DTU

10060 Physics (Polyteknisk grundlag)

The First Law of Thermodynamics

Quizzes

Question 5

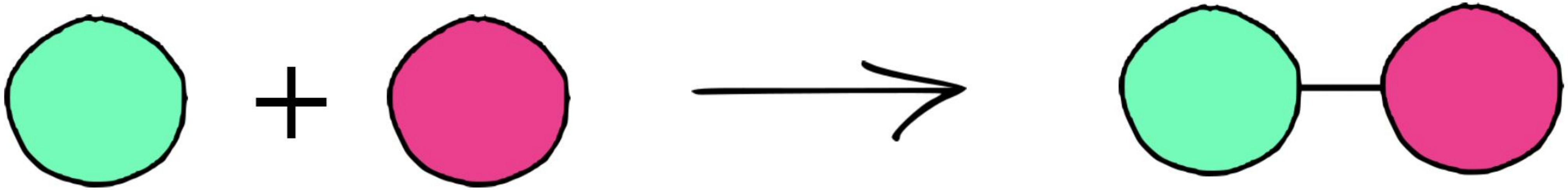
You are boiling water to cook pasta. After the water reaches 100°C and starts boiling, you add 200 g of uncooked pasta at room temperature (25°C). You notice the water stops boiling for a short time after adding the pasta, even though the stove continues to supply heat. Which of the following best explains why the water temporarily stops boiling?

- ◯ The latent heat of vaporization is absorbed by the pasta, preventing the water from boiling.
- ◯ The water transfers heat to the pasta to raise its temperature, so the heat initially supplied to boil the water is now used to warm the pasta.
- ◯ The pasta absorbs all the water's heat due to its higher specific heat capacity, stopping the phase change.
- ◯ The pasta lowers the water's temperature below the boiling point, so the water needs to absorb more heat to return to 100°C and resume boiling.

Question

Two monatomic gases react to form a diatomic gas. Suppose the reaction is performed with 1 mole of each gas, and in a thermally isolated chamber.

What happens to the temperature of the system?



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Thermodynamical Systems and Processes

What is thermodynamics all about?

You have a bicycle tire that is under-inflated, and you're using a hand pump to add air into it. Initially, the air inside the tire and the pump are at room temperature. As you pump air into the tire, you feel the pump getting warmer.

Questions for discussion:

•What is happening to the internal energy of the air inside the tire?

•Is there any heat transfer happening, and what role does work play in this process?

•How would you categorize the system (the tire) in this scenario?

•Can we identify if the process is adiabatic or isothermal?

Discuss with your neighbour

It’s all motivated by energy conservation

- In mechanics there is many situations where energy does not conserve, due to non-conservative forces (friction, drag, etc…) and we do not wonder what happens to the ”lost” energy

- In thermodynamics we care about energy conservation as a whole and we characterizing it in terms of transfer of heat and work

Thermodynamical systems

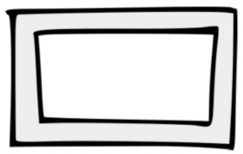
- A thermodynamical system can be considered a continuum since $N \sim N_A$ is big

- We have different systems:

Open system:
Mass and energy can flow in or out

Closed system:
Mass is conserved, but energy can flow in or out

Isolated system:
Mass and energy are conserved (i.e. cannot leave)



Thermodynamical variables

- Thermodynamical variables (like volume, pressure, temperature, internal energy) can be **extensive** and **intensive**

- A thermodynamical state can be associated to many different microscopic states but you do not need to know them all to know the thermodynamical variables

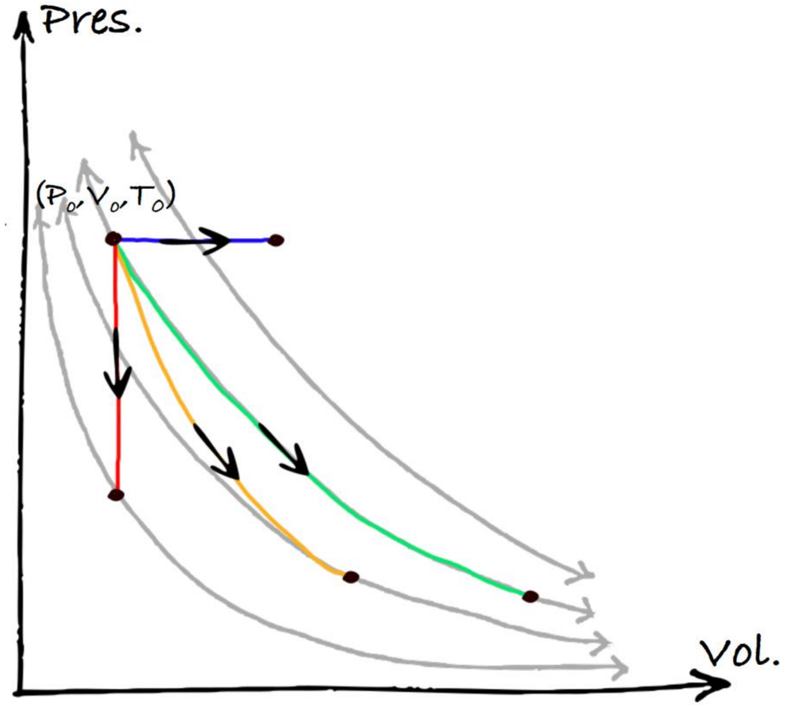
- The equation of state is satisfied at equilibrium $f(p,V,T) = 0$

Thermodynamical transformations

We have seen an example of thermodynamical transformation that transform work into heat: Joule machine

Why do we care?

During a transformation, energy might be stored in internal energy and might be later reused!



Isobaric: $\Delta p = 0$

Isochoric: $\Delta V = 0$

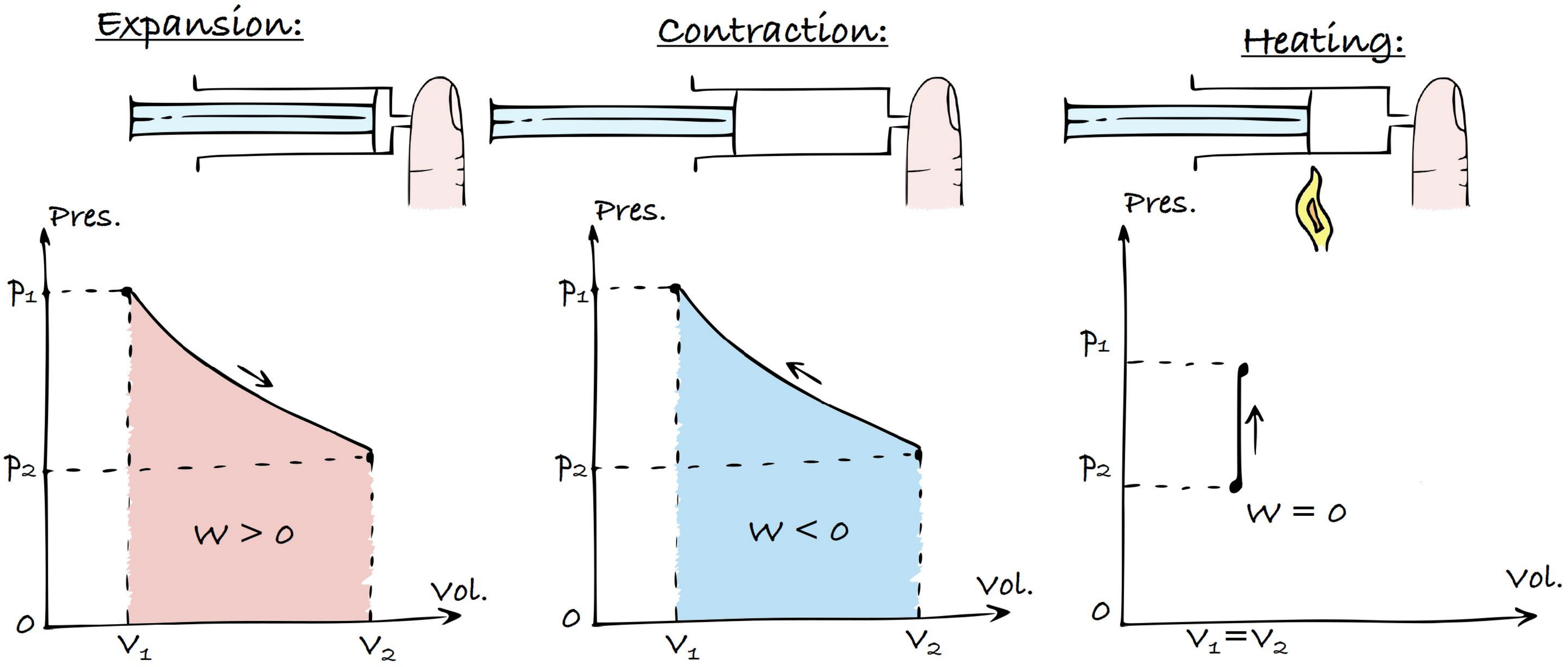
Isothermal: $\Delta T = 0$

Adiabatic: $Q = 0$

Closed loop: $\Delta E_{tot} = 0$

*transfomations can also be reversible and irreversible transformations. This concept is better understood when introducing entropy

Work in a thermodynamical process



1st Law of Thermodynamics

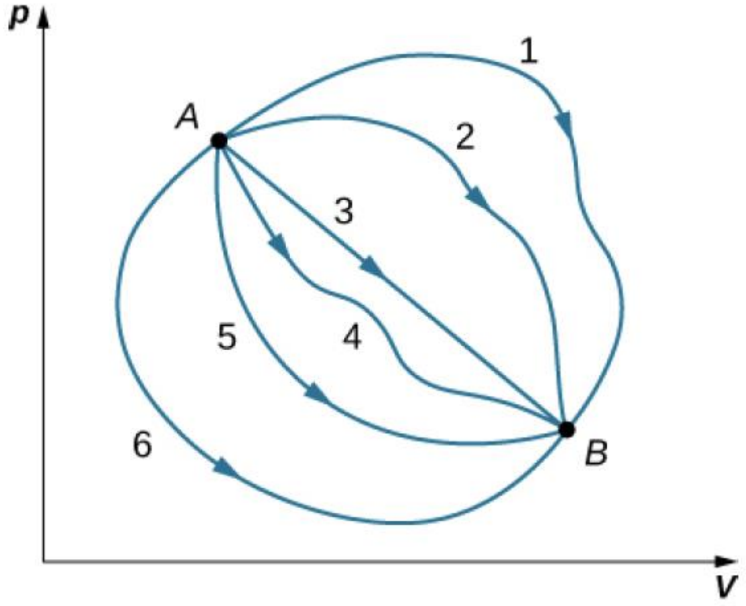
$$\boxed{\Delta U = Q - W}$$

1st law: Conservation of work, energy and heat:

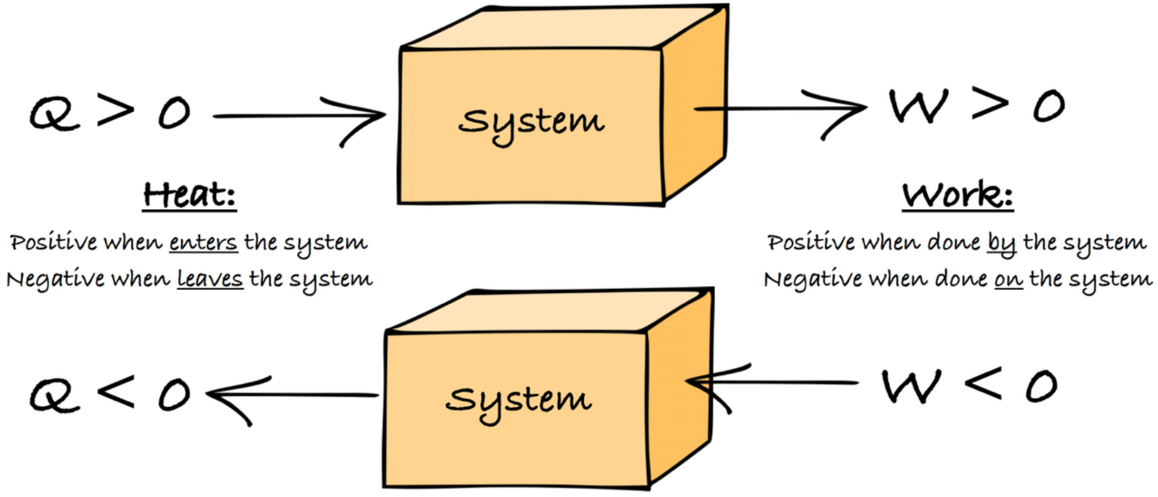
- Heat (Q) is the energy that changes the temperature of the system
- Work (W) is the energy that changes the volume, i.e. $\int_{V_1}^{V_1} PdV$

1st Law of Thermodynamics

- It does not matter which path you take



- Sign conventions



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Thermodynamical Transformations

Quiz time: What transformation is it?

Bicycle Pump Compression

- A student is using a bicycle pump to inflate a tire. They rapidly compress the air inside the pump, and the pump gets noticeably warm to the touch.

Isobaric: $\Delta p = 0$

Isochoric: $\Delta V = 0$

Isothermal: $\Delta T = 0$

Adiabatic: $Q = 0$

Closed loop: $\Delta E_{tot} = 0$

Choose the correct one

Isobaric ##.##%

Isochoric ##.##%

Isothermal ##.##%

Adiabatic ##.##%

Closed loop ##.##%

Choose the correct one

Isobaric	##.##%
Isochoric	##.##%
Isothermal	##.##%
Adiabatic	##.##%
Closed loop	##.##%

RESULTS SLIDE

Quiz time: What's the transformation?

Melting Ice in Water

- A piece of ice is placed in a glass of water. Over time, the ice melts, but the temperature of the system (ice + water) remains constant until all the ice has melted.

Choose the correct one

Isobaric
##.##%

Isochoric
##.##%

Isothermal
##.##%

Adiabatic
##.##%

Closed loop
##.##%

Isobaric: $\Delta p = 0$

Isochoric: $\Delta V = 0$

Isothermal: $\Delta T = 0$

Adiabatic: $Q = 0$

Closed loop: $\Delta E_{tot} = 0$

Choose the correct one

Isobaric	##.##%
Isochoric	##.##%
Isothermal	##.##%
Adiabatic	##.##%
Closed loop	##.##%

RESULTS SLIDE

Quiz time: What’s the transformation?

Heating a Sealed Container of Gas

- A sealed metal container filled with gas is placed in an oven. The container is rigid and doesn’t allow expansion or contraction.

Choose the correct one

Isobaric
##.##%

Isochoric
##.##%

Isothermal
##.##%

Adiabatic
##.##%

Closed loop
##.##%

Isobaric: $\Delta p = 0$

Isochoric: $\Delta V = 0$

Isothermal: $\Delta T = 0$

Adiabatic: $Q = 0$

Closed loop: $\Delta E_{tot} = 0$

Choose the correct one

Isobaric	##.##%
Isochoric	##.##%
Isothermal	##.##%
Adiabatic	##.##%
Closed loop	##.##%

RESULTS SLIDE

Quiz time: What's the transformation?

Quickly Opening a Soda Bottle

- A soda bottle is rapidly opened, and gas escapes quickly with a hissing sound. The temperature of the escaping gas is noticeably lower.

Choose the correct one

Isobaric ##.##%

Isochoric ##.##%

Isothermal ##.##%

Adiabatic ##.##%

Closed loop ##.##%

Isobaric: $\Delta p = 0$

Isochoric: $\Delta V = 0$

Isothermal: $\Delta T = 0$

Adiabatic: $Q = 0$

Closed loop: $\Delta E_{tot} = 0$

Choose the correct one

Isobaric	##.##%
Isochoric	##.##%
Isothermal	##.##%
Adiabatic	##.##%
Closed loop	##.##%

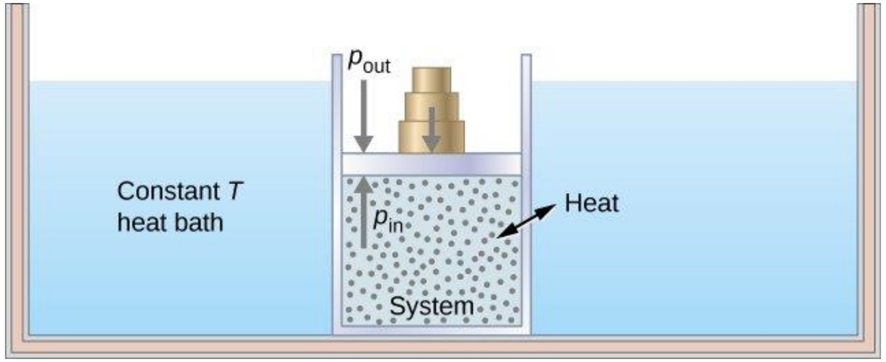
RESULTS SLIDE

Isothermal Transformation

In an isothermal transformation Temperature does not change:

$$\Delta T = 0 \quad \rightarrow \quad \Delta \mathrm{E}_{\mathrm{tot}} = 0 \quad \rightarrow \quad Q = W$$

In an ideal gas: $P_A V_A = P_B V_B$



If reversible:

$$\Delta W_{AB} = \int_A^B P dV = \int_A^B \frac{nRT}{V} dV = nRT \int_A^B \frac{dV}{V} = nRT \ ln \frac{V_B}{V_A}$$

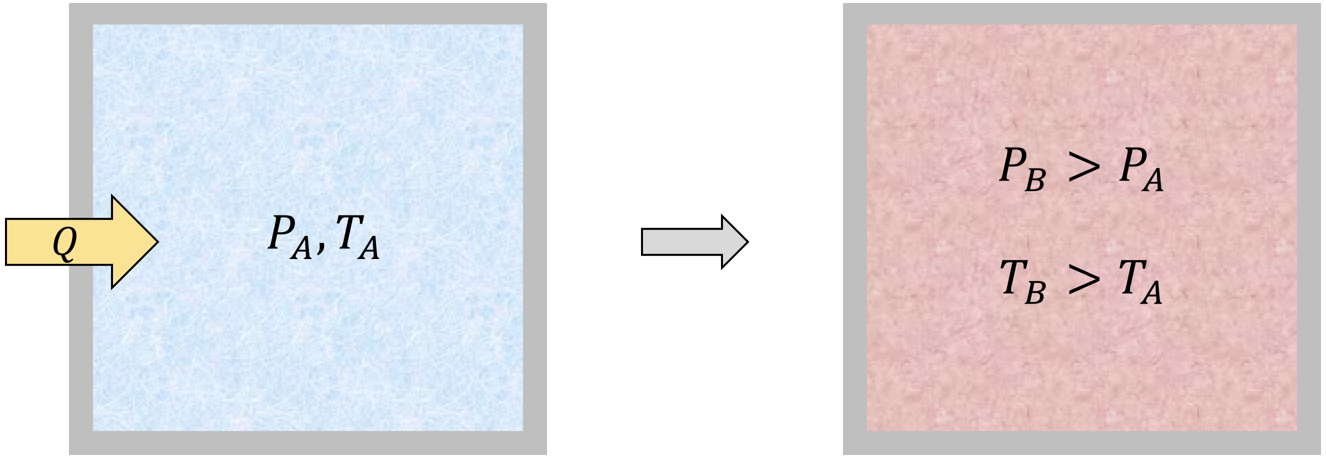
- isothermal expansion $W_{AB} > 0 \quad \rightarrow \quad Q_{AB} > 0$: the gas does work and absorbs heat
- isothermal compression $W_{AB} < 0 \quad \rightarrow \quad Q_{AB} < 0$: work is done on the gas and heat is removed from gas

Isochoric Transformation

In an isochoric transformation volume does not change:

$$\Delta V = 0 \quad \rightarrow \quad W = 0 \quad \rightarrow \quad Q = \Delta E_{tot} = nC_V(T_B - T_A)$$

In an ideal gas: $$\frac{P_A}{T_A} = \frac{P_B}{T_B}$$



Isobaric Transformation

In an isobaric transformation pressure does not change:

$$\Delta P = 0 \quad \rightarrow \quad \Delta \mathrm{E}_{\mathrm{tot}} = \mathrm{Q} - \mathrm{p}\Delta V$$

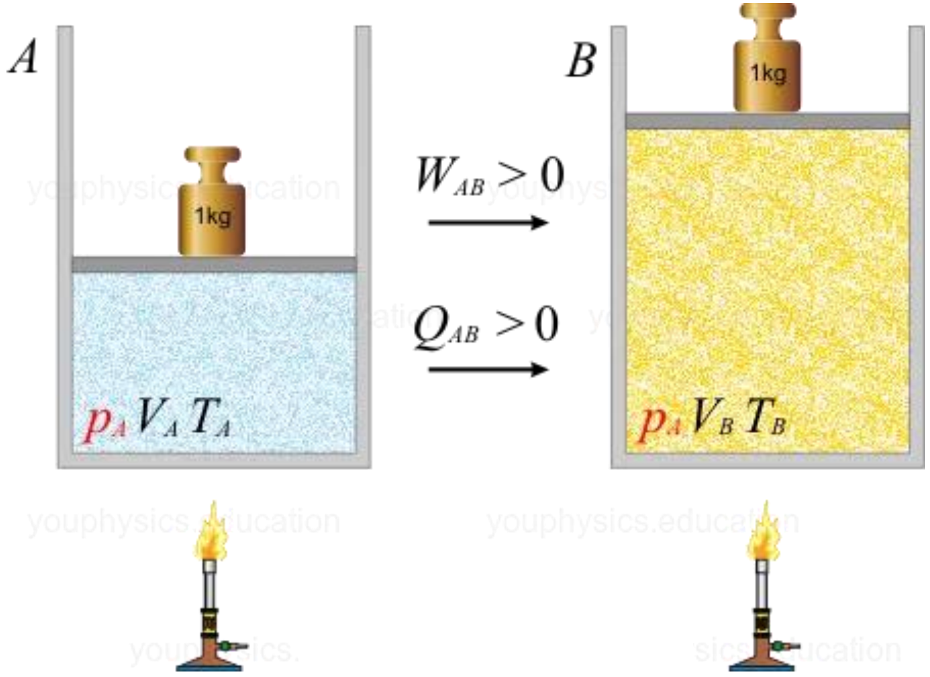
In an ideal gas: $\dfrac{V_A}{T_A} = \dfrac{V_B}{T_B}$

For an infinitesimal transformation:

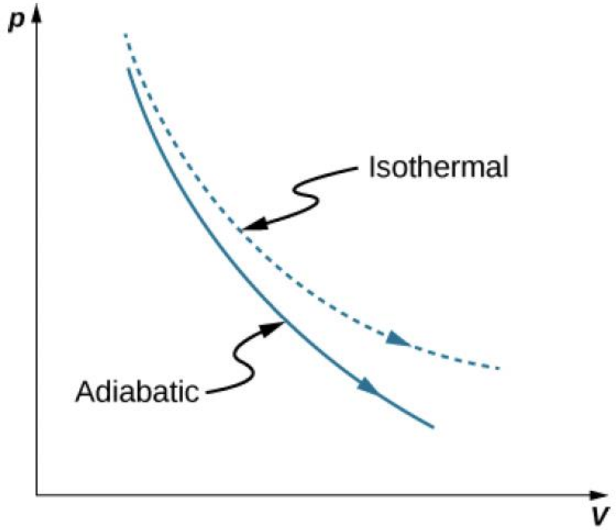
$$dQ = \underbrace{dE_{tot} + PdV}_{\equiv\, dH} = nC_V dT + nRdT = n\underbrace{(C_V + R)}_{\equiv\, \mathrm{C_P}}dT$$

Enthalpy

Molar heat capacity
at constant pressure



Adiabatic Transformation



In an adiabatic transformation heat is not exchanged:

$$Q = 0 \quad \rightarrow \quad \Delta \mathrm{E_{tot}} = -\mathrm{W} = \mathrm{nC_V(T_B - T_A)}$$

If reversible:

$$dQ = 0 \quad \rightarrow \quad dE_{tot} + pdV = 0 \quad \rightarrow \quad nC_V dT + pdV = 0 \quad \rightarrow \quad dT = -\frac{PdV}{nC_V}$$

For ideal gases: $d(PV) = nRdT \quad \rightarrow \quad VdP + PdV = nRdT$

$$\rightarrow VdP + PdV = -\frac{R}{C_V}PdV \quad \rightarrow \quad C_V VdP + (C_V + R)PdV = 0 \rightarrow \quad VdP + \frac{C_P}{C_V}PdV = 0 \quad \rightarrow \quad \frac{dP}{P} = -\gamma\frac{dV}{V}$$

$$\rightarrow \quad \ln\left(\frac{P_B}{P_A}\right) = -\gamma \ln\left(\frac{V_B}{V_A}\right) \rightarrow ln\left(\frac{P_B V_B^\gamma}{P_A V_A^\gamma}\right) = 0 \rightarrow \boxed{PV^\gamma = constant}$$

Recap

W

$E_{tot,B} > E_{tot,A}$

$T_B > T_A$

$P_B > P_A$

$V_B < P_A$

adiabatic compression

W

$E_{tot,B} < E_{tot,A}$

$T_B < T_A$

$P_B < P_A$

$V_B > P_A$

adiabatic expansion

Q

$E_{tot,B} > E_{tot,A}$

$T_B > T_A$

$P_B/T_B = P_A/\mathrm{T_A}$

isochoric heating

Q

$E_{tot,B} < E_{tot,A}$

$T_B < T_A$

$P_B/T_B = P_A/\mathrm{T_A}$

isochoric cooling

W Q

$E_{tot,B} = E_{tot,A}$

$T_B = T_A$

$P_B V_B = P_A V_A$

isothermal compression

Q W

$E_{tot,B} = E_{tot,A}$

$T_B = T_A$

$P_B V_B = P_A V_A$

isothermal expansion

W Q

$E_{tot,B} < E_{tot,A}$

$T_B < T_A$

$V_B/T_B = V_A/\mathrm{T_A}$

isobaric compression

Q W

$E_{tot,B} > E_{tot,A}$

$T_B > T_A$

$V_B/T_B = V_A/T_A$

isobaric expansion

A very last one: Cyclic Transformation

In a cyclic transformation we get back to the original point

$$\Delta E_{tot} = 0 \quad \rightarrow \quad Q = W$$