Reversible Processes & Entropy

Class 18: (ThT Q) Are any real processes reversible?
1. What is a **reversible** process?
   a. 2 processes are **reversible in principle**. Adiabatic and Isotherm.
   b. **Carnot Cycle**: Engine & refrigeration.

2. Entropy computation for 2 kinds of processes: $\Delta T$ and latent heat.

3. Entropy in heat engine. $\Delta S_{\text{gas}} = 0$ (cycle).
   $\Delta S = Q/T$, (isothermal), $\Delta S = 0$ (adiabatic).

4. 2nd Law of Thermodynamics: effict. & Temp.
Refrigerator

\[ Q_h = W + Q_c \]
\[ \rightarrow W = Q_h - Q_c \]

W, Q_h, Q_c all defined to be magnitudes (positive) in context of heat engines and refrigerators

2\textsuperscript{nd} Law of Thermodynamics

W \neq 0
Heat Pump

Heat home in Winter
Heat Pump

Cool Home in Summer
Coefficient of Performance

Refrigerator: $\text{cop} = \frac{Q_c}{W}$

Heat Pump: $\text{cop} = \frac{Q_h}{W}$
Serway, Physics for Scientists and Engineers, 5/e
Figure 22.5

Hot reservoir at $T_h$

$Q_h$

Engine

$Q_c$

Cold reservoir at $T_c$

Refrigerator

W
Ex.-1
Heat pump: \( \text{cop} = 5 \)
Output 125 W of heat into home (winter operation)
\[ \text{cop} = \frac{Q_h}{W} \quad \Rightarrow \quad W = \frac{Q_h}{\text{cop}} \]
\[ \frac{dW}{dt} = \left(\frac{1}{\text{cop}}\right)\left(\frac{dQ_h}{dt}\right) \]
= 25 W

2nd & 3rd rows rest of S & T thru Ti
Example-2: Heat pump: \( \text{cop} = 4 \)

Output 100 W of heat out of home (Summer operation)

\[ \text{cop} = \frac{Q_c}{W} \quad \Rightarrow \quad W = \frac{Q_c}{\text{cop}} \]

\[ \frac{dW}{dt} = \left( \frac{1}{\text{cop}} \right) \left( \frac{dQ_c}{dt} \right) = 25 \text{ W} \]

Note that the heat rejected is 125 W. 100 W from the house and 25 from the work to pump it. This is the same H pump. The difference is in how COP is defined.
But who sets COP? Max.?

Find minimum $W$ required to remove $Q_c$ from refrigerator.

\[
W = Q_h - Q_c \\
= Q_c\left(\frac{Q_h}{Q_c} - 1\right) \\
= Q_c\left(\frac{T_h}{T_c} - 1\right) \text{ Today’s work.}
\]
### Physics 123 Course Schedule, Spring Semester, 2011

<table>
<thead>
<tr>
<th>Date</th>
<th>Read/topic</th>
<th>5th Ed</th>
<th>7th/(6th Ed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Wed. May 4</td>
<td>17.5</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td>8 Wed. May 4</td>
<td>18.1–4</td>
<td>18.1–4</td>
<td></td>
</tr>
<tr>
<td>9 Fri. May 6</td>
<td>18.5,7</td>
<td>18.5,7</td>
<td></td>
</tr>
<tr>
<td>10 Fri. May 6</td>
<td>none</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Mon. May 9</td>
<td>Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Mon, May 9</td>
<td>19.1–5</td>
<td>19.1–5</td>
<td></td>
</tr>
<tr>
<td>13 Wed. May 1</td>
<td>20.1–5</td>
<td>20.1–5</td>
<td></td>
</tr>
<tr>
<td>14 Wed. May 1</td>
<td>20.6–7;</td>
<td>20.6–7;</td>
<td></td>
</tr>
<tr>
<td>15 Fri. May 13</td>
<td>21.1–3</td>
<td>21.1–3</td>
<td></td>
</tr>
<tr>
<td>16 Fri. May 13</td>
<td>21.4–6</td>
<td>21.4–6 (6th 4-6)</td>
<td></td>
</tr>
<tr>
<td>17 Mon. May 16</td>
<td>22.1</td>
<td>22.1</td>
<td></td>
</tr>
<tr>
<td>18 Mon. May 16</td>
<td>22.2–3,5–7</td>
<td>22.2–4,6–7</td>
<td></td>
</tr>
<tr>
<td>19 Wed, May 18</td>
<td>22.8</td>
<td>22.8</td>
<td></td>
</tr>
<tr>
<td>20 Wed. May 18</td>
<td>Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 Fri. May 20</td>
<td>35.1–8</td>
<td>35.1–8</td>
<td></td>
</tr>
<tr>
<td>22 Fri. May 20</td>
<td>36.1–2</td>
<td>36.1–2</td>
<td></td>
</tr>
<tr>
<td>23 Mon. May 23</td>
<td>36.4</td>
<td>36.4</td>
<td></td>
</tr>
<tr>
<td>24 Mon. May 23</td>
<td>36.6–7</td>
<td>36.6–7</td>
<td></td>
</tr>
</tbody>
</table>

Today:
1. review: COP of refrigerators.
2. **Today.** Carnot cycle & Entropy

Remember: the **online** schedule has precedence.
Quiz 18-2: In an irreversible process, the change in entropy of the system plus its surroundings is
A. Always positive,
B. Always negative,
C. Always zero, or
D. Sometimes positive and sometimes negative, depending on the details of the process.
What is difference between a reversible and an irreversible process? Examples?

- Sliding object?
- Ice melts in warm water?
- Ice melts in ice cold water?
- PV processes?
  Some are reversible in principle-
- Isothermal and Adiabatic?
Carnot cycle: reversible steps

MU: 46
Beauty of Carnot cycle?
In isothermal process  Heat flow is reversible
In adiabatic process  Temperature changes are without heat flow
Entropy $\Delta S = \int \frac{dQ}{T}$

Means put in little increments of heat
Each time divide by the temperature
Sum them all up.
Entropy \[ \Delta S = \int \frac{dQ}{T} \]

**Rule:**
- \( S \) **increases** if we put heat into system
- \( S \) **decreases** if we take heat out of system
- \( S \) remains the **same** if there is no heat flow

**Example: Heat some water**
\[
dQ = mc dT \\
\Delta S = \int mc dT / T = mc \ln(T_f / T_i)
\]

**Example: Freeze some ice**
\[
\Delta S = 1/T \int dQ = Q/T = mL/T
\]
Example: Heat some gas at constant $V$
\[dQ = nC_v dT\]
\[\Delta S = \int nC_v dT/T = nC_v \ln(T_f/T_i)\]

Example: Isothermal expansion of gas
\[\Delta T = 0 \Rightarrow \Delta E_{\text{int}} = 0 = Q - W\]
\[Q = W = nRT \ln(V_f/V_i)\]
\[\Delta S = Q/T = nR \ln(V_f/V_i)\]
Quiz 18-3:

If a gas expands at constant temperature, its entropy

A. increases,
B. decreases, or
C. remains the same.
Quiz 18-4 (pp) If a gas expands adiabatically (against a moving piston), its entropy:
A. Increases,  
B. Decreases, or  
C. Remains the same.
Example: Heat some gas at constant $V$
\[ dQ = nC_v dT \]
\[ \Delta S = \int nC_v dT/T = nC_v \ln(T_f/T_i) \]

Example: Isothermal expansion of gas
\[ \Delta T = 0 \quad \Rightarrow \quad \Delta E_{\text{int}} = 0 = Q - W \]
\[ Q = W = nRT \ln(V_f/V_i) \]
\[ \Delta S = Q/T = nR \ln(V_f/V_i) \]

Example: Adiabatic expansion of gas
\[ Q = 0 \quad \Rightarrow \quad \Delta S = 0 \]
2\textsuperscript{nd} Law of Thermodynamics

$\Delta S \geq 0$ \hspace{1cm} \textit{For universe as a whole}

Reversible: $\Delta S = 0$

Irreversible: $\Delta S > 0$
Heat Engines

One Cycle

\[ \Delta S = \Delta S_{\text{gas}} + \Delta S_{\text{h}} + \Delta S_{\text{c}} \]

\[ \Delta S = 0 - \frac{Q_{\text{h}}}{T} + \frac{Q_{\text{c}}}{T} \geq 0 \]

\[ 1 - \frac{Q_{\text{c}}}{Q_{\text{h}}} \leq 1 - \frac{T_{\text{c}}}{T_{\text{h}}} \text{ (after some algebra)} \]

Reversible: \( e_R = 1 - \frac{T_{\text{c}}}{T_{\text{h}}} \)

Irreversible: \( e < e_R \)

For reversible cycles:

\[ \frac{Q_{\text{c}}}{Q_{\text{h}}} = \frac{T_{\text{c}}}{T_{\text{h}}} ; \text{ (looked for )} \]
Quiz 18-5: During one cycle of a heat engine, the entropy of the hot reservoir
A. increases,
B. Decrease,
C. Remains the same.
Quiz 18-6 (pp) After one cycle of a heat engine, the entropy of the engine

A. increases,  
B. decreases, or  
C. remains the same
HW 16

- Next time:
  - Microscopy
  - Entropy
- Review for exam
Example: Heat some gas at constant $V$

$$dQ = nC_v dT$$

$$\Delta S = \int nC_v dT/T = nC_v \ln(T_f/T_i)$$

Example: Isothermal expansion of gas

$$\Delta T = O \quad \Rightarrow \quad \Delta E_{int} = O = Q - W$$

$$Q = W = nRT \ln(V_f/V_i)$$

$$\Delta S = Q/T = nR \ln(V_f/V_i)$$

Example: Adiabatic expansion of gas

$$Q = O \quad \Rightarrow \quad \Delta S = O$$