



ME-251: Thermodynamics and energetics I

First Law of Thermodynamics

Zhengmao Lu
Energy Transport Advances
Laboratory
EPFL Mechanical Engineering

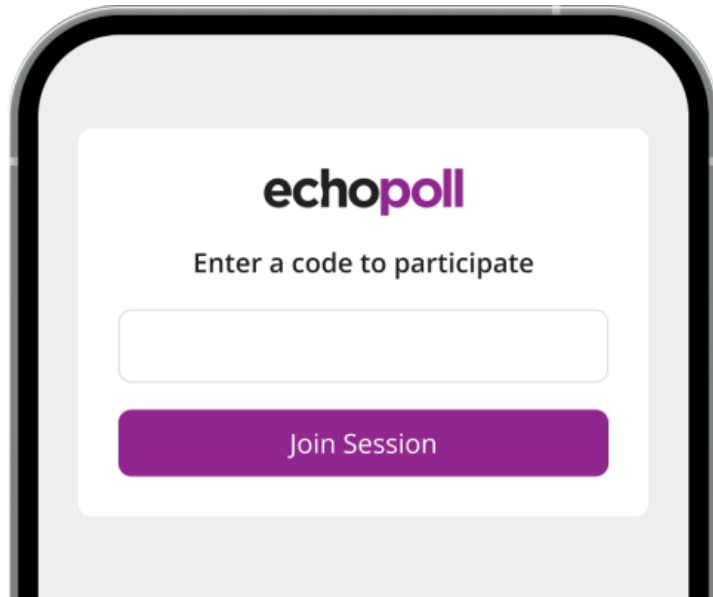
2025 Fall Semester

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

Go to
echo360poll.eu



Enter Code
luepfl

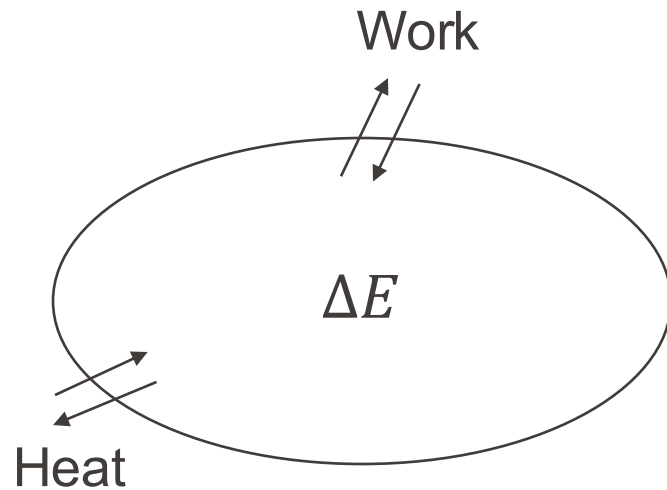
Scan the QR code with
your device



- Which of the following contains only intensive properties
 - A. Volume, mass
 - B. Density, pressure
 - C. Temperature, mass
 - D. Energy, specific volume

- 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

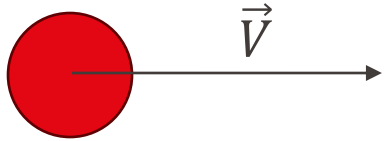


Can be intuitively understood as energy conservation

Energy change = Energy going in – Energy going out

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

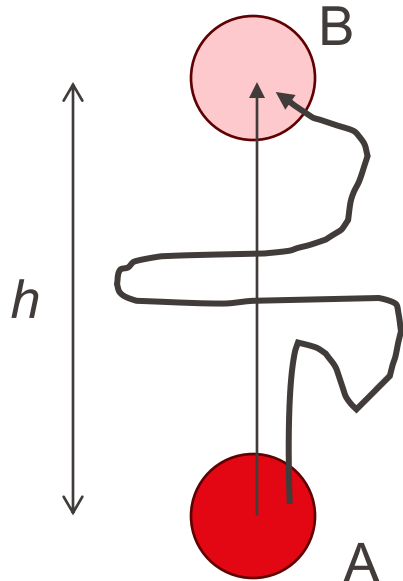
- No heat exchange with the surrounding
- Mechanical work causing changes in kinetic and potential energies



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

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

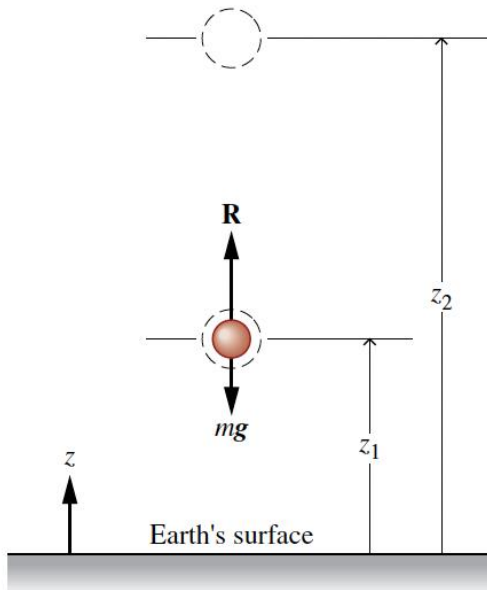


Potential energy is associated with an external (conservative) force field

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

$\Delta KE + \Delta PE =$ Work done to the system by forces NOT accounted for in potential energy



$$\frac{1}{2} m (\vec{V}_2^2 - \vec{V}_1^2) + mg(z_2 - z_1) = \int_{z_1}^{z_2} R dz$$

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
(It's internal to the system)

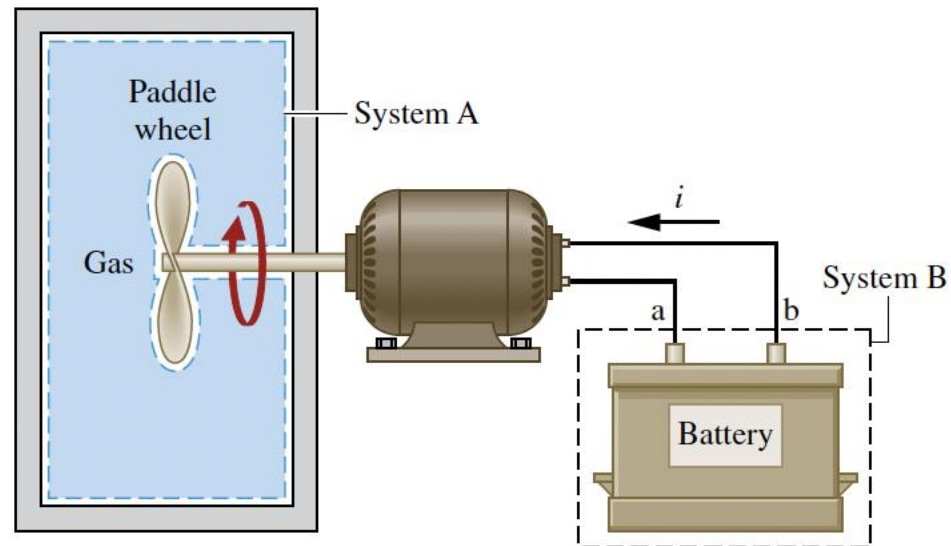
Total energy change of a system

$$E_2 - E_1 = KE_2 - KE_1 + PE_2 - PE_1 + U_2 - U_1$$

$$\Delta E = \Delta KE + \Delta PE + \Delta U$$

Thermodynamics typically deals with energy differences, not absolute values

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

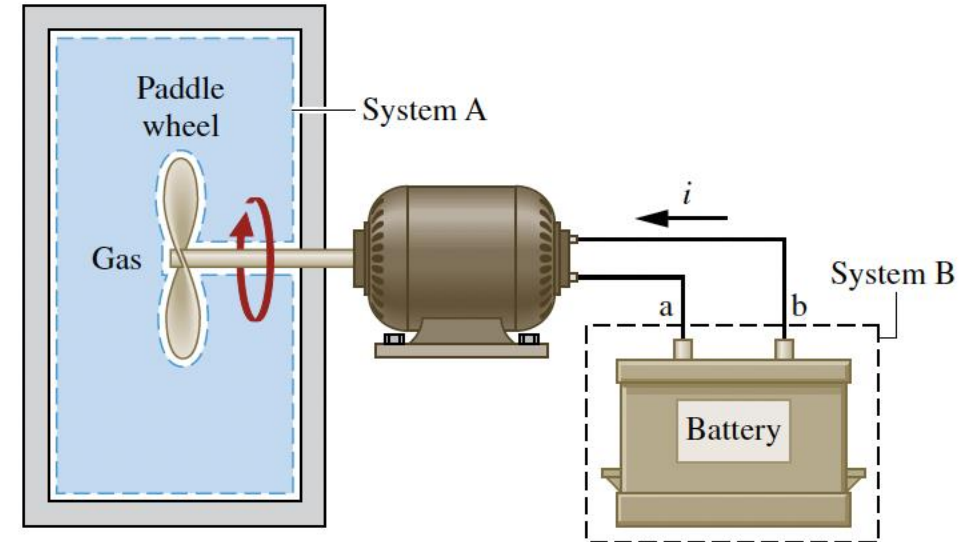
Mechanical work done **to** A by the surrounding as the paddle wheel move the gas

System B : battery

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

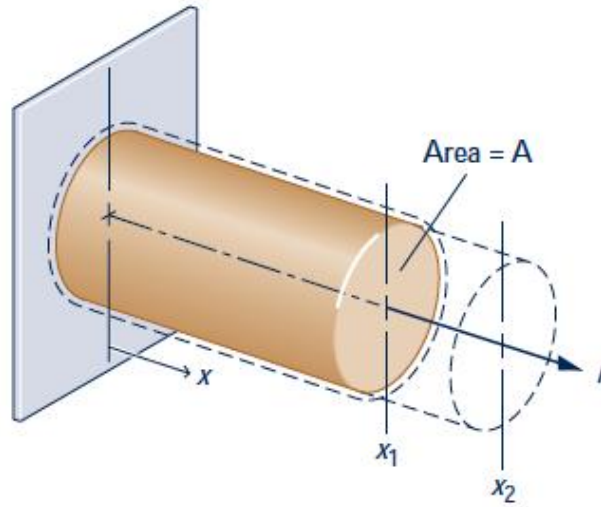
Work done by the system: $W > 0$

Work done on the system: $W < 0$



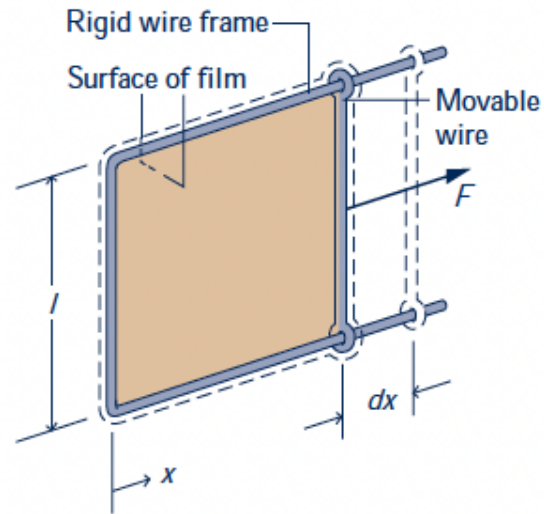
System A: The paddle wheel did work on the system (gas), $W < 0$

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



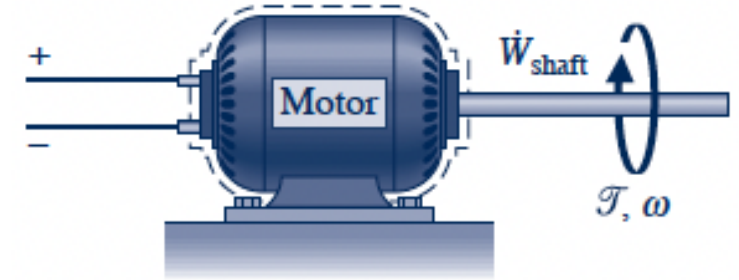
Elongation of a solid bar

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



Stretching of a liquid film

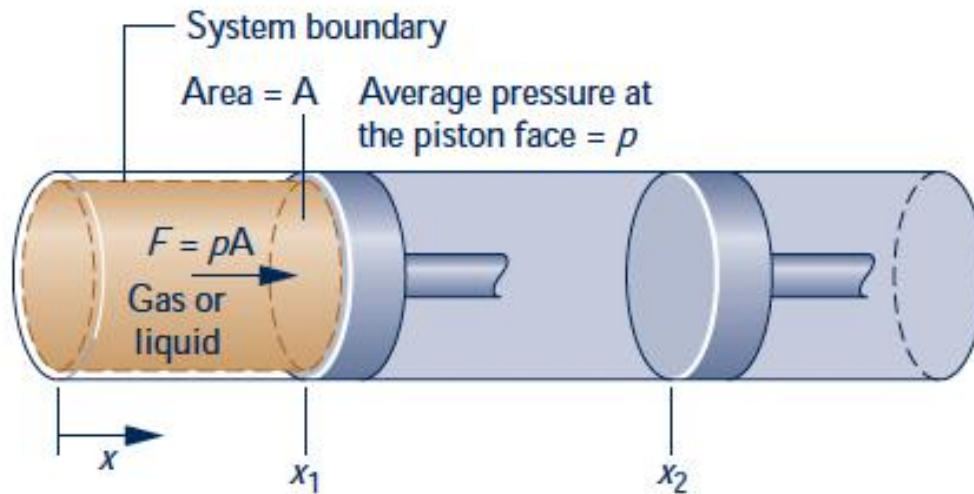
$$W = - \int_{x_1}^{x_2} \tau l dx$$



Work transmitted by a shaft

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

See 2.2.6



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

$$\delta W = pAdx = pdV$$

$\delta W > 0$ for expansion

$\delta W < 0$ for compression

For a change in volume from V_1 to V_2

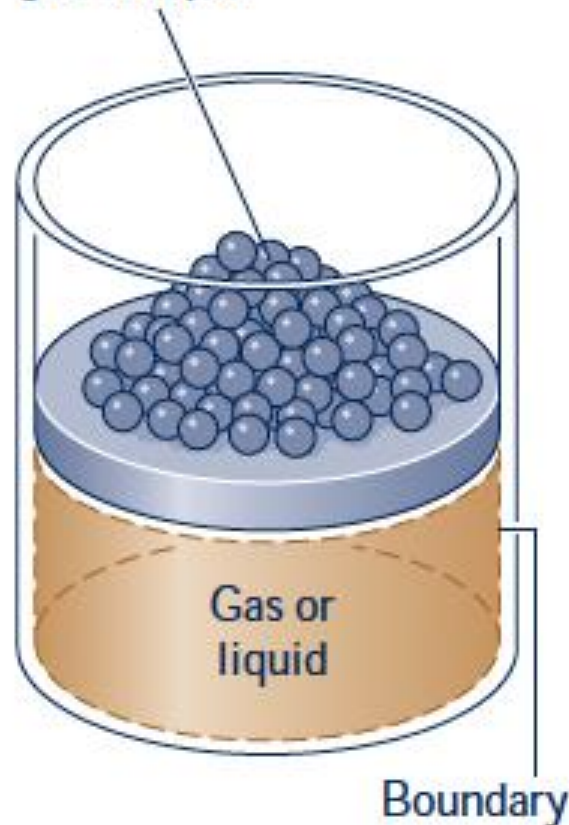
$$W = \int_{V_1}^{V_2} \delta W = \int_{V_1}^{V_2} pdV$$

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.

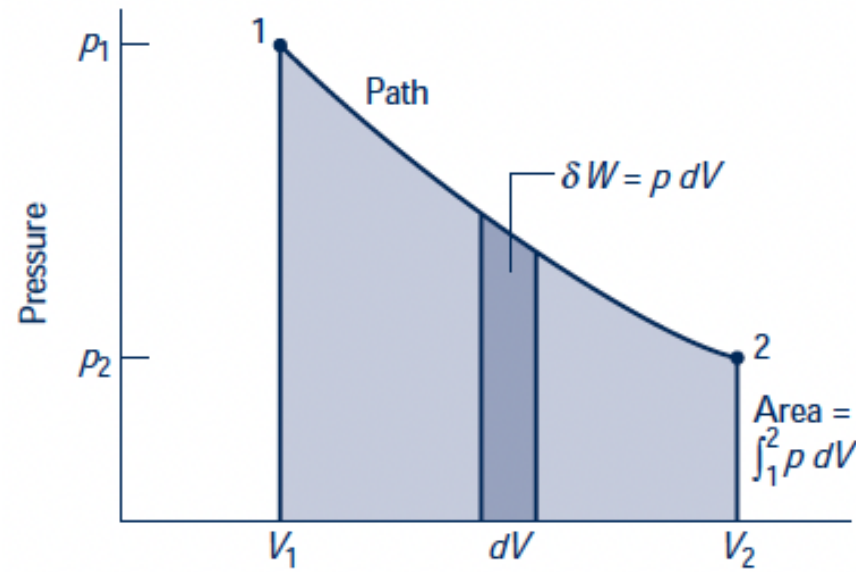
Quasiequilibrium Process

Incremental masses removed during an expansion of the gas or liquid

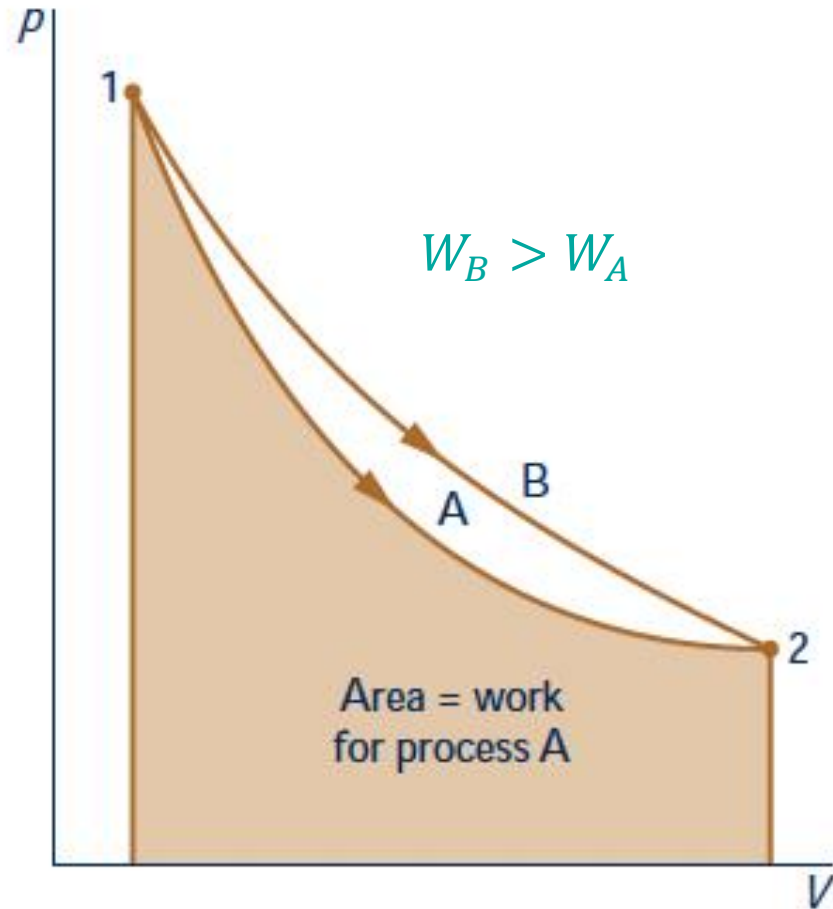


During the transformation, the system is technically in non-equilibrium at every moment.

But we assume that we can assign equilibrium properties to every intermediate state if the process is slow enough

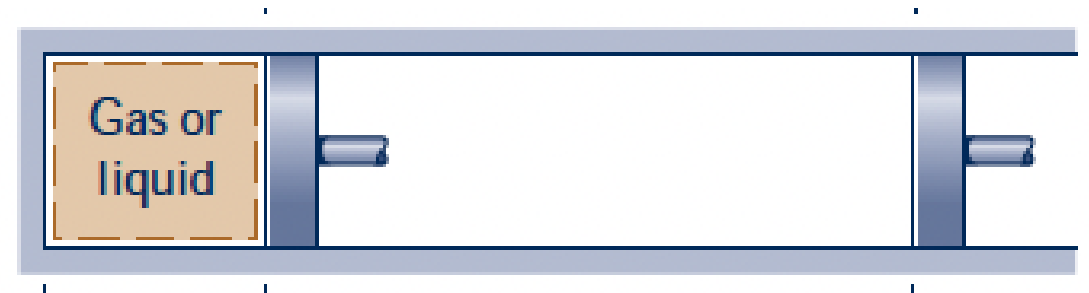


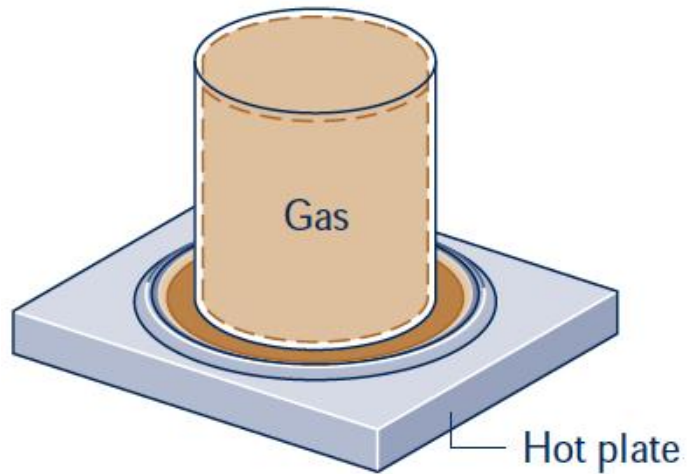
$$W = \int_{V_1}^{V_2} \delta W = \int_{V_1}^{V_2} p dV$$



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

Work is not a thermodynamics property





Gas in a rigid container on a hot plate

No system boundary movement → No work

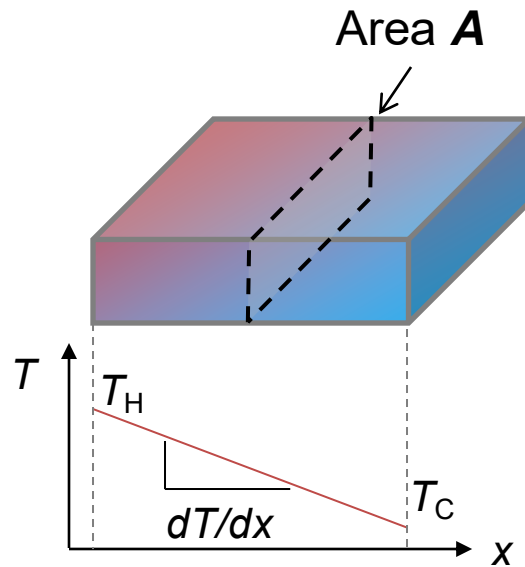
Energy transferred from the hot plate to the system by heat

Heat transferred into the system: $Q > 0$

Heat transferred out of the system: $Q < 0$

Like work, heat is process-dependent

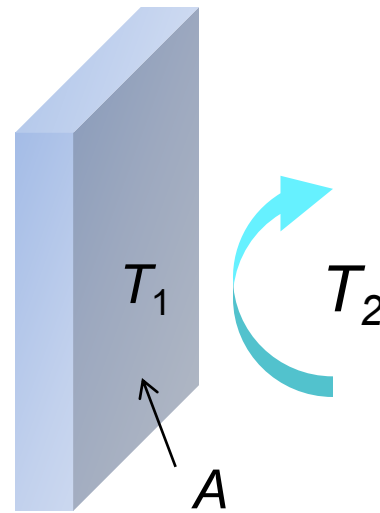
Conduction



Fourier's law

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

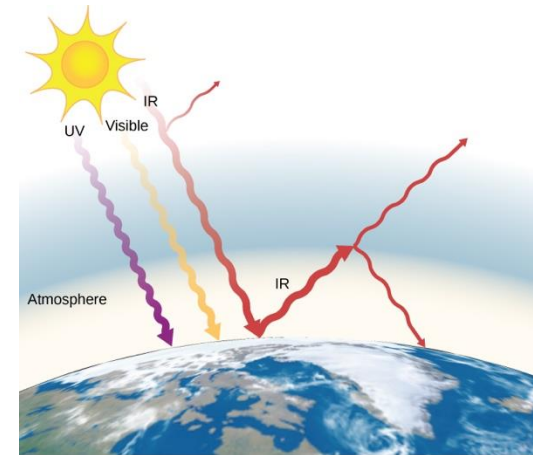
Convection



Newton's law of cooling

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

Radiation



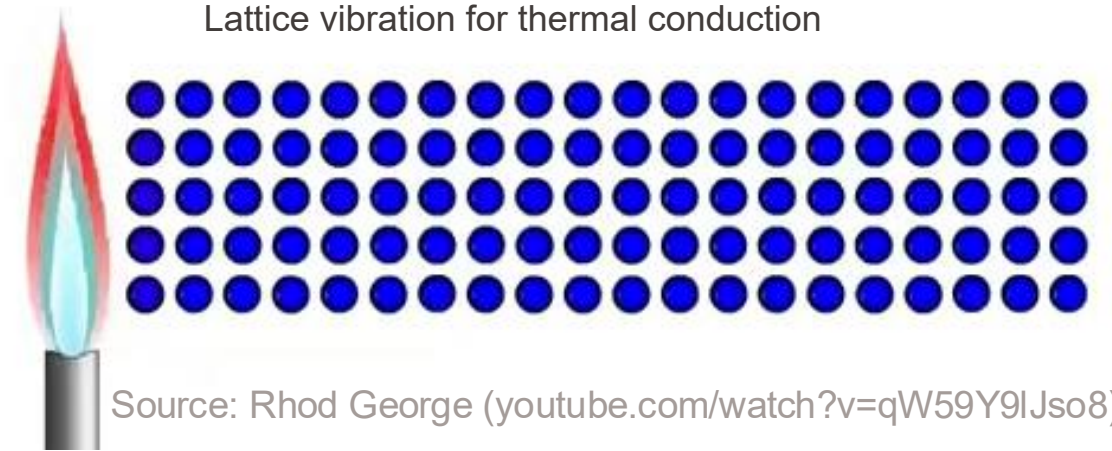
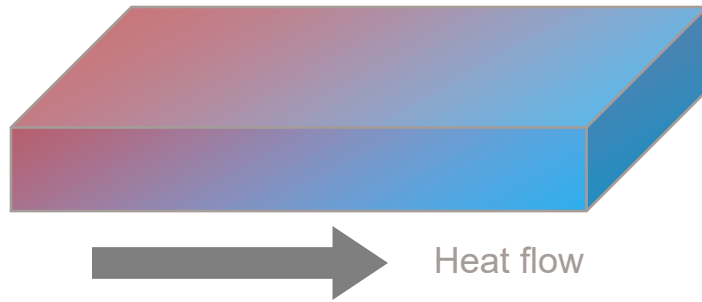
Stefan-Boltzmann Law

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

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

High temperature

Low temperature

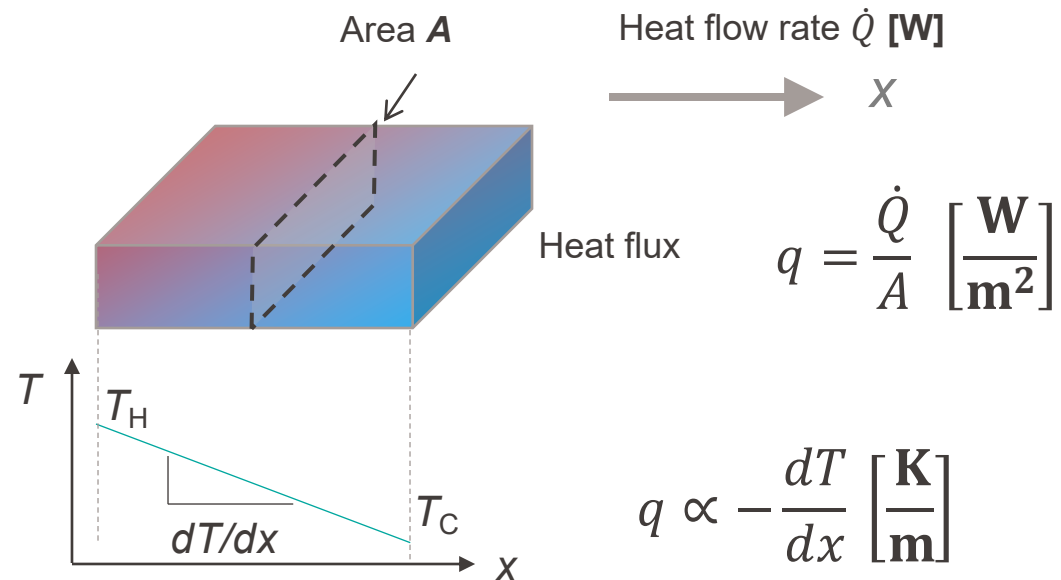


- Phenomenological description: **diffusion of temperature field**
- Mechanistic description: energy transferred from high T to low T location via **interactions between microscopic particles** while bulk materials stay **static**



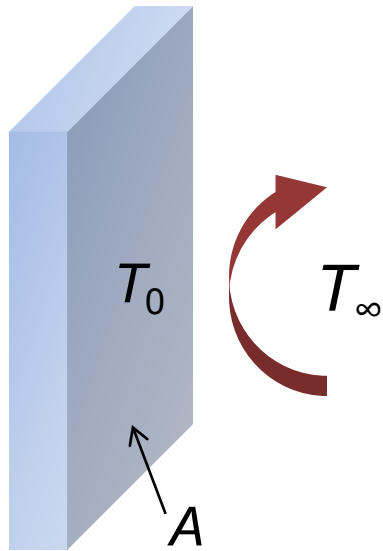
Joseph Fourier
(1768 – 1830)

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



Proportionality k : thermal conductivity

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



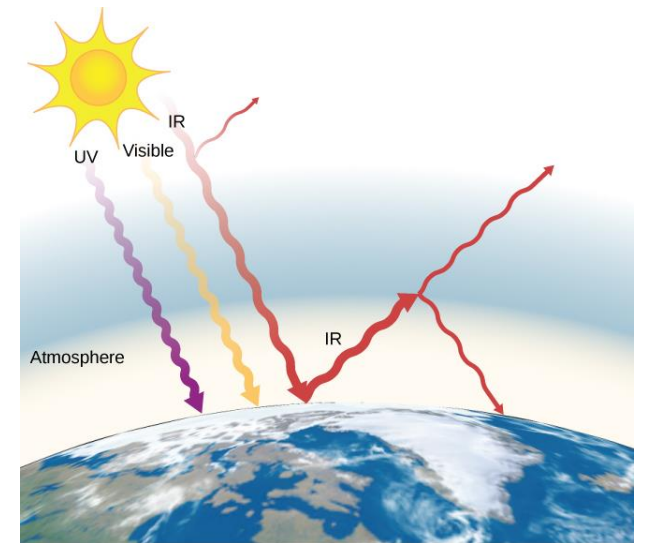
- Mechanism: thermal energy transferred due to **bulk movement** of fluids (gas and liquid)
- Rate Equation: **Newton's Law of Cooling:**

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

Units: \dot{Q} [W], A [m²], $(T_0 - T_\infty)$ [K]

Unit of heat transfer coefficient h : [W/(m²·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**)



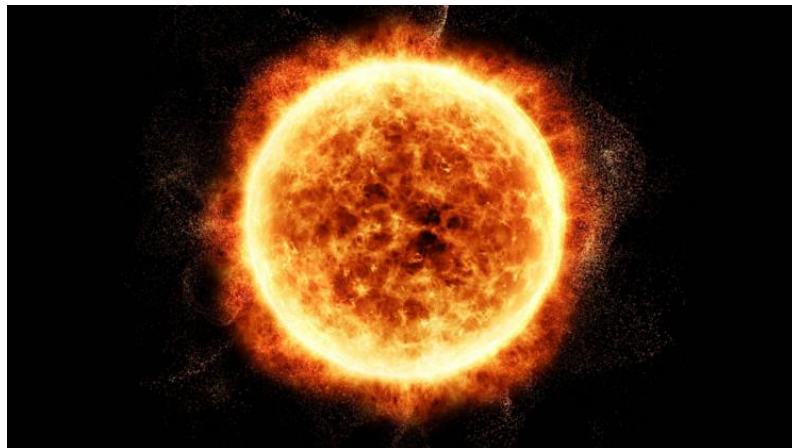
$$q_{\text{emit}} = \varepsilon \sigma T^4$$

q_{emit} : energy flux emitted by thermal radiation [**W/m²**]

T : surface temperature [**K**]

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

σ : Stefan-Boltzmann constant 5.67×10^{-8} [**W/(m²·K⁴)**]



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 ($\varepsilon = 1$)?

$$T_{\text{sun}} = \left(\frac{q_{\text{sun}}}{\sigma} \right)^{1/4} = 5759.1 \text{ K}$$

(Modern measurement for sun surface temperature: 5778K)

- Explain key concepts in the first law of thermodynamics
 - Energy change $\Delta E = \Delta KE + \Delta PE + \Delta U$
 - Work (Work done by the system)
 - Heat (Heat received by the system)

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

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