

**PHYN001**  
**Cairo University, Faculty of Engineering**  
**Credit Hours System**  
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# **Unit 07 Temperature, Heat, and First Law of Thermodynamics**

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## **Reference**

Serway, Raymond A. and Jewett, John W. *Physics for scientists and engineers with modern physics*. 9<sup>th</sup> Ed.

# TEMPERATURE, HEAT, AND FIRST LAW OF THERMODYNAMICS

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- [Temperature](#)
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# TEMPERATURE, HEAT, AND FIRST LAW OF THERMODYNAMICS

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- Temperature
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# TEMPERATURE

## The Celsius and Kelvin Temperature Scales

$$T_C = T_K - 273.15^\circ$$

$$\Delta T_C = \Delta T_K$$

# TEMPERATURE

## Thermal Expansion of Solids and Liquids

If a solid object of length  $L_i$  is heated so that its temperature is raised by  $\Delta T$  its length will increase by  $\Delta L$ . If  $\Delta T$  is not very high, change in length is given by:

$$\Delta L = \alpha L_i \Delta T$$

$\alpha$ : Average coefficient of linear expansion

$$\therefore L_f = L_i (1 + \alpha \Delta T)$$

# TEMPERATURE

## Thermal Expansion of Solids and Liquids

The change in volume is given by:

$$\Delta V = \beta V_i \Delta T$$

$\beta$ : Average coefficient of volume expansion

$$\therefore V_f = V_i(1 + \beta \Delta T)$$

For an **isotropic** solid:  $\beta = 3\alpha$

*Water has a peculiar behavior below 4°C: its volume starts to increase as the temperature decreases*

# TEMPERATURE, HEAT, AND FIRST LAW OF THERMODYNAMICS

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# SPECIFIC HEAT AND LATENT HEAT

## Heat

The **transfer of energy** across the boundary of a system due to a **temperature difference** between the system and its surroundings

$$1 \text{ Calorie} = 4.186 \text{ Joule}$$

“4.186” is called the **mechanical equivalent** of heat.

The unit of energy written on food products as **Calorie** with a capital “C” is actually a **kilocalorie**.



# SPECIFIC HEAT AND LATENT HEAT

## Thermal Equilibrium

Two objects do not **exchange energy** when brought into thermal contact.

## Zeroth Law of Thermodynamics

If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other.

# SPECIFIC HEAT AND LATENT HEAT

## Heat Capacity (C)

The amount of energy needed to raise the temperature of a particular sample of a substance by 1°C

Energy  $Q$  necessary to raise temperature of a sample by  $\Delta T$  :

$$Q = C\Delta T$$

The unit of heat capacity is:

$$\text{J/}^\circ\text{C}$$

# SPECIFIC HEAT AND LATENT HEAT

## Specific Heat ( $c$ )

The heat capacity per unit mass of a substance.

$$c = \frac{Q}{m\Delta T} = \frac{C}{m}$$

$$\therefore Q = mc\Delta T$$

The unit of Specific Heat is:

$$\frac{\text{J}}{\text{kg } ^\circ\text{C}}$$

# SPECIFIC HEAT AND LATENT HEAT

## Heat of Transformation (Latent Heat, $L$ )

Heat of phase transform (fusion / vaporization) per unit mass

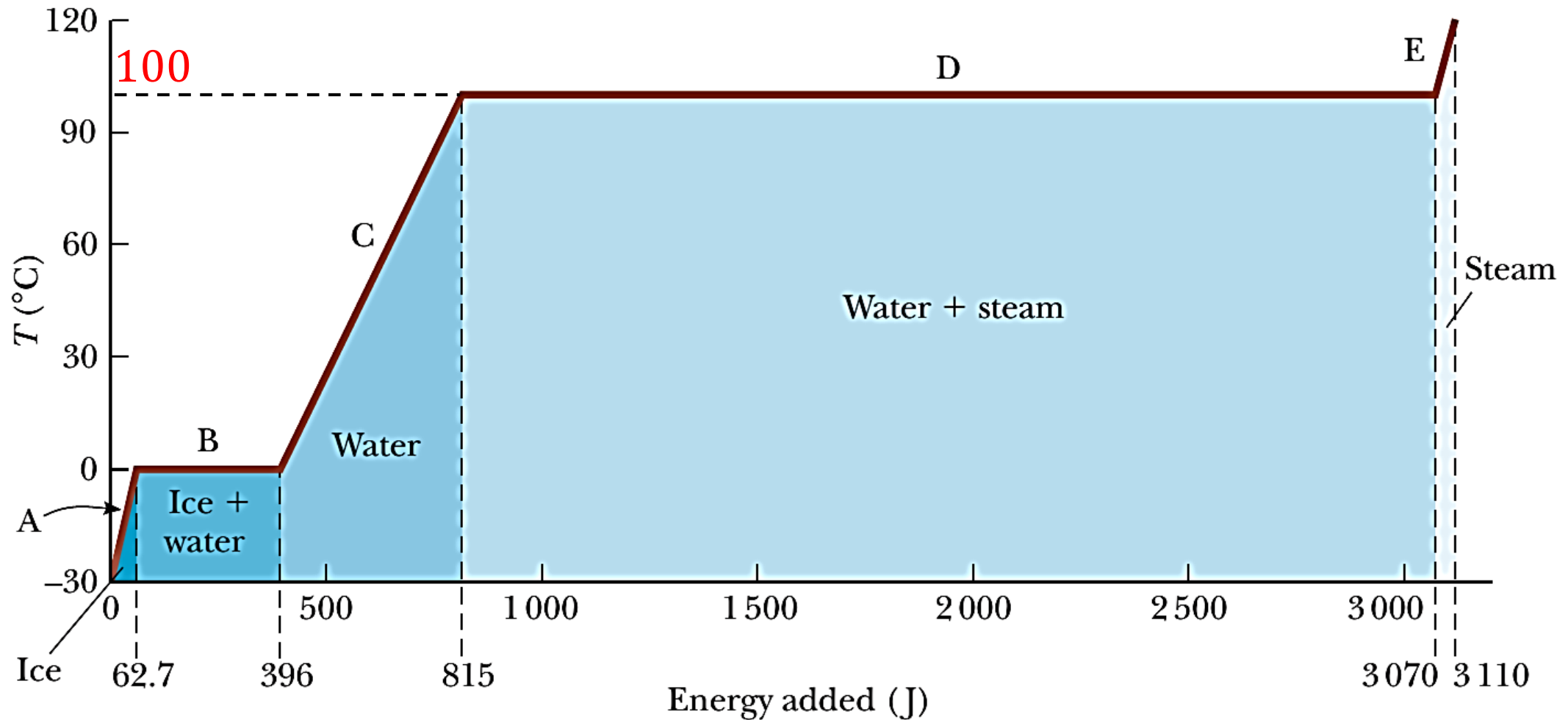
Amount of energy  $Q$  transferred to the substance to fuse/vaporize a mass  $m$  of it :

$$Q = \pm mL$$

The units of  $L$  is:

$$\text{J/kg}$$

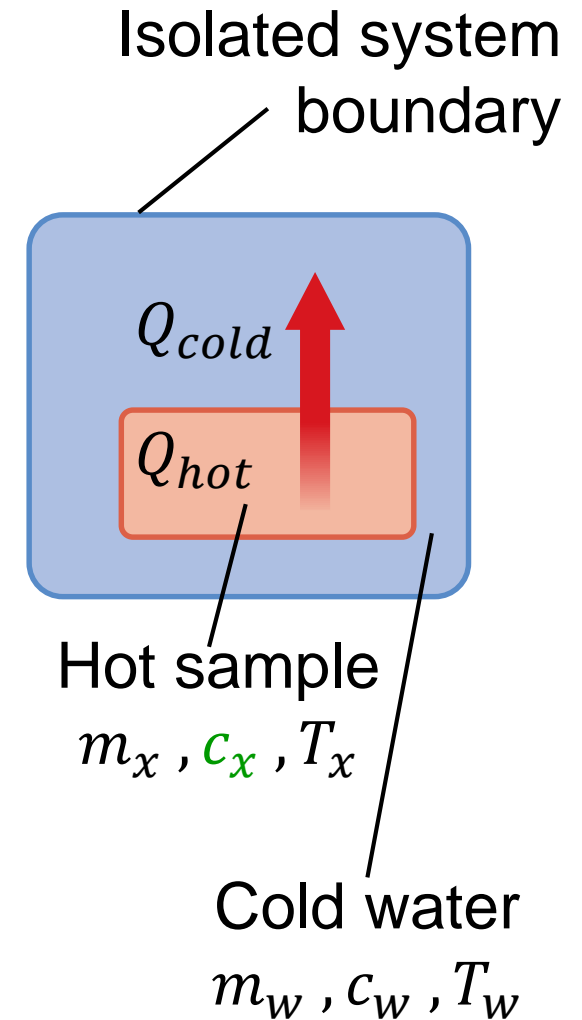
# SPECIFIC HEAT AND LATENT HEAT



# SPECIFIC HEAT AND LATENT HEAT

## Calorimetry: (to measure $c$ )

- Heat to known temperature  $T_x$
- Place in a vessel (calorimeter) of water of known  $m_w$  and  $T_w < T_x$
- After reaching thermal equilibrium final temperature is  $T_f$



# SPECIFIC HEAT AND LATENT HEAT

**Calorimetry:** (to measure  $c$ )

Heat Gained = Heat Lost

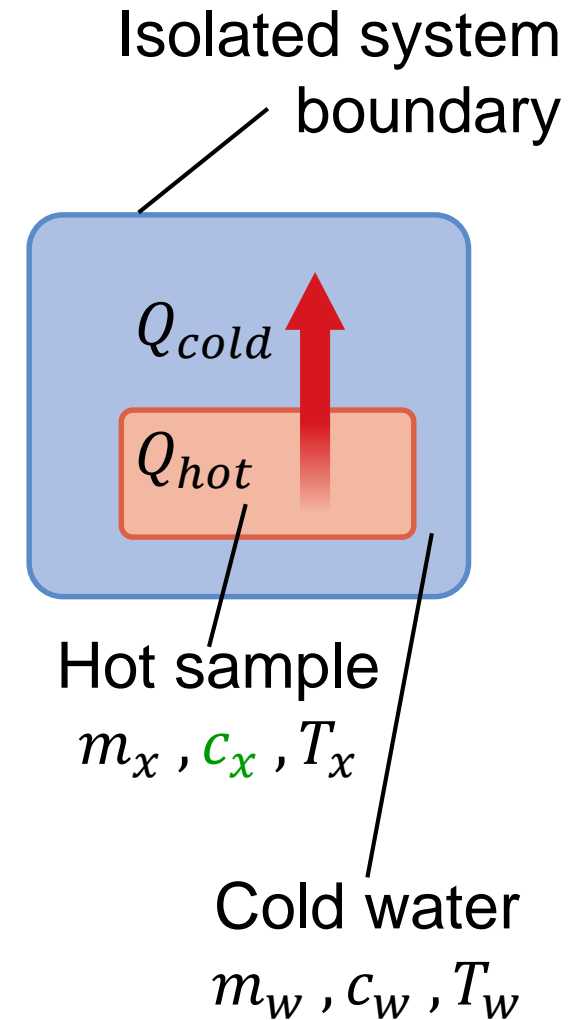
$$Q_{cold} = -Q_{hot}$$

$$(m_w c_w + m_c c_c)(T_f - T_i) = -m_x c_x (T_f - T_x)$$

If  $c_w \gg c_c$

$$m_w c_w (T_f - T_i) = -m_x c_x (T_f - T_x)$$

$$\therefore c_x = \frac{m_w c_w (T_f - T_i)}{m_x (T_x - T_f)}$$



# SPECIFIC HEAT AND LATENT HEAT

**Example 1:** A 0.05-kg ingot of metal is heated to 200.0°C and dropped into a beaker containing 0.4-kg of water initially at 20.0°C. If the final equilibrium temperature of the mix is 22.4°C.

Find the specific heat of the metal.  $c_{beaker} \ll c_w = 4186 \text{ J/kg}^\circ\text{C}$

## Solution

Heat lost by metal = heat gained by water.

$$-m_m c_m (T_f - T_{i_m}) = m_w c_w (T_f - T_{i_w})$$
$$c_m = \frac{m_w c_w (T_f - T_{i_w})}{-m_m (T_f - T_{i_m})} = \frac{(0.4)(4186)(22.4 - 20)}{-(0.05)(22.4 - 200)} = 453 \text{ J/(kg}^\circ\text{C)}$$



# SPECIFIC HEAT AND LATENT HEAT

**Example 2:** A cowboy fires a silver bullet with a speed of 200 m/s into the pine wall of a restaurant. Assume that all the internal energy generated by the impact remains with the bullet.

What is the bullet temperature change?  $c_{silver} = 234 \text{ J/kg } ^\circ\text{C}$

**Solution:** K.E. of the bullet is converted into internal energy

$$\begin{aligned}\therefore \frac{1}{2}mv^2 &= mc_{silver}\Delta T \\ \therefore \Delta T &= \frac{v^2}{2c_{silver}} = \frac{200^2}{2(234)} = 85.5 \text{ } ^\circ\text{C}\end{aligned}$$

# SPECIFIC HEAT AND LATENT HEAT

**Example 3:** 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?  $c_s = 2010 \text{ J/kg } ^\circ\text{C}$   
 $L_{wvap} = 2.26 \times 10^6 \text{ J/kg}$      $c_w = 4186 \text{ J/kg}^\circ\text{C}$      $c_g = 837 \text{ J/kg}^\circ\text{C}$

## Solution

Heat lost by steam = heat gained by water and container

$$-Q_{Hot} = Q_{Cold}$$

$$-\left[m_s c_s (100 - T_{i_s}) + \Delta m_s L + m_s c_w (T_f - 100)\right] = (m_w c_w + m_g c_g)(T_f - T_{i_w})$$

$$\Delta m_s = 0 - m_s$$

$$m_s = \frac{(m_w c_w + m_g c_g)(50 - 20)}{-[c_s(100 - 130) - L + c_w(50 - 100)]} = 0.0109 \text{ kg}$$

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# WORK AND HEAT IN THERMODYNAMIC PROCESSES

## State Variables

- Variables that take definite values which are characteristic of the state of a system in thermal equilibrium in a certain state.  $(T, P, V, \dots)$

## Transfer Variables

- Quantities that are defined only during the process in which the system goes from one state to another.  $(Q, W, \dots)$

# WORK AND HEAT IN THERMODYNAMIC PROCESSES

## Macroscopic Behavior of an Ideal Gas

If **pressure** of a gas is low enough (low density), relationship between its **volume**, **pressure** and **temperature** is

$$PV = nRT$$

Equation of state of an ideal gas

$$n = \text{number of moles of the gas} = \frac{\text{mass of the gas}}{\text{molecular weight}}$$

$$R \equiv \text{Universal gas constant} = 8.314 \text{ J}/(\text{mol} \cdot \text{K})$$

# WORK AND HEAT IN THERMODYNAMIC PROCESSES

Change of  $V$  quasi-statically

- system in thermal equilibrium.

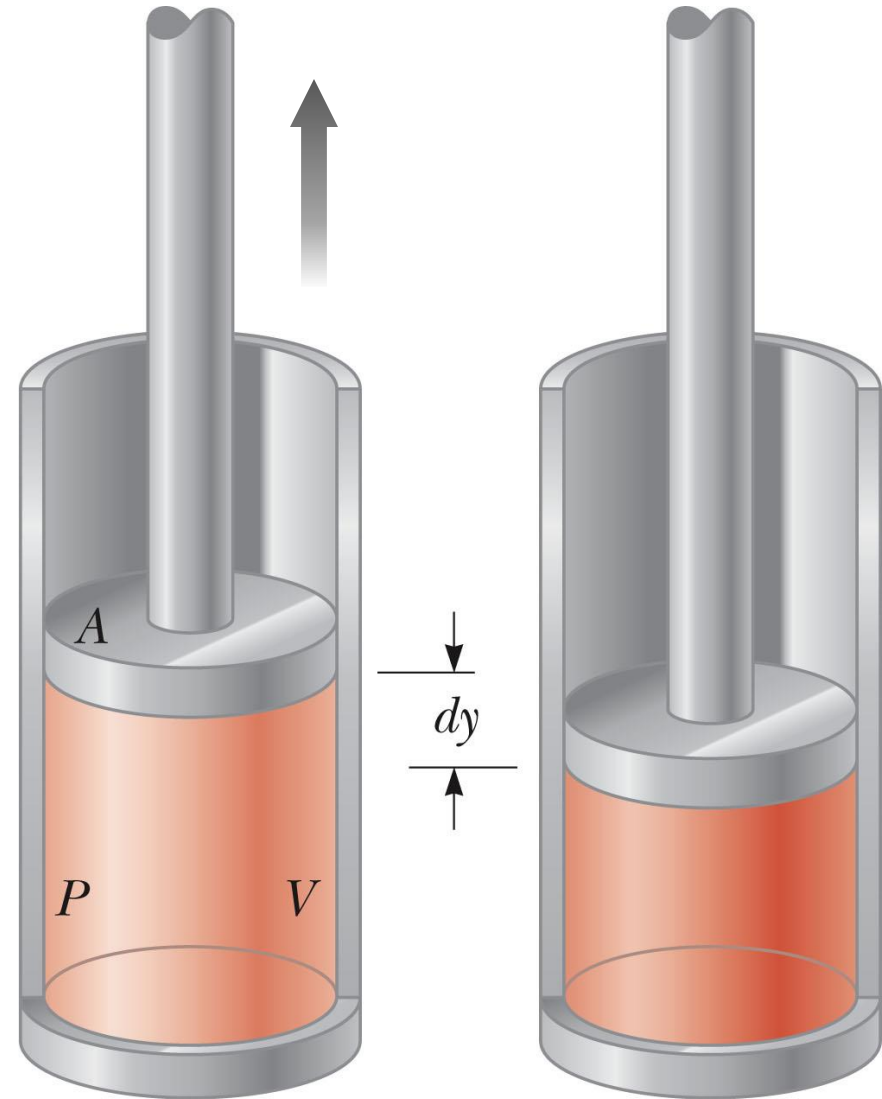
Work done by gas by  $\underline{F}$  during infinitesimal change of volume:

$$dW = \underline{F} \cdot d\underline{\ell}$$

$$dW = (PA\underline{\hat{j}}) \cdot (dy\underline{\hat{j}})$$

$$dW = PA dy$$

$$\therefore dW = PdV$$



# WORK AND HEAT IN THERMODYNAMIC PROCESSES

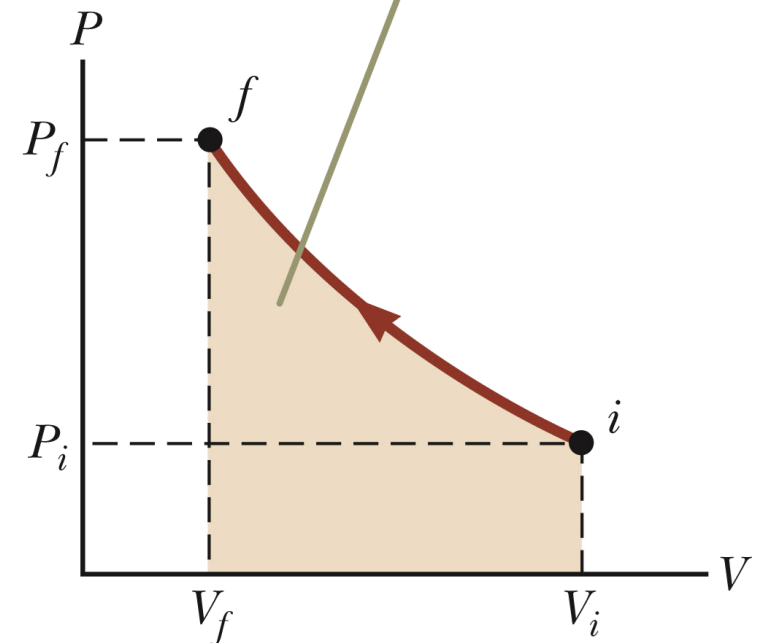
$$\therefore W = \int_{V_i}^{V_f} P dV$$

Total work done by gas:

- Equals the area under the curve.
- Depends on the path between the initial and final states.

Similarly, the heat  $Q$  added to a system during the change from the initial to the final state depends on the path.

The work done on a gas equals the value of the area under the  $PV$  curve. The area is negative here because the volume is decreasing, resulting in negative work.



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# THE FIRST LAW OF THERMODYNAMICS

It was experimentally found that the difference between the heat added to a system and the work done by it ( $Q - W$ ) during a quasi static process is a state variable: *Internal Energy*

$$\Delta E_{int} = Q - W$$

First law of Thermodynamics

$$dE_{int} = dQ - PdV$$

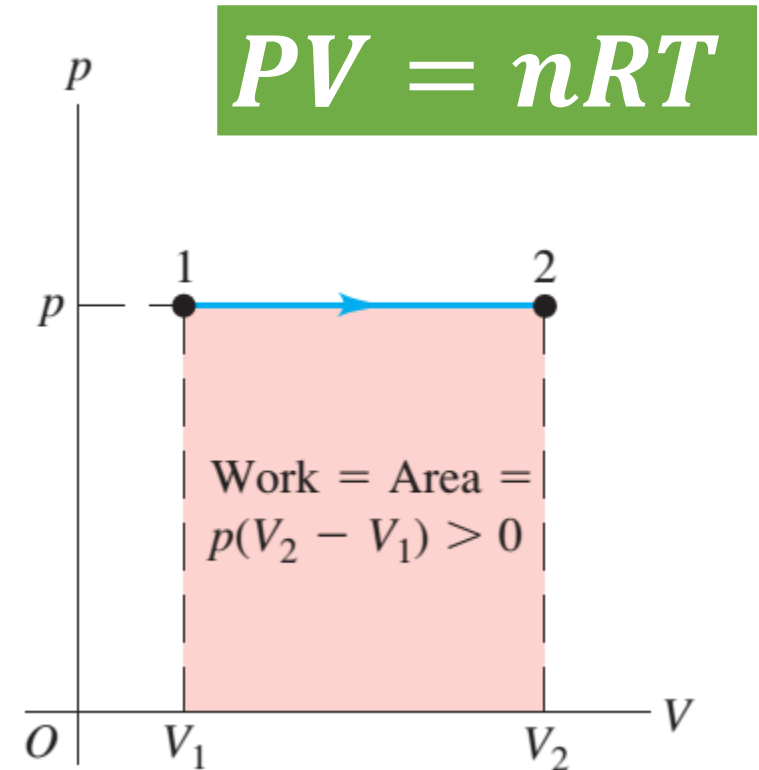
# THE FIRST LAW OF THERMODYNAMICS

## Isobaric Process (Constant Pressure)

$$P = \text{Const}$$

$$W = P(V_f - V_i)$$

$$\Delta E_{int} = Q - P(V_f - V_i)$$



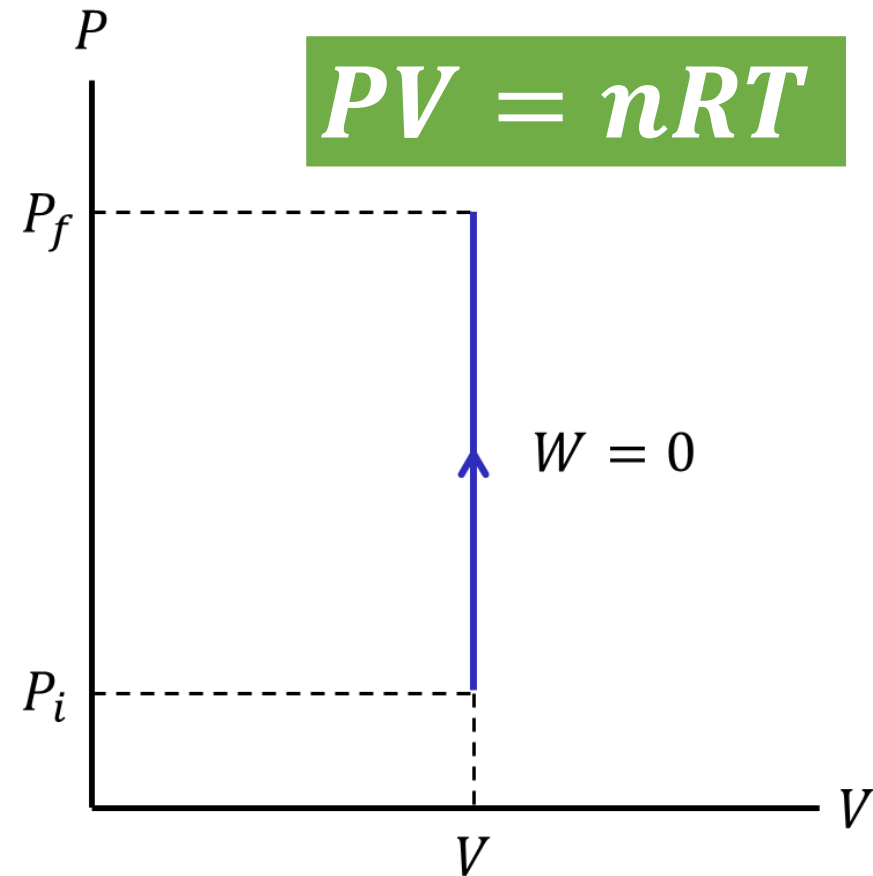
# THE FIRST LAW OF THERMODYNAMICS

## Isovolumetric Process (Constant Volume)

$$V = \text{Const}$$

$$\therefore W = 0$$

$$\therefore \Delta E_{int} = Q$$



# THE FIRST LAW OF THERMODYNAMICS

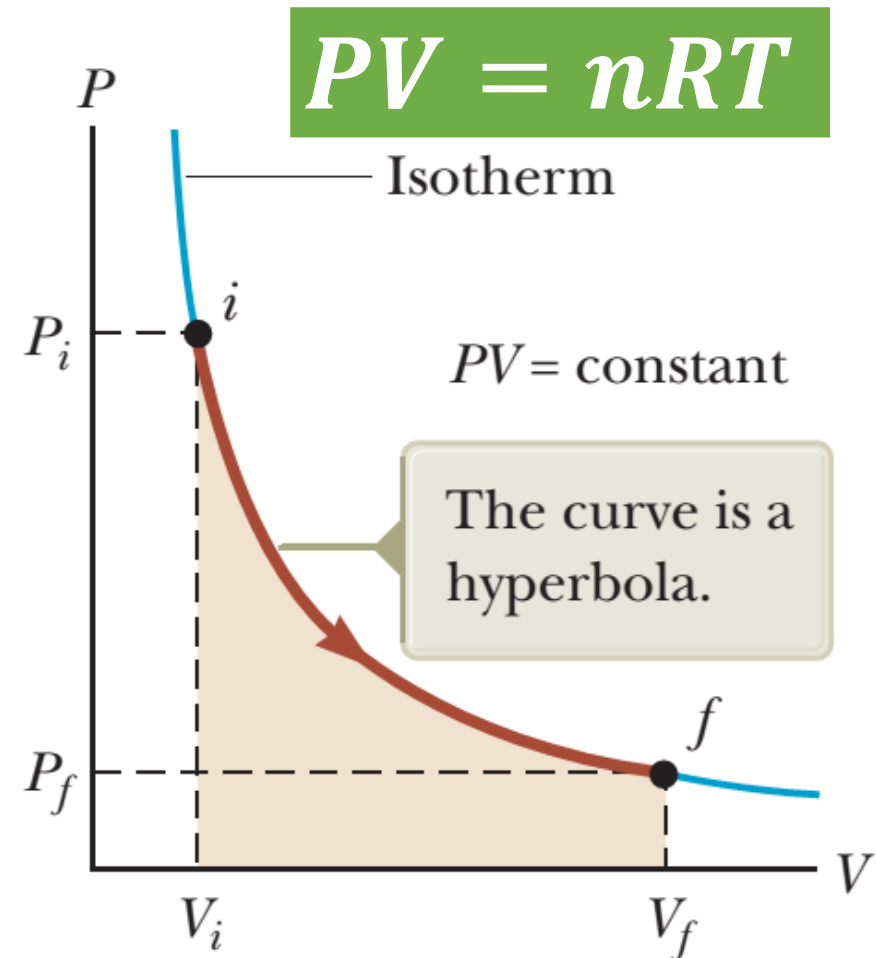
## Isothermal Process (Constant Temperature)

$$T = \text{Const}$$

$$PV = \text{Const}$$

$$\Delta E_{int} = 0$$

$$\therefore Q = W$$

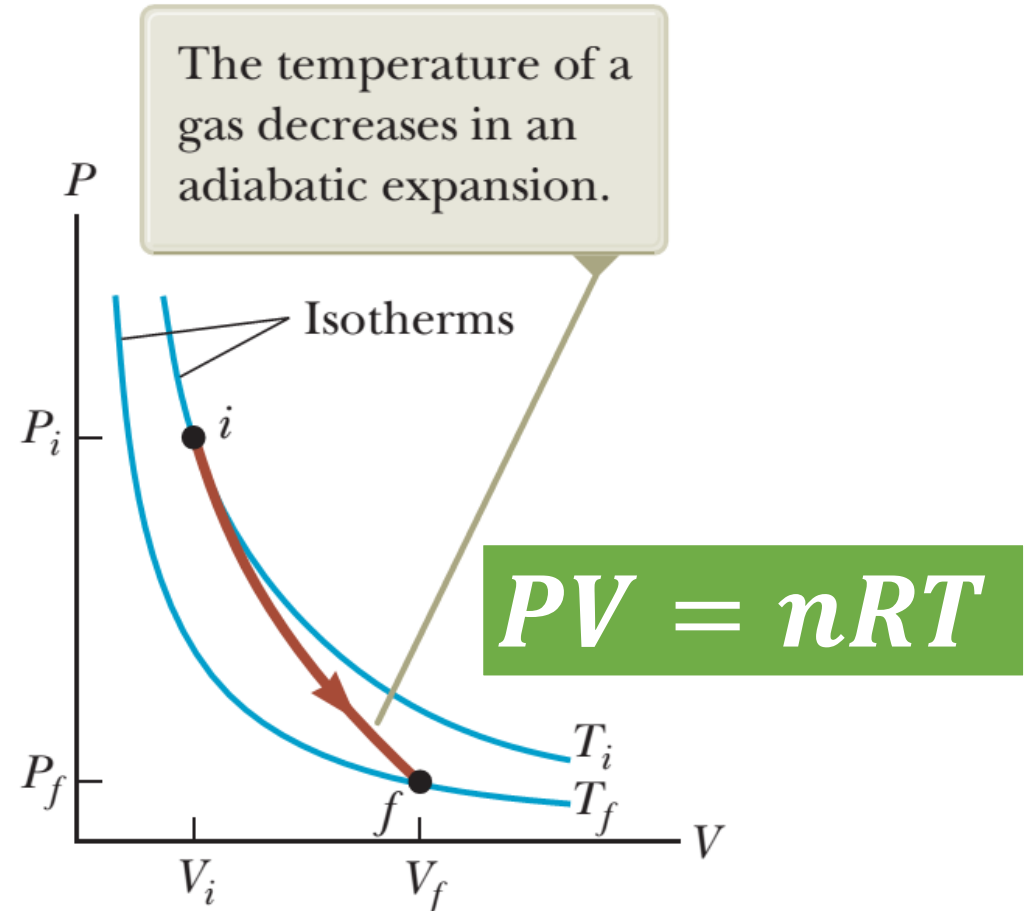


# THE FIRST LAW OF THERMODYNAMICS

## Adiabatic Process (No heat exchange)

$$Q = 0$$

$$\Delta E_{int} = -W$$



# THE FIRST LAW OF THERMODYNAMICS

## Notes

- **Isolated System**: no interaction with surroundings

$$\Delta E_{int} = Q = W = 0$$

- **Cyclic process**: starts and ends in the same state

$$\Delta E_{int} = 0, \quad Q = W = \text{Area enclosed by } PV \text{ path}$$

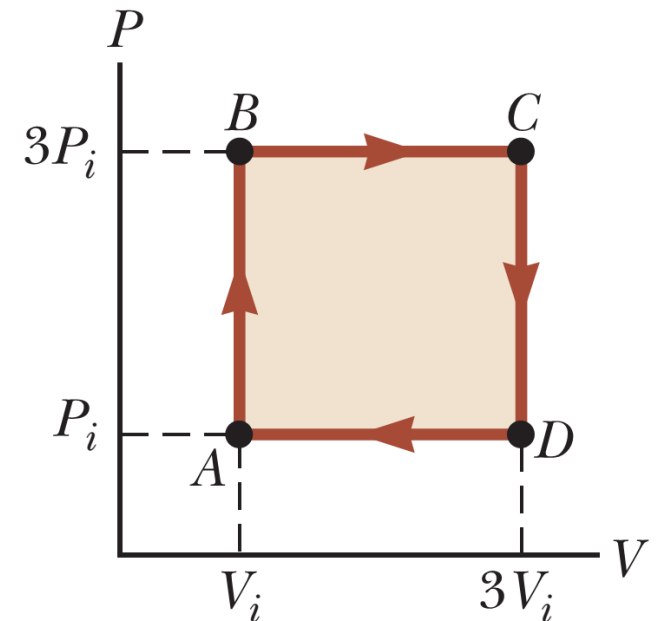
# THE FIRST LAW OF THERMODYNAMICS

**Example:** An ideal gas initially at  $P_i$ ,  $V_i$ , and  $T_i$  is taken through a cycle as in figure.

(a) Find the shown net work done on the gas per cycle for 1 mol of gas initially at  $0^\circ\text{C}$ .

## Solution

$$\begin{aligned}W_{on} &= -(W_{AB} + W_{BC} + W_{CD} + W_{DA}) \\&= 0 - 3P_i(V_C - V_B) + 0 - P_i(V_A - V_D) \\&= -2P_i \times 2V_i \\&= -4P_iV_i = -4nRT_i \\&= -4 \times 1 \times 8.314 \times 273 = -9.08 \text{ KJ}\end{aligned}$$



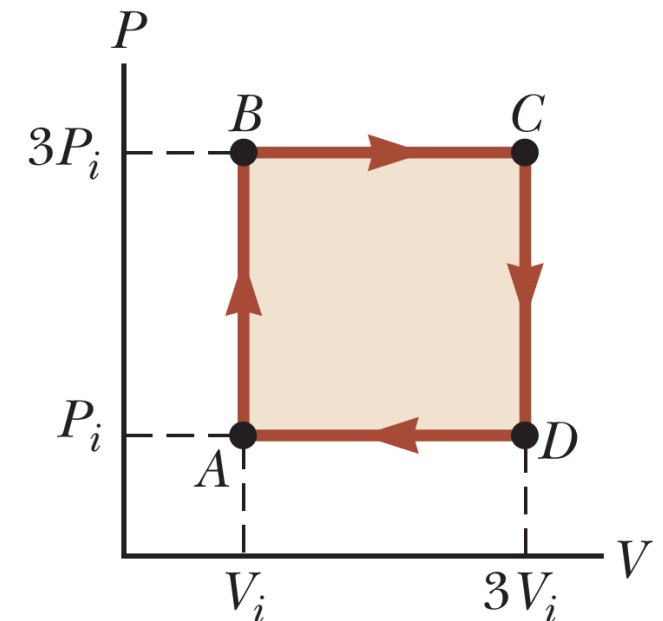
# THE FIRST LAW OF THERMODYNAMICS

**Example:** An ideal gas initially at  $P_i$ ,  $V_i$ , and  $T_i$  is taken through a cycle as in figure.

(b) What is the net energy added by heat to the gas per cycle?

**Solution**

$$\begin{aligned}T_f &= T_i \\ \Delta E_{net} &= 0 \\ \therefore Q &= W = 9.08 \text{ KJ}\end{aligned}$$





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# SUMMARY

## Celsius – Kelvin conversion

$$T_C = T_K - 273.15^\circ$$

## Thermal Expansion

$$\Delta L = \alpha L_i \Delta T, \Delta V = \beta V_i \Delta T$$

For an isotropic solid:  $\beta = 3\alpha$

## Heat Exchange

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

## Equation of state of ideal gas

$$PV = nRT$$

## Work done by gas

$$W = \int_{V_i}^{V_f} P dV$$

## First Law of Thermodynamics

$$\Delta E = \Delta Q - W$$