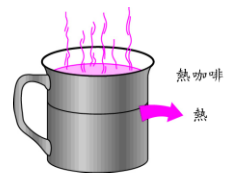
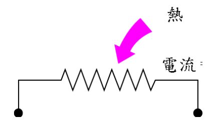
Chapter 6
The Second Law of Thermodynamics
熱力學第二定律

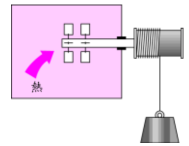
6.1 Introduction to the Second Law



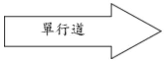
在冷房間內，一杯熱咖啡不會變熱。



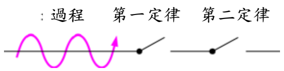
將熱傳至電阻絲不會產生電。



將熱傳至輪葉不會使它旋轉。

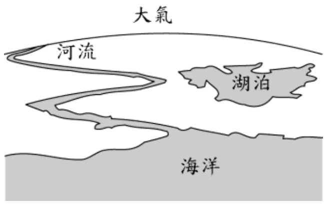


過程發生在特定方向且反向不可行。

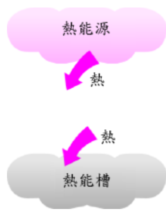


熱力學過程必須同時滿足熱力學 **第一** 及 **第二** 定律。

6.2 Thermal Energy Reservoirs

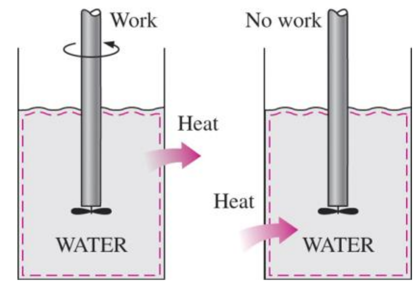


Thermal energy reservoirs - a hypothetical body with a relatively **large thermal energy capacity** that can **supply** or **absorb** **finite amount of heat** **without** undergoing any change in **temperature**.
具有相當大的熱質量物體可視為熱能儲存器。

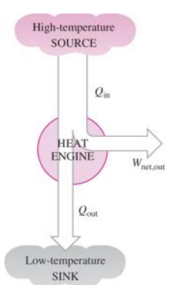


熱源 (heat source) 以熱的方式提供能量，
熱槽 (heat sink) 吸收熱量。

6.3 Heat Engines (熱機)



6-8 功經常可直接且完全轉換為熱，
但反向則不行。

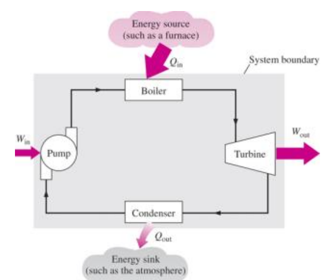


Heat engines

1. **Receive heat from a high-temperature source.**
2. **Convert part of this heat to work.**
3. **Reject the remaining waste heat to a low temperature sink.**
4. **Can operate on a cycle**.

6-9 部分的熱由熱機轉為功，其餘排放至低溫槽。

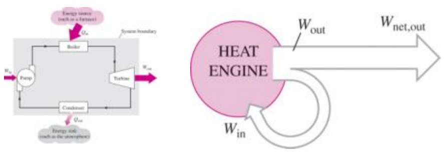
Heat engines



Main Components
1. 熱源 – 鍋爐 (boiler)
2. 渦輪機 (turbine)
3. 冷凝器 (condenser)
4. 壓縮機 (compressor) 或 幫浦 (pump)

6-10 蒸汽動力廠示意圖。

Heat engines



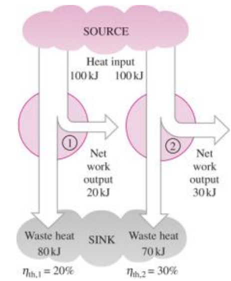
6-11 熱機消耗部分輸出的功以維持連續運轉。

$$Performance = \frac{Desired\ output}{Required\ input}$$

$$Thermal\ efficiency = \frac{Network\ output}{Total\ heat\ input}$$

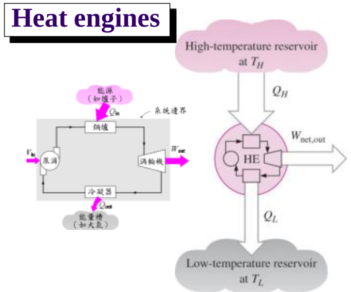
$$\eta = \frac{W_{net,out}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} = 1 - \frac{Q_L}{Q_H}$$

Heat engines

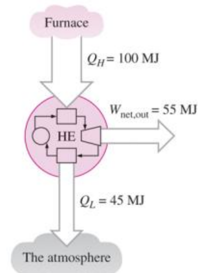


6-12 某些熱機表現比其他熱機好(將更多熱轉換為功)。

Heat engines

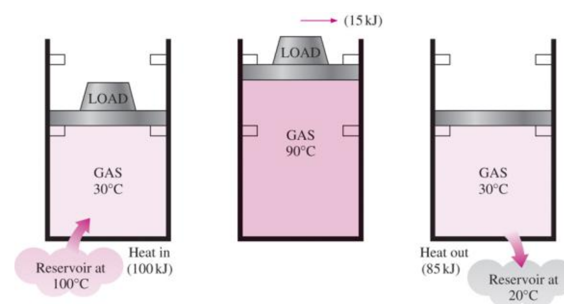


6-13 熱機示意圖。



6-14 即使是最有效率的熱機，幾乎將所接受的一半熱，以廢熱方式排放。

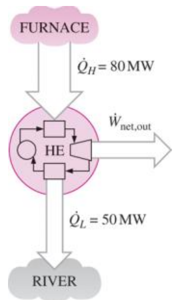
Heat engines



6-15 熱機為完成整個循環，必須排放部分熱至低溫槽。

Heat engines

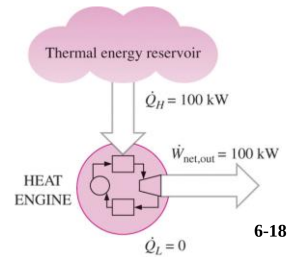
Example 6-1



Heat engines

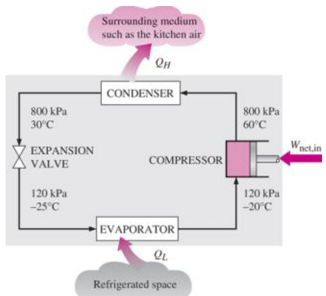
Kelvin-Plank Statement (a statement of the Second-Law)

- ***It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.***



6-18 違反 Kelvin-Planck 第二定律假說的熱機。

6.4 Refrigerators and Heat Pumps (冷凍機及熱泵)

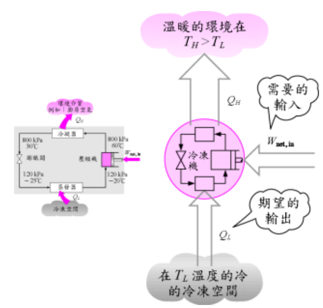


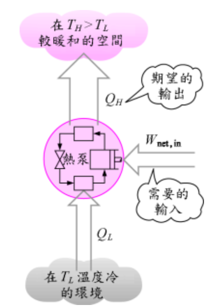
Main Components

1. 蒸發器 (evaporator)
2. 壓縮機 (compressor)
3. 冷凝器 (condenser)
4. 渦輪機 (turbine) 或膨脹閥 (expansion valve)

6-19 冷凍系統的基本元件及典型的操作條件。

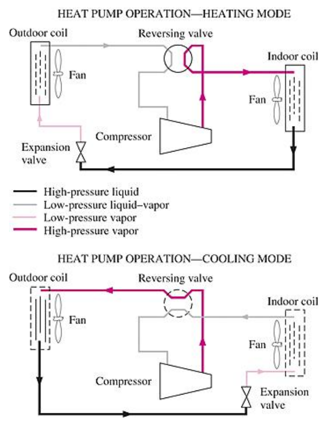
Refrigerators and heat pumps





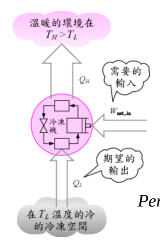
6-20 冷凍機的目的是將 Q_L 熱量從冷的空間移走。

6-21 熱泵的目的在提供 Q_H 的熱量進入較暖和的空間。

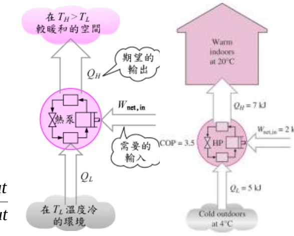


熱泵系統在冬天時可以加熱房子，而在夏天則可以用來冷卻。

Refrigerators and heat pumps



$$Performance = \frac{Desired\ output}{Required\ input}$$



COP: coefficient of performance

$$COP_R = \frac{Q_L}{W_{net,in}} \qquad COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{Q_L + W_{net,in}}{W_{net,in}} = 1 + COP_R$$

Refrigerators and heat pumps

Example 6-3

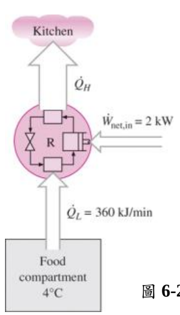


圖 **6-24**

Example 6-4

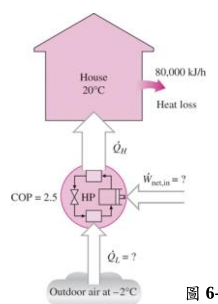
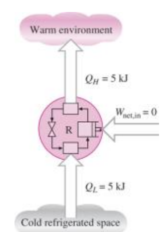


圖 **6-25**

反裝**空調**可作為**熱泵**。

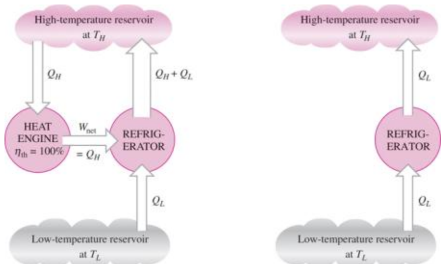
Refrigerators and heat pumps

Clausius Statement **(another statement of the Second-Law) -** ***It is impossible to construct a device that operates in a cycle and produces no effect other than the transfer of heat from a lower-temperature body to a higher-temperature body.***



6-26 違反熱力學第二定律的冷凍機。

Refrigerators and heat pumps

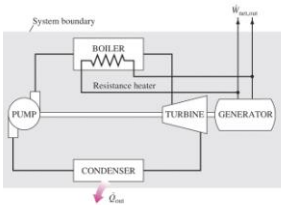


(a) A refrigerator that is powered by a 100 percent efficient heat engine

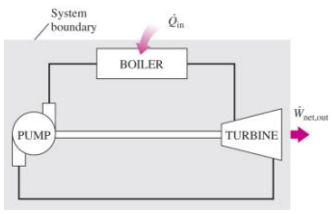
(b) The equivalent refrigerator

6-27 違反 Kelvin-Planck 假說則亦會導致違反 Clausius 假說。

6.5 Perpetual-Motion Machines, PMM (永動機器)

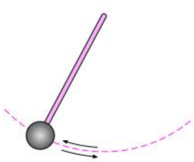


6-28 違反熱力學第一定律的永動機器 (PMM1)。

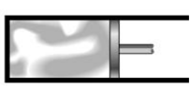


6-29 違反熱力學第二定律的永動機器 (PMM2)。

6.6 Reversible and Irreversible Processes (可逆及不可逆過程)



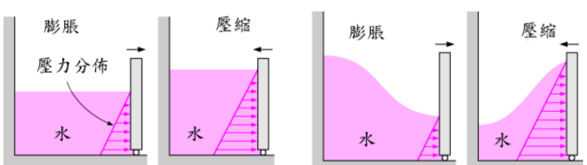
(a) 無摩擦擺錘



(b) 氣體之似平衡膨脹及壓縮

6-30 兩個近似可逆的過程。

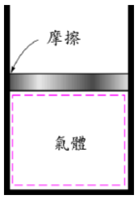
Reversible and irreversible processes



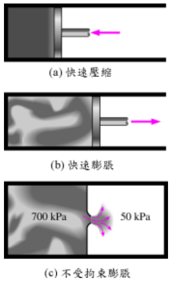
(a) 緩慢 (可逆) 過程　　(b) 快速 (不可逆) 過程

6-31 可逆過程 **傳送最多功 損耗最少功**。

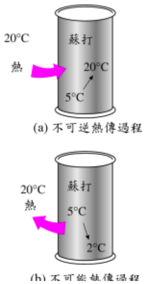
Reversible and irreversible processes



摩擦使過程不可逆。

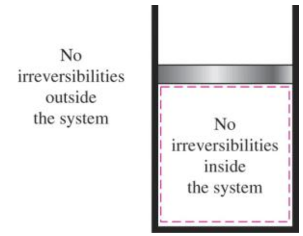


6-33 不可逆壓縮及膨脹過程。



(a) 經由溫度差的熱傳是不可逆；
(b) 反向過程是不可能。

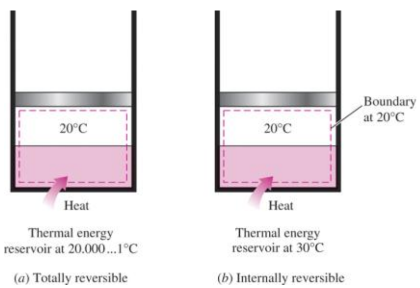
Internally and externally reversible



Explain

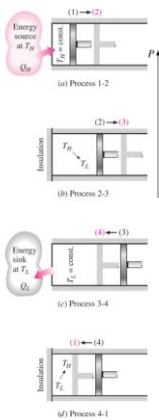
6-35 可逆過程包括 **內可逆 (internally reversible)** 及 **外可逆 (externally reversible)**。

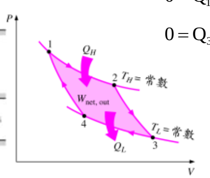
Internally and total reversible



6-36 全部 **(total reversible)** 及內部可逆熱傳過程。

6.7 The Carnot Cycle (卡諾循環)





6-38 卡諾循環之 ***P-v*** 圖。

6-37 封閉系統下進行卡諾循環。

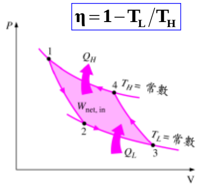
$$0 = Q_{1-2} - W_{1-2} \Rightarrow Q_{1-2} = \int_{V_1}^{V_2} p\,dV = RT_H \ln(V_2/V_1)$$

$$0 = Q_{3-4} - W_{3-4} \Rightarrow Q_{3-4} = \int_{V_3}^{V_4} p\,dV = RT_L \ln(V_4/V_3)$$

$$\eta = (Q_{1-2} + 0 + Q_{3-4} + 0)/Q_{1-2}$$
$$= 1 + (RT_L \ln(V_4/V_3))/(RT_H \ln(V_2/V_1))$$
$$= 1 - (T_L \ln(V_3/V_4))/(T_H \ln(V_2/V_1))$$

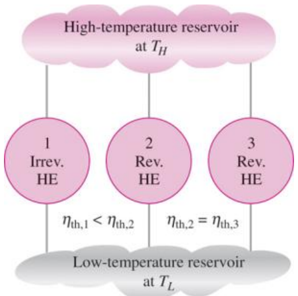
$$T_H V_2^{k-1} = T_L V_3^{k-1},\ T_L V_4^{k-1} = T_H V_1^{k-1}$$
$$\Rightarrow (V_2/V_3) = (V_1/V_4)$$

$$\boldsymbol{\eta = 1 - T_L/T_H}$$



6-39 逆向卡諾循環 *P-v* 圖。

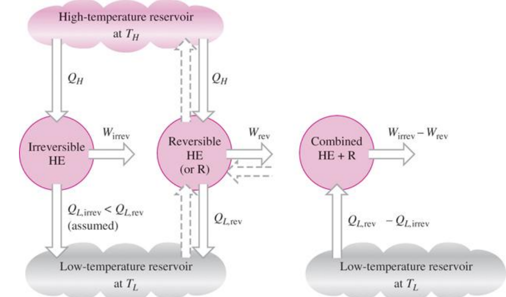
6.8 The Carnot Principles



6-40 卡諾原理。

1. $\eta_{irrev} < \eta_{rev}$, always;
2. η_{rev} are same between the same two reservoirs.

The Carnot principles

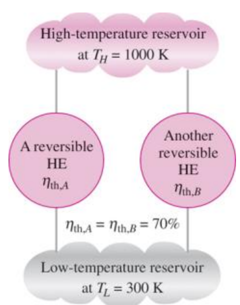


(*a*) A reversible and an irreversible heat engine operating between the same two reservoirs (the reversible heat engine is then reversed to run as a refrigerator)

(*b*) The equivalent combined system

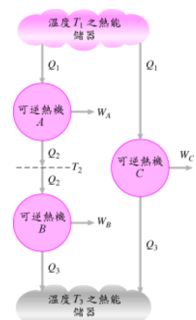
圖 **6-41** 證明卡諾第一原理。

The Carnot principles



6-42 在相同儲器間所有可逆熱機有相同的熱效率(第二卡諾原理)。

6.9 The Thermodynamic Temperature Scale



$$\eta_{th,rev} = \eta(T_H, T_L) = 1 - \frac{Q_L}{Q_H} \Rightarrow \frac{Q_H}{Q_L} = f(T_H, T_L)$$

$$\frac{Q_1}{Q_2} = f(T_1, T_2), \quad \frac{Q_2}{Q_3} = f(T_2, T_3), \quad \frac{Q_1}{Q_3} = f(T_1, T_3)$$

$$\frac{Q_1}{Q_3} = \frac{Q_1}{Q_2}\frac{Q_2}{Q_3} \qquad f(T_1, T_3) = f(T_1, T_2)\cdot f(T_2, T_3)$$

$$f(T_1, T_2) = \frac{\varphi(T_1)}{\varphi(T_2)}, \qquad f(T_2, T_3) = \frac{\varphi(T_2)}{\varphi(T_3)},$$

$$\frac{Q_1}{Q_3} = f(T_1, T_3) = \frac{\varphi(T_1)}{\varphi(T_3)}$$

$$\frac{Q_H}{Q_L} = \frac{\varphi(T_H)}{\varphi(T_L)} \qquad \varphi(T) = T \qquad \left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L}$$

Kelvin temperature scale – absolute temperature

The thermodynamic temperature scale

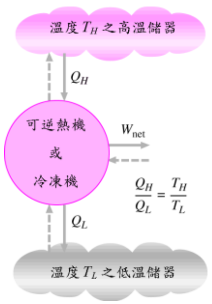
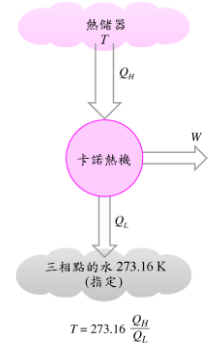


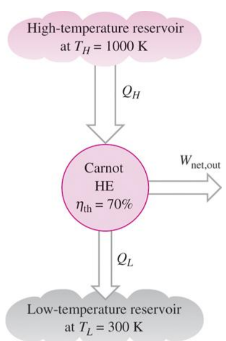
圖 **5-50** 對於可逆循環熱傳率 Q_H/Q_L 可由絕對溫度比 T_H/T_L 所取代。

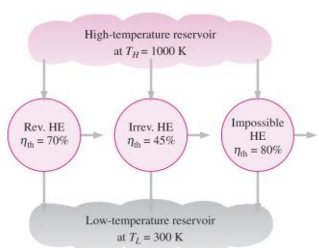
The thermodynamic temperature scale

圖 **5-51** 以測量 Q_H, Q_L 熱傳率的方法決定凱氏標度的實驗概念。



6.10 The Carnot Heat Engine





在相同的高低溫儲器下，卡諾熱機是所有熱機中最有效率者，沒有任何熱機的效率高於可逆熱機。

The Carnot heat engine

Example 6-5

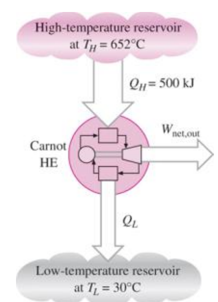
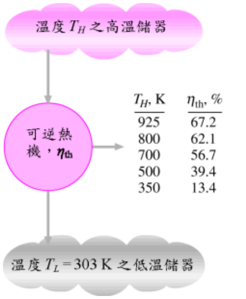
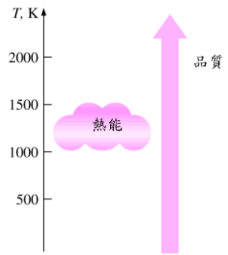


圖 **6-48**

The quality of energy

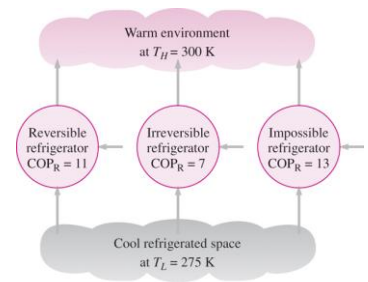


6-49 熱能轉換為功的比率是來源溫度的函數(T_L = 303 K)。



6-50 熱能溫度愈高，品質愈高。

6.11 The Carnot Refrigerator and Heat Pump



6-51 工作於相同溫度限制下沒有任何的冷凍機 COP 值高於可逆冷凍機。

The Carnot refrigerator and heat pump

Example 6-6

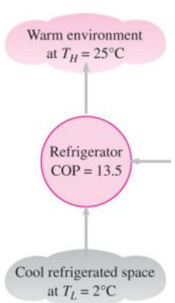


圖 **6-52**

Example 6-7

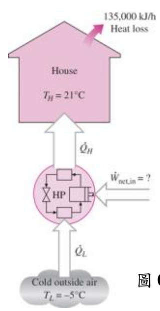


圖 **6-53**

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