

## Thermodynamic processes

### Select LEARNING OBJECTIVES:

- Understand how the first law is used to analyze thermodynamic cycles.
- Be able to identify the different types of thermodynamic processes if given a state variable which is said to be held constant.
- Know how to calculate the pressure or temperature at a given point on a P-V diagram.

### TEXTBOOK CHAPTERS:

- Giancoli (Physics Principles with Applications 7<sup>th</sup>) :: 15-2, 15-6
- Knight (College Physics : A strategic approach 3<sup>rd</sup>) :: 12.3
- BoxSand :: [Processes and PV-Diagrams](#)

**WARM UP:** Can the entropy of a system ever decrease?

Consider gas enclosed inside a container resting on a table. After waiting a long time, the gas will reach an equilibrium condition; we call this the thermodynamic equilibrium state. The gas has a unique pressure, volume, and temperature. But what if we move the container from the table to a location in front of a fireplace? The gas will be heated and the temperature and pressure will increase until the gas again reaches a new equilibrium state with the same volume as before but new temperature and pressure. The changing from one equilibrium state to a new equilibrium state is called a thermodynamic process. In this lecture we will study a few common types of thermodynamic processes, and in the next lecture we will look at what happens when multiple thermodynamic processes are performed in sequence.

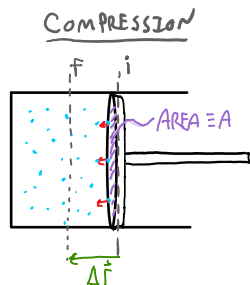
### Another look at work

Recall our definition of work from a constant force is

$$W = \vec{F} \cdot \Delta \vec{r} = |\vec{F}| |\Delta \vec{r}| \cos \theta$$

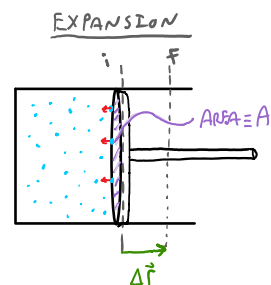
$\uparrow$   
 CONSTANT FORCE

Where the angle theta is the smallest angle between the force and the displacement vectors when placed tail to tail. To help illustrate this, consider a gas enclosed in a container with a movable piston.



$$W = \sum \vec{F}_{\text{of GAS}} \cdot \Delta \vec{r} = \left| \sum \vec{F}_{\text{of GAS}} \right| |\Delta \vec{r}| \cos \theta$$

$\leftarrow \Delta \vec{r}$  }  $W_{\text{of GAS}}$  IS POSITIVE



$$W = \sum \vec{F}_{\text{of GAS}} \cdot \Delta \vec{r} = \left| \sum \vec{F}_{\text{of GAS}} \right| |\Delta \vec{r}| \cos \theta$$

$\leftarrow \Delta \vec{r}$  }  $W_{\text{of GAS}}$  IS NEGATIVE

$$W_{\text{OP GAS}} = \sum \vec{F}_{\text{OP GAS}} \cdot \Delta \vec{l} = \left| \sum \vec{F}_{\text{OP GAS}} \right| |\Delta \vec{l}| \cos \theta$$

$\left. \begin{array}{l} \leftarrow \sum \vec{F}_{\text{OP GAS}} \\ \rightarrow \Delta \vec{l} \end{array} \right\} W_{\text{OP GAS}} \text{ IS POSITIVE}$

$$W_{\text{OP GAS}} = \sum \vec{F}_{\text{OP GAS}} \cdot \Delta \vec{l} = \left| \sum \vec{F}_{\text{OP GAS}} \right| |\Delta \vec{l}| \cos \theta$$

$\left. \begin{array}{l} \leftarrow \sum \vec{F}_{\text{OP GAS}} \\ \rightarrow \Delta \vec{l} \end{array} \right\} W_{\text{OP GAS}} \text{ IS NEGATIVE}$

WITH PRESSURE  $\equiv P = \frac{F_{\perp}}{A}$

$$F_{\perp} = PA$$

$$\left| \sum \vec{F}_{\text{OP GAS}} \right| = PA$$

THEN ...

$$W_{\text{OP GAS}} = P A |\Delta \vec{l}| \cos \theta$$

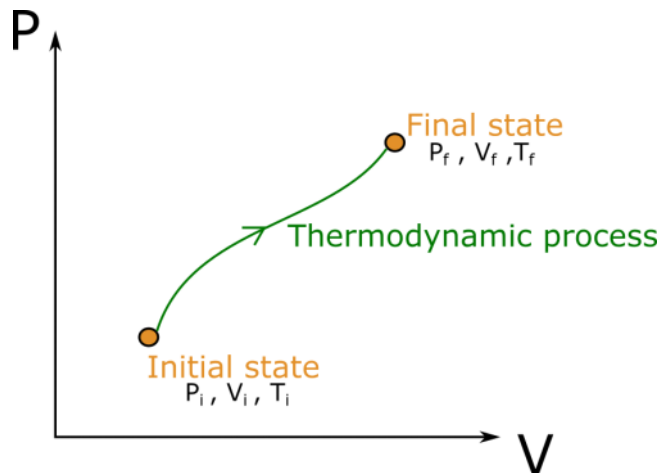
CHANGE IN VOLUME  $\equiv \Delta V$

$$W_{\text{OP GAS}} = -P \Delta V \quad * \text{ VALID FOR CONSTANT PRESSURE}$$

NEED SINCE  $\Delta V = V_f - V_i$

## P-V Diagrams

First look at our new expression for work as a pressure times change in volume. This type of relationship is in a familiar form which suggests that work is the area under a pressure vs volume graph. Thus it is natural to use a P vs V graph to represent the state of our system along with the different types of thermodynamic processes. Recall that the state of a thermodynamic system is characterized by a set of macroscopic variables (state variables): P, V, T, N. Thus the state of a thermodynamic system is represented by a dot on a P-V diagram. Thermodynamic systems can change their state via a thermodynamic process which is represented by a curve/path on a P-V diagram. Also remember we can only specify equilibrium states because they do not change in time. When a thermodynamic system changes its state, we will assume a quasi-static process. A quasi-static process is one where at each instant during a thermodynamic process, the system is very close to an equilibrium state.



## Model and assumptions

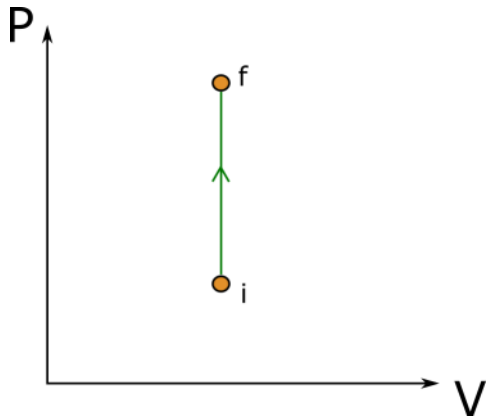
While discussing thermodynamic processes we will limit our study by considering the following constraints.

- Idea gasses are used for all thermodynamic processes.
- The number of particles is constant during all thermodynamic process.
- All thermodynamic processes are quasi-static: at each instant in time the system is very close to

equilibrium. Basically this limits our studies to "slow" processes.

## Thermodynamic processes

### Isochoric (constant volume)



• IDEAL GAS EQUATION OF STATE

$$PV = Nk_B T$$

$$\text{w/ } V_i = V_f \text{ + } N = \text{CONSTANT}$$

$$\boxed{\frac{P}{T} = \text{CONSTANT}}$$

• 1<sup>ST</sup> LAW OF THERMODYNAMICS

$$\Delta E^{th} = W + Q$$

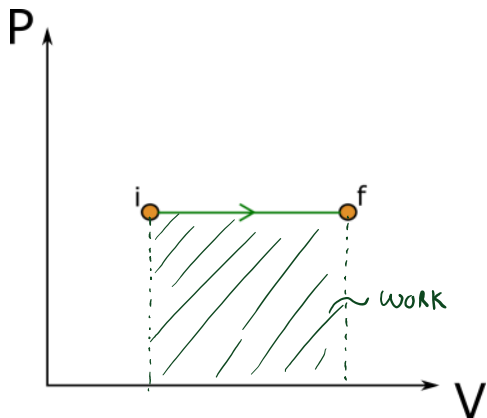
$$\text{w/ AREA} = 0$$

$$W = 0$$

$$\Delta E^{th} = \cancel{W} + Q$$

$$\boxed{\Delta E^{th} = Q}$$

### Isobaric (constant pressure)



• IDEAL GAS EQUATION OF STATE

$$PV = Nk_B T$$

$$\text{w/ } P_f = P_i \text{ + } N = \text{CONSTANT}$$

$$\boxed{\frac{T}{V} = \text{CONSTANT}}$$

• 1<sup>ST</sup> LAW OF THERMODYNAMICS

$$\Delta E^{th} = W + Q$$

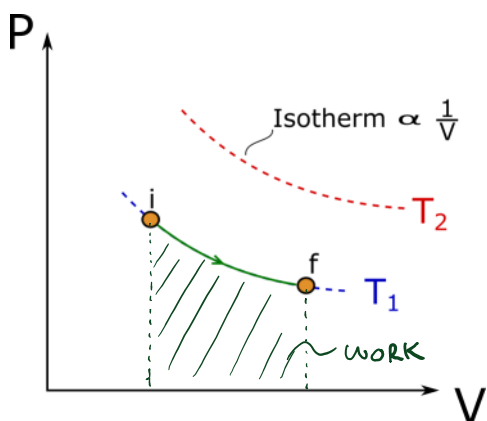
$$W = \pm \text{AREA} = -P \Delta V$$

+ IF COMPRESSED

- IF EXPAND

$$\boxed{\Delta E^{th} = W + Q}$$

### Isothermal (constant temperature)



• IDEAL GAS EQUATION OF STATE

$$PV = Nk_B T$$

$$\text{w/ } T_i = T_f \text{ + } N = \text{CONSTANT}$$

$$\boxed{PV = \text{CONSTANT}}$$

• 1<sup>ST</sup> LAW OF THERMODYNAMICS

$$\Delta E^{th} = W + Q$$

$$\Delta E^{th} = 0$$

$$W = \pm \text{AREA} = -Nk_B T \ln\left(\frac{V_f}{V_i}\right)$$

+ IF COMPRESSED

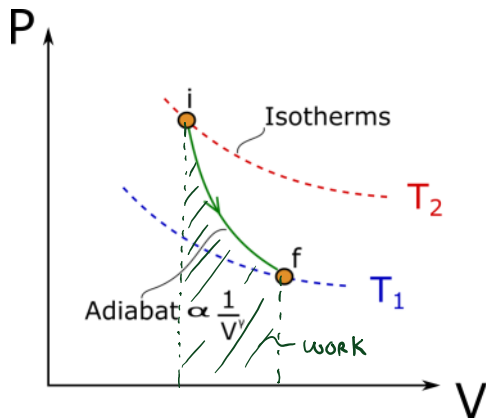
- IF EXPAND

$$\Delta E^{th} = W + Q$$

$$0 = W + Q$$

$$\boxed{W = -Q}$$

Adiabatic (no heat transfer)



• IDEAL GAS EQUATION OF STATE

$$PV = Nk_B T$$

w/ NO Q + N = CONSTANT

$$PV^\gamma = \text{CONSTANT} \dots \gamma = \frac{5}{3} \text{ FOR MONATOMIC GAS}$$

• 1<sup>ST</sup> LAW OF THERMODYNAMICS

$$\Delta E^{\text{th}} = W + Q$$

$$Q = 0$$

$$W = \dots \pm \text{MESSY} \dots$$

$$\Delta E^{\text{th}} = W + \overset{0}{Q}$$

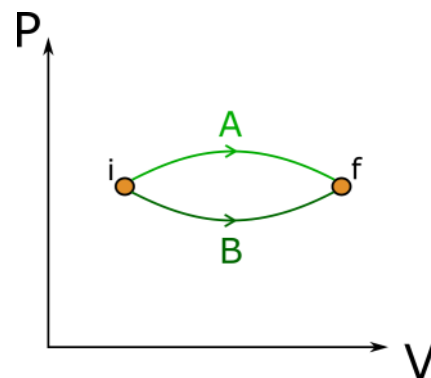
$$\Delta E^{\text{th}} = W$$

**PRACTICE:** A gas cylinder and piston are covered with heavy insulation. The piston is pushed into the cylinder compressing the gas. In this process, the gas temperature

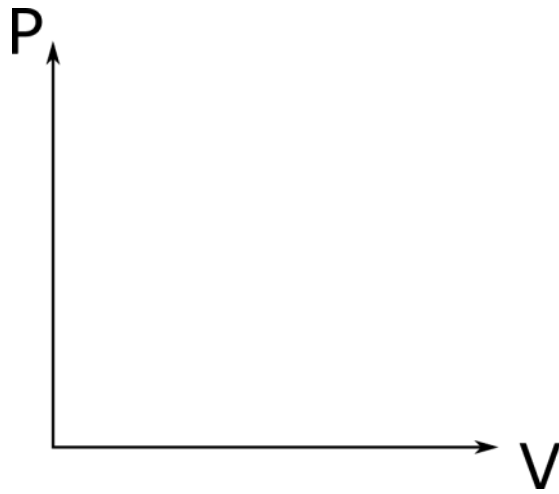
1. Increases.
2. Decreases.
3. Stays the same.
4. Not enough information to determine.

**PRACTICE:** For the two processes shown below, which of the following statements is true?

1.  $Q_A < Q_B$
2.  $Q_A > Q_B$
3.  $Q_A = Q_B$



**PRACTICE:** 1 mole of monatomic gas is enclosed in a cylinder with a piston; the setup is covered with a heavy insulation. The piston is pushed into the cylinder compressing the gas from 2.5 L to 1.0 L while maintaining a constant temperature of 300 K. Sketch this process on the provided axis below. Include labels and axes scales.



**PRACTICE:** Circle the first bar chart that describes the process shown in the PV diagram.

