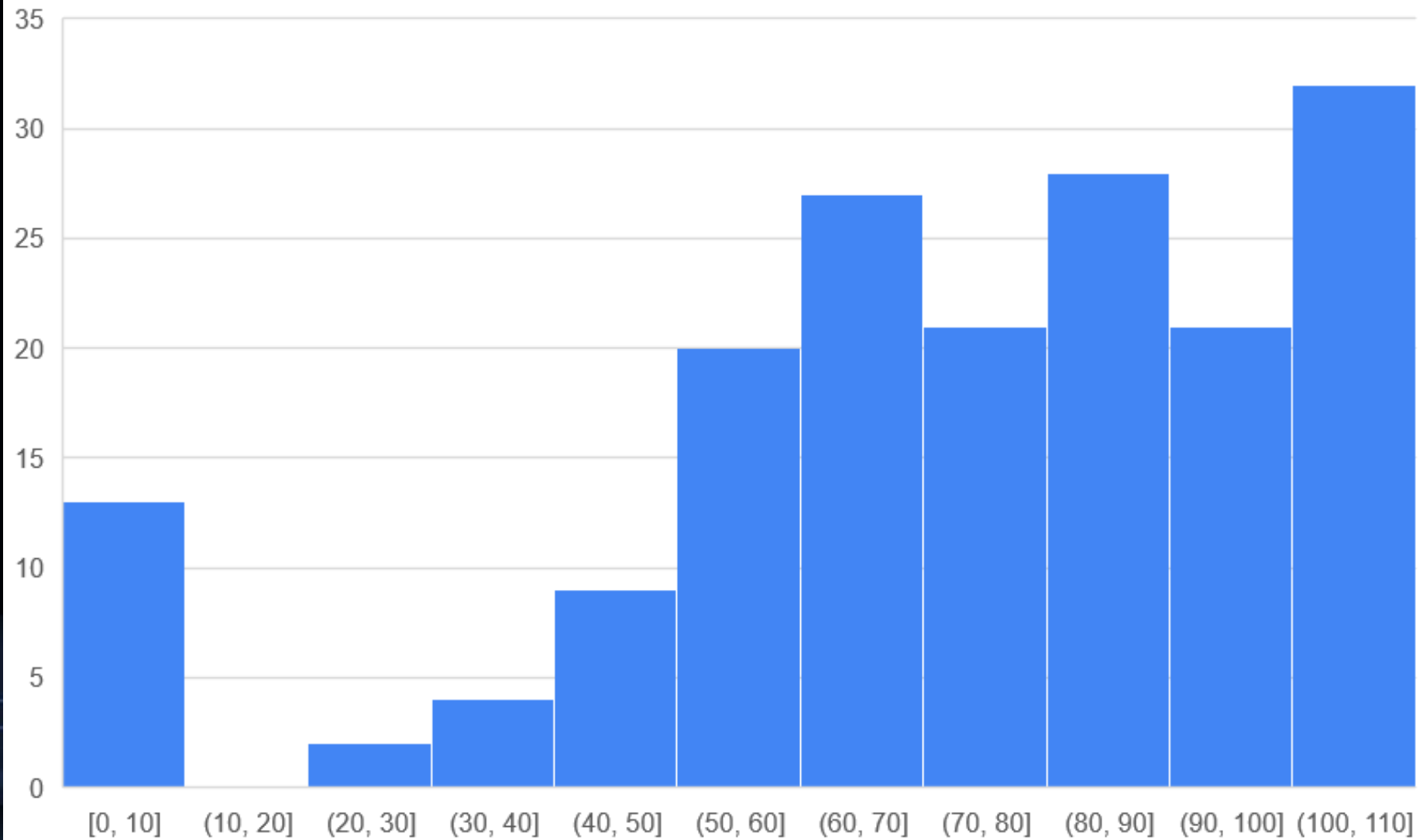


Course announcement

- The 2nd midterm score has been posted on eLearn today. I will bring the answer sheet to class for review from Friday until 12/30. You can also review it during Monday's office hours. If you have any questions about the score, please contact me.
- The 5th homework set will be posted next Tuesday (12/27). And it will be due on (1/3), 5pm.

2nd Midterm Score Distribution



15	12/23(Fri.)	The First Law of Thermal Dynamics: 1st law of thermal dynamics
16	12/27(Tue.)	The First Law of Thermal Dynamics: Thermodynamic processes (Homework5)
16	12/30(Fri.)	Entropy and the Second Law of Thermal Dynamics: entropy
17	1/3(Tue.)	Entropy and the Second Law of Thermal Dynamics: engines and refrigerator

GENERAL PHYSICS B1

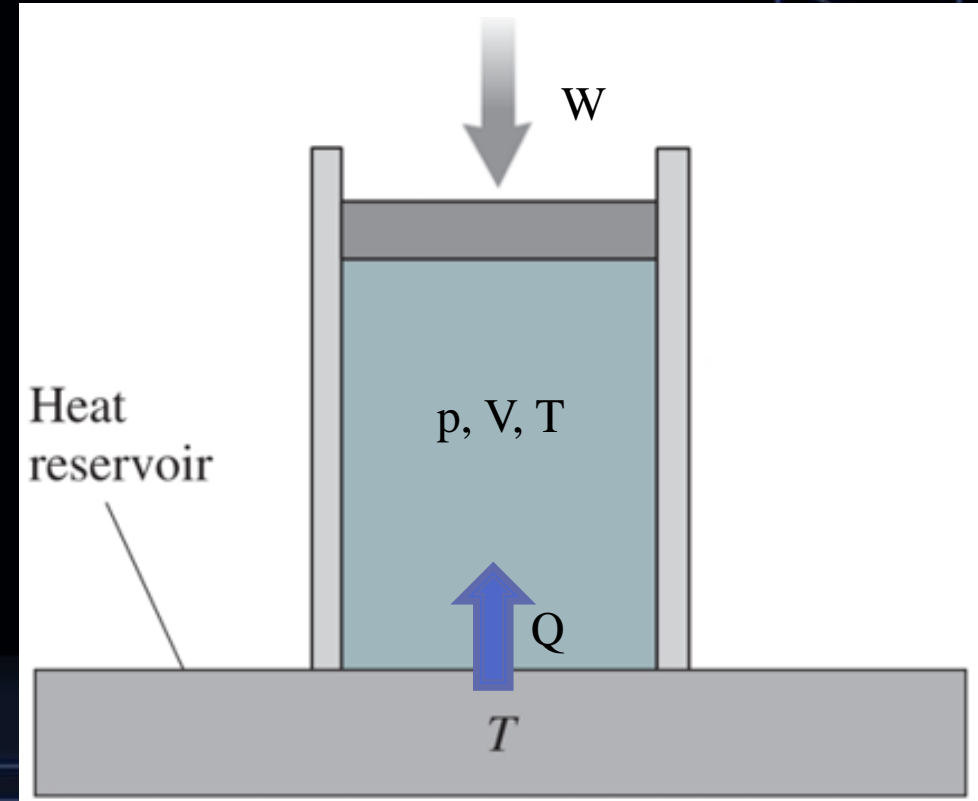
HEAT, WORK, AND THE FIRST LAW OF THERMODYNAMICS

2022/12/20

The First Law of Thermodynamics
Thermodynamic process

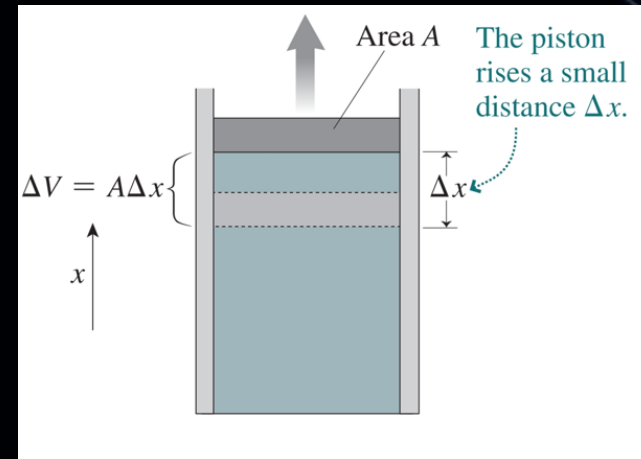
A gas system transferring heat to work

- The system (the gas) starts from an initial state i : described by a pressure p_i , a volume V_i , and a temperature T_i .
- The final state f : described by a pressure p_f , a volume V_f , and a temperature T_f .
- The procedure from its initial state to its final state is called a **thermodynamic process**.



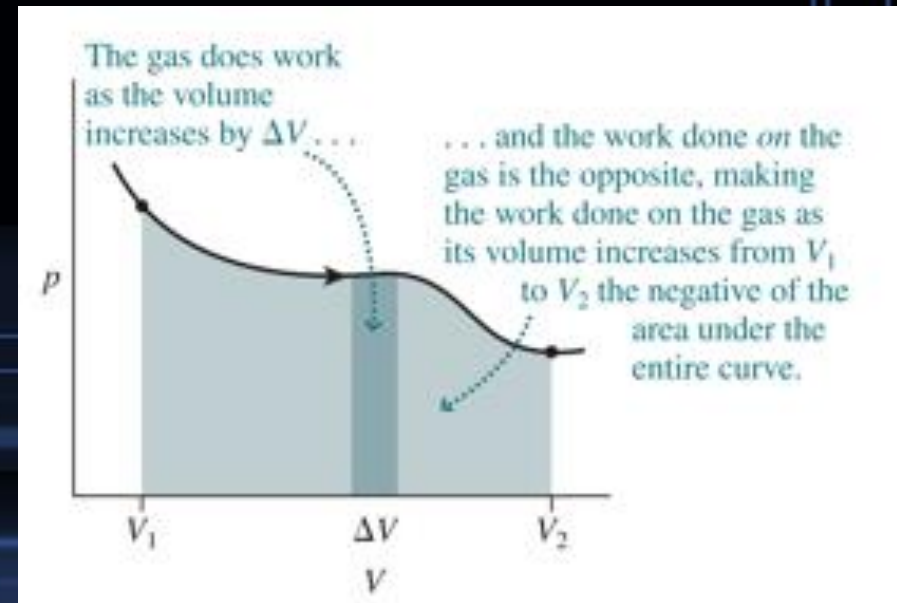
Work done on the gas

- The work done **on** the gas to the piston at a small displacement is:
 $dW = -Fdx = -pAdx = -pdV$



- The work done **on** gas during change from state with volume V_1 to state with volume V_2 :

$$W = -\int_{V_1}^{V_2} p dV$$



The first law of thermodynamics

- When a system changes from a given initial state to a given final state, both the work W and the heat Q depend on the nature of the process. Experimentally, however, we find a surprising thing: **The quantity $Q + W$ is the same for all processes.**
- The quantity $Q + W$ must represent a change in some intrinsic property of the system. We call this property the internal energy E_{int} and **the first law of thermodynamics** is:

$$\Delta E_{\text{int}} = Q + W$$

Meaning of the first law of thermodynamics

- If the thermodynamic system undergoes only a differential change:

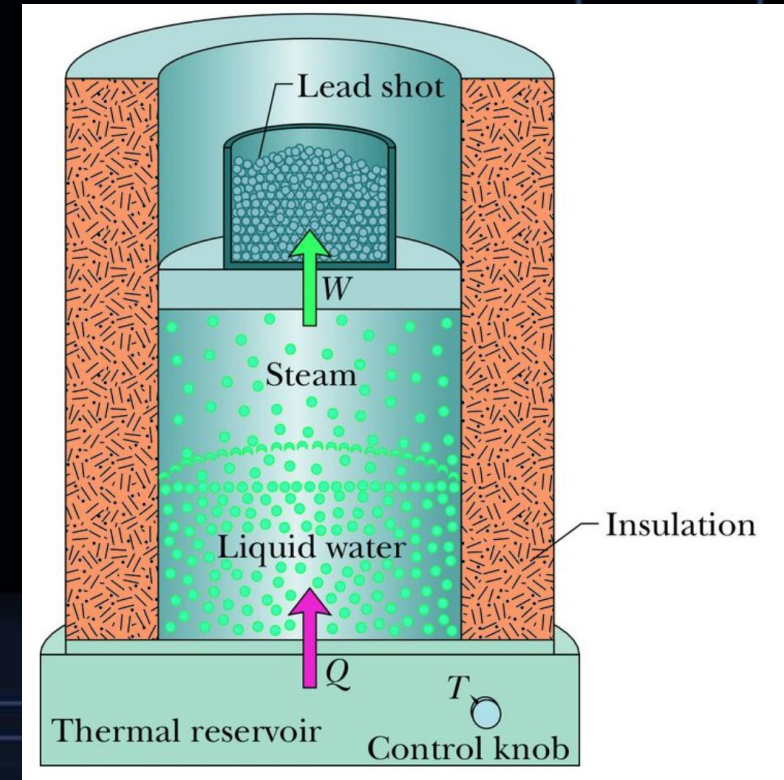
$$dE_{int} = dQ + dW$$

- The internal energy dE_{int} of a system tends to increase if energy is added as heat Q and tends to decrease if energy is lost as work W done by the system. Therefore, the first law of thermodynamics is conservation of energy.

Example

Let 1.00 kg of liquid water at 100°C be converted to steam at 100°C by boiling at standard atmospheric pressure (which is 1.00 atm or 1.01×10^5 Pa). The volume of that water changes from an initial value of $1.00 \times 10^{-3} \text{ m}^3$ as a liquid to 1.671 m^3 as steam.

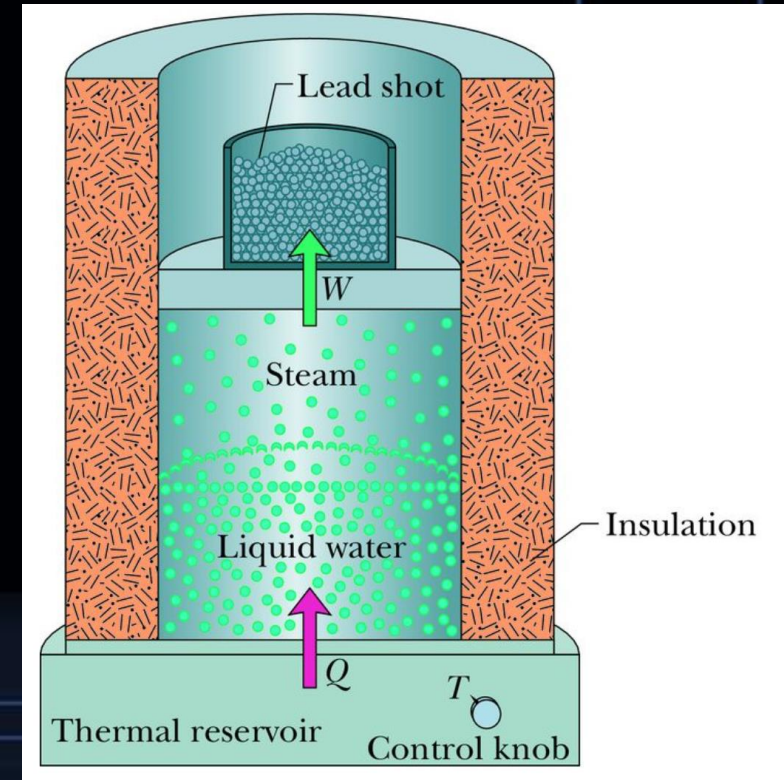
(a) How much work is done by the system during this process?



Example

(1) The system must do work to the outside world because the volume increases. (2) We calculate the work W done by integrating the pressure with respect to the volume

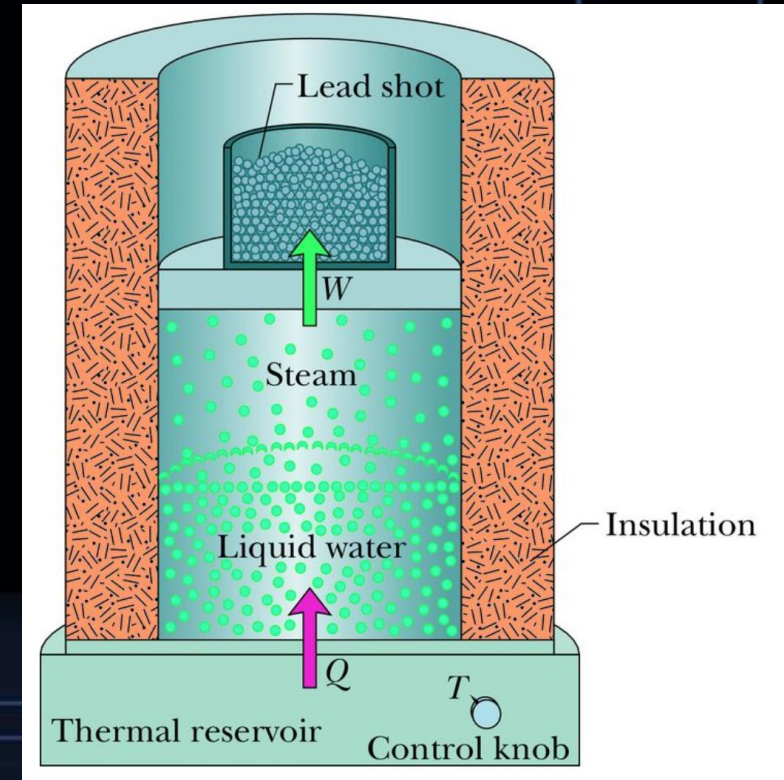
$$\begin{aligned} W &= - \int_{V_i}^{V_f} p dV = -p(V_f - V_i) \\ &= -(1.01 \times 10^5 \text{ Pa})(1.671 \text{ m}^3 - 1.00 \times 10^{-3} \text{ m}^3) \\ &= -1.69 \times 10^5 \text{ J} \end{aligned}$$



Example

(b) How much energy is transferred as heat during the process?

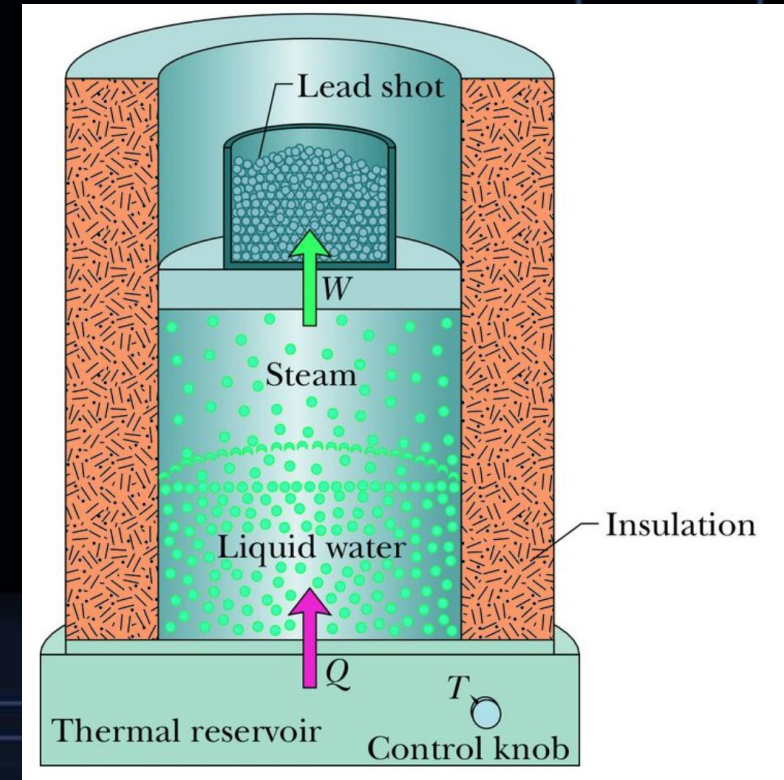
$$\begin{aligned} Q &= L_V m = (2256 \text{ kJ / kg}) (1.00 \text{ kg}) \\ &= 2256 \text{ kJ} \approx 2260 \text{ kJ} . \end{aligned}$$



Example

(c) What is the change in the system's internal energy during the process?

$$\begin{aligned}\Delta E_{int} &= Q + W \\ &= 2256\text{kJ} - 169\text{kJ} \\ &= 2087\text{kJ}\end{aligned}$$

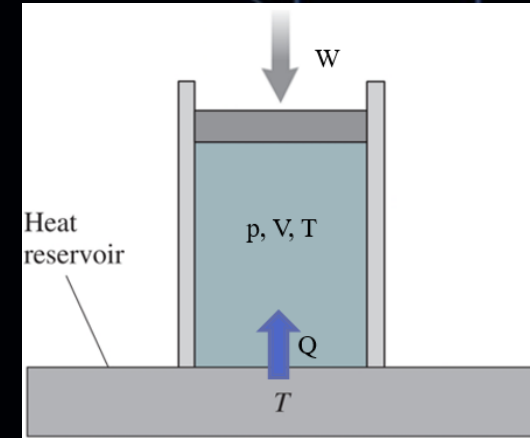


Review of Ideal Gas

To know further detail of thermodynamic process, we consider ideal gas in the gas system. The monatomic ideal gas follows:

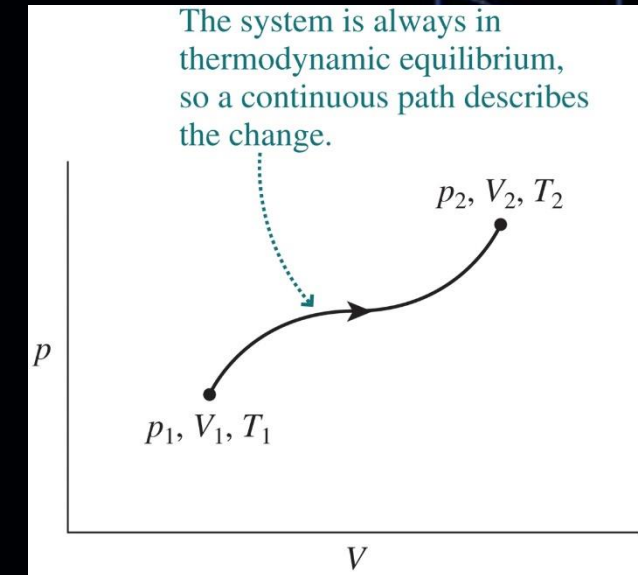
- Ideal gas law: $pV = NkT$ (ideal gas law)
- At a given temperature T , all ideal gas molecules—no matter what their mass—**have the same average translational kinetic energy**—namely, $\frac{3}{2}kT$.
- The internal energy of N monatomic molecules ideal gas only depends on temperature:

$$E_{int} = \frac{3}{2}NkT$$



Quasi-static process

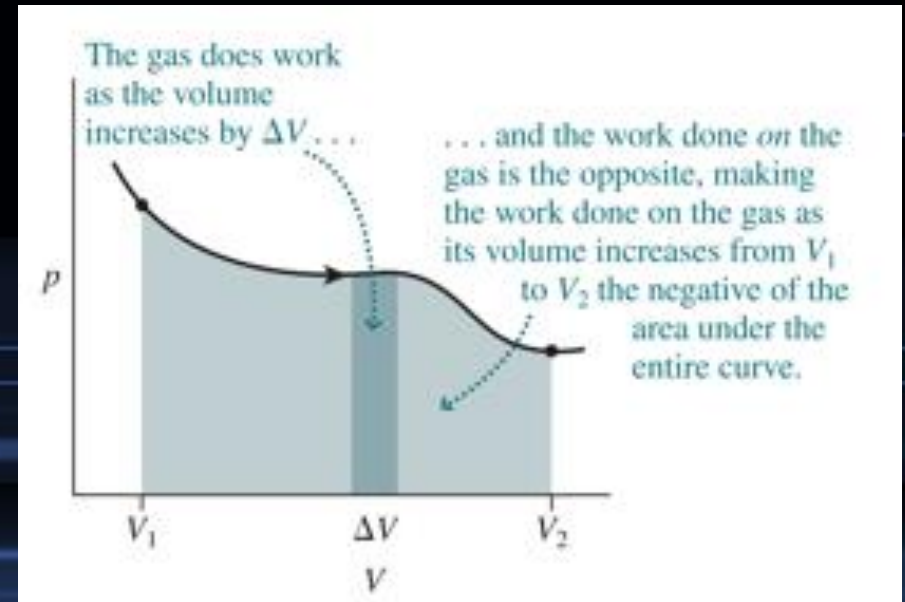
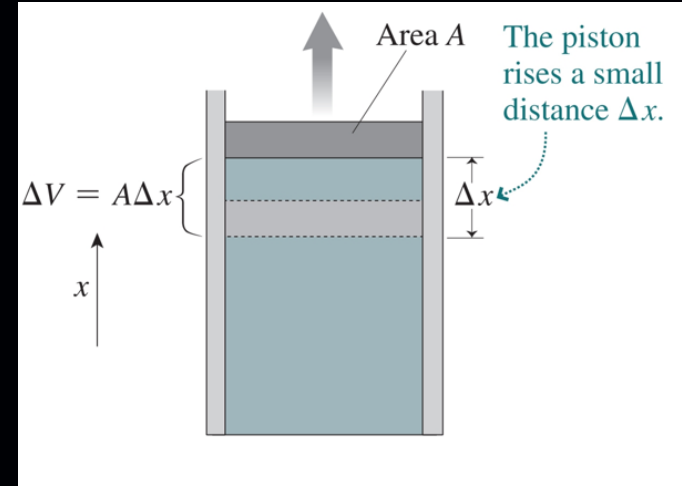
- To describe the status of ideal during thermodynamic processes, the system changes but is always in **thermodynamic equilibrium** and follows a continuous path in its pressure- versus-volume (pV) diagram.
- Any process carried out slowly enough to be **quasi-static** is **reversible**.
- In contrast, an **irreversible process** is the system goes temporarily out of equilibrium, without well-defined values for temperature, pressure, and other quantities.



Work done with ideal gas system

- With ideal gas in a quasi-static process, the work done **on** gas during change from state with volume V_1 to state with volume V_2

$$W = -\int_{V_1}^{V_2} p dV$$



Think about it...

- Two identical ideal gas–cylinder systems are taken from the same initial state to the same final state, but by different processes. Which of the following is or are the same in both cases?
 - a. the work done on or by the gas
 - b. the heat added or removed
 - c. the change in internal energy

Think about it...

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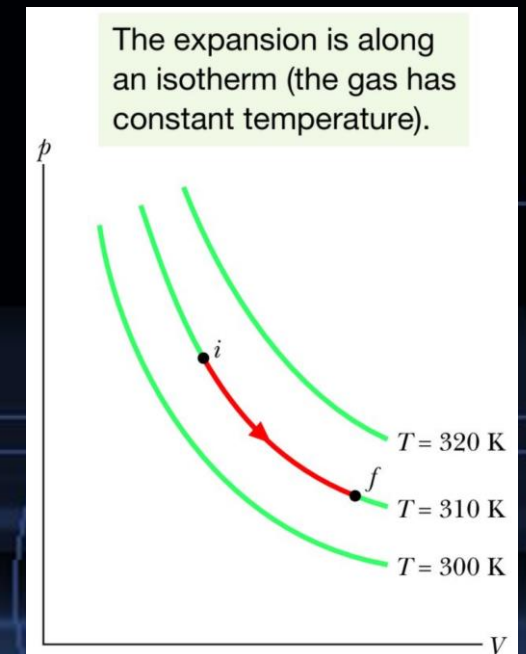
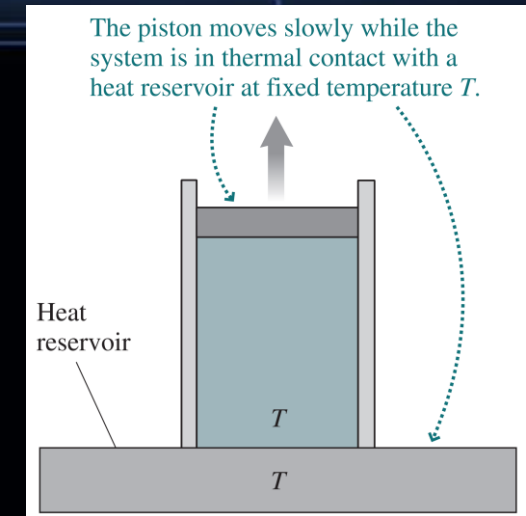
Ideal Gas in different thermodynamic processes

Suppose we put an ideal gas in a piston–cylinder arrangement. We can consider the work, heat, and internal energy change of the ideal gas at:

- Constant temperature (isothermal process)
- Constant volume (isometric, isochoric, or isovolumic process)
- Constant pressure (Isobaric process)
- No heat exchanging (Adiabatic process)

Isothermal Processes

- An **isothermal process** takes place at constant temperature.
- One way to achieve this is to keep the system in thermal contact with a heat reservoir—a much larger system held at constant temperature.
- In a P-V plot, the system moves from its initial state to its final states along a curve of constant temperature—an isotherm during an isothermal process.



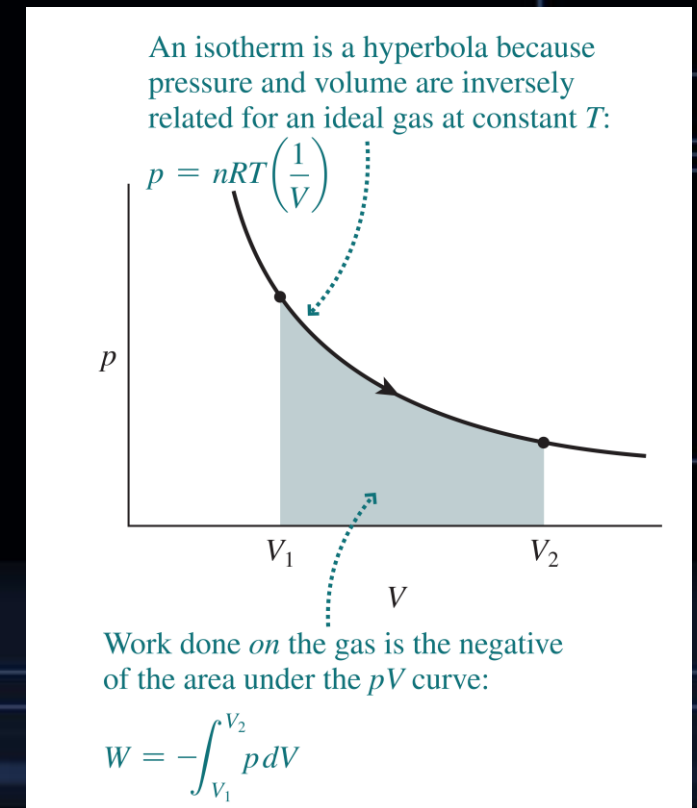
Work, Internal Energy, and Heat in an Isothermal Processes

- We can calculate the work done when an ideal-gas undergoes an isothermal process:
- The ideal-gas law gives $p = nRT / V$
- The work done on the gas is:

$$W = -\int_{V_1}^{V_2} p dV = -nRT \int_{V_1}^{V_2} \frac{dV}{V} = -nRT \ln(V_2 / V_1)$$

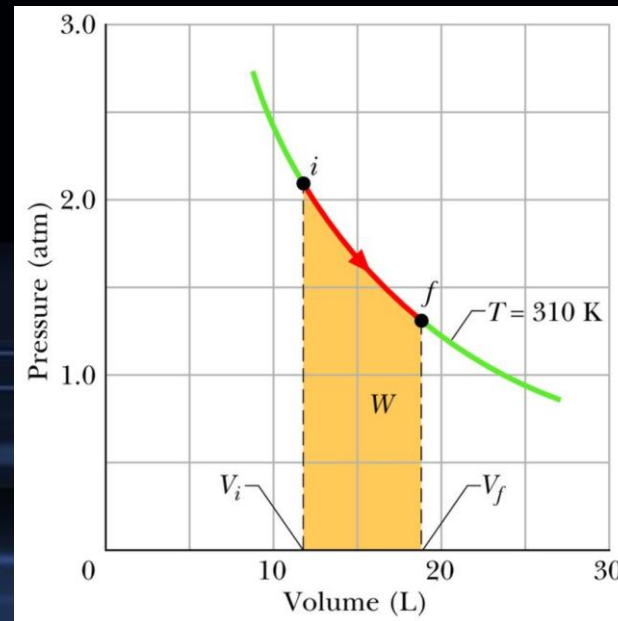
- Temperature doesn't change: $\Delta E_{int} = 0$.
- With 1st law of thermodynamics, heat:

$$Q = -W = nRT \ln(V_2 / V_1)$$



Example of isothermal expansion

One mole of oxygen (assume it to be an ideal gas) expands at a constant temperature T of 310 K from an initial volume V_i of 12 L to a final volume V_f of 19 L. How much work is done by the gas during the expansion?

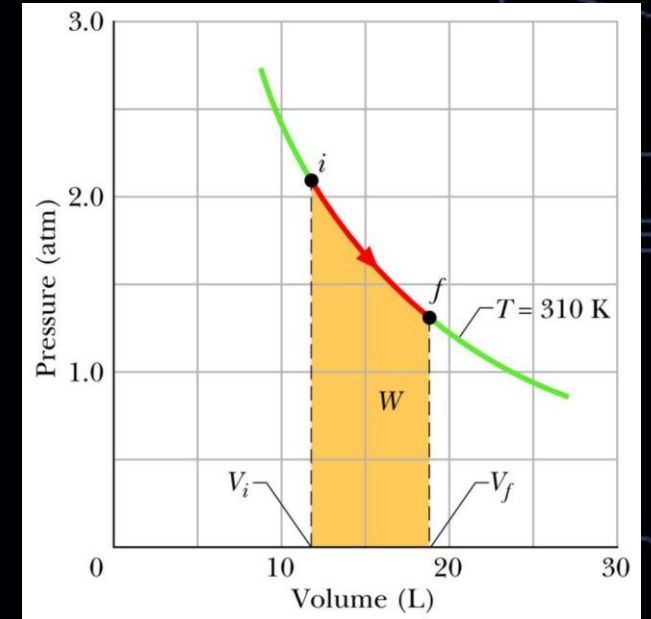


Example of isothermal expansion

Since this is an isothermal process, we can find the work is:

$$\begin{aligned} W &= nRT \ln \frac{V_f}{V_i} \\ &= (1 \text{ mol}) (8.31 \text{ J/mol} \cdot \text{K}) (310 \text{ K}) \ln \frac{19 \text{ L}}{12 \text{ L}} \\ &= 1180 \text{ J.} \end{aligned} \quad (\text{Answer})$$

The work is the area under the curve in p-V plot of the ideal gas

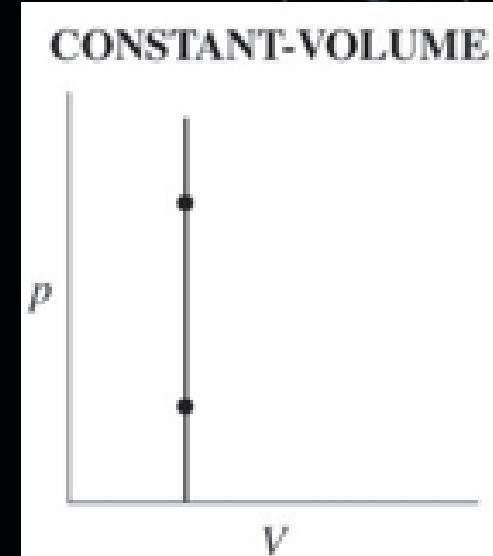


Constant-Volume Processes

- In a **constant-volume** process (also called isometric, isochoric, or isovolumic), no work is done in a constant-volume process, so $W = 0$.
- the heat added to the gas and the resulting temperature change are related by:

$$Q = nC_V \Delta T$$

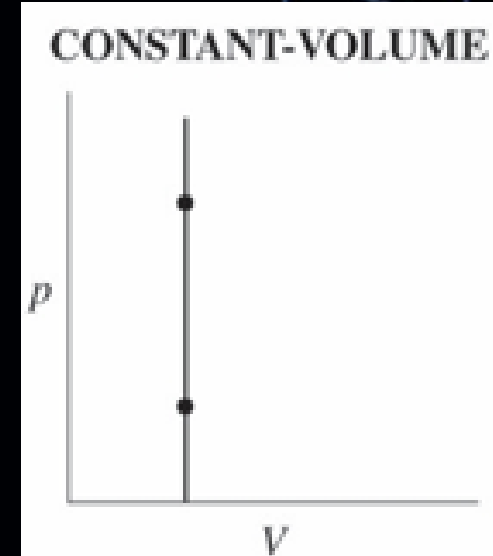
- Here C_V is the **molar specific heat at constant volume**.



Constant-Volume Processes

- The first law gives: $\Delta E_{\text{int}} = Q$
- Therefore, $\Delta E_{\text{int}} = nC_v \Delta T$

For an ideal gas, internal energy depends on temperature alone, so this relationship holds for **any** process.



Isobaric Processes

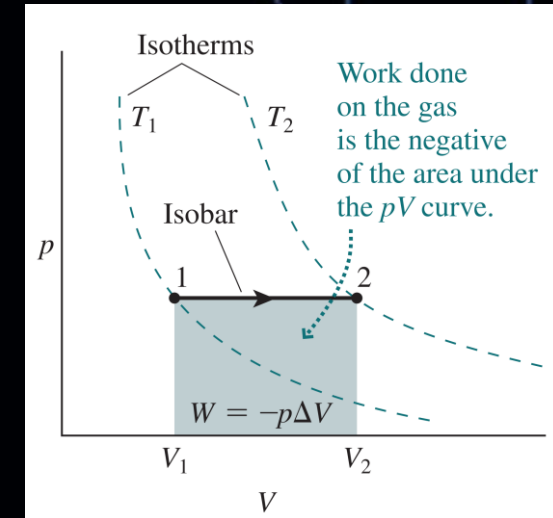
- An **isobaric process** takes place at constant pressure. Then, the work done (on the gas) is

$$W = -p \Delta V$$

- Adding heat to an ideal gas results both in a temperature change and in work being done. Therefore, it takes **more** heat to effect a given temperature change: $Q = nC_V \Delta T + p \Delta V$

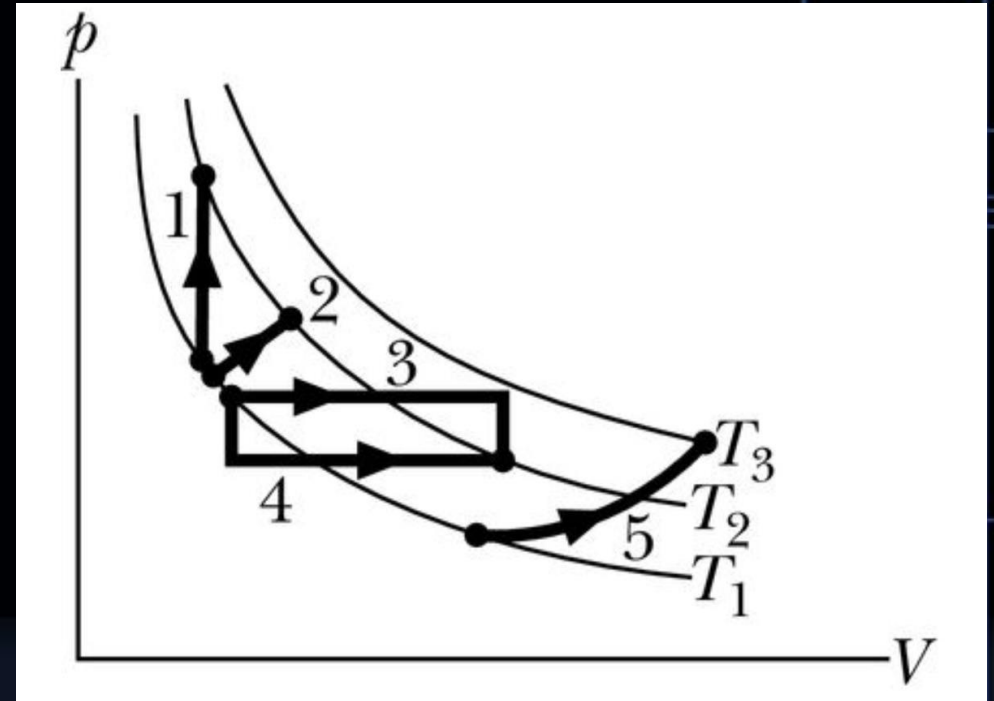
The molar specific heat at constant pressure, C_p , expresses this extra work $nC_p \Delta T = nC_V \Delta T + nR \Delta T$

Thus, we have: $C_p = C_V + R$



Think about it...

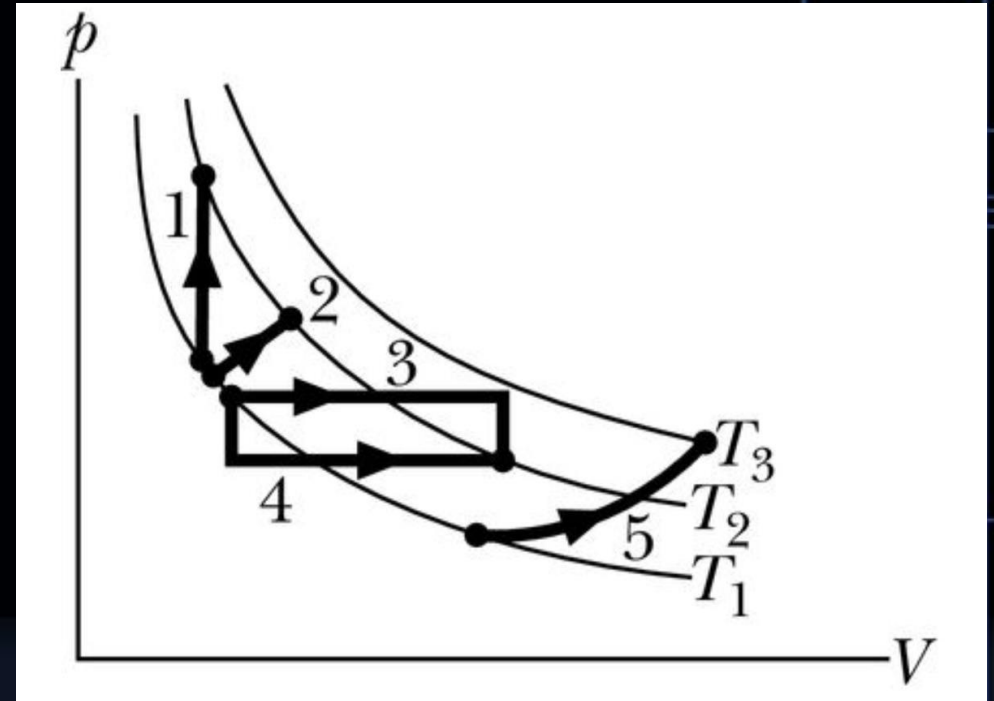
The figure here shows five paths traversed by a gas on a p-V diagram. Rank the paths according to the change in internal energy of the gas, greatest first.



Think about it...

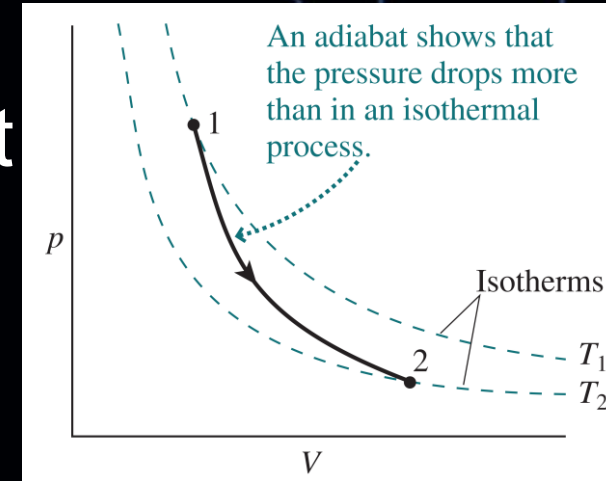
The figure here shows five paths traversed by a gas on a p-V diagram. Rank the paths according to the change in internal energy of the gas, greatest first.

$$5 > 4 = 3 = 2 = 1$$



Adiabatic Processes

- In an **adiabatic process**, no heat flows into or out of the system. Therefore, $Q = 0$ and the first law reads $\Delta E_{int} = W$.
- Analysis of the adiabatic process for an ideal gas shows that: $pV^\gamma = \text{constant}$
 $\gamma = C_p/C_v$ is the ratio of specific heats of the gas.
- An adiabatic curve or adiabat is steeper than an isotherm because the gas loses internal energy as it does work, so its temperature drops. And we have $TV^{\gamma-1} = \text{constant}$



The adiabatic expansion of an ideal gas

Proof:

- Since the volume can change, we rewrite 1st law of thermal dynamics:

$$dE_{\text{int}} = Q - p dV$$

- It is adiabatic, so $Q=0$.
- The change internal energy is $nC_V dT$

Thus, $n dT = - \left(\frac{p}{C_V} \right) dV$

The adiabatic expansion of an ideal gas

Now, we take derivate of $pV=nRT$, we have

$$p dV + V dp = nR dT$$

Since $R=C_p-C_v$, thus we have:

$$n dT = \frac{p dV + V dp}{C_p - C_v}$$

Thus, plug back to the equation in the previous page:

The adiabatic expansion of an ideal gas

We got:

$$\frac{dp}{p} + \left(\frac{C_p}{C_V} \right) \frac{dV}{V} = 0$$

By integrated dp and dV , we have

$$\ln p + \gamma \ln V = \text{a constant.}$$

Thus

$$pV^\gamma = \text{a constant}$$

Summary of ideal gas processes

Table 18.1 Ideal-Gas Processes

	ISOTHERMAL	CONSTANT-VOLUME	ISOBARIC	ADIABATIC
pV diagram				
Defining characteristic	$T = \text{constant}$	$V = \text{constant}$	$p = \text{constant}$	$Q = 0$
First law	$Q = -W$	$Q = \Delta E_{\text{int}}$	$Q = \Delta E_{\text{int}} - W$	$\Delta E_{\text{int}} = W$
Work done on gas	$W = -nRT \ln\left(\frac{V_2}{V_1}\right)$	$W = 0$	$W = -p(V_2 - V_1)$	$W = \frac{p_2V_2 - p_1V_1}{\gamma - 1}$
Other relationships	$pV = \text{constant}$	$Q = nC_V\Delta T$	$Q = nC_p\Delta T$ $C_p = C_V + R$	$pV^\gamma = \text{constant}$ $TV^{\gamma-1} = \text{constant}$