

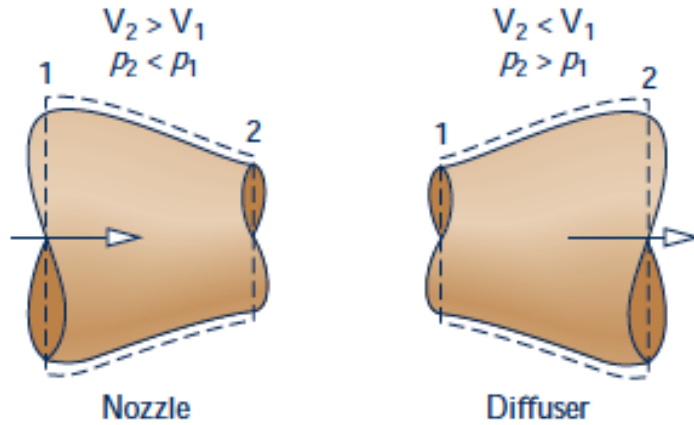
The background image is a composite of two scenes. On the left, a traditional wooden windmill stands on a grassy bank next to a body of water, with high-voltage power lines and pylons in the background. On the right, a large industrial power plant is visible, featuring a prominent cooling tower and various structures. The sky is a mix of blue and light pink, suggesting a sunset or sunrise. A semi-transparent red rectangle is overlaid on the right side of the image, containing the course title in white text.

# ME-251: Thermodynamics and energetics I Open Systems III

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Energy Transport Advances  
Laboratory  
EPFL Mechanical Engineering

2025 Fall Semester

Photo Credit: Trougnouf

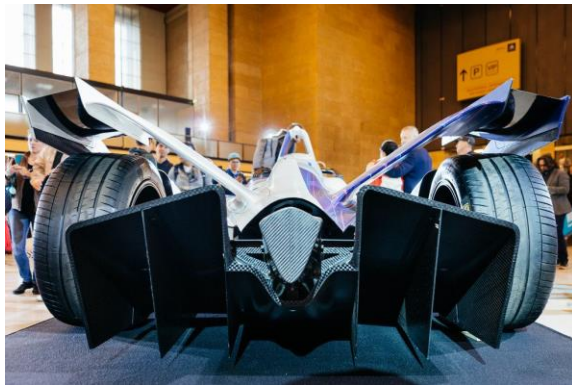


Steady state, one inlet and one exit

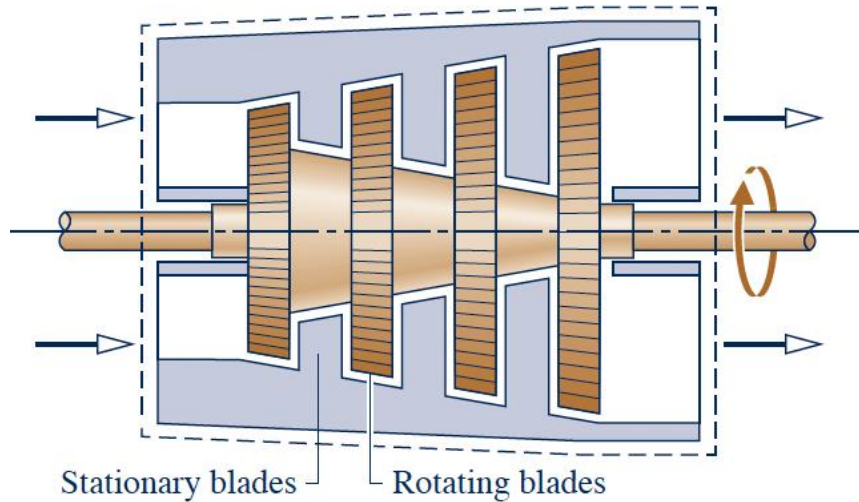
$$\dot{m}_i = \dot{m}_e = \dot{m}$$

Neglecting changes in PE and heat transfer (assumption)

$$h_1 - h_2 + \frac{\vec{V}_1^2 - \vec{V}_2^2}{2} = 0$$



Steady-state steam/gas turbine



Neglecting changes in KE and PE (assumption)

$$\dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}(h_1 - h_2) = 0$$

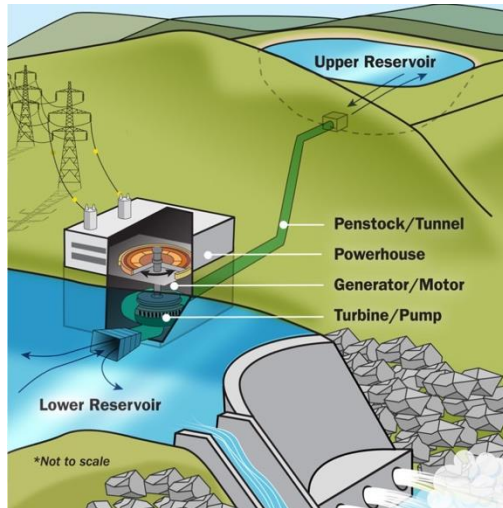
Further neglecting heat transfer (assumption)

$$\dot{W}_{cv} = \dot{m}(h_1 - h_2)$$

One inlet and one exit

$$\dot{m}_i = \dot{m}_e = \dot{m}$$

## Pump and compressor



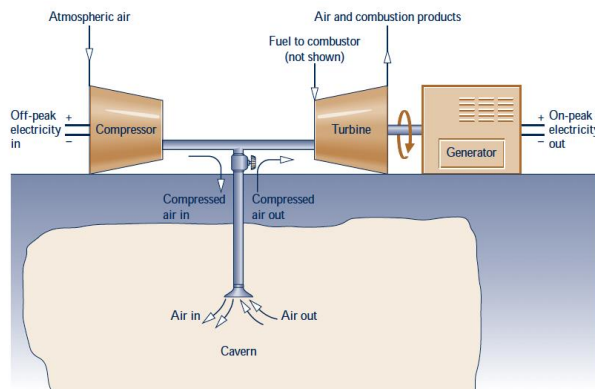
Steady state, one inlet one exit  $\dot{m}_i = \dot{m}_e = \dot{m}$

Ignoring KE change and heat transfer (assumption)

$$-\dot{W}_{cv} + \dot{m}(h_1 - h_2 + g(z_1 - z_2)) = 0$$

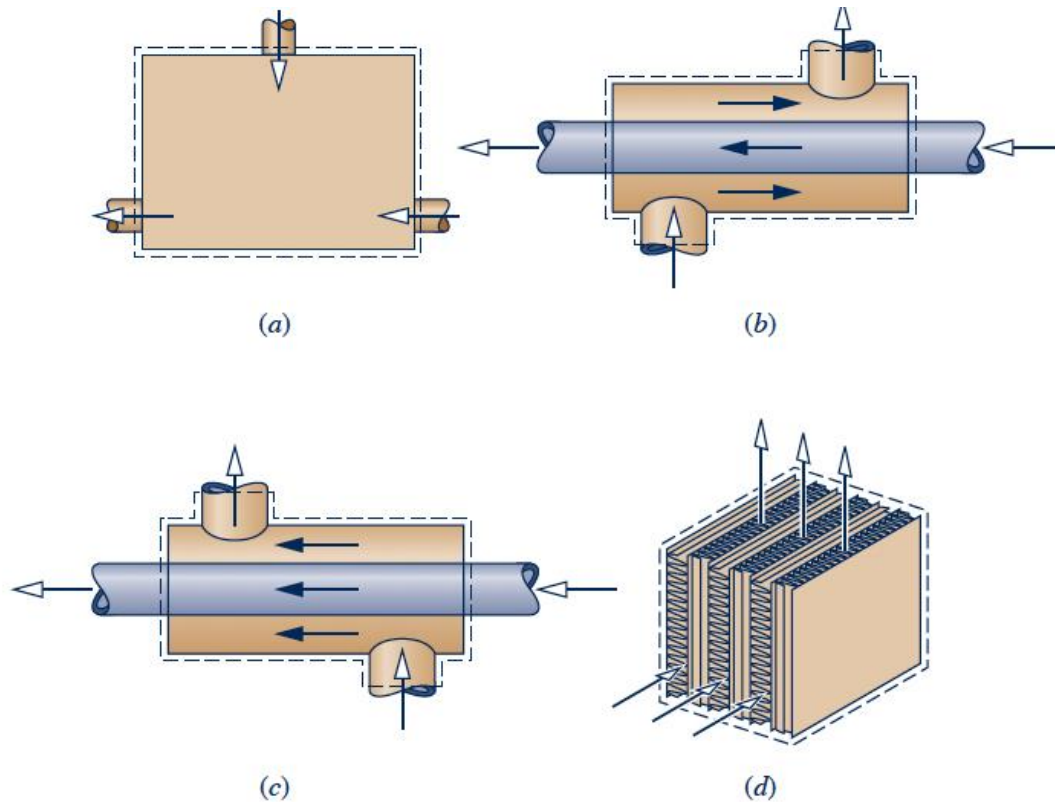
For compressors (gas), often further neglecting PE change (assumption)

$$\dot{W}_{cv} = \dot{m}(h_1 - h_2)$$



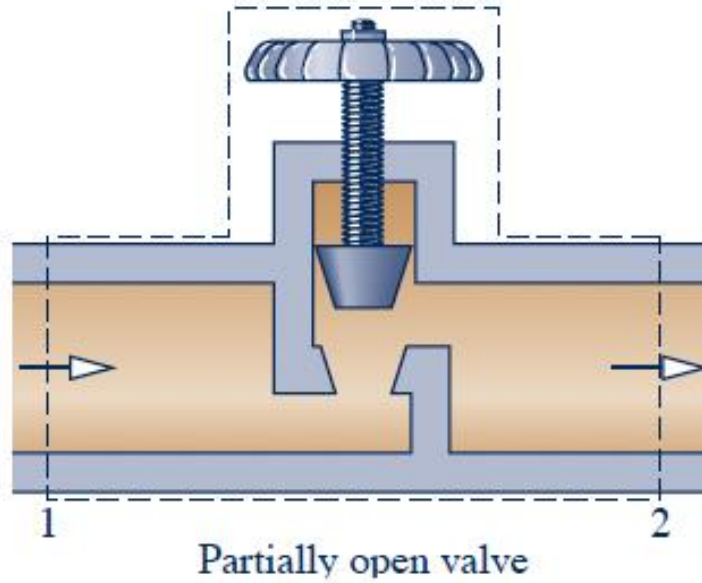
- Apply 1<sup>st</sup> law to heat exchangers and throttling valves
- Quick review of what we have learned so far
- Motivating the 2<sup>nd</sup> law of thermodynamics

Reading: 4.9-4.11, 5.1

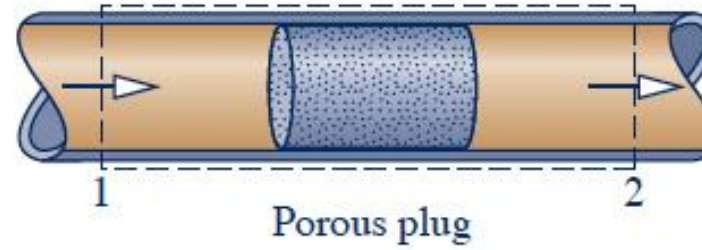


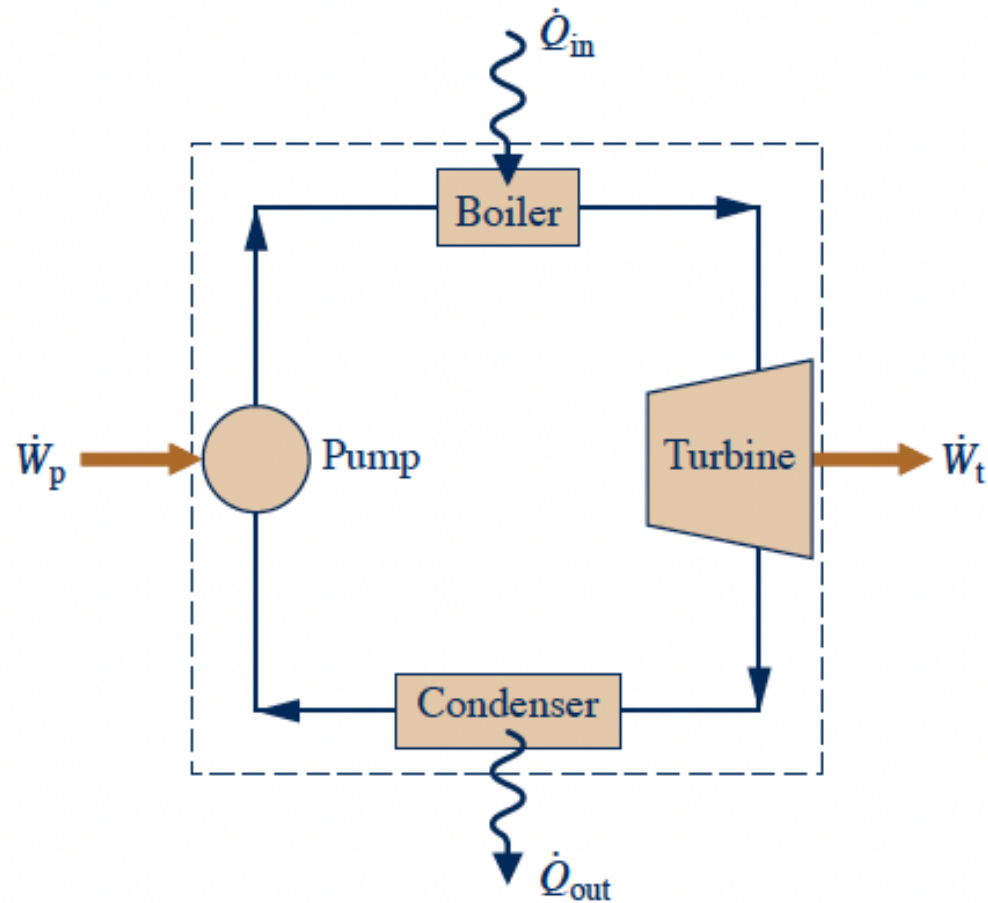
- (a) Direct contact heat exchanger (mixing chamber)
- (b) Tube-within-a-tube counterflow heat exchanger
- (c) Tube-within-a-tube parallel flow heat exchanger
- (d) Cross-flow heat exchanger

Multi-inlets, multi-exits  $\sum_i \dot{m}_i = \sum_o \dot{m}_o$

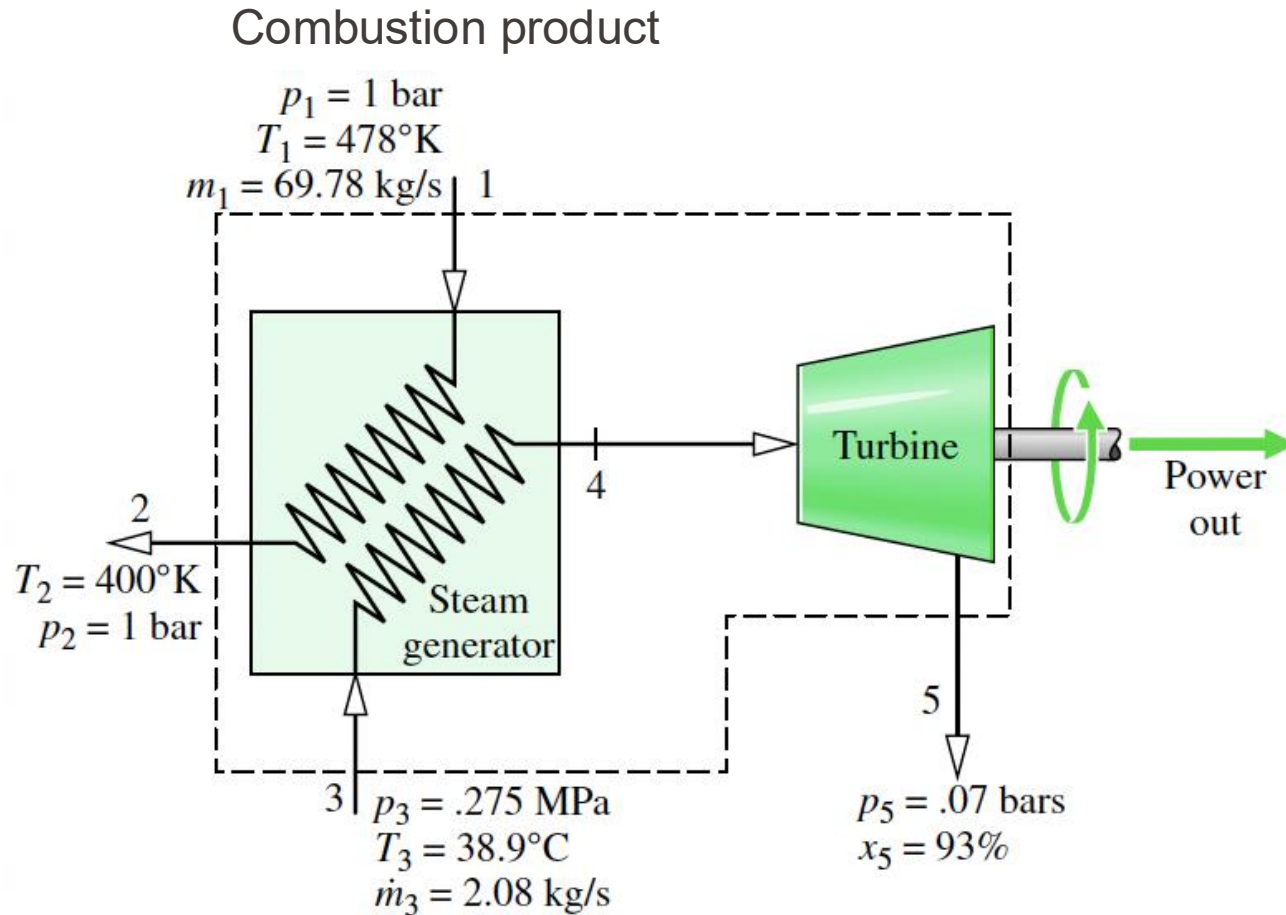


Adding a partially opened valve or a porous plug to reduce pressure





Applying 1<sup>st</sup> law to a simple vapor power cycle at steady state



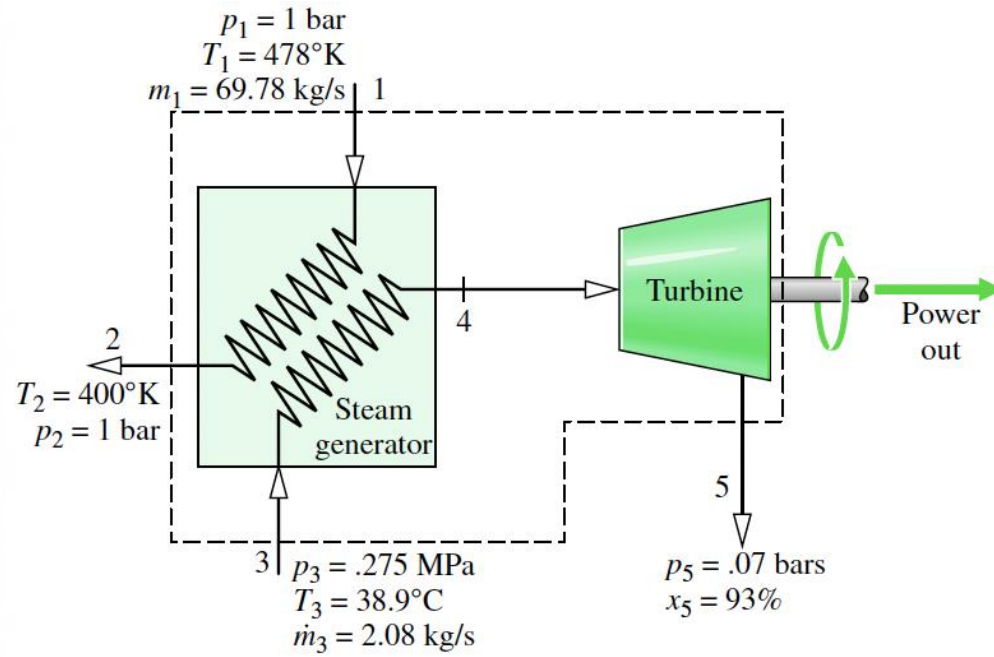
Steady-state waste heat recovery system

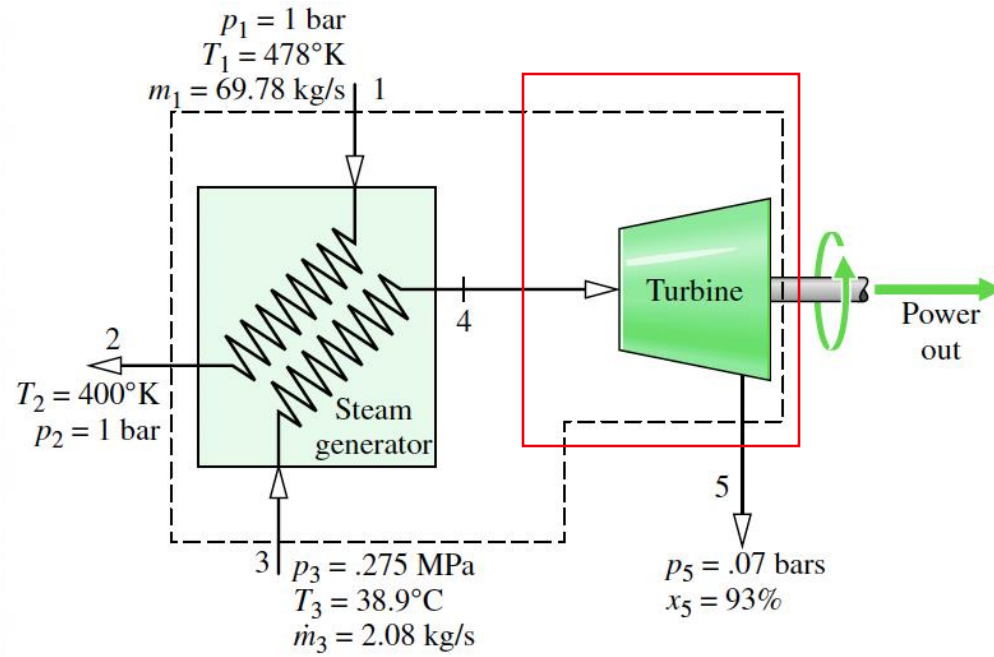
Heat exchange between the CV and the surrounding negligible

Neglect pressure drop for water flowing through the steam generator

Combustion product modeled as air with perfect gas behavior  $c_p = 1005 \text{ J/kg/K}$

Determine the power output of the turbine and the turbine inlet temperature

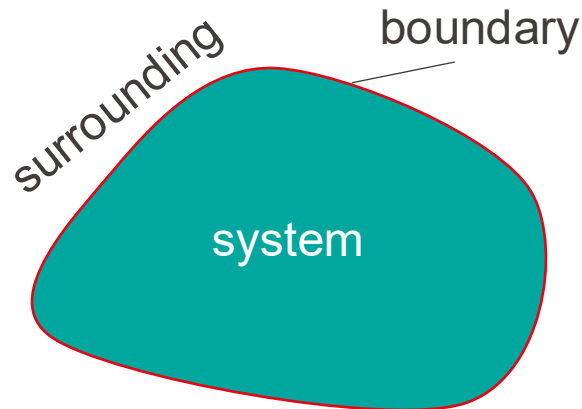






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Thermodynamics is a branch of physics that deals with heat, work, and temperature, and their relation to energy, entropy, and the physical properties of matter and radiation.



To perform thermodynamics analysis, we need to define the **system**, the **surrounding** and the **boundary** that separate the two

We consider **work transfer**, **mass transfer**, **heat transfer** across the boundary

# 1<sup>st</sup> Law for Closed Systems

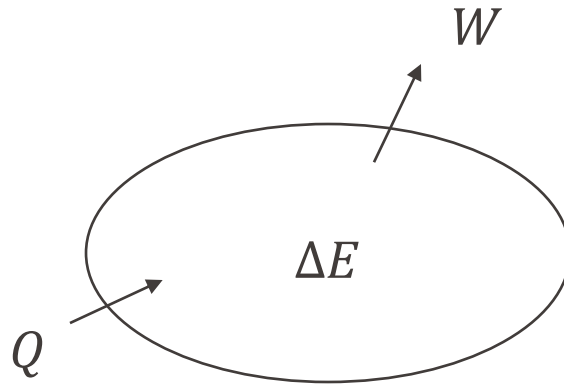
Change in the amount of energy contained within a system during some time interval

=

Net amount of energy transferred into the system by heat transfer during the time interval

−

Net amount of energy transferred out of the system by work during the time interval



$$\Delta E = E_2 - E_1 = Q - W \quad \text{in [J]}$$

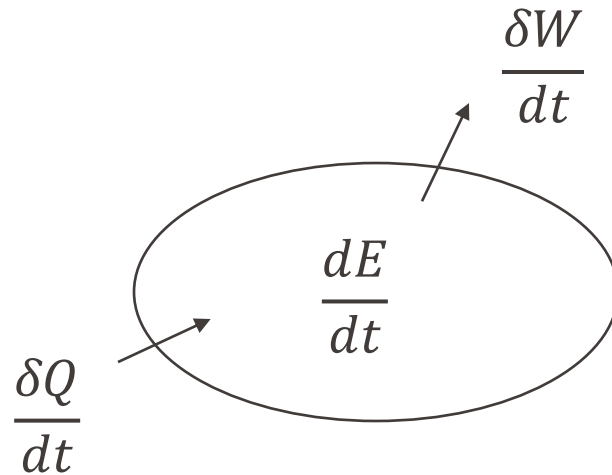
Time rate of change in the amount of energy contained within a system at time  $t$

=

Net rate at which energy is transferred **into** the system by heat transfer at time  $t$

-

Net rate at which energy is transferred **out of** the system by work at time  $t$

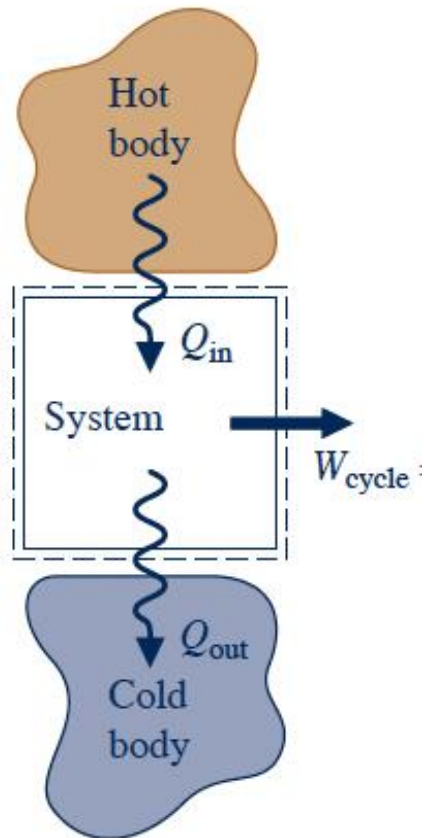


$$\frac{dE}{dt} = \dot{Q} - \dot{W} \quad \text{Heat flow rate - Power}$$

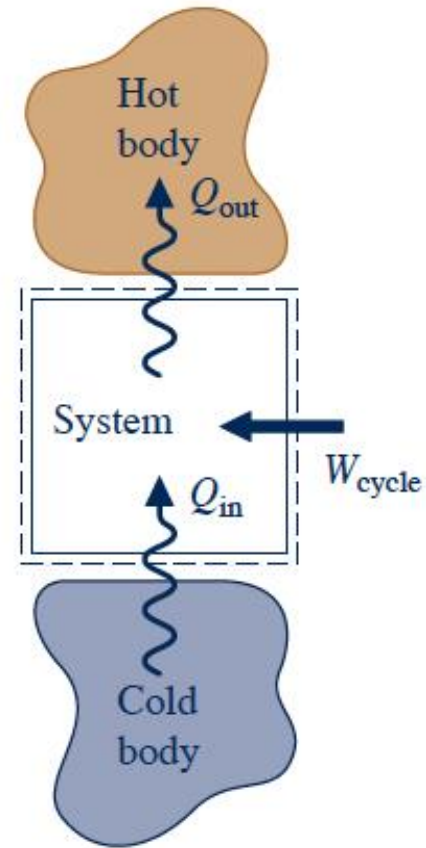
Everything is in [W]

**Energy change in** kinetic energy, potential energy, and internal energy

**Energy transfer:** **work** (expansion/compression, shaft, electric,...)  
**heat** (conduction, convection, radiation)



Power cycle



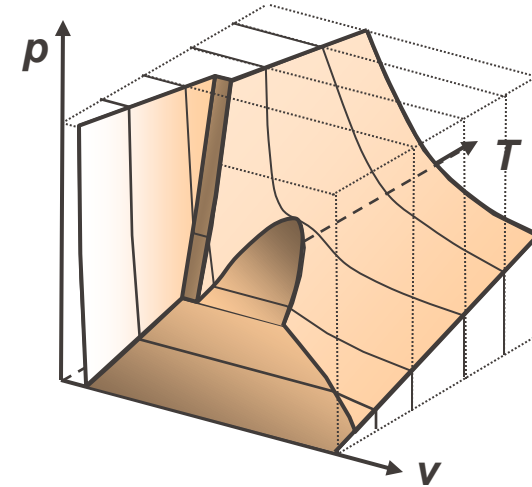
Refrigeration and  
heat pump cycle

- **State principle:** for closed systems

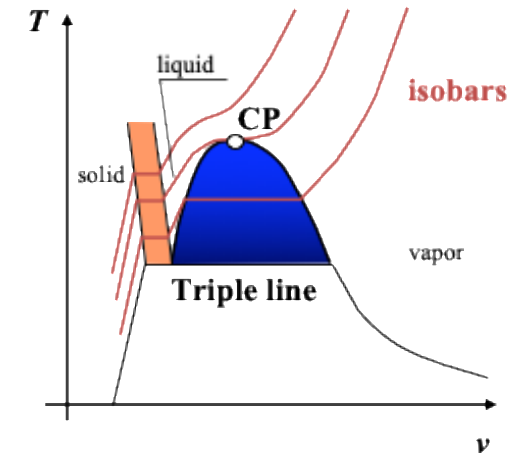
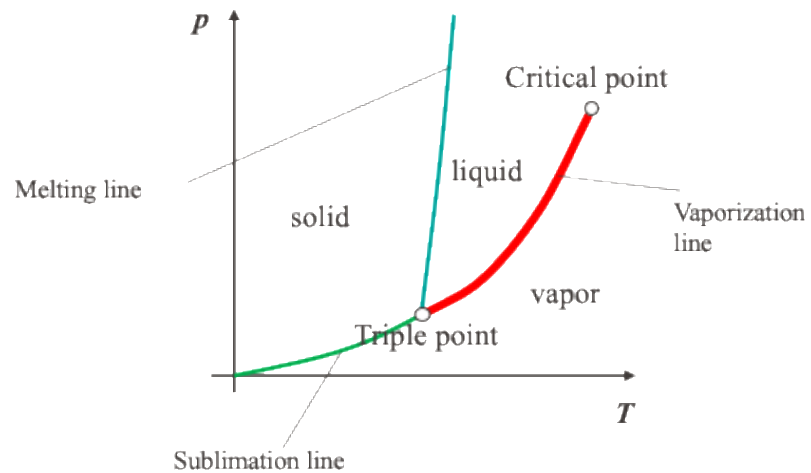
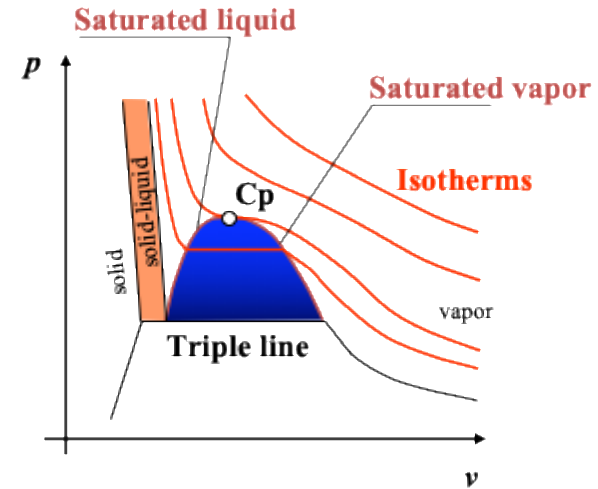
$$\# \text{ of independent properties} = \# \text{ of relevant work exchange modes} + 1 \text{ (associated with heat)}$$

- E.g., for gas in a piston-cylinder assembly, number of independent properties 2 (**temperature** associated with heat transfer and pressure associated with **compression/expansion work**)
- **Simple system:** only one work exchange mode as the system undergoes quasiequilibrium processes (**two independent properties**).

- Single phase region
- Two phase region
- Saturation states
- Critical point
- Triple line



- p-v diagram
- T-v diagram
- p-T phase diagram
- Steam quality



- Specific enthalpy
- Specific heat at a constant volume
- Specific heat at a constant pressure

- Liquids and solids are often modeled as incompressible  $\mathbf{v} = \mathbf{const}$

- $\frac{pv}{RT} = \frac{p\tilde{v}}{\tilde{R}T} = Z \equiv 1$ , the dilute limit of real gases

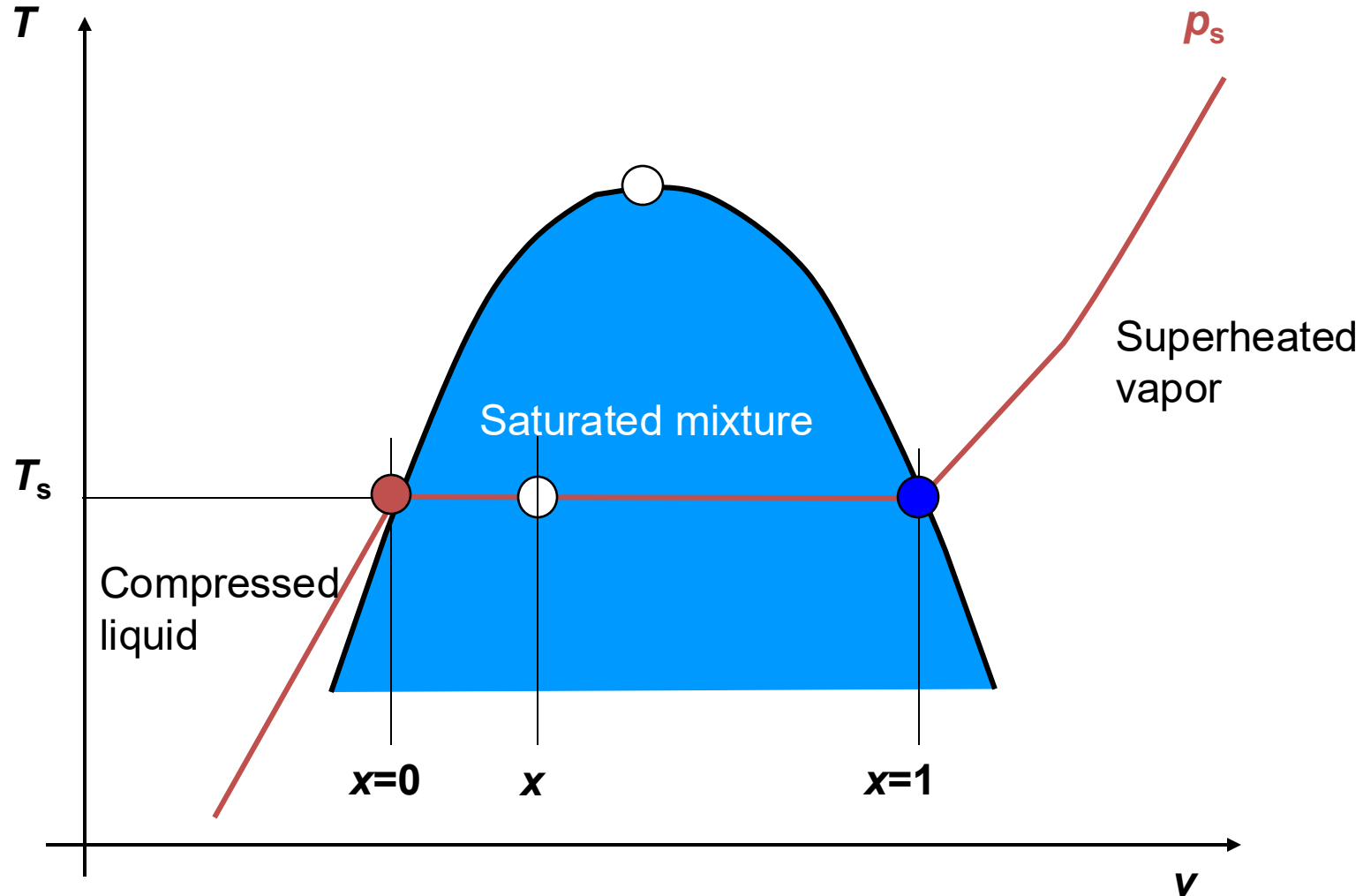
$T$ : temperature [K]

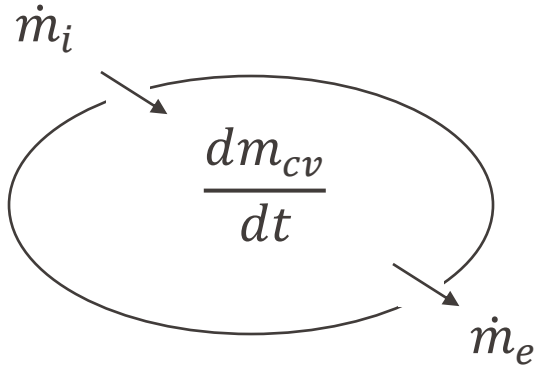
$\tilde{R}$ : universal gas constant [J/K/mol]

$R$ : specific gas constant [J/K/kg]

$\tilde{v}$ : molar volume [m<sup>3</sup>/mol]

# Compressed Liquid and Superheated Vapor

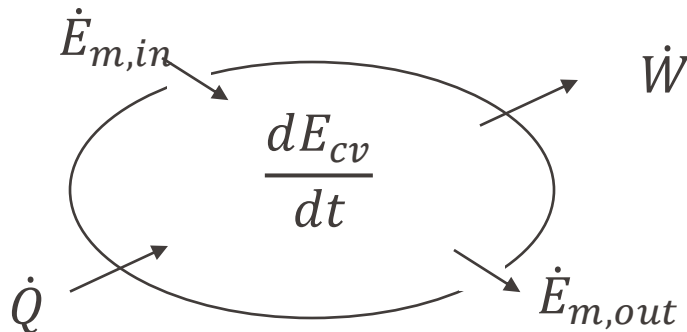




Mass balance

$$\frac{dm_{cv}}{dt} = \sum_i \dot{m}_i - \sum_o \dot{m}_e$$

Energy balance



$$\begin{aligned} \frac{dE_{cv}}{dt} = & \dot{Q} - \dot{W}_{cv} \\ & + \sum_i \dot{m}_i \left( h_i + \frac{\vec{V}_i^2}{2} + gz_i \right) - \sum_o \dot{m}_e \left( h_e + \frac{\vec{V}_e^2}{2} + gz_e \right) \end{aligned}$$

- Nozzle/diffuser
- Turbine, compressor, pump
- Heat exchanger
- Throttling device

Scan the QR code with  
your device

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Enter Code

**luepfl**

You've just scooped yourself a perfect bowl of **ice cream** and left it on the counter in a warm room. According to the 2<sup>nd</sup> Law of Thermodynamics, what will most likely happen over time?

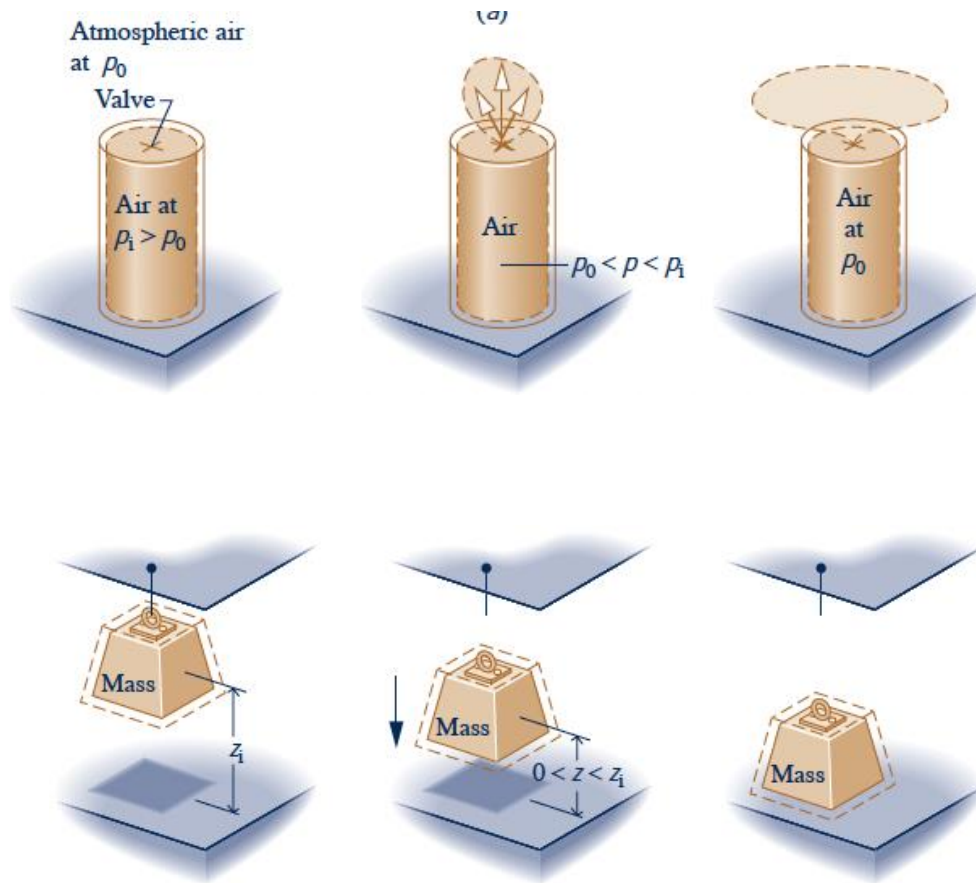
- **A.** The ice cream will stay perfectly frozen as long as you don't touch it.
- **B.** Heat from the room will flow into the ice cream, causing it to melt.
- **C.** The ice cream will get colder because it's losing energy to the surroundings.
- **D.** The ice cream will melt and then refreeze itself once it's absorbed enough heat.



A cup of hot coffee can spontaneously cool down to the ambient temperature by transferring heat to the surrounding

Now imagine a cup of coffee at the ambient temperature, to raise its temperature to be above the ambient, we must **do something**.

This inverse process is not spontaneous although it's not prohibited by the 1<sup>st</sup> law

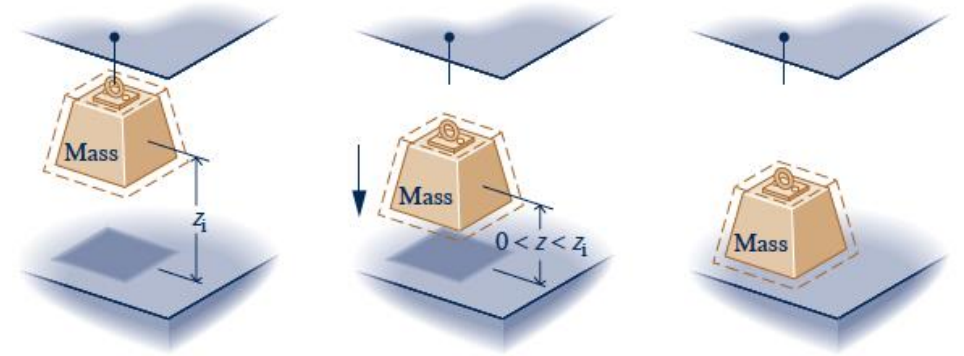
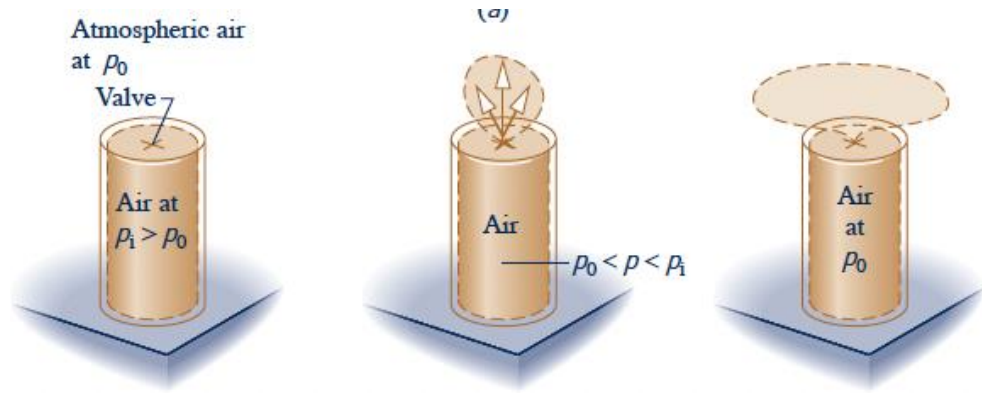


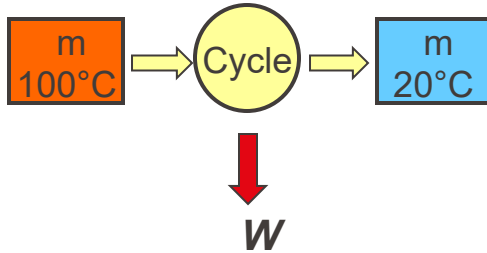
A high-pressure gas tank **spontaneously** reduces to the atmospheric pressure once opened

A mass suspended at an elevation **spontaneously** falls to the ground when released

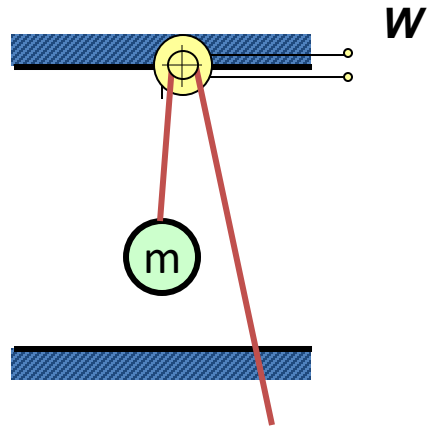
This inverse processes are not spontaneous although it's not prohibited by the 1<sup>st</sup> law

# Motivating the Second Law





The energy transferred to the surrounding by the coffee could be used to drive a power cycle and to extract work



The falling mass can be coupled to a wheel which would allow you to do work, for example, to lift another mass



The opportunity for work would be irreversibly lost if the systems achieves the equilibrium in a spontaneous, uncontrolled way

Energy is not destructed; it's devaluated or dissipated: high quality energy becomes low quality energy

We need the 2<sup>nd</sup> law to quantify this “quality” and determine the maximum obtainable work and how to approach the maximum

With the 2<sup>nd</sup> law of thermodynamics, we will:

- Predict the direction of processes
- Establish conditions for equilibrium
- Determine the best theoretical performance for processes, cycles, ...
- Quantitatively evaluate the factors that hinder the achievement of best theoretical performance
- Define the absolute temperature scale independent of the thermal properties of a substance
- Evaluate enthalpy and internal energy in alternative ways