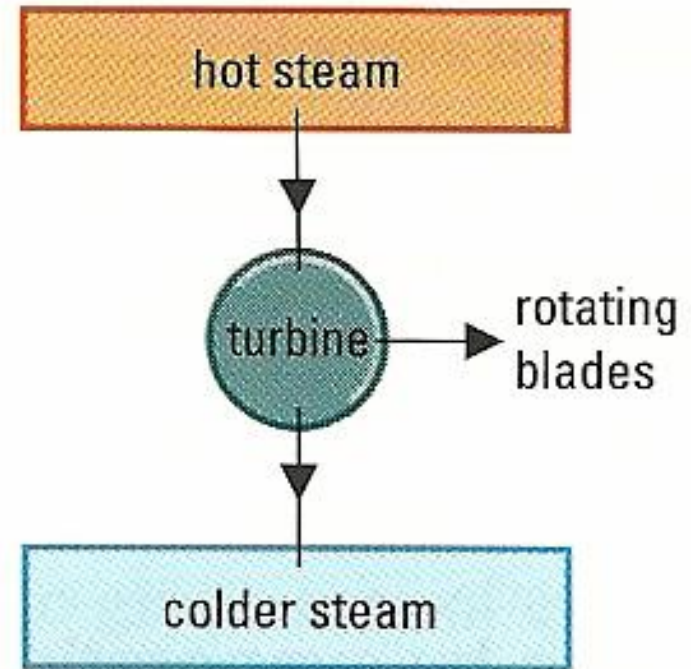
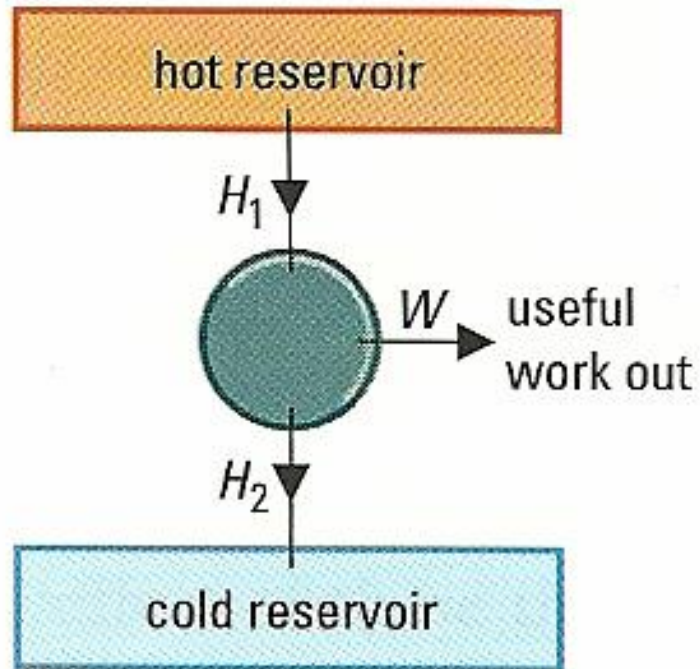


Heat engines

The Carnot cycle

- Heat engines – the internal combustion engine, the turbines that generate electricity in power stations, ...
- The principle of heat engines – energy is extracted as heat from a high-temperature reservoir – a source of energy with a very high thermal capacity so that a great deal of energy can be extracted without changing the temperature noticeably – and some of it is converted into useful work. The remaining energy is dumped into a low-temperature reservoir.
- The first law of thermodynamics implies that the amount of work done by the engine cannot be greater than the heat drawn in from the hot reservoir.
- The second law of thermodynamics requires that the engine can not be 100% efficient – which is the same as saying that some energy must be dumped into the low-temperature reservoir.



1st law of thermodynamics $\Rightarrow H_1 = W + H_2$
2nd law of thermodynamics $\Rightarrow H_2 > 0$

Efficiency of heat engine

- Sadi Carnot (1824) – the first person to study the operation of heat engines.

- Efficiency of heat engine:

efficiency of heat engine < useful work out of engine

heat absorbed from hot reservoir

efficiency of heat engine < $1 - T_{\text{cold reservoir}} / T_{\text{hot reservoir}}$

Work done by heat engines:

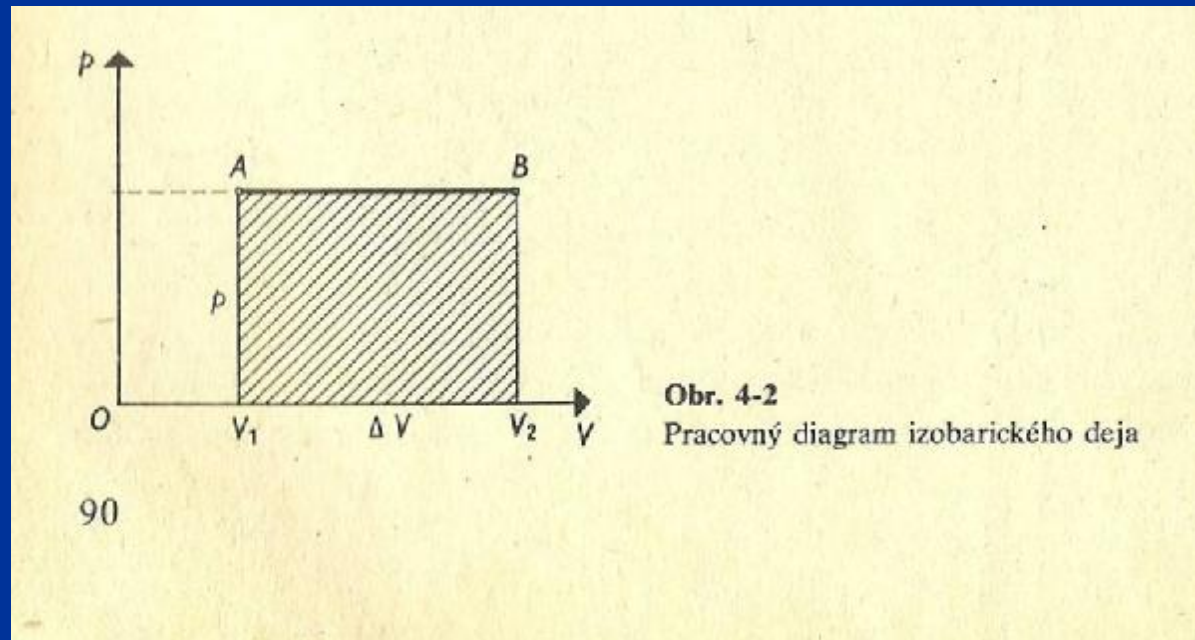
Work done by a gas at isobaric process:

$$W = p \Delta V$$

W – work done (J)

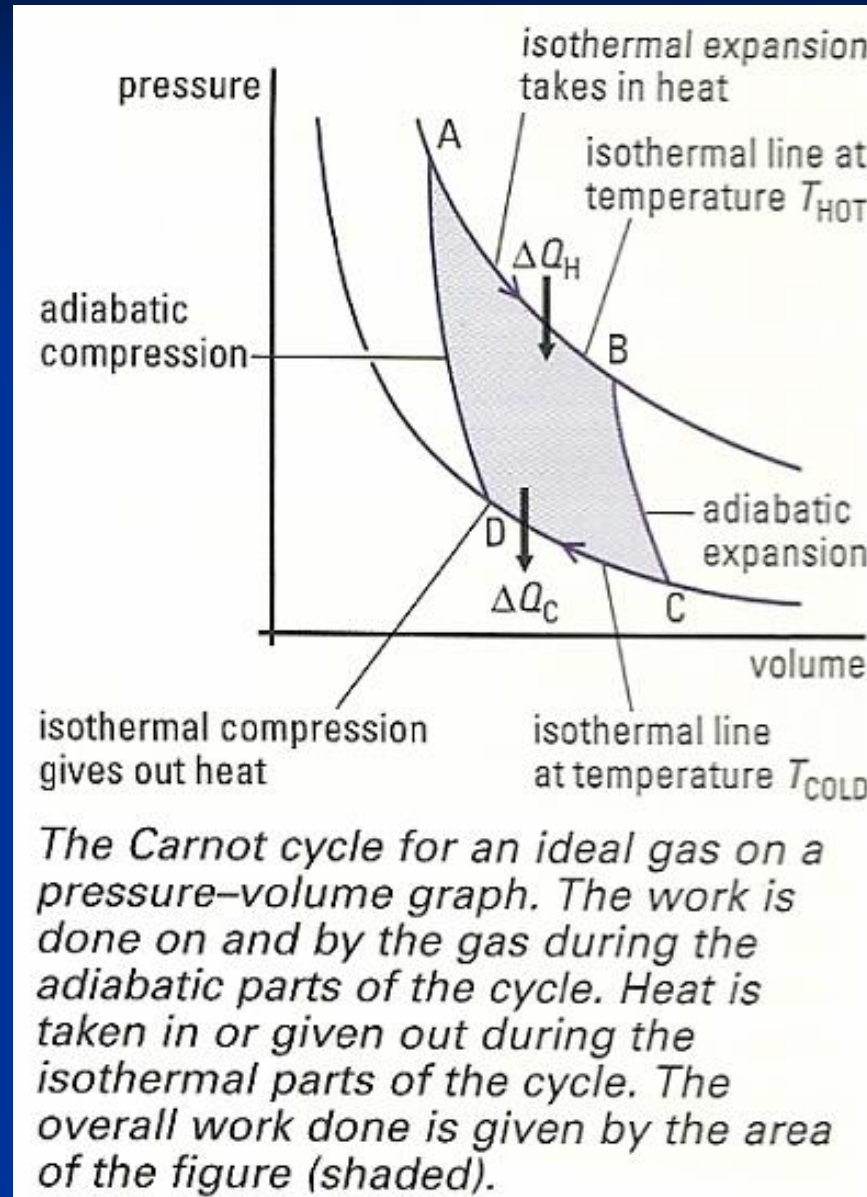
p – pressure (Pa)

ΔV – change in volume (m^3)



The Carnot cycle

- Expansion and compression of an ideal gas.



1. The system starts in the state indicated by point A on the pV diagram – i.e. temperature T_{HOT} , pressure p_A and volume V_A . The gas is then allowed to expand to a new volume V_B while remaining in thermal contact with a hot reservoir of temperature T_{HOT} . This means that the gas can draw in energy as heat (ΔQ_H) and so the expansion is isothermal. The gas does work on the surroundings during this expansion losing an amount of energy equal to the heat it gained – i.e. $\Delta U = 0$ as $\Delta W = -\Delta Q_H$.

2. The gas is now thermally isolated from the hot reservoir, but its expansion continues. This is now an adiabatic expansion and so $\Delta U < 0$ as the energy required to do work on the surroundings has to be provided by the internal energy of the gas. Once the temperature has dropped to T_{COLD} the expansion is halted at volume V_C and pressure p_C .

3. Next the gas is placed in thermal contact with a cold reservoir of temperature T_{COLD} and compressed (isothermally again) until the volume and pressure are now V_D and p_D respectively. During this part of the cycle work is done on the gas, but the energy gained is dumped to the cold (ΔQ_C) reservoir so $\Delta U = 0$.

4. The final stage is the adiabatic compression from D to A, restoring the gas to its initial conditions so that it can be taken round the cycle again. The work done on the gas during this compression is equal to the work that it did in moving from B to C.

Questions:

What is the maximum efficiency of a heat engine with a hot reservoir of 100°C and a cold reservoir of 20°C ? The heat engine works at a rate of 1 kW . What is the rate at which energy is absorbed from the hot reservoir?

A piston of volume 1000 cm^3 contains a gas at a pressure of $1.1 \times 10^5\text{ Pa}$. The gas expands at constant temperature increasing the volume of the piston by 10% .

- a Calculate the work done by the gas.
- b How much energy must be absorbed by the gas from the surroundings in order to maintain the constant temperature?

A piston contains 0.05 mol of an ideal gas at 27 °C. The pressure of the gas is 10^5 Pa.

- a What is the volume of the cylinder?
- b What is the internal energy of the gas?

The gas is now warmed to 77 °C, causing the piston's volume to increase. The pressure remains constant.