

6.2: Irreversible Cycles

Up to this point, we have discussed *reversible* cycles only. Notice that the heat that enters the definition of entropy ([Definition: Entropy](#)) is the heat exchanged at reversible conditions since it is only at those conditions that the right-hand side of [Equation 6.1.5](#) becomes a state function. What happens when we face an irreversible cycle? The efficiency of a Carnot cycle in [Equation 5.3.3](#) is the maximum efficiency that an idealized thermodynamic cycle can reach. As such, any irreversible cycle will incontrovertibly have an efficiency smaller than the maximum efficiency of the idealized Carnot cycle. Therefore, [Equation 6.1.1](#) for an *irreversible* cycle will not hold anymore and must be rewritten as:

$$\overbrace{1 + \frac{Q_3}{Q_1}}^{\varepsilon_{\text{IRR}}} < \overbrace{1 - \frac{T_l}{T_h}}^{\varepsilon_{\text{REV}}}, \quad (6.2.1)$$

and, following the same procedure used in [section 6.1](#), we can rewrite [Equation 6.2.1](#) as:

$$\frac{Q_3^{\text{IRR}}}{Q_1^{\text{IRR}}} < -\frac{T_l}{T_h} \rightarrow \frac{Q_3^{\text{IRR}}}{T_l} + \frac{Q_1^{\text{IRR}}}{T_h} < 0 \rightarrow \sum_i \frac{Q_i^{\text{IRR}}}{T_i} < 0,$$

which can be generalized using calculus to:

$$\oint \frac{dQ_{\text{IRR}}}{T} < 0. \quad (6.2.2)$$

Putting [eqs. 6.1.6](#) and [6.2.2](#) together, we obtain:

$$\oint \frac{dQ}{T} \leq 0, \quad (6.2.3)$$

where the equal sign holds for reversible transformations exclusively, while the inequality sign holds for irreversible ones. [Equation 6.2.3](#) is known as **Clausius inequality**.

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