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 power lines and pylons visible in the distance. On the right, a large industrial power plant with a prominent cooling tower is situated near a waterfront. A semi-transparent red rectangular box is overlaid on the right side of the image, containing the course title in white text.

# ME-251: Thermodynamics and energetics I

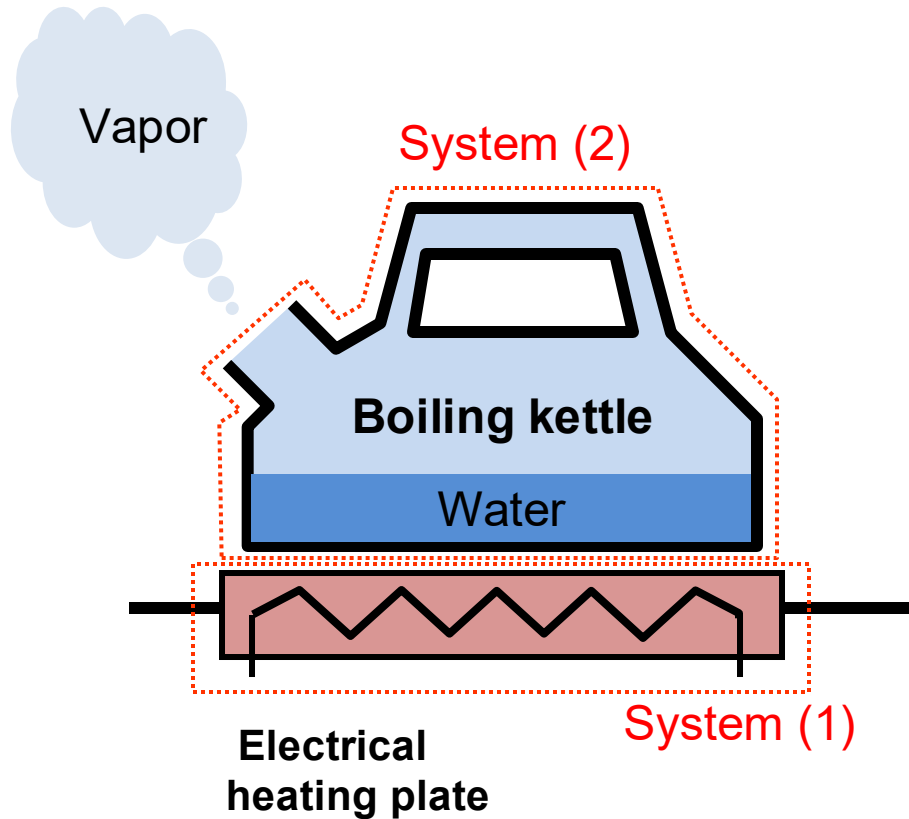
## First Law of Thermodynamics

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Energy Transport Advances  
Laboratory  
EPFL Mechanical Engineering

2025 Fall Semester

Photo Credit: Trougnouf

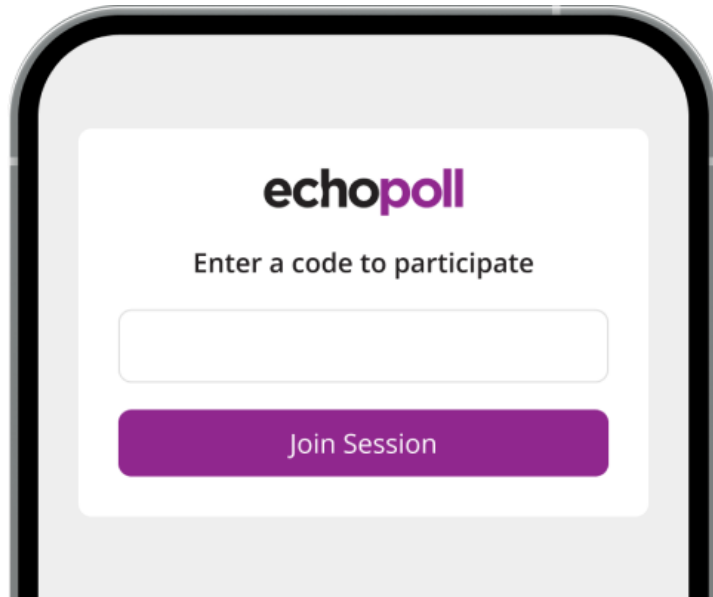
- Scope and application areas of thermodynamics
  
- General thermodynamics concepts
  - System, surrounding, boundary
  - Open vs closed systems
  - State, property, process, equilibrium
  - Intensive and extensive properties



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

Go to  
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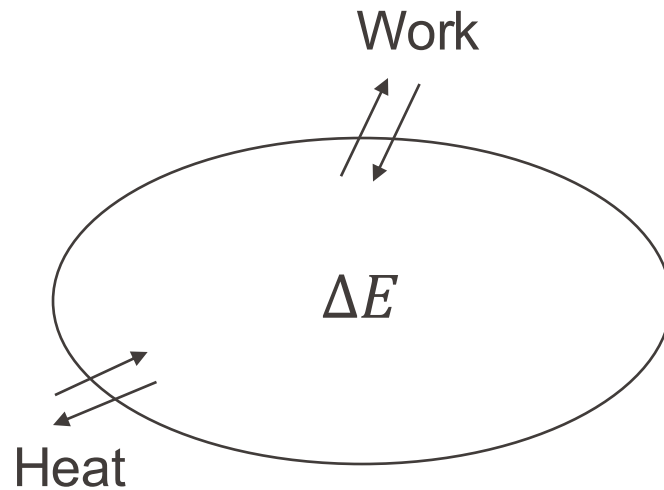
Enter Code  
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- Which of the following options contain only intensive properties
  - A. Volume, mass
  - B. Density, pressure
  - C. Temperature, mass
  - D. Energy, specific volume

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

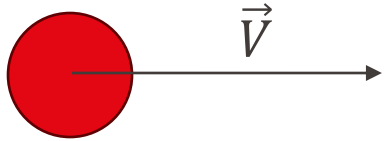


Can be intuitively understood as energy conservation

Energy change = Energy going in – Energy going out

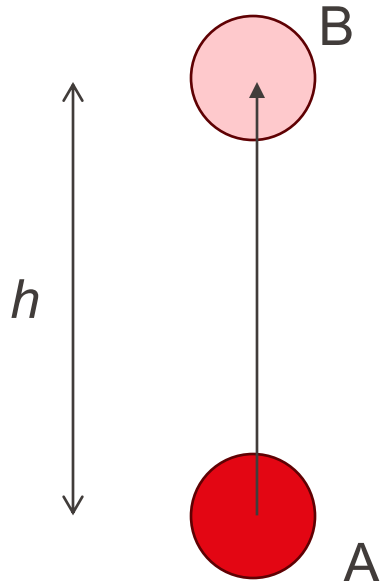
Energy flows can take the form of heat, work, ...

- No heat exchange with the surrounding
- Mechanical work causing changes in kinetic and potential energies



$$KE = \frac{1}{2} m \vec{V}^2$$

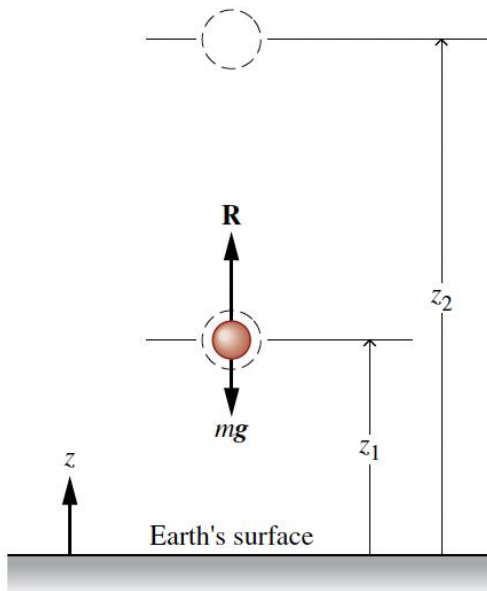
- KE depends on the speed, but not the direction of the velocity
- KE depends on the frame of reference (FOR) that you choose  
Keep your FOR consistent when evaluating change in kinetic energy



Potential energy is associated with an external (conservative) force field

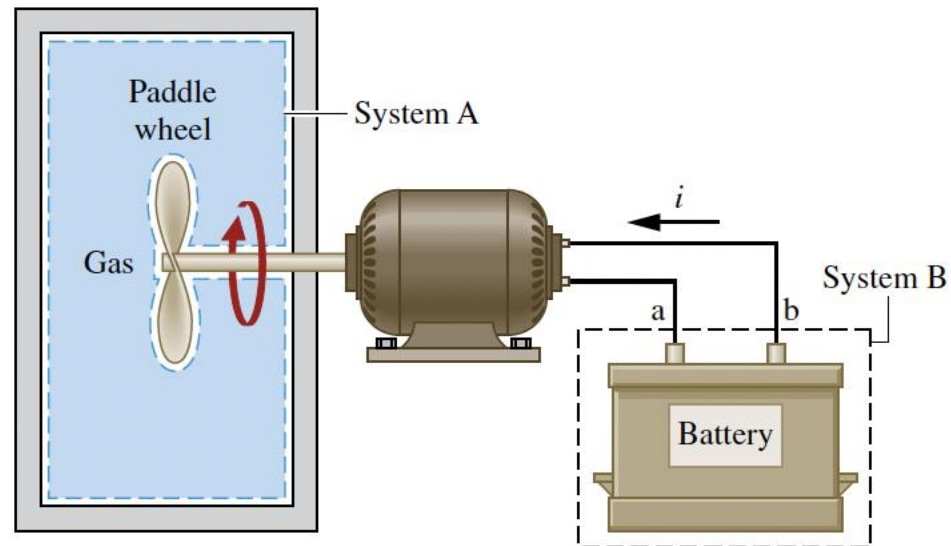
Change in potential energy only depends on starting state and end state, and does not depend the transition path

From A to B, the gravitational energy increases by  $mgh$  regardless of the path taken



The internal energy of the system originates from **microscopic motions and interactions**, is often **related to temperature and chemical bonding**, but does not include the bulk kinetic energy, and bulk potential energy

Thermodynamic definition of work: work is done by a system on its surrounding if the sole effect on everything external to the system **could have been** raising a weight



System A : gas in the chamber

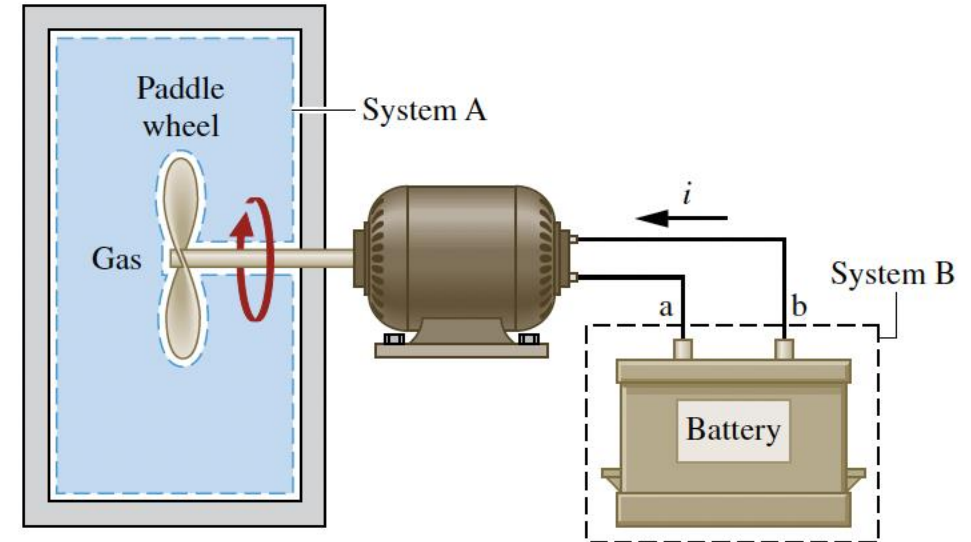
Mechanical work done **to** A by the surrounding as the paddle wheel move the gas

System B : battery

Electrical work done **by** B to the surrounding as electrons are moved by electrical field

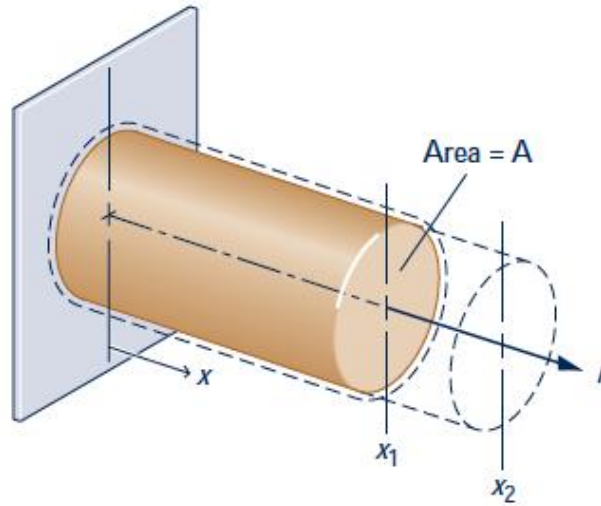
Work done by the system:  $W > 0$

Work done on the system:  $W < 0$



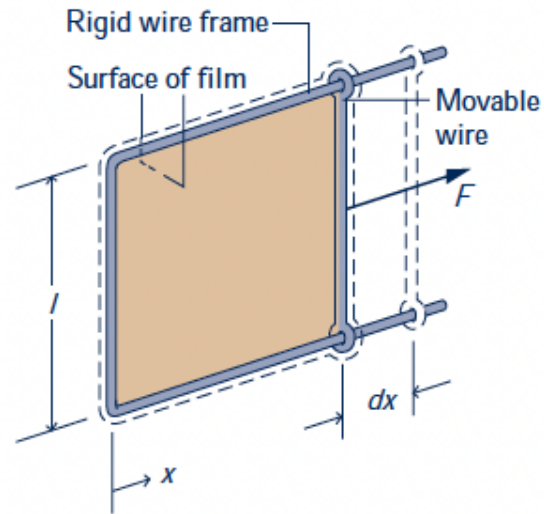
System A: The paddle wheel did work on the system (gas),  $W < 0$

System B: The work was done by the system (battery) to the motor,  $W > 0$



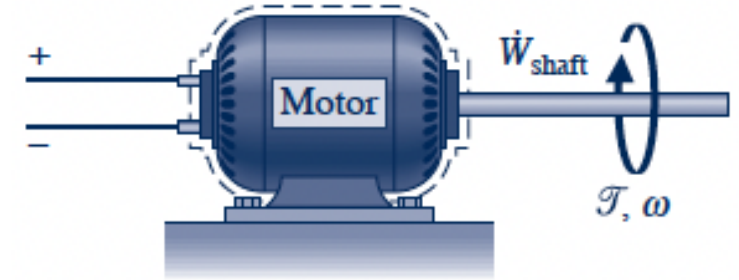
Elongation of a solid bar

$$W = - \int_{x_1}^{x_2} \sigma A dx$$



Stretching of a liquid film

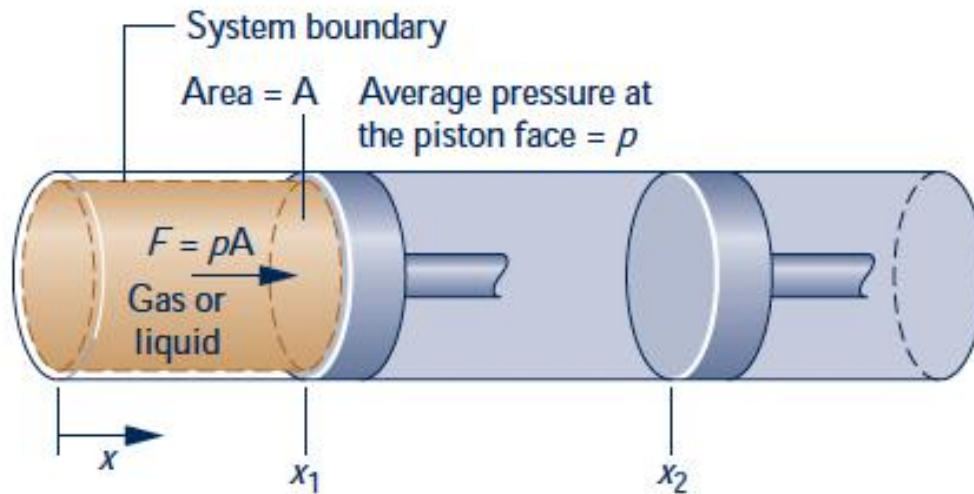
$$W = - \int_{x_1}^{x_2} \tau l dx$$



Work transmitted by a shaft

$$W = \mathcal{T} \omega$$

See 2.2.6

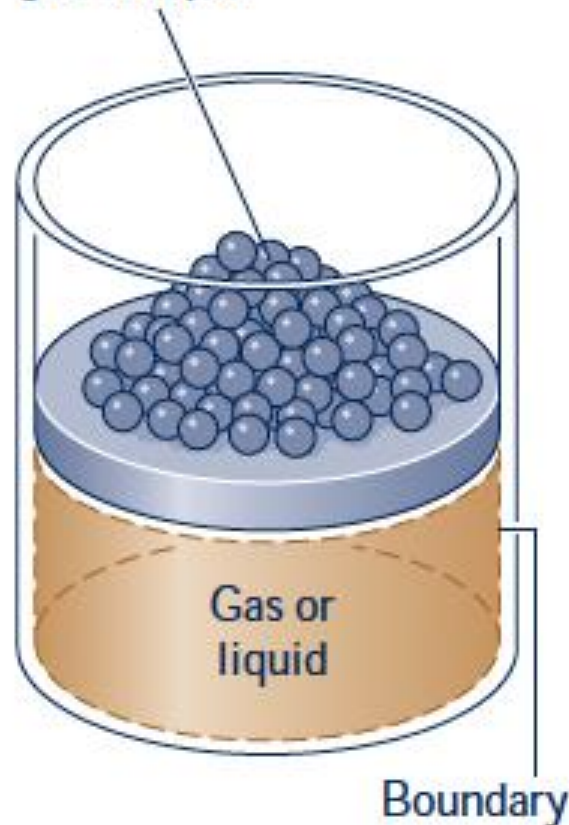


System: gas/liquid contained in a piston-cylinder assembly

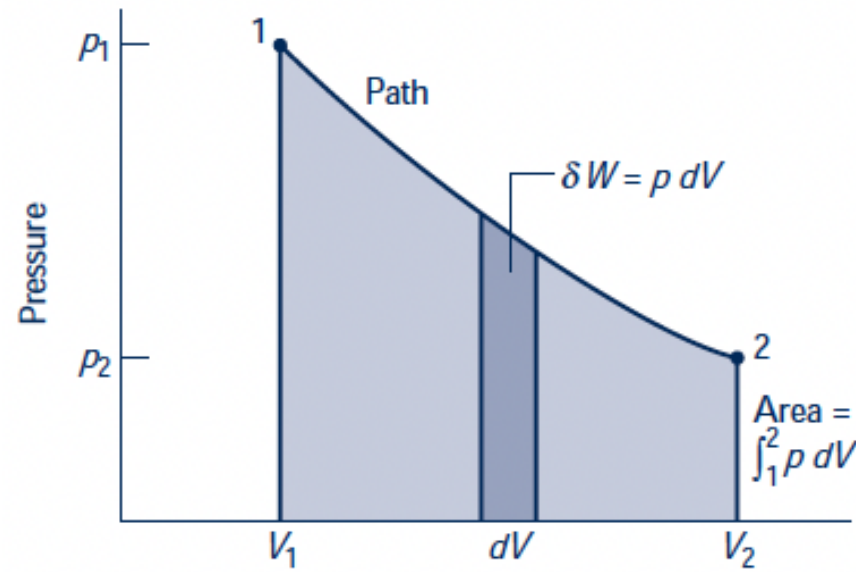
- Consider a process that marks the transformation from one equilibrium state to another.
- When this process is so slow that all the states the system passes can be considered equilibrium states, we call it a quasiequilibrium process.

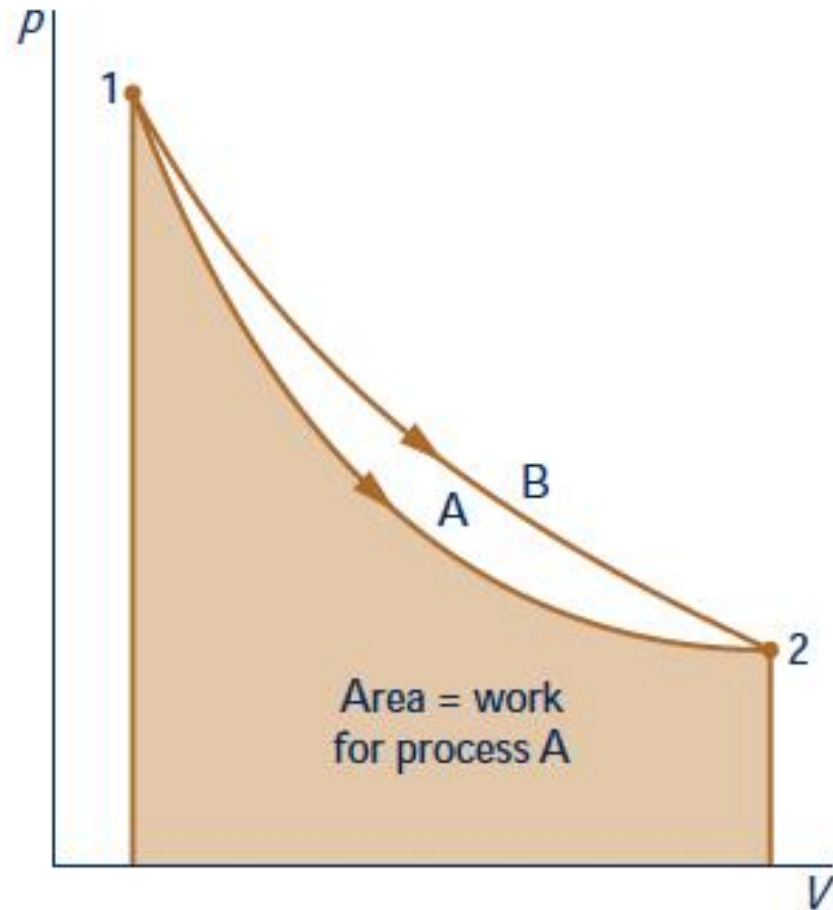
# Quasiequilibrium Process

Incremental masses removed during an expansion of the gas or liquid

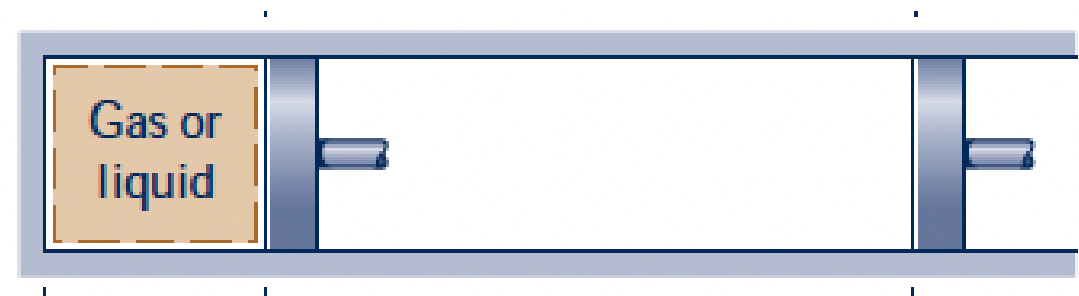


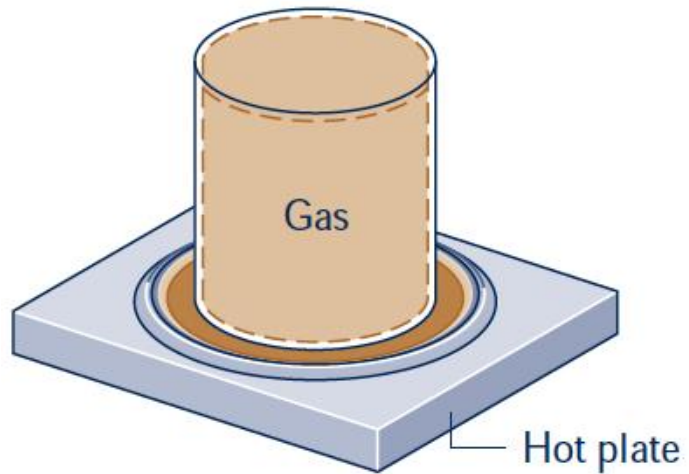
- During the transformation, the system is technically in non-equilibrium at every moment.
- But we assume that we can assign equilibrium properties to every intermediate state if the process is slow enough





Work depends on the specific process the system undertakes to go from one state to another



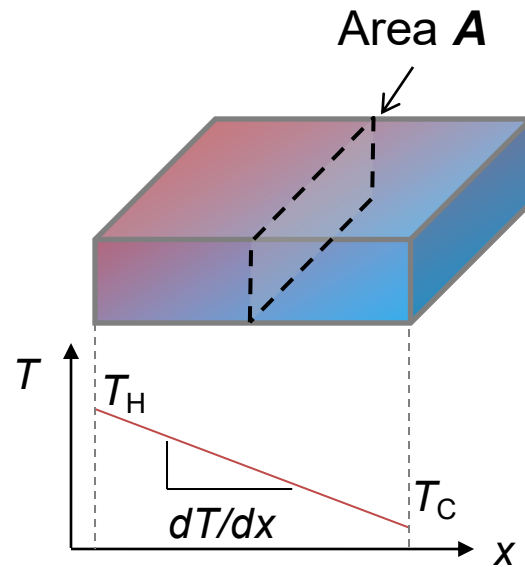


Gas in a rigid container on a hot plate

No system boundary movement  $\rightarrow$  No work

Energy transferred from the hot plate to the system by heat

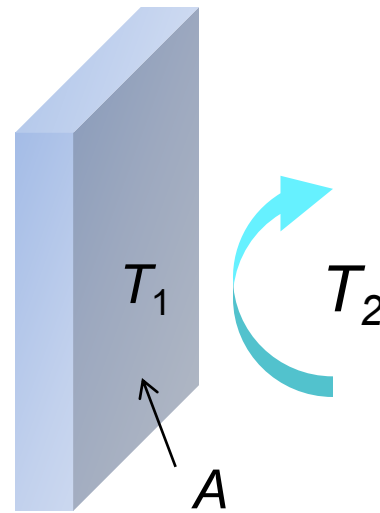
## Conduction



Fourier's law

$$\dot{Q} = -kA \frac{dT}{dx}$$

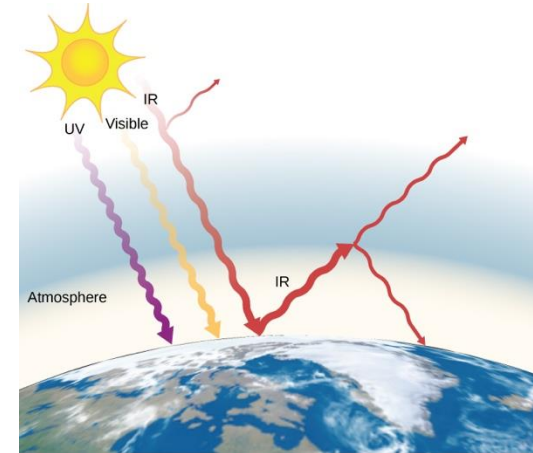
## Convection



Newton's law of cooling

$$\dot{Q} = hA(T_1 - T_2)$$

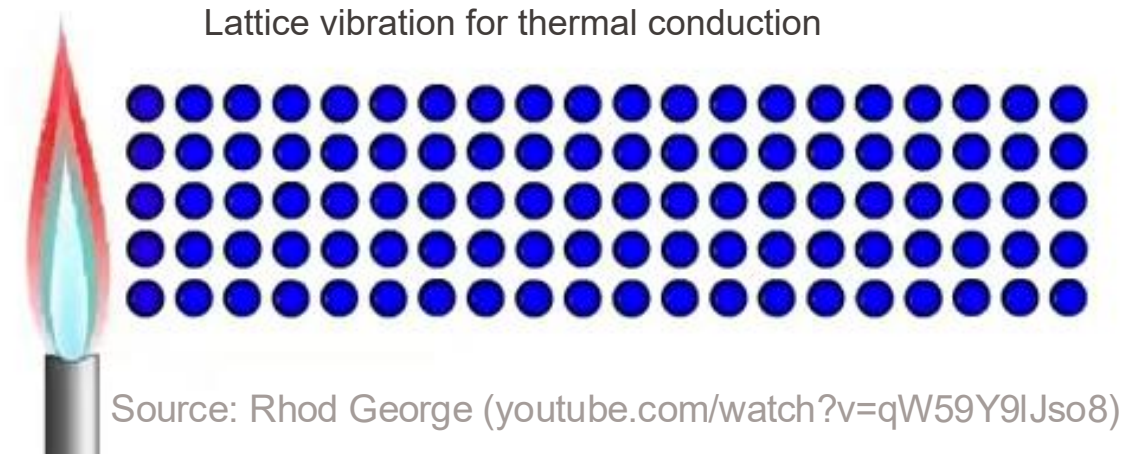
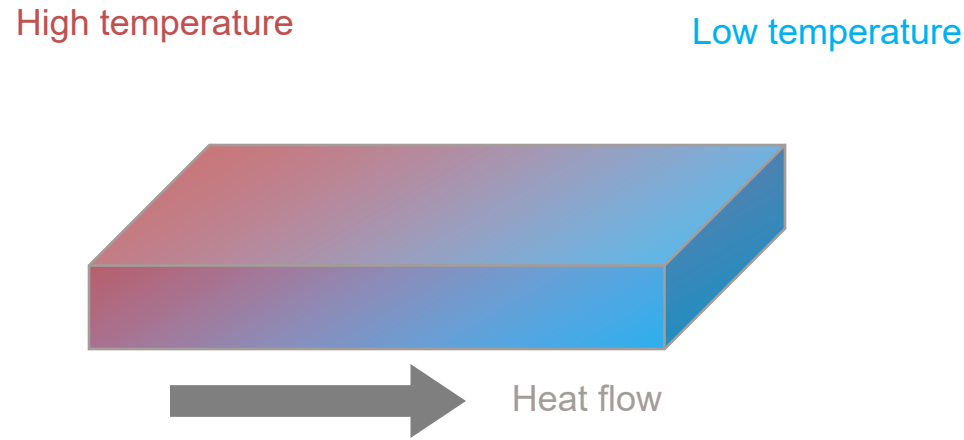
## Radiation



Stefan-Boltzmann Law

$$\dot{Q} = \varepsilon\sigma T^4 A$$

See 2.4.2 in **Moran**; ME-341 is dedicated to Heat Transfer



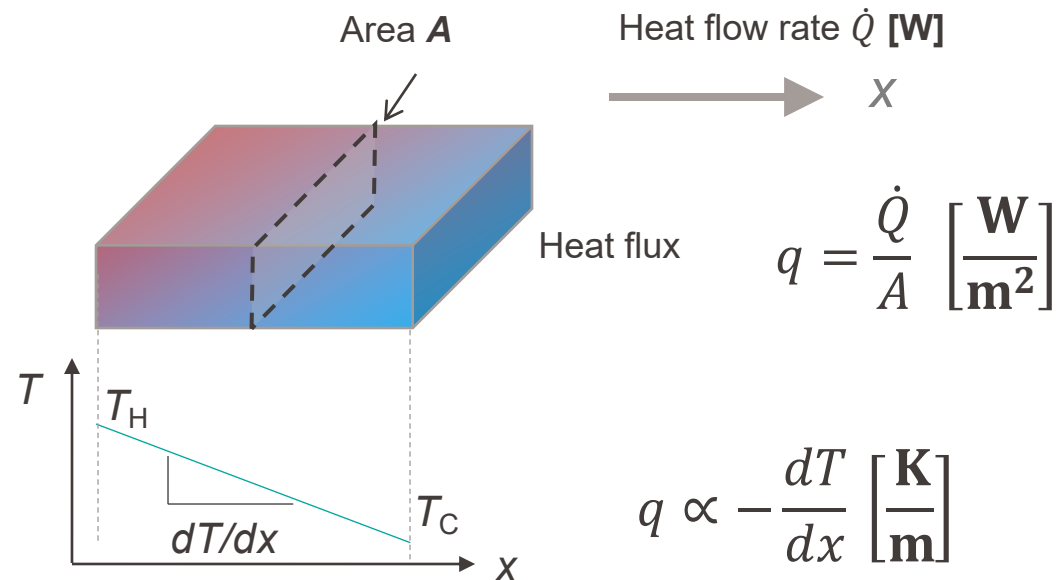
- Phenomenological description: **diffusion of temperature field**
- Mechanistic description: energy transferred from high  $T$  to low  $T$  location via **interactions between microscopic particles** while bulk materials stay **static**

# Rate Equation: Fourier's Law



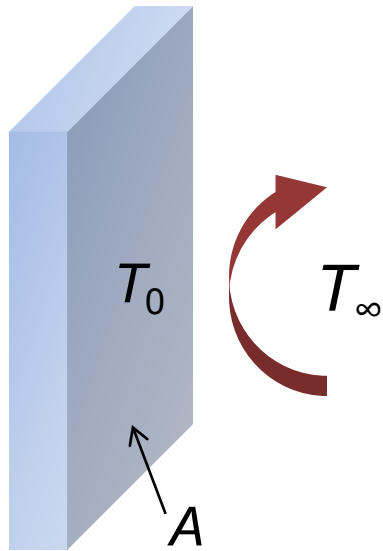
Joseph Fourier  
(1768 – 1830)

$$q = -k \frac{dT}{dx}$$



Proportionality  $k$ : thermal conductivity

$$\left[ \frac{\text{W}}{\text{m} \cdot \text{K}} \right]$$



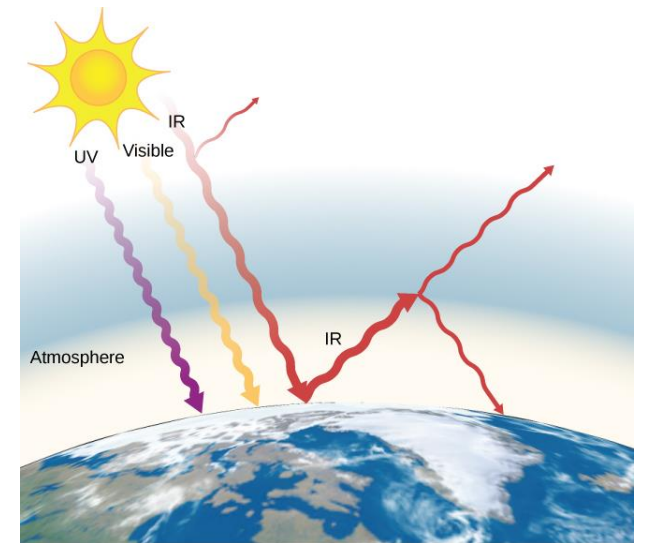
- Mechanism: thermal energy transferred due to **bulk movement** of fluids (gas and liquid)
- Rate Equation: **Newton's Law of Cooling:**

$$\dot{Q} = hA(T_0 - T_\infty)$$

Units:  $\dot{Q}$  [W],  $A$  [m<sup>2</sup>],  $(T_0 - T_\infty)$  [K]

Unit of heat transfer coefficient  $h$ : [W/(m<sup>2</sup>·K)]

- Any surface with  $> 0$  K temperature constantly emits **electromagnetic (EM)** waves.
- Energy can be transferred through **emission and absorption** of the EM waves (which can propagate even in **vacuum**)



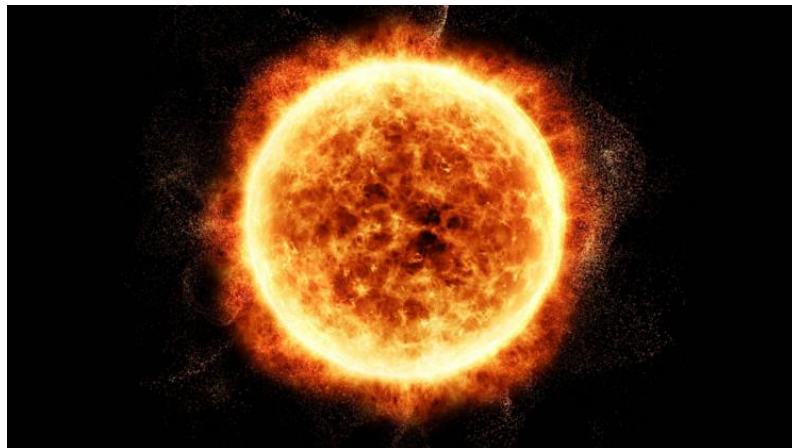
$$q_{\text{emit}} = \varepsilon \sigma T^4$$

$q_{\text{emit}}$  : energy flux emitted by thermal radiation [**W/m<sup>2</sup>**]

$T$  : surface temperature [**K**]

$\varepsilon$  : emittance (unitless;  $0 \leq \varepsilon \leq 1$ ;  **$\varepsilon = 1$  for a black body**)

$\sigma$  : Stefan-Boltzmann constant  $5.67 \times 10^{-8}$  [**W/(m<sup>2</sup>·K<sup>4</sup>)**]



If the surface energy flux of the sun is  $q_{\text{sun}} = 62.4 \times 10^6 \text{ W/m}^2$ , can we calculate the surface temperature of the sun assuming it's a black body ( $\varepsilon = 1$ )?

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



- Apply energy balance to close systems
- Analyze the energy balance of thermodynamic cycles

○ Reading materials: **Moran 2.5, 2.6**