Thermodynamics 2026-1

S9_1: Second Law_Definitions

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Recomendaciones generales:

- Leer antes de clase y entender los conceptos o preguntar si es necesario.
- Practicar bastante:
  - *Ejercicios de clase
  - *Asesorías
  - *Ejercicios del libro resueltos y los de final de capitulo
- Los quizzes virtuales y gradescope úsenlos para aprender de forma honesta (se puede inferir).
- Tengan grupos de estudio y apóyense mutuamente.
- Crear sus propias notas estudio y formulario.
- Son 4 horas de clase en la semana (asistir y ser puntuales, perder alguna es atrasarse mucho)
- Cada hora de clase son 3 horas de estudio por fuera mínimo.
- En la ppt de la semana 1 están todos los links claves para el curso.

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Thermodynamics _ Evaluation

S8 A

S 16 F

COMPONENTE	%
EXAMEN PARCIAL	20
EXAMEN FINAL	30
C	50
APROBACIÓN: 11/20	

EXÁMENES	FECHAS
EXAMEN PARCIAL	(MAYO 11)
EXAMEN FINAL	(JULIO 6)

EXAMEN PARCIAL : Todos los temas vistos hasta la semana 6.

EXAMEN FINAL: Todos los temas vistos hasta la semana 15

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Thermodynamics _ Evaluation

COMPONENTE	%
PARCIAL	**20**
FINAL	**30**
C	**50**
APROBACIÓN: 11/20	

SEMANA 1	TAREA VIRTUAL	SE CALIFICA AUTOMATICO NO NECESITA PROCEDIMIENTO
SEMANA 2	TAREA VIRTUAL	
SEMANA 3	TAREA VIRTUAL	.
SEMANA 4	**TAREA INDIVIDUAL 1** + EVALUACION_ AULA1	TAREA INDIVIDUAL: Esta parte incluye subir un archivo con la solución EVALUACION_ AULA: SEMANAS 1-2
SEMANA 5	TAREA VIRTUAL+ EVALUACION_ AULA2	EVALUACION_ AULA: SEMANAS 1-3
SEMANA 6	TAREA VIRTUAL**+TAREA INDIVIDUAL 2**	
SEMANA 7	TAREA VIRTUAL+ EVALUACION_ AULA3	EVALUACION_ AULA: SEMANAS 1-6
SEMANA 8	**PARCIAL**	
SEMANA 9	EVALUACION_ AULA4+**TAREA INDIVIDUAL 3 +Tarea grupal 1**	EVALUACION_ AULA: SEMANAS 1-8
SEMANA 10	TAREA VIRTUAL	
SEMANA 11	TAREA VIRTUAL	
SEMANA 12	TAREA VIRTUAL+ EVALUACION_ AULA5	EVALUACION_ AULA: SEMANAS 1-11
SEMANA 13	TAREA VIRTUAL**+TAREA INDIVIDUAL 4 + Tarea grupal 2**	
SEMANA 14	EVALUACION_ AULA6	EVALUACION_ AULA : SEMANAS 1-13
SEMANA 15		
SEMANA 16	**FINAL**	

***LAS TAREAS VIRTUALES O LOS GRADESCOPE (TAREA INDIVIDAL) se abren lunes 2pm y se cierran sábado media noche. La tarea virtual se presenta hasta un máximo de 3 veces.**

EVALUACION_ AULA: es un quiz de 20 min aprox. en aula.

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Objectives:

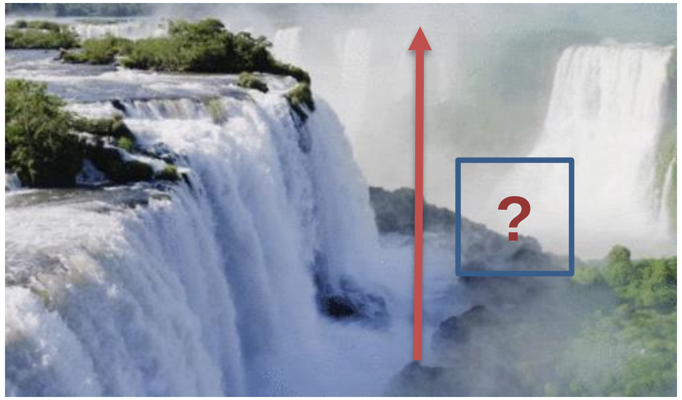
Session 17-18-20:

Session 17: Describe the concepts of reservoir, reversible and irreversible processes, associating them with the refrigeration and power cycles.

Session 18: Explain the postulates of Clausius and Kelvin Planck to formulate the second law of thermodynamics.

Session 20: Apply the second law of thermodynamics to cycles through the calculation of efficiencies and performance coefficients. Apply the ideal cycle concept using the Carnot cycle as a reference

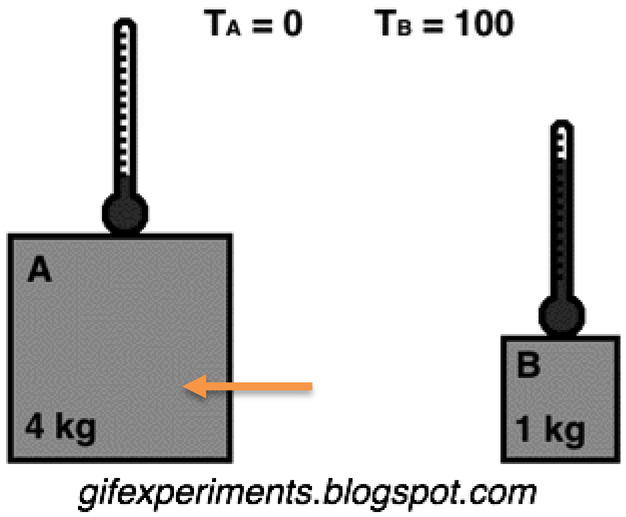
- A waterfall runs downhill, but never up, spontaneously.



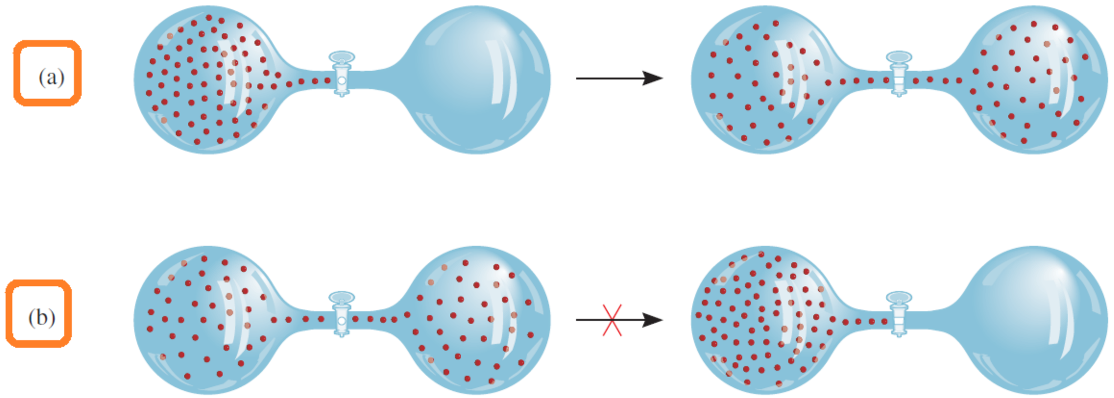
- A lump of sugar spontaneously dissolves in water, but dissolved sugar does not spontaneously reappear in its original form.

- Water freezes spontaneously below 0°C, and ice melts spontaneously above 0°C (at 1 atm).

• Heat flows from a hotter object to a colder one, but the reverse never happens spontaneously.



• The expansion of a gas into an evacuated bulb is a spontaneous process [Figure(a)]. The reverse process, that is, the gathering of all the molecules into one bulb, is not spontaneous [Figure (b)].



- A piece of sodium metal reacts violently with water to form sodium hydroxide (NaOH) and hydrogen gas (H_2). However, hydrogen gas does not react with sodium hydroxide to form water and sodium.

- Iron exposed to water and oxygen forms rust, but rust does not spontaneously change back to iron.

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https://www.youtube.com/watch?v=bCkHpEY9Mdk

Second law of thermodynamics

Why is it important for us?

1. The processes occur in a certain direction

2. Energy has quality as well as quantity.

3. A process cannot take place unless it satisfies both the first and second laws of thermodynamics

1

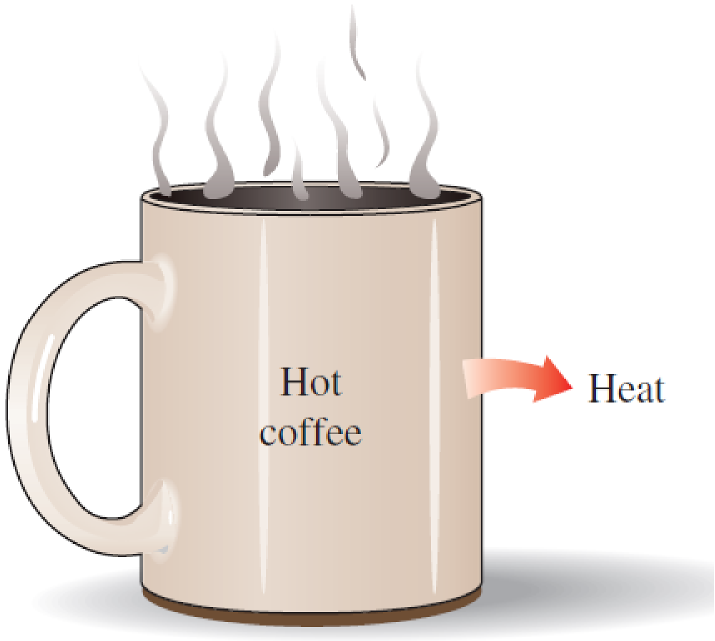


FIGURE 6–1
A cup of hot coffee does not get hotter in a cooler room.

1

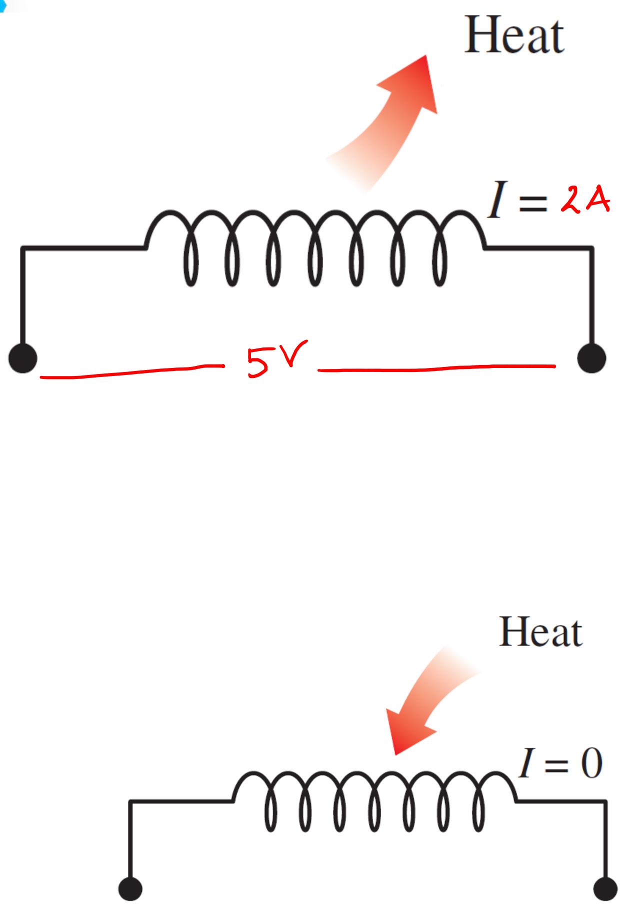
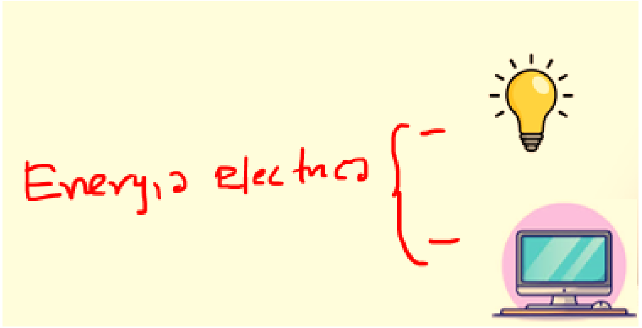


FIGURE 6–2
Transferring heat to a wire will not generate electricity.

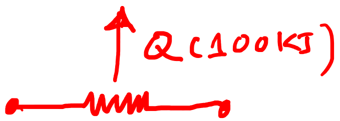
2



Para que sirve ?

aire (ganó 100 KJ) a 25°C

Energía eléctrica 100(KJ)



Other aspects of the second law.

4. Determining the best theoretical performance of cycles, engines, and other devices [COP or η].

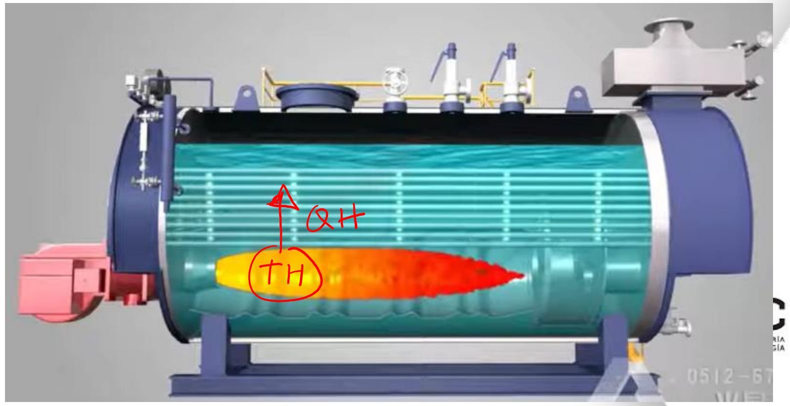
5. Evaluating quantitatively the factors that preclude the attainment of the best theoretical performance level [Friction, finite difference of T ...because increase σ]

La segunda ley antes de ser formulada matemáticamente fue formulada a travez de postulados……

CONCEPTS : THERMAL RESERVOIR

- A large enough system that remains at constant temperature while it receives or gives any amount of heat.
- Some real systems can come close to this idealization:

- A big boiler(**firebox**).



CONCEPTS : THERMAL RESERVOIR

- A large enough system that remains at constant temperature while it receives or gives any amount of heat.
- Some real systems can come close to this idealization:

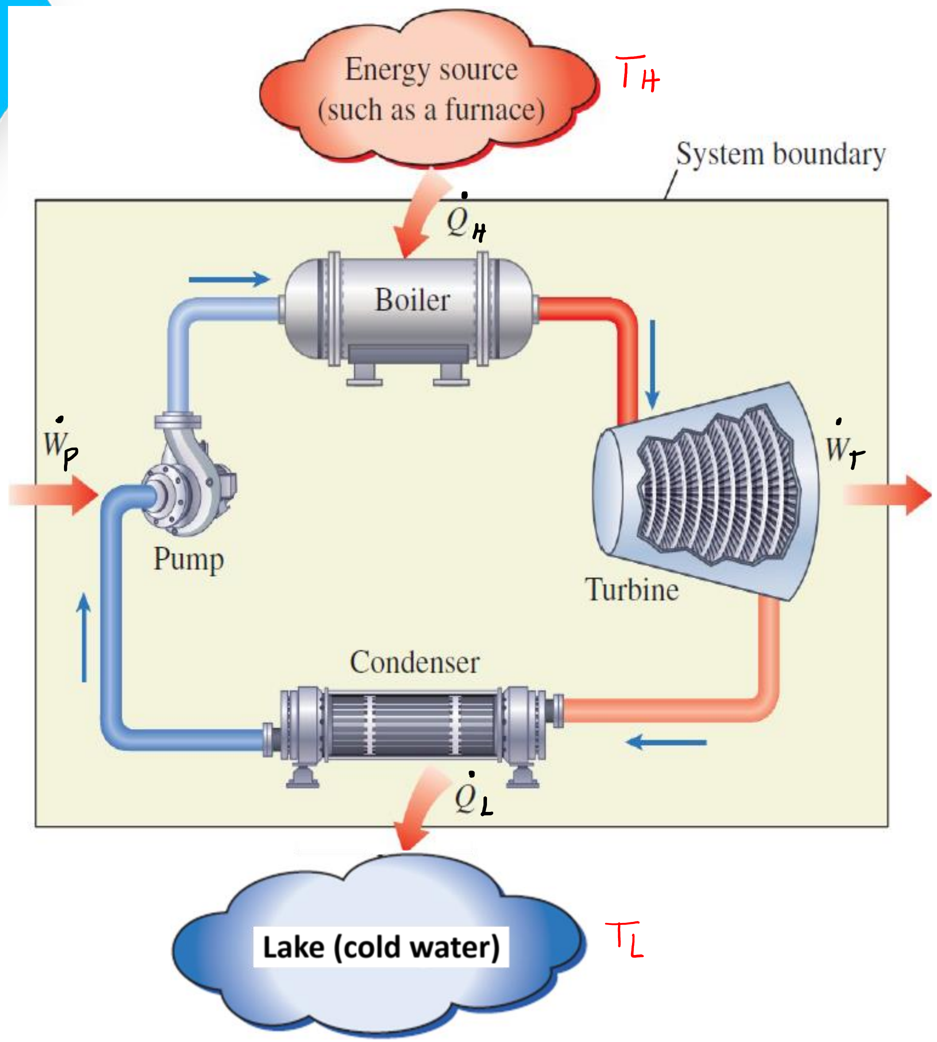
-A large body of water

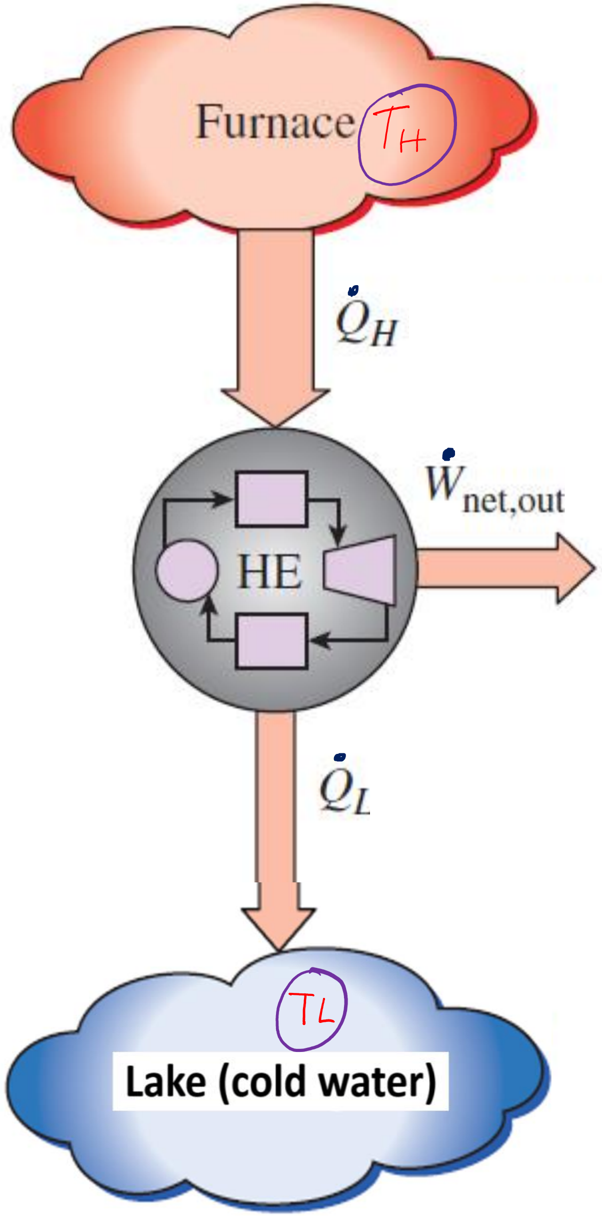
CONCEPTS : THERMAL RESERVOIR

- A large enough system that remains at constant temperature while it receives or gives any amount of heat.
- Some real systems can come close to this idealization:

-The atmosphere

Heat Engine





It operates in a thermodynamic cycle.

Receive HEAT from a HIGH TEMPERATURE RESERVOIR

Turn some of this HEAT into WORK

Reject remaining HEAT to a LOW TEMPERATURE RESERVOIR

Los postulados de Kelvin-planck (K-P) y clausius (C) son enfoques cualitativos de la segunda ley pero son solo para ciclos.

K-P → no puedo obtener $\eta = 1$ (ciclo de potencia) Relacionado con el punto 1

C → El calor no fluye espontáneamente de frío a caliente Relacionado con el punto 4

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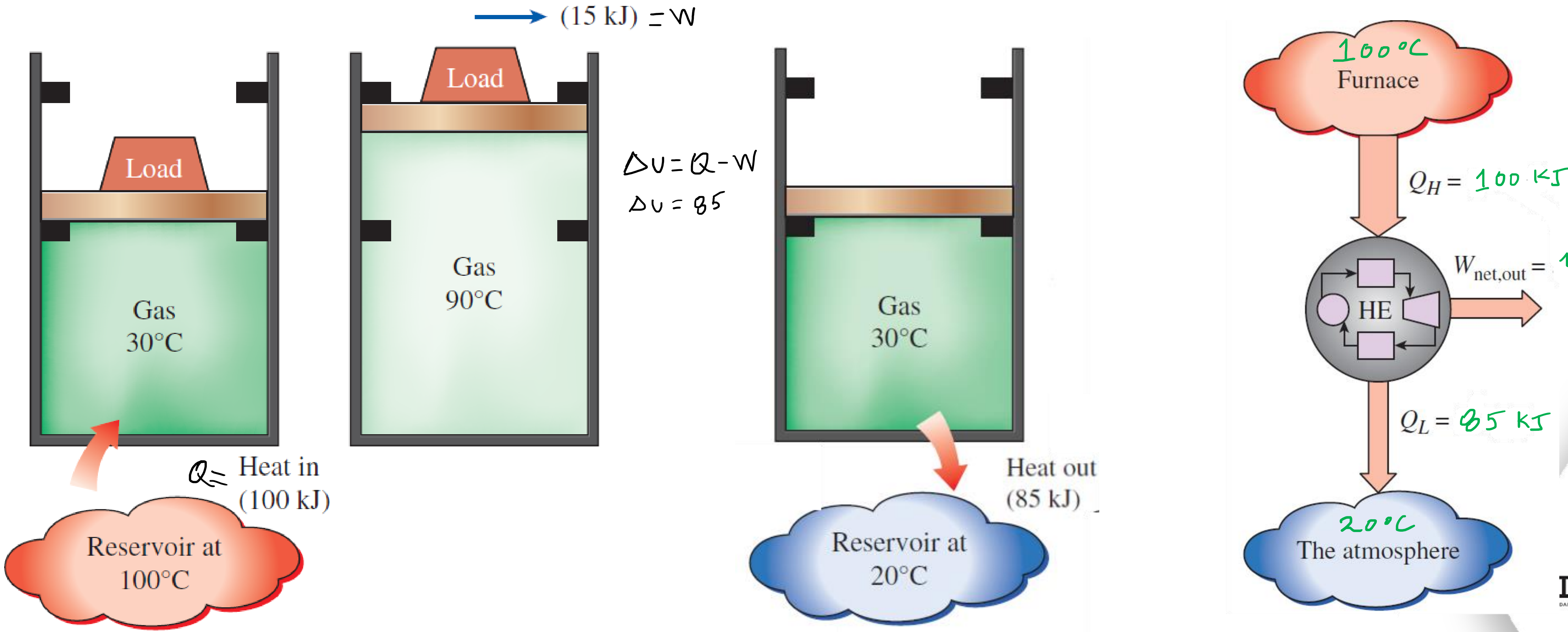
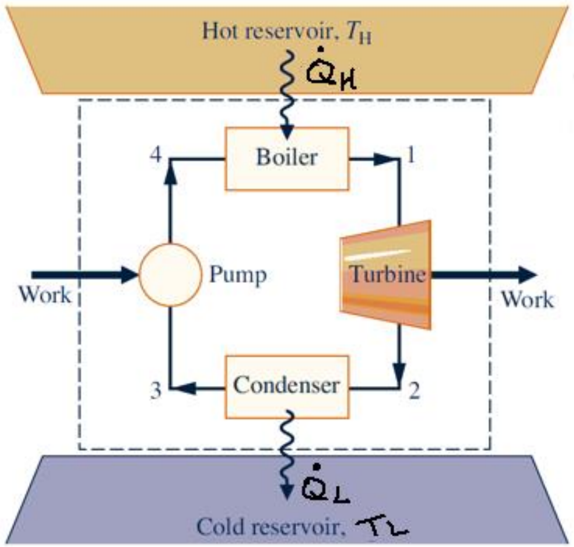


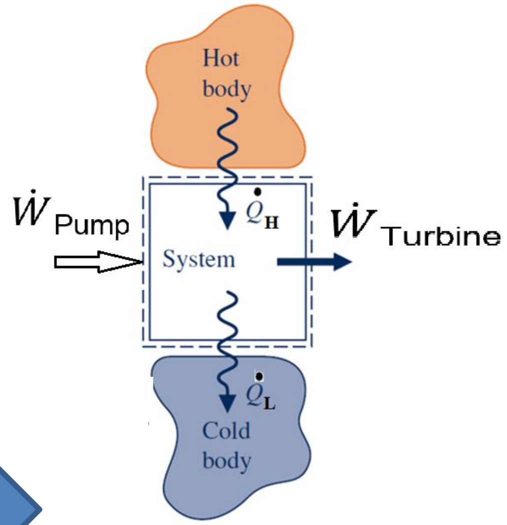
Is it possible to transfer the 85 kJ of excess heat at 90 °C back to the reservoir at 100 °C for later use? If it is, then we will have a heat engine that can have a thermal efficiency of 100% under ideal conditions.

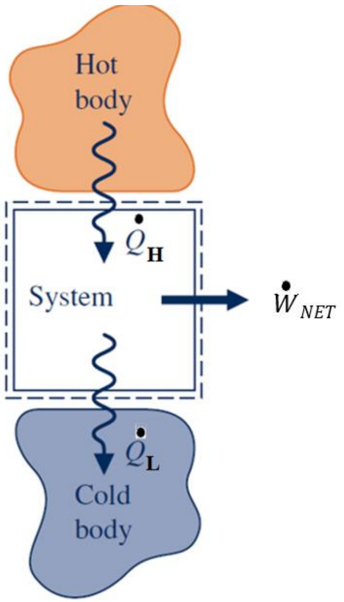
Power Cycles Work-Heat-Firts Law

CONTROL MASS

4. η<100%







Mass control

$$\cancel{\frac{dE}{dt}} = \dot{Q}_{NET} - \dot{W}_{NET}$$

$$|\dot{Q}_H| - |\dot{Q}_L| = |\dot{W}_{NET}|$$

$$\eta = \frac{|\dot{W}_T| - |\dot{W}_P|}{|\dot{Q}_H|} = \frac{|\dot{W}_{NET}|}{|\dot{Q}_H|}$$

$$\eta = \frac{|\dot{Q}_H| - |\dot{Q}_L|}{\dot{Q}_H} = 1 - \frac{|\dot{Q}_L|}{|Q_H|}$$

$$\eta < 1 \;!!!$$

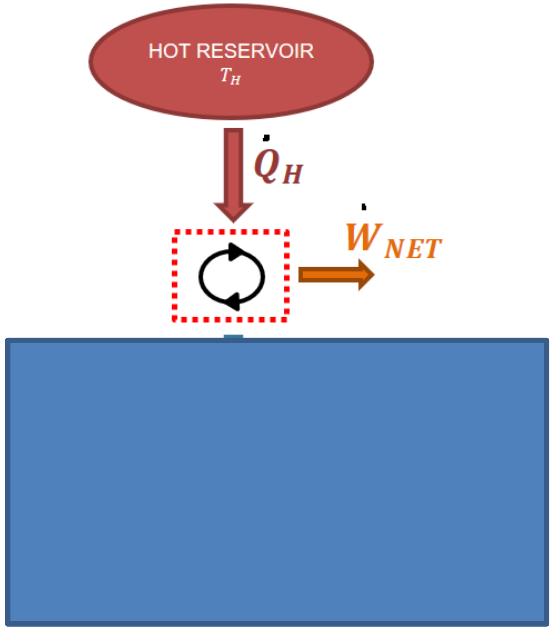
From the previous slides, we can conclude :

→ Incluso ideal

It is impossible to achieve 100% efficiency in a heat engine.

(K-P) statement

CONCEPTS : 2nd LAW (K-P) statement



Efficiency of a Heat Engine

$$\eta = \frac{|\dot{W}_{NET}|}{|\dot{Q}_H|} = \frac{\text{Want}}{\text{Cost}}$$

$$\eta = \frac{|\dot{Q}_H| - |\dot{Q}_L|}{|\dot{Q}_H|} = 1 - \left|\frac{\dot{Q}_L}{\dot{Q}_H}\right|$$

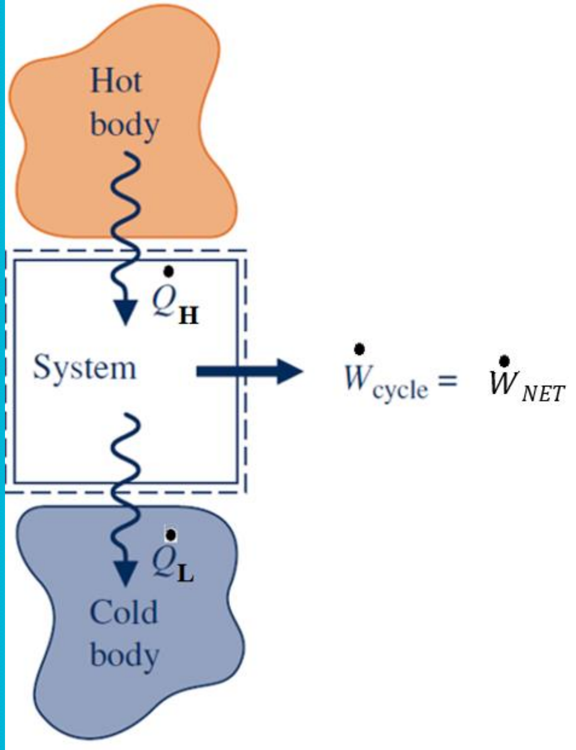
K-P: It is impossible for any system to operate in a cycle that takes heat from a hot reservoir and converts it to work in the surroundings without, at the same time, transferring some heat to a colder reservoir. In other words is impossible to have $\eta = 1$ (since Q_L cannot be zero!).

NOTE: The initial devices satisfy the 1st law if $W_{NET} = Q_H$.
However, They violate the 2nd law!

EXAMPLE 1

For a power cycle operating in steady state as shown in Fig., the energy transfer by heat into the cycle, $\dot{Q}_H$, is 800 kW, and the energy rejected by heat, $\dot{Q}_L$, is 560 kW. What is the thermal efficiency of the cycle? What is the net work developed, in kW?

$$\dot{Q}_{NET} - \dot{W}_{NET} = \cancel{\frac{dE}{dt}}$$



$$\dot{Q}_H + \dot{Q}_L - \dot{W}_{NET} = \cancel{\frac{dE}{dt}} \Rightarrow \dot{Q}_H + \dot{Q}_L = \dot{W}_{NET}$$

1. Calculate the net work developed:

$$\dot{W}_{net} = \dot{Q}_H + \dot{Q}_L$$

Given:

$$\dot{Q}_H = 800 \text{ kW} \quad \text{and} \quad \dot{Q}_L = -560 \text{ kW}$$

Substitute the values:

$$\dot{W}_{net} = 800 \text{ kW} + (-560 \text{ kW}) = 240 \text{ kW}$$

2. Calculate the thermal efficiency:

The thermal efficiency (η) is defined as the ratio of the net work developed to the heat supplied to the cycle:

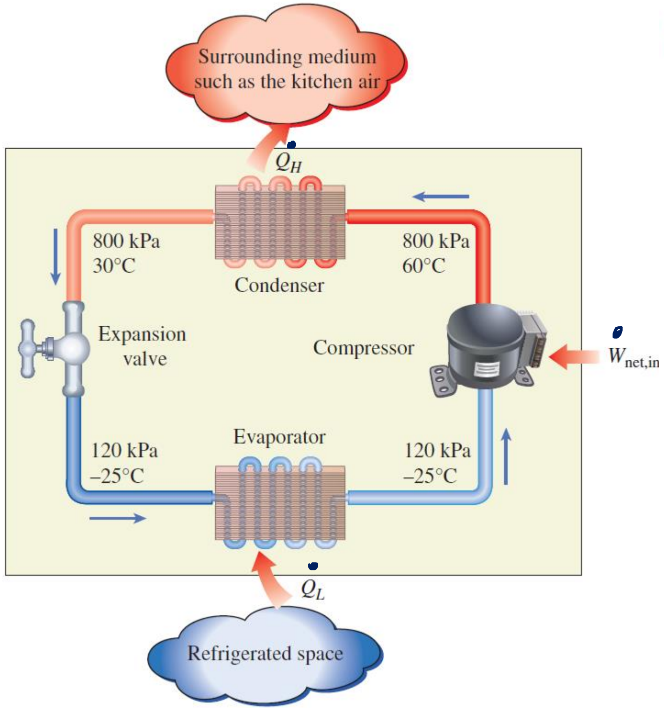
$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_H}$$

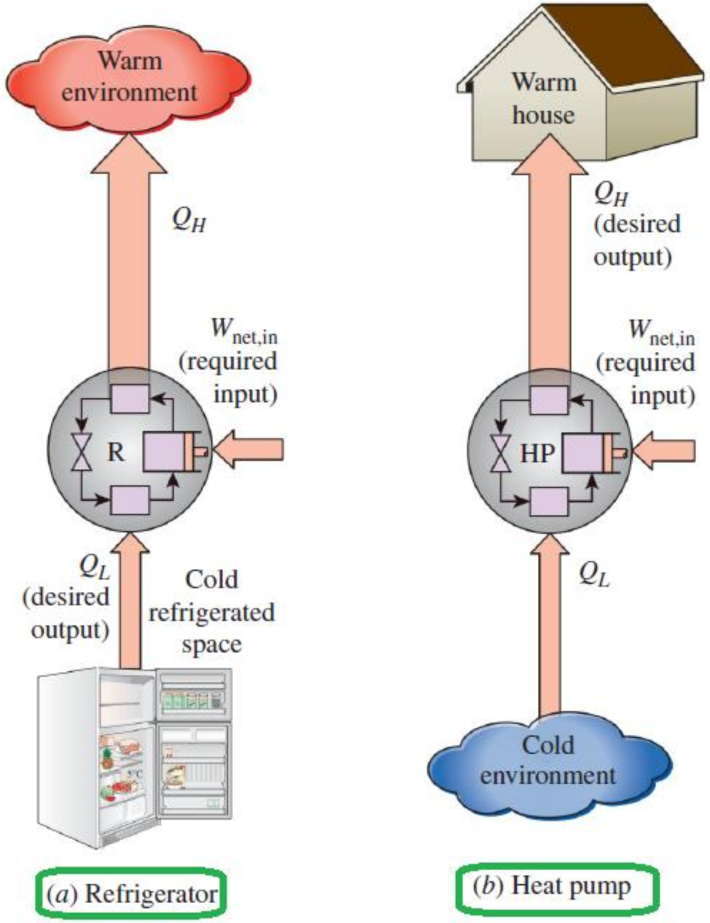
Substitute the values:

$$\eta = \frac{240 \text{ kW}}{800 \text{ kW}} = 0.3 \text{ or } 30\%$$

Does an unplugged refrigerator work?

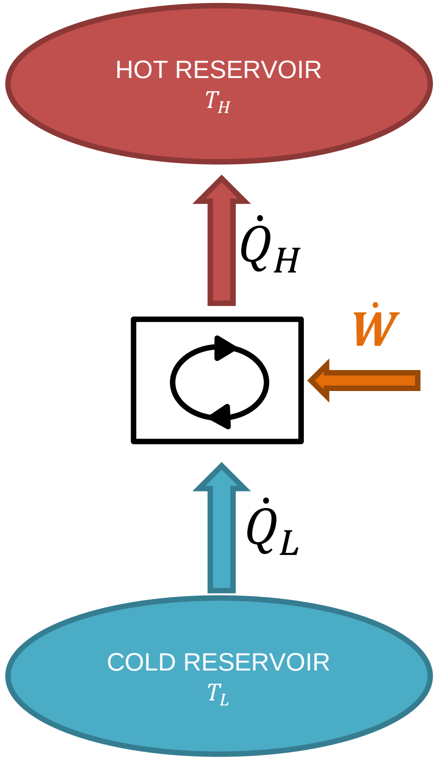
Refrigerating machines and heat pumps





- These machines do the opposite of a heat engine.
- The purpose of a refrigerator is to remove heat from the cold reservoir introducing some work
- The objective of a heat pump is to transfer heat to the hot reservoir introducing work.

CONCEPTS : **REFRIGERATOR**



Coefficient of Performance $\quad COP_R = \dfrac{Want}{Costs}$

$\cancel{\frac{dE}{dt}} = \dot{Q} - \dot{W}$

1st law: $\dot{W} = \dot{Q} = \dot{Q}_H + \dot{Q}_L$

Applying signs' rule

$$-|\dot{W}| = -|\dot{Q}_H| + |\dot{Q}_L|$$

$$COP_R = \beta_R = \frac{|\dot{Q}_L|}{|\dot{W}|} = \frac{|\dot{Q}_L|}{|\dot{Q}_H| - |\dot{Q}_L|}$$

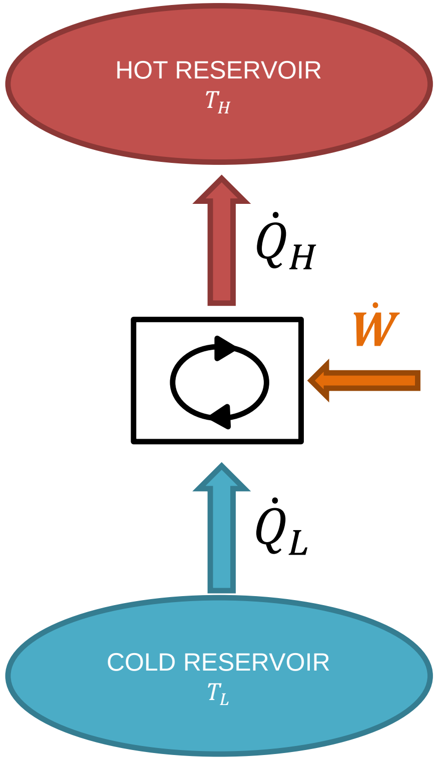
If $\dot{W} = 0,\ COP = \infty$

The ideal scenario is when this machine operates spontaneously with $W = 0$, however, this also implies that the COP would be infinite.

From the previous slides, we can conclude :

Heat always flows from a higher temperature to a lower temperature. → Clausius statement

CONCEPTS : **HEAT PUMP**



Coefficient of Performance $COP_{HP} = \dfrac{Want}{Costs}$

$$COP_{HP} = \beta_{HP} = \frac{|\dot{Q}_H|}{|\dot{W}|} = \frac{|\dot{Q}_H|}{|\dot{Q}_H| - |\dot{Q}_L|}$$

If $\dot{W} = 0,\ COP = \infty$

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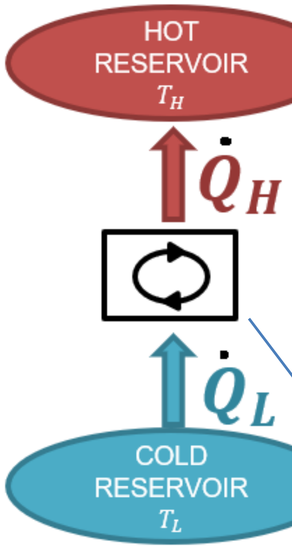
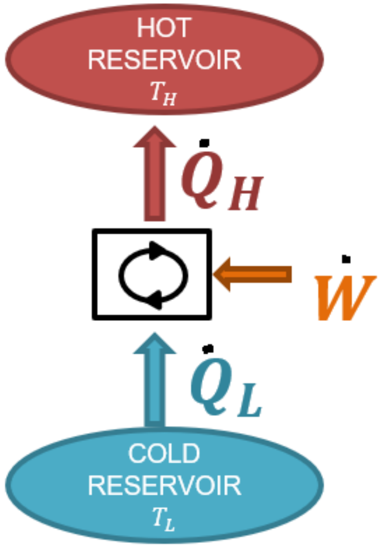
CONCEPTS : **2nd LAW _Clausius statement (C)**





$$COP = \frac{Want}{Costs}$$

$$COP = \beta_R = \frac{|\dot{Q}_L|}{|\dot{W}|} = \frac{|\dot{Q}_L|}{|\dot{Q}_H| - |\dot{Q}_L|}$$

If $\dot{W} = 0,\ COP = \infty$

Clausius: It is impossible for any system to operate in a cycle that takes heat from a cold reservoir and transfers it to a hot reservoir without at the same time converting some work into heat. In other words, a refrigerator does not work spontaneously.

Alternative Clausius statement: All spontaneous processes are **irreversible**

These device satisfy the 1st law : $Q_H = Q_L$, however they violate the 2nd law!!

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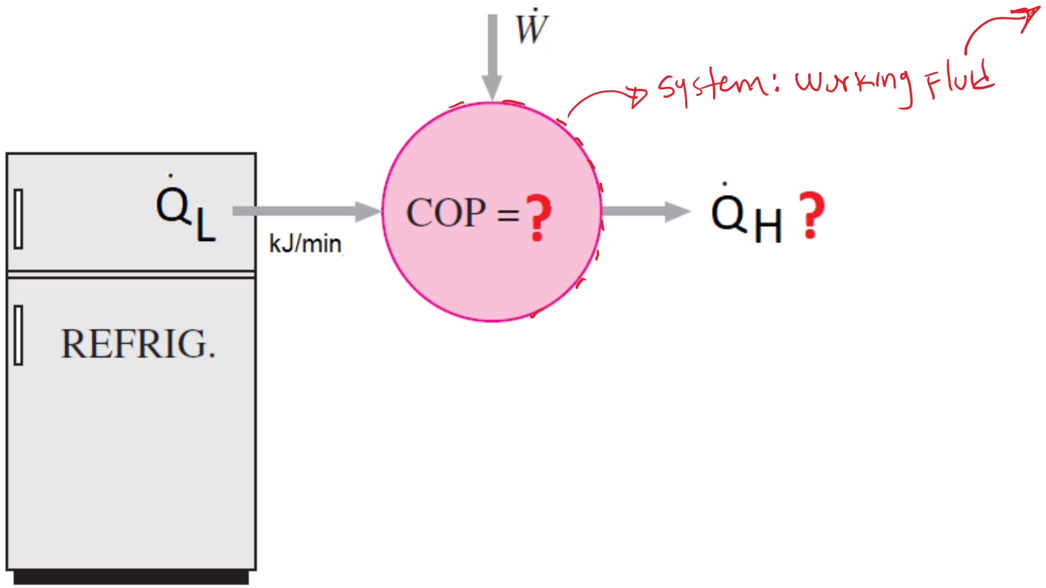
EXAMPLE 2

$\rightarrow |\dot{Q}_L|$

A refrigerator removes heat steadily a rate of 9000 kJ/min while drawing electric power at a rate of 35 kW. Determine **(a) the COP of this refrigerator** and **(b) the rate of heat transfer to the outside air(kW).**

Por concepto es un W de entrada



$$\frac{dE}{dt} = \dot{Q}_H + \dot{Q}_L - \dot{W}_{net}$$

$\dot{Q}_L$ [kW]

$$0 = \dot{Q}_H + \frac{9000}{60} - (-35)$$

$$\boxed{\dot{Q}_H = -185\ kW}$$

$$COP_R = \frac{|\dot{Q}_L|}{|\dot{W}_{net}|} \rightarrow COP_R = \frac{150}{35}$$

$$\boxed{COP_R = 4.2857}$$

Other aspects of the second law.

4. Determining the best theoretical performance of cycles, engines, and other devices [COP or η].

5. Evaluating quantitatively the factors that preclude the attainment of the best theoretical performance level [Friction, finite difference of T ....because increase σ]

Mas adelante

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5. Evaluating quantitatively the factors that preclude the attainment of the best theoretical performance level [Friction, finite difference of T ...because increase σ]

REVERSIBLE PROCESS

A process that can be reversed, returning both the system and the surroundings to their original states

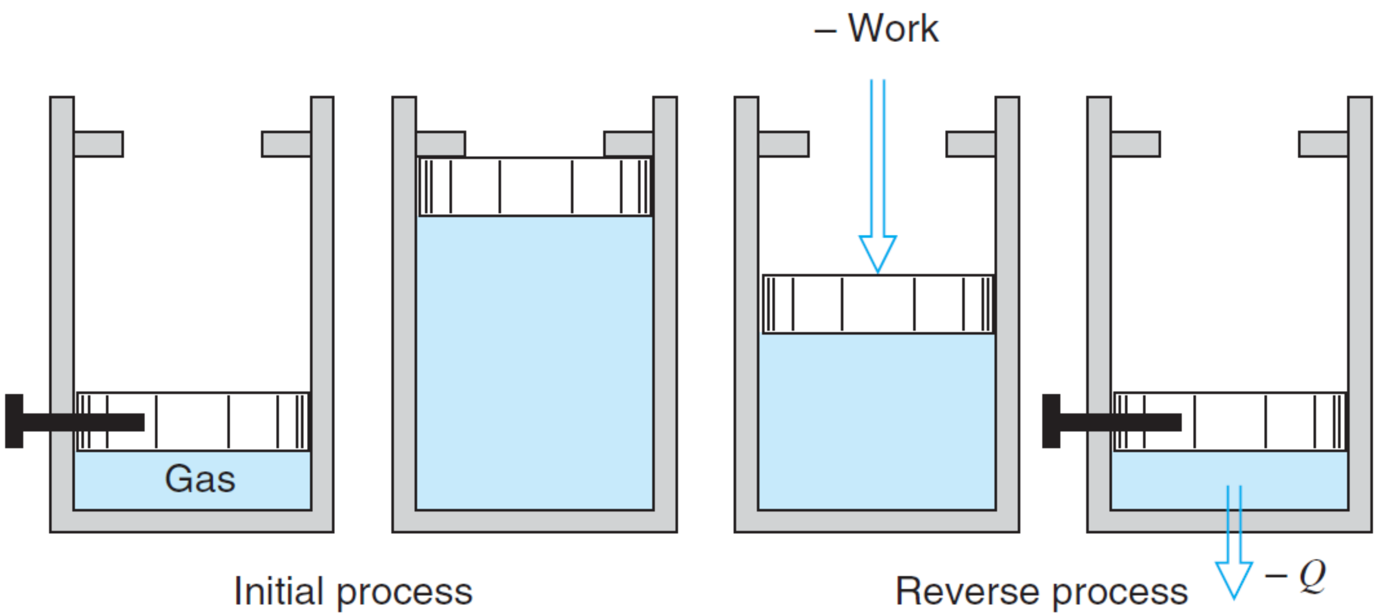
Why don't we have reversible process?

ALL REAL PROCESSES ARE **IRREVERSIBLE**

Some reasons: Friction, unrestrained expansion, heat transfer through a finite temperature difference, finite-time process (this means that the process is not quasistatic).

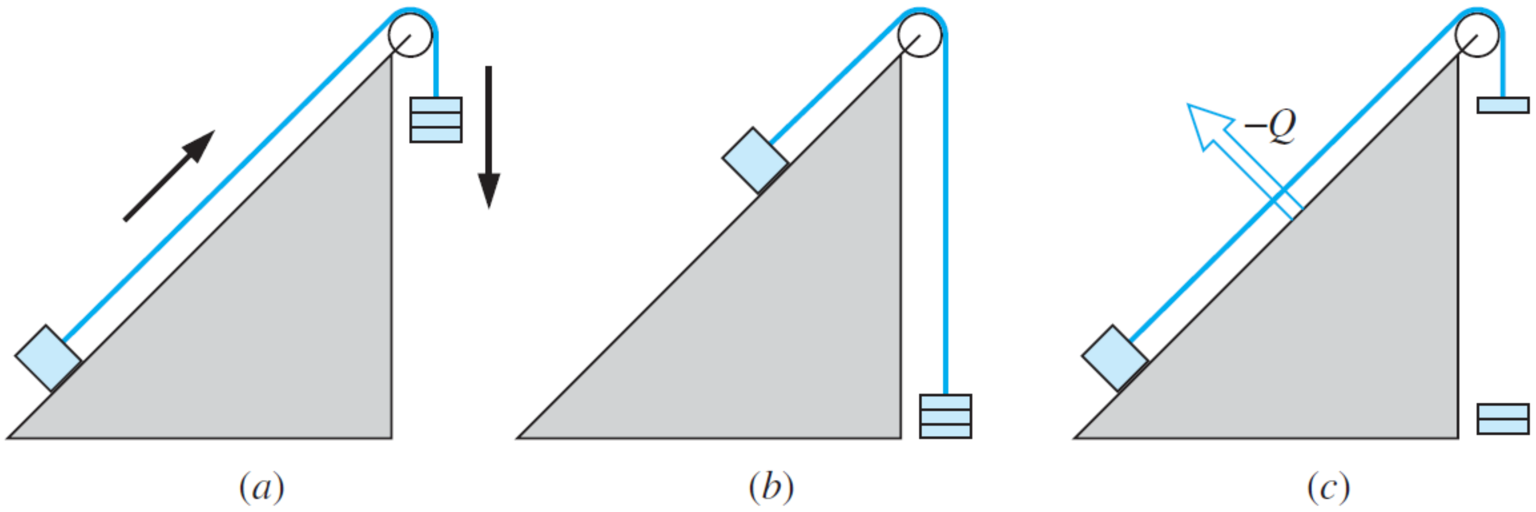
Why don't we have reversible process?

Finite-time process



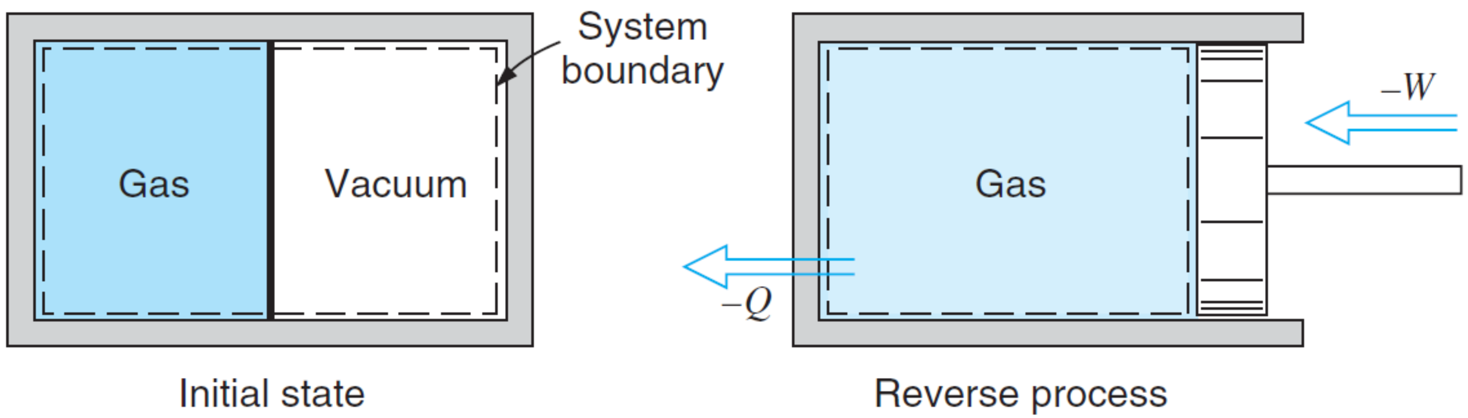
FACTORS THAT RENDER PROCESSES IRREVERSIBLE

Friction



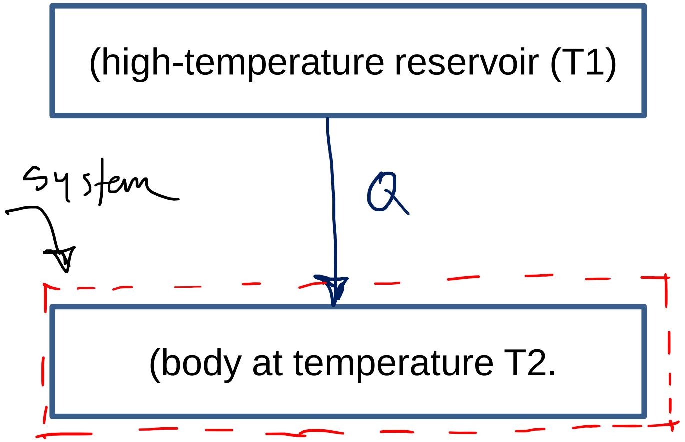
FACTORS THAT RENDER PROCESSES IRREVERSIBLE

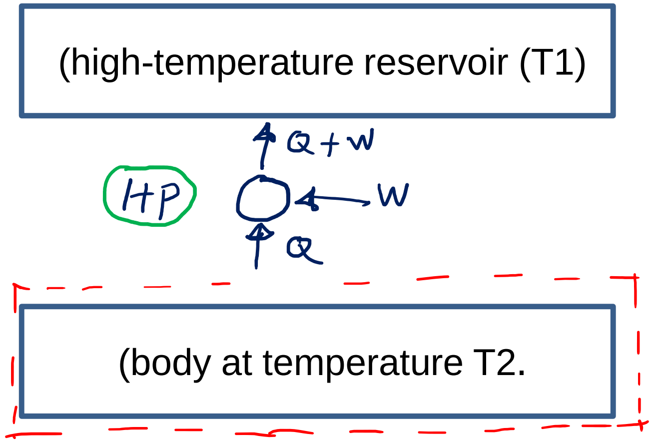
Unrestrained expansion



FACTORS THAT RENDER PROCESSES IRREVERSIBLE

Irreversibility due to finite temperature difference





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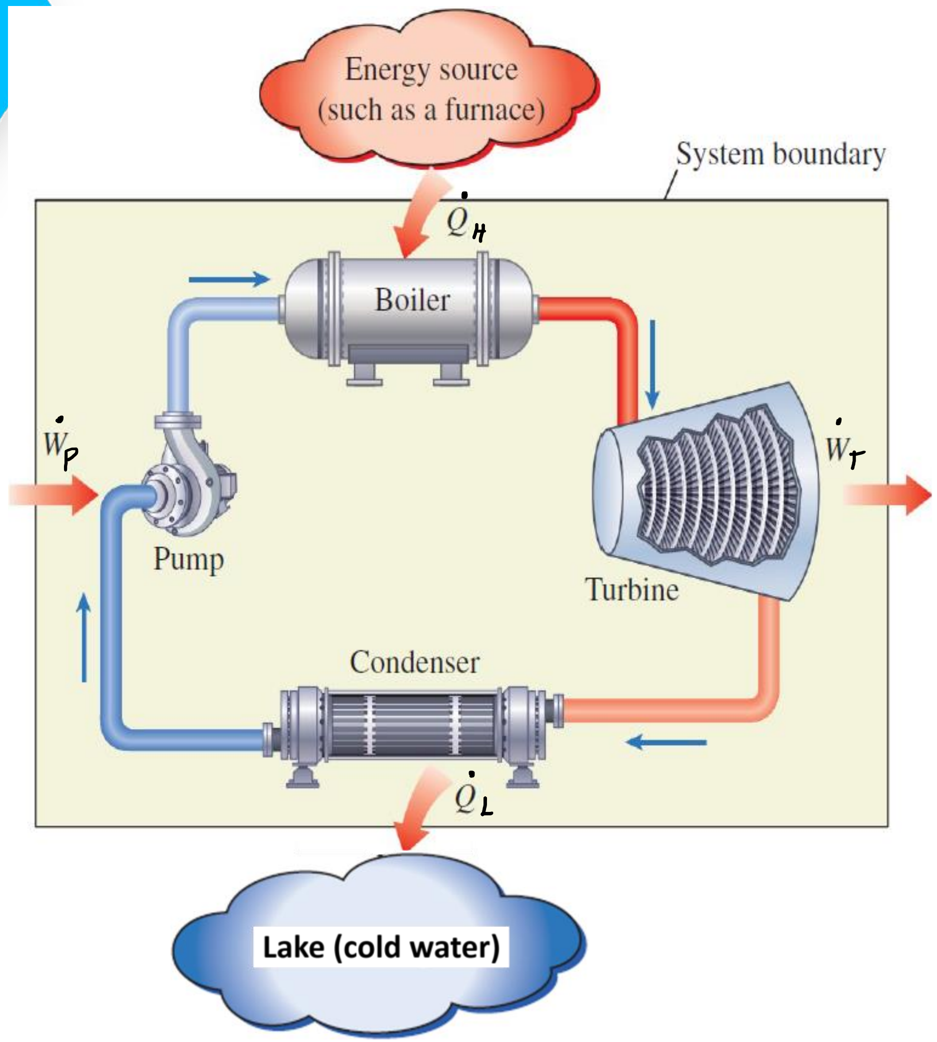
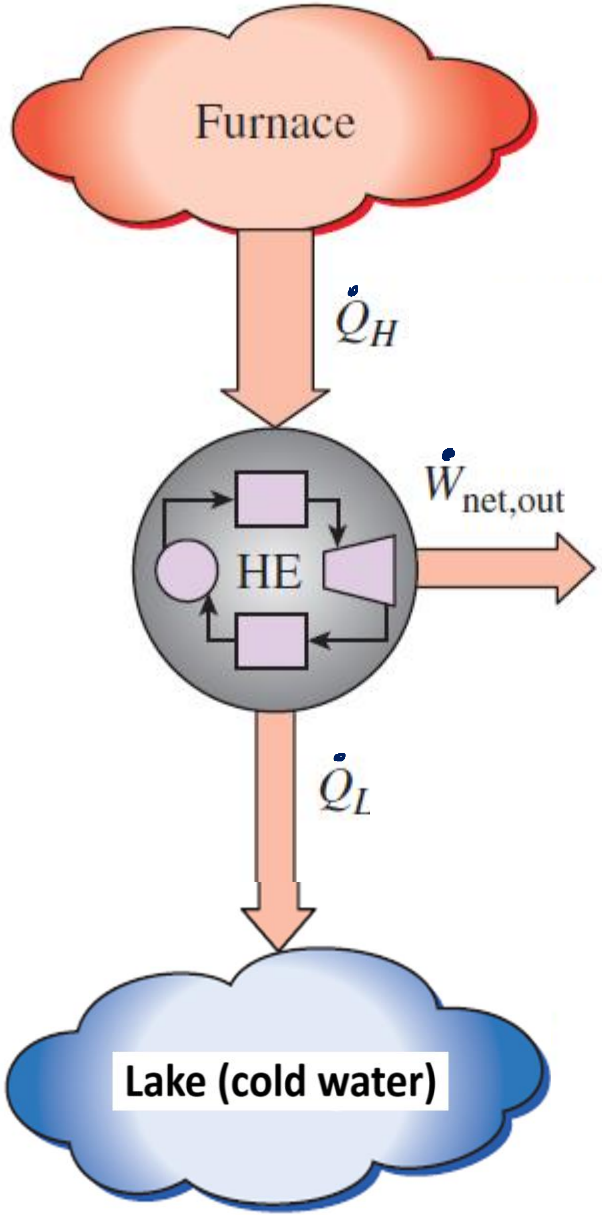
Heat Engine





It operates in a thermodynamic cycle.

Receive HEAT from a HIGH TEMPERATURE RESERVOIR

Turn some of this HEAT into WORK

Reject remaining HEAT to a LOW TEMPERATURE RESERVOIR

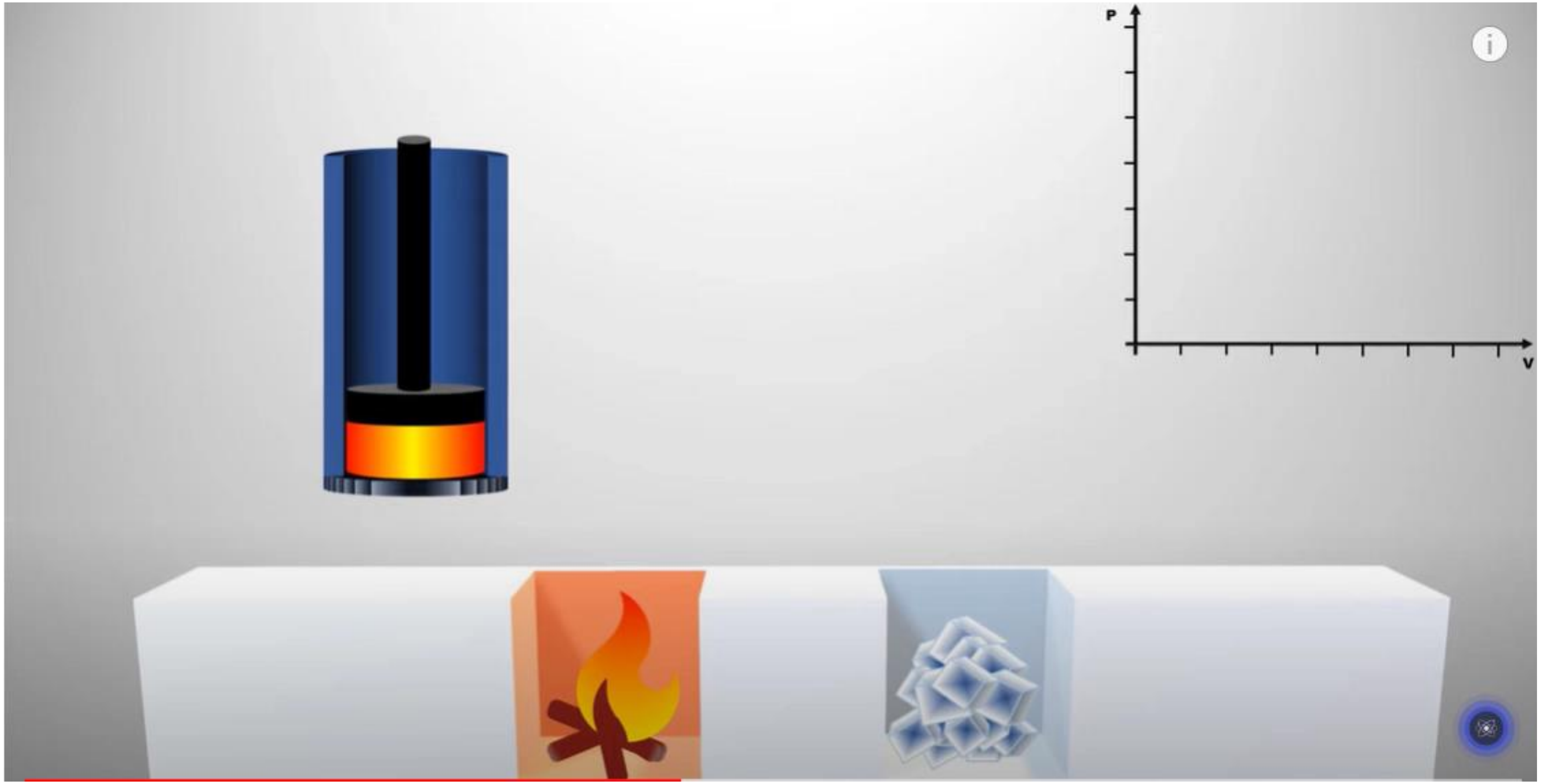
Other aspects of the second law.

→ Aplicar la 2da Ley de forma cuantitativa en ciclos.

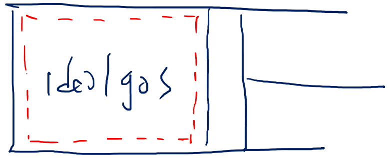
4. Determining the best theoretical performance of cycles, engines, and other devices [COP or η].

5. Evaluating quantitatively the factors that preclude the attainment of the best theoretical performance level [Friction, finite difference of T ...because increase σ]

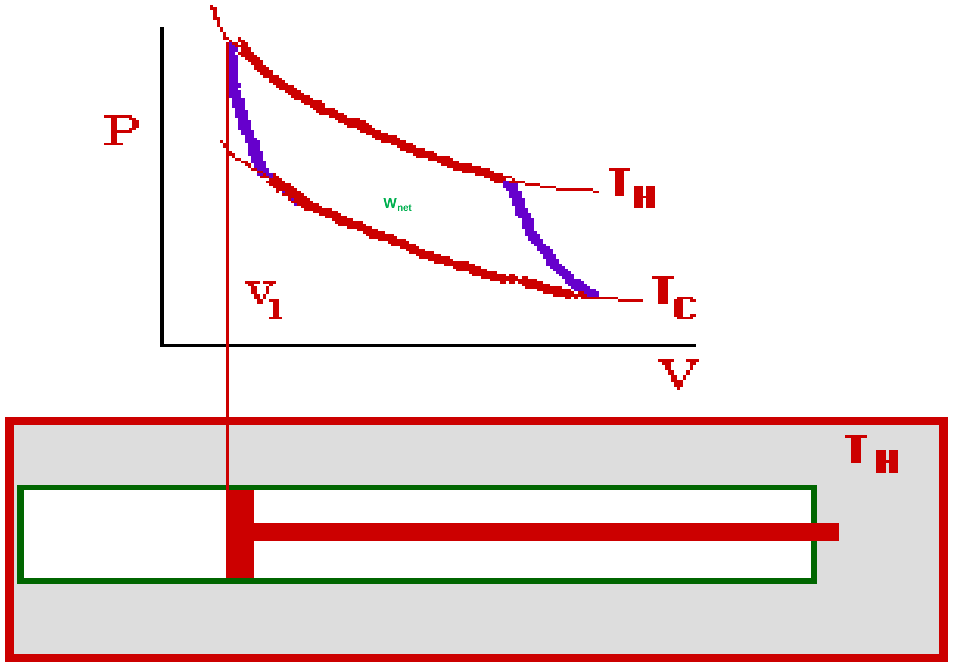
Carnot Cycle _ ideal gas



https://www.youtube.com/watch?v=NasmLQOf30s&ab_channel=Fizic%C4%83

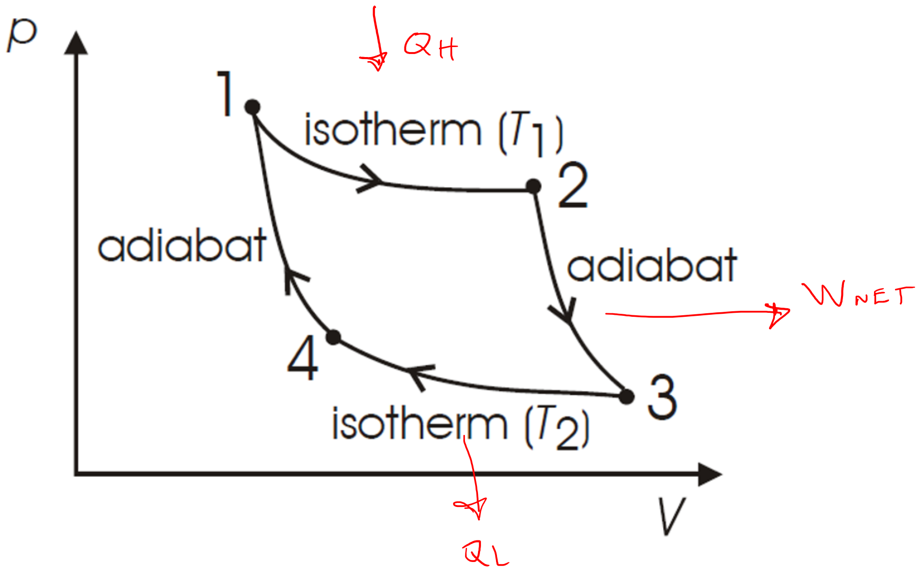


CARNOT_Ideal gas (W_{rev})



$T_C = T_L$

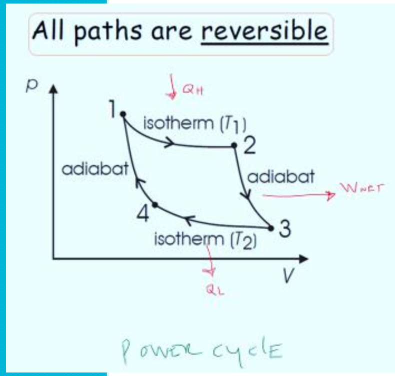
All paths are reversible



Power cycle

Carnot cycle for an ideal gas

_ CONTROL MASS_ 1mol



$\Delta U = Q - W$

$PV = \overset{1}{n} R T$ cte isot.

$1 \rightarrow 2 \qquad \Delta U = 0; \quad Q1 = \; w_1 = \int_1^2 p\,dV = \bar{R} T_1 \ln\left(\frac{V_2}{V_1}\right)$

$\Delta U' = Q - w'$

$2 \rightarrow 3 \qquad Q = 0; \; -w_1' = C_V (T_2 - T_1)$

Rev. adiabat $\Rightarrow \left(\frac{T_2}{T_1}\right) = \left(\frac{V_2}{V_3}\right)^{\gamma - 1}$

$3 \rightarrow 4 \qquad \Delta U = 0; \quad Q2 = \; w_2 = \int_3^4 p\,dV = \bar{R} T_2 \ln\left(\frac{V_4}{V_3}\right)$

$4 \rightarrow 1 \qquad Q = 0; \; -w_2' = C_V (T_1 - T_2)$

Rev. adiabat $\Rightarrow \left(\frac{T_1}{T_2}\right) = \left(\frac{V_4}{V_1}\right)^{\gamma - 1}$

$$\boxed{\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} = 0} \Rightarrow \frac{|Q_L|}{|Q_H|} = \frac{T_L}{T_H}$$

$$\eta_{real} = 1 - \frac{|Q_L|}{|Q_H|}$$

$$\eta_{ideal} = 1 - \frac{T_L}{T_H}$$

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1. THE REVERSE CARNOT CYCLE_ with LV substance

$$COP = \beta_R = \frac{|Q_L|}{|W|} = \frac{|Q_L|}{|Q_H|-|Q_L|} = \frac{1}{\frac{|Q_H|}{|Q_L|}-1}$$

REAL

$$\boxed{\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} = 0} \Rightarrow \boxed{\oint \frac{\delta Q_{rev}}{T} = 0}$$

$$COP = \beta_R = \frac{1}{\frac{T_H}{T_L}-1}$$

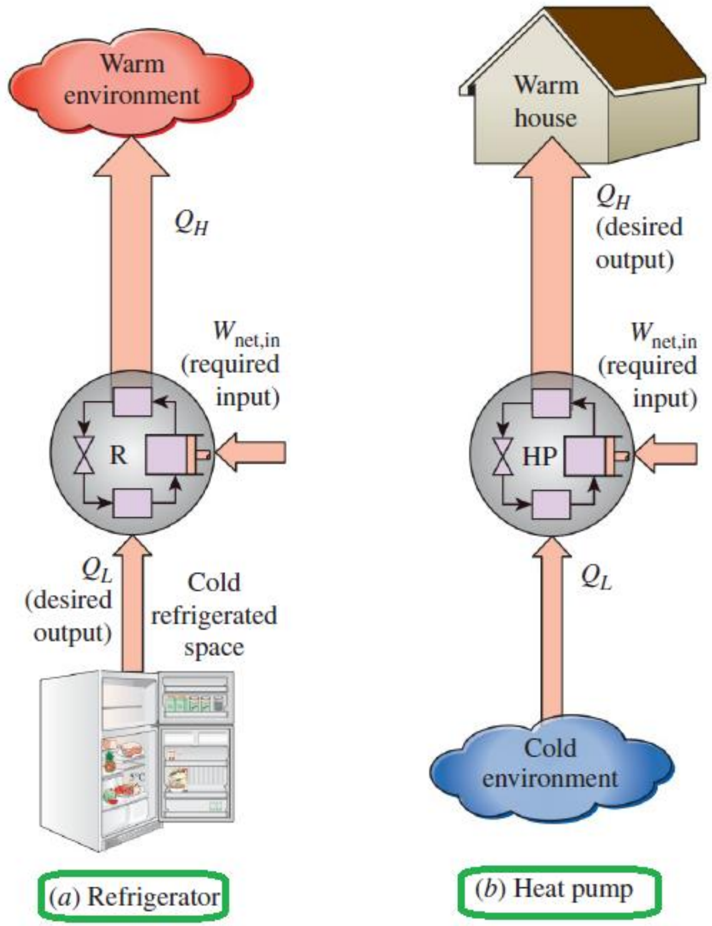
IDEAL

$$COP_{HP} = \beta_{HP} = \frac{|Q_H|}{|W|} = \frac{|Q_H|}{|Q_H| - |Q_L|}$$

REAL

$$COP_{HP} = \beta_{HP} = \frac{1}{1 - \frac{T_L}{T_H}}$$

IDEAL



(*a*) Refrigerator (*b*) Heat pump

Notice that both COPs increase as the difference between the two temperatures decreases, that is, as *TL* rises or *TH* falls.

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Forma cuantitativa:

$$\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} = 0$$

$$\eta = 1 - \left|\frac{Q_L}{Q_H}\right| \rightarrow \text{Real}$$

$$\boxed{\eta_{rev} = 1 - \left|\frac{T_L}{T_H}\right|} \rightarrow \text{Ideal}$$

$$COP_{HP} = \beta_{HP} = \frac{|Q_H|}{|Q_H| - |Q_L|} \rightarrow \text{Real}$$

$$\boxed{{}_{rev}COP_{HP} = \beta_{HP} = \frac{|T_H|}{|T_H| - |T_L|}} \rightarrow \text{Ideal}$$

$$COP_R = \beta_R = \frac{|Q_L|}{|Q_H| - |Q_L|} \rightarrow \text{Real}$$

$$\boxed{{}_{rev}COP_R = \beta_R = \frac{|T_L|}{|T_H| - |T_L|}} \rightarrow \text{Ideal}$$

Real > ideal $\Rightarrow$ Imposible

Real = ideal $\Rightarrow$ Reversible

Real < ideal $\Rightarrow$ Irreversible (posible)
↳ hay fricción ETC

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Example 3:

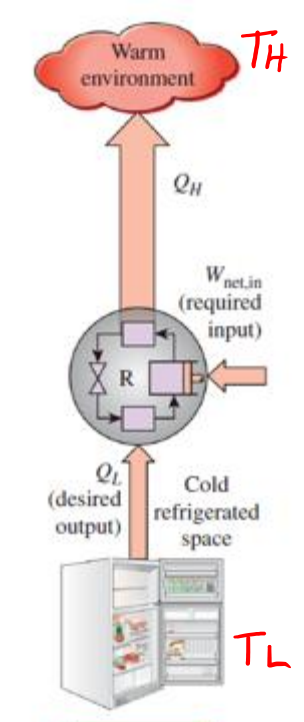
A refrigeration cycle operating between two reservoirs receives energy $\dot{Q}_L$ from a cold reservoir at $T_L = 275\ \mathrm{K}$ and rejects energy $\dot{Q}_H$ to a hot reservoir at $T_H = 315\ \mathrm{K}$. For each of the following cases, determine whether the cycle operates reversibly, operates irreversibly, or is impossible:

(a) $|\dot{Q}_L| = 1000\ \mathrm{kW}, |\dot{W}_{\mathrm{cycle}}| = 80\ \mathrm{kW}$

(b) $|\dot{Q}_L| = 1200\ \mathrm{kW}, |\dot{Q}_H| = 2000\ \mathrm{kW}$

(c) $|\dot{Q}_H| = 1575\ \mathrm{kW}, |\dot{W}_{\mathrm{cycle}}| = 200\ \mathrm{kW}$

(d) $\beta = 6$



(a) Refrigerator

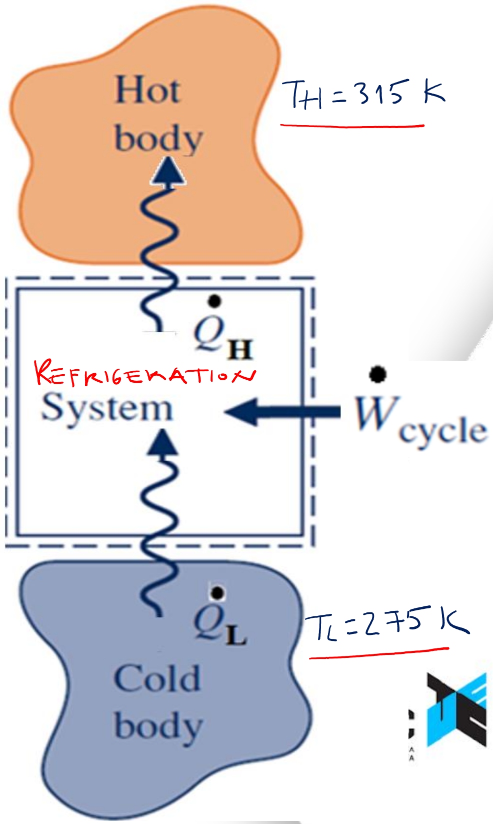
Solution

SCHEMATIC AND GIVEN DATA:

Hot Reservoir: $T_H = 315\ \mathrm{K}$
Cold Reservoir: $T_L = 275\ \mathrm{K}$

ENGINEERING MODEL:

1. The system defined by the dashed line on the accompanying diagram undergoes a refrigeration cycle.



Análisis

The maximum coefficient of performance for a refrigeration cycle operating between two reservoirs is:

$$\beta_{\max} = \frac{T_L}{T_H - T_L} = \frac{275\ \mathrm{K}}{315\ \mathrm{K} - 275\ \mathrm{K}} = 6.875$$

Coefficient of performance for any refrigeration cycle is:

(a) Given $|\dot{Q}_L| = 1000\ \mathrm{kW}$, $|\dot{W}_{\mathrm{cycle}}| = 80\ \mathrm{kW}$, the coefficient of performance determined using these energy data is:

$$\beta = \frac{|\dot{Q}_L|}{|\dot{W}_{\mathrm{cycle}}|} = \frac{1000\ \mathrm{kW}}{80\ \mathrm{kW}} = 12.5$$

Since $\beta = 12.5 > \beta_{\max} = 6.875$, the cycle is impossible.

(b) Given $|\dot{Q}_L| = 1200\ \mathrm{kW}$, $|\dot{Q}_H| = 2000\ \mathrm{kW}$, cycle work can be determined from:

$$|\dot{W}_{\mathrm{cycle}}| = |\dot{Q}_H| - |\dot{Q}_L| = 2000\ \mathrm{kW} - 1200\ \mathrm{kW} = 800\ \mathrm{kW}$$

The coefficient of performance determined using these energy data is:

$$\beta = \frac{|\dot{Q}_L|}{|\dot{W}_{\mathrm{cycle}}|} = \frac{1200\ \mathrm{kW}}{800\ \mathrm{kW}} = 1.5$$

Since $\beta = 1.5 \le \beta_{\max} = 6.875$, the cycle operates irreversibly.

(c) Given $|\dot{Q}_H| = 1575\ \text{kW}$, $|\dot{W}_{\text{cycle}}| = 200\ \text{kW}$, heat transfer associated with the cold reservoir can be determined from:

$$|\dot{Q}_L| = |\dot{Q}_H| - |\dot{W}_{\text{cycle}}| \rightarrow |\dot{Q}_L| = 1575\ \text{kW} - 200\ \text{kW} = 1375\ \text{kW}$$

The coefficient of performance determined using these energy data is

$$\beta = \frac{|1375\text{kJ}|}{|200\text{kJ}|} = 6.875$$

Since $\beta = \beta_{\max} = 6.875$, the cycle operates reversibly.

(d) Given $\beta = 6$, the cycle is irreversible.

Since $\beta = 6 < \beta_{\max} = 6.875$, the cycle operates irreversibly.

- Los enunciados de Kelvin-Planck y Clausius muestran, de manera cualitativa, las restricciones que impone la segunda ley en máquinas térmicas y refrigeradores que operan en ciclo.

- Las eficiencias térmicas y el COP ideales y reales permiten aplicar la segunda ley de forma cuantitativa también para ciclos.

- El balance de entropía generalizará estas ideas anteriores y permitirá cuantificar la s^{da} ley mediante la entropía generada(balance de entropía) esto permitirá no solo analizar ciclos, sino también cualquier proceso, allí podremos ver mas claro los aspectos de la segunda ley tocados hoy.

Thanks!

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