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# Basic Thermodynamics

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## Handout 3

### Carnot's theorem

*No engine operating between two given temperatures can be more efficient than a Carnot engine.*

A proof of Carnot's theorem was given in lectures.

### Refrigerators and heat pumps

The efficiency of refrigerators and heat pumps is measured by the **coefficient of performance** (CoP).

A **refrigerator** has CoP

$$\text{CoP} = \frac{Q_2}{W}.$$

A refrigerator built from a Carnot engine operating in reverse has CoP

$$\text{CoP}_{\text{Carnot}} = \frac{T_2}{T_1 - T_2}.$$

A **heat pump** has CoP

$$\text{CoP} = \frac{Q_1}{W}.$$

A heat pump built from a Carnot engine operating in reverse has CoP

$$\text{CoP}_{\text{Carnot}} = \frac{T_1}{T_1 - T_2} > 1.$$

### Clausius' theorem

For any closed cycle,

$$\oint \frac{dQ}{T} \leq 0,$$

where equality necessarily holds for a reversible cycle.

A proof of Clausius' theorem was given in lectures.