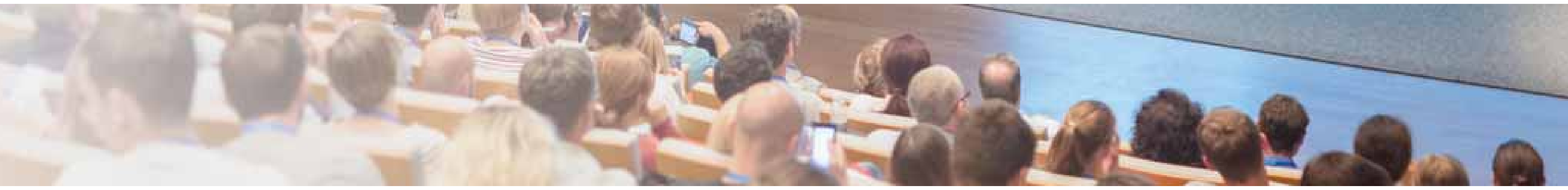


Basic knowledge

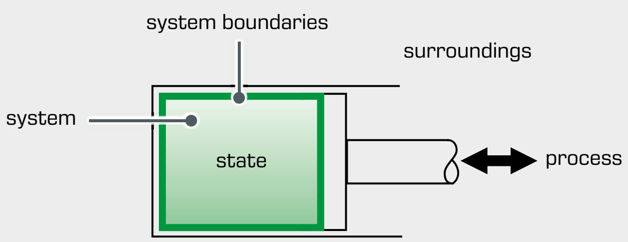
Thermodynamic state variables

Thermodynamic systems and principles

State variables are the measurable properties of a system. To describe the state of a system at least two independent state variables must be given.

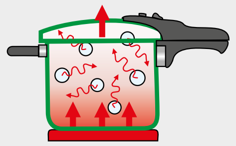
State variables are e.g.:

- pressure (**p**)
- temperature (**T**)
- volume (**V**)
- amount of substance (**n**)



The state functions can be derived from the state variables:

- **internal energy (U):** the thermal energy of a static, closed system. When external energy is added, processes result in a change of the internal energy.
  $\Delta U = Q + W$
  - **Q:** thermal energy added to the system
  - **W:** mechanical work done on the system that results in an addition of heat
- **enthalpy (H):** defined as the sum of internal energy plus work **p × V**
  $H = U + p \times V$
- **entropy (S)**: provides information on the order in a system and the associated arrangement options of particles in that system
  The change in entropy **dS** is known as **reduced heat**.
  $dS = \delta Q_{rev} / T$
  - **δQ_{rev}**: reversible heat change
  - **T:** absolute temperature



An increase in the internal energy of the system using a pressure cooker as an example.

Steam engine

When the steam engine was developed more than 200 years ago, physicists wondered why only a few percent of the thermal energy was converted into mechanical energy. Rudolf Clausius introduced the term entropy to explain why the efficiency of thermal engines is limited to a few percent. Thermal engines convert a temperature difference into mechanical work. Thermal engines include steam engines, steam turbines or internal combustion engines.

V6 engine of a racing car

Disassembled steam turbine rotor

Change of state of gases

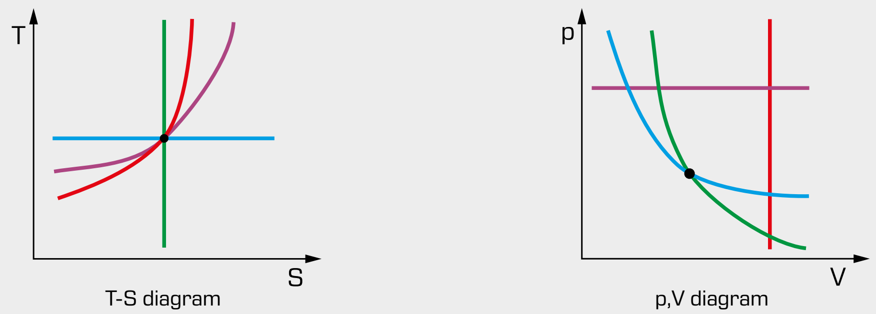
In physics, an idealised model of a real gas was introduced to make it easier to explain the behaviour of gases. This model is a highly simplified representation of the real states and is known as an “ideal gas”. Many thermodynamic processes in gases in particular can be explained and described mathematically with the help of this model.

Equation of state for ideal gases:
$p \times V = m \times R_s \times T$

- **m**: mass
- **R_s**: spec. gas constant of the corresponding gas

Changes of state of an ideal gas

Change of state	isochoric	isobaric	isothermal	isentropic
Condition	V = constant	p = constant	T = constant	S = constant
Result	dV = 0	dp = 0	dT = 0	dS = 0
Law	p/T = constant	V/T = constant	p×V = constant	$p \times V^{\kappa}$ = constant κ = isentropic exponent



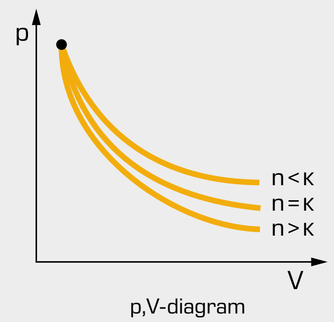
Changes of state can be clearly illustrated in diagrams

Changes of state under real conditions

Change of state	polytropic
Condition	technical process under real conditions
Result	heat exchange with the environment
Law	$p \times V^n$ = constant n = polytropic exponent

The changes of state listed above are special cases of polytropic change of state, in which part of the heat is exchanged with the environment.

- isochoric $n \rightarrow \infty$
- isobaric $n = 0$
- isothermal $n = 1$
- isentropic $n = \kappa$



Polytropic changes of state with different heat exchange:
n < κ heat dissipation,
n > κ heat absorption