

# First Law of Thermodynamics

## 9.1

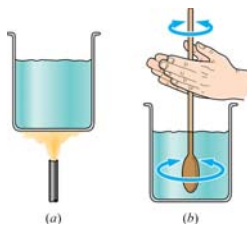
Heat and Work  
Thermodynamic Processes

# Heat and Work



Thermodynamics is the science of heat and work

# Heat is a form of energy



Mechanical work done on a system produces a rise in temperature like heat added to the system.

# Calorimetry



Mechanical equivalent of heat

$$1 \text{ calorie} = 4.184 \text{ J}$$

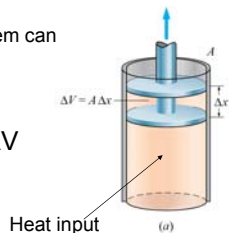
# Work

Heat input into a system can produce work

$$\Delta W = F \Delta x$$

$$\Delta W = P \Delta V = P \Delta x A$$

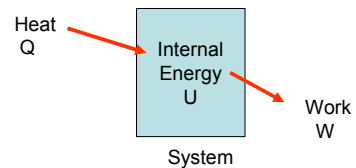
For the case of thermal expansion work is done by the system.



# First Law of Thermodynamics

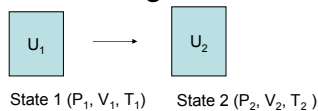
The change in the internal energy of a system  $U$ , is equal to the heat input  $Q$  minus the work done by the system.

$$\Delta U = Q - W$$



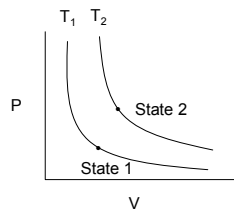
The internal energy is the energy stored in the system.  
For an ideal gas the internal energy is the kinetic energy of the gas

## Thermodynamic processes in an ideal gas



- The state of the ideal gas is determined by the three parameters, PVT.
- A thermodynamic process is the transition between states with input or output of heat and work with changes in internal energy.
- The internal energy  $U$  is a property of the state.  $\Delta U$  determined by the initial and final state and is independent of path.
- The heat absorbed and work done in the process depend on the path.

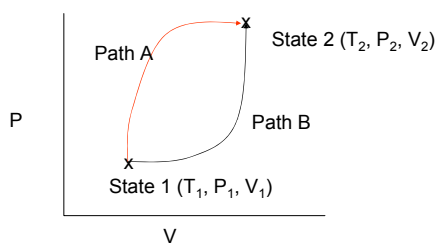
## PV diagram



Each point in the diagram represents a State of the system  
The temperature  $T$  is not plotted but is not an independent variable.  
 $T$  can be calculated from  $P$  and  $V$  using the ideal gas law.

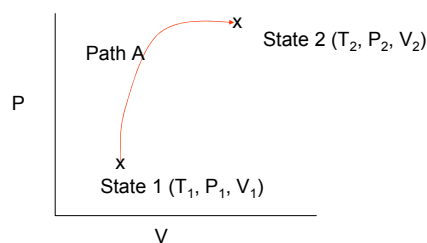
The points of constant temperature on the PV diagram are hyperbola  
$$P = \frac{nRT}{V} \quad \text{For constant } T$$

## Thermodynamic processes



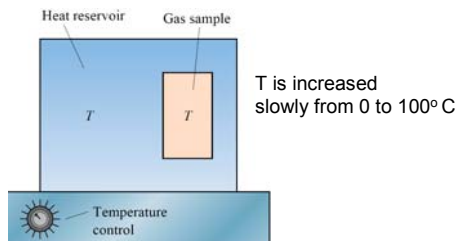
The change in  $U$  going from 1 to 2 is the same for the two paths.  $\Delta U_A = \Delta U_B$   
The change in  $Q$  and  $W$  going from 1 to 2 is different between the two paths.  $Q_A \neq Q_B$ ,  $W_A \neq W_B$

## Work can be calculated if the process is reversible.



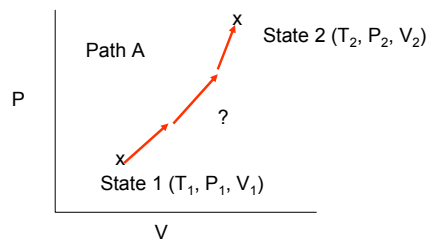
We can calculate the work done in going from 1 to 2 if the change is a **reversible** process. i.e. it goes slowly through well defined states that are in quasi-equilibrium.

## Reversible process



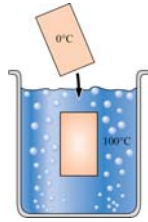
The temperature is changed very slowly so that the gas sample is at a uniform temperature.

## Work cannot be calculated for an irreversible process.



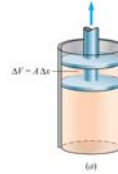
We cannot calculate the work done in going from 1 to 2 if the process is irreversible. i.e. goes rapidly through states that are not well characterized and not in quasi-equilibrium. However, we can determine  $\Delta U$ , since this is a state property.

## Irreversible process

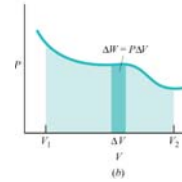


The gas is not in a well defined thermodynamic state as it is heated.

## Work done in a process



$$dW = PdV$$

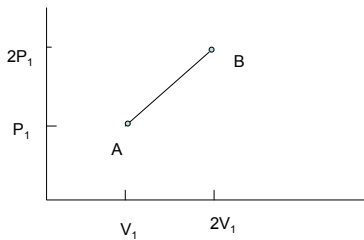


$$W = \int_{V_1}^{V_2} PdV$$

The work is the area under the PV curve.

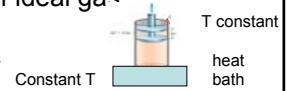
## Question

Find the work done in going from A to B along the line.

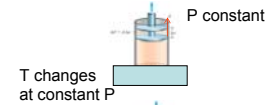


## Some thermodynamic processes expansion of ideal gas

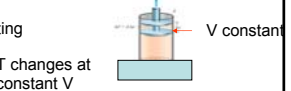
1. Constant Temperature process – Isothermal



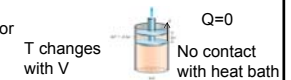
2. Constant Pressure process – Isobaric. e.g heating a balloon



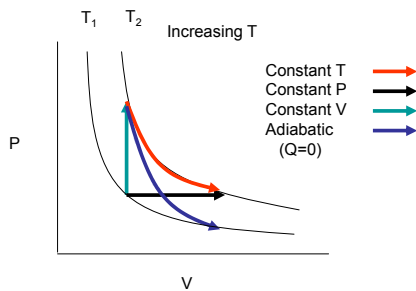
3. Constant Volume process. Heating a gas thermometer



4. Adiabatic process – no heat exchange. Rapid compression or expansion of a gas



## Thermodynamic processes



## Isothermal volume change

T is constant U is constant

$$\Delta U = 0$$

$$W = Q$$

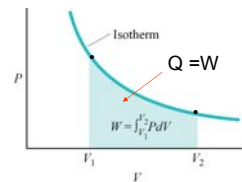
All the heat goes into work

Work

$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{nRT}{V} dV$$

$$P = \frac{nRT}{V}$$

$$W = nRT \ln V_2 - nRT \ln V_1$$



Expansion  $\frac{V_2}{V_1} > 1$  work is positive  
work is done by the gas

Compression  $\frac{V_2}{V_1} < 1$  work is negative  
work is done on the gas

## Constant Volume

At constant volume  
 $W=0$   
 $\Delta U = Q$   
 no work is done all the heat goes into internal energy

We can use this to find  $\Delta U$

$$Q = nc_v\Delta T$$

$$\Delta U = nc_v\Delta T$$

This is true for all processes since U is a State function and only dependent on T.

specific heat at constant volume  
 $c_v = \frac{\Delta U}{n\Delta T}$  the specific heat of the gas  $c_v$  depends on the structure of the gas molecule.  
 Units  $J/mole \cdot K$

## Constant Pressure

Constant Pressure

Work  
 $W = \int_{V_1}^{V_2} PdV = P(V_2 - V_1) = P\Delta V$

Heat input  
 $Q = \Delta U + P\Delta V$   
 $Q = nc_v\Delta T + P\Delta V = nc_v\Delta T + nR\Delta T$   
 $Q = nc_p\Delta T$

Specific heat at constant pressure,  $c_p$

$$c_p = c_v + R$$

the specific heat at constant P is larger than the specific heat at constant V. because work is done by the gas

## Adiabatic Process

Heat input  $Q=0$   
 $\Delta U = -W$  Work is done at the expense of internal energy

Define "Adiabatic exponent"  $\gamma$   
 $\gamma = \frac{c_p}{c_v} = \frac{c_v + R}{c_v} = 1 + \frac{R}{c_v}$

$\gamma$  depends on the nature of the gas,  $\gamma = 1.40$  for air.

PV relationship  $P_1V_1^\gamma = P_2V_2^\gamma$   $PV^\gamma = \text{constant}$   
 TV relationship  $T_1V_1^{\gamma-1} = T_2V_2^{\gamma-1}$   $TV^{\gamma-1} = \text{constant}$

$$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

## Adiabatic compression

The air ( $\gamma=1.40$ ) in an automobile engine is compressed quickly so that appreciable heat exchange does not occur. For a compression ratio  $V_1/V_2=10$ . Find the temperature of the gas compressed from an initial temperature of  $20^\circ\text{C}$ .

## Adiabatic compression

The air ( $\gamma=1.40$ ) in an automobile engine is compressed quickly so that appreciable heat exchange does not occur. For a compression ratio  $V_1/V_2=10$ . Find the work done in compressing a gas from 1atm if the capacity is 2.8 l.

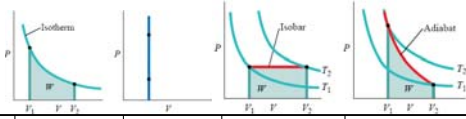
## Santa Anna Conditions

$T = 20^\circ\text{C}$   
 $P = 85\text{ kPa}$   
 $P = 100\text{ kPa}$   
 $T = ?$

High Desert. Coast

Santa Ana winds originate in the high desert region of California and is heated by adiabatic compress during the rapid descent to the coast. For the above conditions what would the temperature at the coast be?

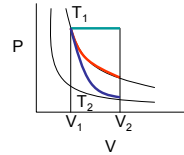
## Thermodynamic processes



Defining Characteristic	T constant $\Delta U=0$	V constant $W=0$	P constant $\Delta U=Q-W$	No Heat input $Q=0$
First Law	$Q=W$	$\Delta U=Q$	$\Delta U=Q-W$	$\Delta U=-W$
Work done by the gas	$nRT \ln(V_2/V_1)$	$W=0$	$P(V_2-V_1)$	$\frac{P_1V_1 - P_2V_2}{\gamma - 1}$
Other relations	$PV=\text{constant}$	$Q=mC_v\Delta T$	$Q=nc_p\Delta T$ $c_p=c_v+R$	$PV^\gamma=\text{constant}$ $TV^{\gamma-1}=\text{constant}$

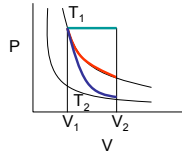
## Work done in expansion

One mole of air ( $\gamma=1.40$ ) at  $P_1 = 0.25$  atm,  $T_1 = 300$  K,  $V_1=0.1\text{m}^3$  expands by a factor of 2. Find the **work done** if the expansion is a) isobaric, b) isothermal c) adiabatic. Which process does the most work?



## Temperature change in expansion

One mole of air ( $\gamma=1.40$ ) at  $P_1 = 0.25$  atm,  $T_1 = 300$  K,  $V_1=0.1\text{m}^3$  expands by a factor of 2. Find the **temperature change** if the expansion is a) isobaric, b) isothermal c) adiabatic. Which process produces the highest temperature rise?



## Heat input on expansion

One mole of air ( $\gamma=1.40$ ) at  $P_1 = 0.25$  atm,  $T_1 = 300$  K,  $V_1=0.1\text{m}^3$  expands by a factor of 2. Find the **heat input** if the expansion is a) isobaric, b) isothermal c) adiabatic. What process results in the largest heat input?  $c_v(\text{air})=5/2R$

