Work and Heat

Readings: Chapter 17

Internal Energy

-Initial kinetic energy is lost due to friction.

-This is not completely true, the initial kinetic energy (or mechanical energy) is transferred into another type of energy, which is inside of the block.

-This energy is called internal energy.

-The internal energy is the sum of thermal energy (energy which depends on the temperature of the object), chemical energy, nuclear energy.

-Usually only thermal energy is changed. $E_{\text{int}} = E_{th} + E_{nuc} + E_{chem} + \ldots$

-If we can measure the temperature of the block we can find that the temperature is increased, which means that the thermal energy of the block is increased.

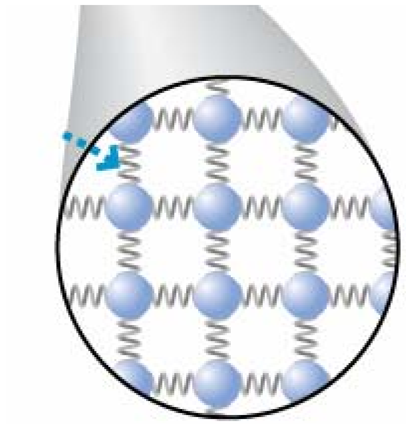
$$\frac{mv_i^2}{2} = \Delta E_{th} = E_{th,final} - E_{th,initial}$$

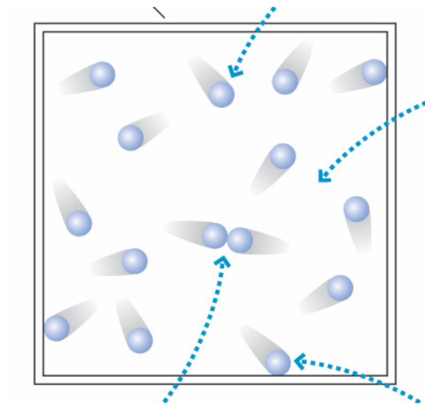
Thermal Energy

THERMAL ENERGY is the MECHANICAL ENERGY of ATOMS inside the object:

- for solids – this is a vibration of atoms;

- for gases – this is a kinetic energy of atoms





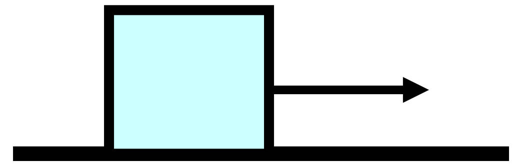
Energy conservation: the total energy (sum of mechanical energy and thermal energy) is constant for closed system.

$$K + E_{th} = const$$

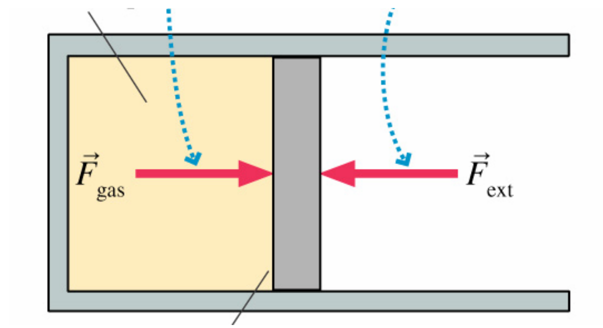
Thermal Energy

How can we change thermal energy of object? Thermal energy is determined by the temperature. How can we change the temperature of the object?

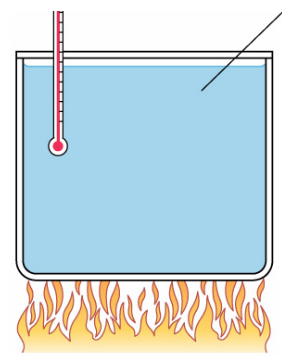
1. **Friction – usually for solid (not gases)**



2. **Work done by external force – usually for gases (not solid)**



3. **Heat transfer – two objects (solids or gases) with different temperature – for solid and for gas.**



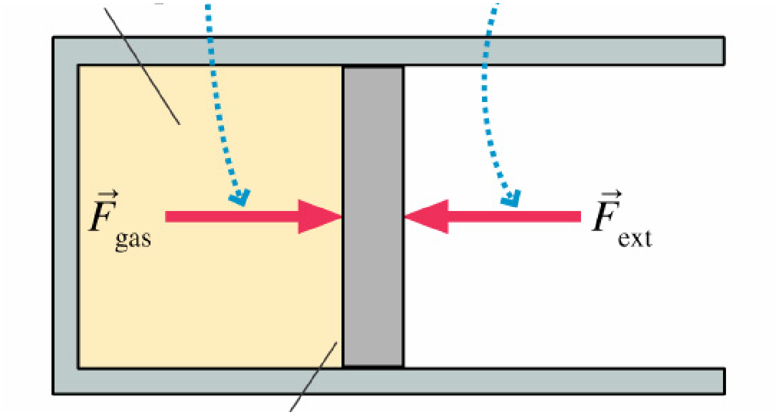
Work in Ideal-Gas process – quasi-static process

Equilibrium:

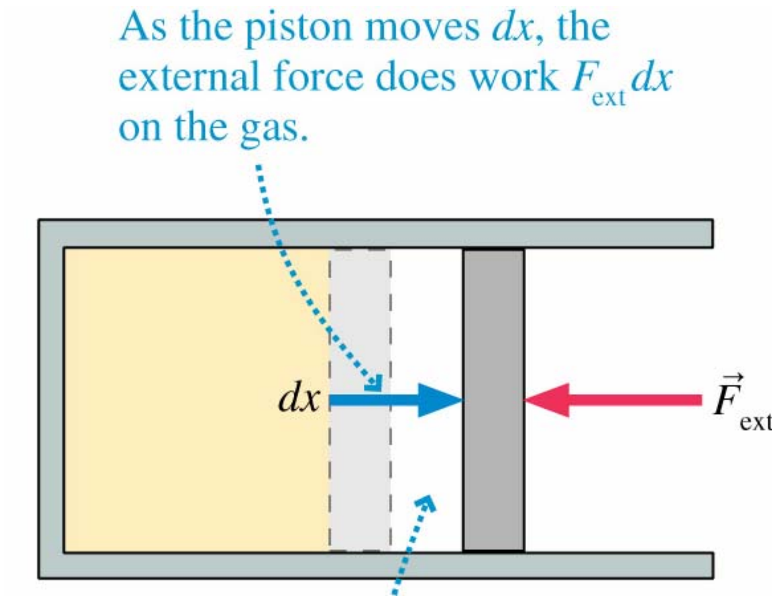
$$\vec{F}_{piston,net} = 0$$

$$\vec{F}_{gas} + \vec{F}_{ext} = 0$$

$$F_{ext} = F_{gas} = pA$$



We move piston (by changing a little bit external force) very slow, so the velocity of the piston is almost 0. Then all the time we have condition



$$F_{ext} = F_{gas} = pA$$

Work:

$$dW = F_{ext}dx = pAdx = -pdV$$

***dV*= – *Adx* is the volume change**

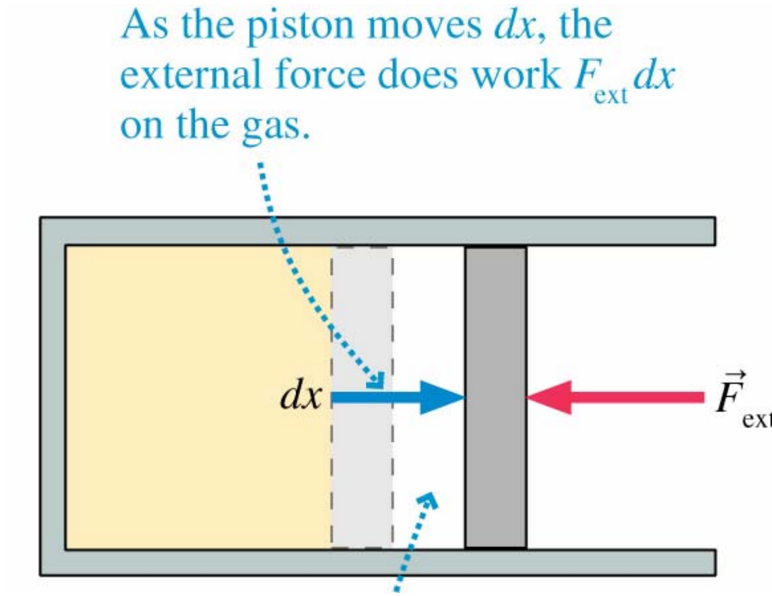
Work in Ideal-Gas process

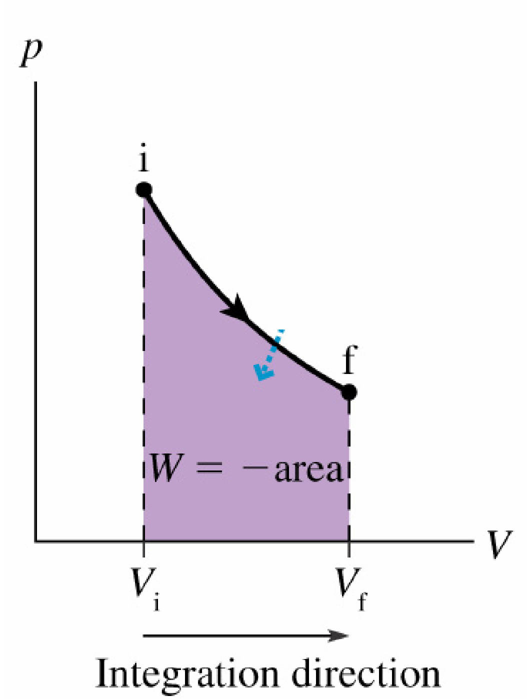
Work done by an external force on a gas:

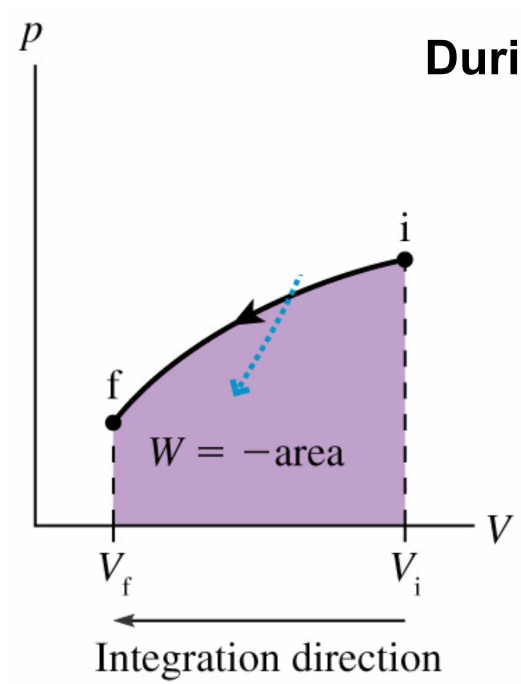
$$dW = F_{ext}dx = pAdx = -pdV$$

Or

$$W = -\int_{initial}^{final} pdV$$







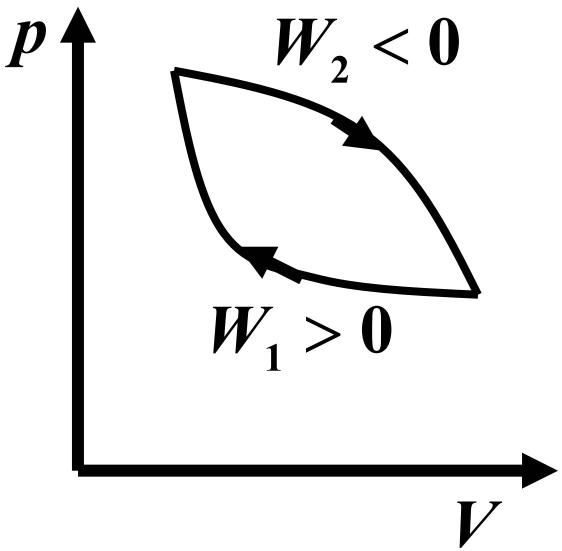
During this very slow motion:

$$pV = nRT$$

Work in Ideal-Gas process

$$W = -\int_{initial}^{final} p dV$$

$$pV = nRT$$



$$W_{net} = W_1 + W_2 < 0$$

Work depends on the path

Work done by external force will increase (or decrease) thermal energy.

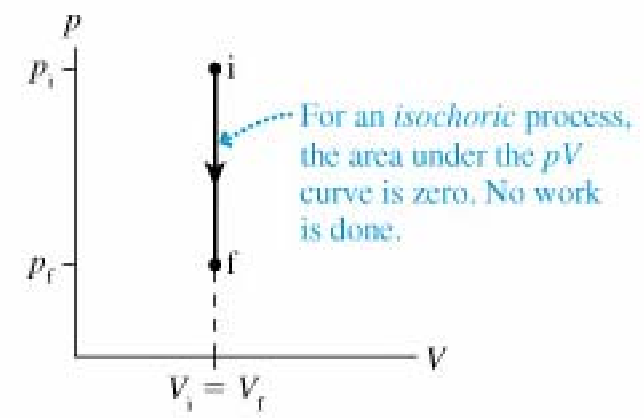
Thermal energy depends only on the temperature of the gas.

Thermal energy is the function of point in *PV* graph.

Work in Ideal-Gas process

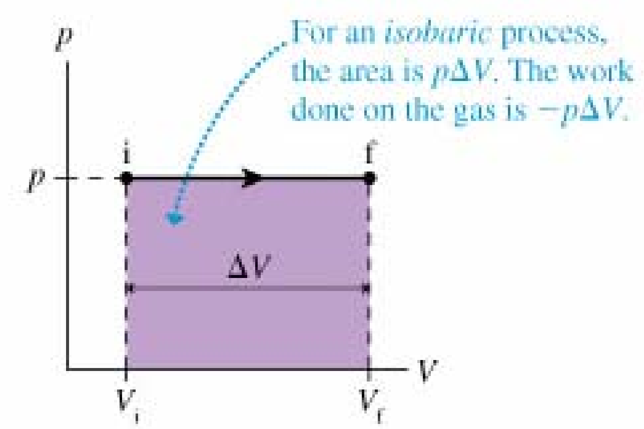
$$W = -\int_{initial}^{final} p dV$$

Isochoric process,
V = const

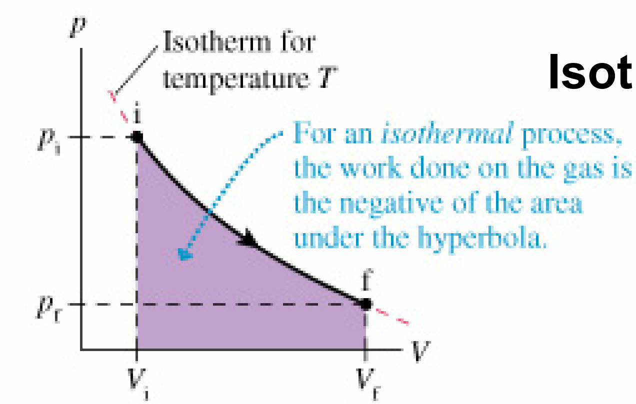


$$W = 0$$

Isobaric process,
p = const



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



Isotherm, T=const

$$p = nRT\frac{1}{V} \qquad pV = nRT$$

$$W = -\int_{V_i}^{V_F} p dV = -\int_{V_i}^{V_F} nRT\frac{1}{V} dV = -nRT\int_{V_i}^{V_F} \frac{1}{V} dV =$$

$$= -nRT\ln\left(\frac{V_F}{V_i}\right)$$

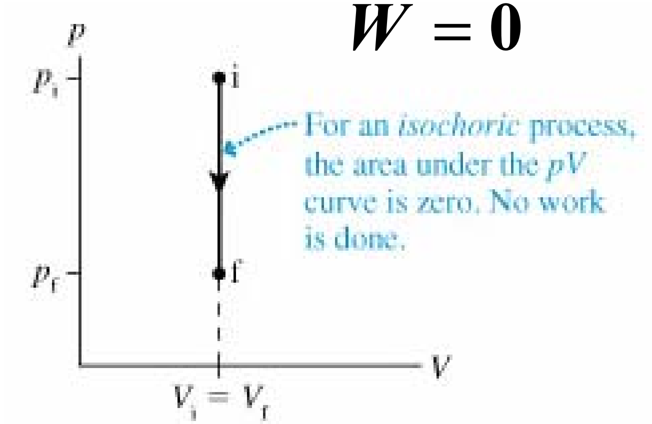
Work done by external force modify thermal energy.

Thermal energy depends only on the temperature of the gas.

Isochoric process,

V = const

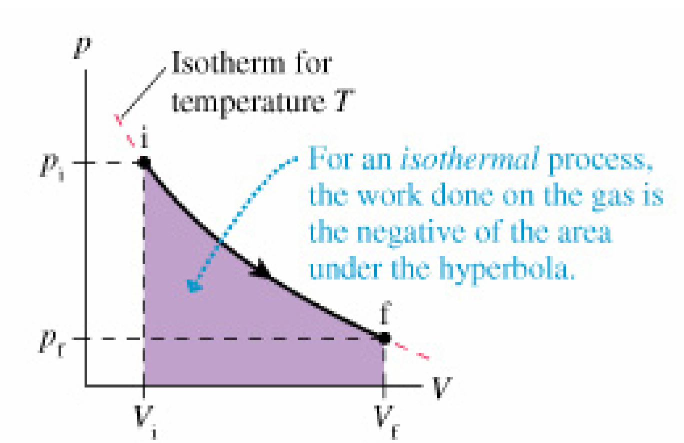
$$W = 0$$



Work is 0, but the temperature and thermal energy is changed.

How can we do this?

Isotherm, T=const



Temperature is constant – thermal energy is constant, but work is not 0.

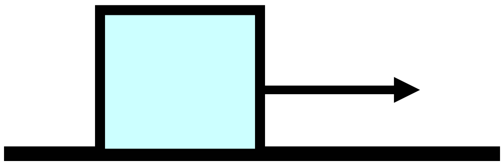
Where will this work be transformed?

$$W = -nRT\ln\left(\frac{V_F}{V_i}\right)$$

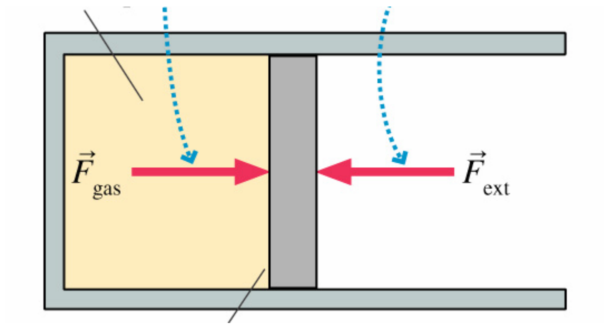
Thermal Energy

How can we change thermal energy of object? Thermal energy is determined by the temperature. How can we change the temperature of the object?

1. **Friction – usually for solid (not gases)**



2. **Work done by external force – usually for gases (not solid)**



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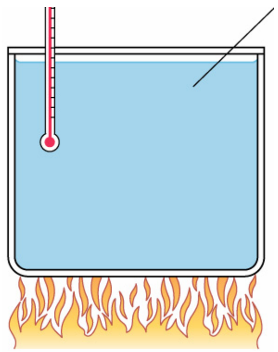
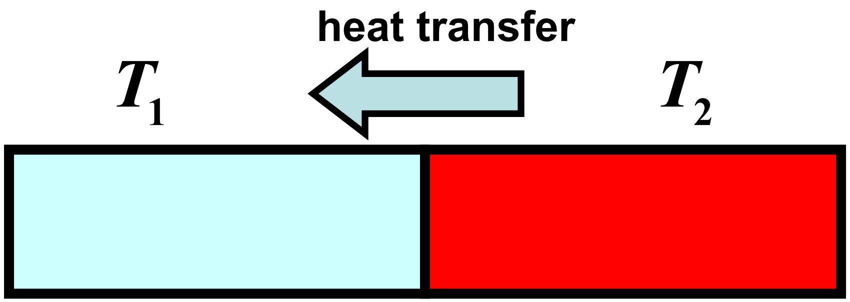
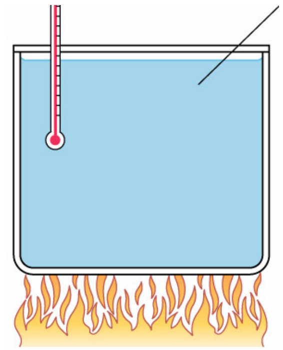


Thermal Energy: Heat transfer

If two objects have different temperature, then there will be heat transfer from one object to another one.





If $T_1 < T_2$ then heat will be transferred from object 2 to object 1.
Or thermal energy will be transferred from object 2 to object 1.

Thermal equilibrium:

$$T_1 = T_2$$

First Law of Thermodynamics

The first law of thermodynamics is the energy conservation:
The change of thermal energy is equal to work done external forces on the system and heat transfer to the system

$$\Delta E_{th} = W + Q$$

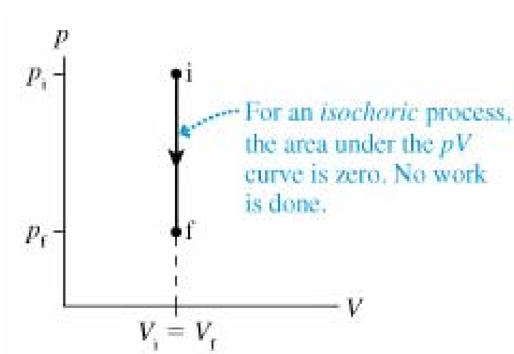
Work done by external force → W

Heat transfer → Q

Isochoric process, V = const

$$W = 0$$

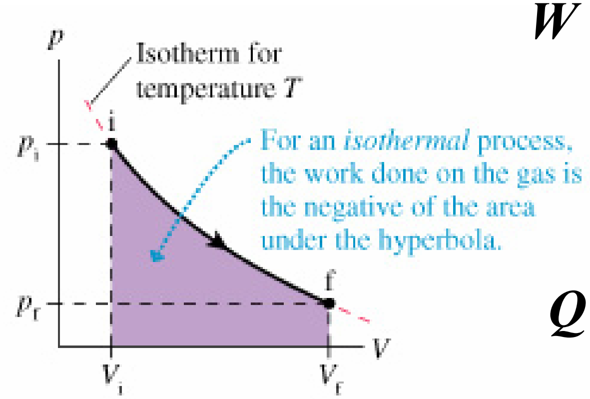
$$\Delta E_{th} = Q$$



Isotherm, T=const

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

$$W = -nRT \ln\left(\frac{V_F}{V_i}\right)$$



$$W + Q = 0$$

$$Q = nRT \ln\left(\frac{V_F}{V_i}\right)$$

Heat: Specific Heat

Specific heat of a substance is related to its thermal energy.
Specific heat is defined as:

The amount of energy that raises the temperature of 1 kg of a substance by 1 K is called specific heat, c.

$$Q = Mc\Delta T$$

Since

$$\Delta E_{th} = W + Q$$

We have

$$Mc\Delta T = \Delta E_{th} - W$$

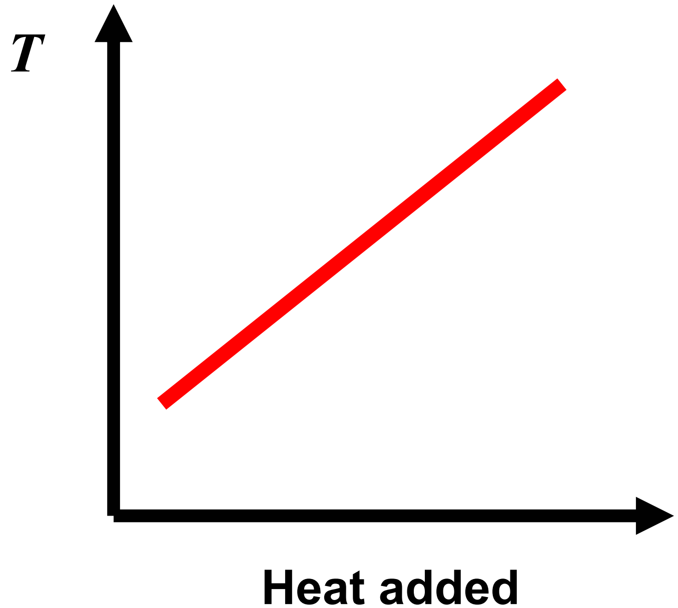
Since work depends on the process (on the path) specific heat depends on the process (path).

Heat: Specific Heat: Solids, Liquids

For solids and for liquids for almost all processes $\Delta V = 0$ then $W = 0$ and

$$Mc\Delta T = \Delta E_{th}$$

The thermal energy of the substance is proportional to its mass, temperature and the coefficient of proportionality is specific heat.



Heat: Specific Heat: Gas

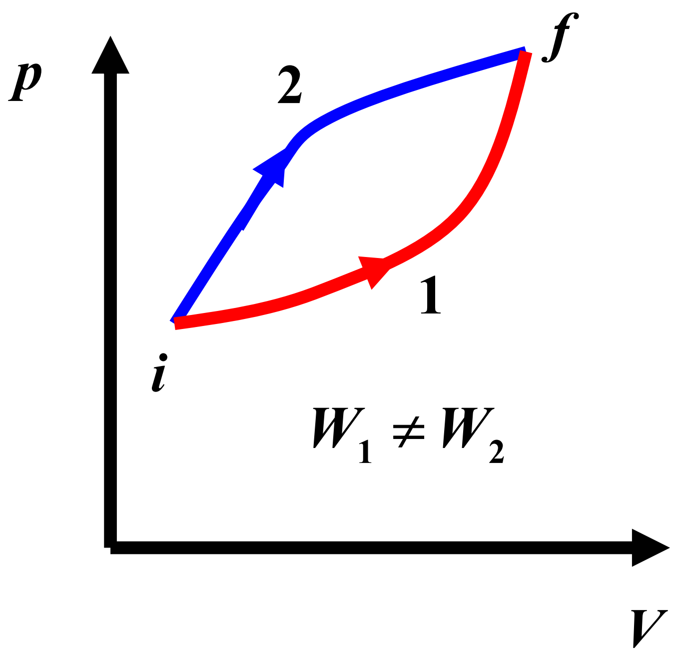
For gasses the molar specific heat is defined as

$$Q = nC\Delta T$$

For gasses $W \neq 0$

$$\Delta E_{th} = W + Q$$

$$nC\Delta T = \Delta E_{th} - W$$



Specific heat depends on the path

For both processes (1 and 2) the initial temperature and the final temperature are the same, but the work different.

$$nC_1\Delta T = \Delta E_{th} - W_1$$

$$nC_2\Delta T = \Delta E_{th} - W_2$$

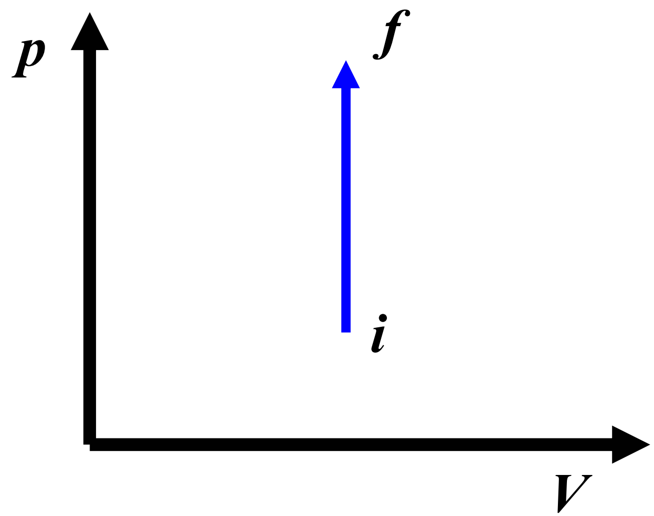
$$C_1 \neq C_2$$

Heat: Specific Heat: Gas

$$nC\Delta T = \Delta E_{th} - W$$

Isochoric process,

V = const



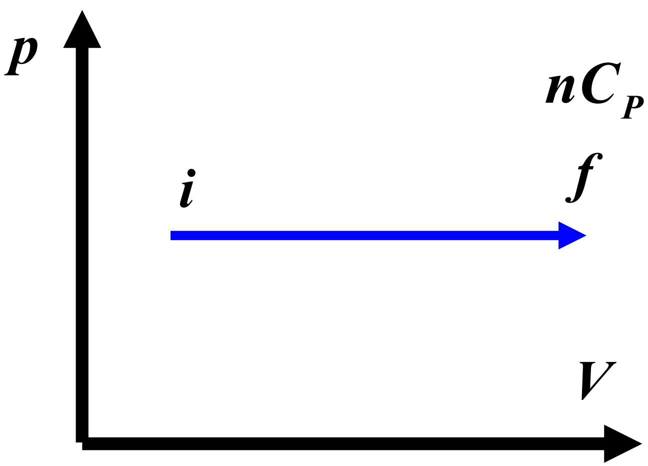
$$W = 0$$

$$nC_V \Delta T = \Delta E_{th}$$

Isobaric process,

p = const

$$W = -p(V_f - V_i) = pV_i - pV_f = nRT_i - nRT_f$$
$$= -nR\Delta T$$



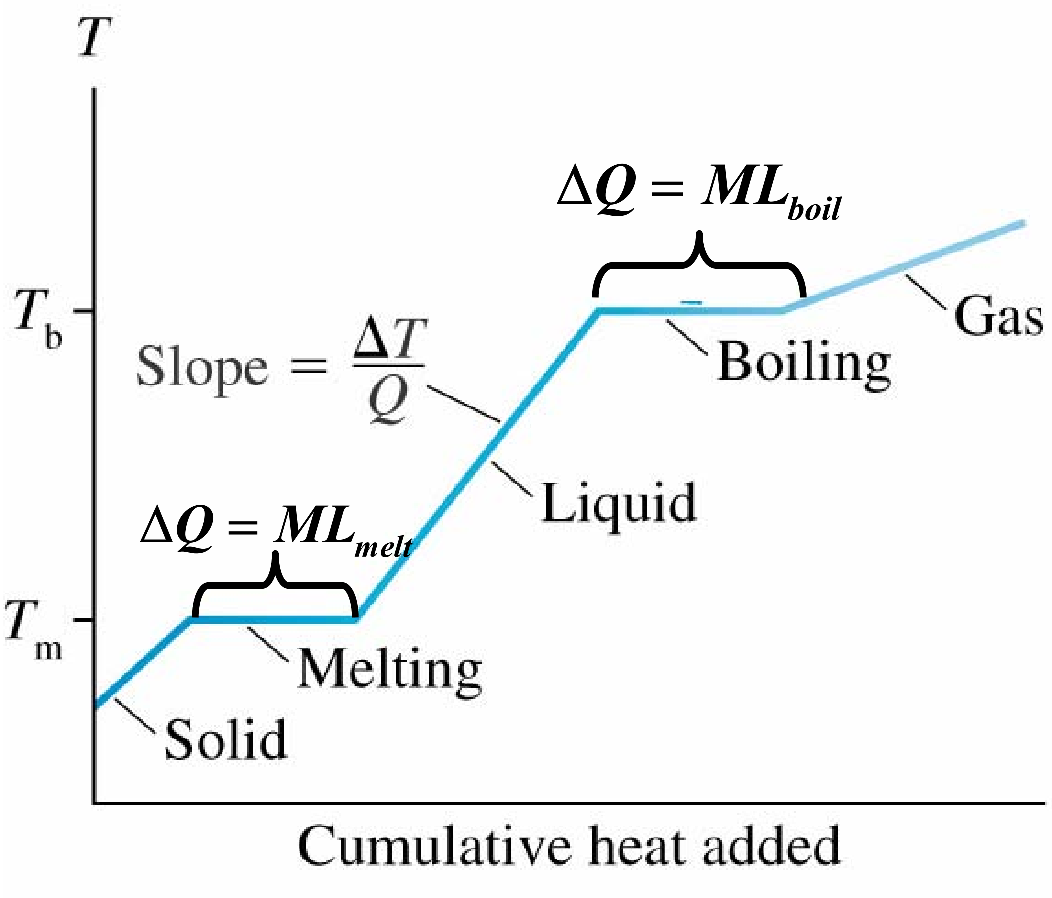
$$nC_P \Delta T = \Delta E_{th} - W = nC_V \Delta T + nR\Delta T = n(C_V + R)\Delta T$$

$$C_P = C_V + R$$

Phase Change: Solid, Liquid, and Gas

Phase change: change of thermal energy without a change in temperature

Heat of transformation (L) : the amount of heat energy that causes 1 kg of a substance to undergo a phase change.



$$Q = ML$$