

Experimentalphysik II (SS 2023/2024)

Übung 3

Tutorium: 2

Abgabe: 28.04.2023

1. Wärmestrahlung

Für die Emission des Kupferballs gilt:

$$\begin{aligned}
 \sigma AT^4 &= P = -\frac{dE}{dt} = -\frac{cMdT}{dt} \\
 \frac{dT}{dt} &= -\frac{\sigma A}{cM} T^4 \\
 &= -\frac{\sigma \cdot 4\pi r^2}{c \cdot \rho \cdot \frac{4}{3}\pi r^3} T^4 \\
 &= -3 \frac{\sigma}{c\rho r} T^4
 \end{aligned}$$

Aufgrund des thermischen Gleichgewichts des Behältnisses gilt:

$$\begin{aligned}
 0 &= \dot{E}_E + \dot{E}_A \\
 &= -\varepsilon \sigma AT_B^4 + \alpha AS \\
 S &= \frac{\varepsilon}{\alpha} \sigma T_B^4 \\
 &= \sigma T_B^4
 \end{aligned}$$

Damit gilt für die Absorption des Kupferballs:

$$\begin{aligned}
 \frac{dE}{dt} &= AS \\
 \frac{cMdT}{dt} &= A\sigma T_B^4 \\
 \dot{T} &= \frac{A\sigma T_B^4}{cM} \\
 &= \frac{4\pi r^2 \cdot \sigma T_B^4}{c \cdot \rho \frac{4}{3}\pi r^3} \\
 &= 3 \frac{\sigma}{c\rho r} T_B^4
 \end{aligned}$$

Insgesamt:

$$\begin{aligned}
 \dot{T} &= \dot{T}_E + \dot{T}_A \\
 &= 3 \frac{\sigma}{c\rho r} (T_B^4 - T^4) \\
 &\approx 3 \frac{5.77 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}}{383 \frac{\text{J}}{\text{K kg}} \cdot 8920 \frac{\text{kg}}{\text{m}^3} \cdot \frac{5}{100} \text{m}} ((30^\circ \text{C})^4 - (5^\circ \text{C})^4) \\
 &\approx 8.20 \cdot 10^{-4} \frac{\text{K}}{\text{s}}
 \end{aligned}$$

2. Arbeit und Leistung

(a)

$$\begin{aligned}|Q_{ab}| &= 4 \text{ J} \\|Q_{zu}| &= (1 - \eta) |Q_{ab}| \\&= \left(1 - \frac{17}{100}\right) 4 \text{ J} \\&\approx 3.32 \text{ J} \\W &= \eta |Q_{ab}| \\&= \frac{17}{100} \cdot 4 \text{ J} \\&\approx 0.68 \text{ J}\end{aligned}$$

(b)

$$\begin{aligned}P &= W \cdot f \\&\approx 0.68 \text{ J} \cdot 10 \frac{1}{\text{s}} \\&\approx 6.80 \text{ W}\end{aligned}$$

3. Erster Hauptsatz

(a)

$$\begin{aligned}\Delta U_{ACB} &= \Delta Q_{ACB} - \Delta W_{ACB} \\&= 220 \text{ J} - 60 \text{ J} \\&= 160 \text{ J}\end{aligned}$$

(b)

$$\begin{aligned}\Delta Q_{ADB} &= \Delta U_{ADB} + \Delta W_{ADB} \\&= \Delta U_{ACB} + \Delta W_{ADB} \\&= 160 \text{ J} + 20 \text{ J} \\&= 180 \text{ J}\end{aligned}$$

(c)

$$\begin{aligned}\Delta U_{BA} &= \Delta Q_{BA} + \Delta W_{BA} \\-\Delta U_{ACB} &= \Delta Q_{BA} + \Delta W_{BA} \\\Delta Q_{BA} &= -\Delta U_{ACB} - \Delta W_{BA} \\&= -160 \text{ J} - 40 \text{ J} \\&= -200 \text{ J}\end{aligned}$$

(d)

$$\begin{aligned}\Delta U_{AD} &= \Delta Q - \Delta W \\&= \frac{3}{2} N k_B \Delta T - p \Delta V \\&= \frac{3}{2} N k_B \cdot \frac{p \Delta V}{N k_B} - p \Delta V \\&= \frac{3}{2} p \Delta V - p \Delta V \\&= \Delta Q - \frac{2}{3} \Delta Q \\ \Delta Q &= 3 \Delta U_{AD} \\&= 3 \cdot 40 \text{ J} \\&= 120 \text{ J}\end{aligned}$$

$$\begin{aligned}\Delta Q_{AB} &= -\Delta Q_{BA} \\&= 200 \text{ J}\end{aligned}$$

4. Ideales Gas

(a)

$$\begin{aligned}\Delta U &= \frac{3}{2} n n_A k_B \Delta T \\&\approx \frac{3}{2} \frac{1}{2} \text{ mol} \cdot 6.022 \cdot 10^{23} \frac{1}{\text{mol}} \cdot 1.381 \cdot 10^{-23} \frac{\text{J}}{\text{K}} \cdot 375 \text{ K} \\&\approx 2340 \text{ J} \\ \Delta Q &= 0 \\ \Delta W &= \Delta U\end{aligned}$$

(b)

$$\begin{aligned}\Delta U &= \frac{3}{2} n n_A k_B \Delta T \\&\approx 2340 \text{ J} \\ \Delta Q &= 2500 \text{ J} \\ \Delta W &= \Delta U - \Delta Q \\&\approx 2340 \text{ J} - 2500 \text{ J} \\&= -160 \text{ J}\end{aligned}$$

(c)

$$\begin{aligned}\Delta U &= \frac{3}{2}nn_Ak_B\Delta T \\ &\approx 2340 \text{ J} \\ \Delta W &= -p\Delta V \\ &= -nn_Ak_B\Delta T \\ &\approx -1560 \text{ J} \\ \Delta Q &= \Delta U - \Delta W \\ &= \frac{5}{2}nn_Ak_B\Delta T \\ &\approx 3900 \text{ J}\end{aligned}$$

(d)

$$\begin{aligned}\Delta U &= \Delta Q \\ \Delta Q &= \frac{3}{2}nn_Ak_B\Delta T \\ &\approx 2340 \text{ J} \\ \Delta W &= 0\end{aligned}$$

5. Stirling-Prozess

(a)

$$\begin{aligned}0 &= \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CD} + \Delta U_{DA} \\ &= \frac{3}{2}Nk_B (\Delta T_{AB} + \Delta T_{BC} + \Delta T_{CD} + \Delta T_{DA}) \\ &= \frac{3}{2}Nk_B (0 + \Delta T_{BC} + 0 + \Delta T_{DA}) \\ &= \Delta U_{BC} + \Delta U_{DA} \\ |\Delta U_{BC}| &= |\Delta U_{DA}|\end{aligned}$$

(b)

$$\begin{aligned}\Delta W_1 &= -p_1 \Delta V \\ &= -\frac{k_B N T_1}{V} \Delta V\end{aligned}$$

$$\begin{aligned}W_1 &= k_B N T_1 (\ln V_1 - \ln V_2) \\ &= k_B N T_1 \ln \frac{V_1}{V_2}\end{aligned}$$

$$\begin{aligned}\Delta Q_2 &= -\frac{3}{2} N k_B \Delta T \\ &= -\frac{3}{2} V_2 \Delta p_1\end{aligned}$$

$$W_2 = k_B N T_2 \frac{V_2}{V_1}$$

$$\Delta Q_4 = -\Delta Q_2$$

$$\begin{aligned}\eta_1 &= -\frac{W}{\Delta Q} \\ &= \frac{W_1 + W_2}{W_1 + Q_2} \\ &= \frac{k_B N T_1 \ln \frac{V_1}{V_2} - k_B N T_2 \frac{V_1}{V_2}}{k_B N T_1 \ln \frac{V_1}{V_2} - \frac{3}{2} N k_B (T_1 - T_2)} \\ &= \frac{T_1 - T_2}{T_1 + \frac{3}{2} \frac{T_1 - T_2}{\ln \frac{V_2}{V_1}}}\end{aligned}$$

$$\begin{aligned}\eta_2 &= -\frac{W}{\Delta Q} \\ &= \frac{W_1 + W_2}{W_1} \\ &= \frac{k_B N T_1 \ln \frac{V_1}{V_2} - k_B N T_2 \frac{V_1}{V_2}}{k_B N T_1 \ln \frac{V_1}{V_2}} \\ &= 1 - \frac{T_2}{T_1}\end{aligned}$$

$$\eta_1 < \eta_2$$

