Thermodynamics tutorhour 1

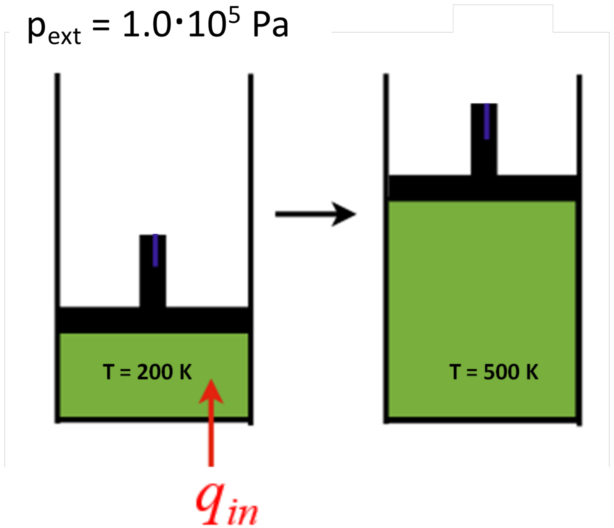
November 8th 2023

- Questions about the lecture or course matter?
- Four thought experiments

Experiment 1

1 mol of helium is heated in a cylinder with a movable piston at constant pressure **(isobaric)** from 200 K to 500 K.

Question 1: What is the amount of heat (Q_{in}) required to achieve this goal?



At highschool we calculated the required heat this way:

$$Q = m \cdot c \cdot \Delta T$$

Q = amount of heat
m = mass
ΔT = change in temperature
c = heat capacity in J **kg**$^{-1}$ K^{-1}
in data sections J **mol**$^{-1}$ K^{-1} is often used.

$$Q = n \cdot c \cdot \Delta T = 1 \cdot 20.783 \cdot 300 = 6235\text{J}$$

In this course and in most books, q (instead of Q) is used as the symbol for heat.

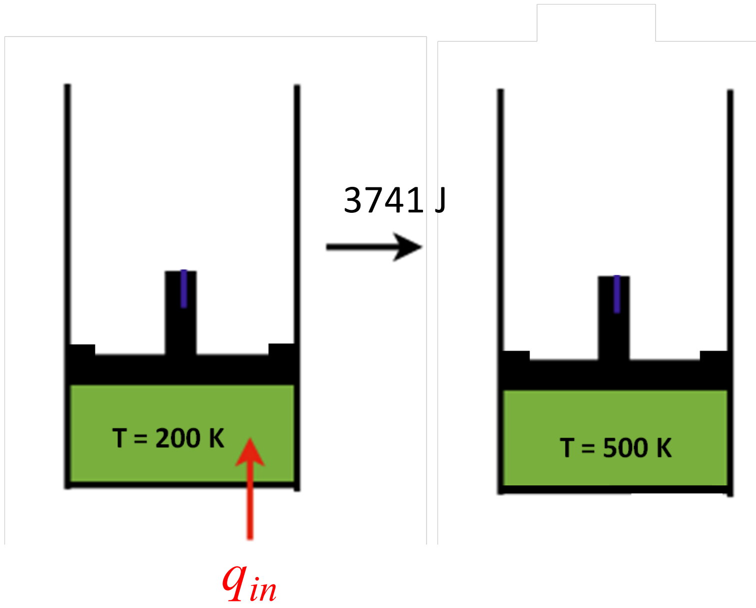
Experiment 2

The movable piston is secured now. Then the gas is heated at constant volume **(isochoric)** from 200 K to 500 K.

Question 2a: Will the amount of heat (q_{in}) required in this case be bigger than,

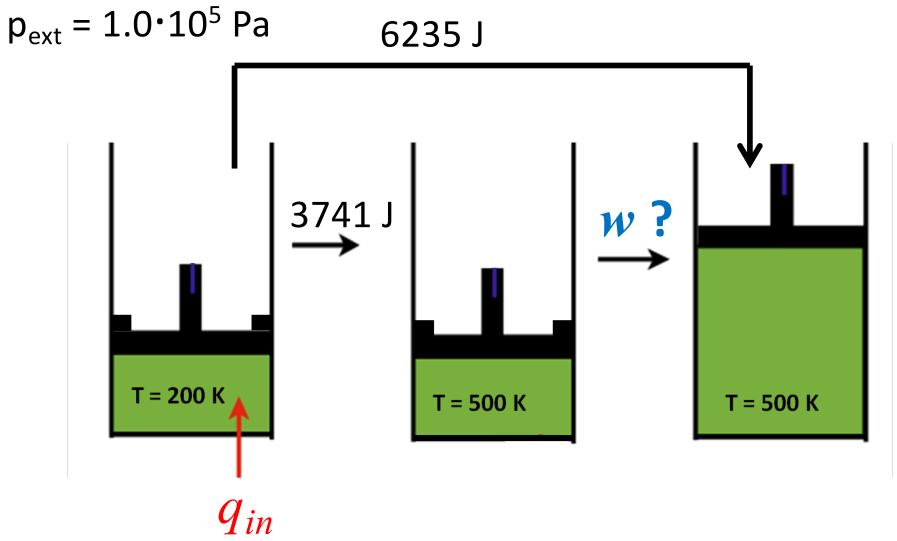
smaller than,

or equal to 6235 J?



We know from experiments that in this case only 3741 J is needed, so smaller than 6235 J.

$$q_{in} = 3741 \text{ J}$$



The **work** done by the gas is negative when the volume of the system increases!

$$dw = -pdV$$

$$w = \int dw = \int -p_{ext}dV = -p_{ext}\int dV$$

$$= -p_{ext}\Delta V$$

an isobaric proces, so p_{ext} is constant

Explanation: When a gas is heated **isobaric**, it expands! The air from the surroundings has to be pushed away.

Question 2b:

Calculate the amount of work (w) done by the gas in two different ways.

$$pV = nRT$$

$$V_{200K} = nRT_{200} / p_{ext}$$

$$V_{500K} = nRT_{500} / p_{ext}$$

$$\Delta V = nR\Delta T / p_{ext} = 1 \cdot 8.3145 \cdot 300 / 1.0 \cdot 10^5 = 0.02494 \mathrm{m}^3$$

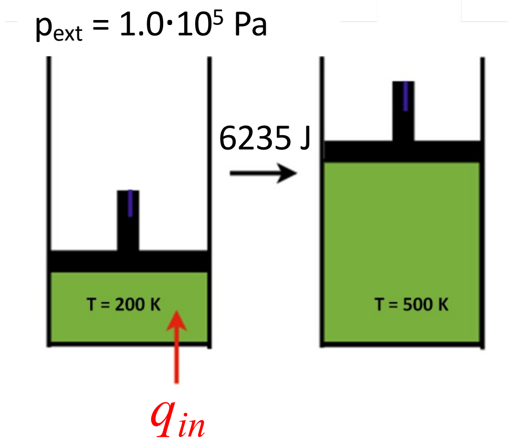
Conservation of energy:

$$w = 3741 - 6235 = -2494 \text{ J}$$

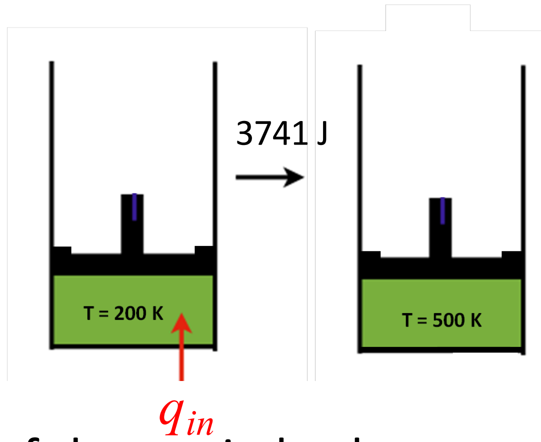
$$w = -p_{ext}\Delta V = -1.0 \cdot 10^5 \cdot 0.02494 = -2494 \text{ J}$$

$Q = n \cdot c \cdot \Delta T$ becomes: $q = n \cdot c_p \cdot \Delta T$ or $q = n \cdot c_V \cdot \Delta T$

isobaric



isochoric



Question 2c: Calculate the change in internal energy (ΔU) of the gas in both cases.

$\Delta U = q + w = q - \mathrm{p}\Delta V$ $\Delta U = q + w = q + 0$

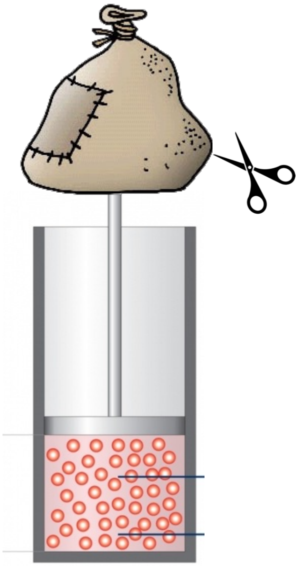
ΔU is **the same** for both processes!

For a mono-atomic perfect gas: U = 3/2·$n\mathrm{R}T$ so ΔU = 3/2·$n\mathrm{R}\Delta T$

Experiment 3: Reversible expansion at constant temperature **(isothermic)**

Question 3: Derive an expression for the work **(w)** done by the gas.

reversible means: the system is in equilibrium during the expansion! So: $p_{ext} = p_{gas}$



$p_{ext} = p_{air} + p_{sand}$

p_{sand} decreases, so p_{ext} is not constant!

$$dw = -pdV$$

$$w = \int dw = \int -p_{ext} dV$$

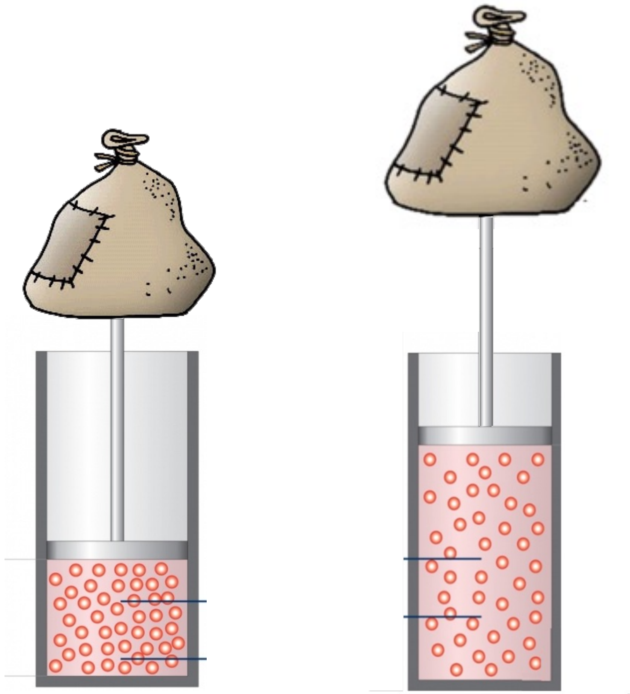
$$p = \frac{nRT}{V}$$

as V increases during an expansion, p of the gas decreases!

$$w = \int -pdV = \int -\frac{nRT}{V} dV = -nRT \int \frac{1}{V} dV = -nRT(\ln V_2 - \ln V_1) = -nRT \ln\left(\frac{V_2}{V_1}\right)$$

Experiment 4: Reversible expansion at constant external pressure **(isobaric)**

Question 4: Derive an expression for the work **(w)** done by the gas.



The bag stays closed.
In order to achieve a reversible expansion, T has to be raised very, very slowly!

$$dw = -pdV$$

$p_{ext} = p_{air} + p_{sand}$ p_{air} and p_{sand} are both constant, so p_{ext} is constant!

$$w = \int dw = \int -\mathrm{p}dV = -\mathrm{p}\int dV = -\mathrm{p}\Delta V$$