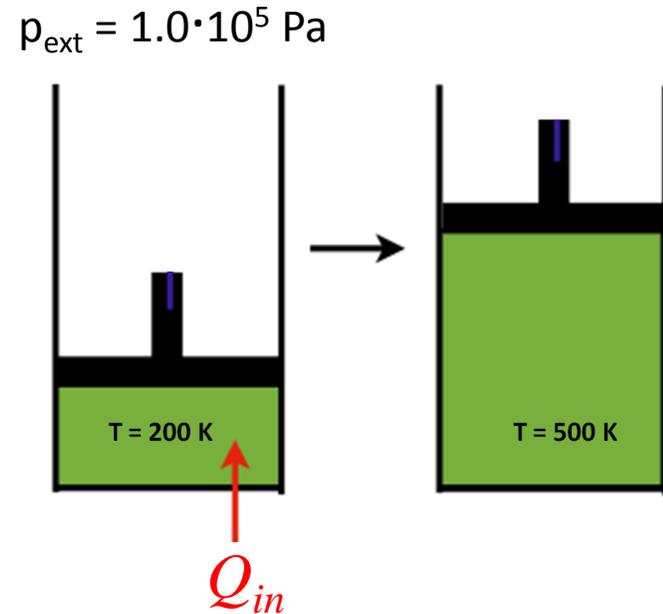# Thermodynamics tutorhour 1

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.

p_{ext} = 1.0·10⁵ Pa

At highschool we calculated the heat needed this way:

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

Q = amount of heat

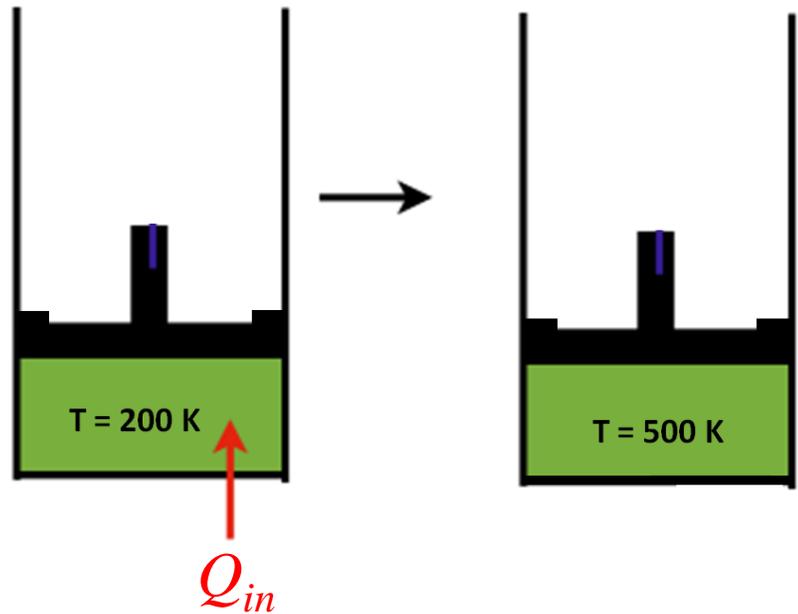m = mass

ΔT = change of temperature

c = heat capacity in J kg^{-1} K^{-1}

in data sections J mol^{-1} K^{-1} is often used.

T = 200 K

T = 500 K

Q_{in}

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

Experiment 2

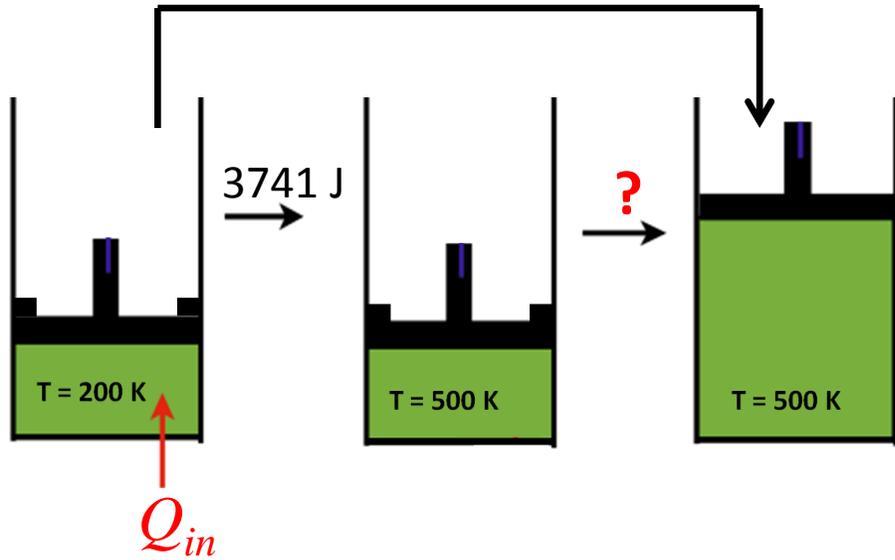The movable piston is secured now. Then the gas is heated at constant volume (isochoric) from 200 K to 500 K.

We know from experiments that only 3741 J is needed:

$$Q = 3741 \text{ J}$$

$p_{ext} = 1.0 \cdot 10^5$ Pa

6235 J

3741 J

?

T = 200 K

T = 500 K

T = 500 K

Q_{in}

The work is negative when the volume of the system increases!

$$W = -\int p_{ext} dV$$

as p_{ext} is constant

When a gas is heated isobaric, it expands!
The air from the surroundings has to be pushed away.
Calculate the amount of work done by the gas in two different ways:

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

$$pV = nRT$$

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

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

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

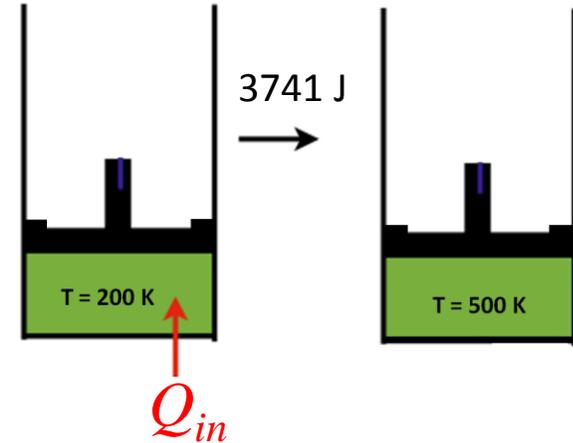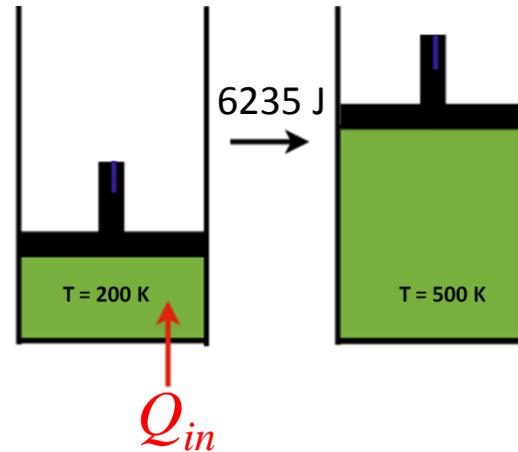$$W = -p\Delta V = -1.0 \cdot 10^5 \cdot 0.02494 = -2494 \text{ J}$$

$Q = n \cdot c \cdot \Delta T$ becomes: $\qquad Q = n \cdot cp \cdot \Delta T \qquad$ or $\qquad Q = n \cdot cV \cdot \Delta T$

$p_{ext} = 1.0 \cdot 10^5$ Pa

6235 J

T = 200 K   T = 500 K

Q_{in}

3741 J

T = 200 K   T = 500 K

Q_{in}

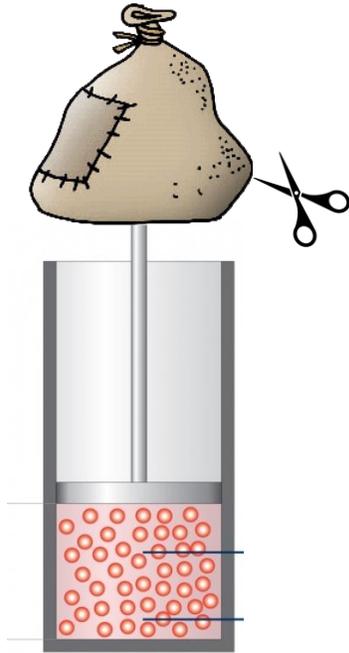What are the consequences for the change in internal energy (ΔU) of the gas?

$$\Delta U = Q + W = Q - p\Delta V \qquad\qquad \Delta U = Q + W = Q + 0$$

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

For a mono-atomic perfect gas: $U = 3/2 \cdot nRT \qquad$ or $\qquad \Delta U = 3/2 \cdot nR\Delta T$

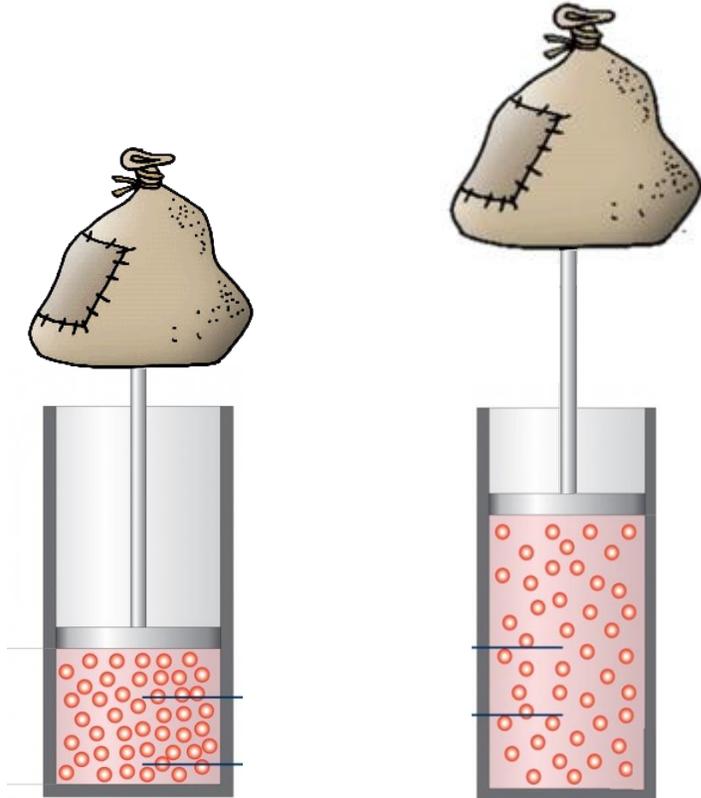# Experiment 3: Reversible expansion at constant temperature

$p_{ext} = p_{air} + p_{sand}$ Now p_{ext} isn't constant!

$p_{ext} = p$
because it is
reversible

$$W = -\int p_{ext} dV$$

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

Experiment 4: Reversible expansion at constant external pressure

The bag stays closed,
T has to be raised very, very slowly.

$p_{ext} = p_{air} + p_{sand}$ Now p_{ext} is constant!

$$dW = -pdV$$

$$W = \int dW = -\int pdV = -p\int dV = -p\Delta V$$

Question 1

a) $pV = nRT$; $V = nRT/p$

$V_{T=100} = nRT/p = 5.0 \cdot 8.3145 \cdot (273 + 100)/1.0 \cdot 10^5 = 0.155 = 0.16 \text{ m}^3$

b) Cooling down leads to a smaller volume. When the gas expands, work is done on the surroundings. In this process the surroundings exert work on the system: $W > 0$

c) $V_{T=0} = nRT / p = 5.0 \cdot 8.3145 \cdot 273/1.0 \cdot 10^5 = 0.113 = 0.11 \text{ m}^3$

d) $\Delta V = V_{T=0} - V_{T=100} = 0.113 - 0.155 = -0.042 \text{ m}^3$

because p is constant:
$W = -p\Delta V$
$W = -1.0 \cdot 10^5 \cdot (-0.042) = 4.2 \cdot 10^3 \text{ J}$

e) $\Delta U = 3/2 \cdot nR\Delta T = -6236 \text{ J} = -6.2 \text{ kJ}$

Question 2

$$W = \int dW = -\int p\,dV = -p\int dV = -p\Delta V = -1.0 \cdot 10^5 \cdot 1.0 \cdot 10^{-3} = -1.0 \cdot 10^2 \text{ J}$$

Question 3

a) $\Delta U = 3/2 nR\Delta T$; isothermic, so $\Delta T = 0$ K and therefore $\Delta U = 0$ J
   $W = -p_{ext}\Delta V$; $p_{ext} = 0$ Pa so $W = 0$ J
   $Q = \Delta U - W = 0 - 0 = 0$ J

b) $\Delta U = 0$ J; $dW = -\int p_{ext}dV$; $p_{ext} = nRT/V$; $W = -nRT\int(1/V)dV = -nRT\ln(V_2/V_1) = -1573$ J
   $Q = \Delta U - W = 1573$ J

c) $\Delta U = 0$ J; $dW = -p_{ext}dV$; p_{ext} is constant, so $W = -p_{ext}\cdot\Delta V = -(nRT/V_f)\cdot\Delta V$
   $W = -(1.0 \cdot 8.3145 \cdot 273/44.8 \cdot 10^{-3})\cdot(22.4 \cdot 10^{-3}) = -1135$ J
   $Q = \Delta U - W = 1135$ J

Question 4

$p_1/T_1 = p_2/T_2$; $p_2 = p_1 \cdot T_2/T_1 = 1.33 \cdot 10^5$ Pa
$\Delta U = 3/2 \cdot nR\Delta T = 1247$ J
$W = -\int p\,dV$ in which $dV = 0$ so $W = 0$ J
$Q = \Delta U - W = 1247 - 0 = 1247$ J