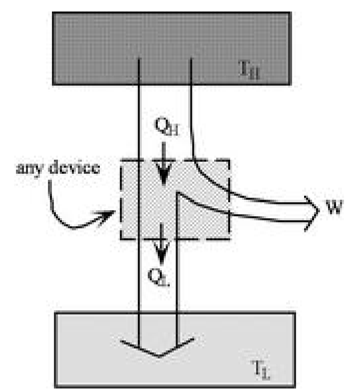
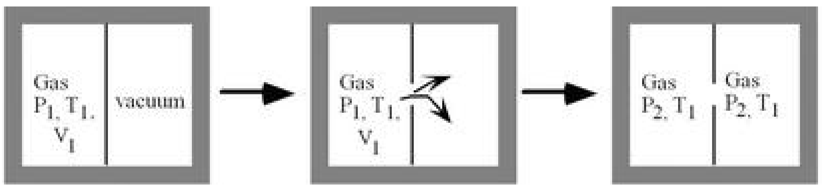
Máquinas térmicas, refrigeradores e 2ª lei da Termodinâmica

- **Processos irreversíveis.**
- **Máquinas térmicas.**
- **Ciclo de Carnot**
- **2ª lei da Termodinâmica: enunciado de Kelvin-Planck.**
- **Refrigeradores.**
- **2ª lei da Termodinâmica: enunciado de Clausius.**

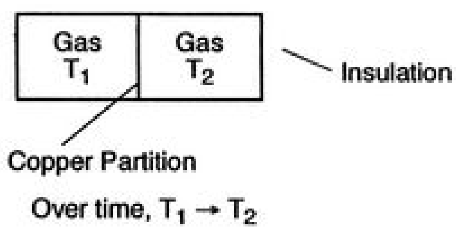


Processos irreversíveis

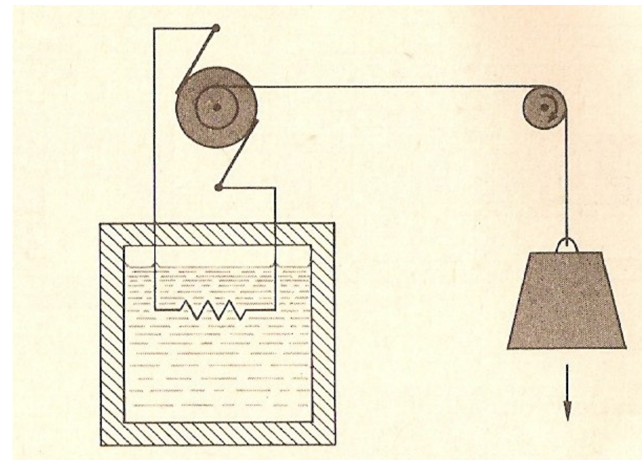
Expansão livre

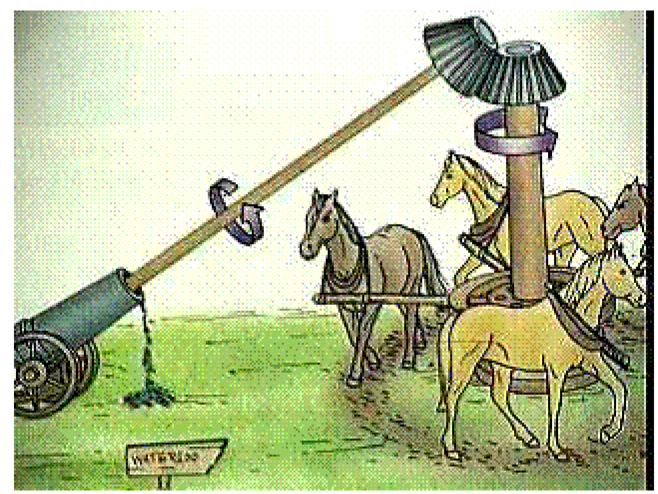


Trocas de calor ($T_1 \neq T_2$)

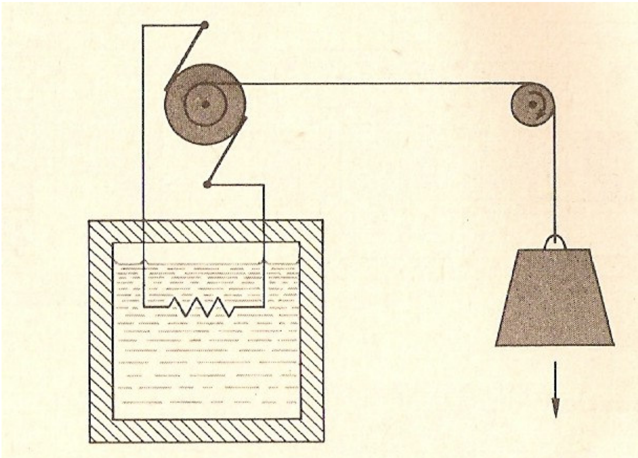


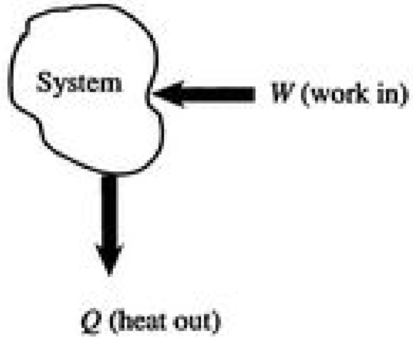
Conversão de trabalho em calor

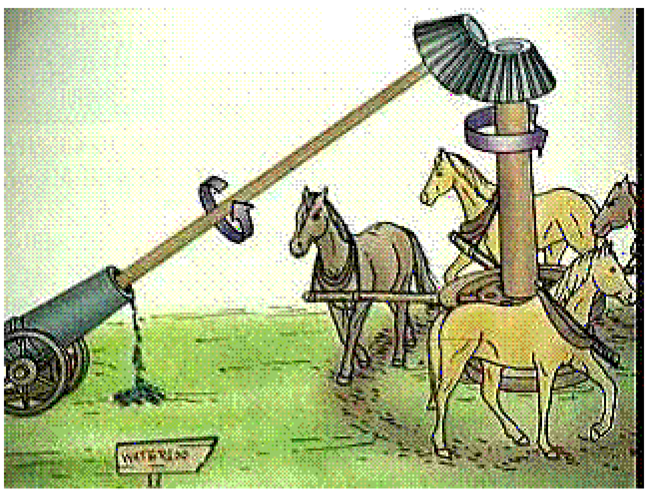




Conversão de trabalho em calor



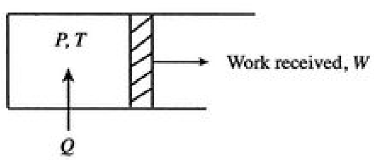


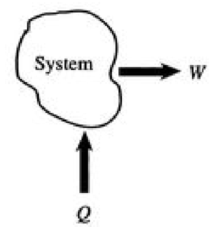


Se o sistema tem a sua energia interna inalterada:

$$Q = W$$

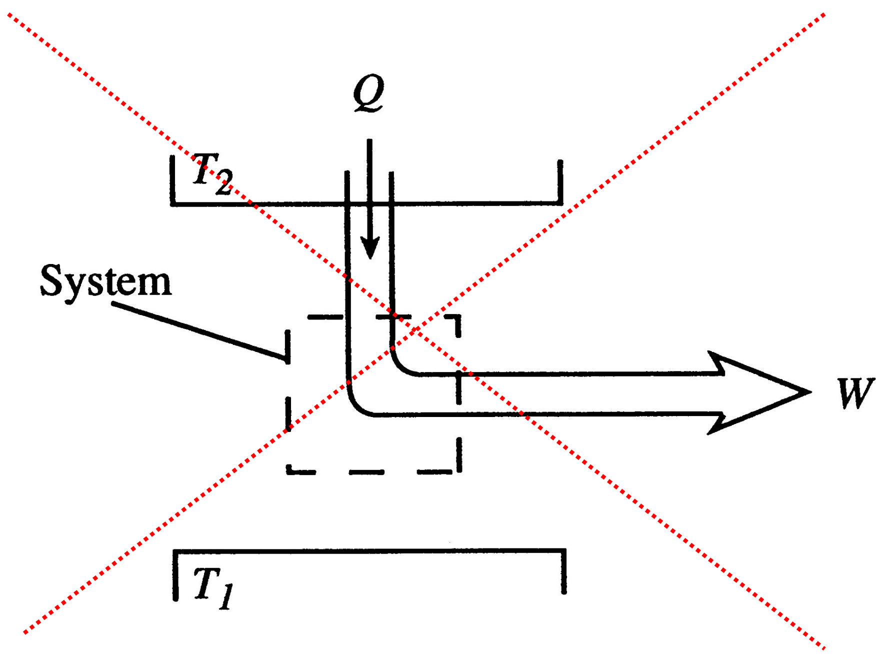
Conversão de calor em trabalho





Se o sistema tem o seu estado final igual ao inicial (ou seja, ao final de um ciclo):

$$W < Q$$

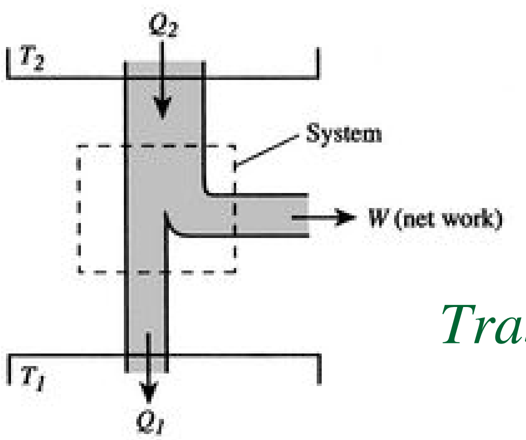


http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node30.html

Máquinas térmicas reais

Sistema operando em ciclo:

Fonte quente



Trabalho útil

Fonte fria

$$\Delta U = 0$$

$$W = Q_2 - Q_1$$

Eficiência térmica da máquina (ou rendimento térmico):

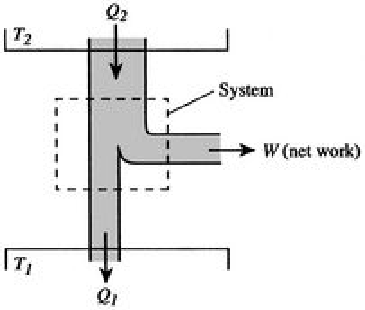
$$\eta = \frac{W}{Q_2} = 1 - \frac{Q_1}{Q_2}$$

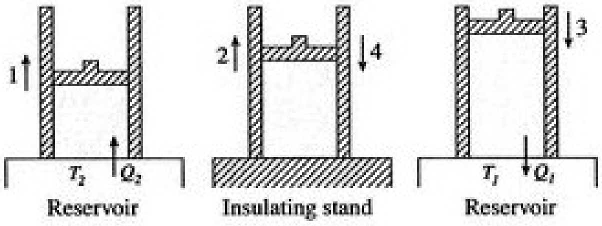
http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node30.html

Ciclo de Carnot

- Trabalho seminal: "Reflexões sobre a potência motriz do fogo" (1824).
- Qual (e como obter) o rendimento máximo de uma máquina térmica?
- Máxima eficiência: processos unicamente reversíveis.
- Eficiência máxima depende apenas das temperaturas das fontes quente e fria.

Nicolas Sadi Carnot (1796-1832)

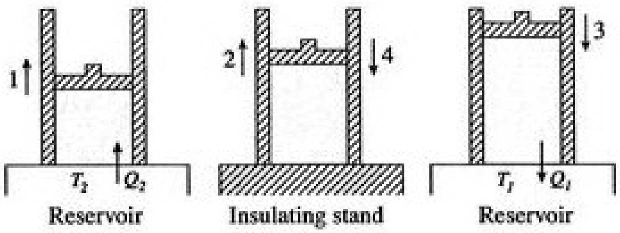


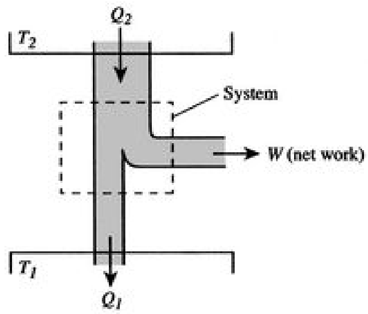


http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node24.html

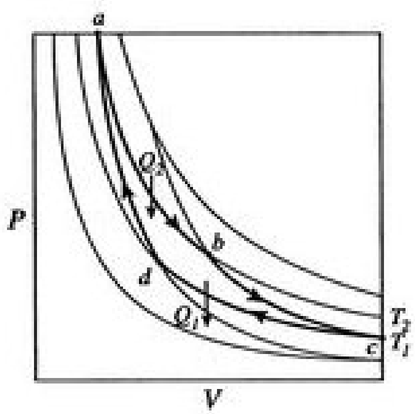
Ciclo de Carnot

Gás ideal:





$$\eta = \frac{W}{Q_2} = 1 - \frac{Q_1}{Q_2}$$



$$\frac{T_1}{T_2} = \frac{Q_1}{Q_2}$$

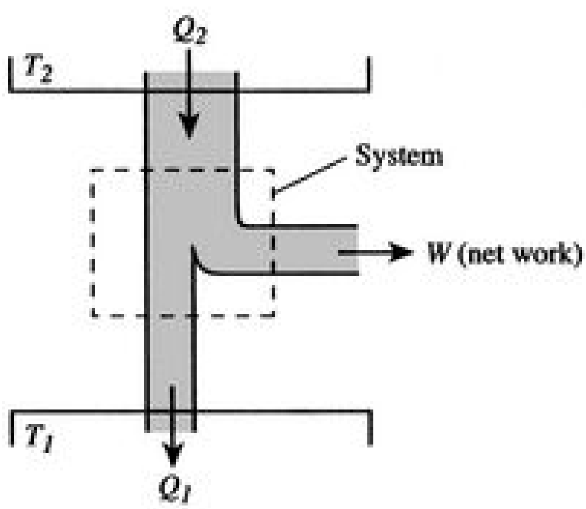
Rendimento da máquina de Carnot ideal:

$$\eta = 1 - \frac{T_1}{T_2}$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node24.html

2ª Lei da Termodinâmica – Enunciado de Kelvin-Planck

- Nenhum processo cujo único resultado seja a absorção de calor de um reservatório e a conversão integral desse calor em trabalho é possível.



Máquinas térmicas reais:

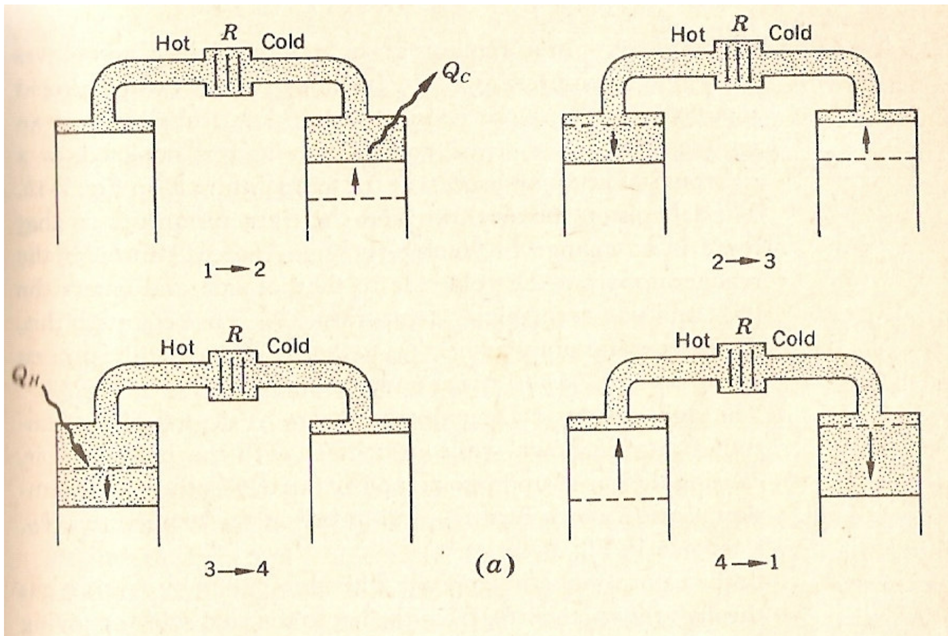
$$W < Q_2$$

$$\eta < 1$$

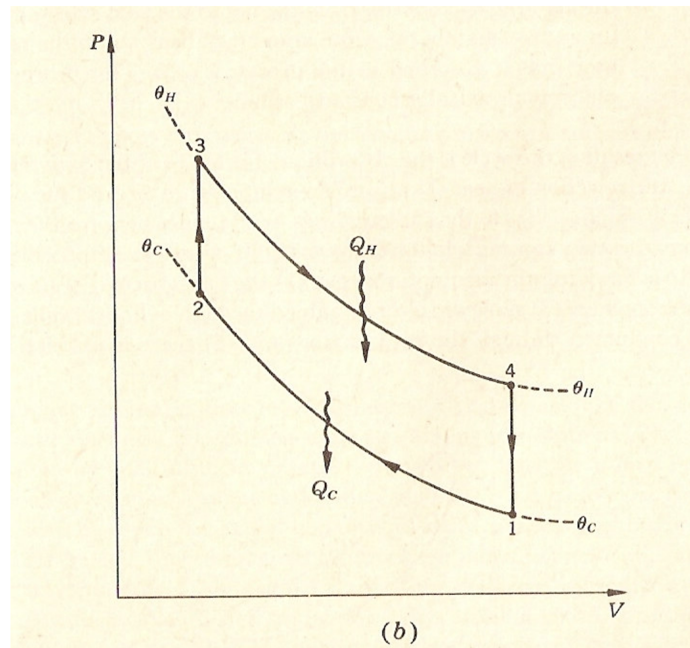
http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node30.html

Motores de combustão externa

- Motor de Stirling:



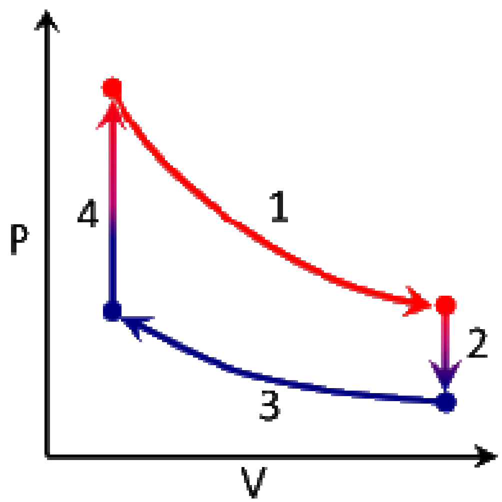
Robert Stirling (1790-1878)

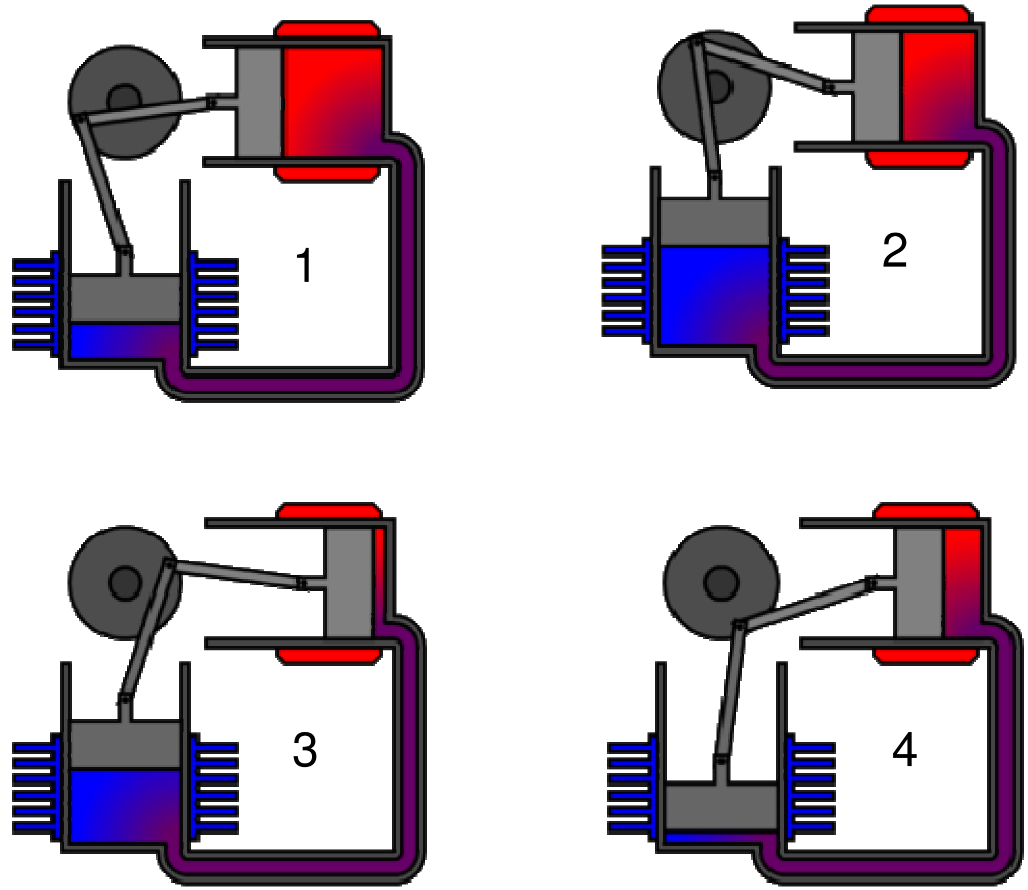


Heat and Thermodynamics, Zemansky

Motores de combustão externa

- Motor de Stirling:

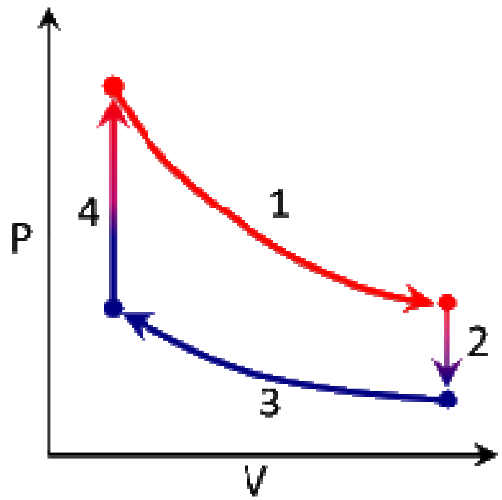


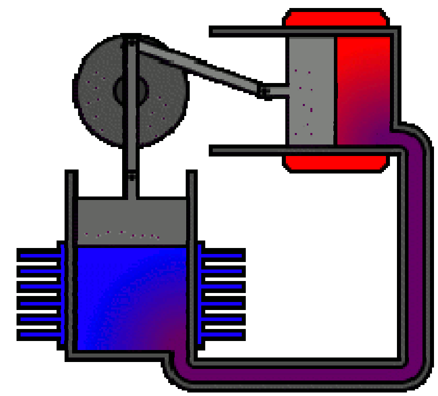


http://en.wikipedia.org/wiki/Stirling_engine

Motores de combustão externa

- Motor de Stirling:





Rendimento do motor de Stirling (ideal):

$$\eta = 1 - \frac{T_C}{T_H}$$

http://en.wikipedia.org/wiki/Stirling_engine

Motores de combustão externa

- Máquina a vapor:

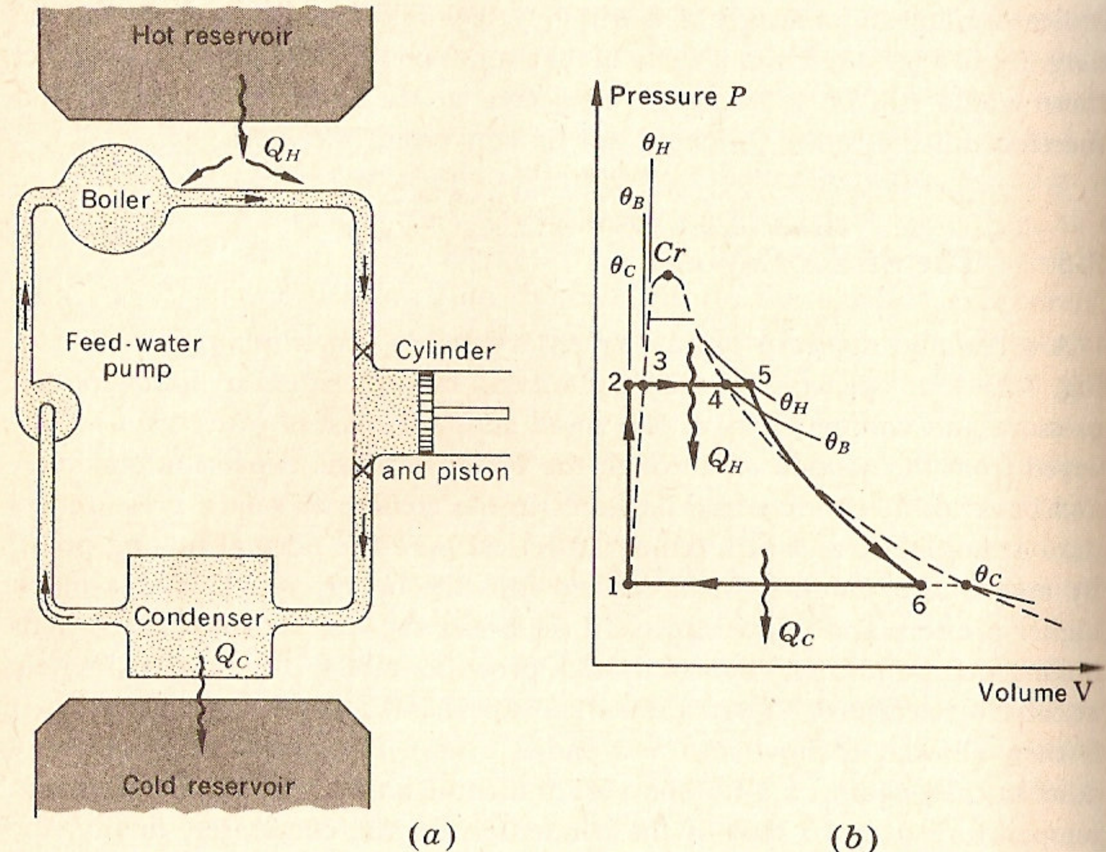
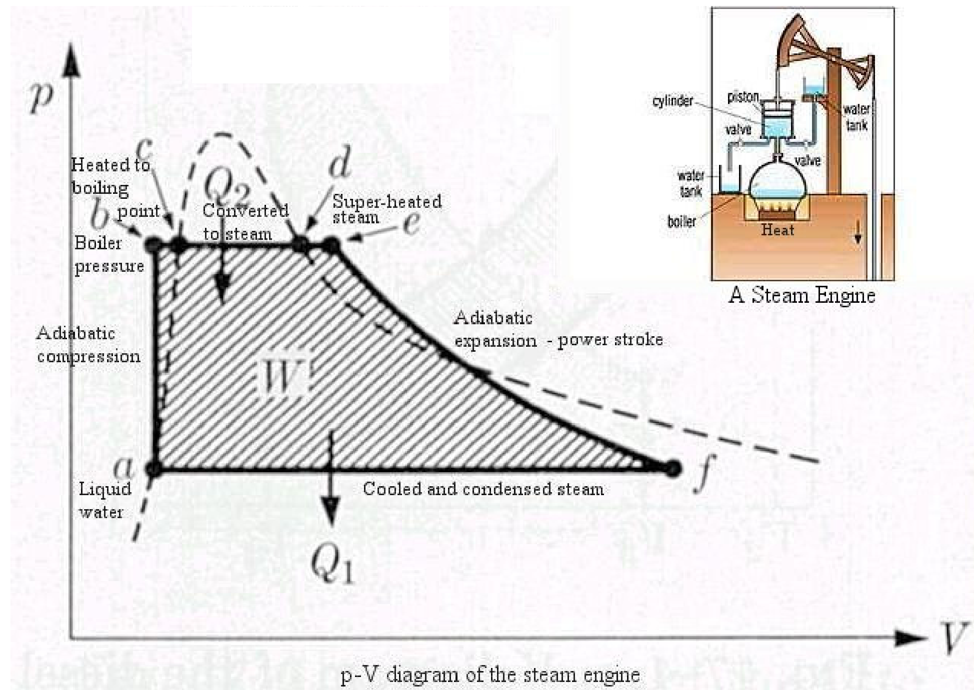


Fig. 7-3 (a) *Elementary steam power plant.* (b) *PV diagram of Rankine cycle.*

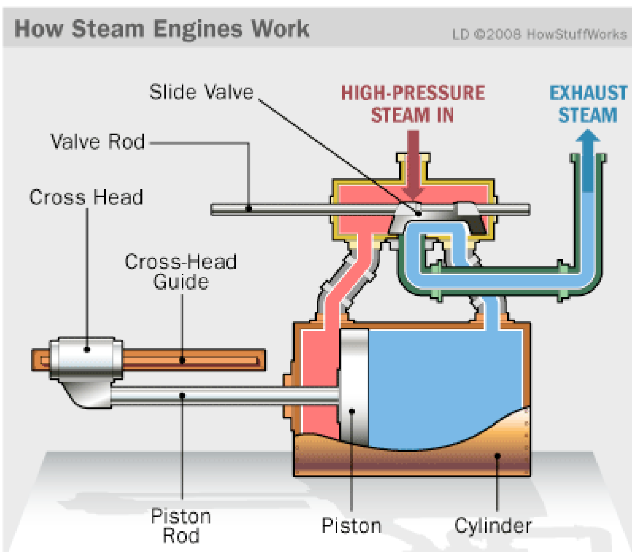
Heat and Thermodynamics, Zemansky

Motores de combustão externa

- Máquina a vapor:



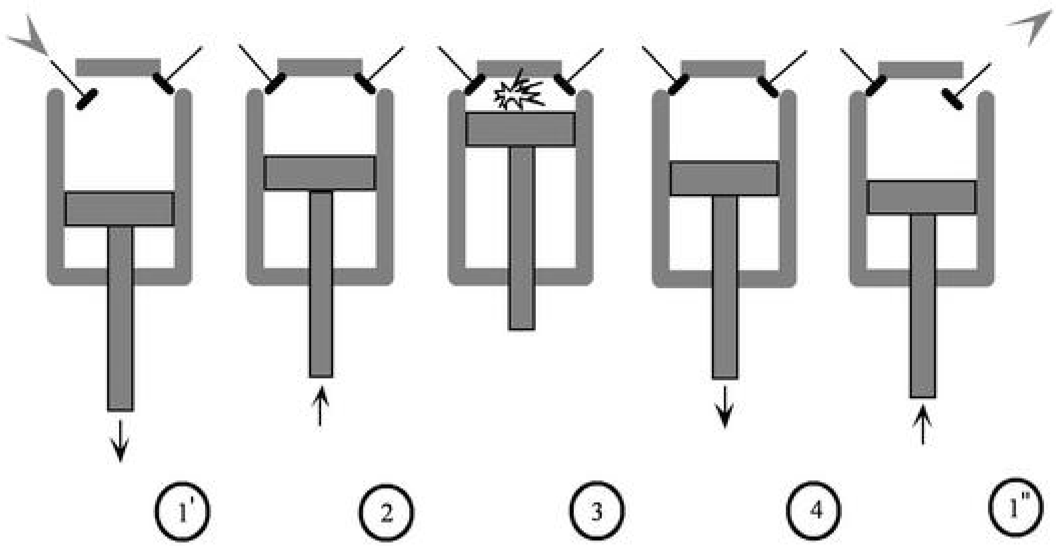
http://universe-review.ca/R13-09-thermodynamics.htm



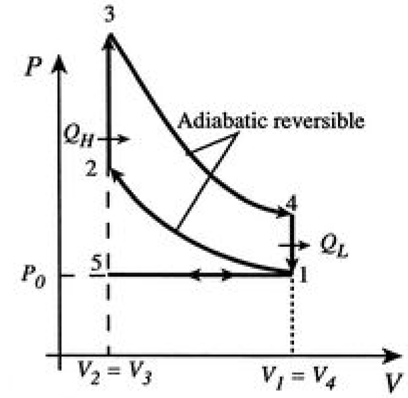
http://www.personal.psu.edu/jun3/blogs/pa_center_for_the_book_workshop/steamengine.gif

Motores de combustão interna

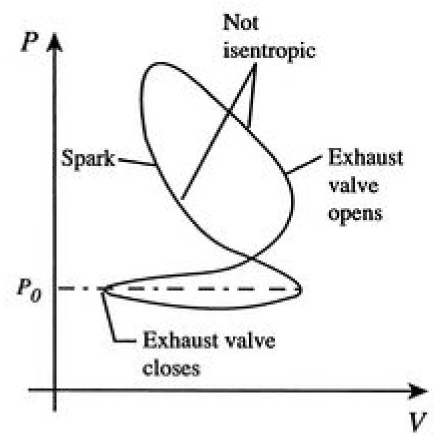
- Motor de quatro estágios (gasolina):



Ciclo de Otto (ideal)



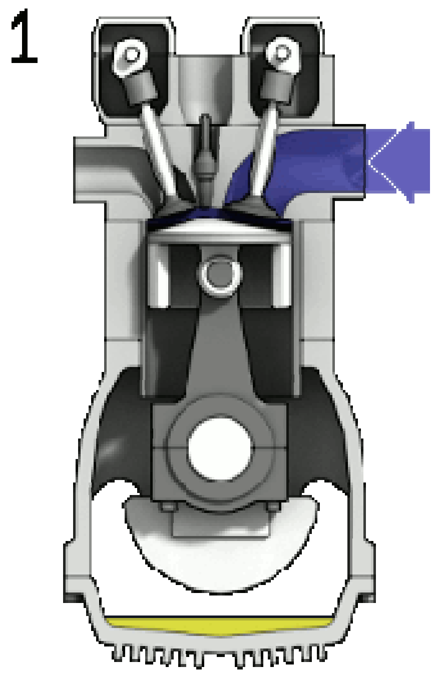
Ciclo de Otto (real)



http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node26.html

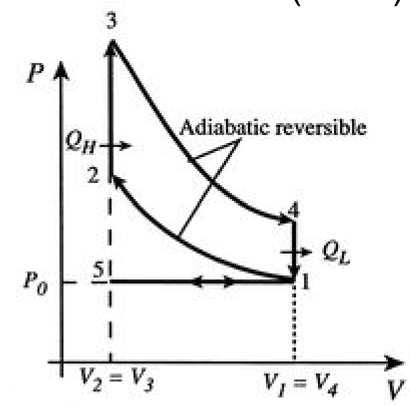
Motores de combustão interna

- Motor de quatro estágios (gasolina):



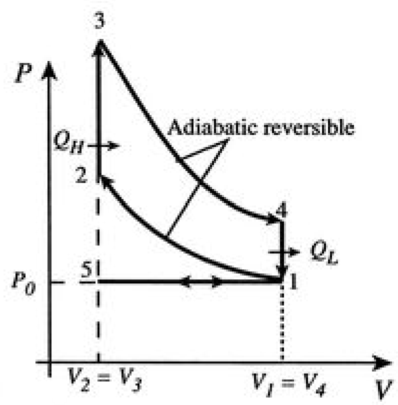
http://en.wikipedia.org/wiki/Petrol_engine

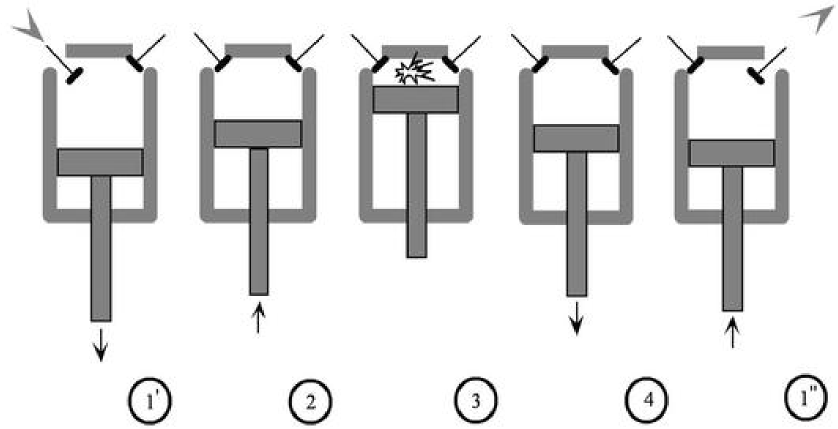
Ciclo de Otto (ideal)



Motores de combustão interna

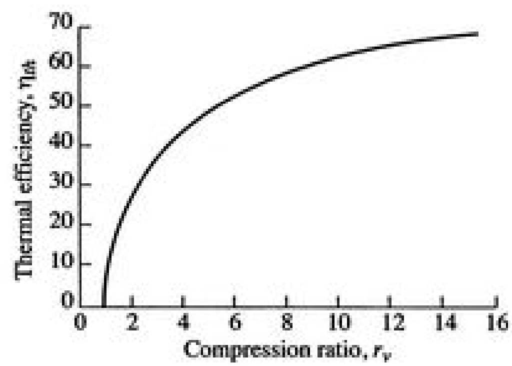
- Rendimento do ciclo de Otto (ideal) :





$$\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2} = 1 - \frac{1}{(V_1 / V_2)^{\gamma - 1}}$$

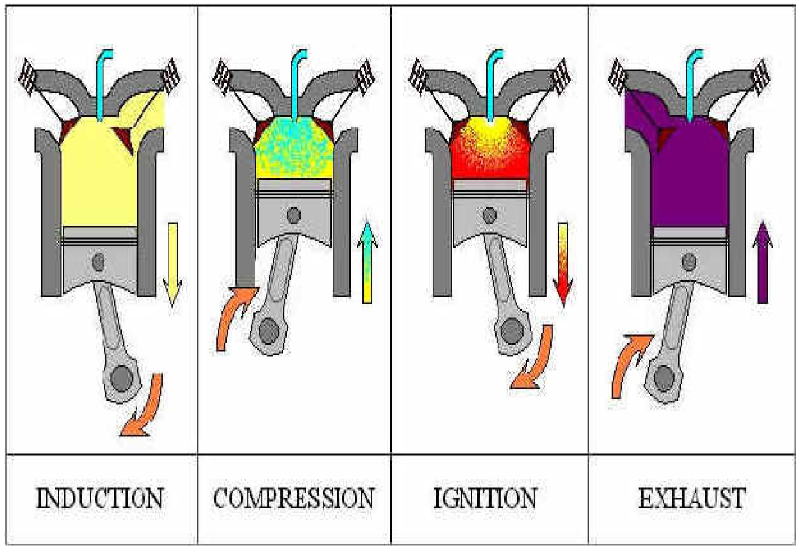
Razão de compressão: $r = V_1/V_2$



http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node26.html

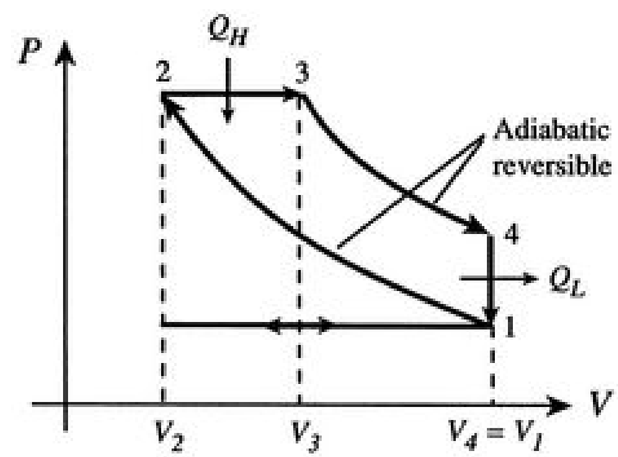
Motores de combustão interna

- Motor Diesel:



http://www.myrctoys.com/faqs/engine-diagrams-and-animations

Ciclo de Diesel (ideal)



- Rendimento do ciclo Diesel (ideal) :

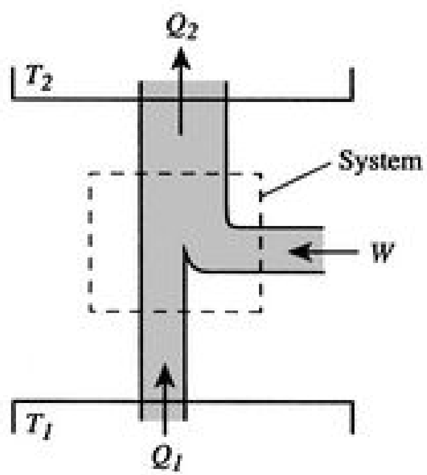
$$\eta = 1 - \frac{T_1}{\gamma T_2} \frac{T_4 / T_1 - 1}{T_3 / T_2 - 1}$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node27.html

Refrigeradores e bombas de calor

Sistema operando em ciclo:

Fonte quente



Fonte fria

Trabalho externo

$$\Delta U = 0$$

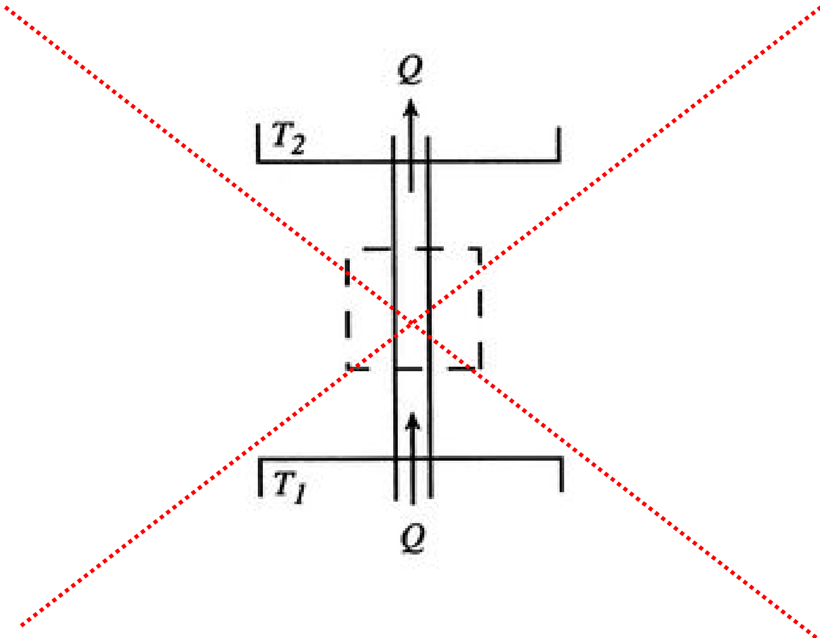
$$W = Q_2 - Q_1$$

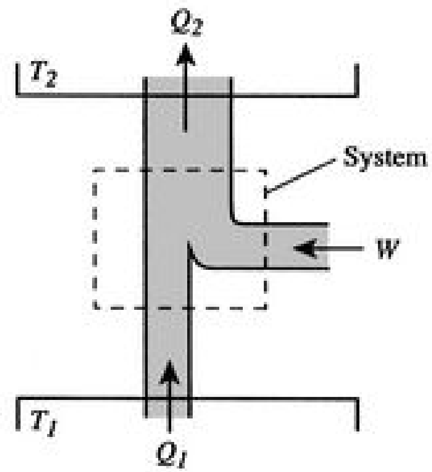
Coeficiente de performance do refrigerador:

$$\omega = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1}$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node25.html

Transferência de calor de um corpo frio para um corpo quente





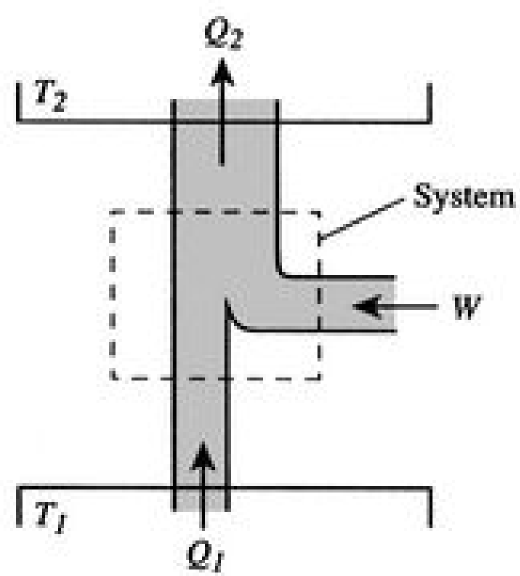
Se o sistema tem o seu estado final igual ao inicial (ou seja, ao final de um ciclo):

$$W = Q_2 - Q_1 \neq 0$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node37.html

2ª Lei da Termodinâmica – Enunciado de Clausius

- Nenhum processo cujo único resultado seja a transferência de calor de um corpo a uma temperatura inferior para outro a uma temperatura superior é possível.

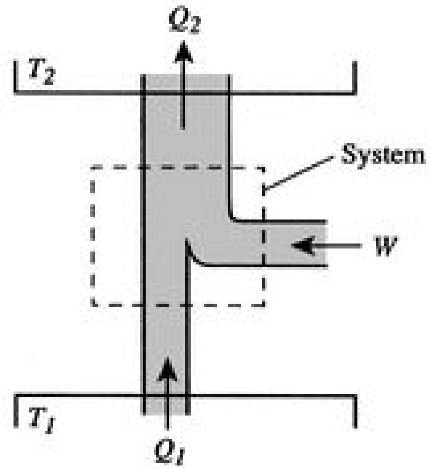


Refrigeradores reais:

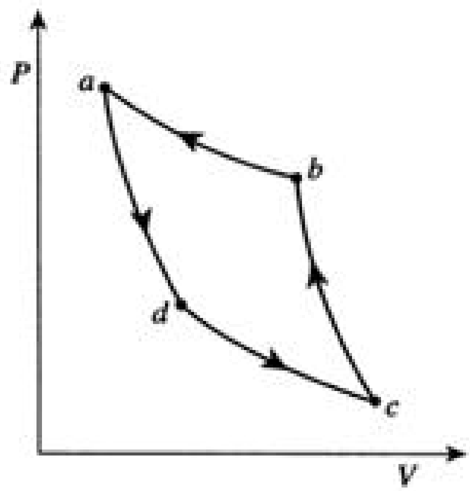
$$W = Q_2 - Q_1 \neq 0$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node25.html

Refrigerador de Carnot



Gás ideal:



$$\frac{T_1}{T_2} = \frac{Q_1}{Q_2}$$

Coeficiente de performance:

$$\omega = \frac{Q_1}{Q_2 - Q_1} = \frac{1}{\frac{T_2}{T_1} - 1}$$

http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node25.html

Refrigeradores comerciais

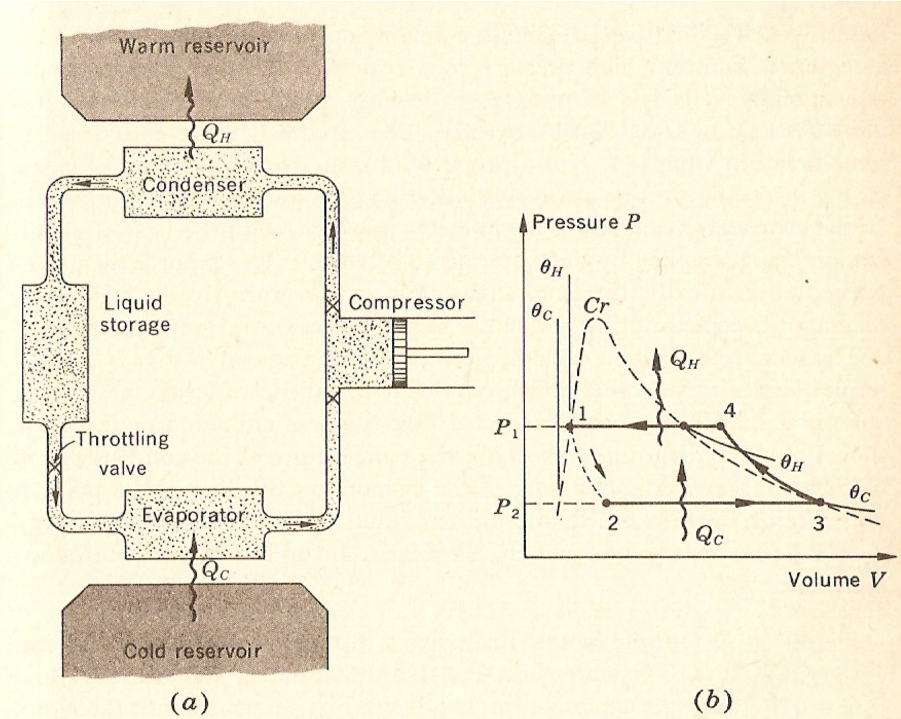
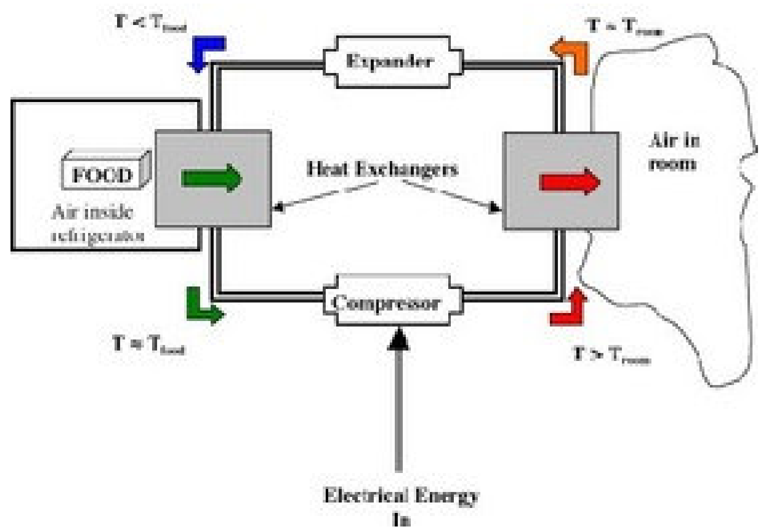


Fig. 7-7 (*a*) *Elementary refrigeration plant.* (*b*) *PV diagram of commercial refrigerator cycle.*

Heat and Thermodynamics, Zemansky



http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node25.html

Equivalência dos enunciados de Kelvin-Planck e Clausius

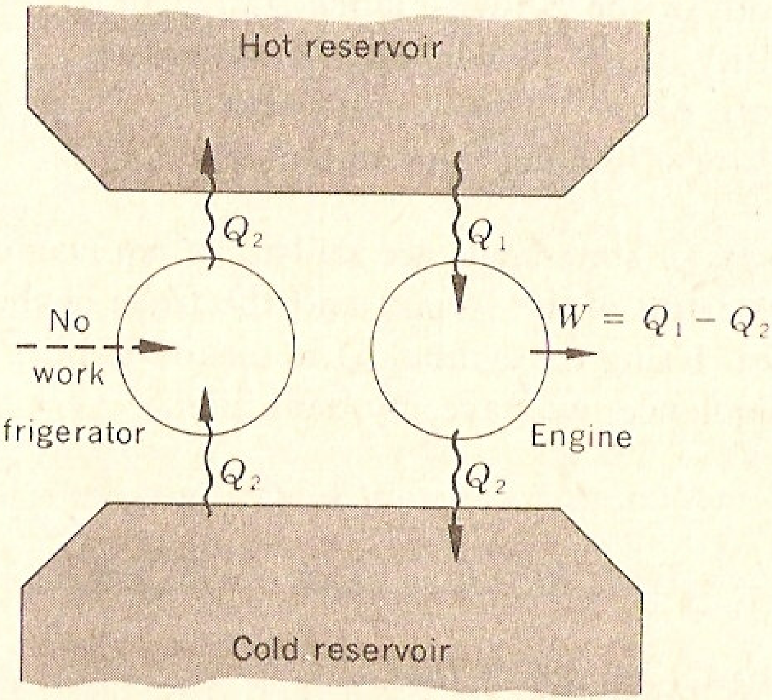


Fig. 7-10 *Proof that* $-C \supset -K$. *The refrigerator on the left is a violation of C; the refrigerator and engine acting together constitute a violation of K.*

Heat and Thermodynamics, Zemansky

Equivalência dos enunciados de Kelvin-Planck e Clausius

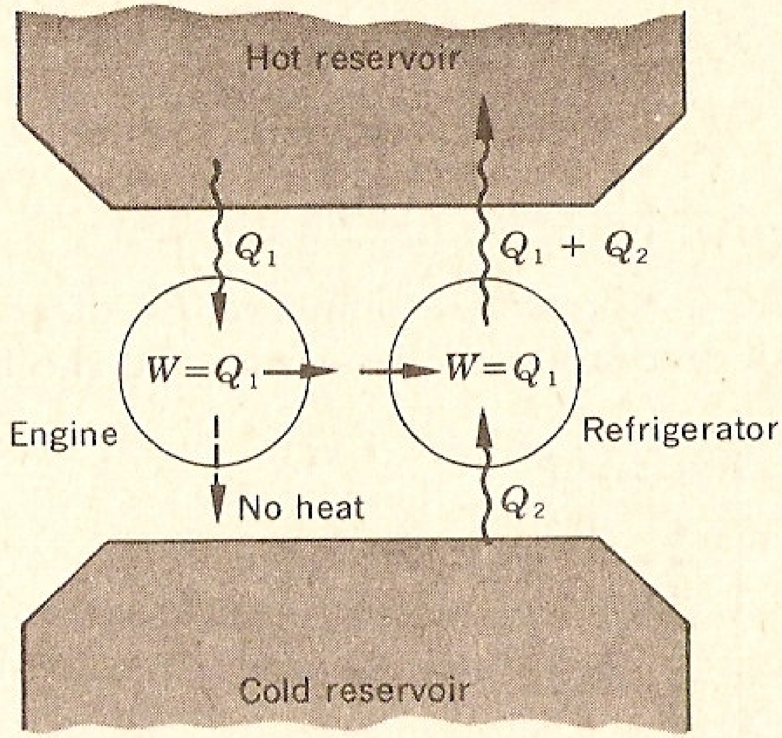


Fig. 7-11 *Proof that* $-K \supset -C$. *The engine on the left is a violation of K; the engine and refrigerator acting together constitute a violation of C.*

Heat and Thermodynamics, Zemansky

Bibliografia e links sugeridos:

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- "*Termodinâmica, Teoria Cinética e Termodinâmica Estatística*", F. W. Sears & G. L. Salinger. Guanabara Dois, Rio de Janeiro, 1979.
- "*A Física e o nosso mundo*", Hans Christian von Baeyer, Elsevier, 2004.
- "Reflexões sobre a contribuição de Carnot à primeira lei da Termodinâmica", C. K. Nascimento, J. P. Braga, J. D. Fabris. *Química Nova* 2004;27:513-515.
- http://www.ias.ac.in/resonance/Nov2001/pdf/Nov2001p42-48.pdf.
- http://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node21.html.
- http://en.wikipedia.org/wiki/Steam_locomotive.
- http://en.wikipedia.org/wiki/Cooling_towers.
- http://en.wikipedia.org/wiki/Steam_engine.