VG100: INTRODUCTION TO ENGINEERING

Energy Conversion

Dr. Qiang Zhang

1

Preview

- Energy
- Energy Transfer of a thermodynamic system
- **Quantity** of Energy – 1^{st} Law
- **Quality** of Energy – 2^{nd} Law
- Efficiency
- Project near-term task

Lets firstly learn some “engineering language” in your future technical report!

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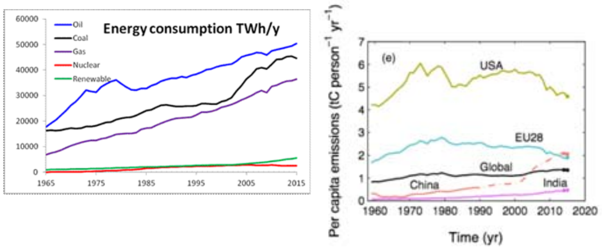


Source: Le Quéré, C. et al. (2016)

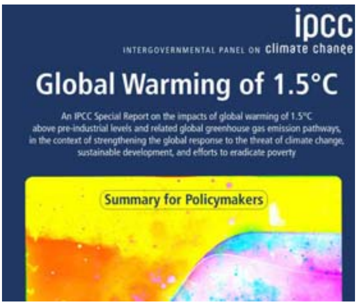
Energy consumption ➔ carbon dioxide emissions

global warming

We MUST spend energy more sensibly….

3

We should care about such news …
as future professional engineer …



October 8, 2018

more than 6,000 scientific references cited and the dedicated contribution of thousands of experts and government reviewers worldwide…

4

Global warming of 1.5°C – IPCC 2018

- 1.5°C is just an global average …

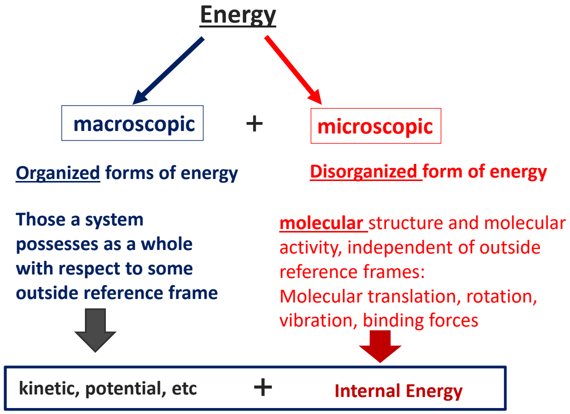
  In 2018:
  - In Pakistan, a May heatwave took temperatures above 43.3 °C and cost 65 lives in one city alone.
  - in Portugal, Temperatures soaring above 46 °C degrees Celsius. The same heatwave broke records in Europe and costing more lives.
  - Himalayan glaciers are melting
  - Stronger storms
- What 1.5°C ➔ 2°C would mean?
  - Severe heatwaves
  - Sea rise …
  - Poverty ...

Climate change: Oceans 'soaking up more heat than estimated'
By Matt McGrath
1 November 2018

The world has seriously underestimated the amount of heat soaked up by our oceans over the past 25 years. The new study suggests that the **seas have absorbed 60% more than previously thought**.

Energy

- How do you define “Energy”?
- How many energy forms do you know?



Energy

macroscopic + microscopic

Organized forms of energy

Those a system possesses as a whole with respect to some outside reference frame

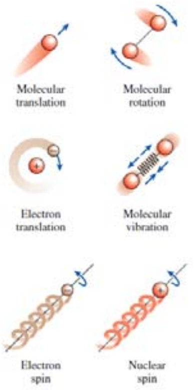
Disorganized form of energy

molecular structure and molecular activity, independent of outside reference frames:
Molecular translation, rotation, vibration, binding forces

kinetic, potential, etc + **Internal Energy**

Internal Energy

Sensible energy: the portion of internal energy associated with the kinetic energy of the atoms.



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Internal Energy

Sensible energy: the portion of internal energy associated with the kinetic energy of the atoms.

Latent energy: the internal energy associated with the ***phase-change*** of a system / the amount of energy required to overcome the binding forces.

Chemical energy: the internal energy associated with the atomic bonds.

Nuclear energy: the internal energy associated with the bonds inside the nucleus (10^6 more than chemical).

$$\text{Internal} = \overset{\text{Thermal}}{\boxed{\text{Sensible + Latent}}} + \text{Chemical} + \text{Nuclear}$$

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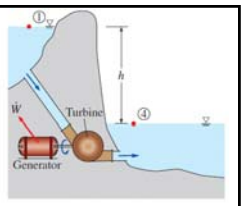
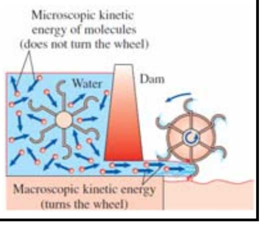
Organised Forms of Energy:

Potential: $m \cdot g \cdot h$

Kinetic: $\frac{1}{2} m \cdot v^2$



$\dot{W}_{max} = \dot{m}\Delta e_{mech} = \dot{m}g(z_1 - z_4) = \dot{m}gh$



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Total energy of a fixed mass (kinetic, potential, and internal):

$$E = U + KE + PE = U + \frac{mv^2}{2} + mgz$$

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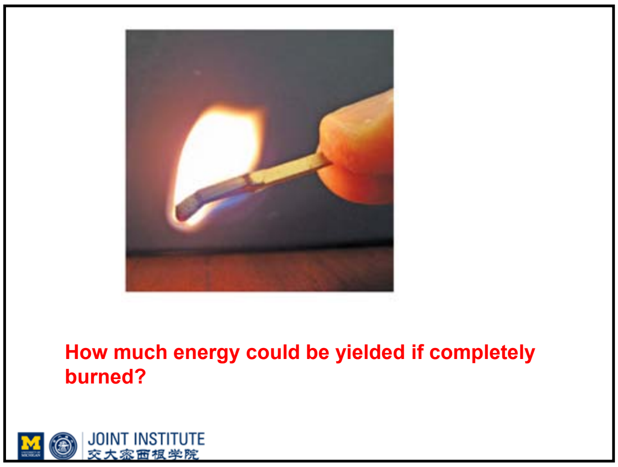
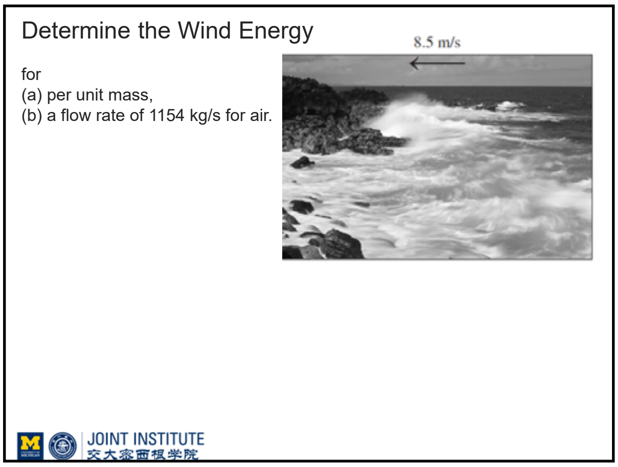
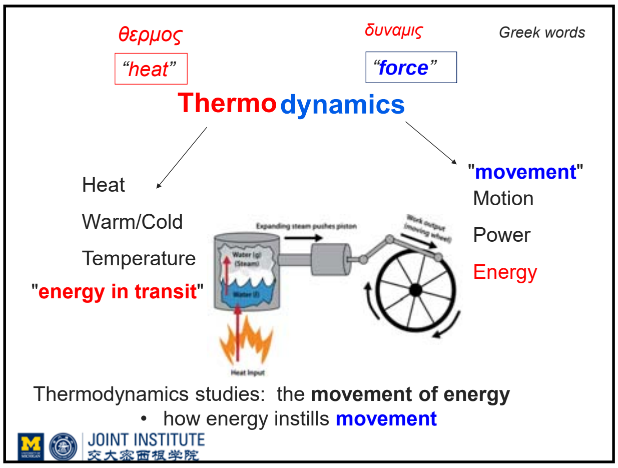


How much energy could be yielded if completely burned?



Determine the Wind Energy

for
(a) per unit mass,
(b) a flow rate of 1154 kg/s for air.



θερμος "heat"

δυναμις "force"

Greek words

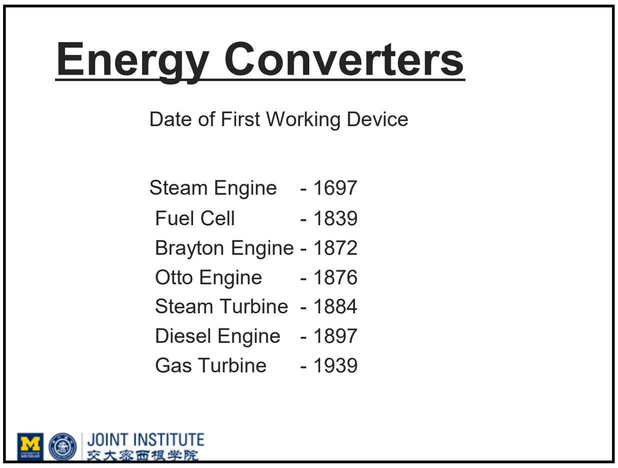
Thermo dynamics

Heat
Warm/Cold
Temperature
"**energy in transit**"

"**movement**"
Motion
Power
Energy

Thermodynamics studies: the **movement of energy**

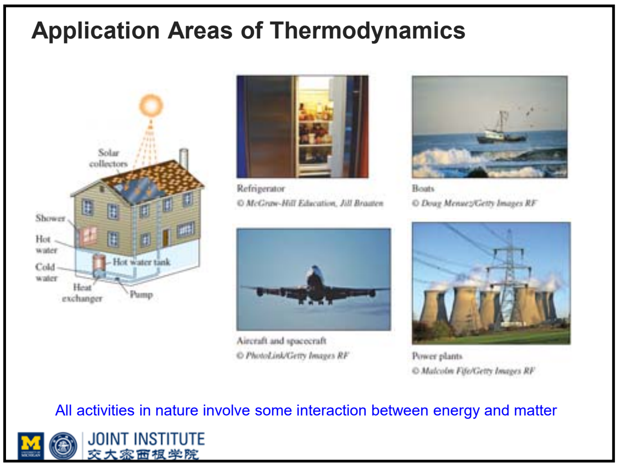
- how energy instills **movement**



Energy Converters

Date of First Working Device

Steam Engine - 1697
Fuel Cell - 1839
Brayton Engine - 1872
Otto Engine - 1876
Steam Turbine - 1884
Diesel Engine - 1897
Gas Turbine - 1939



Application Areas of Thermodynamics

Refrigerator
© McGraw-Hill Education, Jill Braaten

Boats
© Doug Menuez/Getty Images RF

Aircraft and spacecraft
© PhotoLink/Getty Images RF

Power plants
© Malcolm Fife/Getty Images RF

All activities in nature involve some interaction between energy and matter

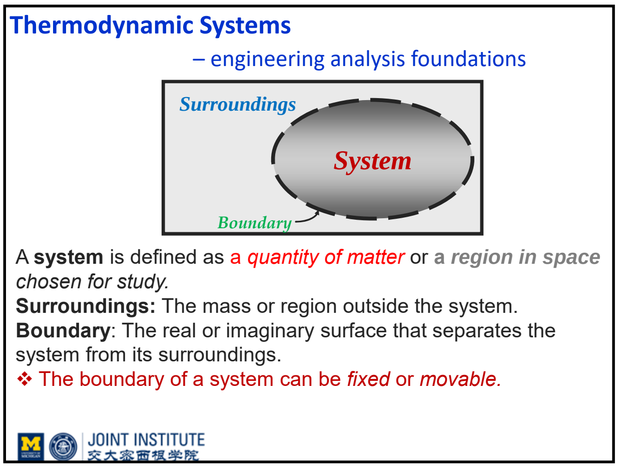
Human body
© Ryan McVay/Getty Images RF

Cars
© Mark Evans/Getty Images RF

Wind turbines
© F. Schussler/PhotoLink/Getty Images RF

Food processing
Glow Images RF

A piping network in an industrial facility.
Courtesy of UMDE Engineering Contracting and Trading. Used by permission



Thermodynamic Systems

– engineering analysis foundations

A **system** is defined as *a quantity of matter* or ***a region in space*** *chosen for study.*
Surroundings: The mass or region outside the system.
Boundary: The real or imaginary surface that separates the system from its surroundings.
❖ The boundary of a system can be *fixed* or *movable.*

Thermodynamic Systems

Systems may be considered to be *closed* or ***open***, depending on whether a fixed mass or a fixed volume in space is chosen for study.

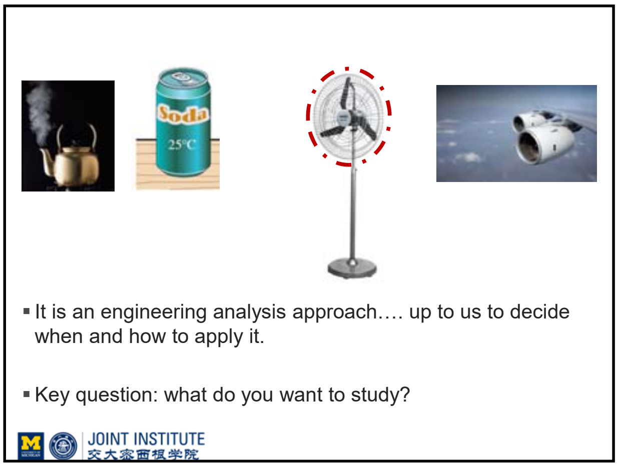
Closed system (**control mass**)
- Consists of a fixed amount of mass, and no mass can cross its boundary. no mass can enter or leave a closed system.
- Energy can cross the boundary; and the volume of a closed system does not have to be fixed.

Open System (control volume):

➢ **A volume in space in which one has interest for a particular study or analysis.**

➢ **Mass crosses the boundary.**

Energy can cross the boundary of a closed system in two distinct forms: ***Heat*** and ***Work***



- It is an engineering analysis approach…. up to us to decide when and how to apply it.
- Key question: what do you want to study?

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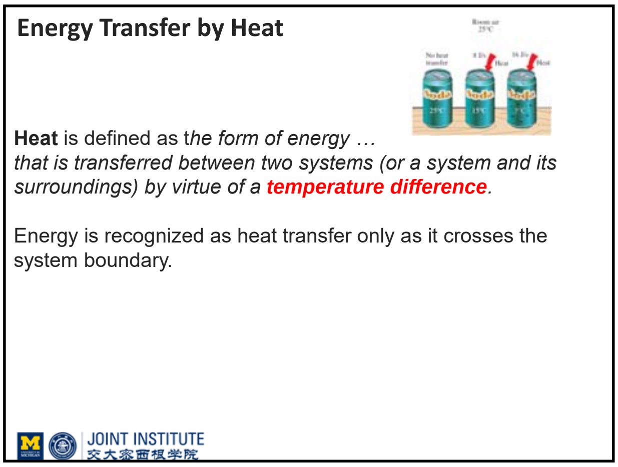

Energy Transfer by Heat

Heat is defined as t*he form of energy …*
that is transferred between two systems (or a system and its surroundings) by virtue of a ***temperature difference****.*

Energy is recognized as heat transfer only as it crosses the system boundary.

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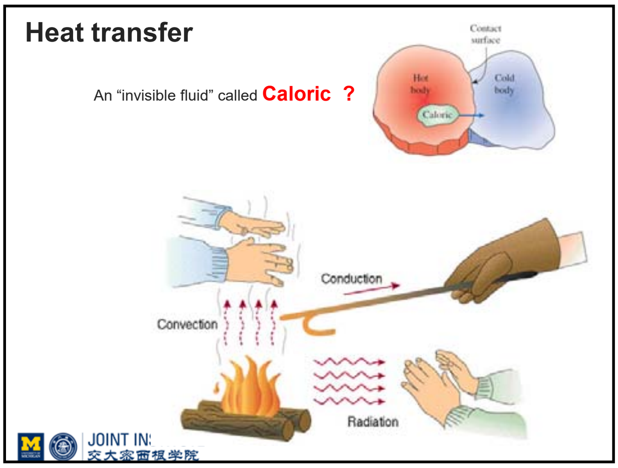

Heat transfer

An “invisible fluid” called **Caloric ?**

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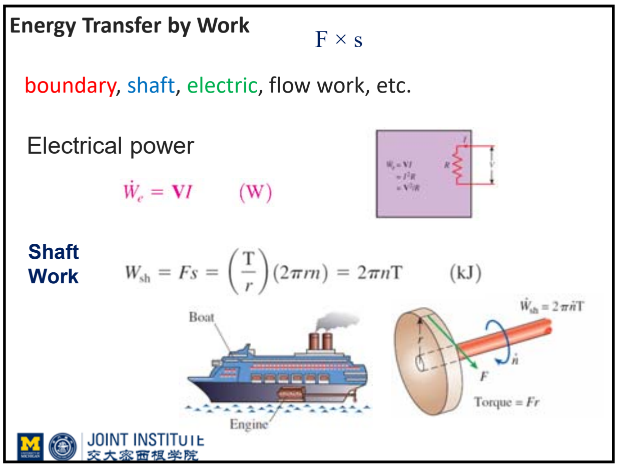

Energy Transfer by Work

F × s

boundary, shaft, electric, flow work, etc.

Electrical power

$$\dot{W}_e = \mathbf{V}I \qquad (\mathrm{W})$$

Shaft Work

$$W_{\mathrm{sh}} = Fs = \left(\frac{\mathrm{T}}{r}\right)(2\pi rn) = 2\pi n\mathrm{T} \qquad (\mathrm{kJ})$$

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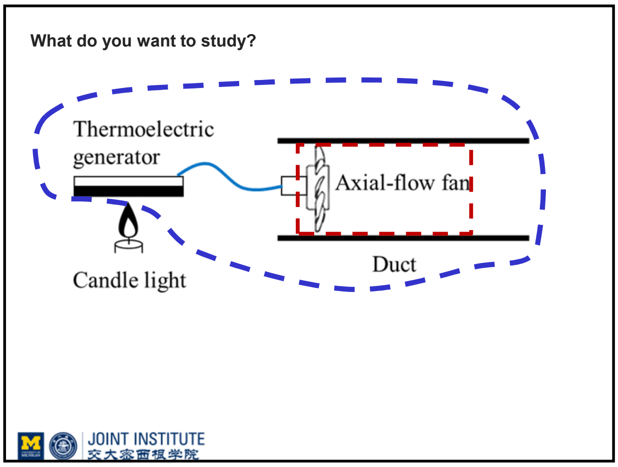
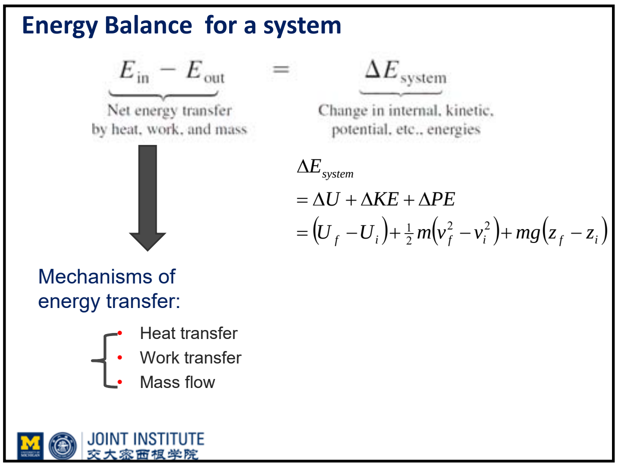


What do you want to study?



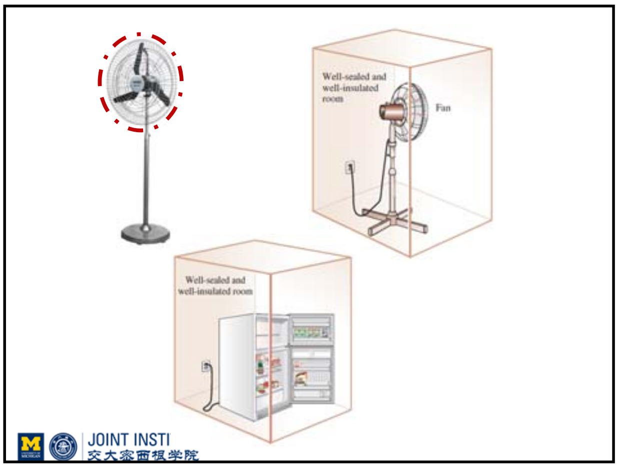
Energy Balance for a system

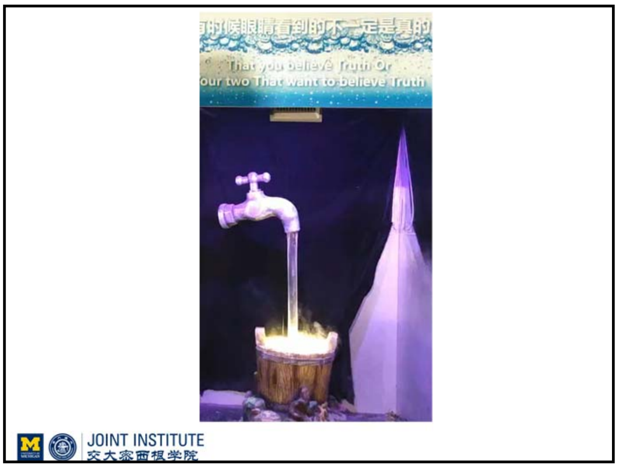
$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}}$$

$$\Delta E_{system}$$
$$= \Delta U + \Delta KE + \Delta PE$$
$$= (U_f - U_i) + \tfrac{1}{2}m(v_f^2 - v_i^2) + mg(z_f - z_i)$$

Mechanisms of energy transfer:

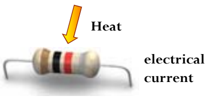
- Heat transfer
- Work transfer
- Mass flow





Quality of Energy – 2nd Law

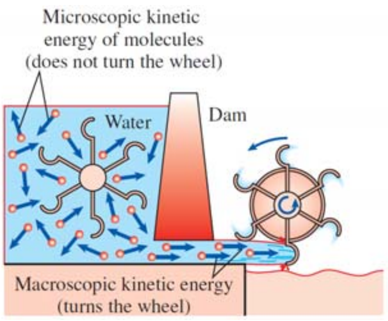
- Why can't the hot coffee get hotter in a cooler room or the iced water lose more heat ?
- Electricity flowing through resistor produces heat, but the opposite does not happen!



- Not all forms of energy are of equal **quality**. ***Some energy conversions are more favorable than others.***

- High quality energy can be converted fully to lower quality energy
- Low quality energy **cannot** be **fully** converted to high quality energy.

1. Electromagnetic	
2. Mechanical	
3. Chemical	 
4.Thermal energy (Heat)	



- Energy quality has to do with the ***order*** of the energy carriers (be it atoms, molecules, electrons...)

The concept of Entropy

- *Entropy can be viewed as a measure of* ***molecular disorder****, or* ***molecular randomness****.*
- Statistical Perspective: entropy is related to **the number of possible micro-states for a given macro-state**. The more possible micro-states in a macro-state, the higher the entropy. The configuration with the highest entropy (i.e. the most micro-states) is the most probable.

Entropy of macrostate →

$$S = k_B \ln \Omega$$

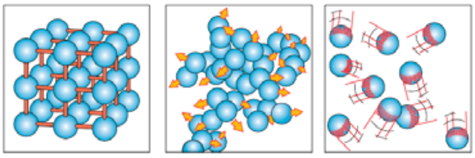
← Number of possible microstates, "Thermodynamic probability"

↗ Boltzmann constant

The concept of Entropy

- Example: phases

Materials may occur as solids, liquid and gases.

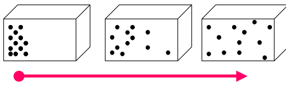


Solid: strong intermolecular forces, well defined arrangement.

Liquid: weak intermolecular forces

Gas: very weak intermolecular forces (only repulsion), no molecular order.

The concept of Entropy



"The increase of disorder or entropy is what distinguishes the past from the future, giving a direction to time." - *Stephen Hawking*

- All natural processes proceed in such a way that the probability of the state increases – law of increasing entropy – one of the most important laws of nature! the Second Law of Thermodynamics.

$$\boxed{\Delta S \geq =0}$$

The concept of Entropy

All irreversible changes $\Delta S > 0$
$\Rightarrow$ entropy is not a conserved quantity

Direction of thermodynamics processes:

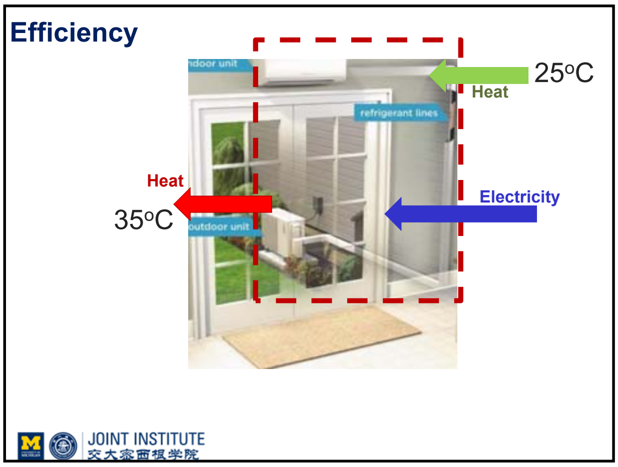
- Perfume from an open bottle will spread throughout a room – the perfume molecules will never spontaneous gather back into the bottle…
- Heat always flows spontaneously from a hot object to a cooler one...

Efficiency

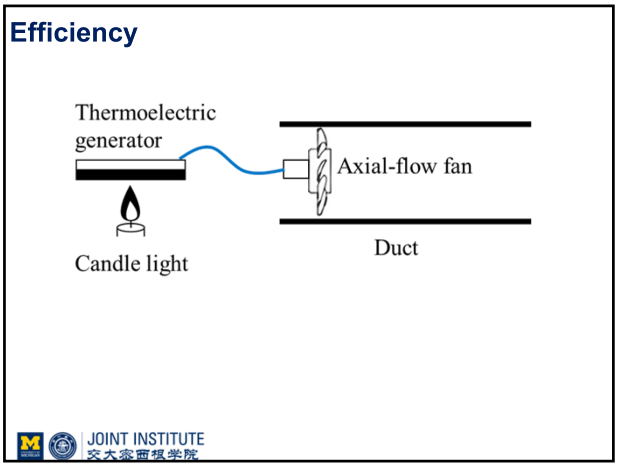
- How do we define Efficiency?

$$\eta = \frac{\text{what you get/}want}{\text{what you give/pay}}$$

- Gasoline IC engine: ~25-30%
- Diesel IC engine: ~40-55% (low speed 2-stroke)
- Gas turbine: ~30-45% (aero-derivatives)
- Combined cycle power plant: ~50-60%



Efficiency



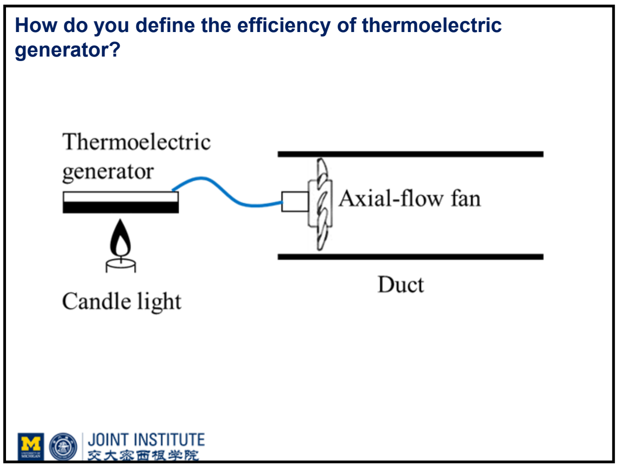
Efficiency

Thermoelectric generator

Axial-flow fan

Candle light

Duct



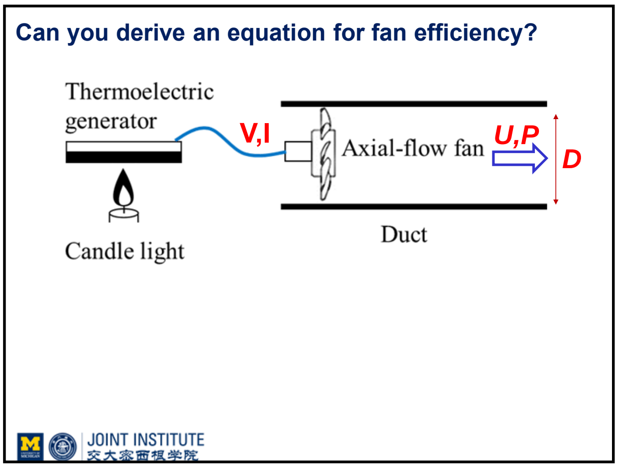
How do you define the efficiency of thermoelectric generator?

Thermoelectric generator

Axial-flow fan

Candle light

Duct



Can you derive an equation for fan efficiency?

Thermoelectric generator

V,I

Axial-flow fan

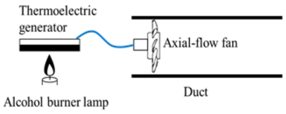
U,P

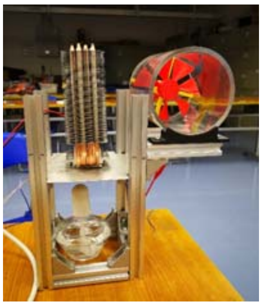
D

Candle light

Duct

Near-term task for our core project





Supporting structure design:

- An iterative process
- No unique solution

- You are expected to deliver a much improved design than this showcase!

Near-term task for our core project

- It should be ONE integrated system.
- The inner diameter of your fan duct should be **no more than 80mm**.
- Frame material can be of your choice. Search around for fire-proof and strong materials.
- No hard limit for the overall size. However, you need provide a reasonable justification for any extra material and space used by your system.
- A protection structure needs to be designed around the alcohol burner lamp
- Do not cool the thermoelectric system with your fan.
- Solidworks: you will learn some entry-level CAD skill for structure design job. http://lic.si.sjtu.edu.cn/softs/good/id/1609

Some Safety Rules (more will be announced in the labs)

- Absolutely NO out-of-lab testing (playing with alcohol burner lamp outside of the lab is forbidden and will lead to failure of this course)
- The lab supervisor/manager, technicians, and teaching assistants will ensure that you know of specific hazards and use personal protection equipment (PPE).
- Read and obey all operational signs and warnings.
- Power must be switched off whenever an experiment or project is being assembled or disassembled.
- Make measurements in live circuits with well-insulated probes and one hand behind your back. Do not allow any part of your body to contact any part of the circuit or equipment connected to the circuit.
- Never handle wet, damp or ungrounded electrical equipment.
- Avoid contact with the hot components.
- Never short-circuit a power source.
- When using a voltmeter or ammeter, begin with the highest range and work your way down to a suitable range.

Review

- Energy
- Energy Transfer of a thermodynamic system
- **Quantity** of Energy – 1st Law
- **Quality** of Energy – 2nd Law
- Efficiency
- Project near-term task

Get ready for your 1st lab!