ME-251: Thermodynamics and energetics I

Zhengmao Lu

Energy Transport Advances Laboratory (ETA-LAB)

EPFL Mechanical Engineering

2025 Fall Semester

Photo Credit: Trougnouf

Instructors

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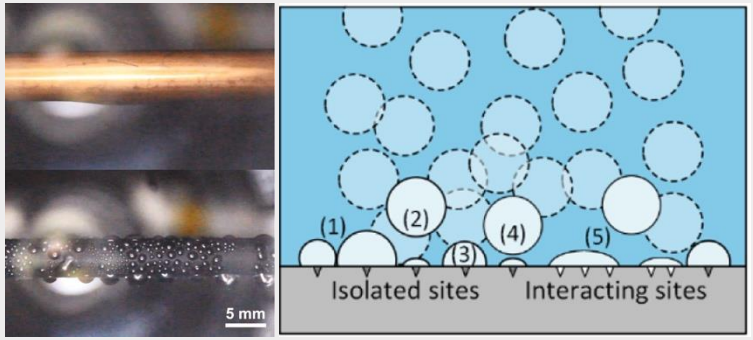
Energy Transport Advances Laboratory

Zhengmao Lu EPFL > STI > IGM > ETA-Lab

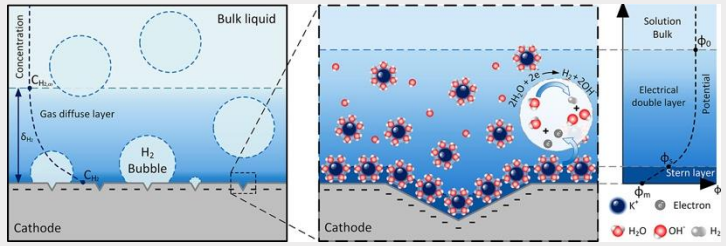
Leverage phase change heat/mass transfer to address the challenge of sustainability

Generation



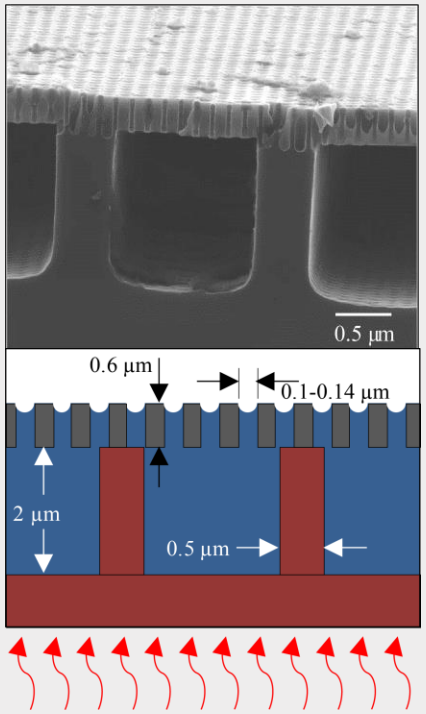
Condensation Boiling

Storage

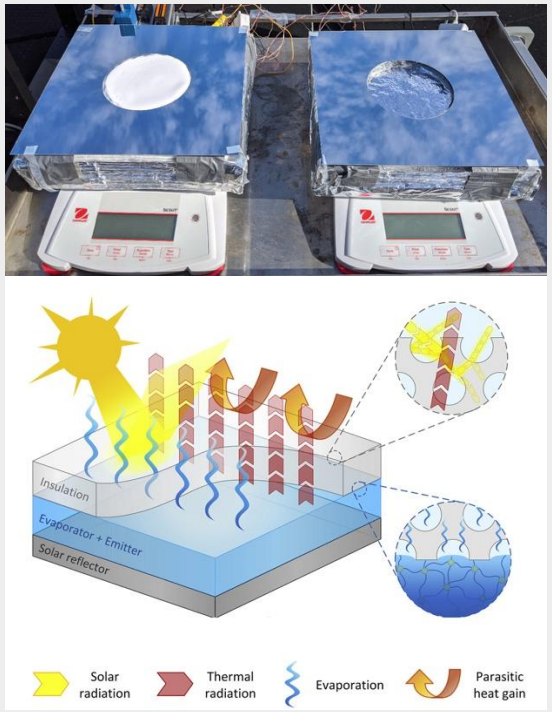


Alkaline water electrolysis

Usage



Electronics cooling



Passive subambient cooling

EPFL

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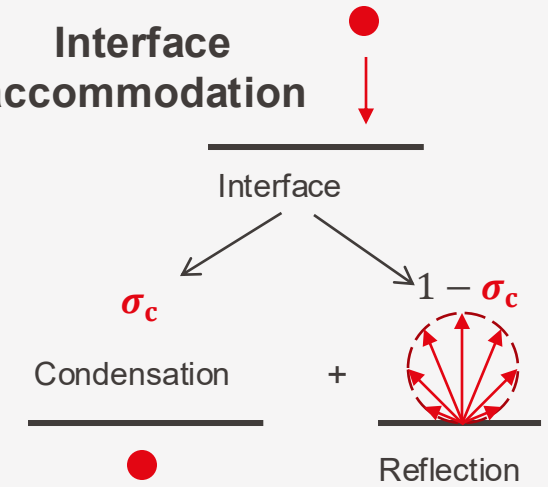
Energy Transport Advances

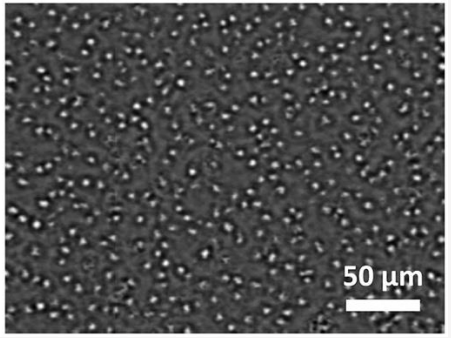
nanometer millimeter meter

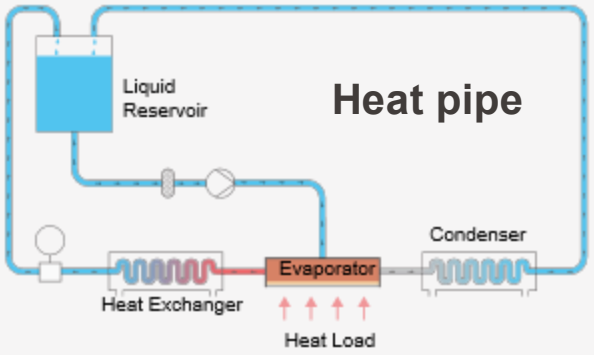
Interface Device System

Interface accommodation



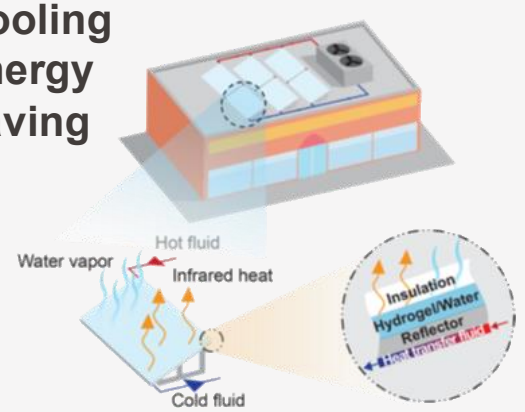
Nucleation process





Boiling bubble dynamics

Cooling energy saving



Course Info

- Course will be taught in English (lectures, exercises, exams,…)

- Lectures
  - Monday 9h15-10h and 10h15-11h, BCH 2201
  - Wednesday 13h15-14h, RLC E1 240
  - Course will be live streamed (link published on Moodle)
  - Recordings will be posted on Mediaspace (link published on Moodle)
  - Course slides will be uploaded to Moodle
  - Moodle: **make sure you can access Moodle! Important course info will be announced through Moodle.**

Course Info

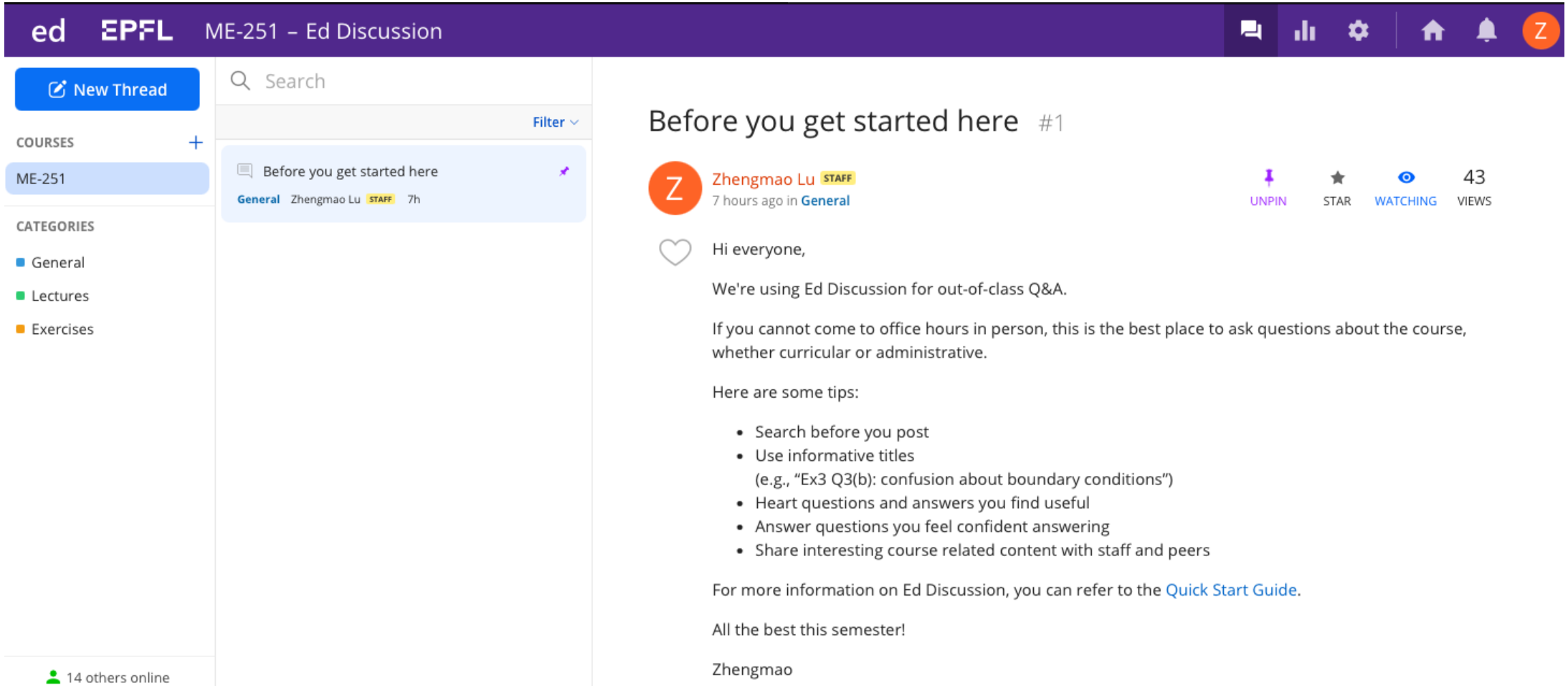
- Exercise
  - Wednesday 14h15-15h, 3 different classrooms (AAC137, SG0211, SG0213)
  - Exercise problems will be posted every Friday
    (First set of exercise problems posted on Moodle already)
  - Room assignment will be announced by September 9, 2025

Course Info

- Office hours
  - I will be available 11h-12h after Monday lectures (BCH 2201)
  - TA office hour: 12h-13h before Wednesday lectures (ME B1 10)

- Exam: 3 hours written exam during the exam period
  - Will be closely related to exercise problems.
  - There will be a review session toward the end of the semester.
  - You are allowed to bring a cheat sheet (one A4 paper double-sided or two A4 papers single-sided) and a **calculator** with you to the exam.

Course Info


ed EPFL ME-251 – Ed Discussion
New Thread
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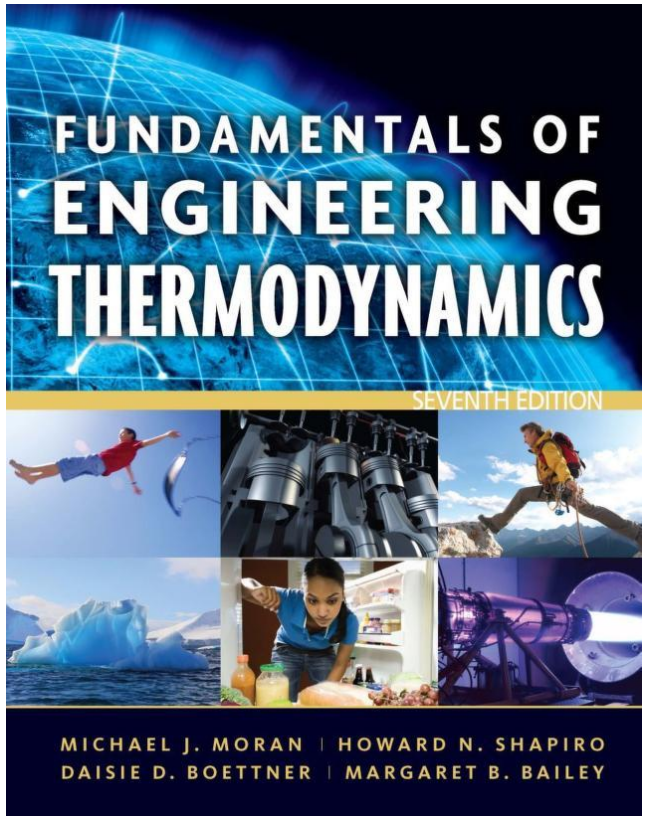
Before you get started here
General Zhengmao Lu STAFF 7h
14 others online
Before you get started here #1
Zhengmao Lu STAFF
7 hours ago in General
UNPIN
STAR
WATCHING
43
VIEWS
Hi everyone,
We're using Ed Discussion for out-of-class Q&A.
If you cannot come to office hours in person, this is the best place to ask questions about the course, whether curricular or administrative.
Here are some tips:
Search before you post
Use informative titles
(e.g., "Ex3 Q3(b): confusion about boundary conditions")
Heart questions and answers you find useful
Answer questions you feel confident answering
Share interesting course related content with staff and peers
For more information on Ed Discussion, you can refer to the Quick Start Guide.
All the best this semester!
Zhengmao

Reference Book

Fundamentals of Engineering Thermodynamics, 7th Edition by Moran, Shapiro, Boettner, Bailey. **(Moran)**



Appropriate Use of AI

- AI tools may be used to support your learning, but they should not replace your own reasoning or understanding of thermodynamics.
- Don’t trust AI (or perhaps anyone) blindly

Image generated by ChatGPT

Course Info

- Remarks:
  - This is a hard and time-consuming course in a foreign language
  - 4 credits ≈ 4x30 hours = 120 hours

    14x4 hours lecture/exercise → 120-56 = 64 hours outside the classroom

What is Thermodynamics

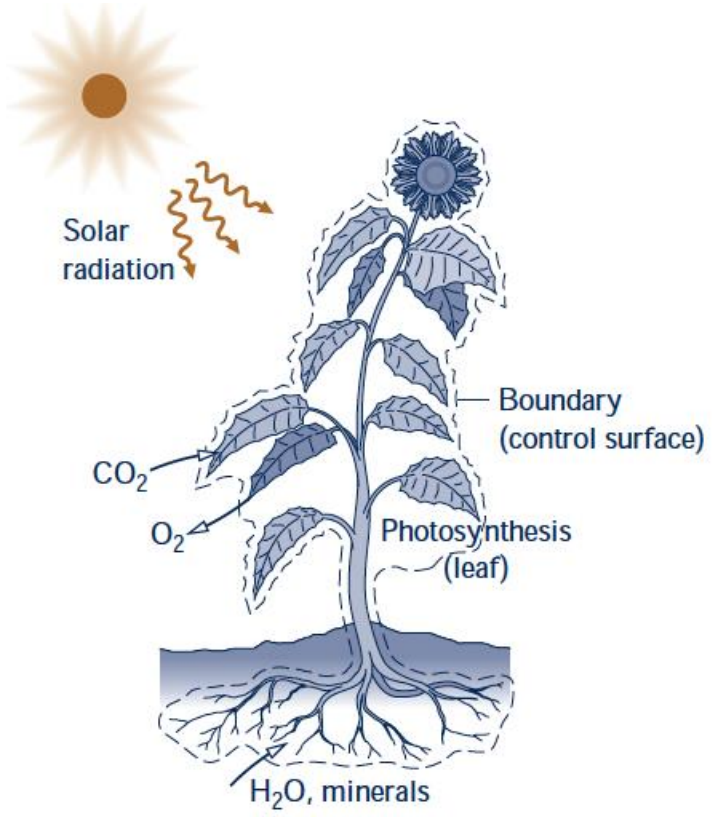
WIKIPEDIA
The Free Encyclopedia

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.

Course Overview

- General concepts
- 1st law for closed systems
- Thermodynamics properties
- 1st law for open systems
- Entropy and 2nd law for closed and open systems
- Exergy
- Applications (vapor power cycle, gas power system, refrigeration)
- Thermodynamic relations, mixtures, psychrometrics

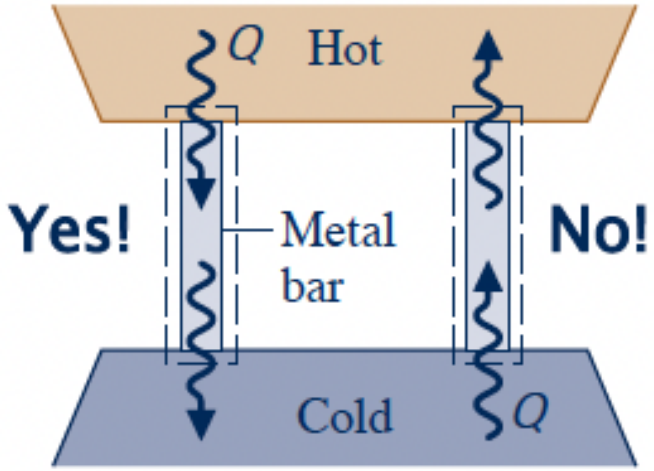
First Law



Can be intuitively understood as energy conservation

Energy change = Energy going in – Energy going out

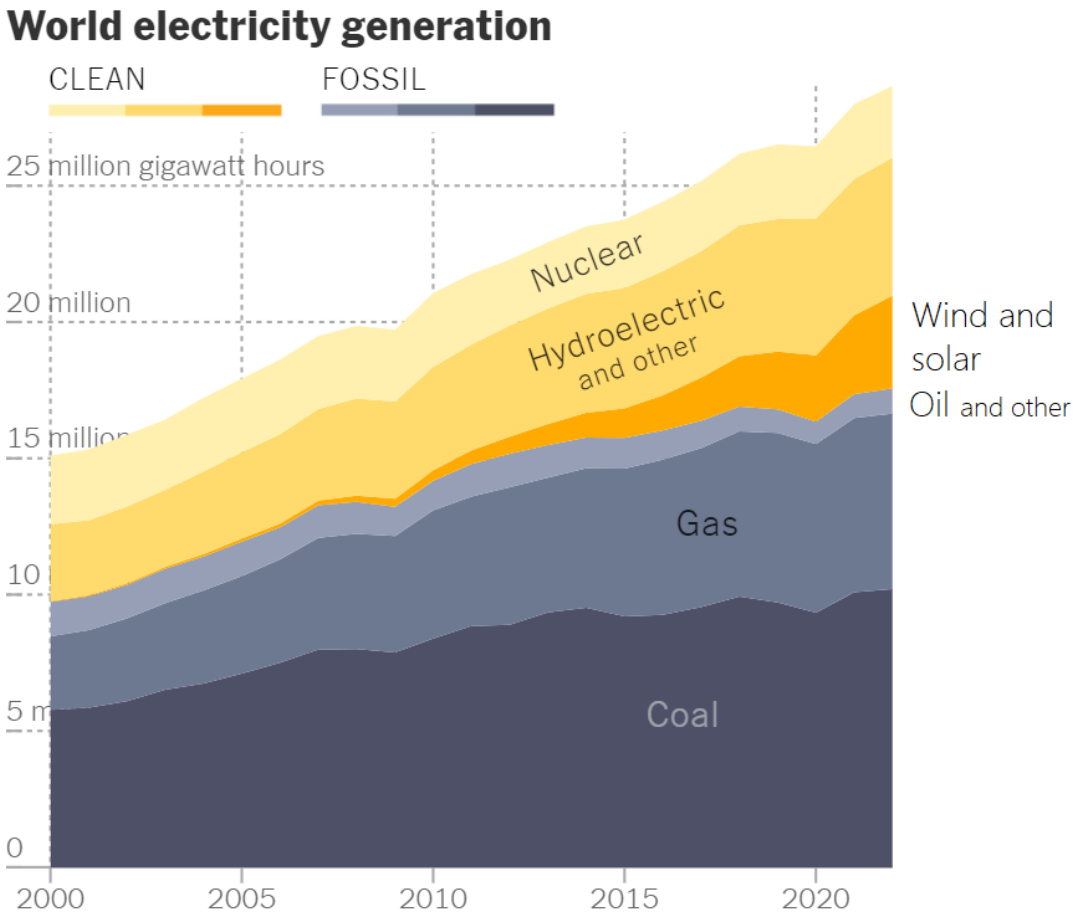
Second Law



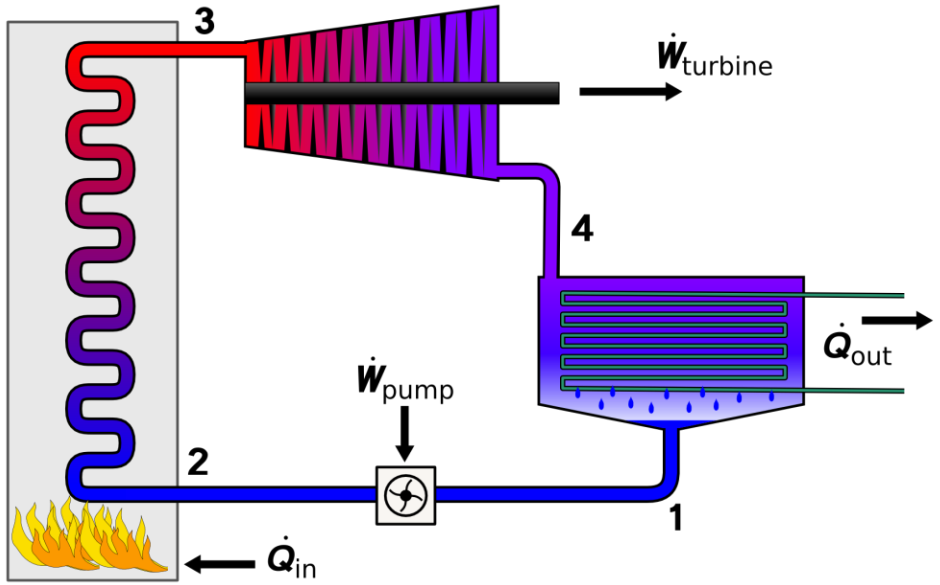
Clausius Statement of the Second Law

It’s impossible for any system to operate in such a way that the sole result would be an energy transfer by heat from a cooler to a hotter body.

Why We Study Thermodynamics



By The Learning Network
Published March 28, 2024; Updated April 15, 2024

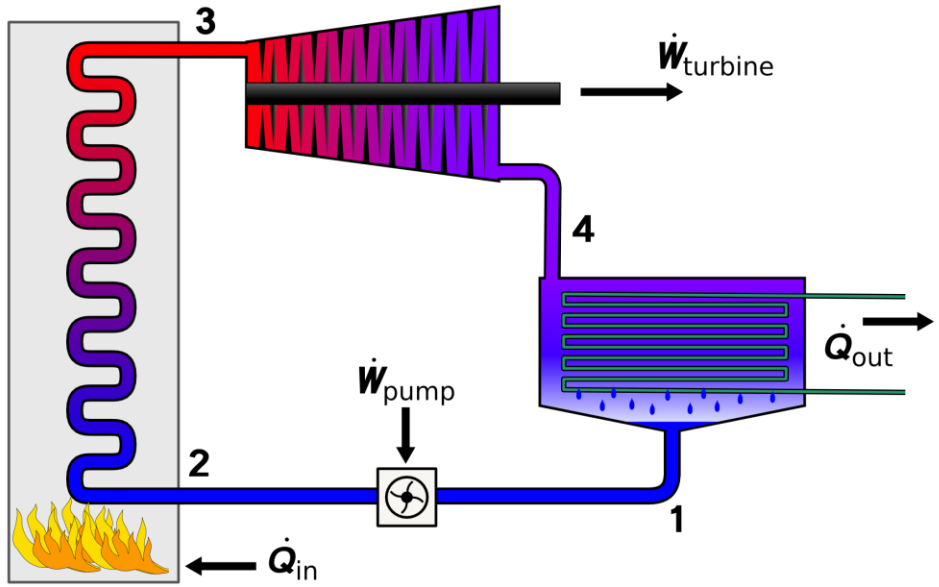


Credit: Andrew Ainsworth

Why We Study Thermodynamics

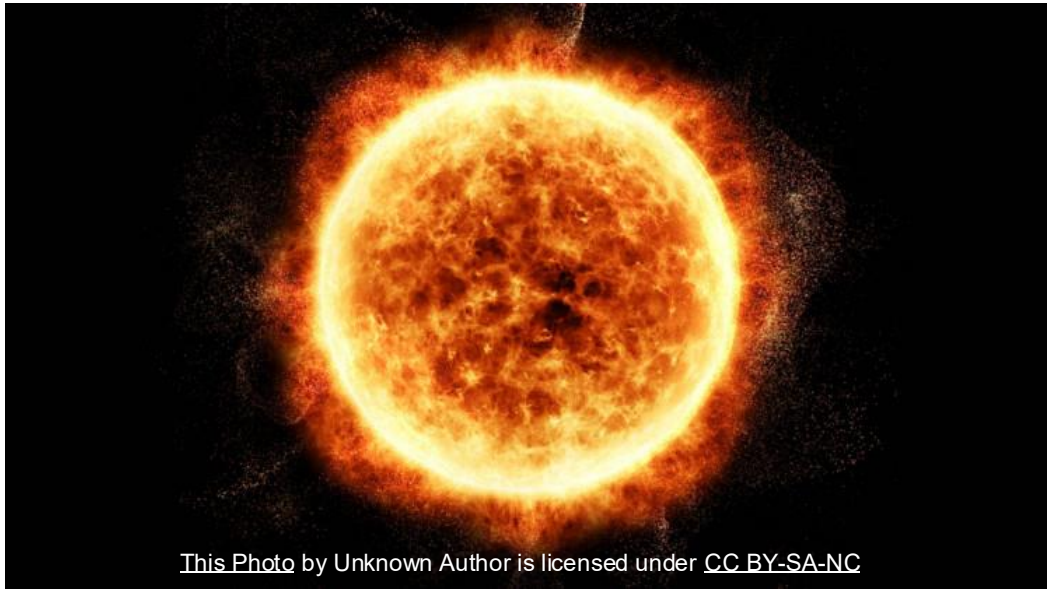
Credit: Koza1983, CC BY 3.0

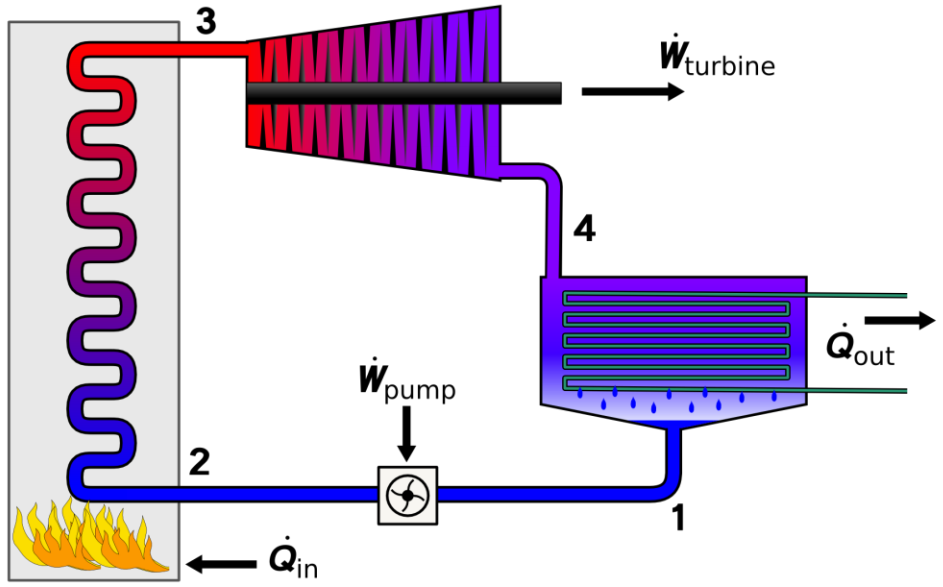
Concentrated solar power plant in Spain



Credit: Andrew Ainsworth

Why We Study Thermodynamics





Power cycle is relevant even for nuclear fusion

Credit: Andrew Ainsworth

Why We Study Thermodynamics

Credit: Andrewglaser, CC BY-SA 3.0

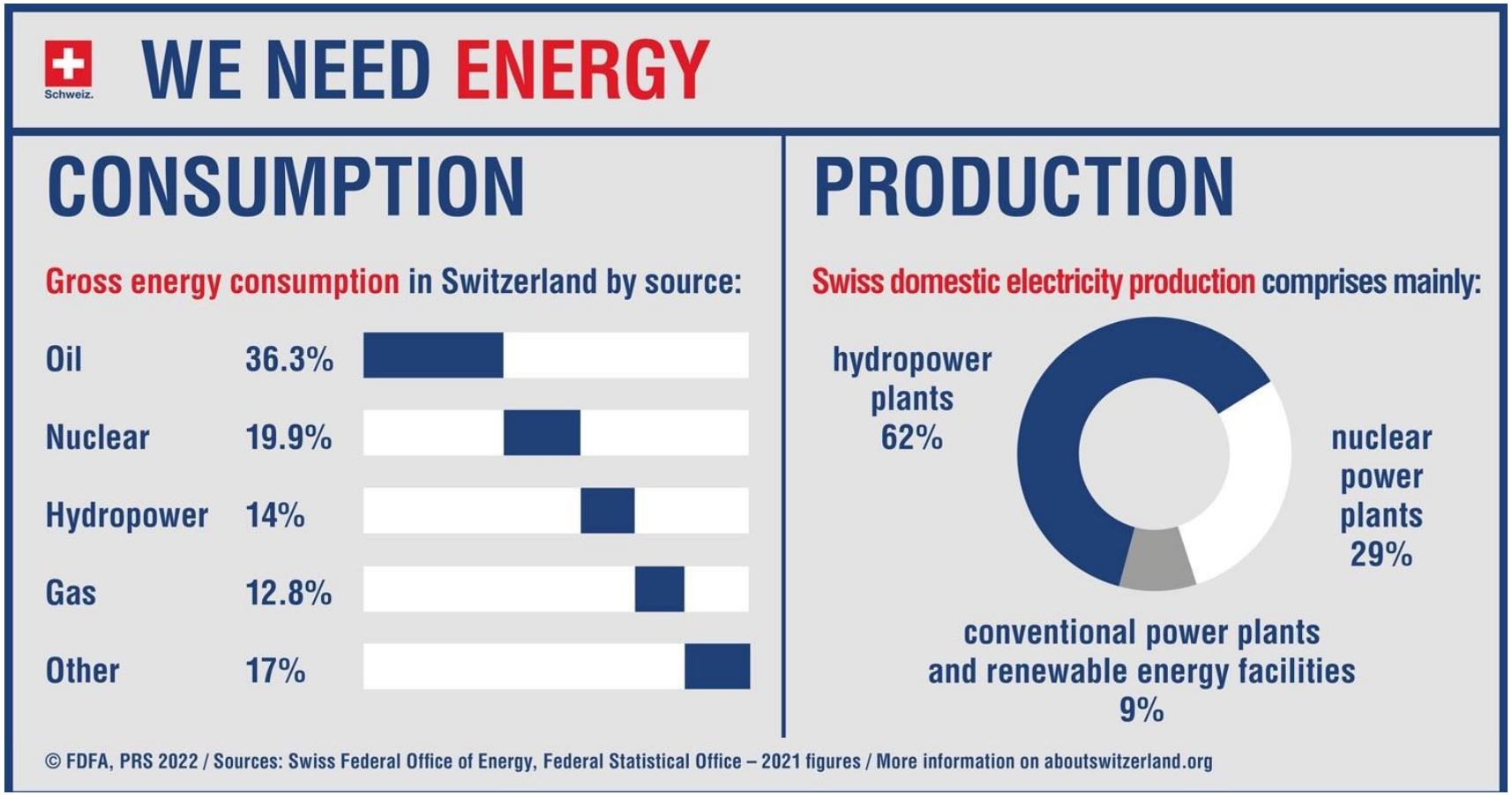
Solar photovoltaic panels

Credit: Jérémy Toma, CC BY-SA 4.0

Hydroelectric dam in Valais

Thermodynamic analysis is needed for all forms of power generation technologies

Why We Study Thermodynamics



Why We Study Thermodynamics

Aircraft

https://www.swiss.com

Train

https://www.sbb.ch/

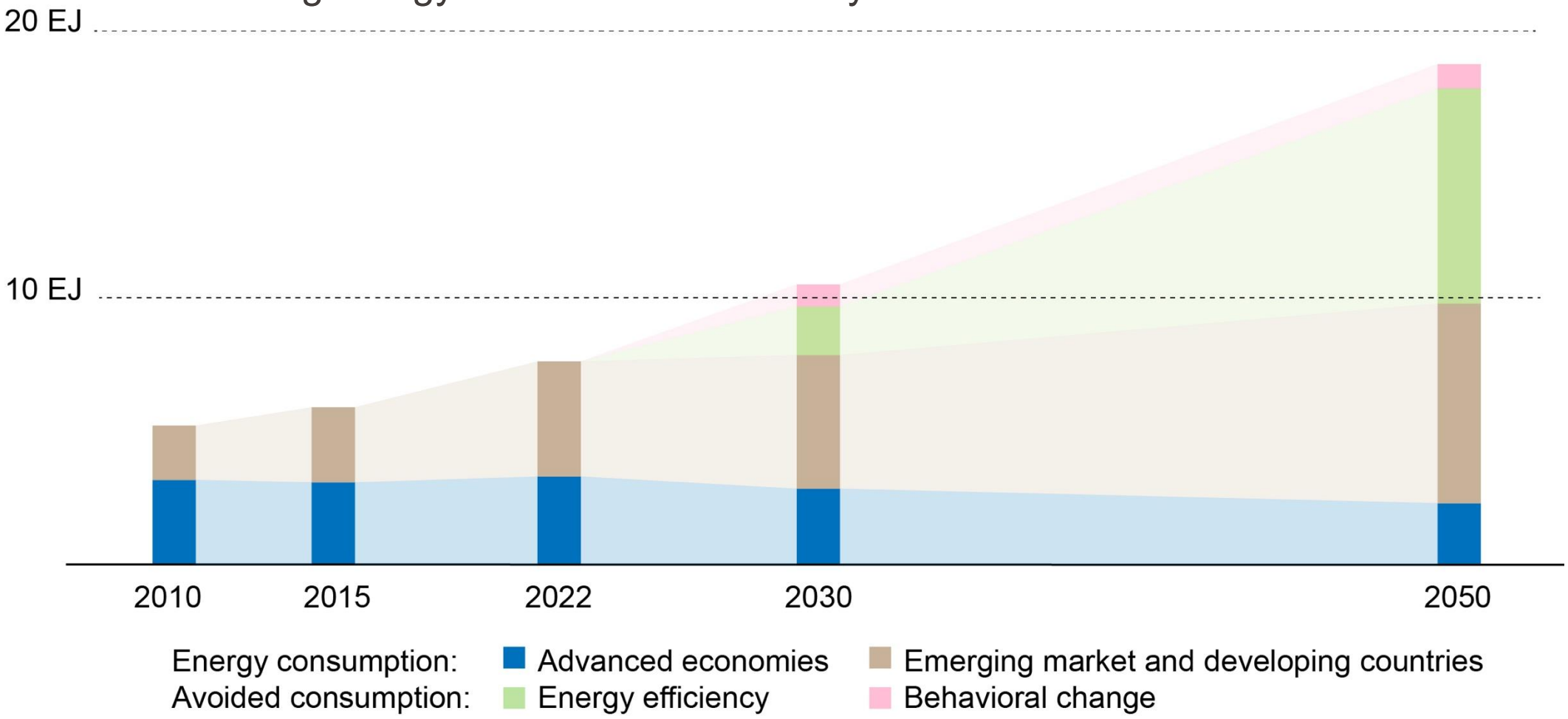
Car

https://www.mobility.ch

Energy conversion for transportation requires thermodynamic analysis

Why We Study Thermodynamics

Cooling energy demand will **double** by 2050 with no action taken



International Energy Agency

Why We Study Thermodynamics

Data Center

Market size expected to **double** by 2025

Cooling pipes in a Google data center
(Credit: Connie Zhou/Google/Zuma)

Improving cooling system's thermodynamic efficiency is critical to addressing the world's ever-increasing cooling demand

Why We Study Thermodynamics

Data Center

Market size expected to **double** by 2025

Cooling Loop

Office/Residential Building

40-60% of energy used for heating

Heating Loop

CDUs

Heat Exchanger

Water flow for Waste Heat Recovery

Why We Study Thermodynamics

- Aircraft/rocket propulsion
- Alternative energy systems:
  - Fuel cells
  - Geothermal systems
  - Magnetohydrodynamic converters
  - Ocean thermal, wave, and tidal power generation
  - Solar-activated heating, cooling, and power generation
  - Thermoelectric and thermionic devices
  - Wind turbines

Table 1.1 in Moran

- Automobile engines
- Bioengineering applications
- Biomedical applications
- Combustion systems
- Compressors, pumps
- Cooling of electronic equipment
- Cryogenic systems, gas separation, and liquefaction
- Fossil and nuclear-fueled power stations
- HVAC systems
- Refrigeration and heat pumps
- Steam and gas turbines
- Power production
- Propulsion

Intended Learning Objectives (ILOs) for Today

- Understand the scope and the applications of thermodynamics

- Define and explain basic thermodynamics concepts
  - System, surrounding, boundary
  - Open vs closed systems
  - State, property, process, equilibrium
  - Intensive and extensive properties

- Reading materials: **Moran** Chapter 1

What We Study in ME-251

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The Free Encyclopedia

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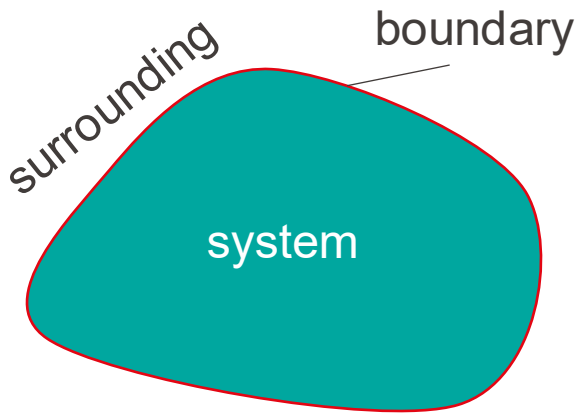
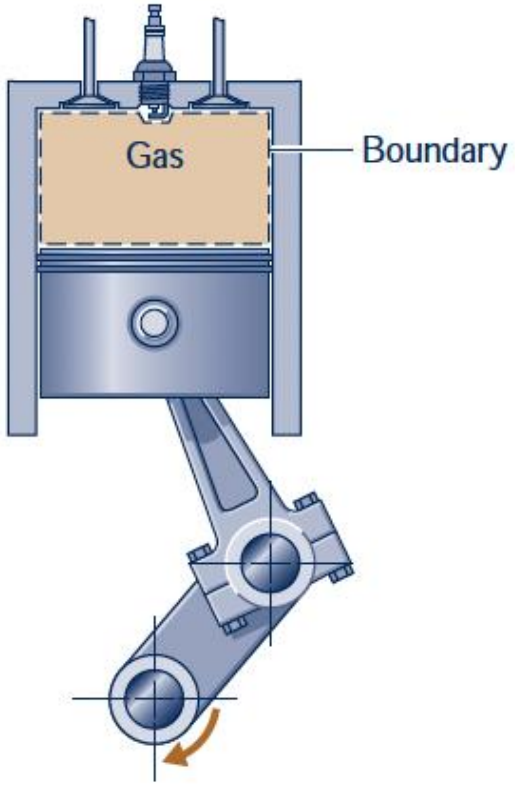


To perform thermodynamics analysis, we need to define the **system**, the **surrounding** and the **boundary** that separate the two

Example

Piston-cylinder assembly



System: gas inside the cylinder

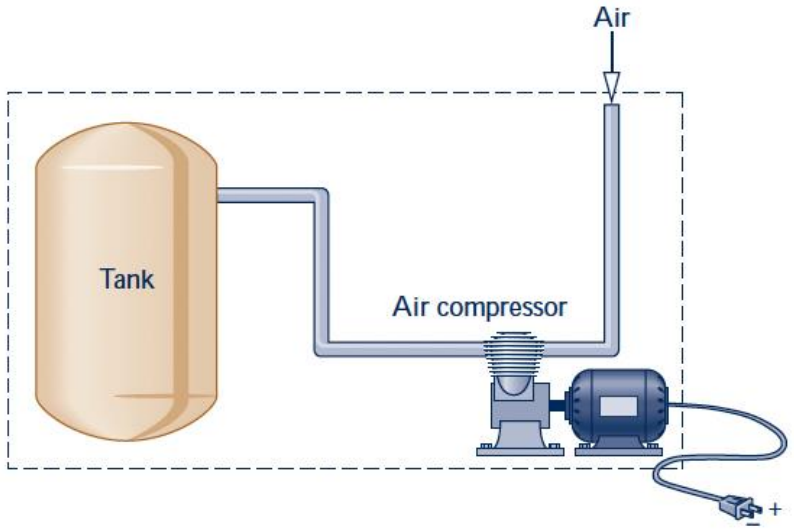
Boundaries: gas-cylinder interface, gas piston interface

Surrounding: the rest of the universe

- If the valve is closed, there is no mass flux across the boundary, and we call this a closed system
- A closed system can still exchange energy (in the form of heat, work, …) with the surrounding

Example

Air compressor and storage tank



System: everything inside the dashed box

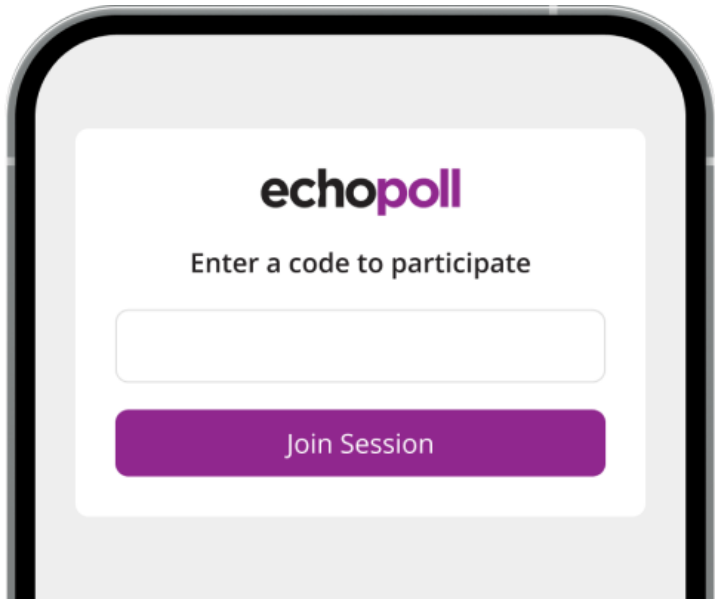
Boundaries: surfaces of the dashed box

Surrounding: the rest of the universe

This is an **open system**: there is a mass flux across the boundary

To join the session

Go to
echo360poll.eu

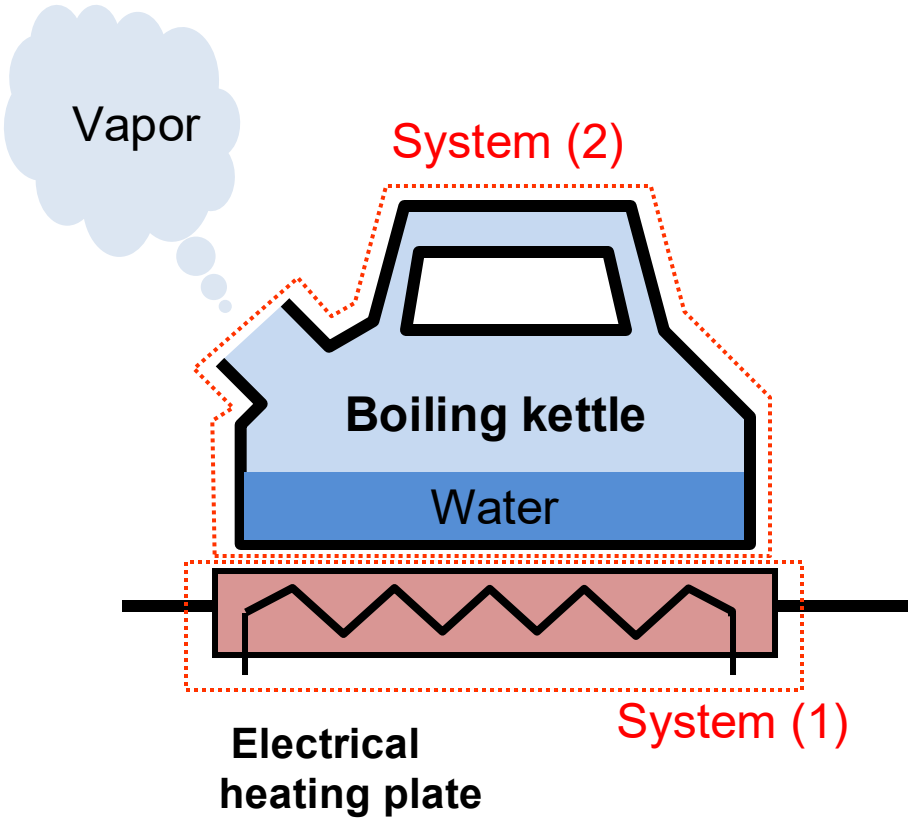


Enter Code

luepfl

Or scan the QR code with your device

Open or Closed



Which of the following statement is correct?

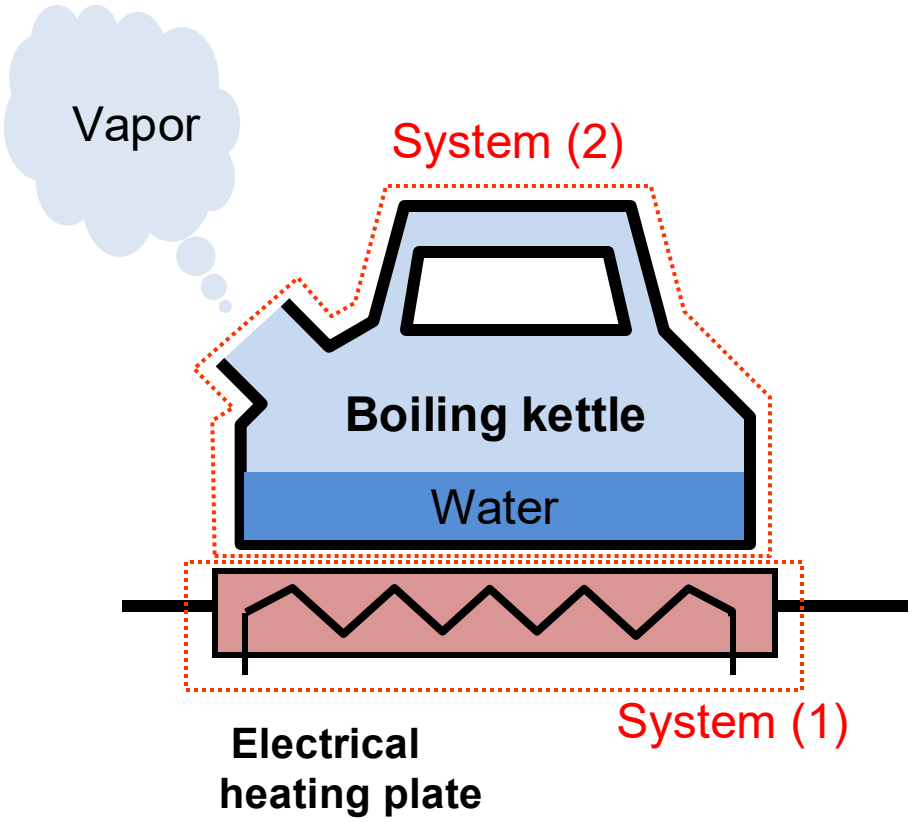
A. (1) is an open system and (2) is a closed system

B. (1) is an open system and (2) is an open system

C. (1) is a closed system and (2) is a closed system

D. (1) is a closed system and (2) is an open system

Open or Closed



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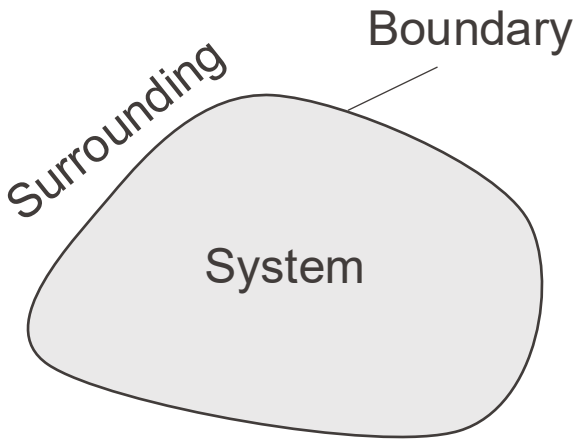
C. (1) is a closed system and (2) is a closed system

D. (1) is a closed system and (2) is an open system

What We Study in ME-251



After identifying the system, we describe its **state** through a set of **thermodynamic properties/state functions** (internal energy, enthalpy, temperature, pressure,…)

We also study the **process** that marks the transformation from one state to another.

Equilibrium

- A system is said to be in equilibrium when its properties do not change over time and there is no energy/mass flux across the boundaries

- At equilibrium, temperature and pressure (after accounting for hydrostatics) should be uniform
  - Otherwise, we will have “mixing” between high T or high P region with low T or low P regions

- ME-251 primarily studies equilibrium states and changes from one equilibrium state to another

Intensive Properties

Properties that are independent of the size of the system

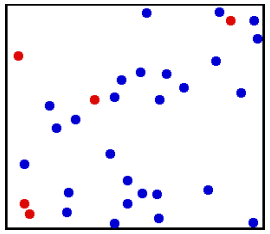
- Temperature
- Pressure
- Density or specific volume

When you combine two systems into one, you cannot add up intensive properties

Temperature

Wikipedia

Temperature is a physical quantity that expresses quantitatively the perceptions of **hotness and coldness**.

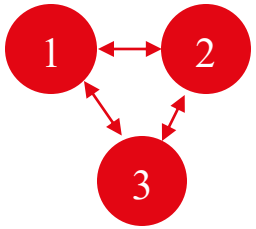


Kinetic theory

Temperature is proportional to the **average kinetic energy of the molecules**

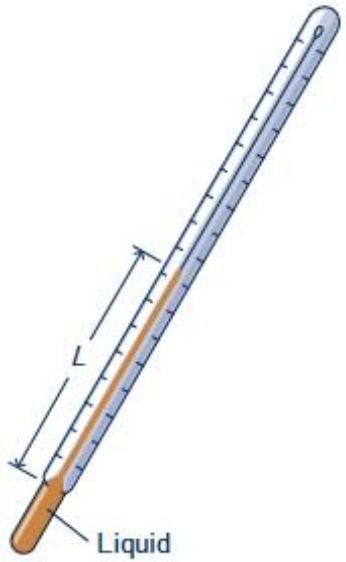
Temperature

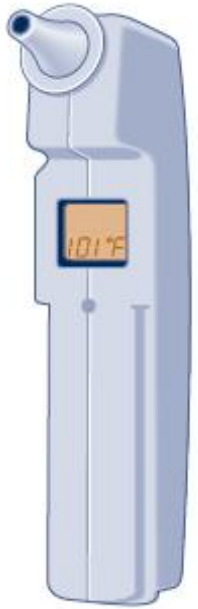
Zeroth law: If two systems are both in thermal equilibrium with a third system, then they are in thermal equilibrium with each other



The zeroth law allows for **temperature measurement with a thermometer** that has measurable properties with known temperature dependence

Thermometers





Liquid in glass Electrical resistance Infrared sensing

Temperature Scales

Celsius Scale (°C)

- 0 °C for the freezing point of water at 1 atm pressure
- 100 °C for the boiling point of water at 1 atm pressure

Fahrenheit (°F)

- 32 °F for the freezing point of water at 1 atm pressure
- 212 °F for the boiling point of water at 1 atm pressure

Kelvin (K)

- 0 K: lowest limit of thermodynamic temperature scale, -273.15 °C
- 1 K interval is the same as 1 °C interval

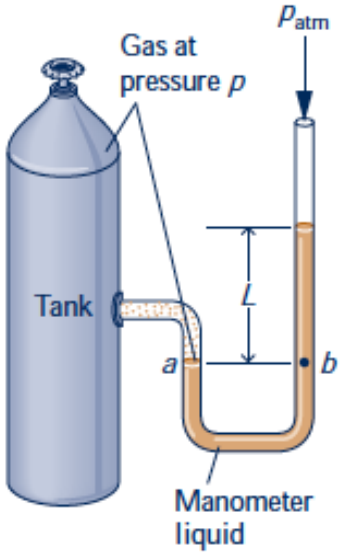
Pressure

Microscopically linked to molecules hitting a surface

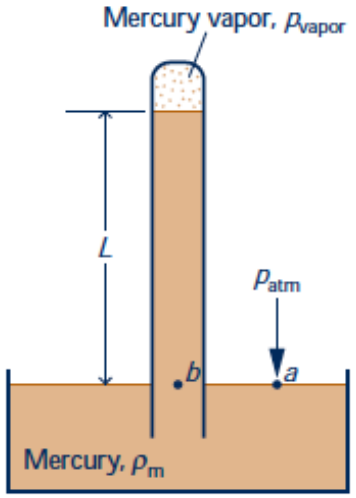
Macroscopically defined as normal force exerted by a fluid per unit area

$p = F_{normal}/A$

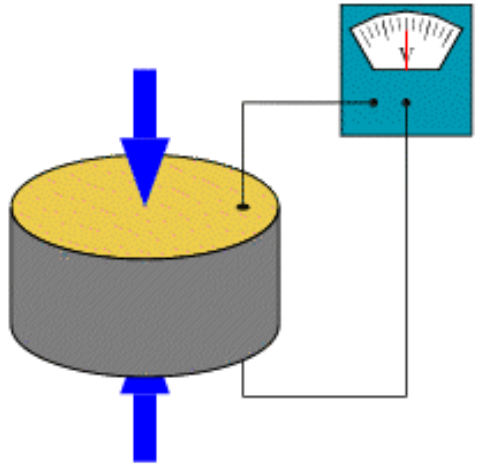
Pressure Measurement



Manometer



Barometer



Piezoelectric sensor

Density, Specific Volume

Continuum hypothesis: the description of matter can be simplified by considering it to be distributed continuously throughout a region.

Density $\rho = m/V$ mass per unit volume

Specific volume $v = 1/\rho$ volume per unit mass

Microscopically, density corresponds to the statistical average of the mass of particles in a unit volume

Phenomenological vs Statistical

Phenomenological description based on experimental observations of macroscopic systems and matters

Statistical treatment based on the average behavior of a large group microscopic particles.

Intensive vs Extensive

The magnitude of an intensive property is independent of the size of the system:

Temperature, pressure, specific volume, …

A property is called extensive if its value for an overall system is the sum of its values for the parts into which the system is divided:

Mass, volume, energy, …

When you combine two systems into one, you can add up extensive properties

Summary for Today

- Understand the scope and the applications of thermodynamics

- Define and explain basic thermodynamics concepts
  - System, surrounding, boundary
  - Open vs closed systems
  - State, property, process, equilibrium
  - Intensive and extensive properties

- Reading materials: **Moran** Chapter 1

Next Lecture

- Explain key concepts in the 1st law of thermodynamics
  - Energy change
  - Work
  - Heat

- Reading materials: **Moran** 2.1-2.4