**Thermodynamics**
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**Lecture 61**
**Second Law of Thermodynamics: Kelvin-Planck and Clausius Statements**

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We looked at the concept of heat engines in the last lecture. We will look at the Kelvin-Planck and Clausius statements of the second law of thermodynamics in the context of heat engines.
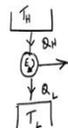
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Figure 1.

Figure 1 shows a direct heat engine operating between a high temperature reservoir at $T_H$ and a low temperature reservoir at $T_L$ in a cycle. It takes in $Q_H$ amount of heat from the reservoir at $T_H$ and rejects $Q_L$ amount of heat to the reservoir at $T_L$, while producing net work W.

Kelvin-Planck statement says it is impossible for a device operating in a thermodynamic cycle to produce work while having heat interaction with a single reservoir at any temperature.

When we looked at a direct heat engine running in a cycle, we saw that the engine interacts with two heat reservoirs, a low temperature reservoir and a high temperature reservoir. It takes in heat from a high temperature reservoir and rejects some heat to a low temperature reservoir while producing some work. According to the Kelvin-Planck statement, it is impossible for such an engine to produce work while interacting with a single reservoir at any temperature.

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The engine violating the Kelvin-Planck statement is called PMM2, perpetual motion machine of second kind. The efficiency of a heat engine $\eta = \frac{W_{net}}{Q_H} = 1 - \frac{Q_L}{Q_H}$. As $Q_L$ is 0 for PMM2, $\eta = 1$. It means $W_{net} = Q_H$. According to the Kelvin-Planck statement, $Q_L$ cannot be 0. Hence, the efficiency of a heat engine (running in a cycle) will always be less than one and $W_{net} \neq Q_H$.

The first law says you cannot get energy from nothing, but you can convert energy from one form to another. The second law says that you can convert heat into work (one form of energy

into another) using a cyclic process, but the complete conversion is not possible. So, that is a consequence of the second law.
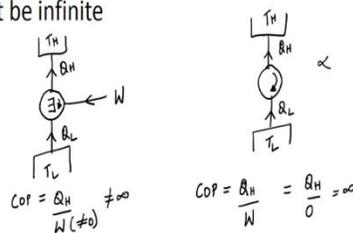
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Figure 2.

Another statement of the second law is the Clausius statement which is given in the context of a heat pump or a refrigerator. A heat pump or a refrigerator transfers heat from a low temperature reservoir to a high temperature reservoir by taking in some work.

The Clausius statement says it is impossible for any device operating in a thermodynamic cycle to transfer heat from a low temperature region to a high temperature region without the help of work interaction from the surroundings.

A heat pump or a refrigerator operating in a cycle cannot transfer heat from a low temperature reservoir to a high temperature reservoir without any work interaction with the surroundings. Figure 2 shows a reverse heat engine operating in a cycle. COP for a heat pump is $COP_{HP} = \frac{Q_H}{W}$ and COP for a refrigerator is $COP_R = \frac{Q_L}{W}$. According to the Clausius statement, W cannot be 0. Hence, the COP for a heat pump or a refrigerator cannot be infinite.

**TABLE 2.1: Star Rating Band valid from 01 May 2011 to 31 December 2011.**

| Star Rating | EER (W/W) Min | Max |
|---|---|---|
| 1 Star * | 2.30 | 2.49 |
| 2 Star ** | 2.50 | 2.69 |
| 3 Star *** | 2.70 | 2.89 |
| 4 Star **** | 2.90 | 3.09 |
| 5 Star ***** | 3.10 | |

**TABLE 2.2: Star Rating Band valid from 01 January 2012 to 31 December 2013.**

| Star Rating | EER (W/W) Min | Max |
|---|---|---|
| 1 Star * | 2.50 | 2.69 |
| 2 Star ** | 2.70 | 2.89 |
| 3 Star *** | 2.90 | 3.09 |
| 4 Star **** | 3.10 | 3.29 |
| 5 Star ***** | 3.30 | |

**TABLE 2.3: Star Rating Band valid from 01 January 2014 to 31 December 2015.**

| Star Rating | EER (W/W) Min | Max |
|---|---|---|
| 1 Star * | 2.70 | 2.89 |
| 2 Star ** | 2.90 | 3.09 |
| 3 Star *** | 3.10 | 3.29 |
| 4 Star **** | 3.30 | 3.49 |
| 5 Star ***** | 3.50 | |

**TABLE 2.4: Star Rating Band valid from 01 January 2016 to 31 December 2017.**

| Star Rating | EER (W/W) Min | Max |
|---|---|---|
| 1 Star * | 2.70 | 2.89 |
| 2 Star ** | 2.90 | 3.09 |
| 3 Star *** | 3.10 | 3.29 |
| 4 Star **** | 3.30 | 3.49 |
| 5 Star ***** | 3.50 | |

Figure 3.

We usually see a sticker with stars on an air conditioner or a refrigerator. These stars are linked to the COP of the air conditioner or a refrigerator in some average sense. Figure 3 shows tables where the COP values/EER values (EER is linked to COP) corresponding to different star ratings are mentioned at different times. It seems that for the same star rating, the EER value is improving with time. In 2011, for a rating of 1 star, EER value lies between 2.3 and 2.5, whereas for the same rating in 2012 and 2013, EER value is higher. It means that we are improving the quality of refrigerators.