THERMODYNAMIC CYCLES

THERMODYNAMICS

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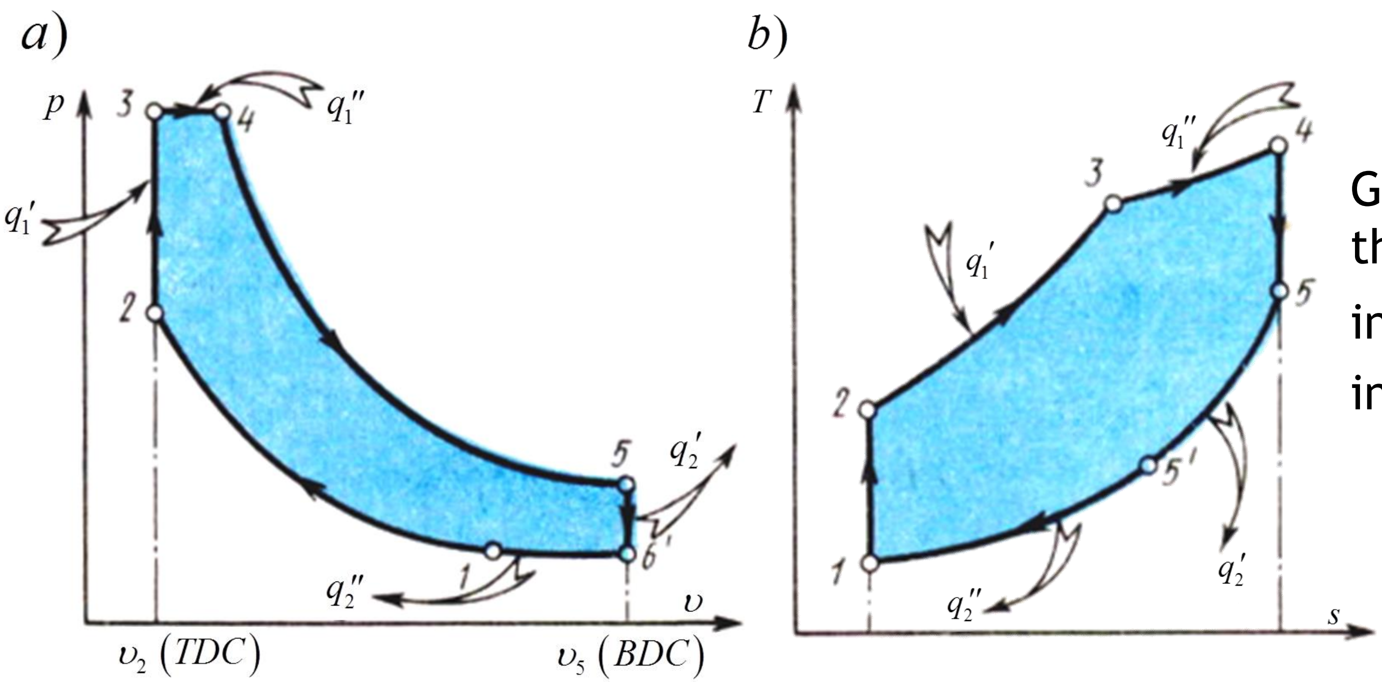
Thermodynamic cycles of heat engines

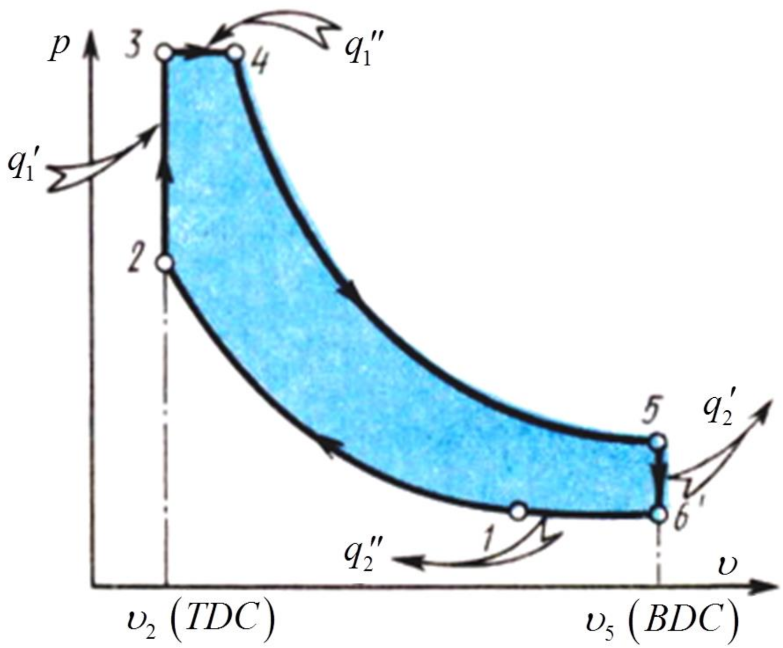
- ***Thermodynamic cycles*** consist of reversible thermodynamic processes operating successively in the way that together they constitute a closed thermodynamic process or cycle.



Generalized thermodynamic cycles in $pυ$-diagram **(a)** and in Ts-diagram **(b)**

TDC – top dead center
BDC – bottom dead center

Thermodynamic cycles of heat engines



Any process in a cycle is characterized by one equation with two variables (p, v, T or s), and the nodal point is determined by one parameter.

While assessing the efficiency of cycles, various conditions are applied, for example, the condition of equal heat supplied to the working medium or equal work, etc.

Direct and Reverse cycles

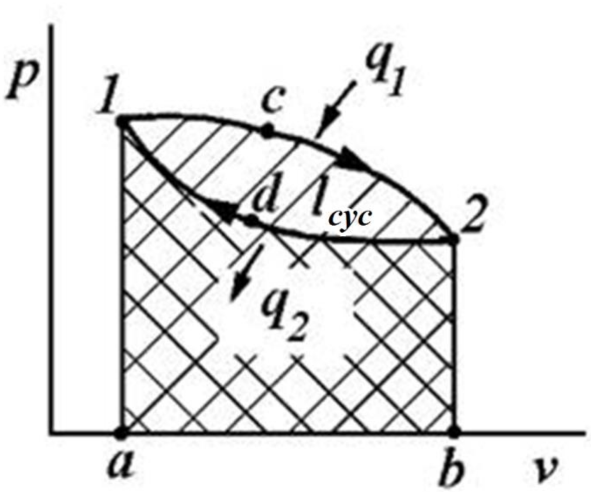
The cycles are divided into:

Direct → Cycles in which heat is converted into work **(heat engines)**

Reverse → Cycles in which heat is transferred from cooler body to more heated body **(refrigerators)**

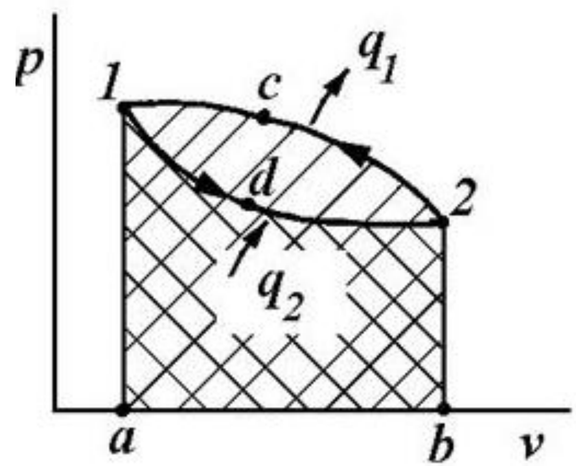
Direct and Reverse cycles

Direct cycle



The process moves clockwise around the loop

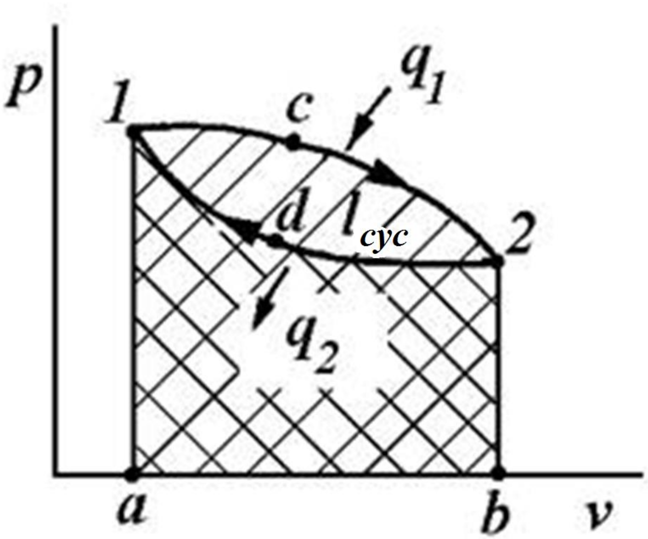
Reverse cycle



The process moves counter-clockwise around the loop

System usually consists of two heat sources and a working medium

Direct cycle



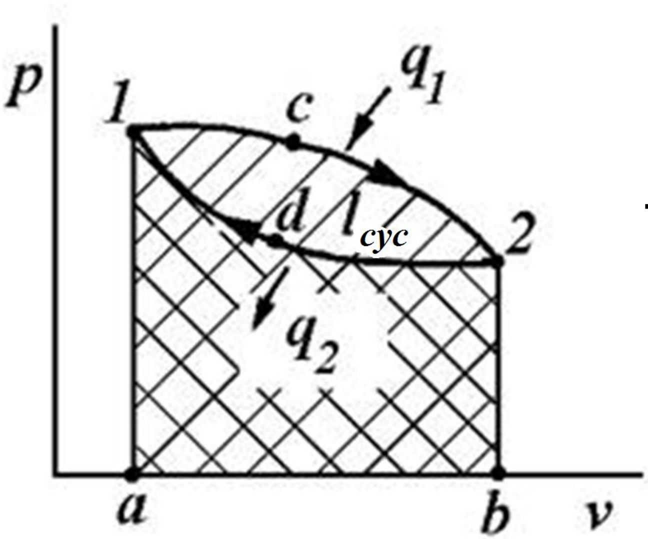
1) From more heated source q_1 the heat is supplied to the working medium → the working medium expands along 1–c–2

2) In the process 2-d–1 the working medium interacts with the source of low temperatures; the heat q_2 is removed, and the working medium compresses

The work of expansion is equal to the area of the area of the shape → 1-c-2-b-a-1

The work of compression is equal to the area of the shape → 2-d-1-a-b-2

Direct cycle



$$1 - c - 2 - b - a - 1 \rightarrow l_{expansion}$$

$$2 - d - 1 - a - b - 2 \rightarrow l_{compression}$$

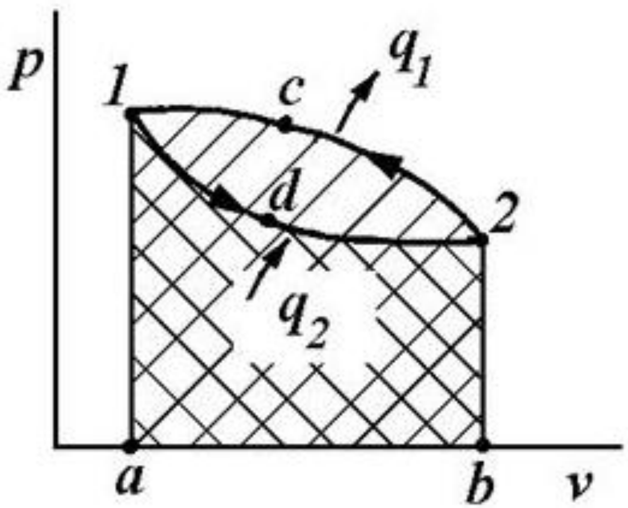
Then the work of cycle is: $l_{cyc} = l_{expans} - l_{compres}$

For the circular process under consideration Δu=0, so, according to the first law of thermodynamics: $\Delta q = l_{cycle} = q_1 - q_2$

The efficiency of this cycle (thermodynamic efficiency):

$$\boxed{\eta_t = \frac{l_{cyc}}{q_1} = \frac{q_1 - q_2}{q_1} = 1 - \frac{q_2}{q_1}}$$

Reverse cycle

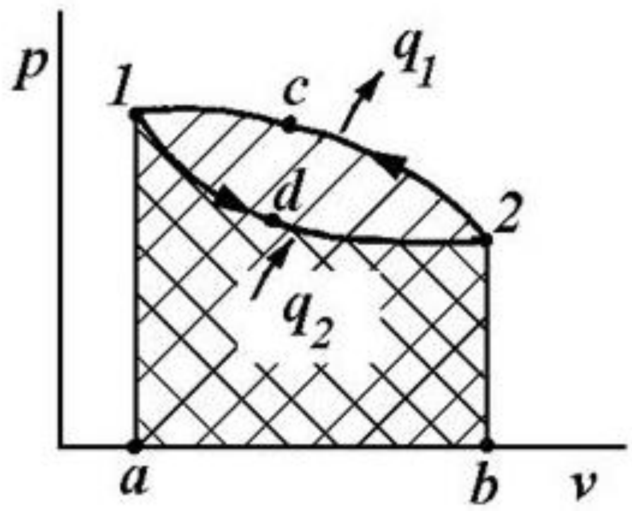


1) The working medium transfers heat $\boldsymbol{q_2}$ from the source with low temperature to the source with higher temperature. A spontaneous process of this kind requires the work $l_{compression}$
2) In the course of compression the working medium interacts with the source of higher temperature and transfers the heat $\boldsymbol{q_1}$

The work of expansion is equal to the area of the area of the shape → 1-d-2-b-a-1

The work of compression is equal to the area of the shape → 2-c-1-a-b-2

Reverse cycle



$$1-d-2-b-a-1 \rightarrow l_{expansion}$$

$$2-c-1-a-b-2 \rightarrow l_{compression}$$

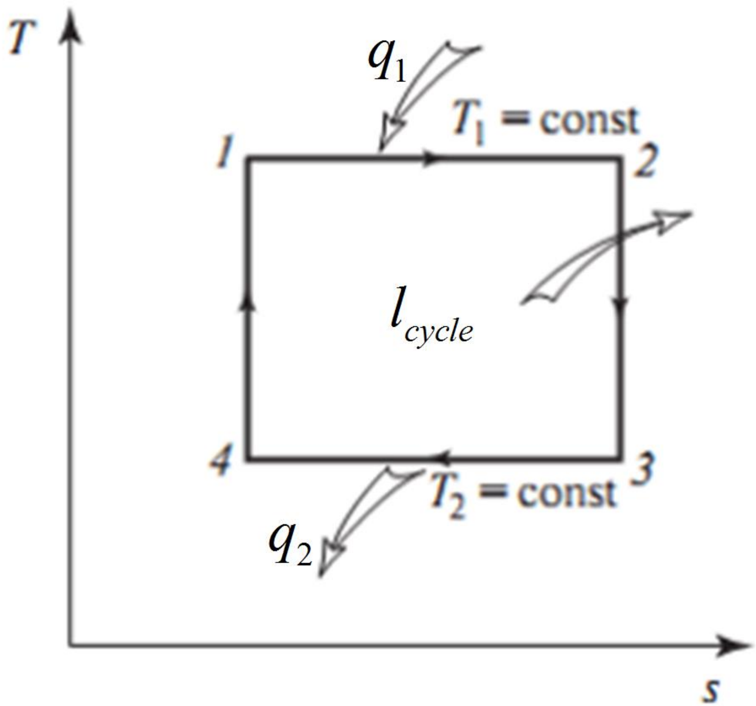
Then the work is: $l_{cyc} = l_{expans} - l_{compres} < 0$

Thus, heat is transferred from a cool body to a heated body (and $\boldsymbol{q_1}$ is emitted into the atmosphere)

For assessment of the work of such a cycle ***coefficient of performance (CoP)*** is used:

$$\boxed{\varepsilon = \frac{q_2}{l_{cyc}} = \frac{q_2}{q_1 - q_2}}$$

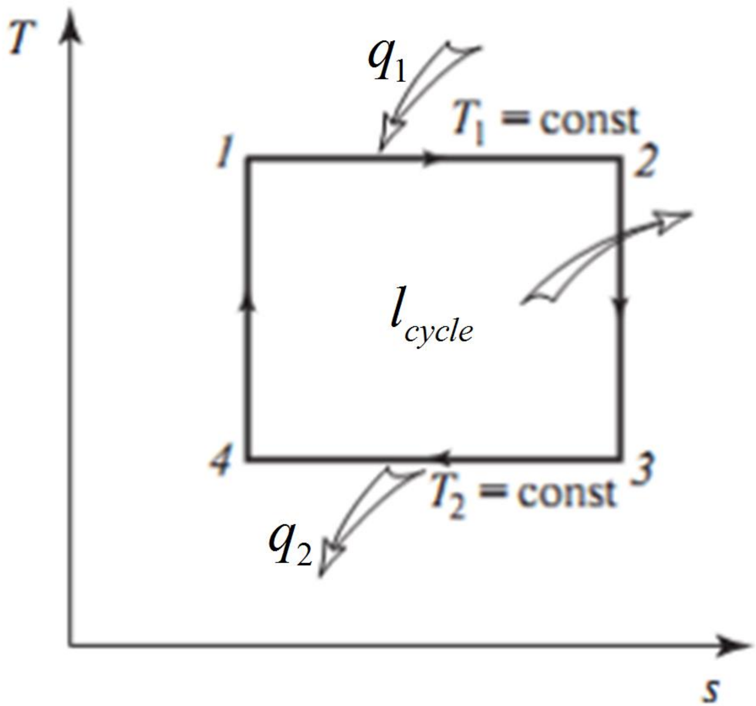
Carnot cycles and analysis of their characteristics



Carnot cycle is a reversible process in which: 1) heat exchange occurs at constant temperature;
2) transfer from one heat source to another occurs without heat exchange (adiabatically);
3) there is no friction in all the processes.

Thus, the Carnot cycle consists of **two isotherms** *(T=const) 1-2, 3-4* and **two adiabats** *(s=const)* 1-4, 2-3

Carnot cycles and analysis of their characteristics



Thermal efficiency of the cycle:

$$\eta_t = 1 - \frac{T_2(s_3 - s_4)}{T_1(s_2 - s_1)}$$

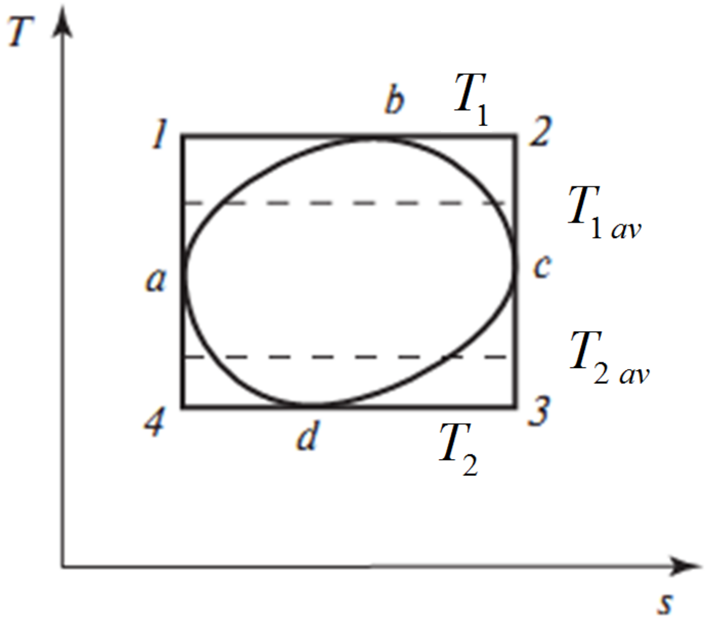
from which $\boxed{\eta_t = 1 - \frac{T_2}{T_1}}$

Thus, thermal efficiency of the cycle depend only on *temperatures of sources*.

Thermal efficiency of the Carnot cycle is the limit of heat conversion into work by means of a heat engine under given conditions

Carnot cycles and analysis of their characteristics

We illustrate the Carnot cycle *(1-2-3-4)* and arbitrary reversible cycle *(a-b-c-d)* in Ts-diagram



For the reversible cycle:

$T_{1\,av}$ - average temperature of heat supply

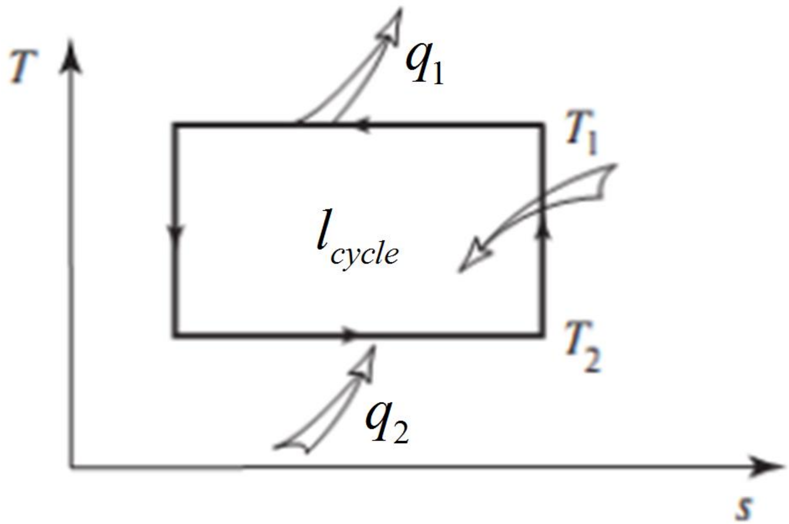
$T_{2\,av}$ - average temperature of heat remove

$$T_{1\,av} < T_1, \quad T_{2\,av} > T_2$$

$$\eta_t = 1 - \frac{T_{2\,av}}{T_{1\,av}}, \quad \text{consequently} \quad \boxed{\eta_t^C > \eta_t}$$

where η_t^C - thermal efficiency of the Carnot cycle

Carnot cycles and analysis of their characteristics



Reverse reversible Carnot cycle

In this cycle due to energy expenditure the heat of low temperature source is transferred to a source with higher temperature.

Depending on the aim and temperature range, it is conventional to distinguish:

Cycle of refrigerator

Cycle of heat pump

Carnot cycles and analysis of their characteristics

Refrigerator

Heat q_2 is removed from refrigerator at temperature T_2 (also, T_2 less than temperature of surroundings T_1), and heat q_1 is transferred to surroundings due raising the temperature of refrigerant.

Coefficient of performance:

$$\boxed{\varepsilon = \frac{q_2}{l_{cyc}} = \frac{T_2}{T_1 - T_2}}$$

Heat pump

Heat q_1 is transferred to consumers, using heat q_2 at temperature T_2, and increasing temperature of working medium from T_2 to T_1 by means of its work.

Coefficient of performance:

$$\boxed{\mu = \frac{q_1}{l_{cyc}} = \frac{T_1}{T_1 - T_2}}$$