Thermodynamica 1

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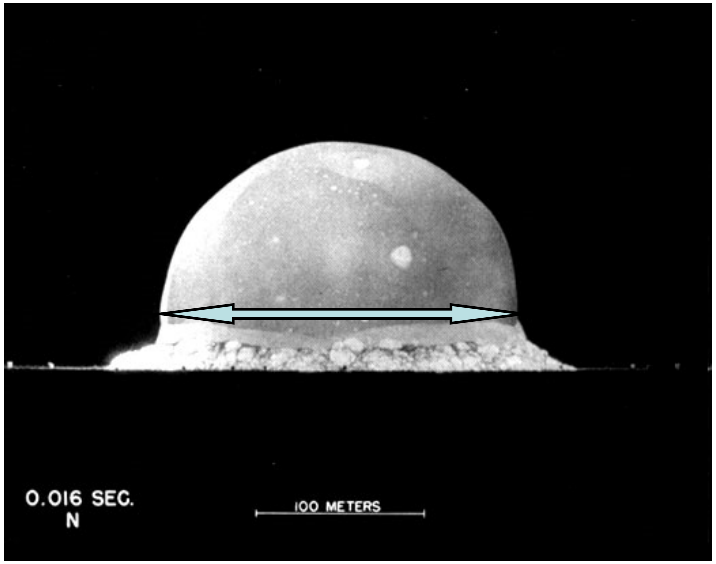
college 8 – boek hoofdstuk 5

College 7

- Massa en energie behoud open systemen
- Dimensie analyse
- Warmte transport
  - → Geleiding
  - → Convectie
  - → Straling

Dimensie analyse

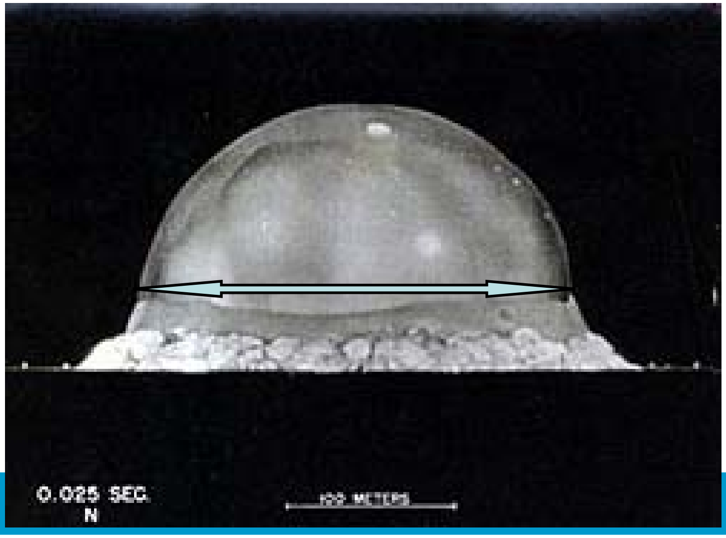


$$E = f(\rho, R, t)$$

$$E[kgm^2/s^2] = c\rho^{\alpha} \bullet R^{\beta} \bullet t^{\gamma} = c\left[\frac{kg}{m^3}\right]^{\alpha}[m]^{\beta}[s]^{\gamma}$$

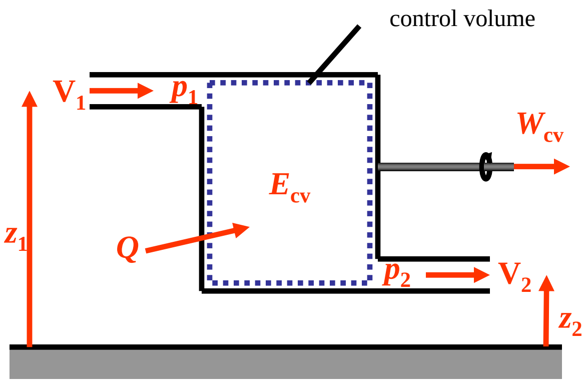
$$E = c \cdot \frac{\rho R^5}{t^2}$$

t = 0.016 s, R= 100 m
t = 0.025 s, R= 121 m
t = 0.030 s, R = 130 m
E~1x10^21 ergs
$\Rightarrow$ *E* ~ 100×10^12 J (100 TJ)
25kTON TNT



G.I. Taylor, 1947

1st law for stationary open system from lecture 6



general:

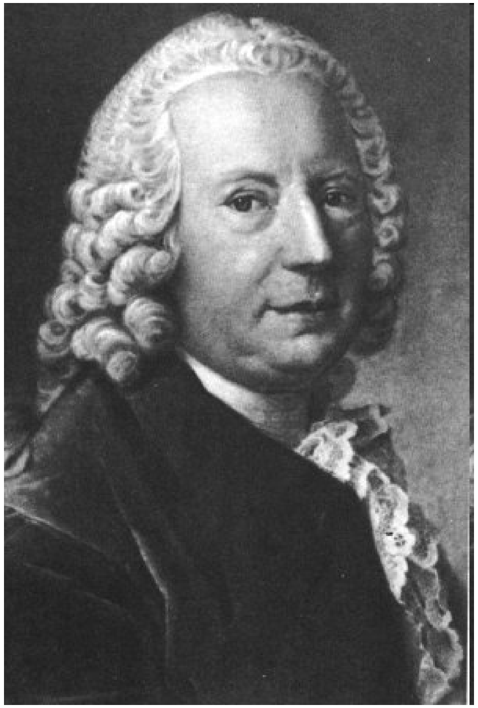
$$\dot{Q} = \dot{E}_{\text{cv}} + \dot{W}_{\text{cv}} + \dot{m}_2\left(h_2 + \tfrac{1}{2}\text{V}_2^2 + gz_2\right) - \dot{m}_1\left(h_1 + \tfrac{1}{2}\text{V}_1^2 + gz_1\right)$$

stationary: $\dot{E}_{\text{cv}} = 0$ and $\dot{m}_{cv} = 0 \rightarrow \dot{m}_2 = \dot{m}_1 = \dot{m}$

$$\boxed{\dot{Q} = \dot{W}_{\text{cv}} + \dot{m}\left[\left(h_2 - h_1\right) + \tfrac{1}{2}\left(\text{V}_2^2 - \text{V}_1^2\right) + g\left(z_2 - z_1\right)\right]}$$

Wet van Bernoulli

$$\dot{Q} = \dot{W}_{cv} + \dot{m}\left[\left(h_2 - h_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right]$$



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$$h = u + pv$$

$$\dot{Q} = \dot{W}_{cv} + \dot{m}\left[\left(u_2 - u_1 + p_2 v_2 - p_1 v_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right]$$

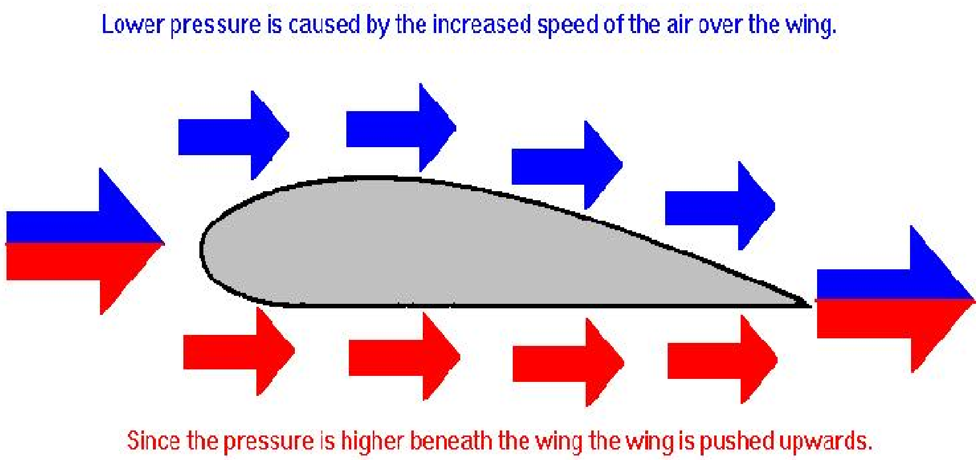
$$\dot{Q} = \dot{W}_{cv} + \dot{U}_2 - \dot{U}_1 + \dot{m}\left[\left(p_2 v_2 - p_1 v_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right]$$

Neem nu aan dat warmte en arbeid nul zijn en de interne energie constant

$$\left[\left(p_2 v_2 - p_1 v_1\right) + \tfrac{1}{2}\left(V_2^2 - V_1^2\right) + g\left(z_2 - z_1\right)\right] = 0; \; v = \frac{1}{\rho}$$

$\frac{p}{\rho} + \frac{1}{2}V^2 + gz = Const$ ➔ Wet van Bernoulli

Bernoulli, lift van een vleugel

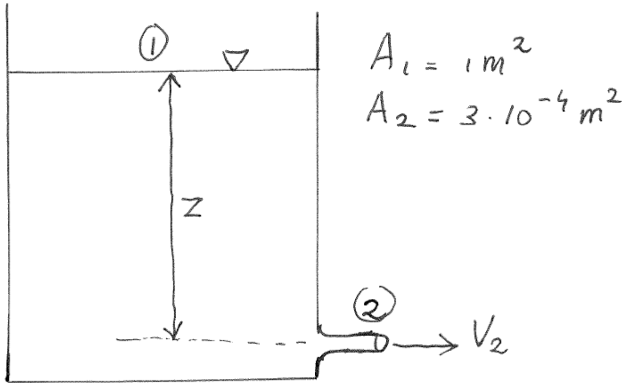


$$P + \frac{1}{2}\rho V^2 = Const$$

Hoge snelheid → lage druk

Lage snelheid → hoge druk

Leeglopend vat, p 4.16 (editie 6)



$$p_1 + \frac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2$$

$$p_1 = p_2$$

neem aan dat, $V_1 << V_2 \Rightarrow V_2 = \sqrt{2g(z_1 - z_2)} = \underline{\sqrt{2gz}}$

$$\frac{dm_{cv}}{dt} = -\dot{m}_2 \Rightarrow \frac{d\rho A_1 z}{dt} = -\rho A_2 \sqrt{2gz}$$

$$\frac{dz}{dt} = -\frac{A_2}{A_1}\sqrt{2g}\sqrt{z}$$

$$\frac{dz}{\sqrt{z}} = -\frac{A_2}{A_1}\sqrt{2g}dt \Rightarrow 2\sqrt{z} = -\frac{A_2}{A_1}\sqrt{2g}t + C$$

$$t = 0, z = z_1 \Rightarrow C = 2\sqrt{z_1}$$

$$\sqrt{z} = -\frac{A_2}{2A_1}\sqrt{2g}t + \sqrt{z_1}$$

vat leeg op tijd t als $\left(\frac{A_2}{2A_1}\sqrt{2g}t = \sqrt{z_1}\right) = 0 \Rightarrow t_{leeg} = 2\frac{A_1}{A_2}\sqrt{z_1 / 2g}$

$$\frac{dy}{dt} = y^{1/2}$$

$$\frac{dy}{y^{1/2}} = dt$$

$$2y^{1/2} = t + c$$

Leerstoel Energietechniek

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Problem 4.51

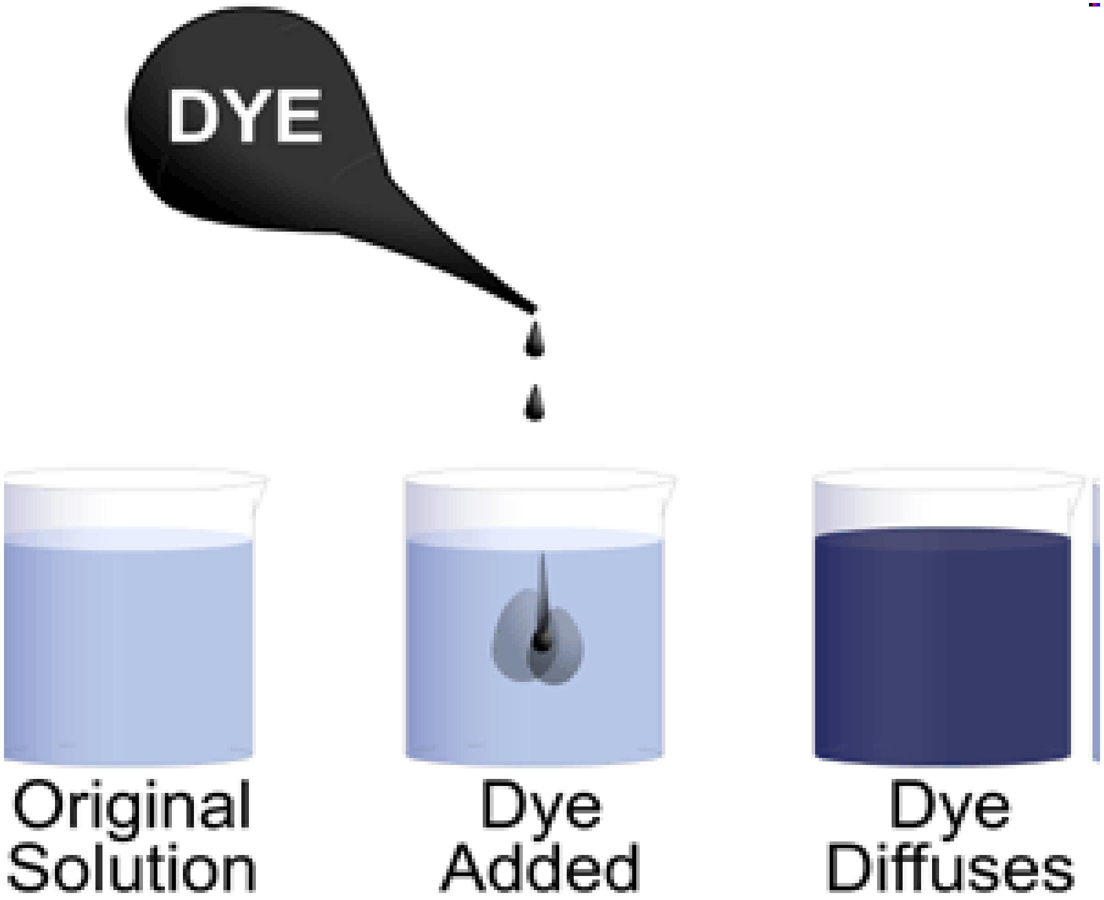
$$\dot{Q} = \dot{W} + m\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1) \right]$$

$$\text{vgl (3.43)} \Rightarrow h(T_2) - h(T_1) = \int_{T_1}^{T_2} C_p dT$$

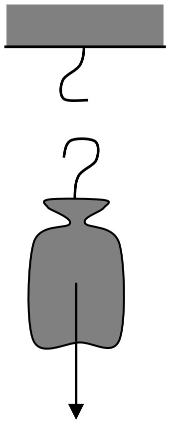
$$\dot{m} = 0.011 kg / s$$

$$\dot{Q} = -0.033 kW$$

The 2nd law of Thermodynamics



Motivation



Observations

- the 1st law states that energy is conserved, but it says nothing about the direction of energy-conversion processes. Nature, however, very well prescribes a direction, in which processes occur (spontaneously).

⇒ a 2nd law of Thermodynamics is needed

- whenever a process does occur spontaneously, then there is an imbalance between begin- and end-state – there is a non-equilibrium. This non-equilibrium condition can be used to obtain work (Arbeidspotentieel).

⇒ how much work can potentially be obtained from a process? (The 2nd law gives an answer)

Spontane processen en het Arbeidspotentieel

Spontaneous processes

- have driving forces, so that process occurs spontaneously
- are thus in non-equilibrium

⇒ the driving forces can be used to obtain work (Arbeidspotentieel)

Spontaneous processes never reverse spontaneously and are hence called irreversible

The reversed process is only possible with external influence

High pressure air (driving force) can be used to drive a turbine and obtain net work W (Arbeidspotentieel)

A second law of Thermodynamics

… is needed in order to answer:

- what is the direction in which an energy conversion takes place spontaneously. (And what processes do not occur by themselves)

- what is the theoretical maximum value of work that can be obtained from a process

- what is the value of work that can be realized technically. And how can one approach the theoretical maximum

Relevance of these questions and the 2nd law

any energy conversion system, like

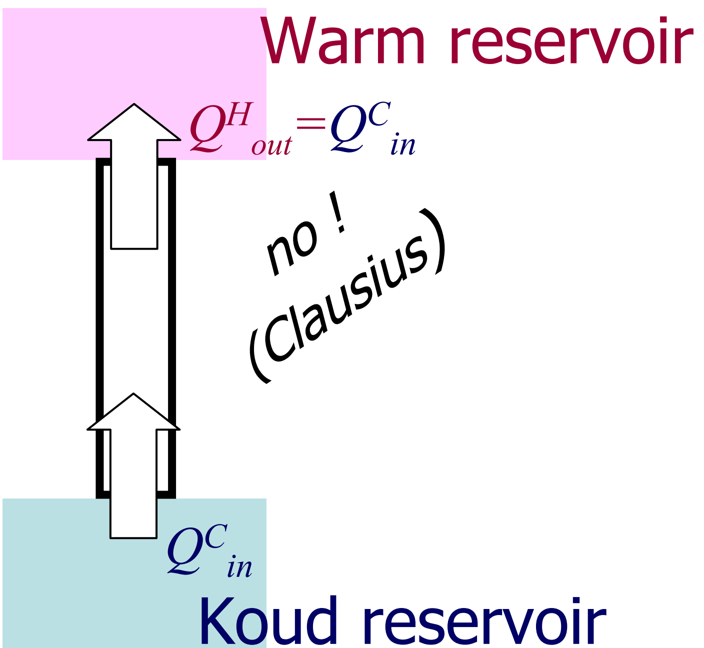
- power plants and their efficiency
- biological (biochemical) conversions & muscular action
- astronomy

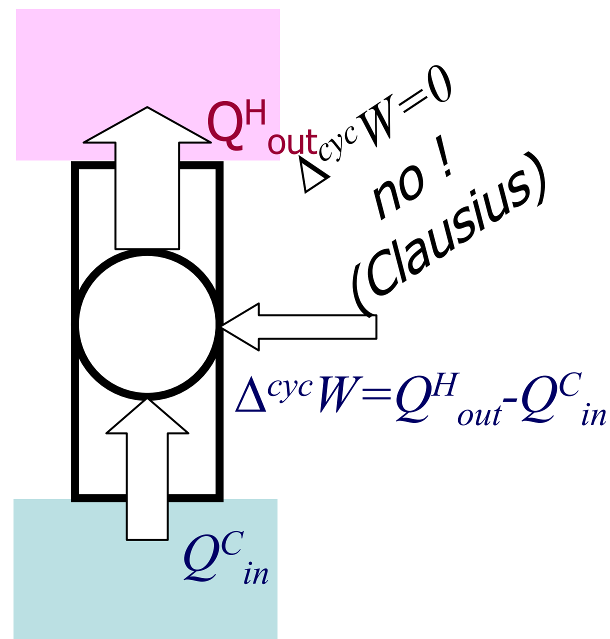
$\Rightarrow$ Thermodynamics determines the processes that do or do not occur in nature. It determines the processes that can not be realized technologically.

(Historische) **Formulering van 2^de HW - Clausius**

Het is onmogelijk om, zonder meer, warmte van lagere naar hogere temperatuur te brengen

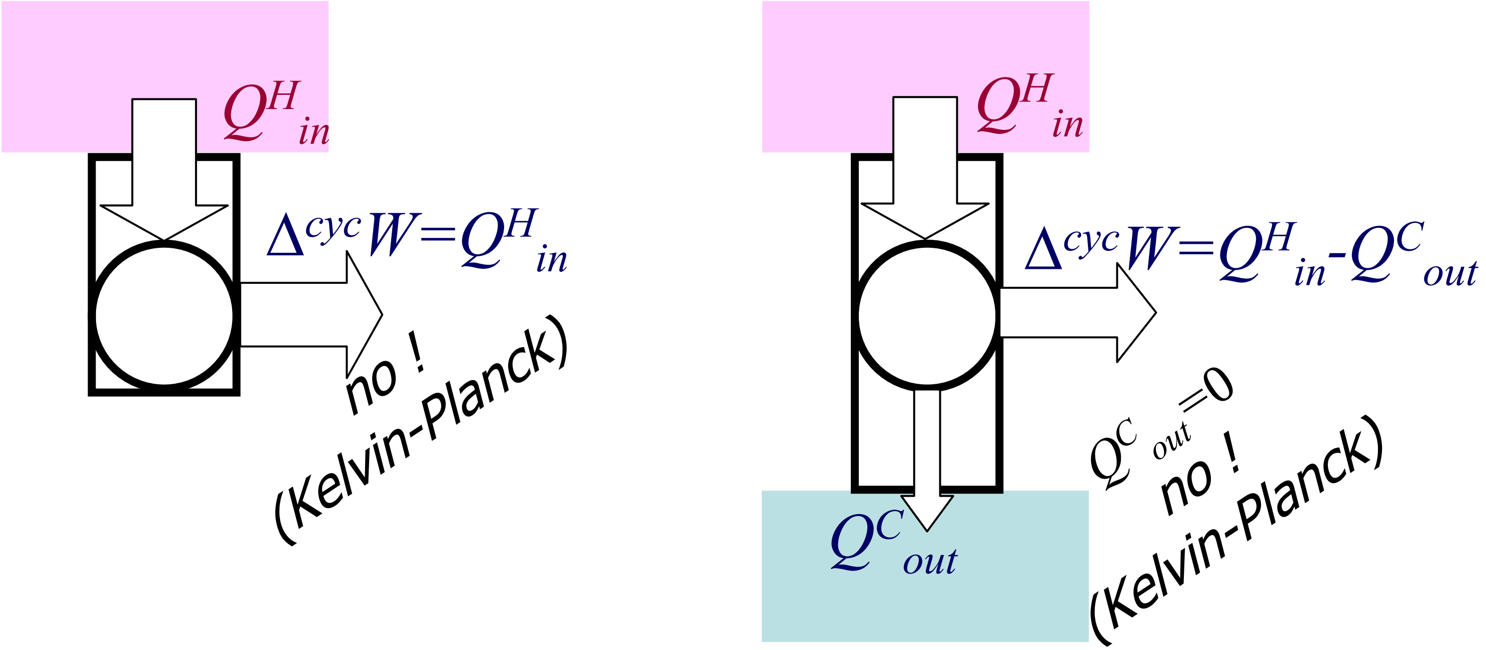
Dit betekent dat om dit toch te bereiken, arbeid toegevoerd moet worden op het systeem.





(Historische) **Formulering van 2de HW – Kelvin-Planck**

Het is onmogelijk dat een systeem als een thermodynamisch kringproces functioneert en een netto hoeveelheid arbeid levert aan de omgeving terwijl het warmte ontvangt van één enkel warmte reservoir.



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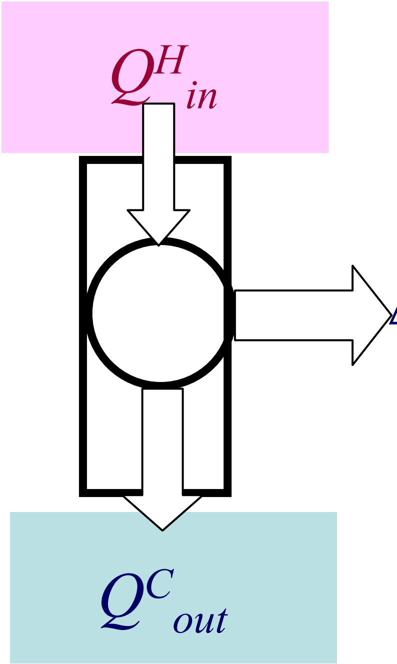


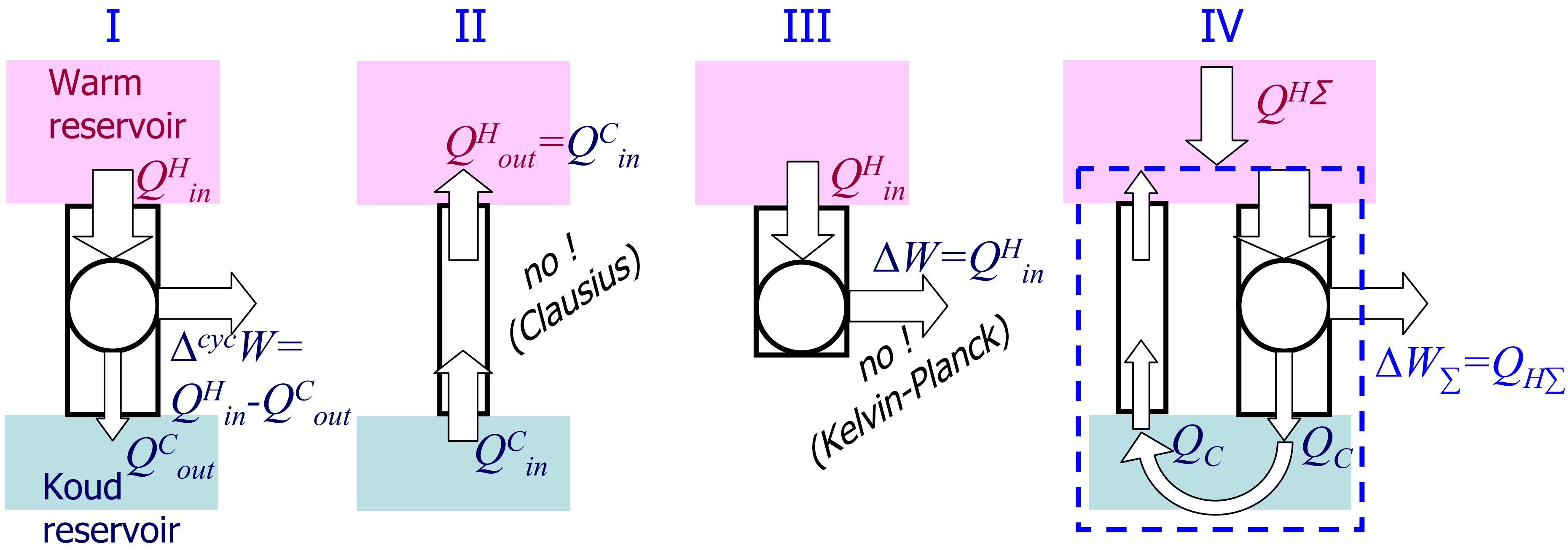
$\Delta^{cyc}W = Q^H{}_{in} - Q^C{}_{out}$

$Q^C{}_{out} = 0$ no ! (Kelvin-Planck)

$$\eta = \frac{W_c}{Q_{in}}$$

altijd < 100% !

Equivalence of Clausius and Kelvin-Planck



We know I exists.

Because II violates Clausius

...we know that Kelvin-Planck (III) also violates Clausius

... because IV is equivalent to III (as the blue dashed system is equivalent to III)

$\Rightarrow$ Formulation of Kelvin-Planck (III) is equivalent to formulation of Clausius (II)

For an ***ir****reversible process: the system and the surrounding never spontaneously return to the initial state*

8. Spontane processen zijn:
   (a) reversibel
   (b) onmogelijke processen
   (c) omkeerbaar zonder ingreep van buitenaf
   (d) omkeerbaar met ingreep van buitenaf

Reversible processes

- The system and its surrounding can for a reversible process at all times return to their initial state
- If a reversible process is reversed, then the backward process path for the system and its surrounding is identical to the forward path
- In practice reversible processes can only be approached but never fully reached; the environment will always be altered to some extent
- A perfectly reversible process can not deviate from thermal equilibrium and would be infinitely slow

Irreversibility

- friction (in flow of fluids as well as sliding friction)
- any (non-utilized) heat transfer through a temperature difference (because the reverse is not possible, Clausius!)
- non-utilized expansions of a fluid to lower pressure
- electric current flow through a resistance
- mixing of substances

- Irreversibilities are those parts of a process that reduce the work that would theoretically be obtainable if the process was reversible

$\Rightarrow$ Irreversibilities = "lost work"

(the work is lost as heat)

Inwendige reversibele processen

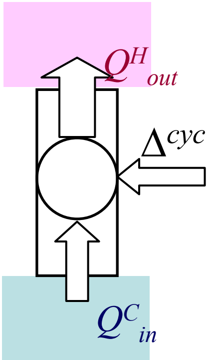
- Voor alle toestanden van een inwendig reversibel proces dat een gesloten systeem ondergaat, blijven alle intensieve toestandsgrootheden uniform in elk van de aanwezige fasen.

$\Rightarrow$ Temperatuur, druk, specifieke volume en andere intensieve grootheden veranderen niet met de plaats.

- Verschillen in intensieve grootheden zouden moeten leiden tot drijvende krachten terwijl reversibiliteit eist dat er geen spontane processen kunnen plaatsvinden.

TUDelft

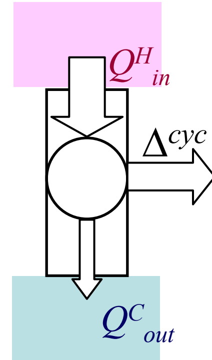
Result of the 2nd law for cycle-processes



$\Delta^{cyc}W = Q^H{}_{out} - Q^C{}_{in}$

$\Delta^{cyc}W = 0$ not feasible (Clausius)

refrigeration/
heat pump cycle



$\Delta^{cyc}W = Q^H{}_{in} - Q^C{}_{out}$

$Q^C{}_{out} = 0$ not feasible (Kelvin-Planck)

power cycle

The thermal efficiency η^{rev} of reversible a power cycle, is

$$\eta^{rev} = \frac{\Delta^{cyc}W}{Q^H_{in}} = 1 - \frac{Q^C_{out}}{Q^H_{in}} < 1$$

$Q^{cyc}_C > 0$ Kelvin-Planck

$\Delta^{cyc}W = Q^H_{in} - Q^C_{out}$

$\Rightarrow$ thermal efficiency η^{rev} even of a reversible power cycle is lower than unity, $\eta^{rev} < 1$

Results of the 2nd law for cycle-processes

$\Rightarrow$ even a reversible (i.e. idealized) power cycle has an efficiency of $\eta^{rev} < 1$

  $\Rightarrow$ "heat can not fully be converted to work"

$\Rightarrow$ all reversible Carnot-like* power cycles operating between the same temperature of two thermal reservoirs have the same thermal efficiency η^{rev}

  $\Rightarrow$ η^{rev} does not depend on the working fluid

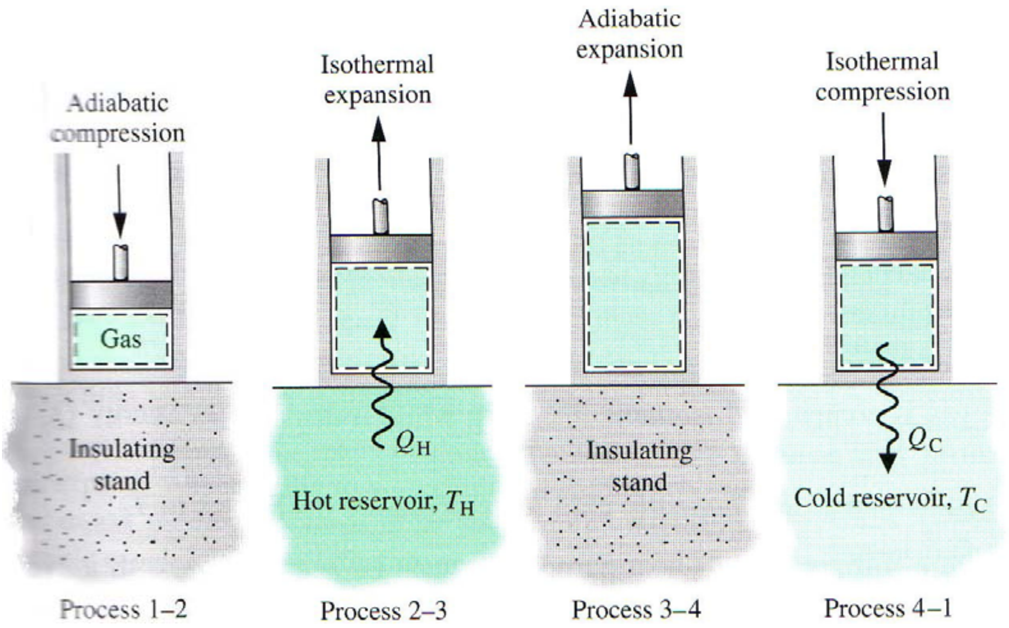
  $\Rightarrow$ η^{rev} does not depend on the process steps making up the power cycle

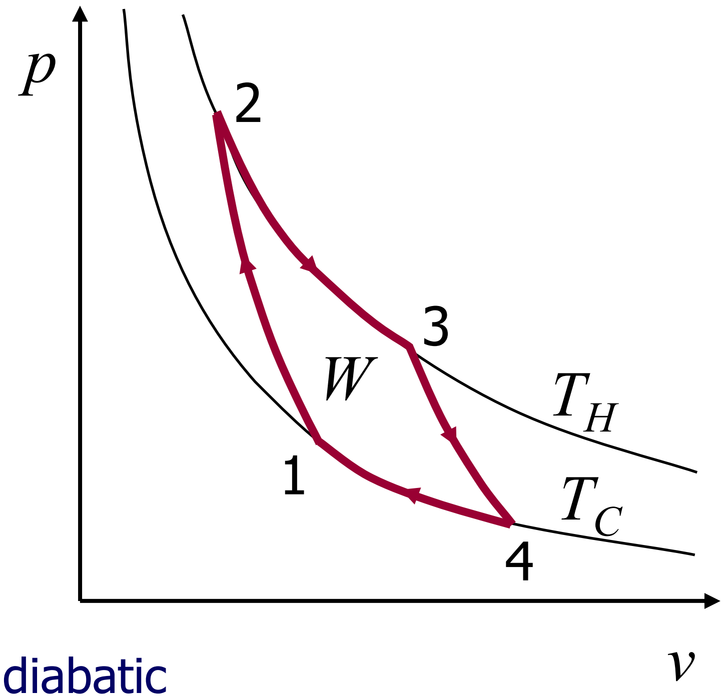
$\Rightarrow$ an irreversible (i.e. real) power cycle has yet a lower efficiency $\eta^{real} < \eta^{rev} < 1$

book page 187

* Carnot-like means that all external heat transfer is realized isothermally with the two thermal reservoirs

The Carnot power cycle process





A reversible cycle comprising 2 isothermal and 2 adiabatic process steps

- 1-2 adiabatic compression, T increases from T_C to T_H
- 2-3 expansion of the gas at const. $T=T_H$ (isothermal)
- 3-4 adiabatic expansion, T decreases from T_H to T_C
- 4-1 compression of gas at const. $T=T_C$ (isothermal)

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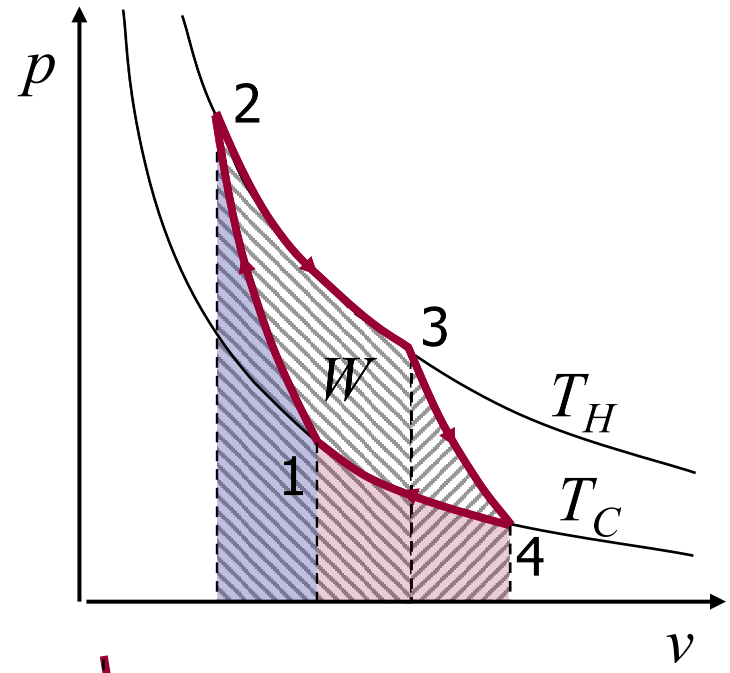
Carnot power cycle of an ideal gas

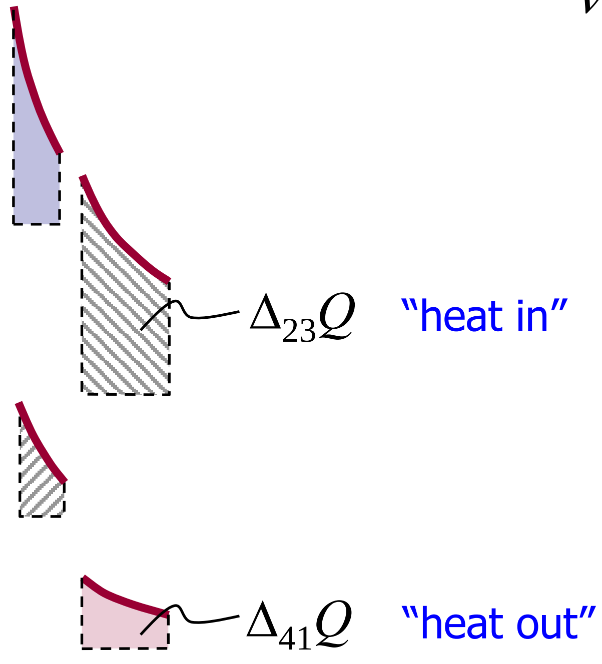
first law for closed systems

$$dU = \delta Q - \delta W \qquad \delta W = pdV;\ \delta Q = TdS$$

$$\Delta U = \delta Q - \delta W \qquad \Delta_{1234} W = \int pdV$$

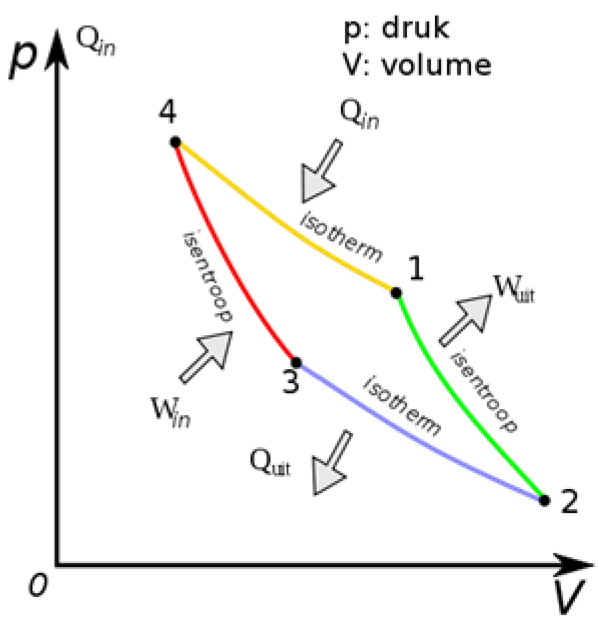


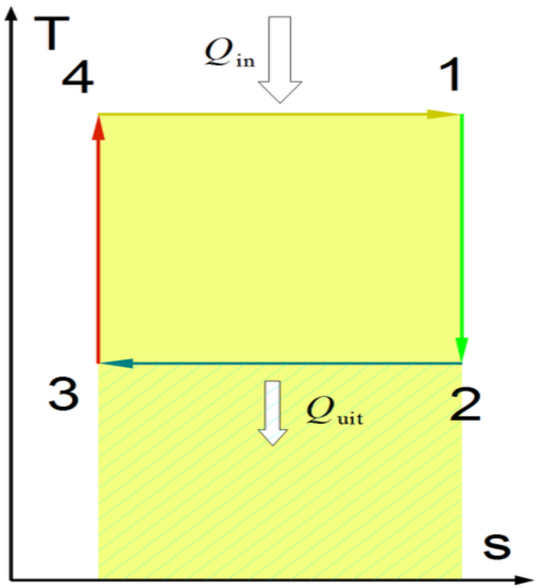
process steps	ΔU	δQ
1 – 2	$\Delta_{12}U = m\hat{c}_v\left(T_H - T_C\right) = -\Delta_{12}W$	0
2 – 3	0	$\Delta_{23}Q = \Delta_{23}W = mRT\ln\frac{v_3}{v_2}$
3 – 4	$\Delta_{34}U = m\hat{c}_v\left(T_C - T_H\right) = -\Delta_{34}W$	0
4 – 1	0	$\Delta_{41}Q = \Delta_{41}W = mRT\ln\frac{v_4}{v_1}$



Entropy S

- Arbeidsdiagram P versus V $\delta W = pdV$
- Warmtediagram T versus S $\delta Q = TdS$





Adiabatisch reversible proces is isentroop, dus S=constant

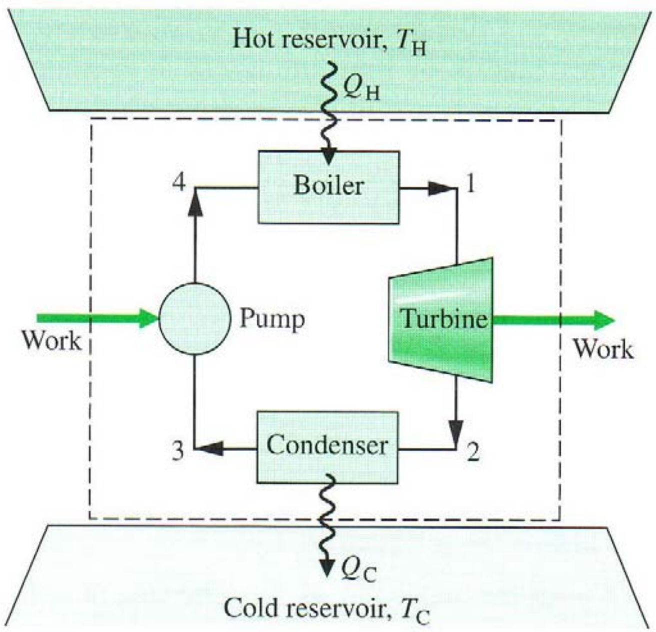
Oppervlakken zijn precies even groot omdat $Q_{cyc} = W_{cyc}$

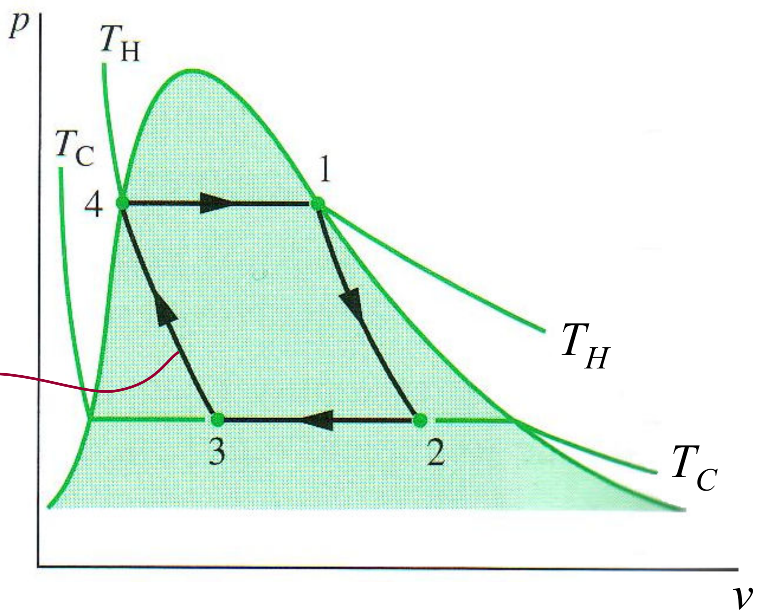
$$\int TdS = \int PdV$$

Carnot vapor power cycle

The most obvious isothermal expansion is given by an evaporation step. The isotherm is then also an isobar.

Ditto for condensation as an isothermal compression





The compression of a two-phase system has (technical) disadvantages and power-cycles with full condensation will later be discussed

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Resume

- Hoofdstuk 1-5 zijn nu behandeld
- Maak opgaves!
- Aanbevolen opgaves: 5.22, 5.24, 5.26, 5.36, 5.41, 5.48