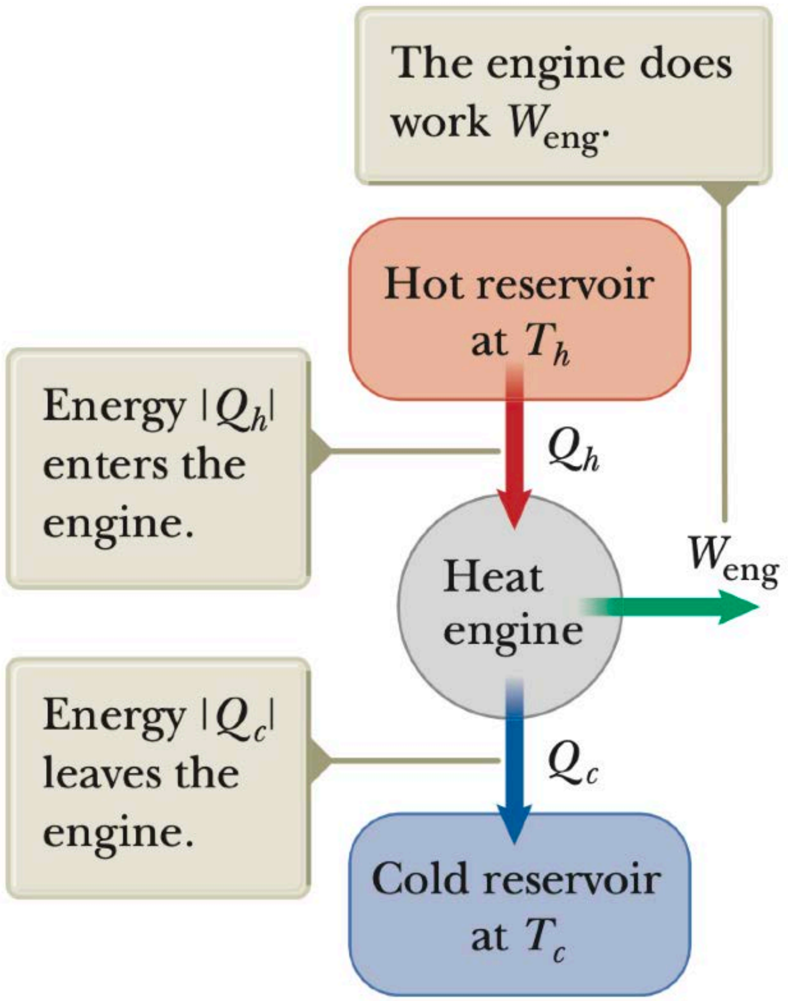
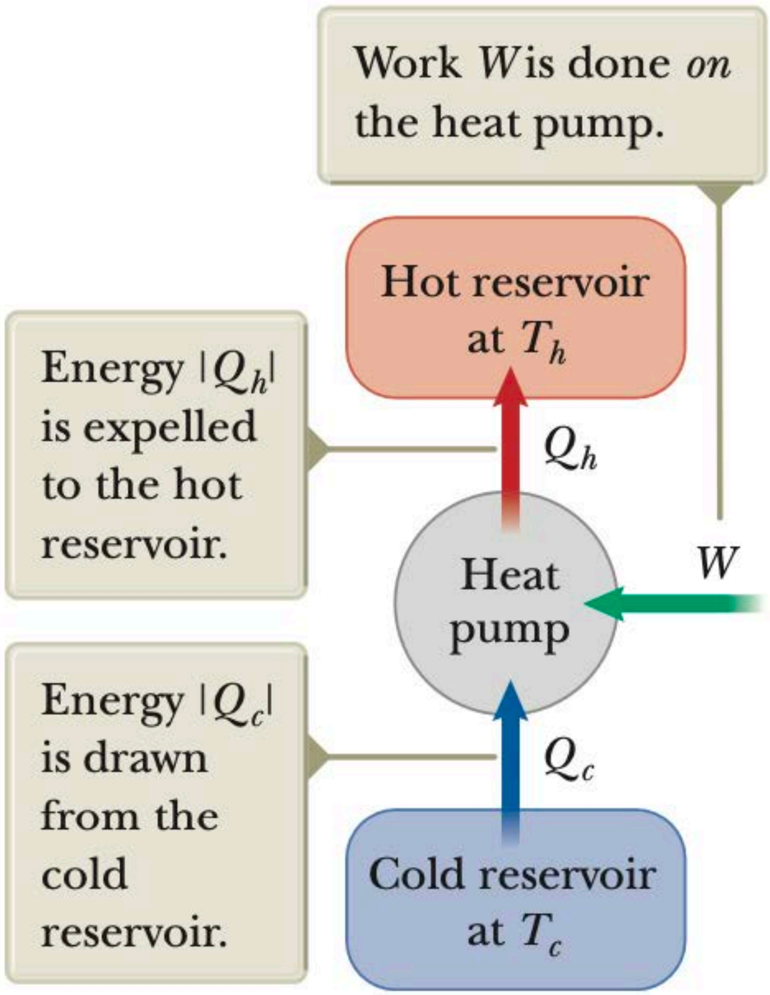
Heat engine and heat pump



Kelvin–Planck form of the second law of thermodynamics

It is impossible to construct a heat engine that, operating in a cycle, produces no effect other than the input of energy by heat from a reservoir and the performance of an equal amount of work.

Heat engine and heat pump



Clausius statement

It is impossible to construct a cyclical machine whose sole effect is to transfer energy continuously by heat from one object to another object at a higher temperature without the input of energy by work.

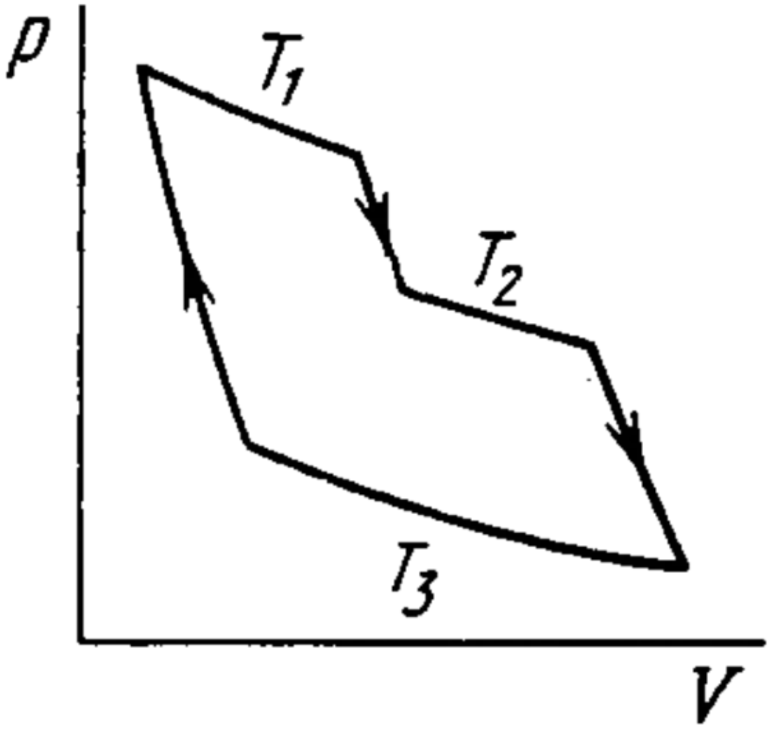
Exercise - 1

Suppose a heat engine is connected to two energy reservoirs, one a pool of molten aluminum (660°C) and the other a block of solid mercury (238.9°C). The engine runs by freezing 1.00 g of aluminum and melting 15.0 g of mercury during each cycle. The heat of fusion of aluminum is 3.97×10^5 J/kg; the heat of fusion of mercury is 1.18×10^4 J/kg. What is the efficiency of this engine?

Exercise - 2

A heat pump has a coefficient of performance equal to 4.20 and requires a power of 1.75 kW to operate. (a) How much energy does the heat pump add to a home in one hour? (b) If the heat pump is reversed so that it acts as an air conditioner in the summer, what would be its coefficient of performance?

Exercise - 3

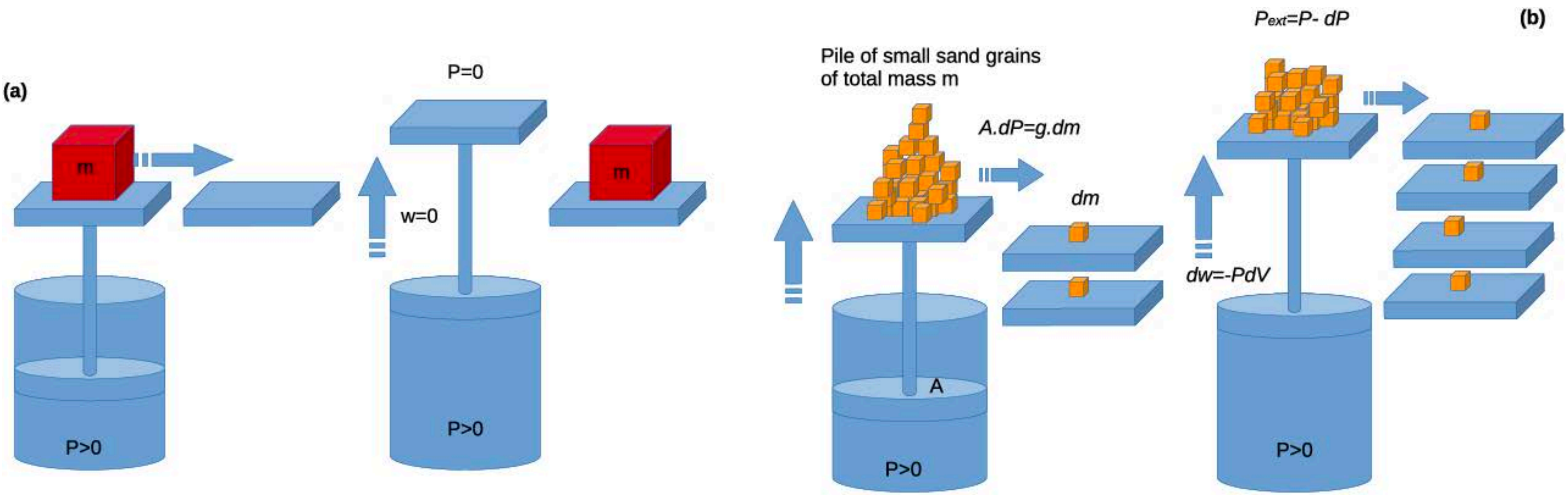


An ideal gas goes through a cycle consisting of alternate isothermal and adiabatic curves. The isothermal processes proceed at the temperatures T_1, T_2, and T_3. Show that the efficiency of such a cycle can be written as

$$1 - \frac{2T_3}{T_1 + T_2}$$

if in each isothermal expansion the gas volume increases in the same proportion.

Reversible and irreversible processes



Non quasi-static expansion

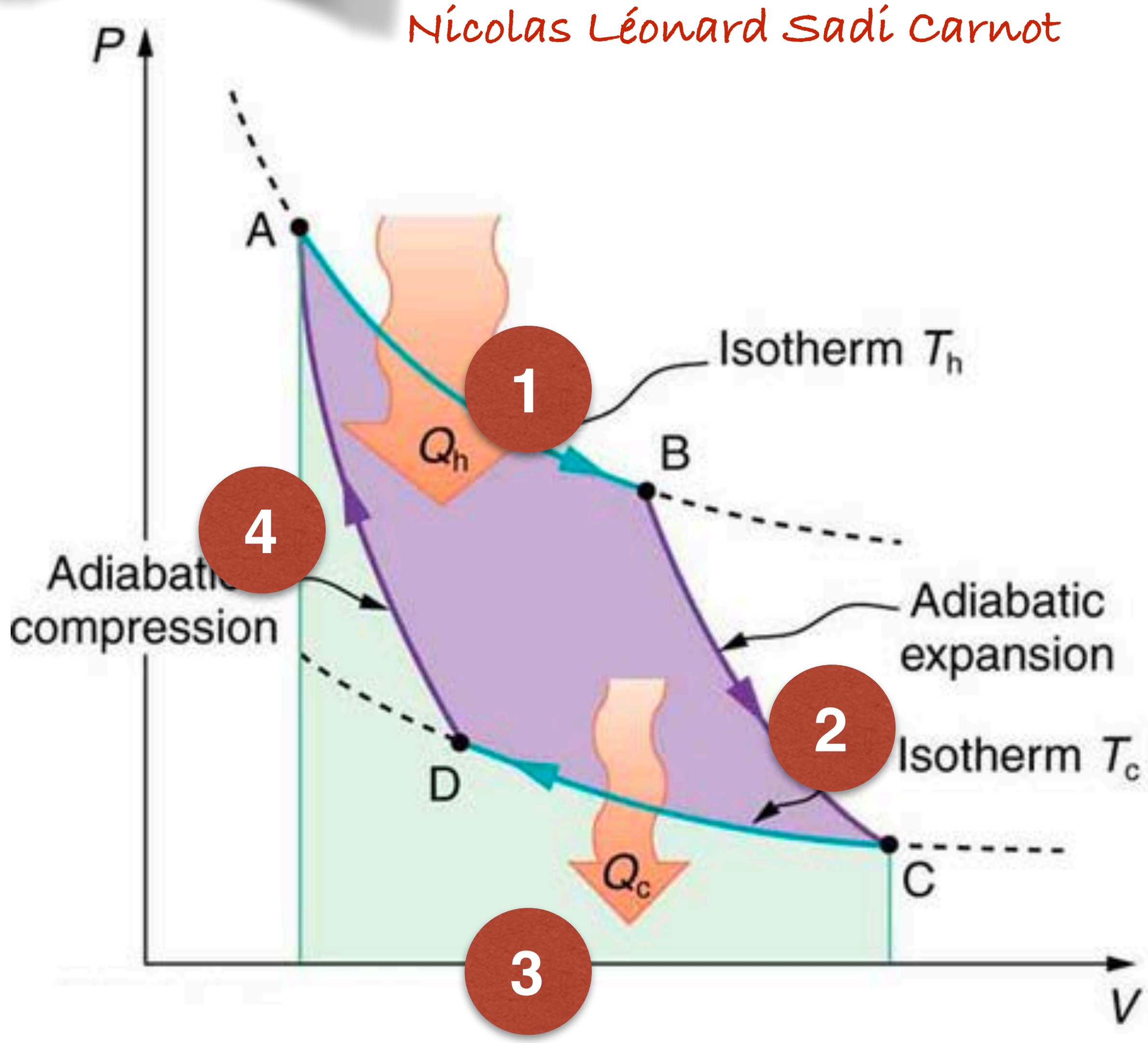
quasi-static expansion

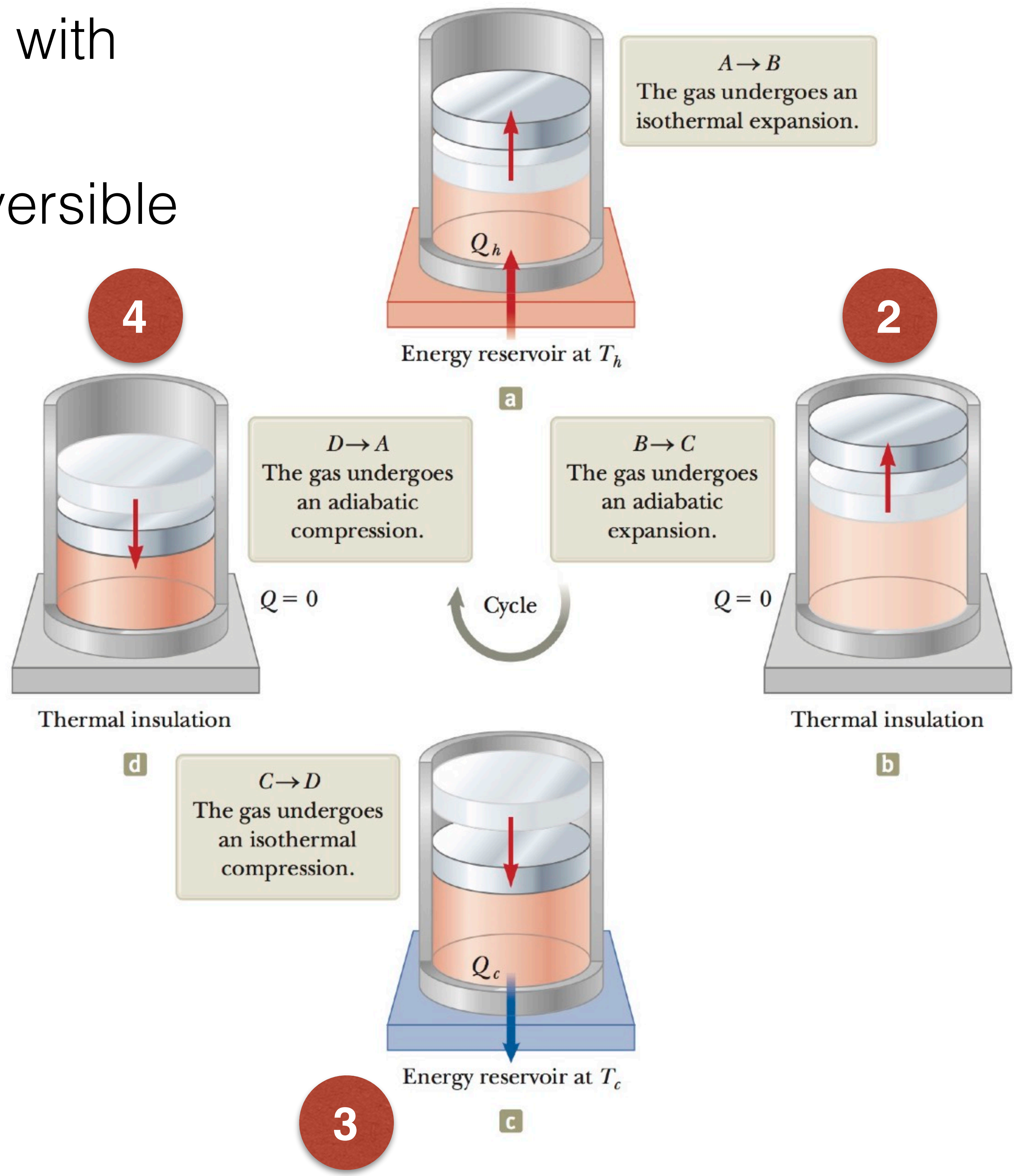
Carnot engine

Nicolas Léonard Sadi Carnot

Consider the engine with the following cycle:

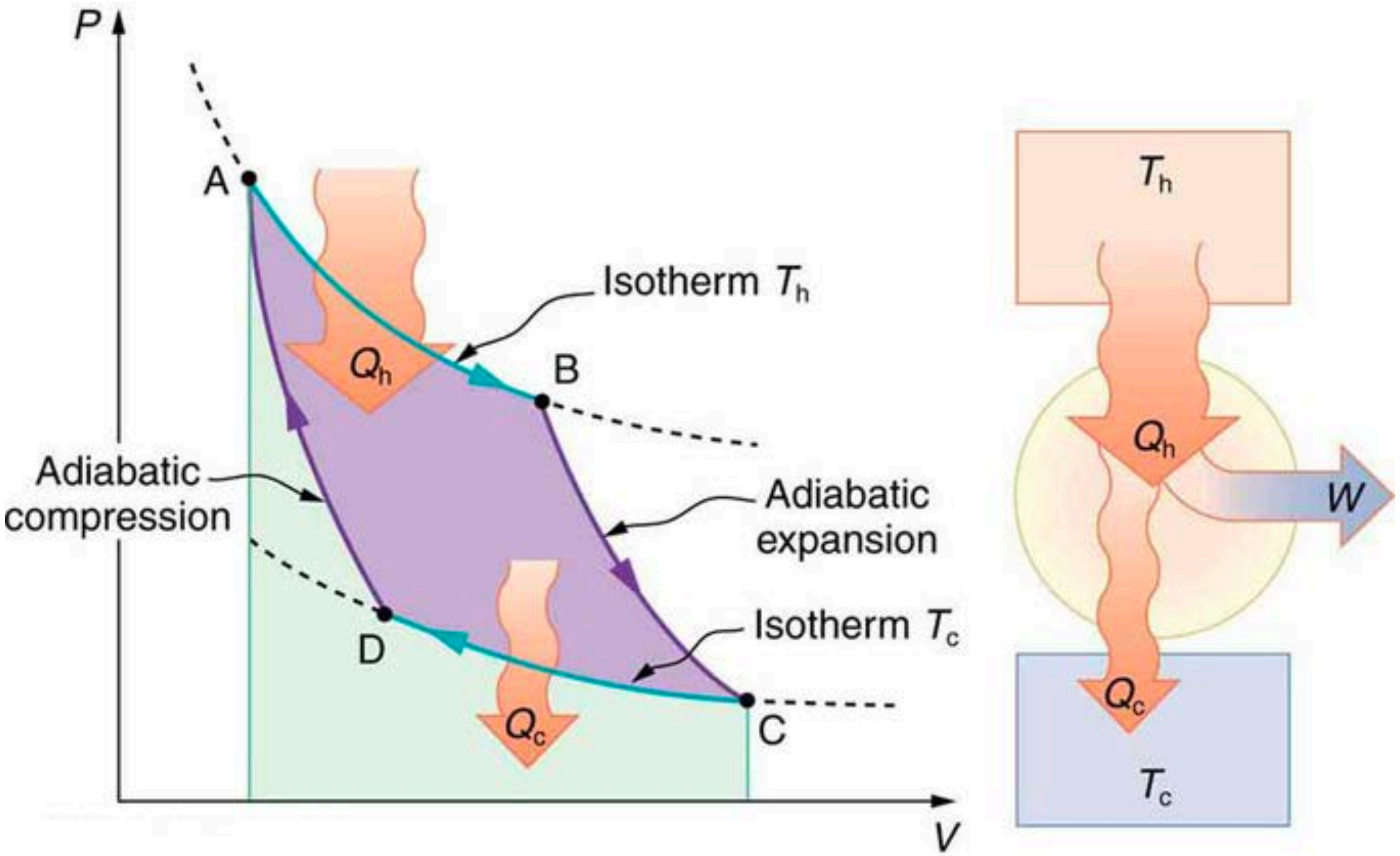
Note: Carnot is a reversible process





https://courses.lumenlearning.com/boundless-physics/chapter/the-second-law-of-thermodynamics/

Carnot engine



Thermal efficiency of the engine:

$$e = 1 - \frac{|Q_C|}{|Q_H|}$$

Exercise - 4

An ideal gas is taken through a Carnot cycle. The isothermal expansion occurs at 250°C, and the isothermal compression takes place at 50.0°C. The gas takes in 1.20×10^{3} J of energy from the hot reservoir during the isothermal expansion. Find (a) the energy expelled to the cold reservoir in each cycle and (b) the net work done by the gas in each cycle.

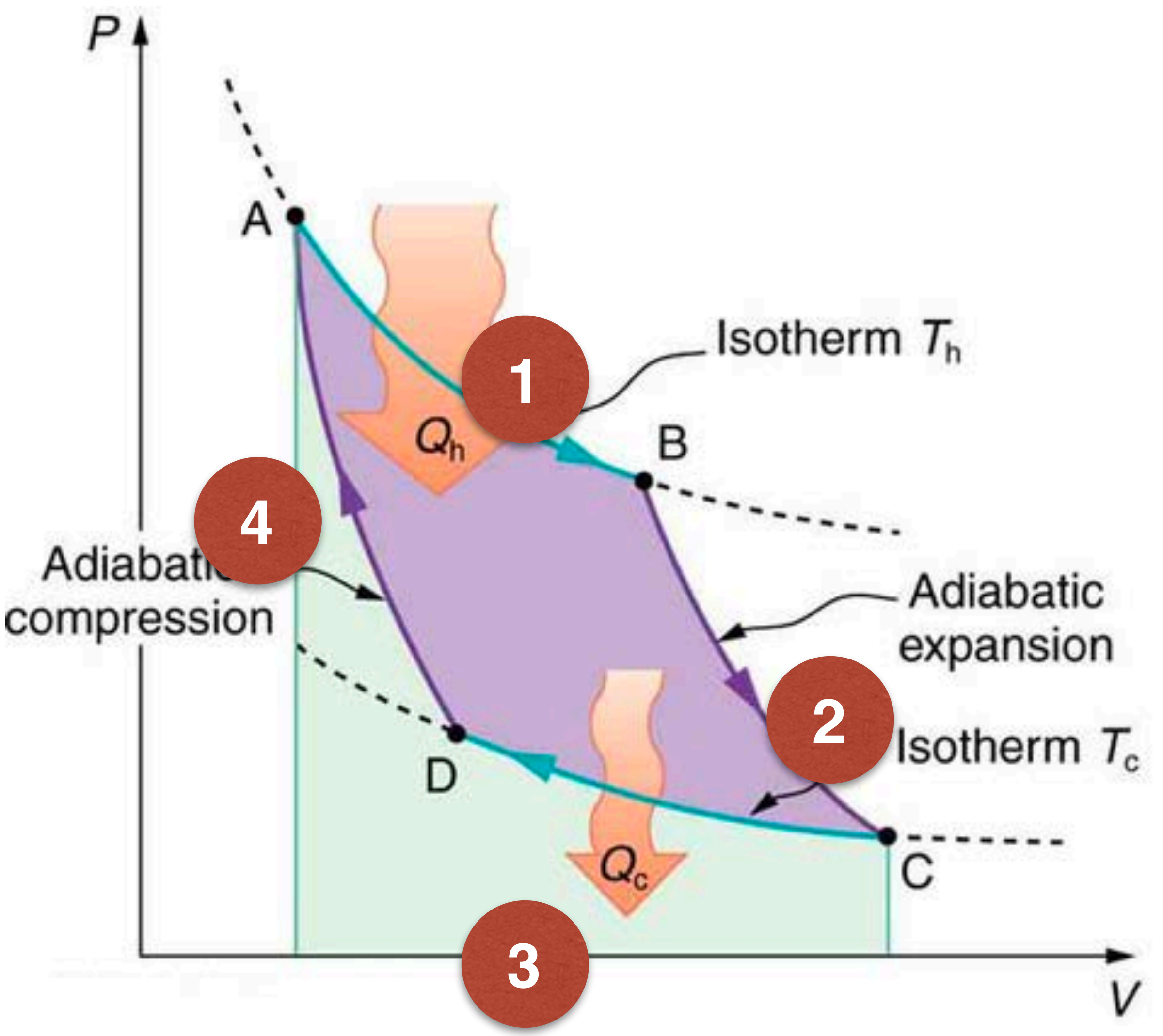
Exercise - 5

In which case will the efficiency of a Carnot cycle be higher:
When the hot body temperature is increased by ΔT, or when the cold body temperature is decreased by the same magnitude?

Carnot's principle

Carnot's principle
"The efficiency of a quasi-static or reversible Carnot cycle depends only on the temperatures of the two heat reservoirs, and is the same, whatever the working substance. A Carnot engine operated in this way is the most efficient possible heat engine using those two temperatures."

Carnot Engine and the Concept of Entropy

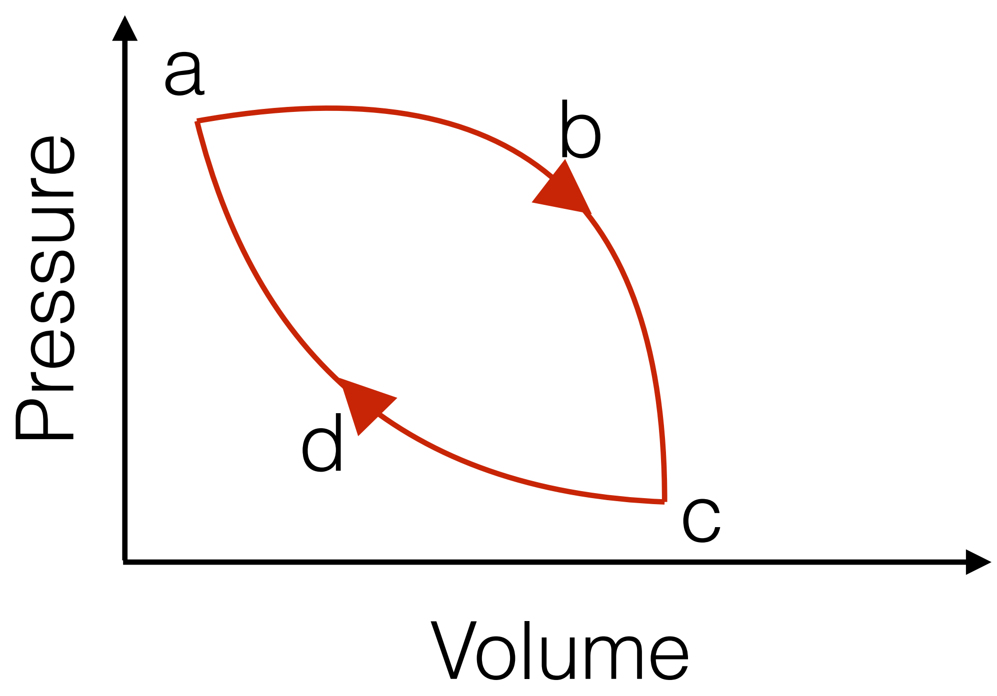


State variables

Do you understand the following statement?

- Internal energy is a state variable
- Heat is not a state variable

You can start by considering the cyclic process



Entropy

Entropy is a scientific concept, as well as a measurable physical property, that is most commonly associated with a state of disorder, randomness, or uncertainty. The macroscopic state of a system that has a large number of microstates has four qualities that are all related:

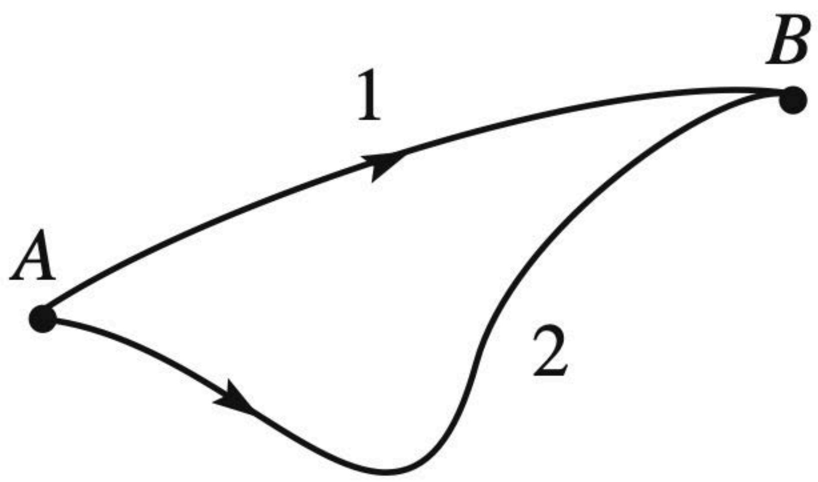
(1) **uncertainty**: because of the large number of microstates, there is a large uncertainty as to which one actually exists;

(2) **choice**: again because of the large number of microstates, there is a large number of choices from which to select as to which one exists;

(3) **probability**: a macrostate with a large number of microstates is more likely to exist than one with a small number of microstates;

(4) **missing information**: because of the large number of microstates, there is a high amount of missing information as to which one exists.

Changes in Entropy (for Thermodynamic Systems)



Consider two reversible processes, 1 and 2, between the equilibrium states A and B:

The correct procedure for calculating entropy differences is as follows:

Exercise - 6 (Entropy Change in a Carnot Cycle)

Imagine a Carnot engine that operates between the temperatures T_H = 850 K and T_L = 300 K. The engine performs 1200 J of work each cycle, which takes 0.25 s.

(a) What is the efficiency of this engine?

(b) What is the average power of this engine?

(c) How much energy $|Q_H|$ is extracted as heat from the high-temperature reservoir every cycle

(d) How much energy $|Q_L|$ is delivered as heat to the low- temperature reservoir every cycle?

(e) By how much does the entropy of the working substance change as a result of the energy transferred to it from the high-temperature reservoir? From it to the low-temperature reservoir?

Exercise - 7 (Entropy Change in Thermal Conduction)

When a metal bar is connected between a hot reservoir at T_h and a cold reservoir at T_c, the energy transferred by heat from the hot reservoir to the cold reservoir is Q. In this irreversible process, find expressions for the change in entropy of (a) the hot reservoir, (b) the cold reservoir, and (c) the Universe, neglecting any change in entropy of the metal rod.

Exercise - 8 (Entropy Change in Adiabatic Process)

From

$$\Delta S = nR\ln(V_f/V_i) + nc_v\ln(T_f/T_i),$$

show that the change of entropy in the reversible adiabatic process is 0.

Exercise - 9 (Entropy change in free expansion and adiabatic)

A weightless piston divides a thermally insulated cylinder into two equal parts. One part contains one mole of an ideal gas, the other is evacuated. The piston is released and the gas fills the whole volume of the cylinder. Then the piston is slowly displaced back to the initial position. Find the increment of the entropy of the gas resulting from these two processes.

Exercise - 10

A mole of an ideal gas with the adiabatic exponent γ goes through a direct (clockwise) cycle consisting of adiabatic, isobaric, and isochoric lines. Show that the efficiency of the cycle if in the adiabatic process the volume of the ideal gas increases f-fold (i.e. from V to fV) can be written as

$$\text{efficiency} = 1 - \frac{\gamma(f-1)}{f^{\gamma-1}}$$

2nd Law of the Thermodynamics

The second law of thermodynamics states that a closed system has entropy that may

increase: irreversible process

or otherwise

remain constant: reversible process

If

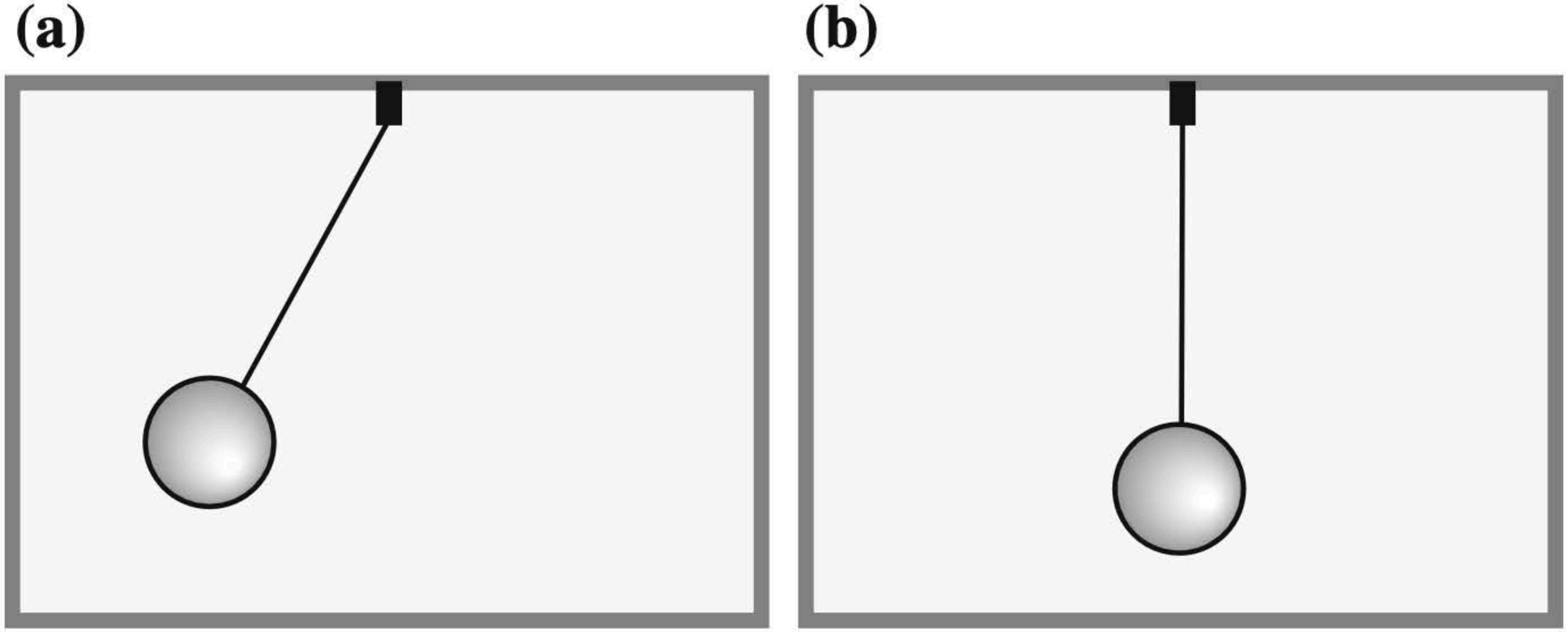
$$\Delta S = \Delta S_{\text{gas}} + \Delta S_{\text{res}}$$

And processes can happen if

$$\Delta S \geq 0$$

Exercise - 11

Consider a pendulum enclosed in an adiabatic container with air at atmospheric pressure. In the initial state, the pendulum is moved out of its mechanical equilibrium position and is let go. The temperatures of the pendulum and the air are both T_i. The pendulum will oscillate for a while, with oscillations of decreasing amplitude, due to the resistance of the air. Consider as the final state, the state in which the pendulum is at rest and its temperature and that of the air are equal. The final temperature, T_f, is obviously larger than T_i. Calculate the change of entropy of the system.



Exercise - 11