PHYSICS 231
INTRODUCTORY PHYSICS I

Lecture 18
Chapter 12

The Laws of Thermodynamics
Principles of Thermodynamics

• Energy is conserved
  • FIRST LAW OF THERMODYNAMICS
  • Examples:
    • Engines (Heat -> Mechanical Energy)
    • Friction (Mechanical Energy -> Heat)
• All processes must increase entropy
  • SECOND LAW OF THERMODYNAMICS
  • Entropy is measure of disorder
  • Engines can not be 100% efficient
Work done on a gas

• Adding heat $Q$ can:
  • Change temperature
  • Change state of matter

• Can also change $\Delta U$ by doing work on the gas

\[ W = \vec{F} \cdot \Delta \vec{x} = F(-\Delta y) = (PA)(-\Delta y) \]

\[ W = -P\Delta V \]

Work done on the gas
First Law of Thermodynamics

\[ \Delta U = Q + W \]

- Conservation of Energy
- Can change internal energy \( \Delta U \) by
  - Adding heat to gas: \( Q \)
  - Doing work on gas: \( W = -P\Delta V \)

Note:
(Work done by the gas) = - (Work done on the gas)
\[ W_{\text{by the gas}} = +P\Delta V \]

\[ Q = \Delta U + W \] by the gas

Add heat => Increase Int. Energy & Gas does work
Example 12.1

A cylinder of radius 5 cm is kept at pressure with a piston of mass 75 kg.

a) What is the pressure inside the cylinder?
   \[ 1.950 \times 10^5 \text{ Pa} \]

b) If the gas expands such that the cylinder rises 12.0 cm, what work was done by the gas?
   \[ 183.8 \text{ J} \]

c) What amount of the work went into changing the gravitational PE of the piston?
   \[ 88.3 \text{ J} \]

d) Where did the rest of the work go?
   Compressing the outside air
Example 12.2a

A massive copper piston traps an ideal gas as shown to the right. The piston is allowed to freely slide up and down and equilibrate with the outside air.

The pressure inside the cylinder is _________ the pressure outside.

a) Greater than
b) Less than
c) Equal to
Example 12.2b

A massive copper piston traps an ideal gas as shown to the right. The piston is allowed to freely slide up and down and equilibrate with the outside air.

The temperature inside the cylinder is ____________ the temperature outside.

a) Greater than  
b) Less than  
c) Equal to
Example 12.2c

A massive copper piston traps an ideal gas as shown to the right. The piston is allowed to freely slide up and down and equilibrate with the outside air.

If the gas is heated by a steady flame, and the piston rises to a new equilibrium position, the new pressure will be _________ than the previous pressure.

a) Greater than  
b) Less than  
c) Equal to
Some Vocabulary

- **Isobaric**
  - $P = \text{constant}$

- **Isovolumetric**
  - $V = \text{constant}$
  - $W = 0$

- **Isothermal**
  - $T = \text{constant}$
  - $\Delta U = 0$ (ideal gas)

- **Adiabatic**
  - $Q = 0$
Example 12.3a

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a).

Weight is slowly added to the piston, isothermally compressing the gas to half its original volume (b).

$P_b$ is ________ $P_a$

a) Greater than
b) Less than
c) Equal to

$$
\Delta U = Q - P\Delta V
$$

$W$ by the gas $= P\Delta V$
Example 12.3b

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)

Weight is slowly added to the piston, isothermally compressing the gas to half its original volume (b)

$T_b$ is _________ $T_a$

$\Delta U = Q - P\Delta V$

$W_{\text{by the gas}} = P\Delta V$

a) Greater than
b) Less than
c) Equal to
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a) 

Weight is slowly added to the piston, isothermally compressing the gas to half its original volume (b) 

\[ W_{ab} \text{ is } \square 0 \]

a) Greater than 
b) Less than 
c) Equal to

\[ \Delta U = Q - P\Delta V \]
\[ W \text{ by the gas } = P\Delta V \]

Vocabulary: \( W_{ab} \) is work done by gas between a and b
Example 12.3d

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)
Weight is slowly added to the piston, isothermally compressing the gas to half its original volume (b)

\( U_b \) is __________ \( U_a \)

\( \Delta U = Q - P\Delta V \)

\( W_{\text{by the gas}} = P\Delta V \)
Example 12.3e

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)
Weight is slowly added to the piston, isothermally compressing the gas to half its original volume (b)

\( Q_{ab} \) is ________ 0

a) Greater than
b) Less than
c) Equal to

\[ \Delta U = Q - P\Delta V \]

\[ W_{by \ the \ gas} = P\Delta V \]

Vocabulary: \( Q_{ab} \) is heat added to gas between a and b
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a). Weight is slowly added to the piston, adiabatically compressing the gas to half its original volume (b)

\[ P_b \text{ is } \underline{\text{_______}} P_a \]

a) Greater than
b) Less than
c) Equal to

\[ \Delta U = Q - P \Delta V \]
\[ W \text{ by the gas } = P \Delta V \]
Example 12.4b

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)

Weight is slowly added to the piston, _adiabatically_ compressing the gas to half its original volume (b)

\[ W_{ab} \text{ is } \underline{0} \]

- a) Greater than
- b) Less than
- c) Equal to

\[ \Delta U = Q - P\Delta V \]

\[ W_{\text{by the gas}} = P\Delta V \]
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a) Weight is slowly added to the piston, adiabatically compressing the gas to half its original volume (b)

\[ Q_{ab} \text{ is } \underline{0} \]

a) Greater than
b) Less than
c) Equal to

\[ \Delta U = Q - P\Delta V \]

\[ W_{by \text{ the gas}} = P\Delta V \]
Example 12.4d

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)

Weight is slowly added to the piston, adiabatically compressing the gas to half its original volume (b)

$U_b$ is _______ $U_a$

a) Greater than
b) Less than
c) Equal to

\[ \Delta U = Q - P\Delta V \]

\[ W_{\text{by the gas}} = P\Delta V \]
Example 12.4e

Outside Air: Room T, Atm. P

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)

Weight is slowly added to the piston, adiabatically compressing the gas to half its original volume (b)

\[ T_b \text{ is ________ } T_a \]

a) Greater than
b) Less than
c) Equal to

\[ \Delta U = Q - P\Delta V \]

\[ W \text{ by the gas} = P\Delta V \]
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a) The gas is cooled, \textit{isobarically} compressing the gas to half its original volume (b) 

$P_b$ is \underline{________} $P_a$

\begin{align*}
PV &= nRT \\
\Delta U &= Q - P\Delta V \\
W_{\text{by the gas}} &= P\Delta V
\end{align*}
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down.

The system initially equilibrates at room temperature (a)
The gas is cooled, *isobarically* compressing the gas to half its original volume (b)

\[ W_{ab} \text{ is } \text{________}_0 \]

\[ Pv = nRT \]
\[ \Delta U = Q - P\Delta V \]
\[ W_{by \text{ the gas}} = P\Delta V \]

Outsides Air: Room T, Atm. P

a) Greater than
b) Less than
c) Equal to
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a) 
The gas is cooled, isobarically compressing the gas to half its original volume (b) 

\[ T_b \text{ is } \underline{\text{Equal to}} \text{ } T_a \]

**Example 12.5c**  

Outside Air: Room T, Atm. P

**a) Greater than**  
**b) Less than**  
**c) Equal to**

\[ PV = nRT \]
\[ \Delta U = Q - P\Delta V \]
\[ W_{\text{by the gas}} = P\Delta V \]
A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a)

The gas is cooled, isobarically compressing the gas to half its original volume (b)

$U_b$ is ________ $U_a$

Outside Air: Room T, Atm. P

$PV = nRT$

$\Delta U = Q - P\Delta V$

$W_{by the gas} = P\Delta V$

a) Greater than  
b) Less than  
c) Equal to
Example 12.5e

A massive piston traps an amount of Helium gas as shown. The piston freely slides up and down. The system initially equilibrates at room temperature (a) The gas is cooled, *isobarically* compressing the gas to half its original volume (b)

\[ Q_{ab} \text{ is } \underline{0} \]

Outside Air: Room T, Atm. P

\[ PV = nRT \]
\[ \Delta U = Q - P\Delta V \]
\[ W_{\text{by the gas}} = P\Delta V \]

a) Greater than
b) Less than
c) Equal to
P-V Diagrams

Path moves to right:

\[ W_{\text{by the gas}} = \text{Area under curve} \]

Path moves to left:

\[ W_{\text{by the gas}} = - \text{Area under curve} \]

\((W_{\text{on the gas}} = - W_{\text{by the gas}})\)
Consider cycle $A \rightarrow B \rightarrow A$

$W_{A \rightarrow B} = \text{Area}$

$W_{B \rightarrow A} = -\text{Area}$

(work done by gas)
Work from closed cycles

Consider cycle $A \rightarrow B \rightarrow A$

$W_{A\rightarrow B\rightarrow A} = \text{Area}$

(work done by gas)
Work from closed cycles

Reverse the cycle, make it counter clockwise

\( W_{B \rightarrow A} = - \text{Area} \)

\( W_{A \rightarrow B} = \text{Area} \)

(work done by gas)
Work from closed cycles

Reverse the cycle, make it counter clockwise

\[ W_{A \rightarrow B \rightarrow A} = - \text{ Area} \]

(work done by gas)
Internal Energy in closed cycles

\[ \Delta U = 0 \] in closed cycles
Example 12.6

a) What amount of work is performed by the gas in the cycle IAFI?

\[ W = 3.04 \times 10^5 \text{ J} \]

b) How much heat was inserted into the gas in the cycle IAFI?

\[ Q = 3.04 \times 10^5 \text{ J} \]

c) What amount of work is performed by the gas in the cycle IBFI?

\[ W = -3.04 \times 10^5 \text{ J} \]
Consider a monotonic ideal gas.

a) What work was done by the gas from A to B?
   
   20,000 J

b) What heat was added to the gas between A and B?
   
   20,000

C) What work was done by the gas from B to C?
   
   -10,000 J

d) What heat was added to the gas between B and C?
   
   -25,000 J

e) What work was done by the gas from C to A?
   
   0

f) What heat was added to the gas from C to A?
   
   15,000 J
Example Continued

Take solutions from last problem and find:

a) Net work done by gas in the cycle
b) Amount of heat added to gas

\[ W_{AB} + W_{BC} + W_{CA} = 10,000 \text{ J} \]
\[ Q_{AB} + Q_{BC} + Q_{CA} = 10,000 \text{ J} \]

This does NOT mean that the engine is 100% efficient!
Consider an ideal gas undergoing the trajectory through the PV diagram. In going from A to B to C, the work done BY the gas is _______ 0.

a) >
b) <
c) =
In going from A to B to C, the change of the internal energy of the gas is \[ \_\_\_\_\_\_ \ 0. \]

\[ \begin{align*} 
a) &> \\
b) &< \\
c) &= 
\end{align*} \]
In going from A to B to C, the amount of heat added to the gas is ______ 0.

a) >  
b) <  
c) =  

Example 12.8c
In going from A to B to C to D to A, the work done by the gas is _______ 0.

a) >
b) <
c) =
In going from A to B to C to D to A, the change of the internal energy of the gas is _______ 0.

a) > 
b) < 
c) =
In going from A to B to C to D to A, the heat added to the gas is ______ 0.

- a) >
- b) <
- c) =