

Introduction to Chemical Engineering

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Office hours: Mondays 16h-19h (CH H4 625) or schedule by email

Fridays, 14 - 17h
2025-2026

Course Schedule

Date	Subject
12-Sep	1. Fundamentals of Material Balances 1.1. Process definition and classification 1.2. Material balance calculations 1.3. Balances on multiple-unit processes
19-Sep	Exercises
26-Sep	1.4. Chemical reaction stoichiometry 1.5. Balances on reactive processes
03-Oct	Review on Material Balances
10-Oct	1.6. Balances on multiple unit reactive processes
17-Oct	2. Energy and Energy Balances 2.1. Energy balances on closed systems 2.2. Open systems at steady state
31-Oct	3. Balances on Non-Reactive Processes 3.1. Energy balance calculation 3.2. Changes in Pressure, Temperature, Phases 3.3. Mixing and Solution
07-Nov	4. Balances on Non-Reactive Processes Problems: Mass and Energy Balances on non-Reactive Systems
14-Nov	Midterm Exam: Mass & Energy Balances non-Reactive Systems
21-Nov	Review Midterm
28-Nov	5. Balances on Reactive Processes 5.1. Heats of reaction/combustion 5.2. Combustion reactions 5.3. Enthalpy of reaction 5.4. Energy balance calculation
05-Dec	6. Energy balances on mixing processes Review
12-Dec	Review and Study Session

Recommended textbook:
Elementary Principles of Chemical Processes
Richard M. Felder & Ronald W. Rousseau

Session V: Friday 17 October 2025

After studying this session you will be able to:

1. Understand the concepts of work and heat (signs!), intrinsic and extensive properties
2. Identify non-reactive **closed** systems & Define an energy balance on them
3. Identify non-reactive **open** systems & Define an energy balance on them

1. Introduction

Introduction to energy balances

By performing energy balances, we answer questions like:

- How much energy is required for pumping 1000 m³/h?
- What is the rate of energy supply in a distillation column?
- A→B exothermic and 75% conversion @400k, what is the rate of energy removal to achieve the target?
- ...
- Is there a cheaper way of achieving my process specifications?
→ Energy is expensive!!!

In the design of a process, we must account for:

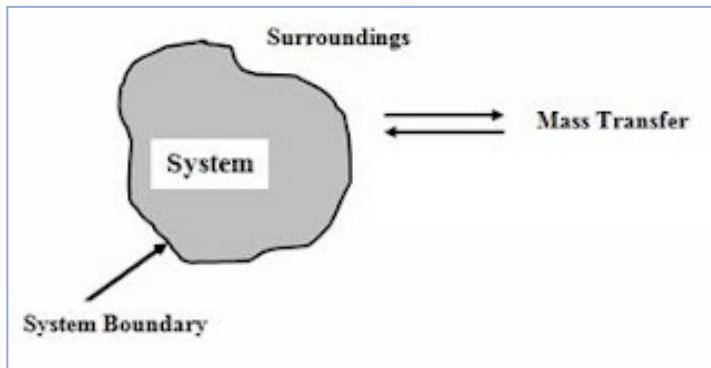
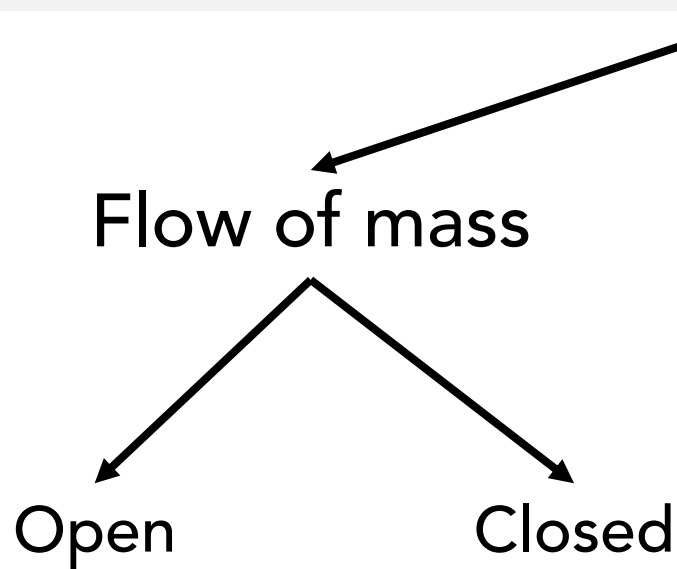
- ✓ the flow of energy into and out of each process unit
- ✓ the overall energy requirement of the process

Recalling the definition of a system

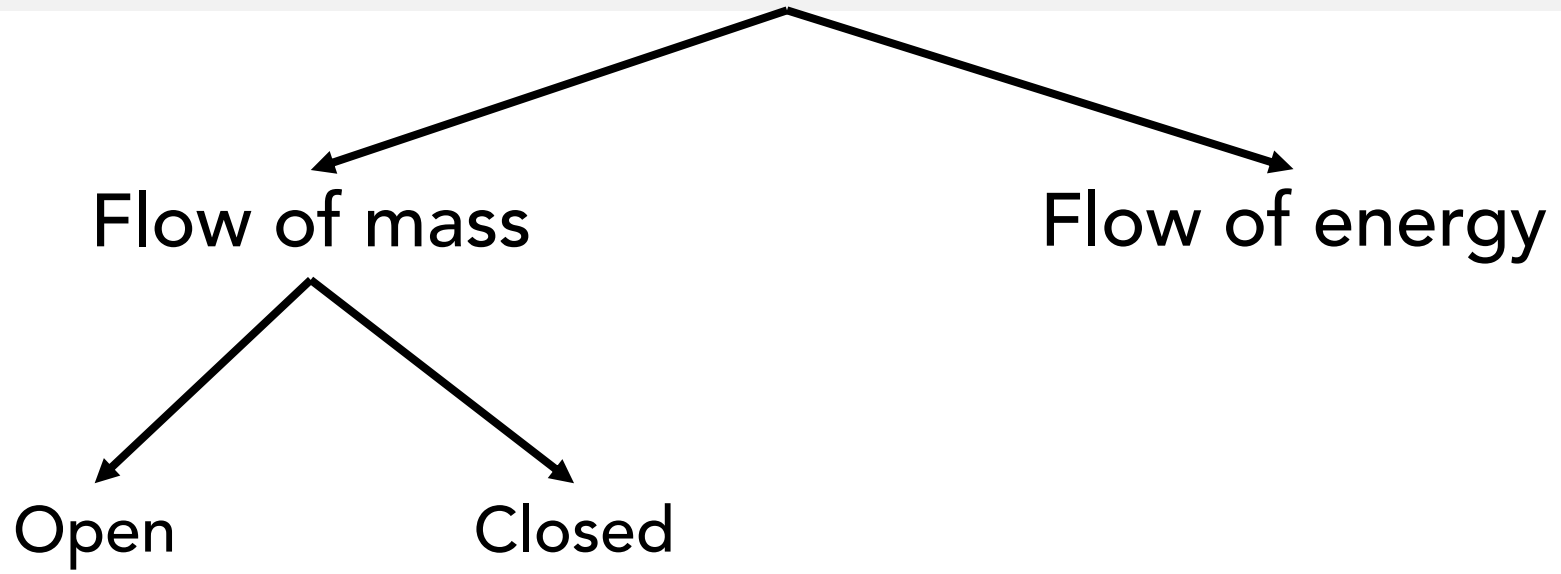


Flow of mass

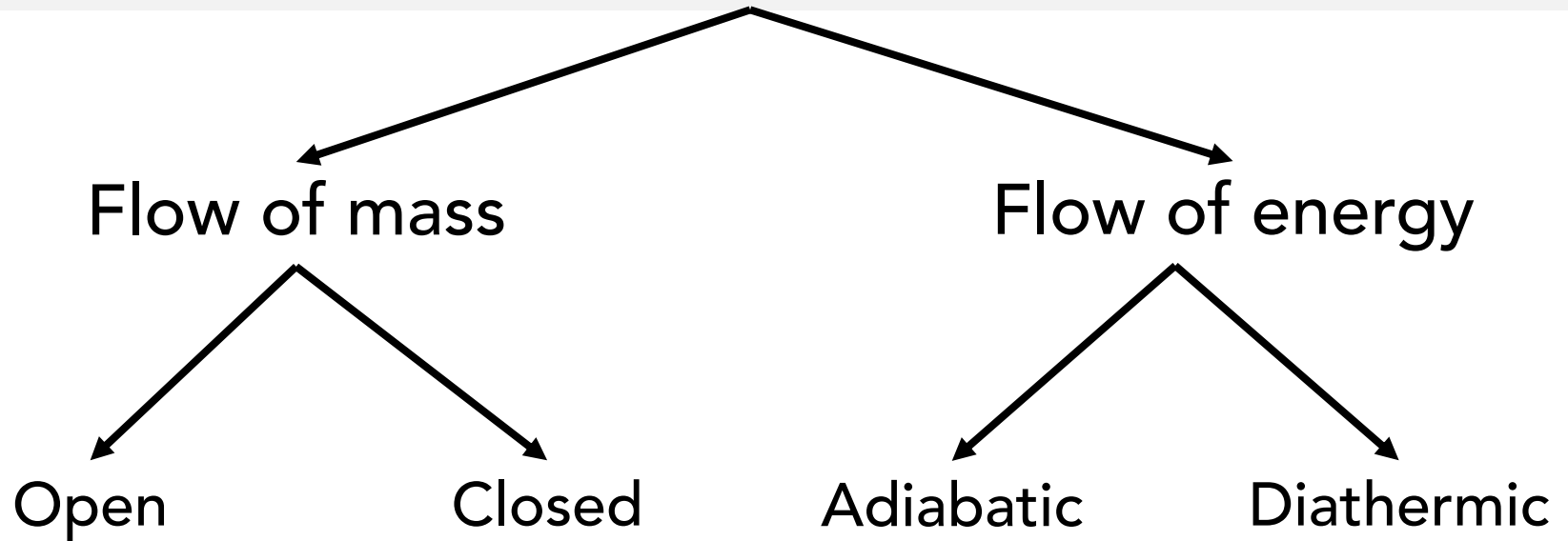
Recalling the definition of a system



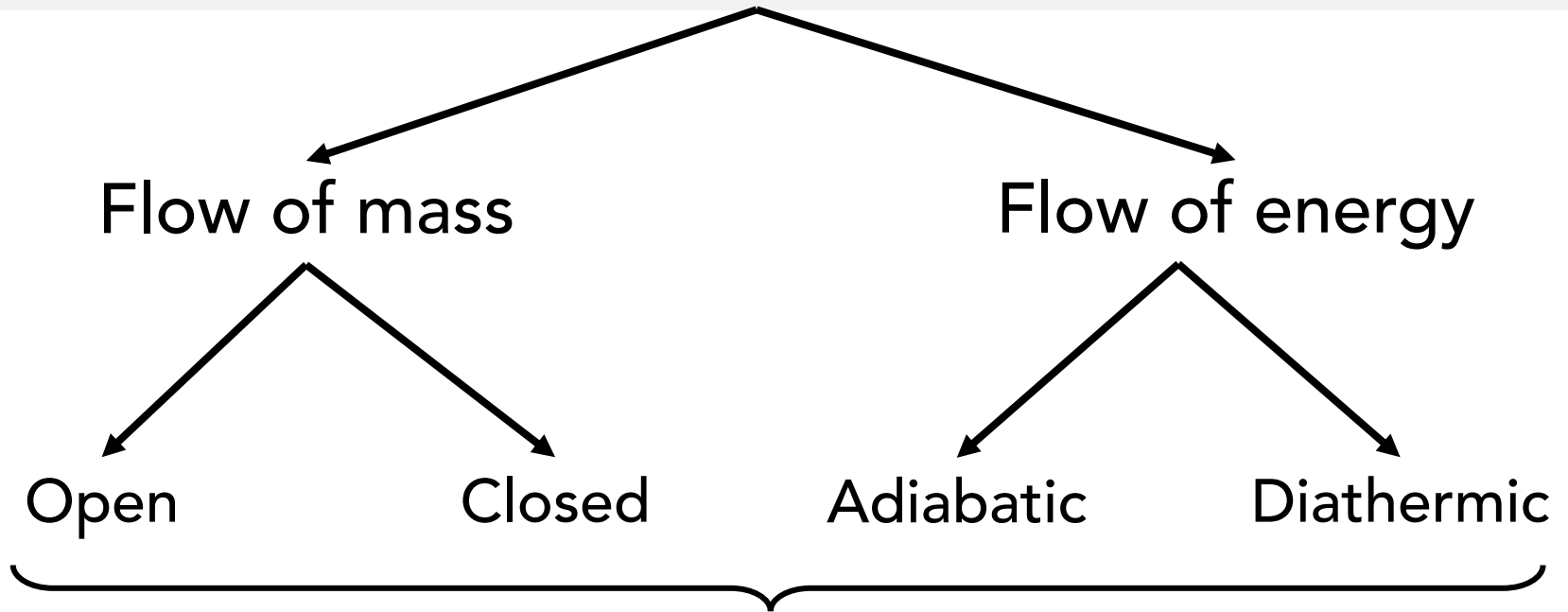
Recalling the definition of a system



Recalling the definition of a system

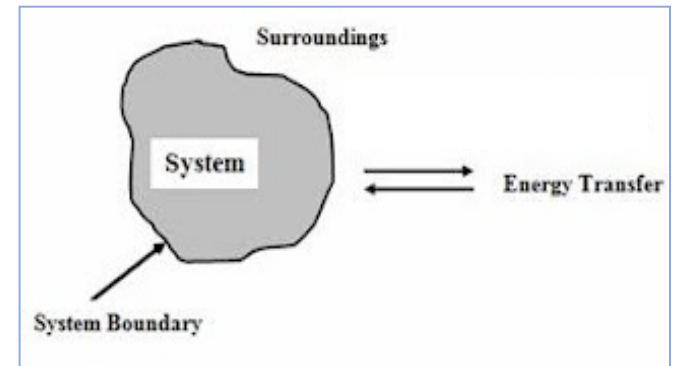
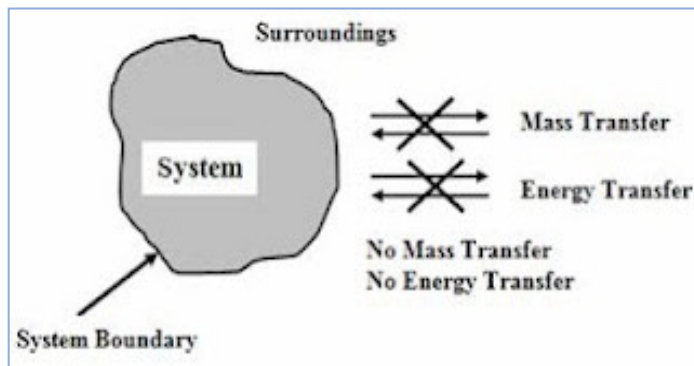


Recalling the definition of a system



Closed + Adiabatic

Closed + Diathermic



Forms and Transfer of energy of a system

The total energy of a system has 3 forms

① Kinetic energy

Energy associated with
movement

② Potential energy

Energy in a potential field
Gravitational, electromagnetic,
...

③ Internal energy

"Everything else"
Molecular energy ...

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The energy is transferred from the environment to a process system (and vice-versa) in 2 ways

A Heat (Q): flow or exchange of energy due to ΔT

- Could enter the system via conduction, convection, or radiation

B Work (W): flow or exchange of energy due to "driving forces" other than temperature (e.g.: voltage, force)

- Could be done on, or by, the system

Clarifications

- Q , W are transferred energies: a system does not possess heat or work
- Signs of Q and W according to this course conventions:

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Heat is positive because the system in effect gains energy when heat enters
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- Signs of Q and W according to this course conventions:
 - $Q > 0$: heat entering the system
Heat is positive because the system in effect gains energy when heat enters
 - $Q < 0$: heat leaving the system
 - $W > 0$: work done BY the system
 - $W < 0$: work done ON the systemThe choice for the sign of work is arbitrary but facilitates the reading of the expression of energy transferred to the system (see next slides):

$$E_{\text{transferred}} = Q - W$$

Types of work

- W_m : mechanical work which is due to movement of the boundary, (e.g., piston)
- W_{el} : electrical work (e.g., electrical generator)
- W_s : shaft work (e.g., mixing, turbine, pump)
- W_{fl} : flow work
 - Work done to push a fluid into system (use example of pistons moving fast)
 - Work done to push fluid out of system

Example 1: Determine the sign of the work transferred to the system in the following cases:

- a piston compress the system
- a generator gives energy to the system
- a pump applies work into a stream (system)
- a turbine acts on a stream (system)
- a fluid (system) flows into a piston

Classification of properties

- Intensive property: is a physical property of a system that does not depend on the system size or the amount of material in the system.

E.g.: density, P, T

- Extensive property: is a property that is directly proportional to the amount of material in the system.

E.g.: mass and volume, internal energy (U)

- Specific property: is a property that depends on, or is calculated based on, another measurable property, and are denoted with a "hat".

E.g.: density is considered 'specific' because it can be calculated from volume and mass

How to calculate an extensive property for the whole system?

- for internal energy of the system: $U(\text{J}) = m(\text{kg}) \hat{U}(\text{J/kg})$
- for the continuous flow: $\dot{U}(\text{J/s}) = \dot{m}(\text{Kg/s}) \hat{U}(\text{J/kg})$

Defining the energy balance on a system

Recall the mother of all equations for conservation of mass:

$$\text{Acc} = \text{In} - \text{Out} + \text{Gen} - \text{Cons}$$

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Law of conservation of energy:

This states that: if E is the entire amount of energy in the system, then:

$$E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$$

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$$E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$$

$$E_{\text{in}} = \sum_{\text{input streams}} m_j \hat{E}_j \quad , \quad E_{\text{out}} = \sum_{\text{output streams}} m_j \hat{E}_j$$

$$E_{\text{transferred}} = Q - W$$

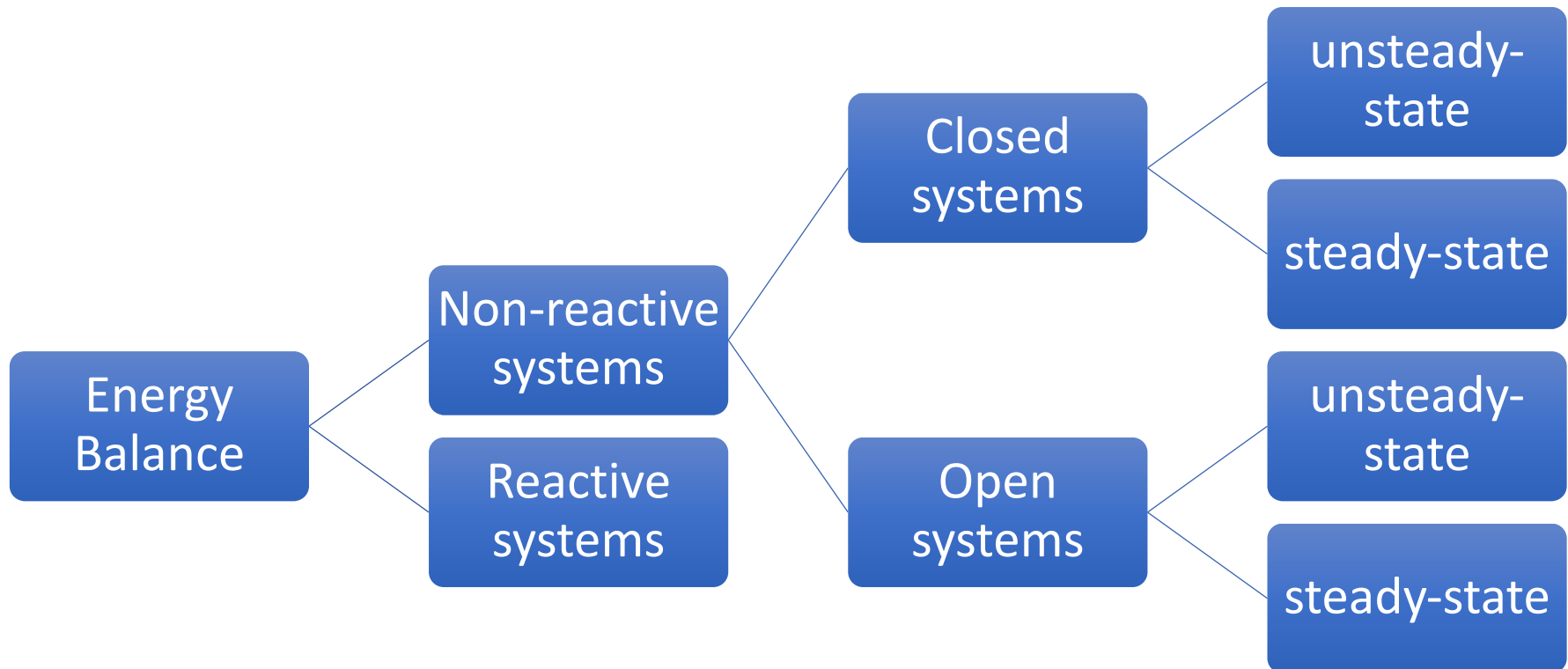
Q: heat transferred to the system from its surrounding (+ sign: gain of energy)

W: work done by system on its surrounding (+ sign so that $-W$ is negative)

Energy balances overview

Depending on the system under study, the energy balance equation will simplify:

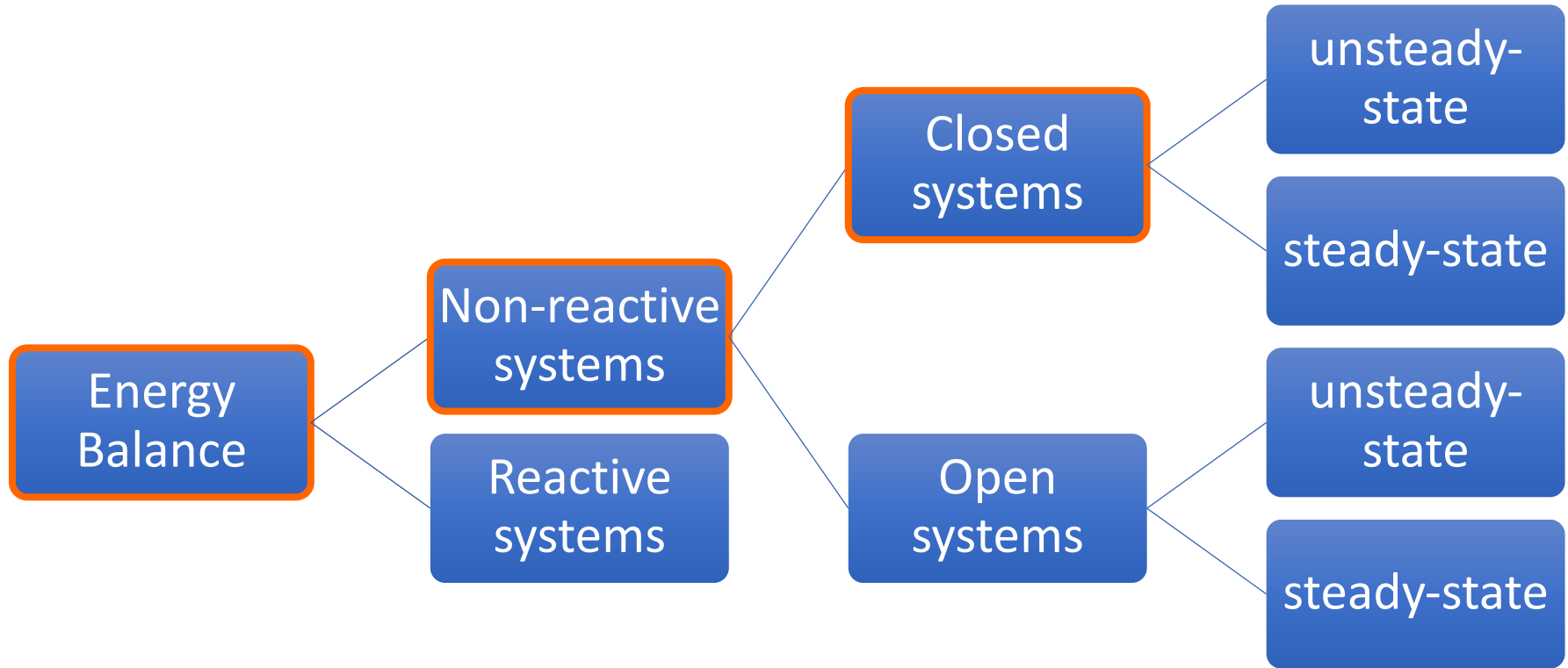
$$E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$$



2. Energy balances on closed non-reactive systems

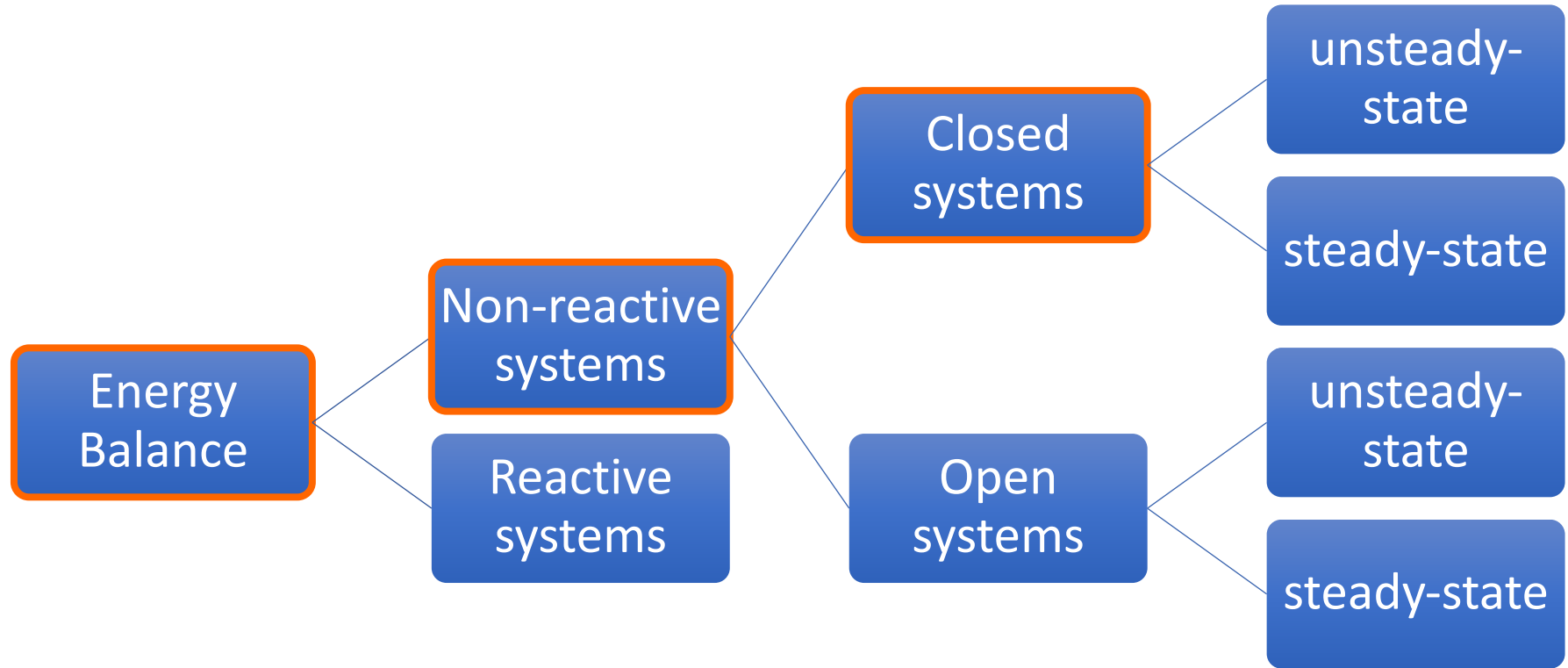
Energy balances on closed non-reactive systems

The simplest case consists in closed systems:



Energy balances on closed non-reactive systems

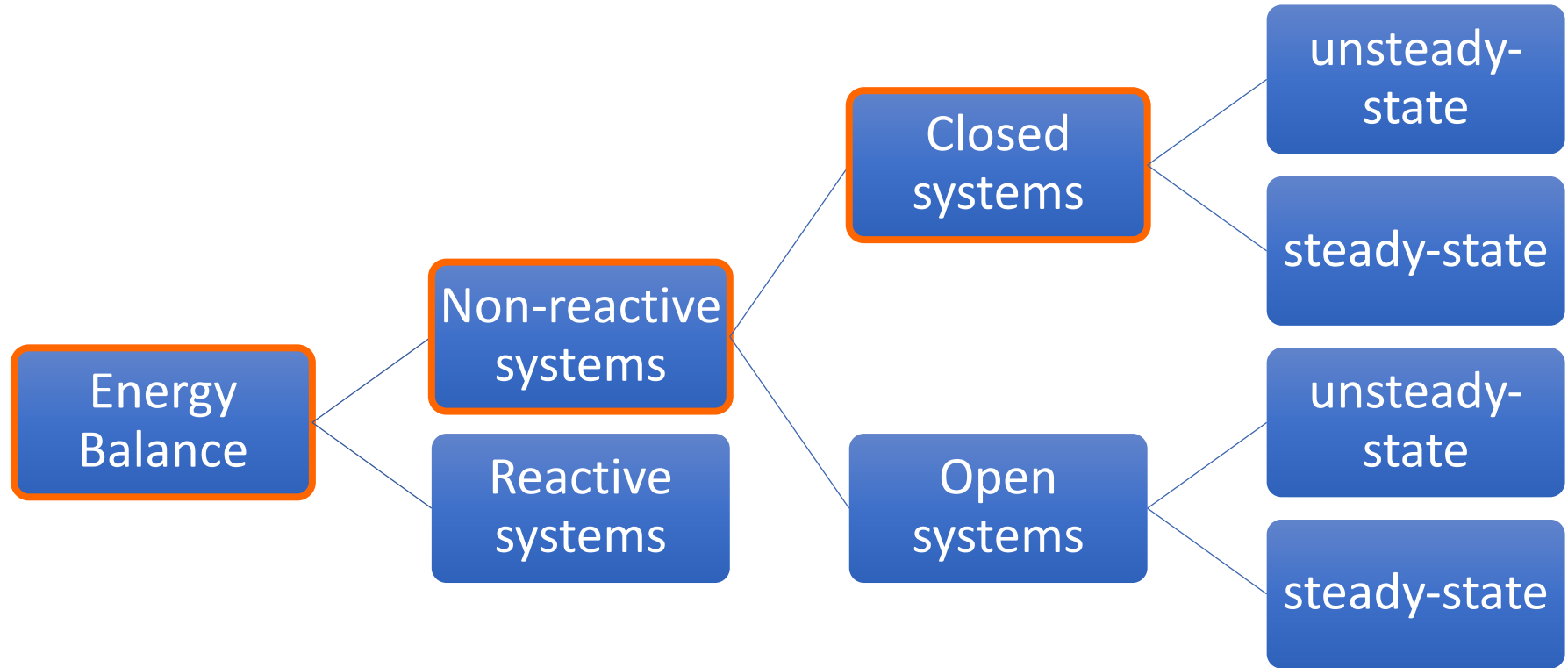
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Energy balances on closed non-reactive systems

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$$E_{\text{accumulated}} = \cancel{E_{\text{input}}} - \cancel{E_{\text{output}}} + \cancel{E_{\text{gen}}} + E_{\text{transferred}}$$

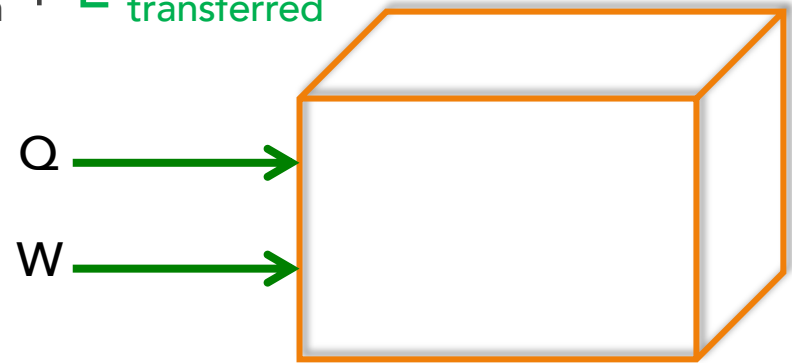
$$E_{\text{accumulated}} = E_{\text{transferred}}$$

Energy Balance on a Closed System

$$E_{\text{accumulated}} = \cancel{E_{\text{input}}} - \cancel{E_{\text{output}}} + \cancel{E_{\text{gen}}} + E_{\text{transferred}}$$

$$E_{\text{accumulated}} = E_{\text{transferred}} = \Delta E$$

$$\Delta E = Q - W$$

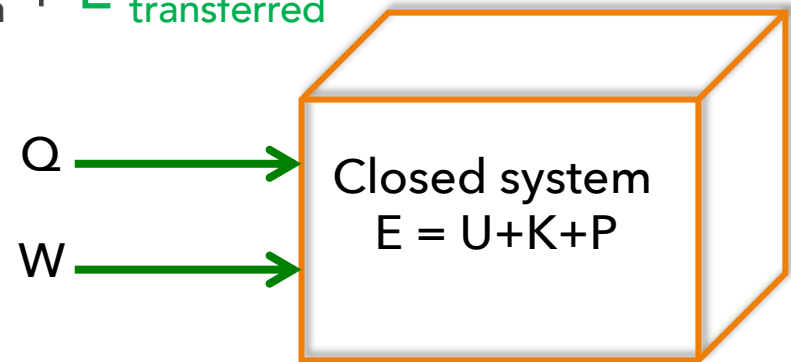


Energy Balance on a Closed System

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$$E_{\text{accumulated}} = E_{\text{transferred}} = \Delta E$$

$$\Delta E = Q - W$$



The total energy (E) may be regarded as composed of many forms. Obvious contributions to the total energy arise from the **internal** **kinetic** and **potential** energies

$$Q - W = \Delta U + \Delta E_k + \Delta E_p$$

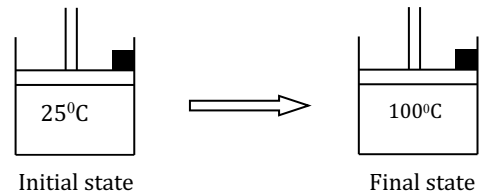
- ΔE_p is change in potential energy
- Q is heat transferred to the system
 - If the system is adiabatic, there is neither gain by the system nor heat loss and Q is zero
- W is work done by the system
 - If there are no moving parts, then $W=0$

Example: Energy Balance on a Closed System

1 mole of gas contained in a cylinder fitted with movable piston:

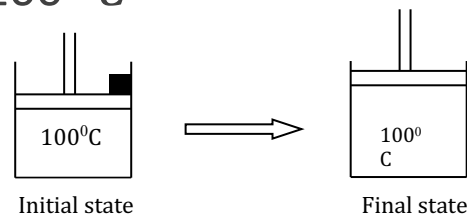
The cylinder is placed in boiling water and

I) Equilibrated: to 100 °C



II) The piston is then released, and the gas does 100 J of work to move the piston to its new equilibrium position.

The final gas temperature is 100 °C



Write and solve energy balances. For two stage with assuming:

- No changes in m , E_k & E_p
- Ideal gas
- $\hat{C}_v = 2 \text{ kcal.mol}^{-1}\text{.K}^{-1}$

Example: Energy Balance on a Closed System (Continued)

I) $E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$

$$E_{\text{accumulated}} = E_{\text{transferred}}$$

$$\Delta U + \Delta E_k + \Delta E_p = Q - W$$

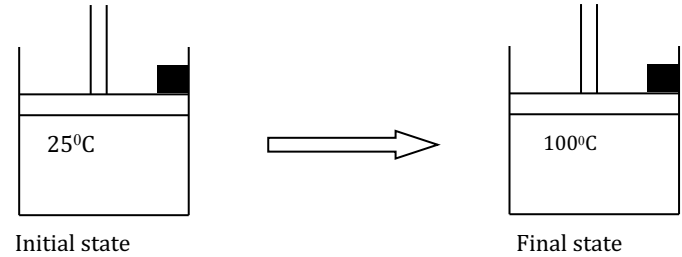
$$m \Delta \hat{U} + m \Delta \hat{E}_k + m \Delta \hat{E}_p = Q - W$$

$$m (\hat{U}_f - \hat{U}_i) + m (\hat{E}_{k,\text{final}} - \hat{E}_{k,\text{initial}}) + m (\hat{E}_{p,\text{final}} - \hat{E}_{p,\text{initial}}) = Q - W$$

$$m (\hat{U}_f - \hat{U}_i) = m \Delta \hat{U} = Q$$

$$\Delta \hat{U} = \hat{C}_v (\Delta T) = 2.75 \text{ k} = 150 \text{ kcal} = 627.6 \text{ kJ}$$

$$\hat{C}_v \text{ for 1 mol of gas} = 2 \text{ kcal} \cdot \text{mol}^{-1} \cdot \text{k}^{-1} \cdot 1 \text{ mol} = 2 \text{ kcal} \cdot \text{k}^{-1}$$

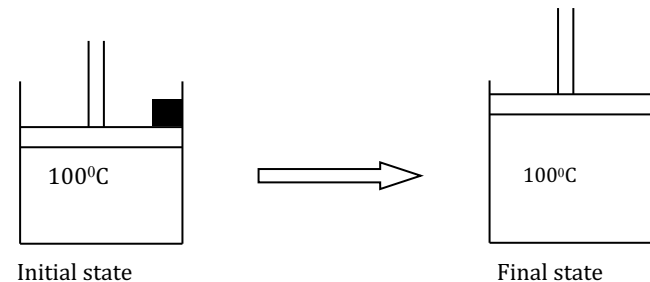


- No changes in m , E_k & E_p
- Ideal gas
- $\hat{C}_v = 2 \text{ kcal} \cdot \text{mol}^{-1} \cdot \text{k}^{-1}$

II) $U_{\text{final}} = U_{\text{initial}}$, because $\Delta T = 0$

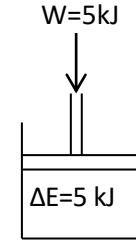
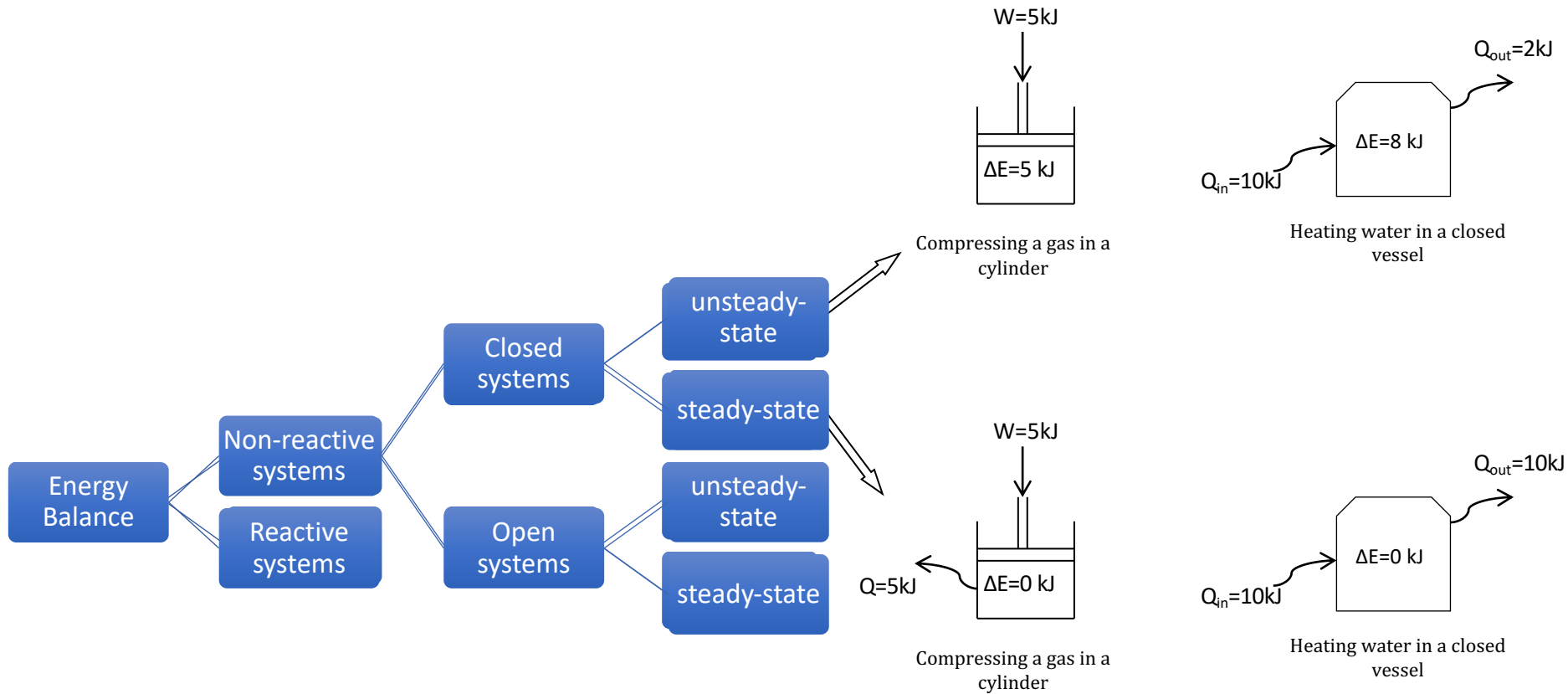
$$\Delta U + \Delta E_k + \Delta E_p = Q - W \quad \text{boundaries move so } W \neq 0!$$

$$\Rightarrow 0 = Q - W \Rightarrow Q = W = 100 \text{ J} > 0$$

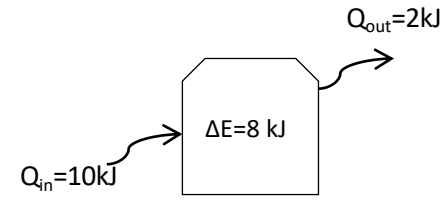


What does $Q > 0$ mean? The system further absorbs energy in form of heat to do work

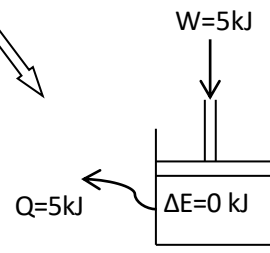
Examples of closed systems



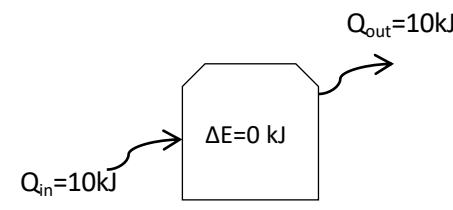
Compressing a gas in a cylinder



Heating water in a closed vessel



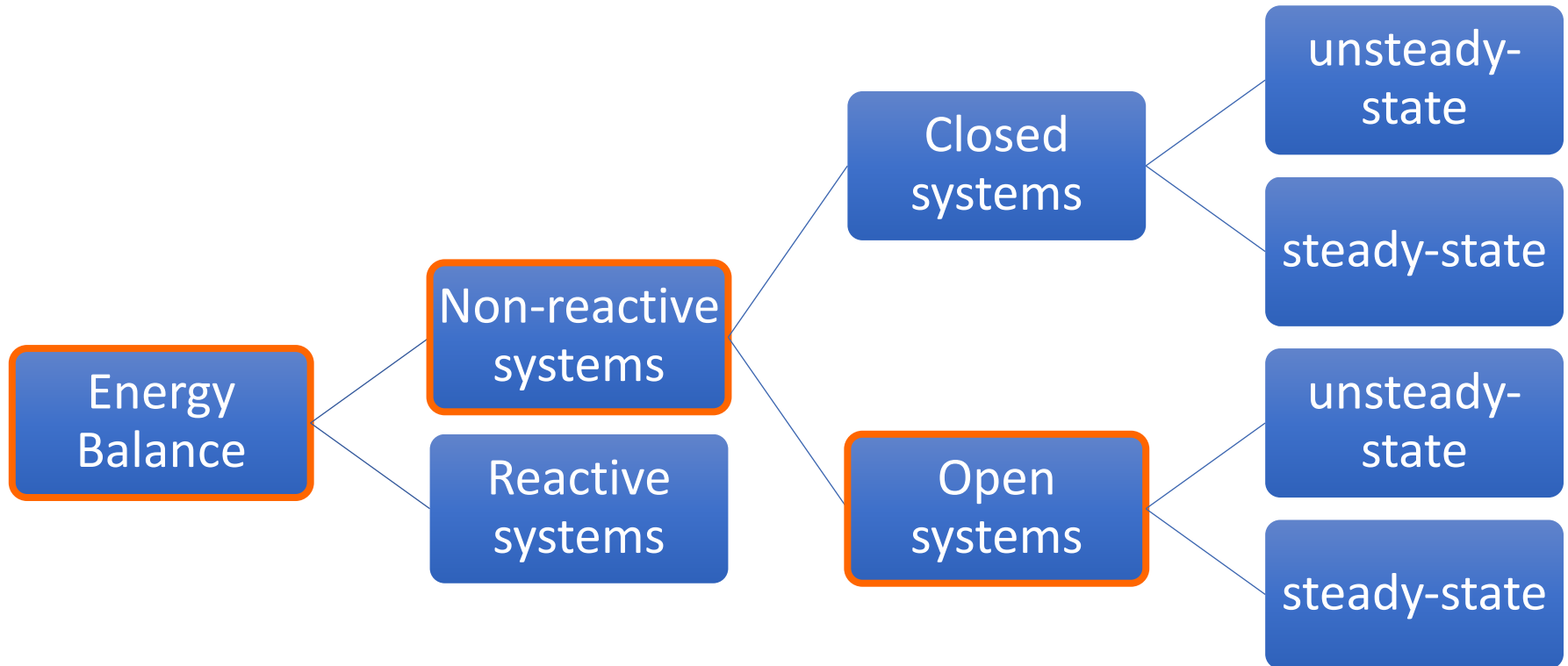
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Heating water in a closed vessel

3. Energy balances on open non-reactive systems

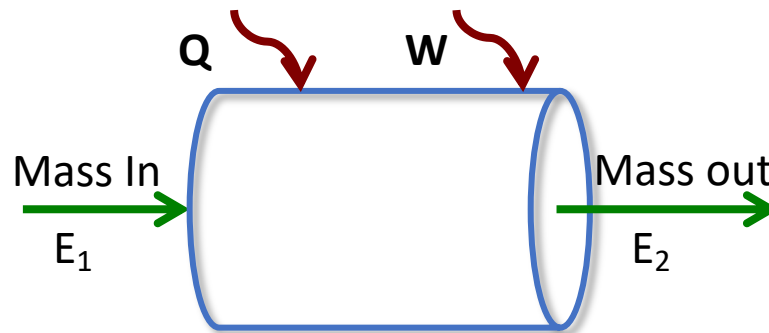
Energy balances on open non-reactive systems



$$E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$$

Energy Balance on an Open System

A system is open if mass crosses the system boundary



law of conservation of energy:

$$E_{\text{accumulated}} = E_{\text{input}} - E_{\text{output}} + E_{\text{gen}} + E_{\text{transferred}}$$

$$E_{\text{in}} = \sum_{\text{input streams}} m_j \hat{E}_j \quad , \quad E_{\text{out}} = \sum_{\text{output streams}} m_j \hat{E}_j$$

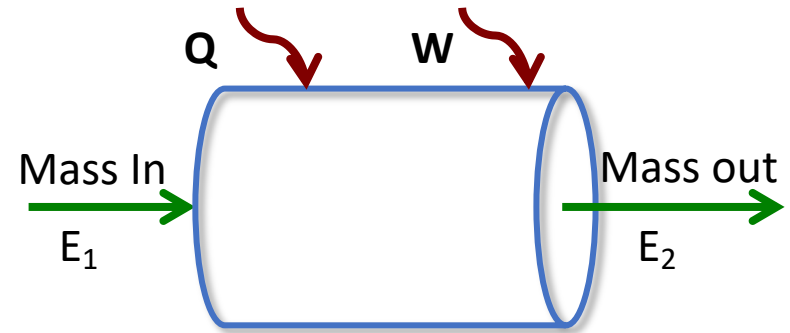
$$E_{\text{transfer}} = Q - W$$

$$\dot{m}_{\text{sys}} \hat{E}_{\text{acc}} = \dot{m}_{\text{in}} \hat{E}_1 - \dot{m}_{\text{out}} \hat{E}_2 + Q - W$$

(hat indicates energy per unit mass)

Energy Balance on an Open System

$$\dot{m}_{\text{sys}} \hat{E}_{\text{acc}} = \dot{m}_{\text{in}} \hat{E}_1 - \dot{m}_{\text{out}} \hat{E}_2 + Q - W$$



- For such a system, work must be done on the fluid mass to push it into the system; flow work
- Work could also be done by the fluid mass on moving parts of the system (example: steam driving a turbine); shaft work

$$W = W_s + W_{\text{fl}}$$

Accumulation=0



$$\dot{m}_1 (\hat{U}_1 + \cancel{\hat{E}k_1} + \cancel{\hat{E}p_1}) - \dot{m}_2 (\hat{U}_2 + \cancel{\hat{E}k_2} + \cancel{\hat{E}p_2}) + \dot{Q} - (\cancel{W_s} + W_{\text{fl}})$$

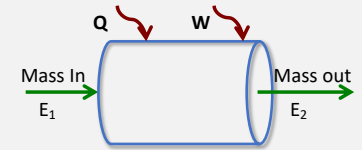
$m_1 = m_2 = m$



if $W_s, E_k, E_p = 0$

$$\dot{m} \Delta \hat{U} + Q - W_{\text{fl}} = 0$$

What is W_{fl} ?



Work required to push the mass in = $P_{in} V_{in}$ ($N/m^2 * m^3 = N.m = J$)

Work done by the fluid exiting the system = $P_{out} V_{out}$

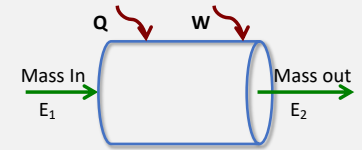
The net rate of work done by the system = $W_{fl} = P_{out} V_{out} - P_{in} V_{in}$

$$\boxed{\dot{m} \Delta \hat{U}} + \boxed{\dot{Q}} - \boxed{W_{fl}} = \boxed{\dot{m}_1 \hat{U}_1 - \dot{m}_2 \hat{U}_2} + \boxed{\dot{Q}} - \boxed{P_{out} V_{out} + P_{in} V_{in}} = 0$$

$P_{out} V_{out} \rightarrow$ Work done by system to push **out**

$P_{in} V_{in} \rightarrow$ Work done on system by pushing **in**

Definition of Enthalpy



$$\dot{m} \Delta \hat{U} + \dot{Q} - \dot{W}_{\text{fl}} = \dot{m}_1 \hat{U}_1 - \dot{m}_2 \hat{U}_2 + \dot{Q} - P_{\text{out}} V_{\text{out}} + P_{\text{in}} V_{\text{in}} = 0$$

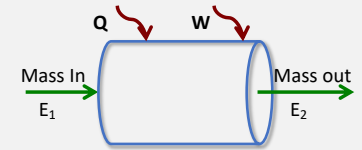
$$\dot{m}_1 \hat{U}_1 - \dot{m}_2 \hat{U}_2 + \dot{Q} - \dot{m}_2 P_2 \hat{V}_2 + \dot{m}_1 P_1 \hat{V}_1 = 0$$

$$\Rightarrow \dot{m}_1 (\hat{U}_1 + P_1 \hat{V}_1) - \dot{m}_2 (\hat{U}_2 + P_2 \hat{V}_2) + \dot{Q} = 0$$

$$\hat{U} + P \hat{V} = ?$$

$$\dot{m}_1 \hat{H}_1 - \dot{m}_2 \hat{H}_2 + \dot{Q} = 0$$

Definition of Enthalpy



$$\hat{U} + P\hat{V} = ? \Rightarrow \hat{U} + P\hat{V} = \hat{H}$$

$$\dot{m}_1\hat{H}_1 - \dot{m}_2\hat{H}_2 + \dot{Q} = 0$$

- **So, using the enthalpy of streams takes into account the W_{fl} for streams in open systems**
- \hat{U} is specific internal energy, P is pressure, and \hat{V} is specific volume
- It is not possible to know or estimate the absolute values of **internal energy and enthalpy**. We need to find only the change in these properties to make an energy balance
- The general energy equation for an open system with flow work, shaft work, kinetic energy changes, potential energy changes and heat transfer becomes:

$$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$$

Remarks

Closed system : $\Delta U + \Delta E_k + \Delta E_p = Q - W$

Open system: $\Delta \dot{H} = \sum_{out} \dot{n}_i \hat{H}_i - \sum_{in} \dot{n}_i \hat{H}_i$ or $\Delta \dot{H} = \sum_{out} \dot{m}_i \hat{H}_i - \sum_{in} \dot{m}_i \hat{H}_i$

Open system : $\Delta \dot{H} + \Delta \dot{E}_k + \Delta \dot{E}_p = \dot{Q} - \dot{W}_s$

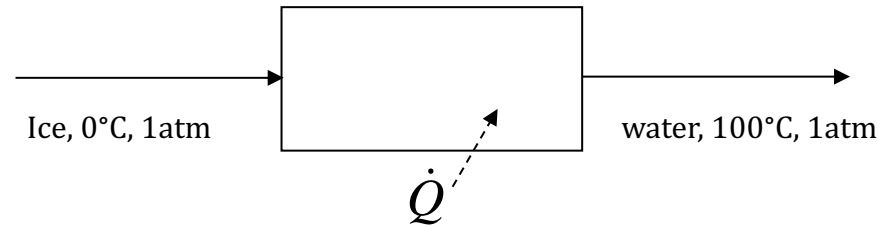
ΔU only depends on the temperature: $\Delta \hat{U} = \int_{T_1}^{T_2} (C_v)_T dT$

so for constant T: $\Delta U = 0 \rightarrow \Delta H = \Delta U + \Delta(PV) = V\Delta P$

For the ideal gas, liquids and solids:

- For the solids and liquids : $C_p = C_v$
- For the gases : $C_p = C_v + R$ (from thermodynamics course!)

Example: Energy balance on an open system



The process is st.st and it reach to a final stable situation

$\dot{Q} = ?$ Kcal / min kg H₂O

$$\Delta\dot{H} + \Delta\dot{E}_k + \Delta\dot{E}_p = \dot{Q} - \dot{W}_s$$

$$\dot{m}_{\text{out}} \hat{H}_{\text{out}} - \dot{m}_{\text{in}} \hat{H}_{\text{in}} = \dot{Q}$$

$$\rightarrow \dot{Q}/\dot{m} = \hat{H}_{\text{out}} - \hat{H}_{\text{in}}$$

For a system with one flux in and one flux out without any accumulation:
the mass in the system $\dot{m}_{\text{in}} = \dot{m}_{\text{out}} = \dot{m}$

$$\dot{Q} / \dot{m} = \hat{H}_{\text{out}} - \hat{H}_{\text{in}}$$

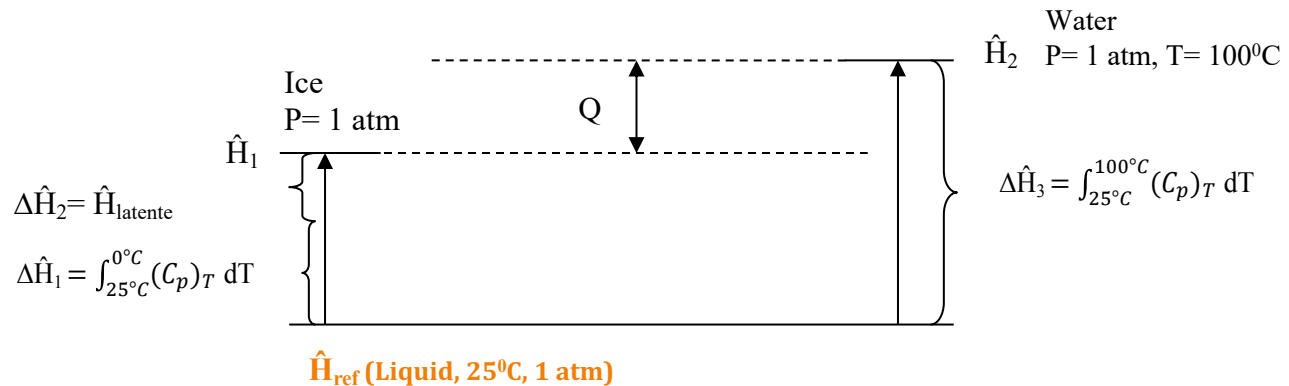
- To get the **thermodynamic properties**

- using the tables, for a substrate by knowing T and P, we get (\hat{H} , \hat{U} , V , \hat{C}_p , \hat{C}_v)
- given information for the reference state (P,T)

Species	\dot{m}_{in} (mole/h)	\hat{H}_{in} (KJ/mole)	\dot{m}_{out} (mole/h)	\hat{H}_{out} (KJ/mole)
H ₂ O(s)	\dot{m}_1	$\hat{H}_{\text{water(s)}} (\hat{H}_1)$	–	–
H ₂ O(l)	–	–	\dot{m}_2	$\hat{H}_{\text{water(l)}} (\hat{H}_2)$

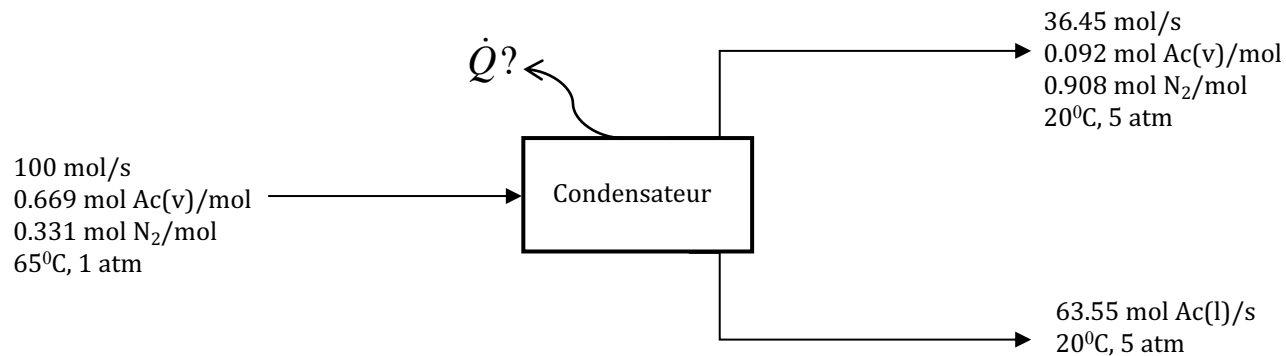
- We need a **reference state** to calculate \hat{H} for the corresponding T and P

- $\hat{H}_1 = \Delta\hat{H}_1 + \Delta\hat{H}_2$
- $\hat{H}_2 = \Delta\hat{H}_3$



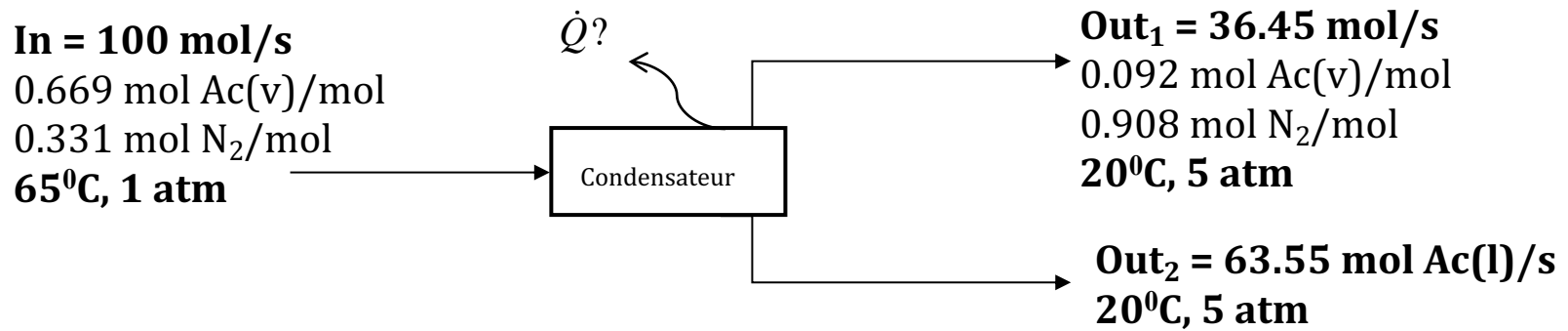
Example: Energy balance on a NR Open System

A mixture of Acetone and Nitrogen is entering in a cooling system (condenser) to separate the Acetone. based on the information given on the flowchart, calculate the Q needed to be removed from the system for this separation process.



1. Mass balance : already done
2. From the general **energy balance equation to the simplified system energy balance equation**

$$\Delta \dot{H} + \Delta \dot{E}_k + \Delta \dot{E}_p = \dot{Q} - \dot{W}_s \quad (\Delta E_k = 0, \Delta E_p = 0, \dot{W}_s = 0) \quad \rightarrow \quad \dot{Q} = \Delta H = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$$



3. Reference states (for each specie in the system):

Ac (liq, 20°C, 5atm), N₂ (gas, 25°C, 1atm)

4. Open systems → inlet-outlet enthalpy table

Species	\dot{n}_{in} (mol/s)	\hat{H}_{in} (kJ/mol)	\dot{n}_{out} (mol/s)	\hat{H}_{out} (kJ/mol)
Ac(v)	66.9	\hat{H}_1	3.35	\hat{H}_3
Ac(l)	—	—	63.55	0
N ₂	33.1	\hat{H}_2	33.1	\hat{H}_4

All the species in the system

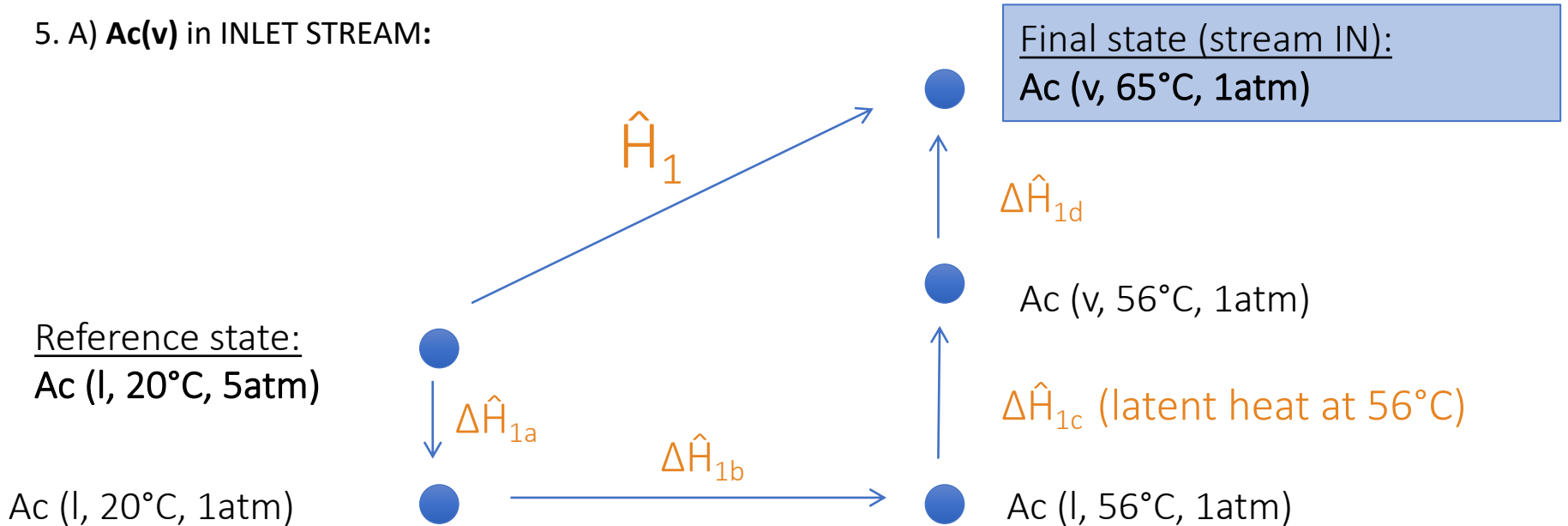
INLET stream(s):
 Flowrates and specific enthalpies*

OUTLET stream(s):
 Flowrates and specific enthalpies*

* \hat{H}_i (specific enthalpy of specie i): should be calculated at the state of that specie in the inlet and outlet streams

5. Construct **process paths**: calculate the **specific enthalpies**

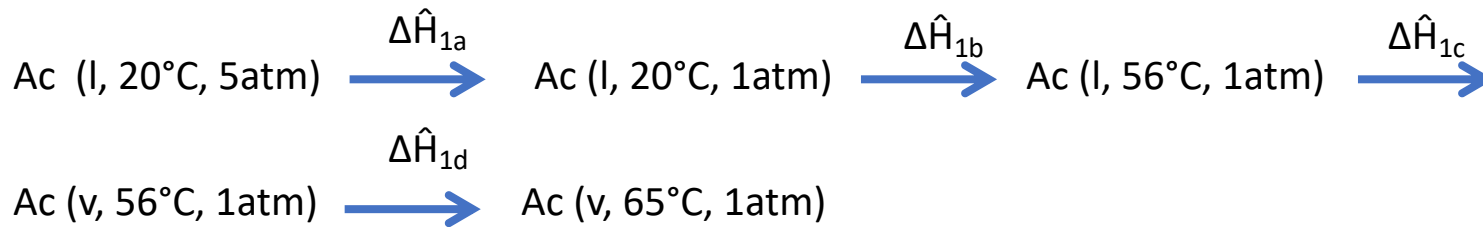
5. A) **Ac(v)** in INLET STREAM:



$$\hat{H}_1 = \Delta\hat{H} \text{ for Ac (l, 20°C, 5atm)} \rightarrow \text{Ac (v, 65°C, 1atm)}$$

$$\hat{H}_1 = \Delta\hat{H}_{1a} + \Delta\hat{H}_{1b} + \Delta\hat{H}_{1c} + \Delta\hat{H}_{1d}$$

Recalling: Enthalpy and internal energy are state properties. In other words, the change in enthalpy of a specie depends only on the final and initial states and not on how the final state is reached from the initial state, they are path independent



CHANGE IN PRESSURE AT CONSTANT TEMPERATURE (LIQUID PHASE → CONSTANT VOLUME):

$$\Delta\hat{H}_{1a} = \hat{V} \Delta P \quad (\text{the specific gravity of Ac is 0.791 and the MW is 0.058 kg/mol,}$$

$$\text{so } \hat{V} = 0.0734 \text{ L/mol})$$

$$\Delta\hat{H}_{1a} = \frac{(-4 \times 10^5 \text{ Pa}) \times (0.0734 \times 10^{-3} \text{ m}^3/\text{mol})}{1000} = -0.0297 \text{ kJ/mol}$$

Pay attention to units! to find $\Delta\hat{H}_{1a}$ in KJ/mol, \hat{V} should be in m^3/mol and ΔP in Pa

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (LIQUID PHASE):

○ from table B.2: Ac (l) : $C_p \text{ (kJ/mol } ^\circ\text{C)} = 0.123 + 18.6 \times 10^{-5} T$, for T in $^\circ\text{C}$

$$\Delta\hat{H}_{1b} = \int_{20^\circ\text{C}}^{56^\circ\text{C}} (C_p)_{Ac(l)} dT = 4.68 \text{ kJ/mol}$$

CHANGE OF STATE (LATENT HEAT) AT CONSTANT PRESSURE AND TEMPERATURE:

$$\Delta\hat{H}_{1c} = 30.2 \text{ kJ/mol} \quad (\text{latent heat at boiling point, from Table B.1})$$

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

○ from table B.2: Ac (v) : $C_p \text{ (kJ/mol}^\circ\text{C)} = 0.07196 + 20.10 \times 10^{-5} T - 12.78 \times 10^{-8} T^2 + 34.76 \times 10^{-12} T^3$

$$\Delta\hat{H}_{1d} = \int_{56^\circ\text{C}}^{65^\circ\text{C}} (C_p)_{Ac(v)} dT = 0.753 \text{ kJ/mol}$$

$$\hat{H}_1 = (-0.0297 + 4.68 + 30.2 + 0.753) = 35.6 \text{ kJ/mol}$$

5. A) N_2 in INLET STREAM:

$$\hat{H}_2 = \Delta \hat{H} \text{ for } \text{N}_2 (\text{g}, 25^\circ\text{C}, 1\text{atm}) \rightarrow \text{N}_2 (\text{g}, 65^\circ\text{C}, 1\text{atm})$$

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

$$\text{From Table B.2: } C_{p,\text{N}_2,\text{g}} = 0.029 + 0.2199 \times 10^{-5}T + 0.5723 \times 10^{-8}T^2 - 2.871 \times 10^{-2}T^3$$

$$\hat{H}_2 = \int_{25^\circ\text{C}}^{65^\circ\text{C}} (C_p)_{\text{N}_2(\text{g})} dT = 1.16 \text{ kJ/mol}$$

5. B) $\text{Ac}(\text{v})$ in OUTLET STREAM:

CHANGE OF STATE (LATENT HEAT) AT CONSTANT PRESSURE AND TEMPERATURE:

$$\hat{H}_3 = \Delta \hat{H} \text{ for } \text{Ac} (\text{l}, 20^\circ\text{C}, 5\text{atm}) \rightarrow \text{Ac} (\text{v}, 20^\circ\text{C}, 5\text{atm})$$

$$\hat{H}_3 = 32 \text{ kJ/mol} \quad (\text{creating a path, since we only have the latent heat at the b.p.})$$

5. B) N_2 in OUTLET STREAM:

$$\hat{H}_4 = \Delta \hat{H} \text{ for } \text{N}_2 (\text{g}, 25^\circ\text{C}, 1\text{atm}) \rightarrow \text{N}_2 (\text{g}, 20^\circ\text{C}, 5\text{atm})$$

$$\hat{H}_4 = \text{N}_2 (\text{g}, 25^\circ\text{C}, 1\text{atm}) \rightarrow \text{N}_2 (\text{g}, 20^\circ\text{C}, 1\text{atm}) \rightarrow \text{N}_2 (\text{g}, 20^\circ\text{C}, 5\text{atm})$$

CHANGE IN TEMPERATURE AT CONSTANT PRESSURE (GAS PHASE):

$$\hat{H}_4 = \int_{25^\circ\text{C}}^{20^\circ\text{C}} (C_p)_{\text{N}_2(\text{g})} dT = -0.1 \text{ kJ/mol}$$

CHANGE IN PRESSURE AT CONSTANT TEMPERATURE (GAS PHASE):

For $\text{N}_2 (\text{g}, 20^\circ\text{C}, 1\text{atm}) \rightarrow \text{N}_2 (\text{g}, 20^\circ\text{C}, 5\text{atm})$ there is a very small change of enthalpy that can be neglected

6. Solve the simplified energy balance equation:

$$\dot{Q} = \Delta H = \sum_{out} n_i \hat{H}_i - \sum_{in} n_i \hat{H}_i$$

Species	\dot{n}_{in} (mol/s)	\hat{H}_{in} (kJ/mol)	\dot{n}_{out} (mol/s)	\hat{H}_{out} (kJ/mol)
Ac(v)	66.9	$\hat{H}_1 = 35,6$	3.35	$\hat{H}_3 = 32$
Ac(l)	–	–	63.55	0
N ₂	33.1	$\hat{H}_2 = 1,16$	33.1	$\hat{H}_4 = -0,1$

$$\Delta \dot{H} = [(3.35) (32.0) + (63.55) (0) + (33.1) (-0.10)] \text{ kJ/s} + \dots$$

$$\dots - [(66.9) (35.6) + (33.1) (1.16)] \text{ kJ/s} = -2320 \text{ kJ/s}$$

$$\Delta \dot{H} = \dot{Q} = -2320 \text{ kJ/s} = -2320 \text{ kW}$$

Thermodynamics data

- **Enthalpy and internal energy** are state properties. In other words, the change in enthalpy of a species depends only on the final and initial states and not on how the final state is reached from the initial state, **they are path independent**
- Enthalpy and internal energy of species could be tabulated with respect to a **reference state** (temperature, pressure and phase)
- There are “**tables**” at the end of the book that the thermodynamic properties can be looked up from them instead of calculating them every time
- You should get used to knowing how to **read these tables!!**

Procedure for Energy Balance Calculations

1. Make **material balance** calculations and find **flow rates** (or masses) of all streams
2. Write the generalized **energy balance equation** and cancel all the terms that are either zeros or can be neglected
3. Choose **reference states for each specie** involved. By reference state we mean **T, P and the phase** of the species. A proper choice of the reference states enables easy calculation of enthalpies and hence, energy balances
4. For **open systems**: construct an **inlet-outlet enthalpy table** with mass or molar flow rates

For **closed systems**: the table should contain **initial-final amounts of species and internal energies**
5. Estimate the specific enthalpies or internal energies and insert the values in the Table constructed in step 4. You need to **construct process paths to determine specific enthalpies and internal energies**
6. **Solve** the simplified **energy balance** equation (from step 2) and calculate the unknowns