Department of Physics
Summer 2024
Nonequilibrium Thermodynamics
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https://www2.physik.uni-muenchen.de/lehre/vorlesungen/sose_24/thermodynamik/index.html

# Sheet 04

Discussion: Thursday 06.06.2024

**Exercise 1** Helmholtz equations

Write down the Gibbs-Helmholtz equations that relate $E \leftrightarrow H$, $F \leftrightarrow G$ and $G \leftrightarrow H$, i.e. relate $H(S, P, N)$ to some derivative of $E(S, V, N)$ and vice versa.

**Exercise 2** Clausius inequality

In Chapter 27.6.6 we recover the Clausius inequality in the form

$$\frac{\mathrm{d}S_V}{\mathrm{d}t} \geq -\int \mathbf{n} \cdot \frac{\mathbf{j}_q}{T}. \tag{1}$$

Here, we will derive a less refined version of the Clausius inequality and relate it to Eq. 1.

1. What is $\mathbf{j}_q$?
2. Consider the a thermodynamic system exchanging heat with an external thermal reservoir $\mathcal{E}$. Use the Gibbs fundamental form and the first law of thermodynamics to derive the Clausius inequality

$$\Delta S \geq \int \frac{\omega}{T_{\mathcal{E}}}. \tag{2}$$

   What is $\omega$?
3. Do we need reversibility in order to derive the Clausius inequality?
4. How are Eqs. (1) and (2) related?

**Exercise 3** Entropy

Following Section 27.4, argue that entropy is frame invariant (no explicit calculation needed).
Hint: Think of ways how to change between different frames.