Thermodynamica 1

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Afdeling Process en Energie
Sectie energietechniek
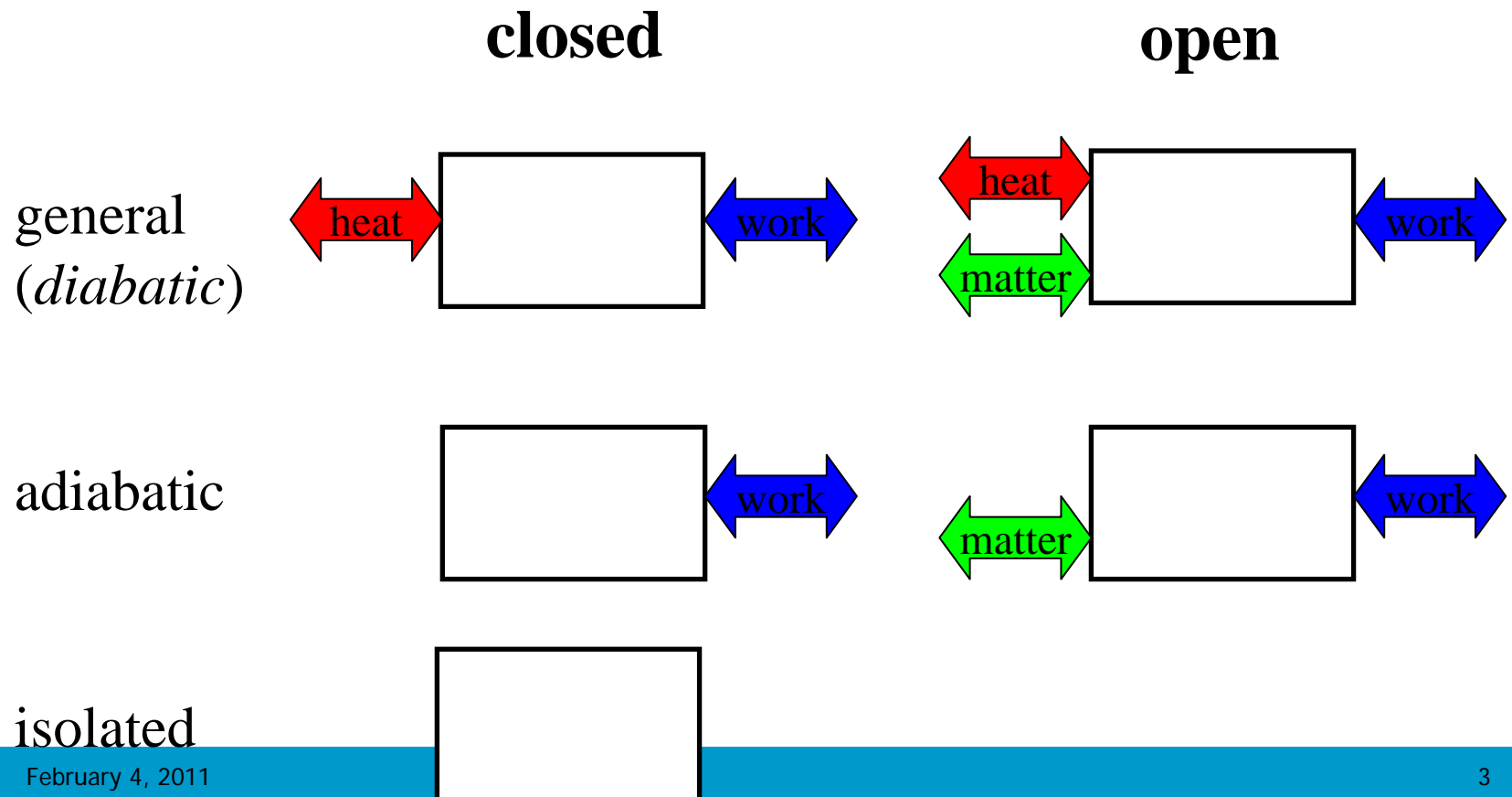
February 4, 2011

college 2 – boek hoofdstuk 1

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summary lecture 1

- **system** (closed, open, adiabatic, isolated)
- **state** and **properties**
- **intensive**, **extensive** and **specific** properties
- **process**

Energietechniek

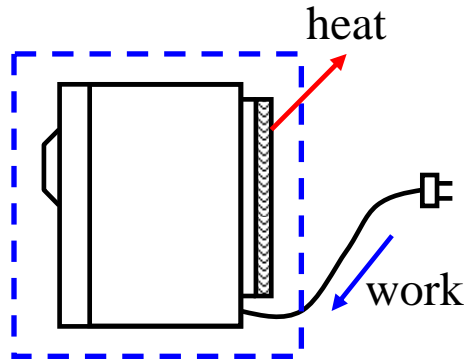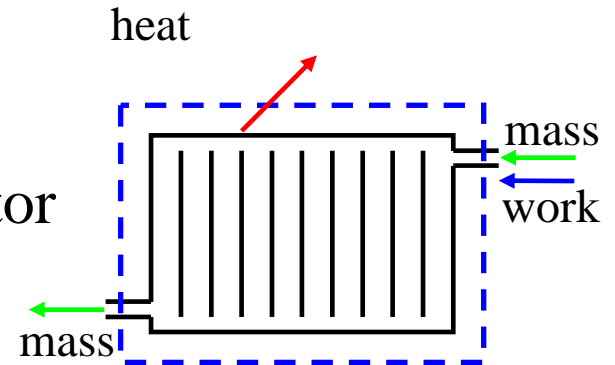**T**UDelft

systems: summary

	closed	**open**
general (*diabatic*)	← heat → [box] ← work →	← heat → [box] ← work → ← matter →
adiabatic	[box] ← work →	← matter → [box] ← work →
isolated	[box]	

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systems: examples

closed:
refrigerator

heat

work

open:
radiator

heat

mass

work

mass

adiabatic:
coffee maker

work
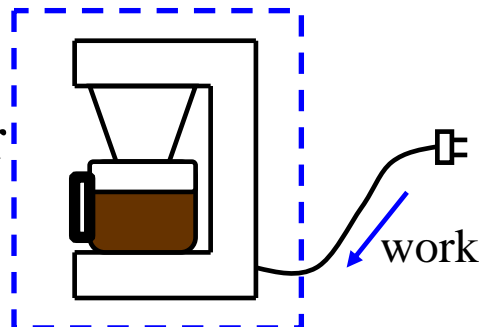
isolated:
cooler with
hot bottle and
freezer pack

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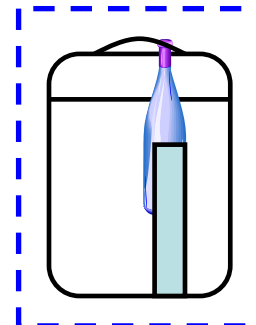
process

A **process** is defined as the change of the state of a system.

We only consider changes from one equilibrium state to another

The state of a system has changed when the properties (in an equilibrium state) have changed. During the change the system is not in equilibrium.
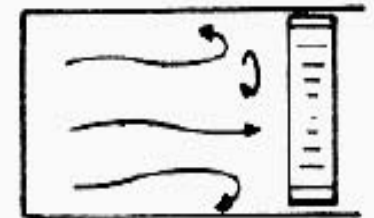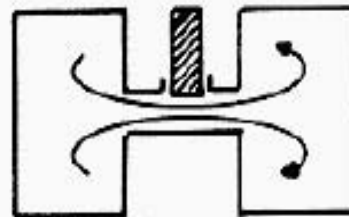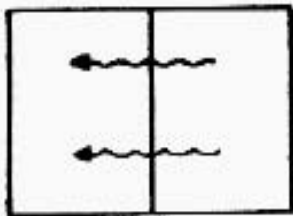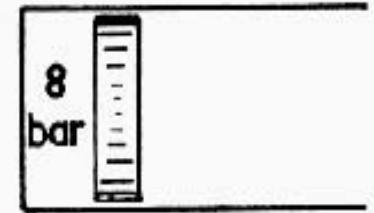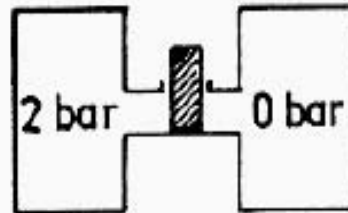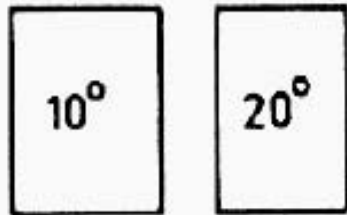
A (thermodynamic) **cycle** is a process where the initial and final states are identical.

adiabatic system $\rightarrow$ adiabatic process
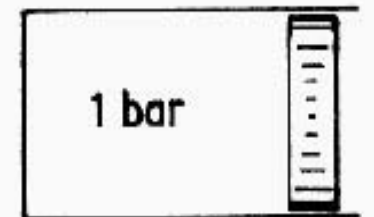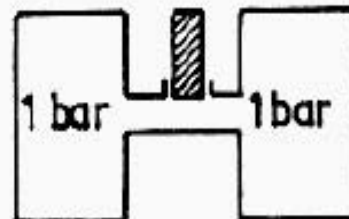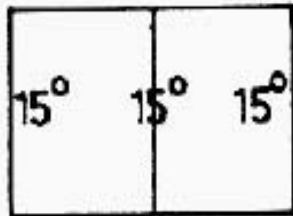isolated system $\rightarrow$ isolated process

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process: examples A→ B

A

B

a.　　　　　　　　b.　　　　　　　　c.

Reversible/irreversible?

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Lecture 2

Energietechniek

interpolation

Properties of gases and liquids are given in tables (e.g., Table A-3).

TABLE A-3 Properties of Saturated Water (Liquid–Vapour): Pressure Table

Press. bars	Temp. °C	Specific Volume m³/kg	
		Sat. Liquid $v_f \times 10^3$	Sat. Vapour v_g
0.80	93.50	1.0380	2.087
0.90	96.71	1.0410	1.869
1.00	99.63	1.0432	1.694
1.50	111.4	1.0528	1.159
2.00	120.2	1.0605	0.8857

What is the boiling point at 1.3 bar?

Similar triangles:

$$\frac{T_1 - T_0}{p_1 - p_0} = \frac{T - T_0}{p - p_0} \quad \Rightarrow$$

$$\boxed{T = T_0 + \frac{T_1 - T_0}{p_1 - p_0} \times (p - p_0)}$$

Answer:

$$T = 106.7 \ °C$$

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TABLE A-3 Properties of Saturated Water (Liquid–Vapour): Pressure Table

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What is the boiling point at 1.3 bar?

$$T = T_0 + \frac{T_1 - T_0}{p_1 - p_0} \times (p - p_0)$$

106.7C

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thermal equilibrium

heat conducting wall
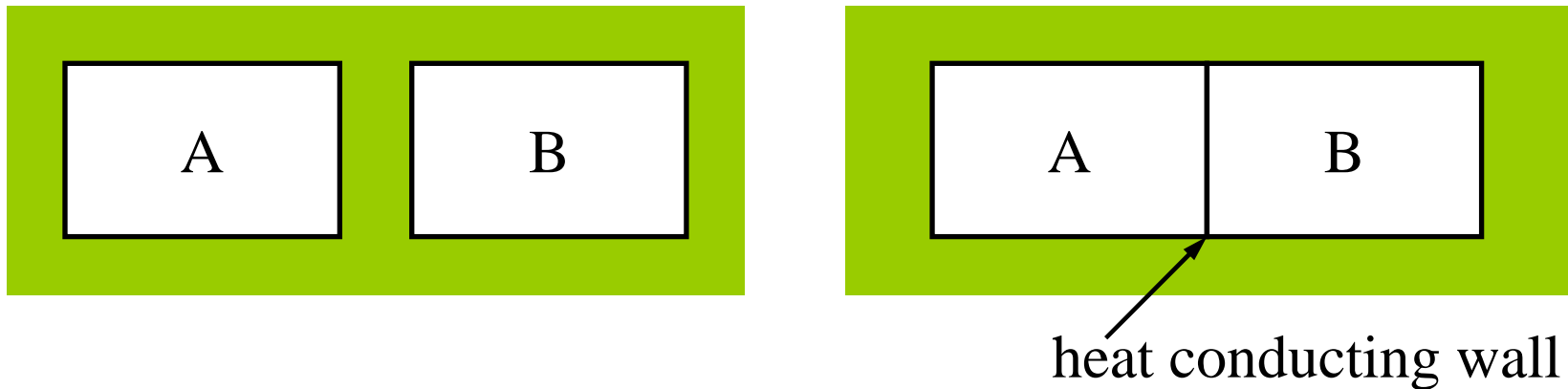
Two equilibrium systems that are brought into contact (via a heat-conducting wall) will eventually reach a new equilibrium. This new equilibrium is such that both systems feel 'equally warm/cold': they are said to have the same *temperature*.
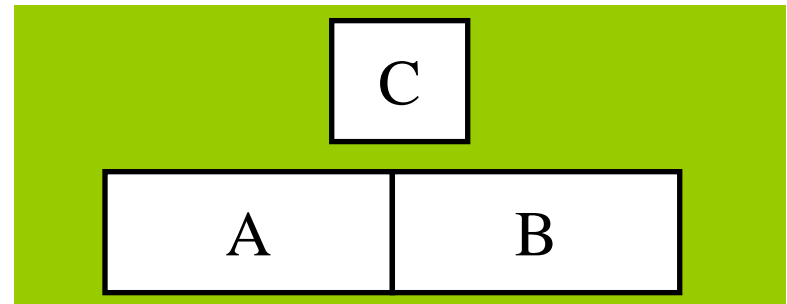
How to quantify temperature?

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0th Law of Thermodynamics
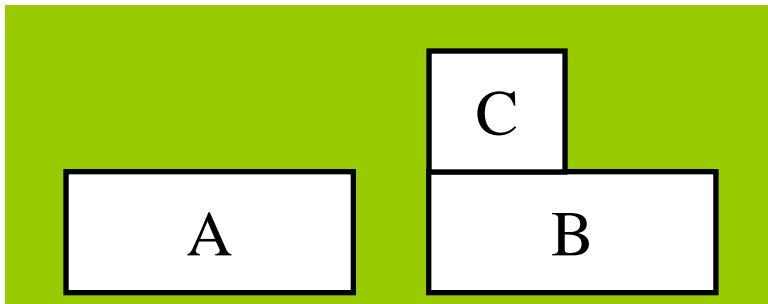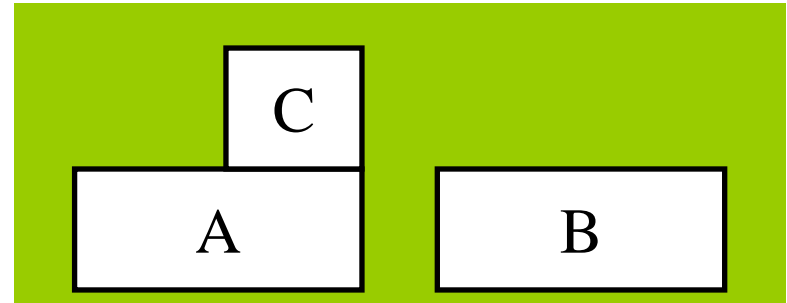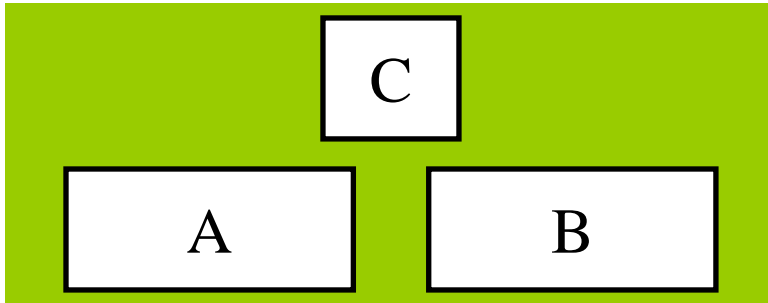
When C is in thermal equilibrium with A and B, then A and B are also in thermal equilibrium.

This defines the *experimental temperature* for 'thermometer C' by measuring a property that uniquely depends on the temperature.

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the experimental temperature

Example: the property is the expansion of a fluid (mercury or alcohol). The centigrade scale is obtained at atmospheric pressure (1.01325 bar) by calling the freezing point 0° C and the boiling point 100° C.
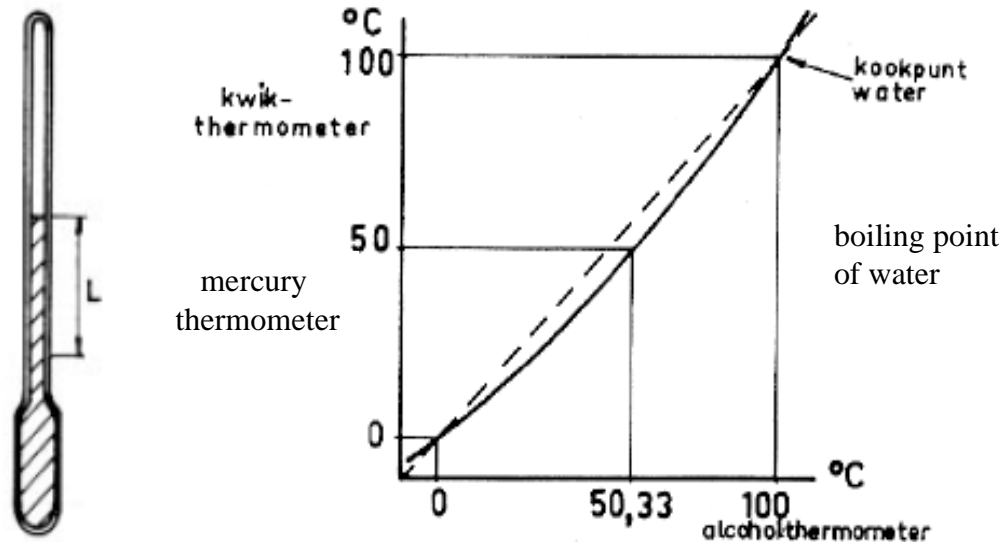
We have a problem: what is the correct value?

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the gas temperature scale (page 16-17)

for the gas temperature scale we use a constant-volume gas thermometer
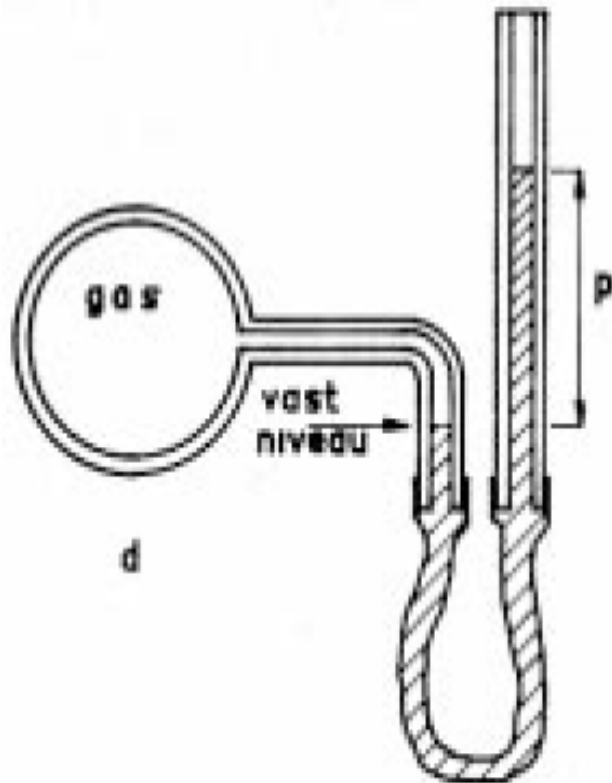
The experimental gas temperature is defined as: $T_{\exp} = \alpha p$

The constant α is fixed for the water triple point (0.01° C) and refer to this value as 273.16 on the scale:

where p_{tp} is the triple point gas pressure

$$T_{\exp} = 273.16 \frac{p}{p_{\text{tp}}}$$

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the gas temperature scale

when the amount of gas is reduced we find for different gases:
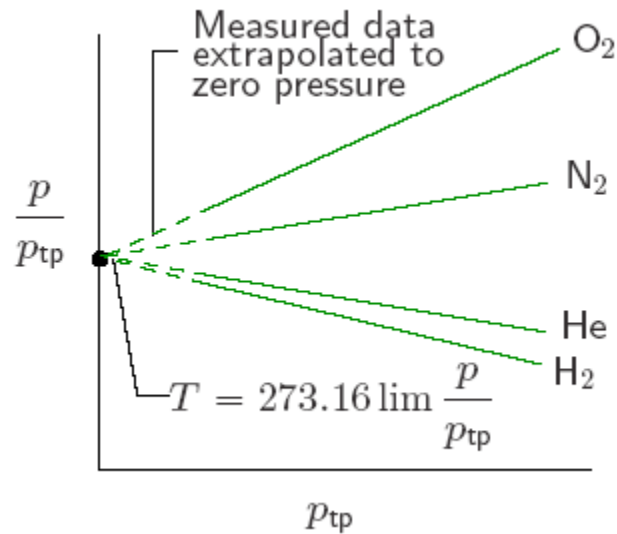
$$T_{\text{exp}} = 273.16 \lim_{p_{\text{tp}} \to 0} \frac{p}{p_{\text{tp}}}$$

After consideration of the 2nd Law it will be shown that this scale is identical to the thermodynamic temperature scale when we use the triple point as a calibration point.

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Temperatuur

- Bij thermo berekeningen moet je onzettend opletten met de temperatuur schaal, Kelvin of Celsius.
- Celsius werkt soms, Kelvin werkt altijd.

Reken alle temperaturen altijd eerst om naar Kelvin!!!

Wordt het antwoord gevraagd in Celsius reken dit dan pas helemaal op het eind om van Kelvin naar Celsius!!!

Energietechniek

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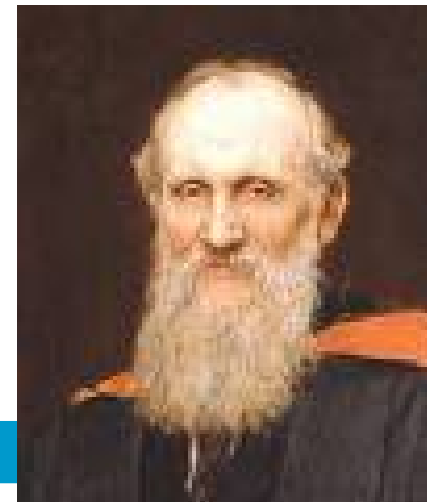
Potential energy→ Kinetic energy →?

PE = 10,000
KE = 0

PE = 7500
KE = 2500

PE = 5000
KE = 5000

PE = 2500
KE = 7500

PE = 0
KE = 10,000

Energietechniek

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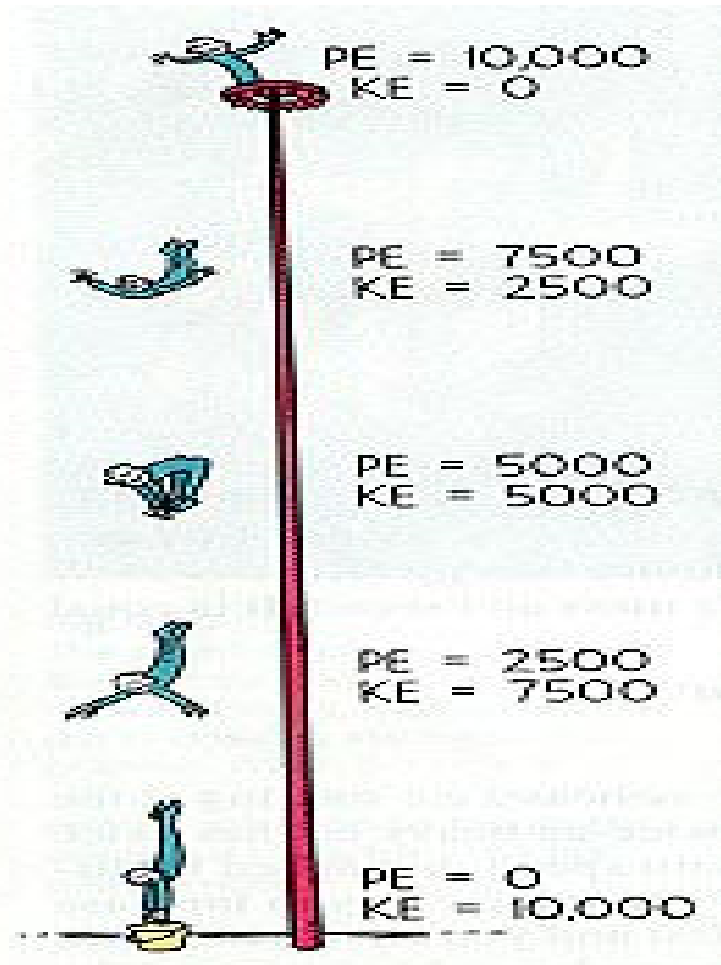
Kinetic, potential energy and heat
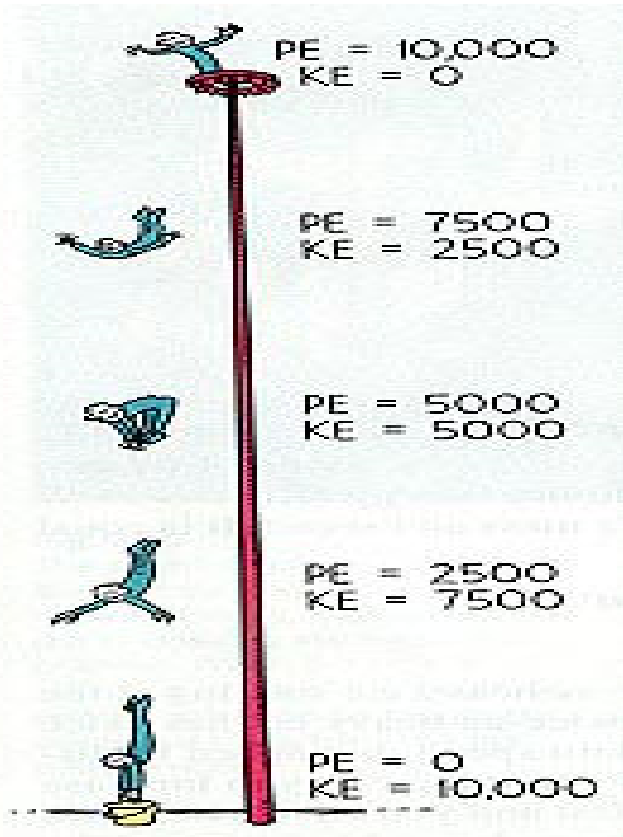
$$PE \rightarrow KE \rightarrow Heat$$

$$mgh = \frac{1}{2}mV^2$$

$$\frac{1}{2}mV^2 = mC_p\Delta T$$

$$PE \rightarrow .. \rightarrow Heat \Rightarrow \Delta T = \frac{gh}{C_p}$$

Experiment with small lead ($C_p = 130 J / Kg \cdot K$)

or brass ($C_p = 380 J / Kg \cdot K$) balls

$h = 20$ meters, $\Delta T = ?$

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mechanical energy
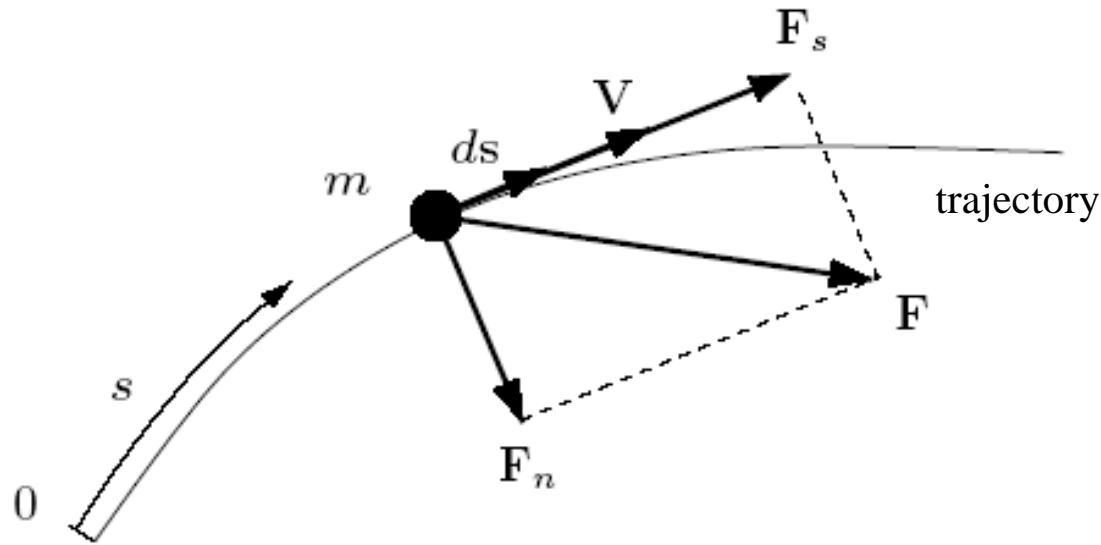
$$\text{Newton:} \quad \mathbf{F} = m \cdot \frac{d\vec{\mathbf{V}}}{dt}$$

V (bold) is velocity vector

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We find that:

$$\mathbf{F} \cdot \mathbf{V} = m \frac{d\mathbf{V}}{dt} \cdot \mathbf{V} = m \frac{d\left(\frac{1}{2} \mathbf{V} \cdot \mathbf{V}\right)}{dt} = m \frac{d\left(\frac{1}{2} V^2\right)}{dt} = \frac{d\left(\frac{1}{2} m V^2\right)}{dt}$$

and so:

$$\int_{t_1}^{t_2} \mathbf{F} \cdot \mathbf{V} \, dt = \tfrac{1}{2} m V_2^2 - \tfrac{1}{2} m V_1^2$$
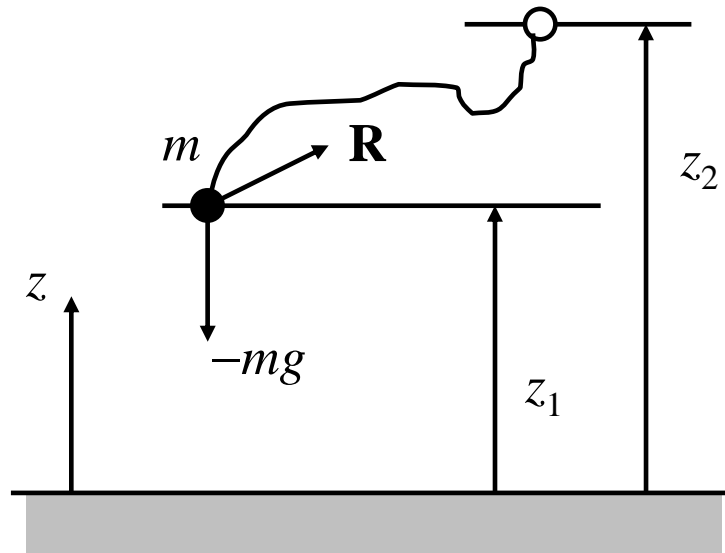
where:

external work: $\quad \int_{t_1}^{t_2} \mathbf{F} \cdot \mathbf{V} \, dt = \int_{s_1}^{s_2} \mathbf{F} \cdot d\mathbf{s} = \int_{s_1}^{s_2} F_s \, ds$

kinetic energy (KE): $\quad \tfrac{1}{2} m V^2$

thus:

$$\text{external work} = \text{KE}_2 - \text{KE}_1 = \Delta\text{KE}$$

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$$\mathbf{F} = -mg\mathbf{e}_z + \mathbf{R}$$

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External work:

$$\int_{s_1}^{s_2} \mathbf{F} \cdot d\mathbf{s} = -mgz_2 + mgz_1 + \int_{s_1}^{s_2} \mathbf{R} \cdot d\mathbf{s}$$

Substitute:

$$\int_{s_1}^{s_2} \mathbf{R} \cdot d\mathbf{s} = \tfrac{1}{2} mV_2^2 - \tfrac{1}{2} mV_1^2 + mgz_2 - mgz_1$$

where:

potential energy of gravity (PE): $\quad mgz$

thus:

External work of $\mathbf{R}$ = KE$_2$ $-$ KE$_1$ + PE$_2$ $-$PE$_1$ = ΔKE + ΔPE

When $\mathbf{R} = \mathbf{0}$: $\quad \Delta$KE + ΔPE = 0 $\quad$ or $\quad$ KE + PE = *constant*

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work

The work *W* is the work acted by the system on the surroundings

$\qquad W > 0 \;$: work is done *by* the system

$\qquad W < 0 \;$: work is done *on* the system

$$\Delta W_{1\to2} = \int_{t_1}^{t_2} \vec{F}_{\text{sur}} \cdot \vec{V}\, dt = \int_{s_1}^{s_2} \vec{F}_{\text{sur}} \cdot d\vec{s}$$

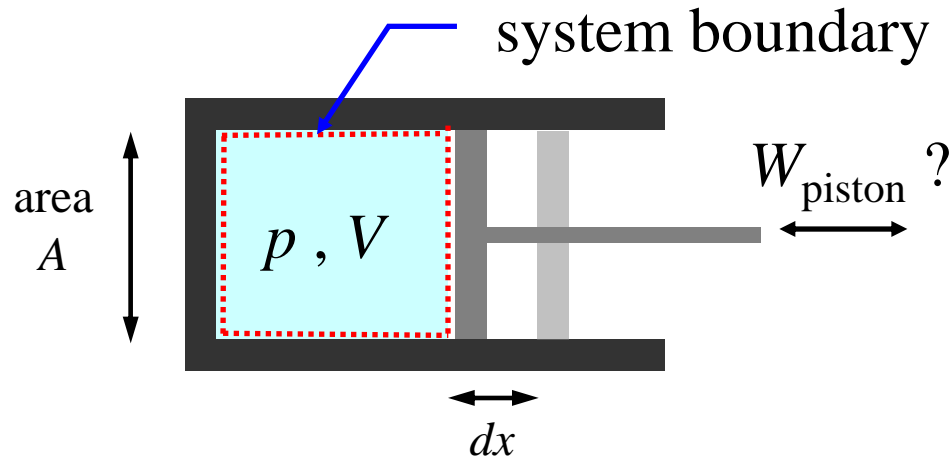In general, the work *W* depends on the trajectory:

$$\Delta W_{1\to2} = \int_1^2 \delta W \neq W_2 - W_1 \qquad \text{Work is \textbf{not} a \textit{property}.}$$

Power (work per unit time): $\dot{W} = \mathbf{F}_{\text{sur}} \cdot \mathbf{V}$

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example

Work exerted by a gas on a piston. Consider a quasi-static process.

system boundary

area A

p , V

W_{piston} ?

dx

$$\delta W = F_{\text{ext}} dx = pAdx = pdV$$

$$W_{12} = \int_1^2 \delta W = \int_{V_1}^{V_2} pdV$$

Quasi-static→ P will be uniformly distributed

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$W_{12} > 0$
expansion

V_1 dV V_2

$W_{12} < 0$
compression

V_2 dV V_1

Energietechniek
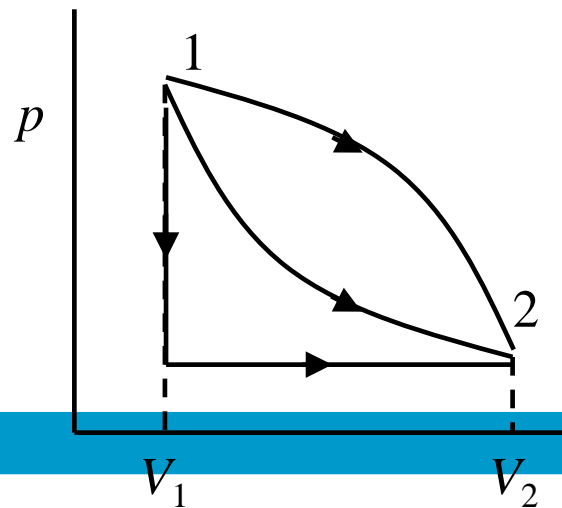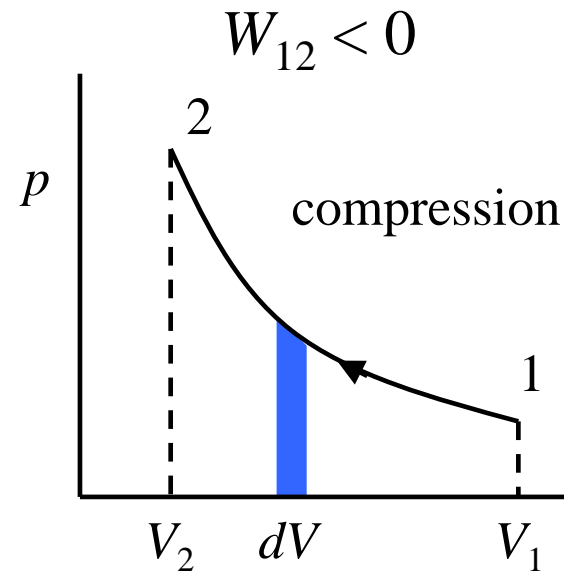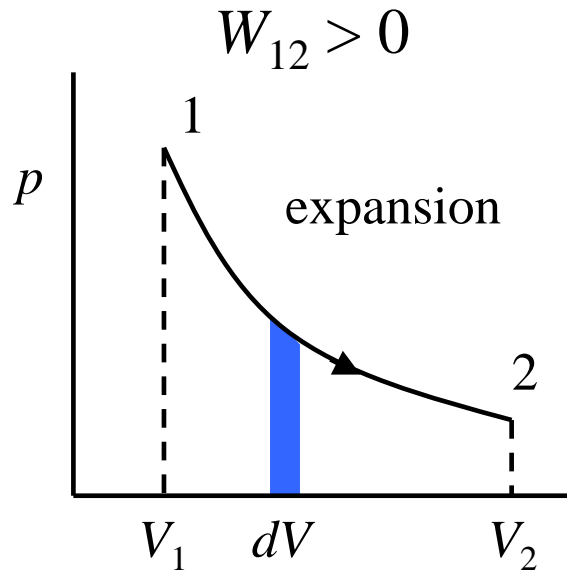
Water raket wedstrijd 25 maart, 2011
Mekelpark (voor de faculteit)

- Plastic cola fles (0.5 liter)
- Rubber stop of kurk
- Fiets pomp
- Prijs: 100 Euro voor grootste afstand (mits > 50 meter)
- 1 poging per deelnemer (team)

Energietechniek
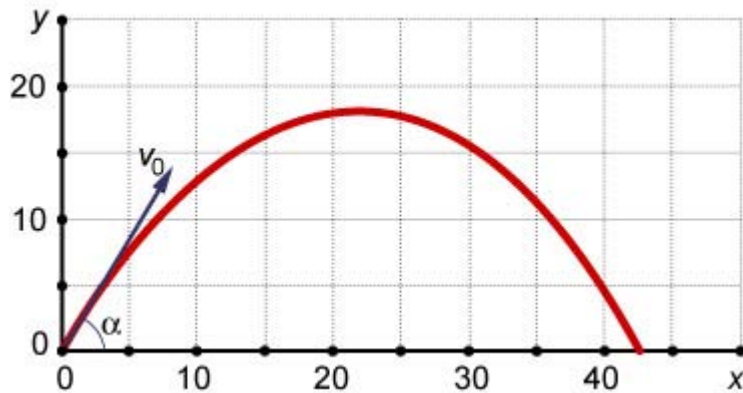
Question 2.18

•Gas expands from 500kPa to 100kPa, the initial volume is 0.1m^3. Sketch the process in a P-V diagram and determine the work. (You can assume P V = Const).

system
boundary

$$pV = C$$

$$p_1V_1 = p_2V_2$$

$$V_2 = V_1 \frac{p_1}{p_2} = 0.1 * 500/100 = 0.5 m^3$$

area
A

p , V

W_{piston} ?

dx

$$W = \int_1^2 pdV = \int_1^2 \frac{C}{V} dV = C\int_1^2 \frac{1}{V} dV = C \ln \frac{V_2}{V_1} = 50 \cdot 10^3 * \ln(5) = 80.4 KJ$$

let op $C[\ln(V_2) - \ln(V_1)]$ is wiskundig gezien

het zelfde maar fysisch gezien niet. We kunnen

geen ln(.) nemen van een volume ivm dimensies

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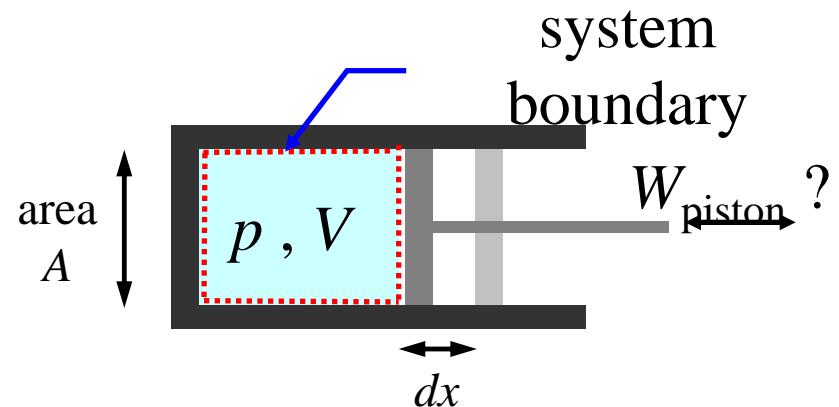
•Question 2.18 (modified)

•Consider the expansion on the previous slide to be at T=500K and P V = C T➜C=100

•Subsequently the same gas is compressed from 2 to 1 at a temperature of 300K calculate the work for both steps.

$$\text{I: } pV = CT \rightarrow C = p_1 V_1 / T_1 = 100 \, Pa \cdot m^3 / K$$

$$\Delta W_{1\rightarrow 2} = \int_1^2 pdV = \int_1^2 \frac{CT}{V} dV = CT \ln \frac{V_2}{V_1} = 100 \cdot 500 * \ln(5) = 80.4 kJ$$

$$\text{II : } pV = CT$$

$$\Delta W_{2\rightarrow 1} = \int_2^1 pdV = \int_2^1 \frac{CT}{V} dV = CT \ln \frac{V_1}{V_2} = 100 * 300 * \ln\left(\frac{0.1}{0.5}\right) = -48 kJ$$

$$\Delta W_{1\rightarrow 2} + \Delta W_{2\rightarrow 1} > 0 \text{ systeem levert netto arbeid } \Rightarrow \text{ motor!!}$$

•**Verandering in temperatuur (toe of afvoer van warmte) geeft aanleiding tot netto arbeid!**

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Remark on work

$$\delta W = p dV \Rightarrow \Delta W_{1 \rightarrow 2} = \int_{1}^{2} p dV$$

- **Alleen voor een gesloten systeem**

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instructions

- Ch. 1 & Ch. 2 up to §2.2 have been treated. Read this carefully before the next lecture.

- Make (some of) the exercises 2.1-2.10.

- Make one or more of the exercises 2.11-2.14 (work by a gas in a quasi-static equilibrium under compression or expansion)

- The next lecture will deal with the remainder of Ch. 2 (except §2.4.2, this will be done later) and Ch. 3 up to §3.2

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