal energy means a higher temperature. **Adiabatic expansion of a gas will lower its temperature; adiabatic compression of a gas will increase its temperature.**

Adiabatic processes occur when an object is thermally insulated. When the volume of a system changes rapidly a adiabatic analysis may also be assumed.

**Second Law of Thermodynamics:** Throughout history, there are many claims of inventions that demonstrate "perpetual motion." Once started, perpetual motion machines supposedly operate without any additional source of energy. "Inventors" often claim that their output is used as input energy to keep them working. Many fools have completely lost their investments in these machines because the concept of perpetual motion fundamentally violates the laws of thermodynamics.

**Perpetual motion machines of the first kind** are systems that do work on their surrounding without any input of additional energy. This idea clearly violates the first law of thermodynamics because these machines would have to create their own energy to do their work. When a machine does work on its surroundings, energy is transferred out of the system, so all machines must eventually use all their stored energy.
Unlike perpetual motion machines, refrigerators and air conditioners are realistic devices that rely on the laws of thermodynamics in order to operate. Both devices move heat energy from one location to another through the change of phase of a refrigeration fluid (like freon).

The **second law of thermodynamics** states that heat naturally flows from warm regions to cold regions. Heat will NEVER spontaneously flow from cold regions to hot regions. This is bad news for refrigerators. In order to keep the interior of a refrigerator cold, a pump must do work to force the refrigerant through small openings inside the cooling unit. As the refrigerant evaporates, unwanted interior heat is transferred into it. Thus, the refrigerant enters the exterior condenser coils of the refrigerator as a gas. When the gas condenses back into the liquid phase in these coils, it releases heat energy into the kitchen before it is pumped back into the cooling unit to repeat the cycle. Air conditioners operate in the same way as refrigerators, except they pump heat energy from inside the house to the outdoors.

**Question:** Is it possible to cool your house by leaving the door of the refrigerator open?
The Carnot Cycle: Consider a heat engine operating between a single hot reservoir at the fixed temperature \( (T_h) \) and a single cold reservoir \( (T_c) \). Carnot theorized the following:

1) If a engine operating between the two reservoirs is to have maximum efficiency, it must be an engine in which all of the processes are reversible.
2) A reversible engine operating between the same two temperatures \( T_h \) & \( T_c \) have the same efficiency.

Carnot’s efficiency equation is as follows:

\[
e_{\text{max}} = 1 - \frac{T_c}{T_h}
\]

Note#1: **Engine processes can NEVER be perfectly reversible!**
Carnot’s analysis just provides the upper limit to an engine’s efficiency. Technology cannot improve the efficiency beyond this point.

Note #2: The maximum efficiency has nothing to due with the type of fuel or the design of the engine. The only thing that makes a difference is \( T_h \) & \( T_c \)!

Question: A heat engine operates in two modes. Mode #1 operates between two reservoirs at 200 and 400K. Mode #2 operates between 400K and 600K. How do their maximum efficiencies of the modes compare?