Thermodynamic

2026-1

NEDHER SÁNCHEZ RAMÍREZ

NAUDY LOPEZ

Work-Heat-First Law_S_6 _2_Mass control

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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.

Thermodynamics _ Evaluation

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

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

EXAMEN 1: Todos los temas vistos hasta la semana 6.
EXAMEN 2: Todos los temas vistos hasta la semana 15

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.

OBJECTIVE:

1. **Session 9-10-11: Describe the concepts of energy, heat and work and relate them to the principle of conservation of energy (first law of thermodynamics): Enthalpy, ….Cycles.**

1ra ley → Masa de control (semanas 5-6)

$\Delta E = Q_{NET} - W_{NET}$ (*)

$\Delta E = \Delta U + \Delta E_c + \Delta E_p$

$\Delta H = Q_{NET} - W_{\neq PV}$ ($P = cte$)

↳ AUDITORIO 6.1

* Recordar que existen 2 formas de hacer los balances (AULA 5-2)

Para procesos que ocurren continuamente.

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

↳ Ya lo vimos, practicaremos Hoy

① Visto en semanas 1-4 para estos tipos de sustancia

② Despejamos de la ecuación (*)

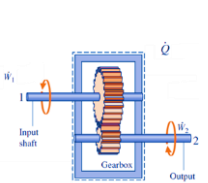
③ Despejamos o lo hallamos analítico

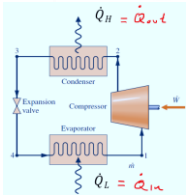
AUDITORIO 6-1

$W_e = IVt$

$W_{PV} = \int P_{ext} dV$

↳ Ya lo vimos
- Resorte lineal
- $P = cte$
- $PV = cte$
- $PV^n = cte$





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Energy Accounting: Energy Balance for Closed Systems

[*change* in the amount of energy contained within a system during some time interval] = [*net* amount of energy transferred *in* across the system boundary by *heat* transfer during the time interval] − [*net* amount of energy transferred *out* across the system boundary by *work* during the time interval]

$$E_2 - E_1 = Q_{NET} - W_{NET}$$ [KJ]

$$\frac{dE}{dt} = \dot{Q}_{NET} - \dot{W}_{NET}$$ $\left[\frac{KJ}{s}\right] = [KW]$

$$\Delta KE + \Delta PE + \Delta U = Q_{NET} - W_{NET}$$ [KJ]

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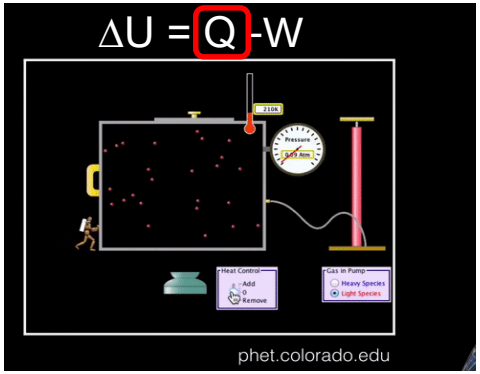
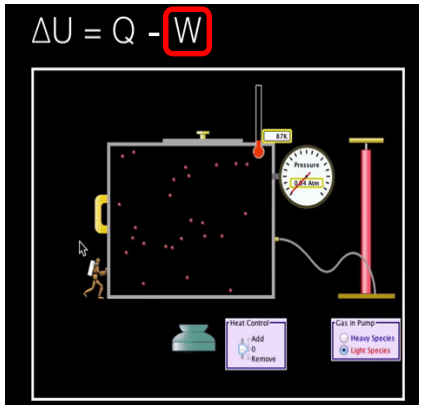
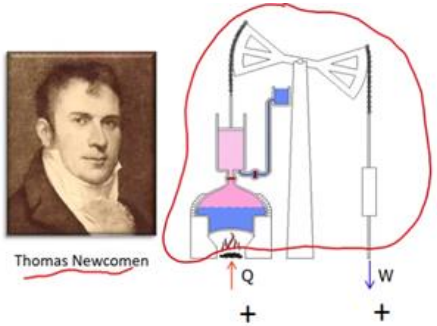
Work, Heat, and the First Law_ Closed system

Let's assume $\Delta V = 0$



Let's assume adiabatic process





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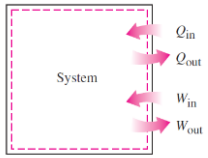
First law of thermodynamics _Closed system_ Multiple inputs

What happens if we have several inputs of heat and work?

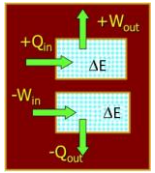
$$(Q_{in} - Q_{out}) + (W_{in} - W_{out}) = \Delta E_{system}$$ or $$Q_{NET} - W_{NET} = \Delta E$$

it is not necessary to assume the convention of signs in the solution, instead know if it is in or out:



Specifying the directions of heat and work.

Assume the convention of signs in the solution



- ***Both need to know the directionality of the W and Q to know if it is in or out or positive or negative.***

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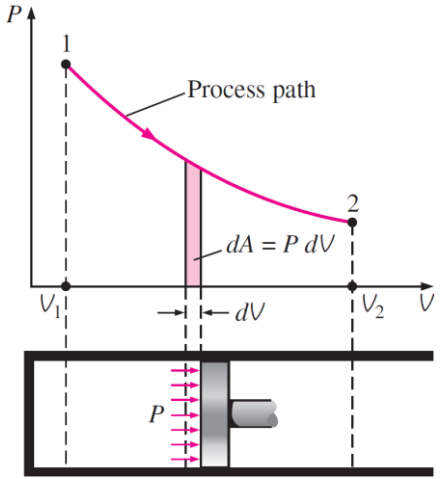
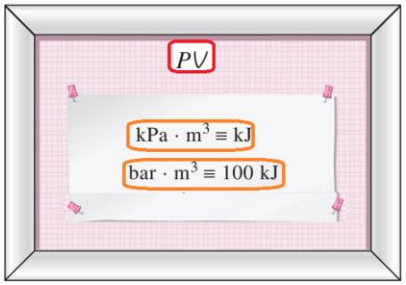
The Moving Boundary Work (PV -Work)

In Mechanics: $W = \int_1^2 \delta W = \int_1^2 \vec{F} \cdot d\vec{x}$

Moving Boundary Work: $\delta W = PAdx \rightarrow \delta W = PdV \rightarrow W = \int_1^2 PdV = W_{boundary} = W_b = W_{pv}$



If the process is quasistatic (or reversible), the pressure within the system can be considered uniform at each instant. Therefore, a single pressure value is representative of the system, and the boundary work can be written as above



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Which of the following equations FOR WORK can be used for any substance, ideal gas or not?

$P = cte$

$$W_b = \int_1^2 P\,dV = P_0 \int_1^2 dV = P_0(V_2 - V_1)$$

$PV^n = cte$

$$C = P_1V_1^n = P_2V_2^n$$

→ UNIVERSAL

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-n}\,dV = C\frac{V_2^{-n+1} - V_1^{-n+1}}{-n+1} = \frac{P_2V_2 - P_1V_1}{1-n}$$

For an ideal gas ($PV = m\bar{R}/\mathrm{M}T$)

$$W_b = \frac{m\bar{R}/\mathrm{M}(T_2 - T_1)}{1-n}$$

↳ GAS IDEAL

$PV = cte$

$$P_1V_1 = P_2V_2 = C$$

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-1}\,dV = PV\ln\left(\frac{V_2}{V_1}\right)$$

↳ UNIVERSAL

Isothermal Compression of an Ideal Gas

$$P_1V_1 = P_2V_2 = C = m\bar{R}/\mathrm{M}T_0$$

$$W_b = \int_1^2 P\,dV = \int_1^2 CV^{-1}\,dV = m\bar{R}/\mathrm{M}T_0\ln\left(\frac{V_2}{V_1}\right)$$

↳ GAS IDEAL

→ $P = C_1 + C_2V$

* RESORTE LINEAL

↳ UNIVERSAL

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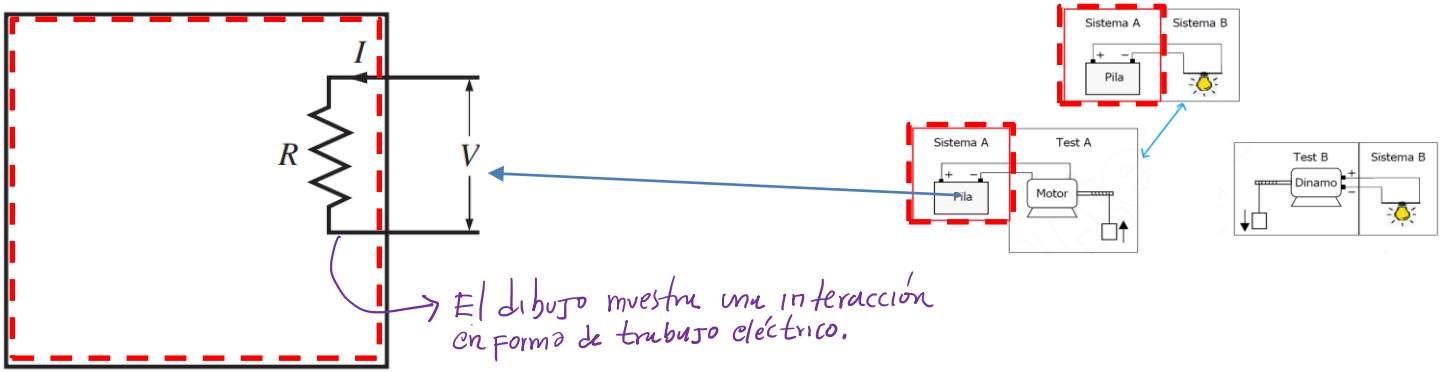
- **DEFINITION: Work -- is done by a system (on its surroundings) if the sole effect on everything external to the system could have been the raising of a weight**



When both **V** and I remain constant during the time interval Δt

$$|\dot{W}_e| = \mathbf{V}I \quad \text{(W)} \quad \text{(J/s = W)} \qquad |W_e| = \mathbf{V}I\,\Delta t \quad \text{(J)} \qquad |W_e| = \mathbf{V}I\,\Delta t = (\text{V})(\text{A})(\text{s}) = \text{J}$$

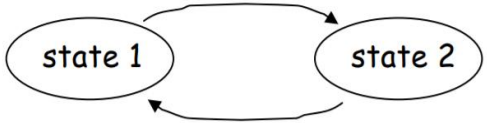
$$|W_e| = (\text{V})(\text{A})(\text{s})\left(\frac{1\ \text{kJ/s}}{1000\ \text{VA}}\right) = \text{kJ}$$

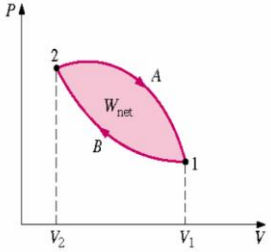
Work, Heat, and the First Law

WORK

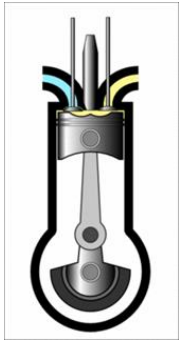
Work (w) is not a function of state.

For a cyclic process, it is possible for $\oint \delta W \neq 0$



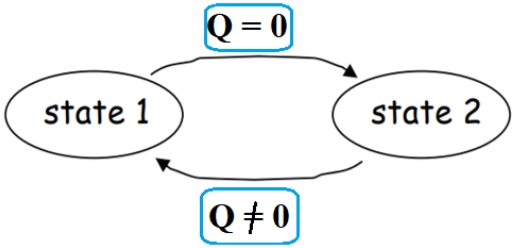


$$\oint \delta W = \oint P dV \neq 0$$



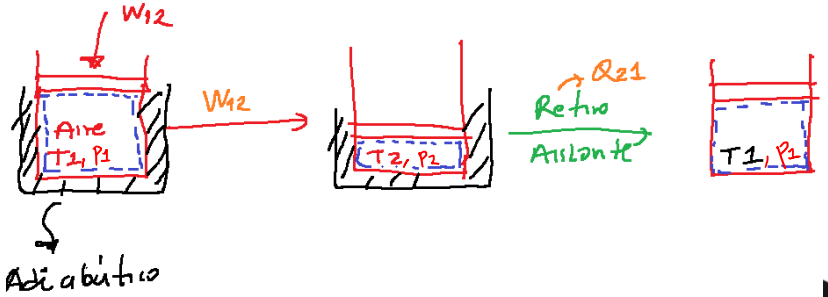
HEAT

Heat (**Q**), like W, is a function of path. Not a state function



$$\oint \delta Q \neq 0$$

System: air inside



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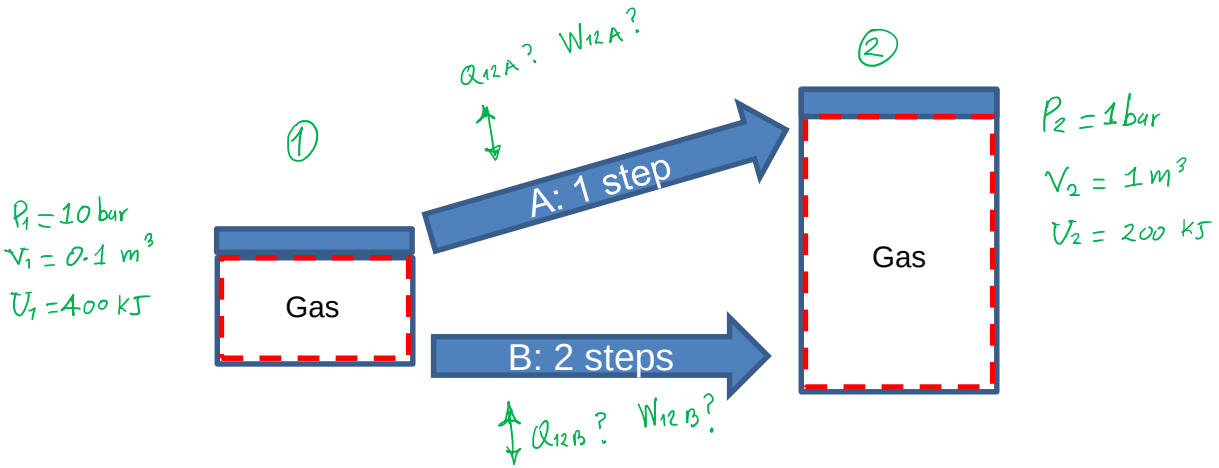
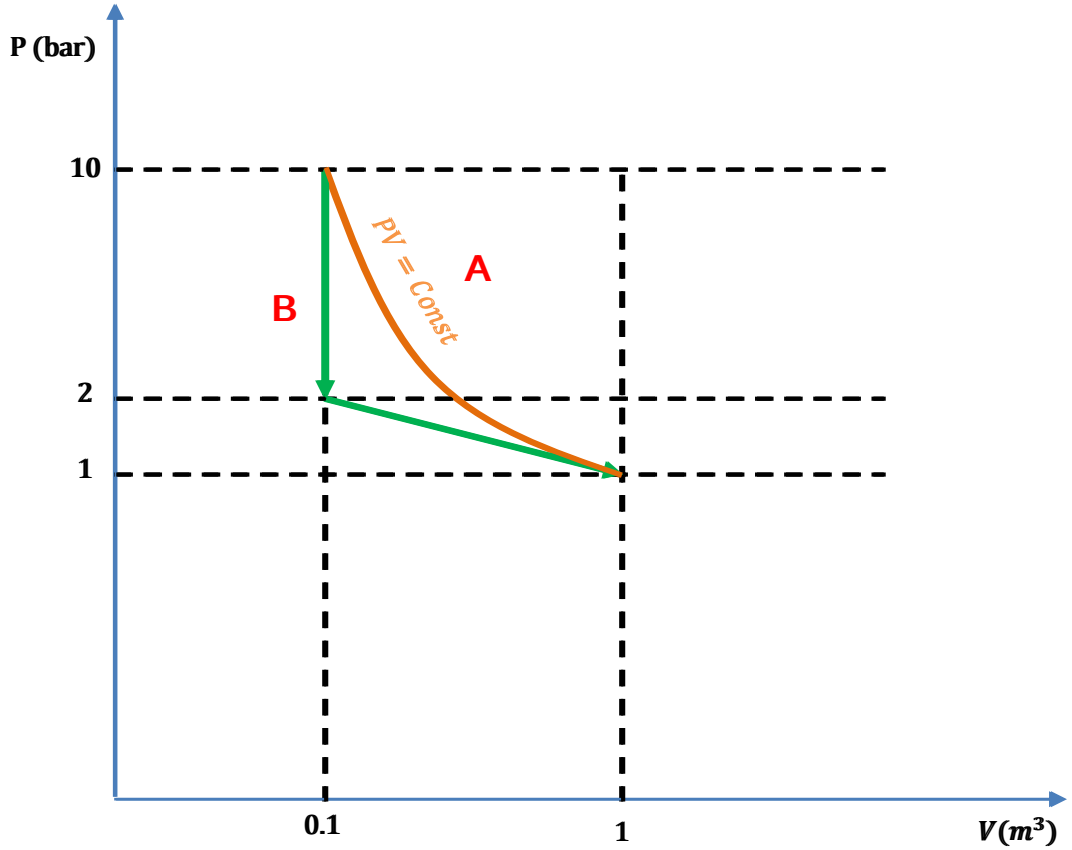
EXAMPLE 2

A gas contained within a piston–cylinder assembly undergoes two processes, A and B, between the *same end states,* 1 and 2, where $P_1 = 10\,bar$, $V_1 = 0.1\,m^3$, $U_1 = 400\,kJ$ and $P_2 = 1\,bar$, $V_2 = 1\,m^3$, $U_2 = 200\,kJ$:

Process A: Process from 1 to 2 during which the pressure volume relation is $PV = constant$.
Process B: **(1-2 but in two steps)** Constant-volume process from state 1 to a pressure of 2 bar, followed by a linear pressure-volume process to state 2.
(a) sketch the <u>two</u> processes on *p[bar]–V[m³]* coordinates, (b) evaluate the work [kJ], and (c) the heat transfer [kJ], for each process (**A** and **B**).
*Kinetic and potential energy effects can be ignored.



a) Processes:



$V(m^3)$

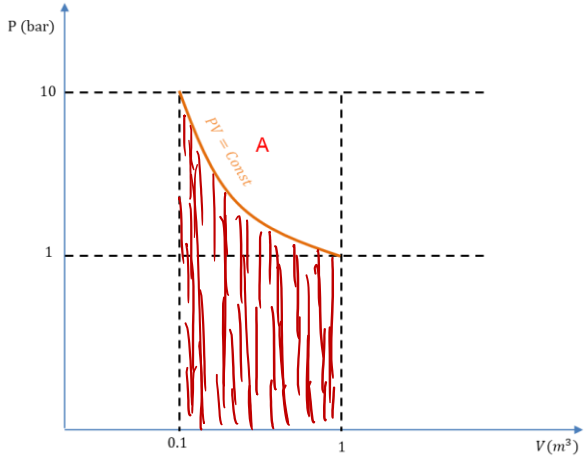
b) Work:

PROCESS A

$$PV = C \rightarrow P = \frac{C}{V}$$

$$W = \int_{V_1}^{V_2} PdV = \int_{V_1}^{V_2} \frac{C}{V} dV = C \ln \frac{V_2}{V_1}$$

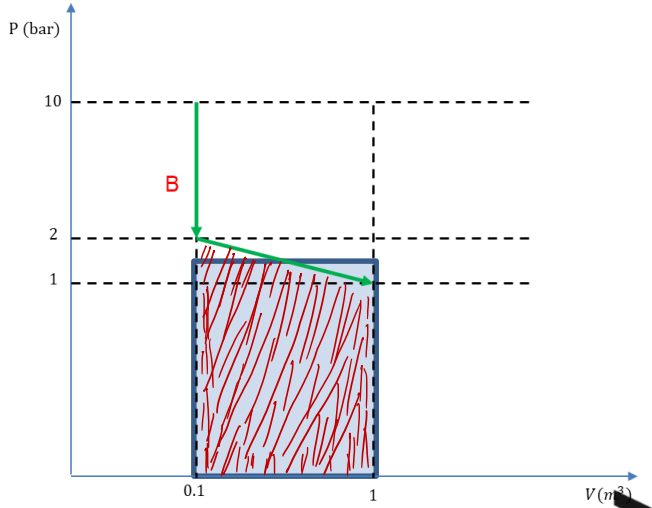
$$W = C \ln \frac{V_2}{V_1} \rightarrow W = (1000 \times 0.1) \times \ln \frac{1}{0.1} \rightarrow \boldsymbol{W = 230.26\ kJ}$$



PROCESS B

$$W = Area\ under\ the\ line\ P = f(V)$$

$$W = \frac{200 + 100}{2} \times (1 - 0.1) \rightarrow \boldsymbol{W = 135\ kJ}$$



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b) Heat transfer:

PROCESS A: First law for closed systems

$$U_2 - U_1 = Q_A - W$$
$$200 - 400 = Q_A - 230.26$$
$$\boxed{Q_A = 30.26\ kJ}$$

PROCESS B: First law for closed systems

$$U_2 - U_1 = Q_B - W$$
$$200 - 400 = Q_B - 135$$
$$\boxed{Q_B = -65\ kJ}$$

ΔU es igual pero Q_{12} y W_{12} dependen del proceso.

Porque si es isotérmico $\Delta U \neq 0$ para el gas? { IDEAL? REAL?

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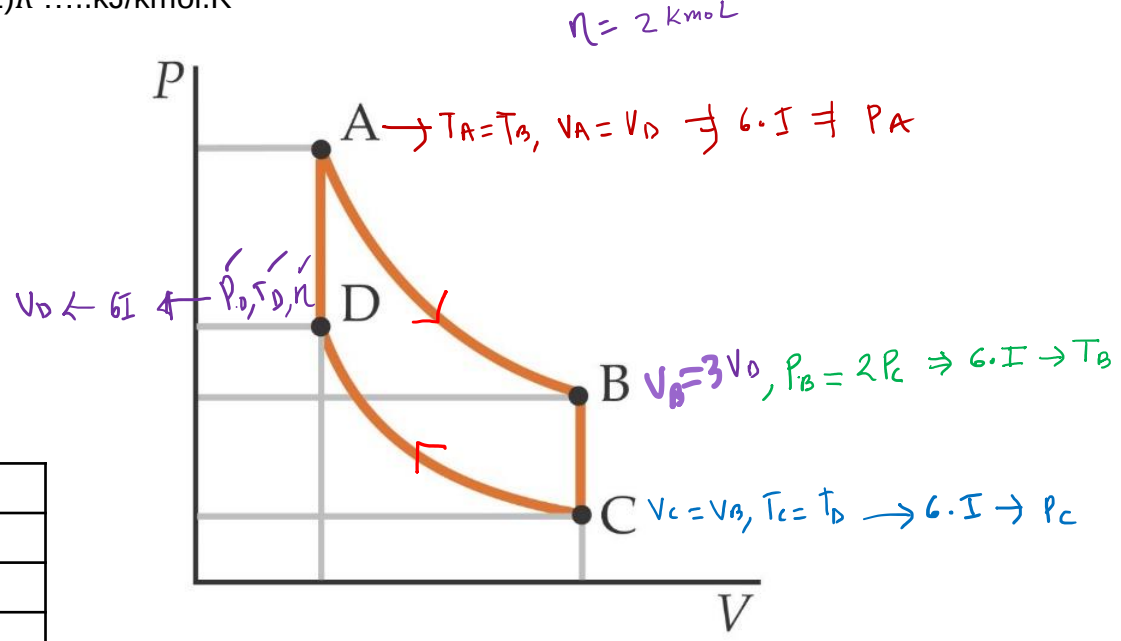
4.The First Law of Thermodynamics. Cyclic Processes. P-V Diagrams

At point D in figure the pressure and temperature of 2 kmol of an ideal monoatomic gas are 2 atm and 360 K. The volume of the gas at point B on the PV diagram is three times that at point D and its pressure is twice that a point C. Paths AB and DC represent isothermal processes. The gas is carried through a complete cycle along the path DABCD. Determine the total work done by the gas and the heat supplied to the gas along each portion of the cycle. Cv = (3/2)$\overline{R}$ …..kJ/kmol.K



State	P	V	T
	(kPa)	(m^3)	(K)
A			
B			
C			
D			

The First Law of Thermodynamics. Cyclic Processes. P-V Diagrams

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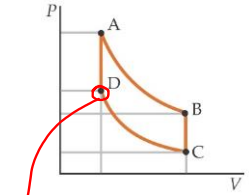
We can find temperatures, pressures and volumes at all points for this idea monoatomic gas (3 degrees of freedom) using the ideal-gas law and the work for each process by finding the areas under each curve. We can find de heat exchanged for each process from de heat capacities and the initial and final temperatures for each process.

Total work done by the gas

$$W_{tot} = W_{D\to A} + W_{A\to B} + W_{B\to C} + W_{C\to D}$$



Todo conocido excepto V_D

Volume of state D

$$V_D = \frac{n\bar{R}T_D}{P_D}$$

dato

$$V_D = \frac{2 \times 8.314 \times 360}{2 \times 101.3}$$

dato → atm to kpa

$$V_D = 29.5463\ \mathrm{m}^3$$

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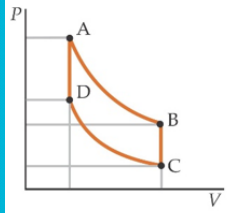

Defining state C

$V_C = V_B = 3V_D$ (Isobaric; data)

$V_C = 88.6389\ \text{m}^3$

$T_C = T_D = 360\ \text{K}$ (Isothermal)

$$P_C = \frac{n\bar{R}T_C}{V_C} = \frac{2 \times 8.314 \times 360}{88.6389}$$

$P_C = 67.5333\ \text{kPa}$

Defining state B

$P_B = 2P_C = 135.0666\ \text{kPa}$

$$T_B = \frac{P_B V_B}{n\bar{R}} = \frac{135.0666 \times 88.6389}{2 \times 8.314}$$ ($V_B = V_C$)

$T_B = 719.9997\ \text{K}$

Defining state A

$T_A = T_B = 719.9997\ \text{KK}$

$V_A = V_D = 29.5463\ \text{m}^3$

$$P_A = \frac{n\bar{R}T_A}{V_A} = \frac{2 \times 8.314 \times 719.9997}{29.5463}$$

$P_A = 405.1998\ \text{kPa}$

State	P	V	T
	(kPa)	(m^3)	(K)
A	405.1998	29.5463	719.9997
B	135.0666	88.6389	719.9997
C	67.5333	88.6389	360
D	202.60	29.5463	360

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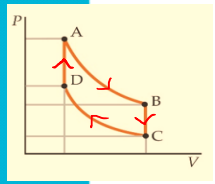

Path D-A
(V = constant)

$W_{D-A} = 0$ kJ

$\Delta U_{D-A} = Q_{D-A} - W_{D-A}$

$nc_v\Delta T = Q_{D-A} - 0$

$$Q_{D-A} = 2 \times \left(\frac{3}{2} \times 8.314\right) \times (719.9997 - 360)$$

$Q_{D-A} = 8979.1125$ kJ

Path B-C
(V = constant)

$W_{B-C} = 0$ kJ

$\Delta U_{B-C} = Q_{B-C} - W_{B-C}$

$nc_v\Delta T = Q_{B-C} - 0$

$$Q_{B-C} = 2 \times \left(\frac{3}{2} \times 8.314\right) \times (360 - 719.9997)$$

$Q_{B-C} = -8979.1125$ kJ

Path A-B
(T = constant)

$\Delta U_{A-B} = 0$ kJ

$0 = Q_{A-B} - W_{A-B}$

$$Q_{A-B} = n\bar{R}T_{A-B} \ln\frac{V_B}{V_A}$$

$$Q_{A-B} = 2 \times 8.314 \times 719.9997 \times \ln\frac{88.6389}{29.5463}$$

$Q_{A-B} = 13152.7566$ kJ

Path C-D
(T = constant)

$\Delta U_{C-D} = 0$ kJ

$0 = Q_{C-D} - W_{C-D}$

$$Q_{C-D} = n\bar{R}T_{C-D} \ln\frac{V_D}{V_C}$$

$$Q_{C-D} = 2 \times 8.314 \times 360 \times \ln\frac{29.5463}{88.6389}$$

$Q_{C-D} = -6576.3810$ kJ

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The First Law of Thermodynamics. Cyclic Processes. P-V Diagrams

Summarizing

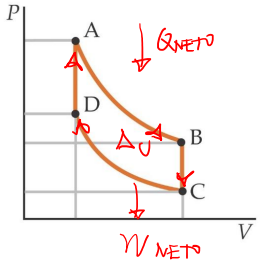
Proceso	Q (kJ)	W (kJ)	ΔU (kJ)
D→A (isócoro)	8979.1125	0	8979.1125
A→B (isotérmico)	13152.7566	13152.7566	0
B→C (isócoro)	-8979.1125	0	-8979.1125
C→D (isotérmico)	-6576.381	-6576.381	0

Total work done by the gas

$$W_{tot} = W_{D\to A} + W_{A\to B} + W_{B\to C} + W_{C\to D}$$

$$W_{tot} = 0 + 13152.7566 + 0 + (-6576.381)$$

$$W_{tot} = 6576.3756 \text{ kJ}$$



$\Delta U = 0$ → ciclo

$\Delta U = Q_{NETO} - W_{NETO} \Rightarrow Q_{NETO} = W_{NETO}$

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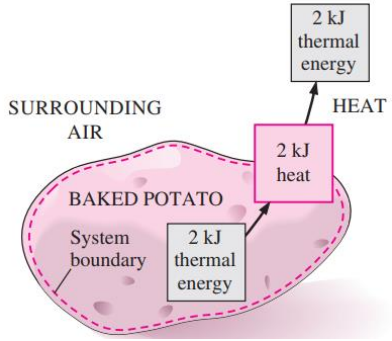
HOW CAN A SYSTEM EXCHANGE ITS ENERGY?

a) Heat

Work too!

Heat is energy in transition. It is recognized only as it crosses the boundary of a system:



$$\frac{dE}{dt} = \dot{Q} - \dot{W} \quad [kW]$$

$$\Delta U = Q - W \quad [kJ]$$

$$\Delta u = q - w \quad \left[\frac{kJ}{kg}\right]$$

Heat transfer *per unit mass* of a system is denoted $\boldsymbol{q}$ and is determined from:

$$q = \frac{Q}{m} \qquad (kJ/kg)$$

$$\dot{Q} \ (kJ/s) \ \text{or} \ kW$$

$$Q = \int_{t_1}^{t_2} \dot{Q}\, dt \ \text{kJ}$$

$w \rightsquigarrow \frac{kJ}{kg}$

$\dot{W} \rightsquigarrow \frac{kJ}{s}$ or kW

$W \rightsquigarrow kJ$

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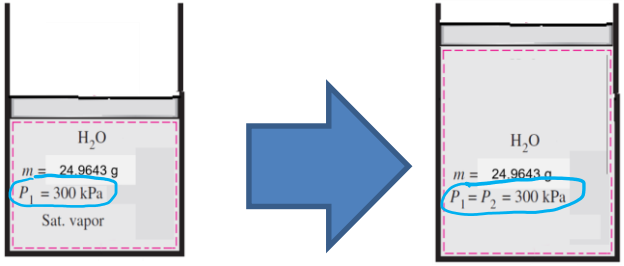

$\Delta U = Q - W$ si $p = cte$ y solo hay trabajo $P-V$ *

$U_2 - U_1 = Q - P(V_2 - V_1)$

$U_2 - U_1 = Q - PV_2 + PV_1$

$(U_2 + PV_2) - (U_1 + PV_1) = Q$

$H_2 \qquad H_1$

$H_2 - H_1 = Q$

En síntesis para un proceso a $P = cte$ (W_{pv} únicamente)

$\Delta U = Q - W \iff \Delta H = Q$

↳ una aplicación es la calorimetría

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First Law_Energy Balance_ Closed system_ Application

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First Law_Energy Balance_ Closed system_ Application

BIOCONNECTIONS The energy required by animals to sustain life is derived from oxidation of ingested food. We often speak of food being *burned* in the body. This is an appropriate expression because experiments show that when food is burned with oxygen, approximately the same energy is released as when the food is oxidized in the body. Such an experimental device is the well-insulated, constant-volume *calorimeter* shown in Fig. 2.15.

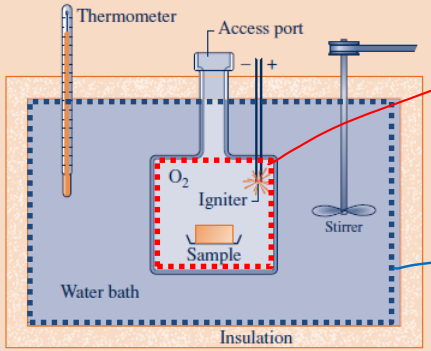

Fig. 2.15 Constant-volume calorimeter.

A carefully weighed food sample is placed in the chamber of the calorimeter together with oxygen (O_2). The entire chamber is submerged in the calorimeter's water bath. The chamber contents are then electrically ignited, fully oxidizing the food sample. The energy released during the reaction within the chamber results in an increase in calorimeter temperature. Using the measured temperature rise, the energy released can be calculated from an energy balance for the calorimeter as the system. This is reported as the calorie value of the food sample, usually in terms of kilocalorie (kcal), which is the "Calorie" seen on food labels.

$V = cte$

$\Delta U = Q - W$

↳ Energía que contiene la comida

$P = cte$

$\Delta H = Q$

$m(h_2 - h_1) = Q$

↳ conocido para el H_2O

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First Law_Energy Balance_ Closed system_ Application

until 2

How is the energy balance for the system?

$$Q - W = \Delta U$$

https://www.youtube.com/watch?v=wwJG2JVg6qM

First Law_Energy Balance_ Closed system_ Application

Constant Pressure Calorimeter

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

sistema: H_2O ($p = cte$)

$\Delta H = Q$

↳ calor liberado en la Rxn química

$m(h_2 - h_1)$

↳ propiedades conocidas para el H_2O

https://www.youtube.com/shorts/NMGRQhygMEM

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4–5 ▪ INTERNAL ENERGY, ENTHALPY, AND SPECIFIC HEATS OF SOLIDS AND LIQUIDS

A substance whose specific volume (or density) is constant is called an **incompressible substance**. The specific volumes of solids and liquids essentially remain constant during a process (Fig. 4–33). Therefore, liquids and solids can be approximated as incompressible substances without sacrificing much in accuracy. The constant-volume assumption should be taken to imply that the energy associated with the volume change is negligible compared with other forms of energy. Otherwise, this assumption would be ridiculous for studying the thermal stresses in solids (caused by volume change with temperature) or analyzing liquid-in-glass thermometers.

It can be mathematically shown that (see Chap. 12) the constant-volume and constant-pressure specific heats are identical for incompressible substances (Fig. 4–34). Therefore, for solids and liquids, the subscripts on c_p and c_v can be dropped, and both specific heats can be represented by a single symbol c. That is,

$$c_p = c_v = c \tag{4–32}$$

This result could also be deduced from the physical definitions of constant-volume and constant-pressure specific heats. Specific heat values for several common liquids and solids are given in Table A–3.

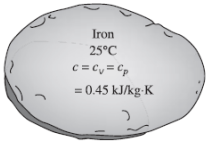


FIGURE 4–34
The c_v and c_p values of incompressible substances are identical and are denoted by c.

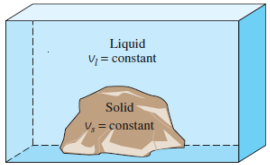


FIGURE 4–33
The specific volumes of incompressible substances remain constant during a process.

Internal Energy Changes

Like those of ideal gases, the specific heats of incompressible substances depend on temperature only. Thus, the partial differentials in the defining equation of c_v can be replaced by ordinary differentials, which yield

$$du = c_v dT = c(T)\, dT \tag{4–33}$$

The change in internal energy between states 1 and 2 is then obtained by integration:

$$\Delta u = u_2 - u_1 = \int_1^2 c(T)\, dT \quad \text{(kJ/kg)} \tag{4–34}$$

The variation of specific heat c with temperature should be known before this integration can be carried out. For small temperature intervals, a c value at the average temperature can be used and treated as a constant, yielding

$$\Delta u \cong c_{avg}(T_2 - T_1) \quad \text{(kJ/kg)} \tag{4–35}$$

Enthalpy Changes

Using the definition of enthalpy $h = u + Pv$ and noting that v = constant, the differential form of the enthalpy change of incompressible substances can be determined by differentiation to be

$$dh = du + v\, dP + P\, \overset{\nearrow 0}{dv} = du + v\, dP \tag{4–36}$$

Integrating,

$$\Delta h = \Delta u + v\, \Delta P \cong c_{avg}\, \Delta T + v\, \Delta P \quad \text{(kJ/kg)} \tag{4–37}$$

For *solids*, the term $v\,\Delta P$ is insignificant and thus $\Delta h = \Delta u \cong c_{avg}\Delta T$. For *liquids*, two special cases are commonly encountered:

1. *Constant-pressure processes,* as in heaters ($\Delta P = 0$): $\Delta h = \Delta u \cong c_{avg}\Delta T$
2. *Constant-temperature processes,* as in pumps ($\Delta T = 0$): $\Delta h = v\,\Delta P$

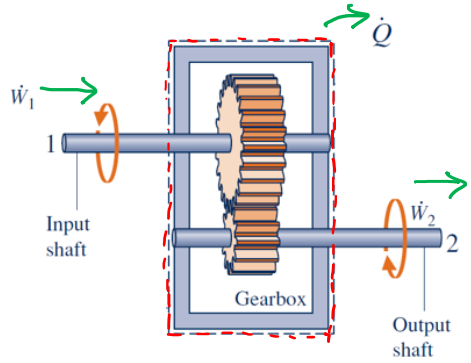
For a process between states 1 and 2, the last relation can be expressed as $h_2 - h_1 = v(P_2 - P_1)$. By taking state 2 to be the compressed liquid state at a given T and P and state 1 to be the saturated liquid state at the same temperature, the enthalpy of the compressed liquid can be expressed as

$$h_{@P,T} \cong h_{f\,@\,T} + v_{f\,@\,T}(P - P_{sat\,@\,T}) \tag{4–38}$$

as discussed in Chap. 3. This is an improvement over the assumption that the enthalpy of the compressed liquid could be taken as h_f at the given temperature (that is, $h_{@\,P,T} \cong h_{f\,@\,T}$). However, the contribution of the last term is often very small, and is neglected. (Note that at high temperature and pressures, Eq. 4–38 may overcorrect the enthalpy and result in a larger error than the approximation $h \cong h_{f\,@\,T}$.)

Let's see what happens in continuous operation

Energy Accounting: Energy Balance for Closed Systems



The instantaneous **time rate form of the energy balance** is :

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

Ejemplo 2.4 Shapiro.

Cycles

HOMEWORK-SEE EXAMPLE 2.4 SHAPIRO

EXAMPLE 2.4

Evaluating Energy Transfer Rates of a Gearbox at Steady State

During steady-state operation, a gearbox receives 60 kW through the input shaft and delivers power through the output shaft. For the gearbox as the system, the rate of energy transfer by convection is

$$\dot{Q} = -hA(T_b - T_f)$$

where $h = 0.171\ \text{kW/m}^2 \cdot \text{K}$ is the heat transfer coefficient, $A = 1.0\ \text{m}^2$ is the outer surface area of the gearbox, $T_b = 300\ \text{K}$ (27°C) is the temperature at the outer surface, and $T_f = 293\ \text{K}$ (20°C) is the temperature of the surrounding air away from the immediate vicinity of the gearbox. For the gearbox, evaluate the heat transfer rate and the power delivered through the output shaft, each in kW.

SOLUTION

Known: A gearbox operates at steady state with a known power input. An expression for the heat transfer rate from the outer surface is also known.

Find: Determine the heat transfer rate and the power delivered through the output shaft, each in kW.

Schematic and Given Data:

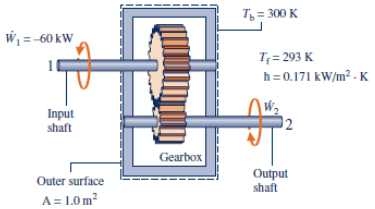


Fig. E2.4

Engineering Model:

1. The gearbox is a closed system at steady state.
2. For the gearbox, convection is the dominant heat transfer mode.

Analysis: Using the given expression for $\dot{Q}$ together with known data, the rate of energy transfer by heat is

❶
$$\begin{aligned}\dot{Q} &= -hA(T_b - T_f)\\ &= -\left(0.171\frac{\text{kW}}{\text{m}^2 \cdot \text{K}}\right)(1.0\ \text{m}^2)(300 - 293)\ \text{K}\\ &= -1.2\ \text{kW}\end{aligned}$$

The minus sign for $\dot{Q}$ signals that energy is carried *out* of the gearbox by heat transfer.

The energy rate balance, Eq. 2.37, reduces at steady state to

❷
$$\frac{dE}{dt}^{0} = \dot{Q} - \dot{W} \quad \text{or} \quad \dot{W} = \dot{Q}$$

The symbol $\dot{W}$ represents the *net* power from the system. The net power is the sum of $\dot{W}_1$ and the output power $\dot{W}_2$

$$\dot{W} = \dot{W}_1 + \dot{W}_2$$

With this expression for $\dot{W}$, the energy rate balance becomes

$$\dot{W}_1 + \dot{W}_2 = \dot{Q}$$

Solving for $\dot{W}_2$, inserting $\dot{Q} = -1.2\ \text{kW}$, and $\dot{W}_1 = -60\ \text{kW}$, where the minus sign is required because the input shaft brings energy *into* the system, we have

❸
$$\begin{aligned}\dot{W}_2 &= \dot{Q} - \dot{W}_1\\ &= (-1.2\ \text{kW}) - (-60\ \text{kW})\\ &= +58.8\ \text{kW}\end{aligned}$$

❹ The positive sign for $\dot{W}_2$ indicates that energy is transferred from the system through the output shaft, as expected.

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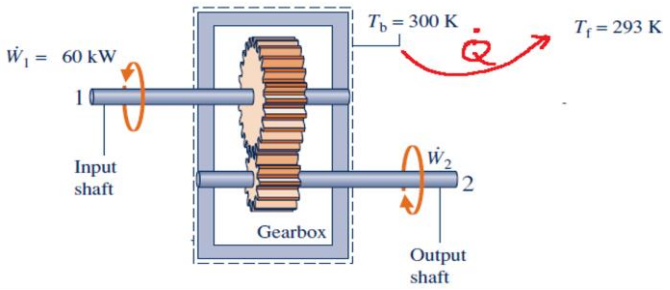
EXAMPLE 4

Evaluating Energy Transfer Rates of a Gearbox at Steady State

During steady-state operation, a gearbox receives 60 kW through the input shaft and delivers power through the output shaft. For the gearbox as the system, the rate of energy transfer by convection is $\dot{Q} = -1.2$ kW.

For the gearbox, the power delivered through the output shaft, each in kW.

Schematic and Given Data:



SOLUTION

Known: A gearbox operates at steady state with a known power input. The heat transfer rate is also known.

Find: Determine power delivered through the output shaft, in kW.

Engineering Model:

1. The gearbox is a closed system at steady state.

$\frac{dE}{dt}^{E.E} = \dot{Q}_{NETO} - \dot{W}_{NETO}$ $\quad -(\dot{W}_1 + \dot{W}_2)$

$\Rightarrow \quad 0 = \dot{Q} - \dot{W}_1 - \dot{W}_2$?

-1.2 KW $\quad -60$ KW

$\Rightarrow \quad \dot{W}_2 = -1.2 + 60$ [KW]

$= 58.8$ KW

Next week: $\frac{dE}{dt} = \dot{Q}_{NET} - \dot{W}_{NET} + \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$

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Let's see what happens in continuous operation
IN A CYCLE

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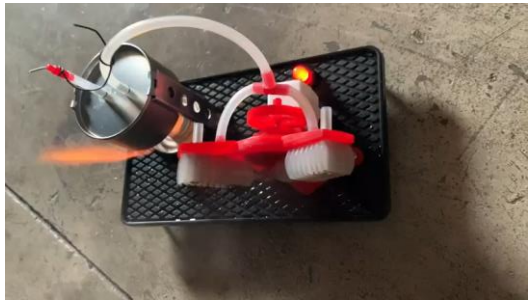
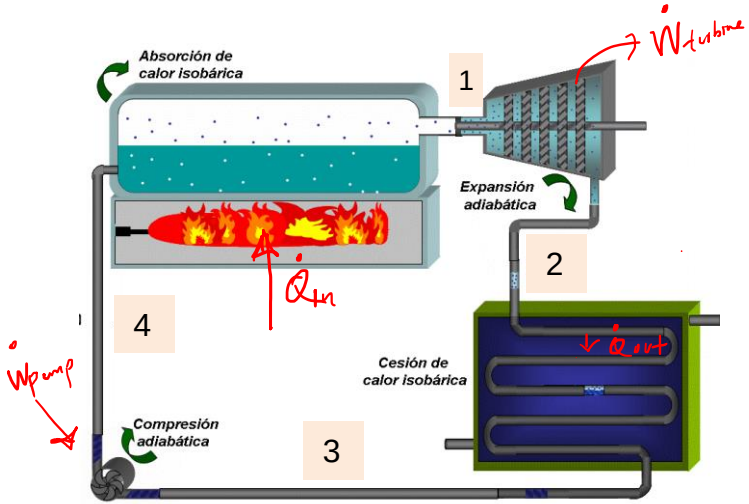
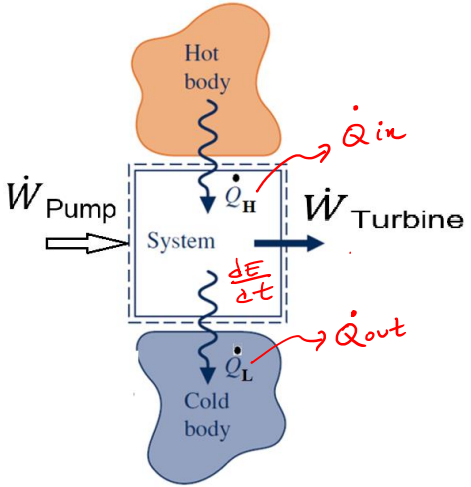
Work-Heat-Firts Law

Remembering the concept of control mass from week 1.and 5





CONTROL MASS

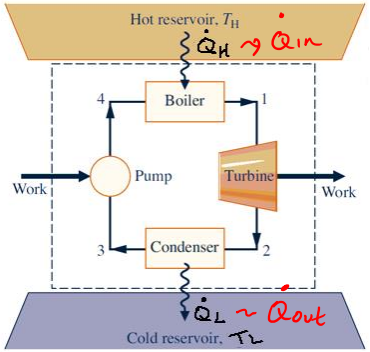


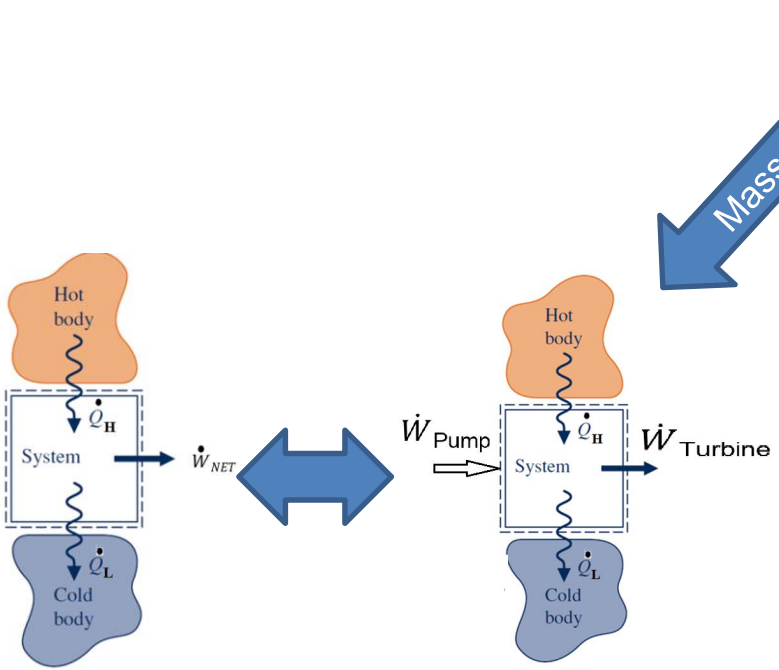
$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$

Work-Heat-Firts Law

Power Cycles

CONTROL MASS





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

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

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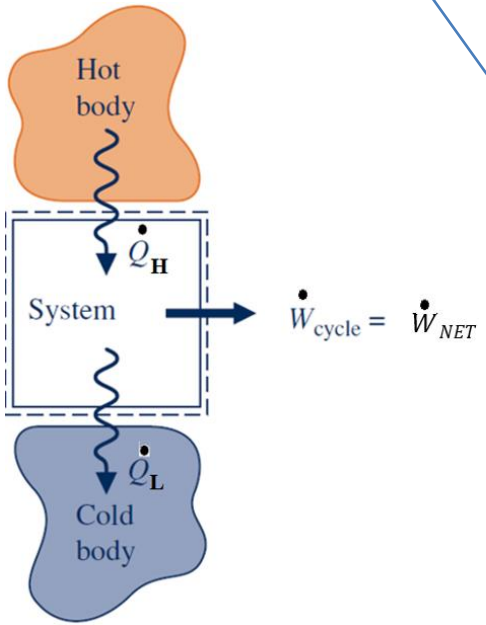
EXAMPLE 5: For a power cycle operating in steady state as shown in Fig., the energy transfer by heat into the cycle, $\dot{Q}_H$, is 800 kW. What is the net work developed, in kW, if the cycle thermal efficiency is 30%? What is the value of $\dot{Q}_L$, in kW?



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

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

$$\eta = \left|\frac{\dot{W}_{NET}}{\dot{Q}_H}\right|$$

$$0.3 = \left|\frac{\dot{W}_{NET}}{800\ kW}\right|$$

$$|\dot{W}_{NET}| = 240\ kW \quad (por\ concepto\ es > 0$$

E.E.

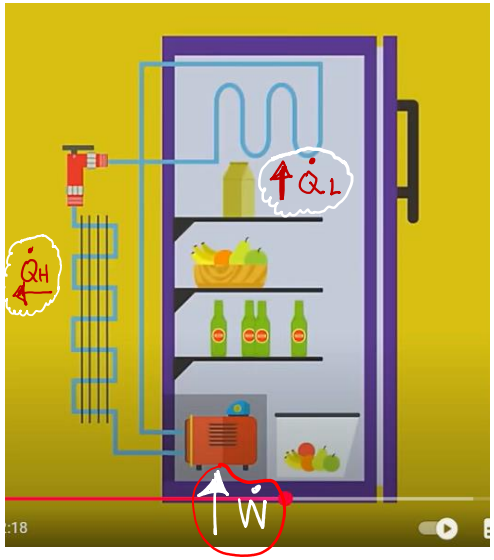
$$\dot{Q}_H + \dot{Q}_L - \dot{W}_{NET} = \frac{dE}{dt}$$

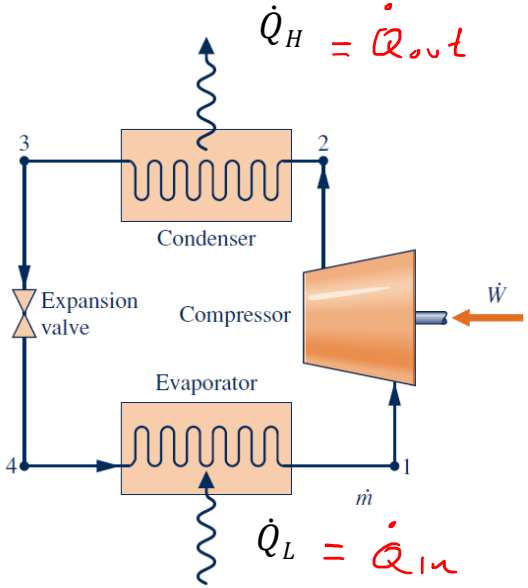
(+) (+)

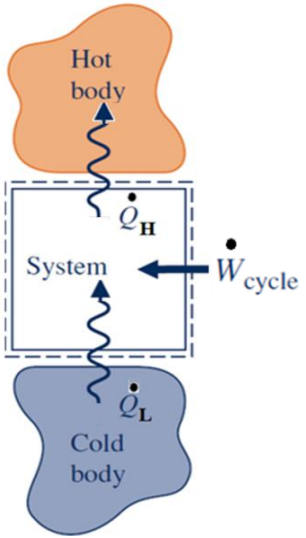
$$800\ \text{kW} + \dot{Q}_L - 240\ kW = 0$$

$$\dot{Q}_L = -560\ kW$$

Refrigeration cycle







$$\mathrm{COP_R} = \boldsymbol{\beta}_\mathrm{R} = \left|\frac{\dot{Q}_L}{\dot{W}}\right|$$

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

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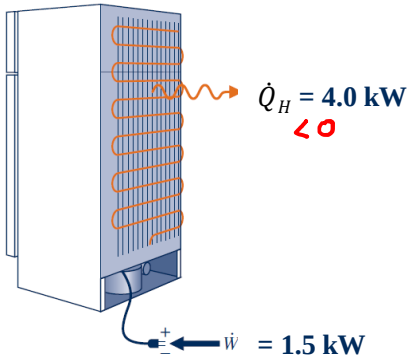
EXAMPLE 6: **The refrigerator shown in Fig. steadily receives a power input of 1.5 kW while rejecting energy by heat transfer to the surroundings at a rate of 4.0 kW. Determine the rate at which energy is removed by heat transfer from the refrigerated space, in kW, and the refrigerator's coefficient of performance.**

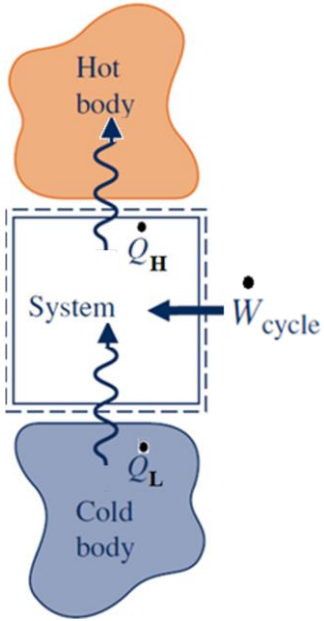


(-) (-)

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

$$-4.0\ kW + \dot{Q}_L + 1.5\ kW = 0$$

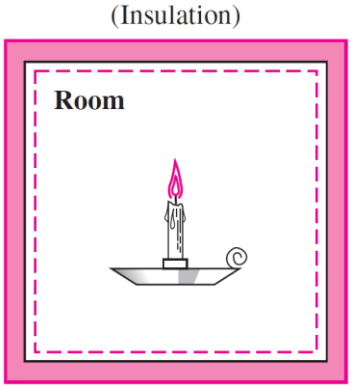
$$\dot{Q}_L = \mathbf{2.5\ kW}$$



$$\text{COP}_R = \boldsymbol{\beta}_R = \left|\frac{\dot{Q}_L}{\dot{W}}\right| = \left|\frac{2.5\ kW}{-1.5\ kW}\right| = \mathbf{1.6667}$$

Burning of a Candle in an Insulated Room

A candle is burning in a well-insulated room. Taking the room (the air plus the candle) as the system, determine **(*a*) if there is any heat transfer during this burning process** and **(*b*) if there is any change in the internal energy of the system.**



Analysis

(*a*) The interior surfaces of the room form the system boundary, as indicated by the dashed lines in the Fig. Heat is recognized as it crosses the boundaries. Since the room is well insulated, we have an adiabatic system and no heat will pass through the boundaries. Therefore, $Q = 0$ for this process.

(*b*) The internal energy involves energies that exist in various forms (sensible, latent, chemical, nuclear). During the process just described, part of the chemical energy is converted to sensible energy. Since there is no increase or decrease in the total internal energy of the system, $\Delta U = 0$ for this process.

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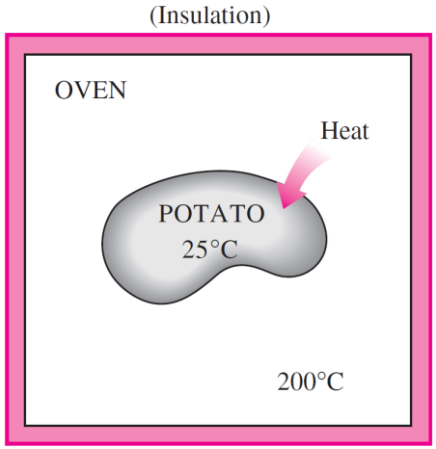
Heating of a Potato in an Oven

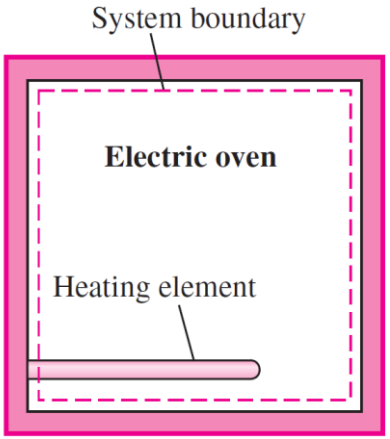
A potato initially at room temperature (25°C) is being baked in an oven that is maintained at 200°C, as shown in the Fig. **Is there any heat transfer during this baking process?**



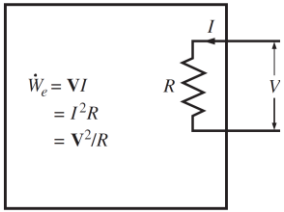
Analysis This is not a well-defined problem since the system is not specified. Let us assume that we are observing the potato, which will be our system. Then the skin of the potato can be viewed as the system boundary. Part of the energy in the oven will pass through the skin to the potato. Since the driving force for this energy transfer is a temperature difference, this is a heat transfer process.

Heating of an Oven by Work/heat Transfer

A well-insulated electric oven is being heated through its heating element. If the entire oven, including the heating element, is taken to be the system, **determine whether this is a heat or work interaction.**



Analysis For this problem, the interior surfaces of the oven form the system boundary, as shown in the Fig. The energy content of the oven obviously increases during this process, as evidenced by a rise in temperature. This energy transfer to the oven is not caused by a temperature difference between the oven and the surrounding air. Instead, it is caused by *electrons* crossing the system boundary and thus doing work. Therefore, **this is a work interaction.**



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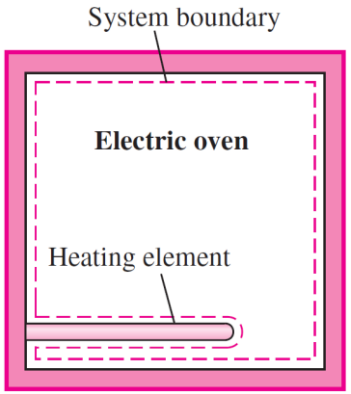
Heating of an Oven by Work/heat Transfer

If the system is taken as only the air in the oven without the heating element. **Determine whether this is a heat or work interaction.**



Analysis This time, the system boundary will include the outer surface of the heating element and will not cut through it, as shown in Fig. Therefore, no electrons will be crossing the system boundary at any point. Instead, the energy generated in the interior of the heating element will be transferred to the air around it as a result of the temperature difference between the heating element and the air in the oven. Therefore, this is a heat transfer process.

Discussion For both cases, the amount of energy transfer to the air is the same. These two examples show that an energy transfer can be heat or work, depending on how the system is selected.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Thanks!