Thermodynamica 1

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February 8, 2011

college 3 – boek hoofdstuk 2

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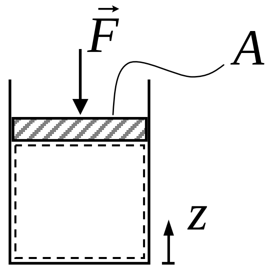
summary lecture 2

- thermal equilibrium
- 0^{th} Law of Thermodynamics
- temperature
- kinetic and potential energy
- work

recap: “volume-work”



pressure $p = \frac{|\vec{F}|}{A}$

work $\Delta W = \int \vec{F} \bullet d\vec{s} = \int p\,A\,dz = \int p\,d(Az) = \int p\,dV$

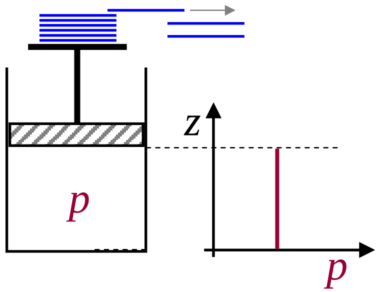
$\Rightarrow$ work through volume change $\Delta W_{1\to 2} = \int_{V_1}^{V_2} p\,dV$

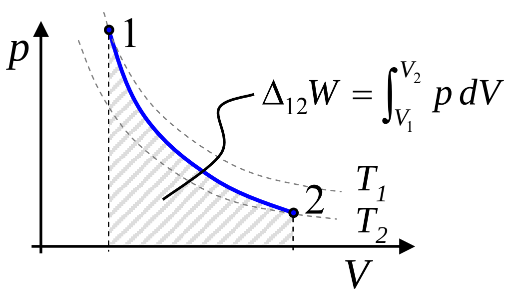
- W>0 work is done ***by*** the system
- W<0 work is done ***on*** the system

two cases of adiabatic expansions

case 1 (reversible)

- weights taken off the cylinder one at a time
- **slow** expansion
- work is done by lifting weights





pressure is spatially uniform in system

⇒ no gradients of intensive properties

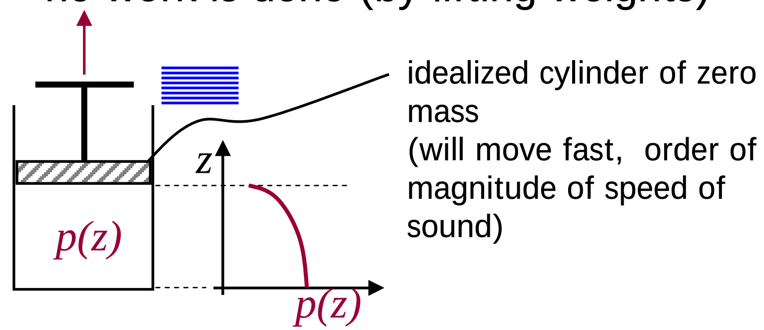
⇒ quasi-equilibrium process

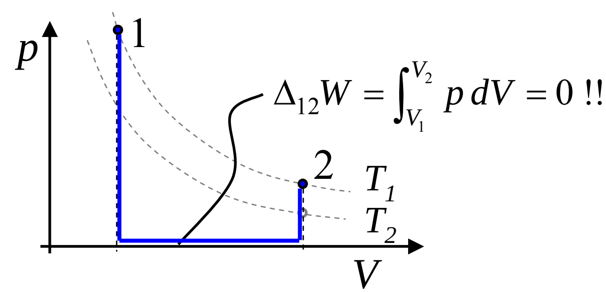
⇒ reversible process

⇒ most efficient process

case 2 (irreversible)

- weights are taken off at once
- **fast**, spontaneous expansion
- no work is done (by lifting weights)





fast process leads to a pressure-profile $p(z,t)$ during expansion

⇒ gradient van $p(z,t)$ not zero

⇒ irreversible process

⇒ inefficient

reversible and irreversible volume-work

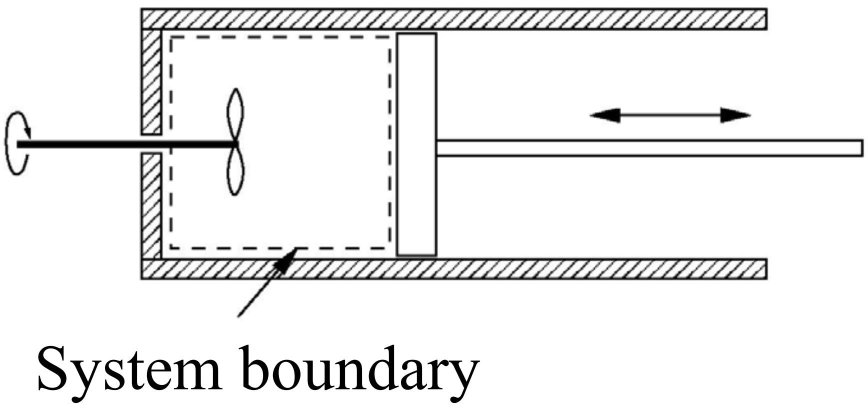
$\Rightarrow$ (from previous slide we conclude) $\Delta_{12}W$ with $\Delta_{12}W = \int_{V_1}^{V_2} p\,dV$ is dependent on the process path; it depends on *how* we change the volume V. We say it is a process quantity, not a state property

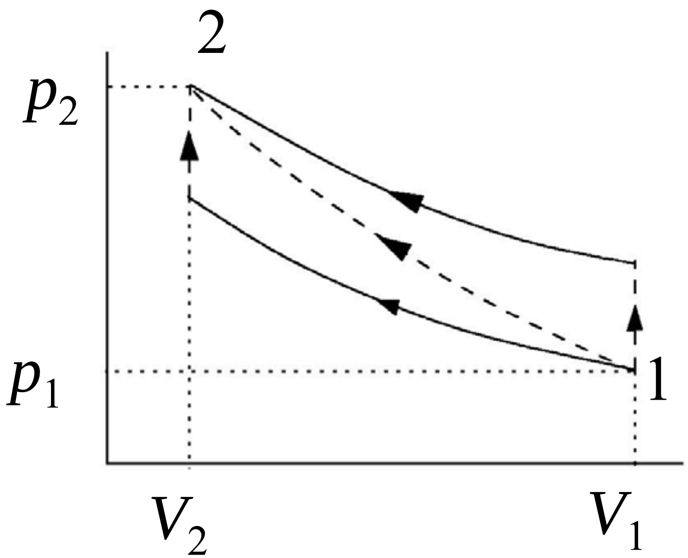
$$\Rightarrow \quad \Delta_{12}W = \int_{V_1}^{V_2} p\,dV \neq W_2 - W_1$$

$\rightarrow$ the differential $\delta W = p\,dV$ is then called an inexact differential (with operator δ)

internal energy U

consider **adiabatic** process (neglect differences in KE and PE)



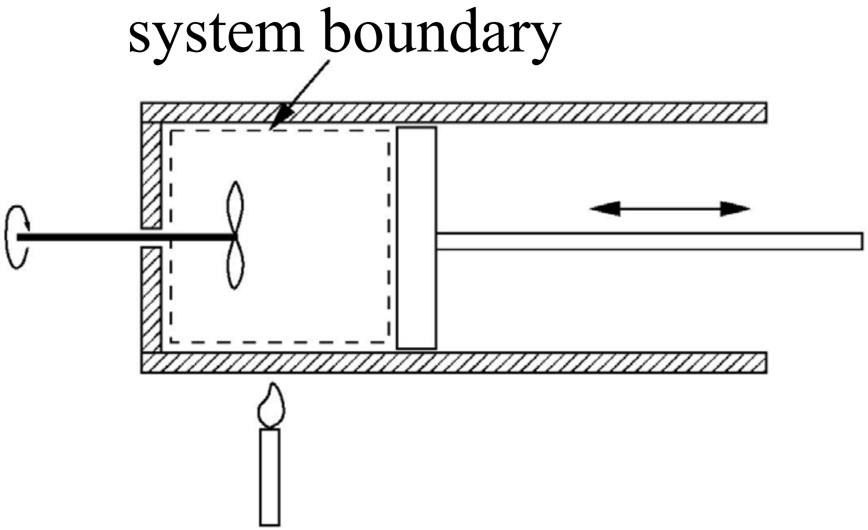


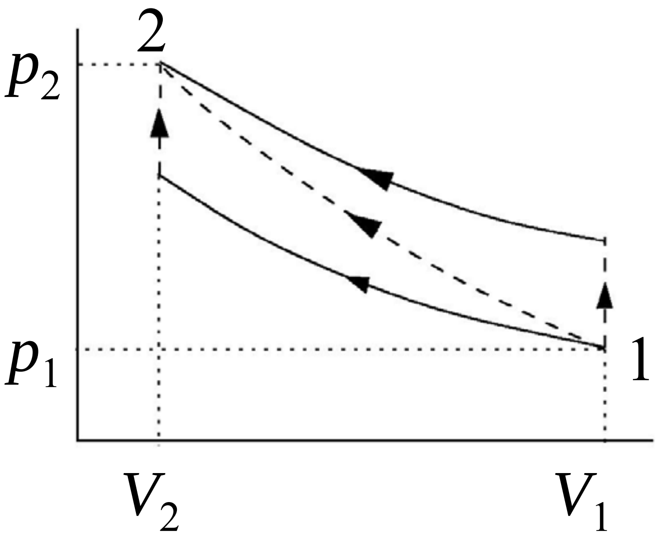
$$\text{work}_{\text{paddle}} + \text{work}_{\text{piston}} = \text{independent of process}$$

$$U_2 - U_1 = -W_{\text{total}}$$

heat

consider **non-adiabatic** process (neglect differences in KE and PE)

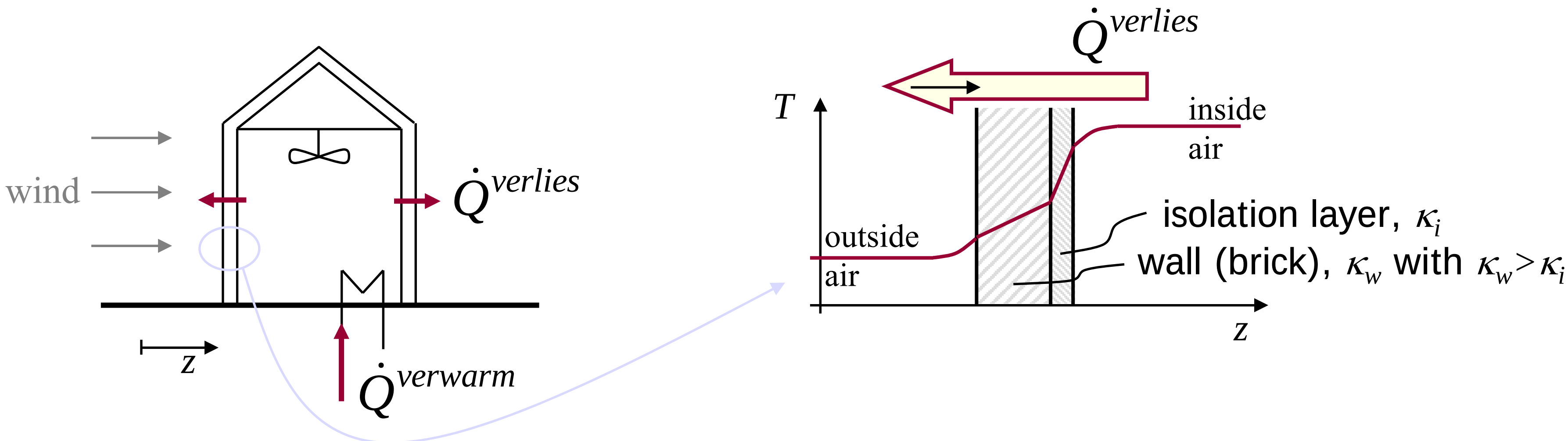




$$U_2 - U_1 \neq -W \quad \rightarrow \quad U_2 - U_1 = Q - W$$

energy transfer by heat

- energy transfer of heat is due to a temperature-difference (temp.-gradient)
- the energy transfer is in the direction of decreasing temperature



- energy transfer by heat conduction follows the Fourier's law $$\dot{Q} = -\kappa A \frac{dT}{dz}$$

heat-conductivity coefficient κ
(warmtegeleidingscoëfficiënt)

surface area

- an energy-package of heat is defined as $\Delta_{12} Q = \int_{t_1}^{t_2} \dot{Q}\, dt$

- $\Delta_{12} Q$ depends on the process path, it is a process quantity (no state property)
- $\delta Q = \dot{Q} dt$ is an inexact differential

1st Law of Thermodynamics

Each **closed** system has a property *U*, the **internal energy**, for which:

- (neglect differences in KE and PE)
- the change in *U* for an **adiabatic** process is equal to the work *W* by the system;
- the added heat *Q* for a **non-adiabatic** process is given by

$$\boxed{U_2 - U_1 = Q - W}$$

- heat & work are process quantities; internal energy U is a state quantity

- $Q>0$ heat is transferred ***to*** the system
- $Q<0$ heat is transferred ***from*** the system

- $W>0$ work is done ***by*** the system
- $W<0$ work is done ***on*** the system

remarks

- the first law cannot be proven;
- the internal energy is an **extensive** property;
- the first law represents conservation of **energy** in a system;

- for a quasi-static process: $dU = \delta Q - \delta W$
- *ditto* for a gas: $dU = \delta Q - pdV$
- *ditto* per unit of mass: $du = \delta q - pdv$
- per unit of time: $\dot{U} = \dot{Q} - \dot{W}$

energy balance

- First law

$$E_2 - E_1 = Q - W$$

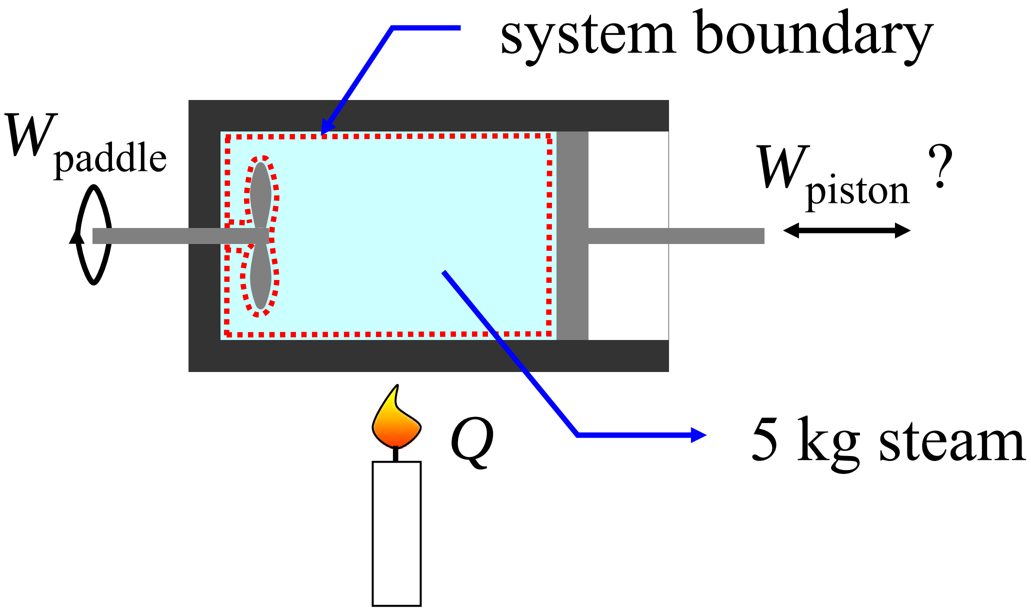
- For the energy difference we can write

$$E_2 - E_1 = \left(U_2 - U_1\right) + (KE_2 - KE_1) + (PE_2 - PE_1)$$

- Usually (but not always), differences in KE and PE can be neglected so we end up with

$$Q = U_2 - U_1 + W$$

example



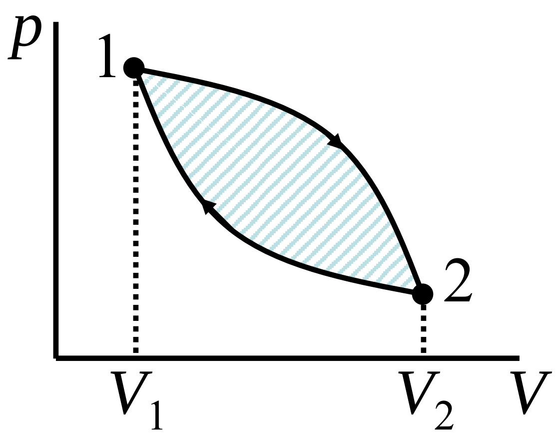
$$W_{\text{paddle}} = -18.5 \text{ kJ}$$
$$Q = +80 \text{ kJ}$$

process 1→2 with: $u_1 = 2709.9$ kJ/kg, $u_2 = 2659.6$ kJ/kg

what is W_{piston} ?

$$m(u_2 - u_1) = Q - W_{paddle} - W_{piston}$$
$$5(2659.6 - 2709.9) = 80 - -18.5 - W_{piston}$$
$$W_{piston} = 350kJ$$

cycles



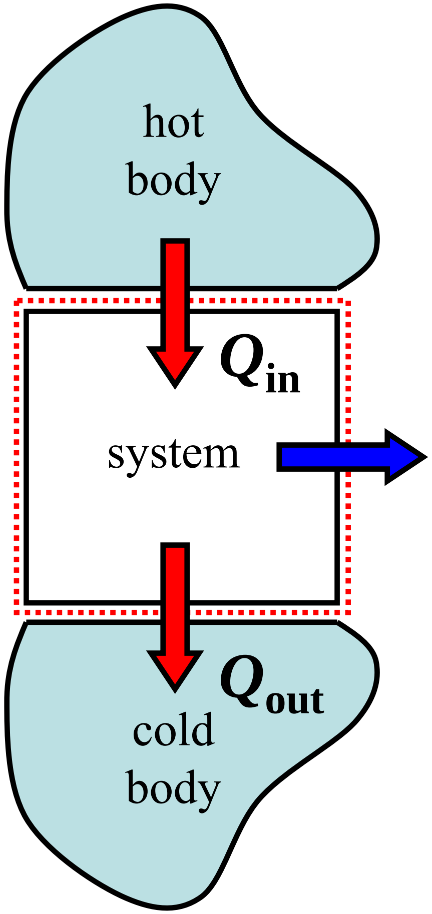
$$W_{12} = \int_{V_1}^{V_2} p dV \qquad W_{21} = \int_{V_2}^{V_1} p dV$$

$$W_{\text{cycle}} = W_{12} + W_{21} = \oint p dV = \text{enclosed area}$$

$$\text{First Law:} \quad \Delta U = Q_{\text{cycle}} - W_{\text{cycle}}$$

$$\text{cycle:} \quad \Delta U = 0 \quad \Rightarrow \quad \boxed{Q_{\text{cycle}} = W_{\text{cycle}}}$$

power cycle



W_{cycle} =
Q_{in}–Q_{out}

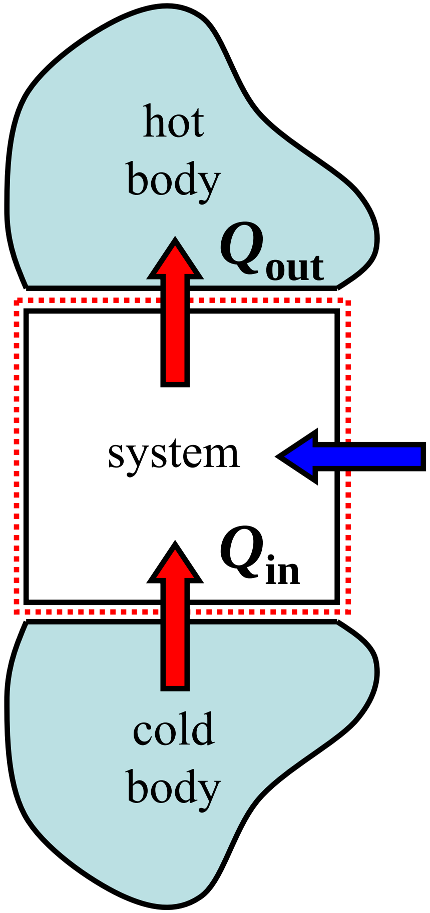
thermal efficiency:

$$\eta = \frac{W_{\text{cycle}}}{Q_{\text{in}}}$$

$$\eta = \frac{Q_{\text{in}} - Q_{\text{out}}}{Q_{\text{in}}} = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$$

2^{nd} Law: $Q_{\text{out}} > 0 \Rightarrow \eta < 1$

refrigeration & heat pump cycle



W_{cycle} = $Q_{out} - Q_{in}$

coefficients of **performance**:

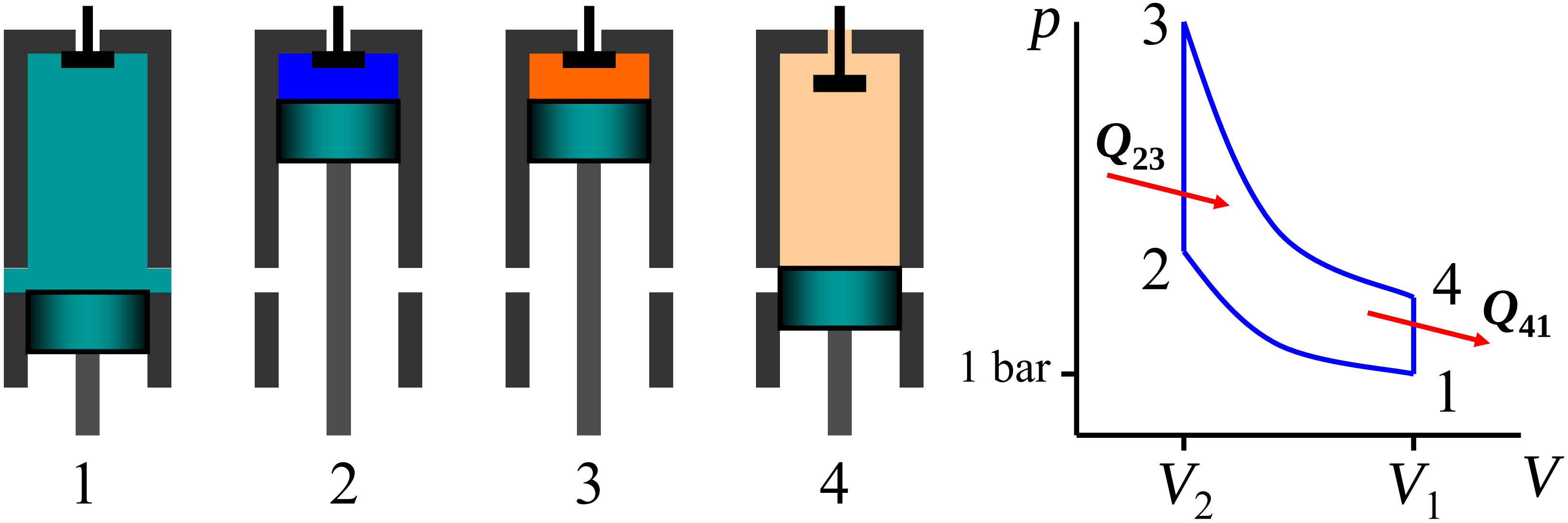
- **refrigeration** cycle

$$\beta = \frac{Q_{in}}{W_{cycle}}$$

- **heat pump** cycle

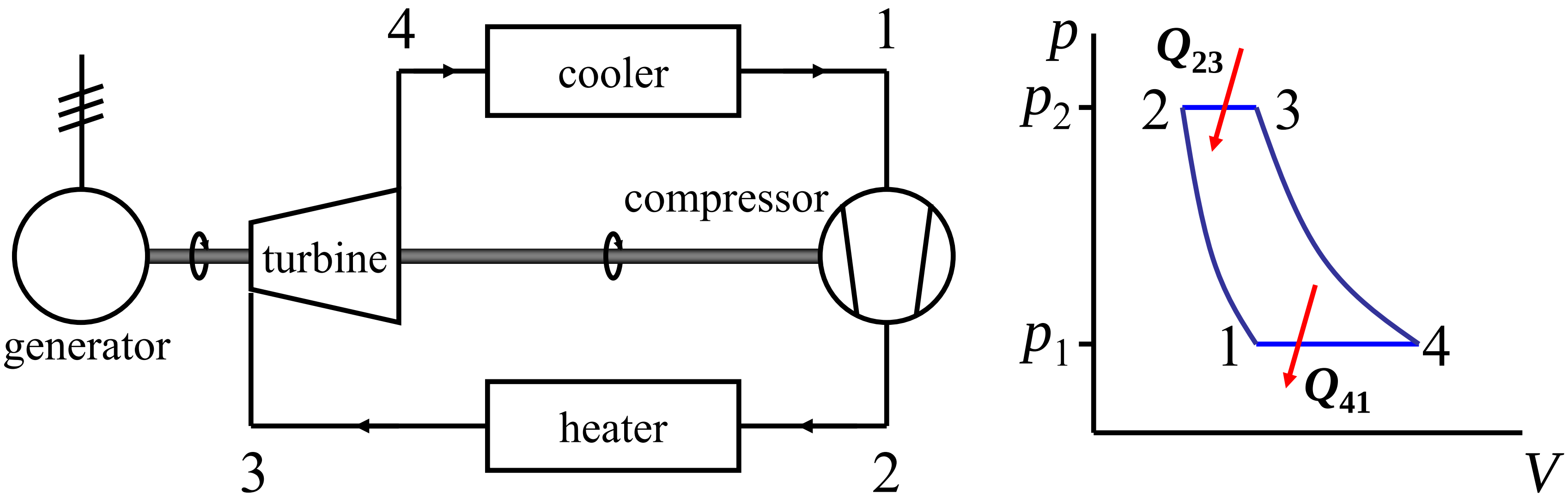
$$\gamma = \frac{Q_{out}}{W_{cycle}}$$

the 2-stroke Otto cycle



gas turbine cycle

the Joule cycle



exercise

A gas undergoes a thermodynamic cycle consisting of the following processes:

Process 1-2: constant pressure, $p = 1.4$ bars, $V_1 = 0.028$ m^3, $W_{12} = 10.5$ kJ

Process 2-3: compression with pV = constant, $U_3 = U_2$

Process 3-1: constant volume, $U_1 - U_3 = -26.4$ kJ

There are no significant changes in kinetic or potential energy.

a) Sketch the cycle on a p-V diagram.

b) Calculate the net work for the cycle, in kJ (-8.3kJ).

c) Calculate the heat transfer for process 1-2, in kJ (Q=36.9kJ)

directions for home study

- Ch. 1 & 2 (except §2.4.2) have been treated; read this thoroughly!
- Especially study §2.5 & §2.6 (including all examples, in particular 2.3 & 2.4).
- Do problems 2.15 & 2.16. Do one of the problems on work (2.17-2.25); one of the problems on the energy balance of closed systems (2.30-2.40); do problems 2.41 & 2.42; do one of the problems on cycles (2.43-2.51)