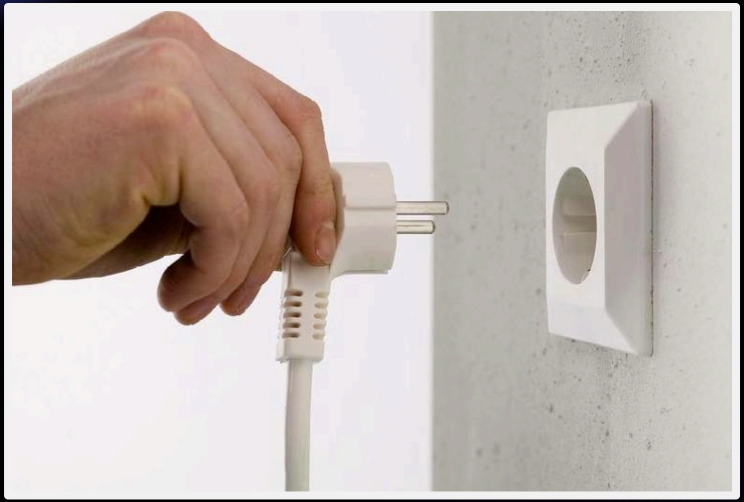
Lecture #1

Energy & Heat Transfer



Mohammad Mehrali
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Thermal Engineering Department

Research Focus

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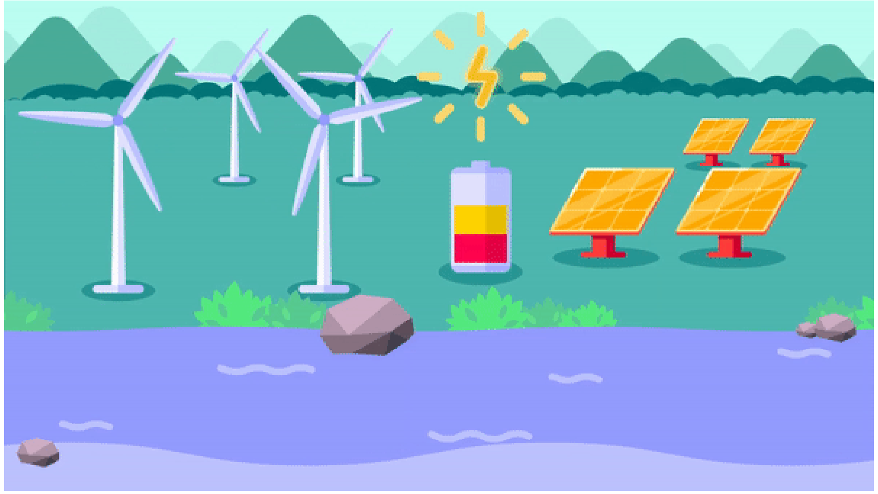

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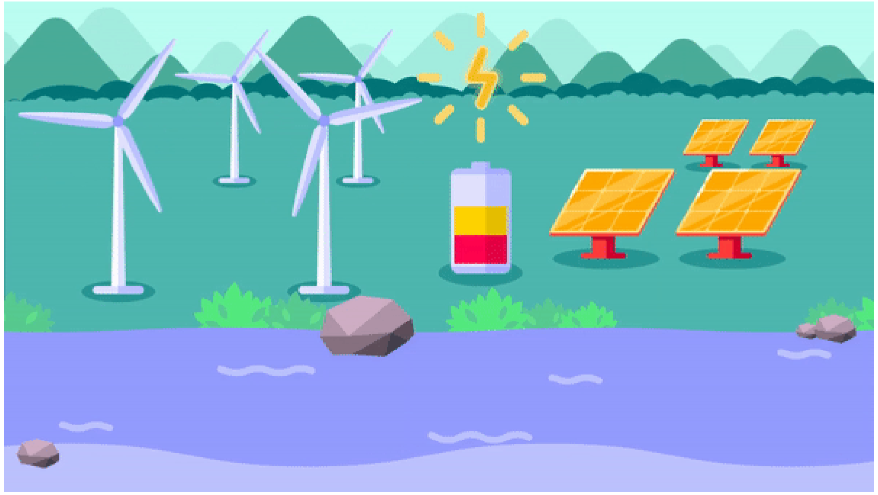

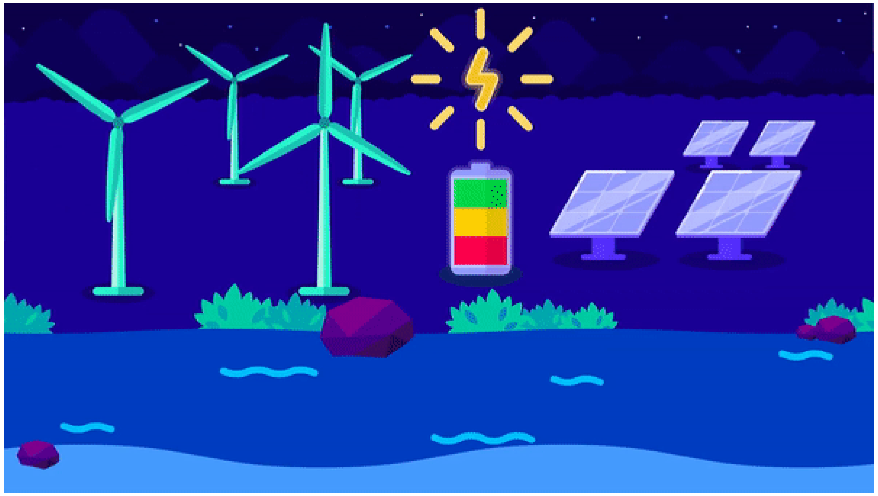

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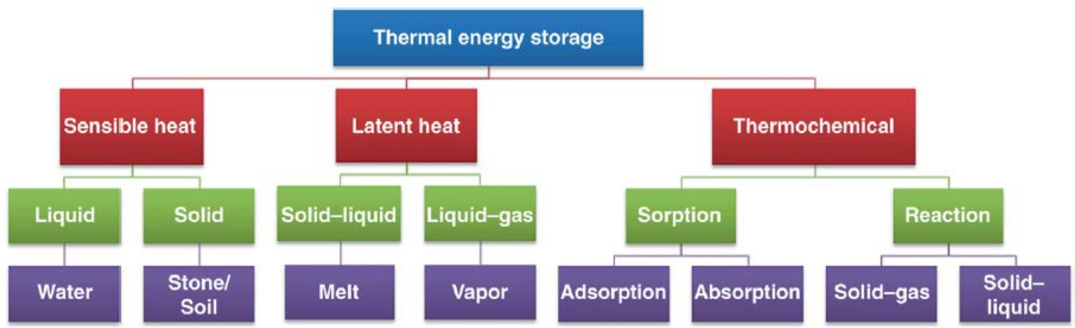
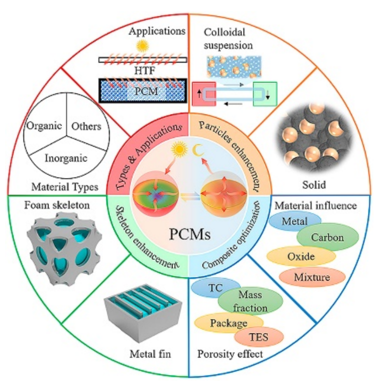
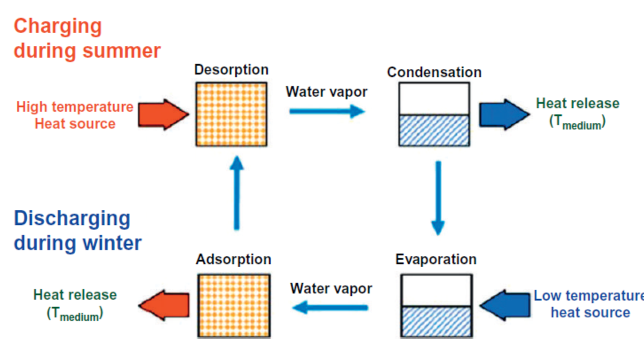






INTRODUCTION

Teacher

- Dr. Mohammad Mehrali (HR-N224, m.mehrali@utwente.nl)

Teaching assistants

- Evert van der Hoek (e.j.vanderhoek@student.utwente.nl)
- Harold Steenstra (h.steenstra@student.utwente.nl)
- Jeroen Kin (j.kin@student.utwente.nl)

Examination committee

- Dr. Mohammad Mehrali
- Dr. Yashar Hajimolana
- Dr. Genie Stoffels

All information is available on CANVAS (subscribe)

Course organization

Fundamentals (3 weeks)

- Seven lectures and Six Lectorials
- Study material: sheets &Book :

Y. A. Cengel & A. J. Ghajar. Heat and Mass Transfer: Fundamental & Application.

- Submit weekly assignments in groups.

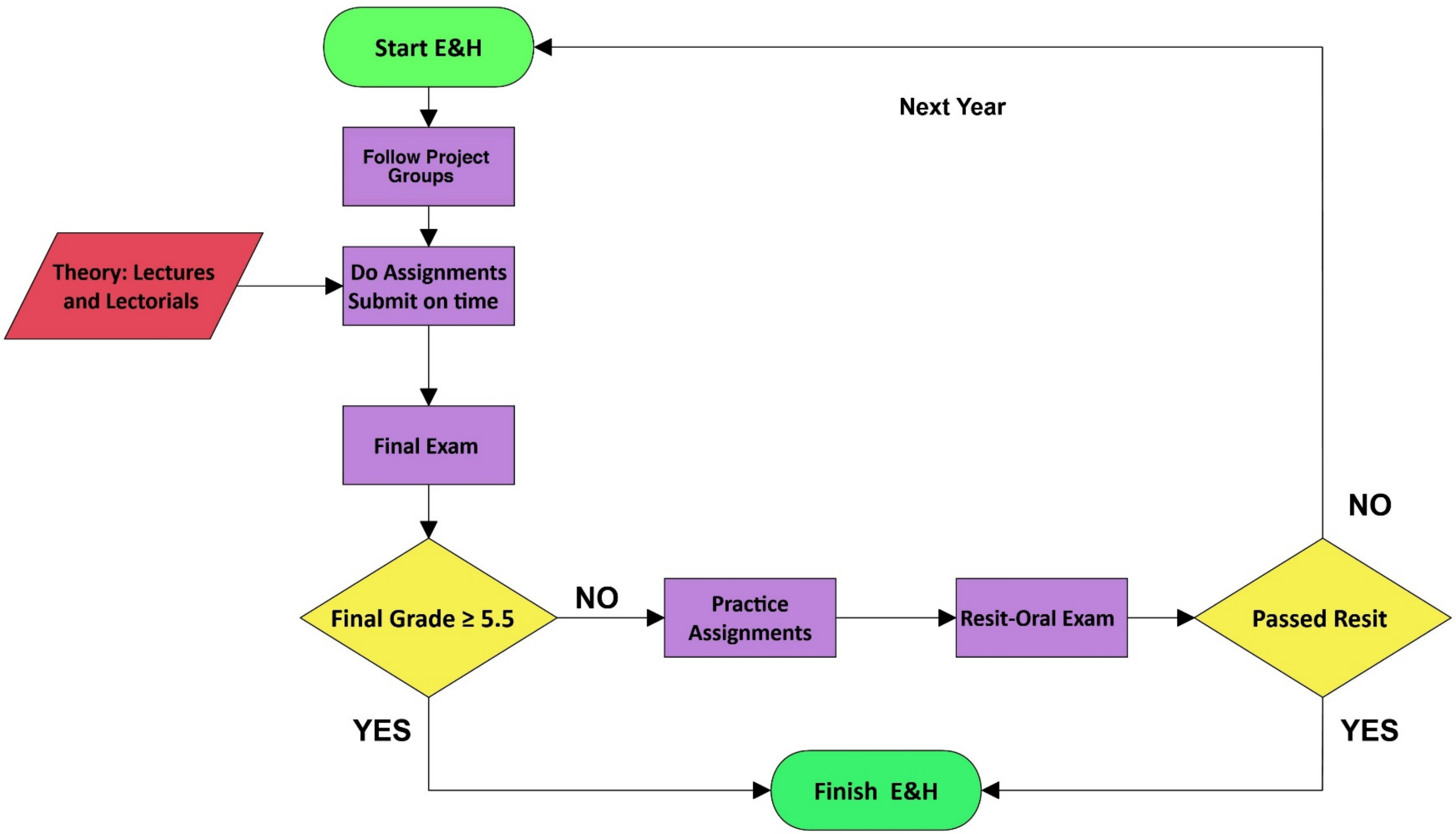
Application (4 weeks)

- Assignments in same groups
- Extra gatherings

Finalizing

- Individual written exam (both calculations and understanding)

The “how-to-pass-E&HT” scheme



Grading

- **Final grade**
- 80% final exam (individual)
- 20 % of Weekly assignment(group mark)
- Extra 10% Lectorial assignment (Individual mark)

Requirements to Pass EHT ≥ 5.5

- It is required to obtain a minimum grade of ≥ 5.5 from the total grade (Final Exam+ Weekly Assignments+ Lectorial)

COURSE CONTENTS

Fundamentals (3 weeks)

Energy	1: Introduction, organization, work, energy forms, energy contents, power, units
	2a: Energy balance, efficiency, electricity
Heat Transfer	2b: Heat transfer through conduction
	3: Heat transfer through convection (forced)
	4: Heat transfer through convection (natural)
	5: Heat transfer through radiation + simultaneous heat transfer
	6: Time-dependent heat problems

Complete schedule on Canvas

Course contents

Additionally another 1 lecture:

Lecture	
7	Summary

Question hours : can be done in the class (scheduled) or by making appointment with Mohammad or student assistants

Did you check the **learning activities** in Canvas for this lecture?

A. Yes

B. No

Is it useful to share the **lecture slides** before the lectures in Canvas?

A. Yes

B. No

Why Energy and Heat Transfer?

Dutch demand for energy in five domains. Source: CBS

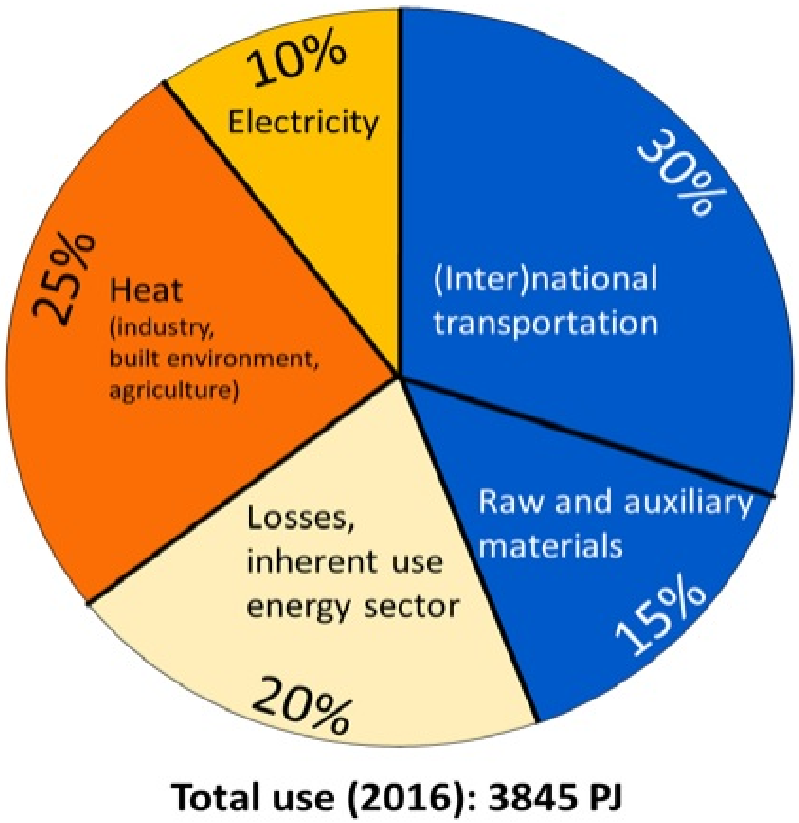
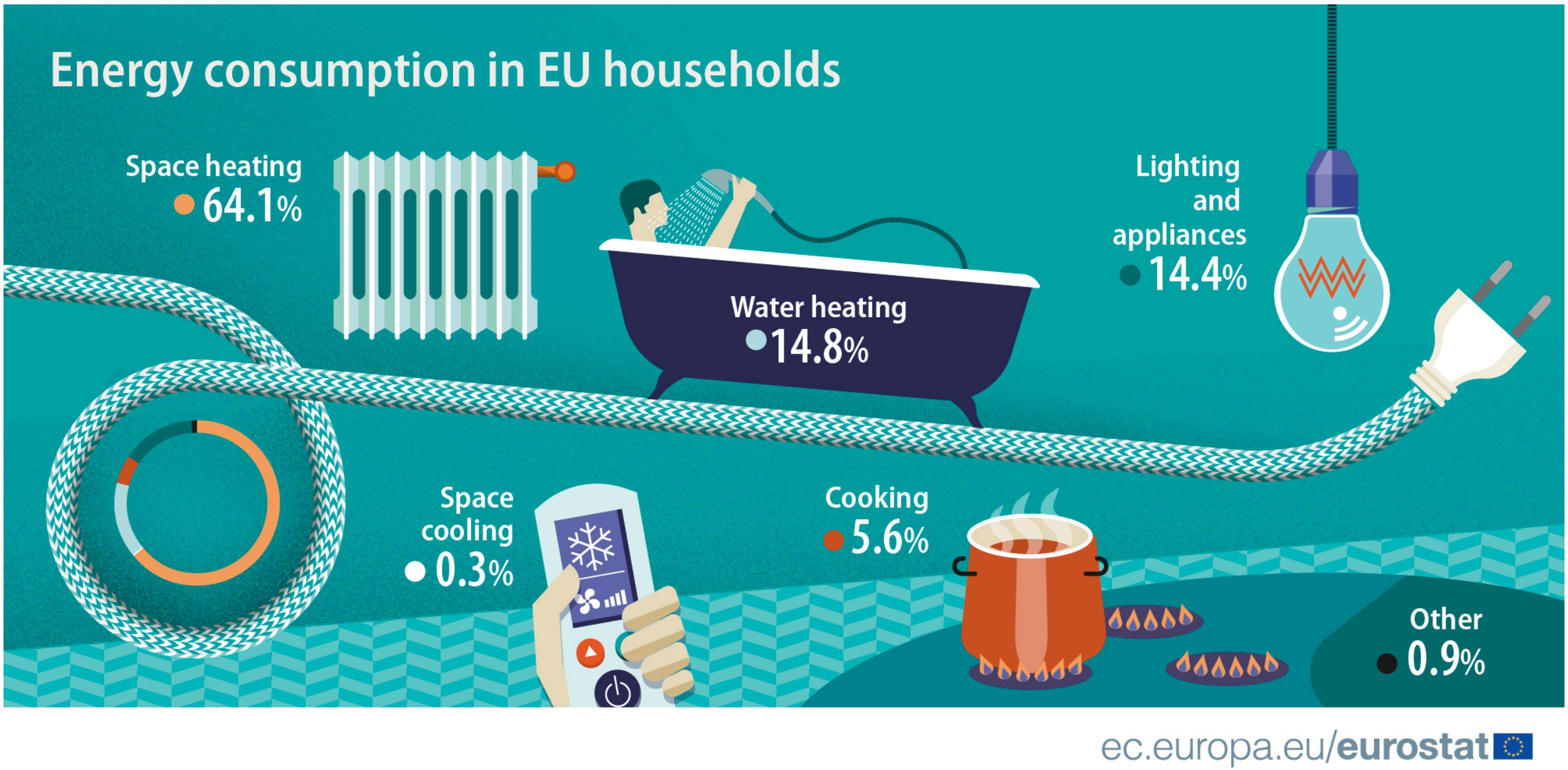


Figure 4. Dutch demand for energy in five domains. Source: CBS [13].

Why Energy and Heat Transfer?



Why Energy & Heat Transfer?

Why Energy & Heat Transfer?

84%

Fossil Fuels

WHY ENERGY & HEAT TRANSFER?

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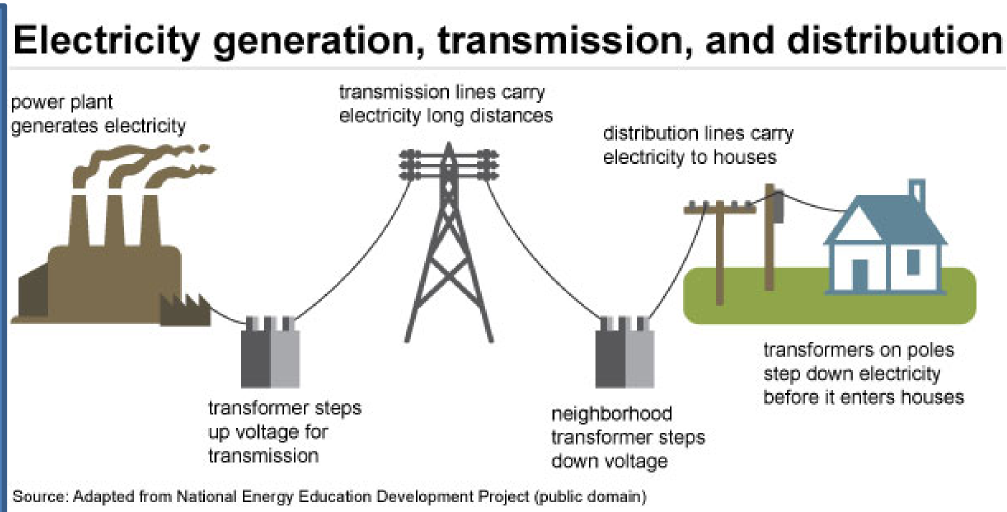
Fossil Fuels



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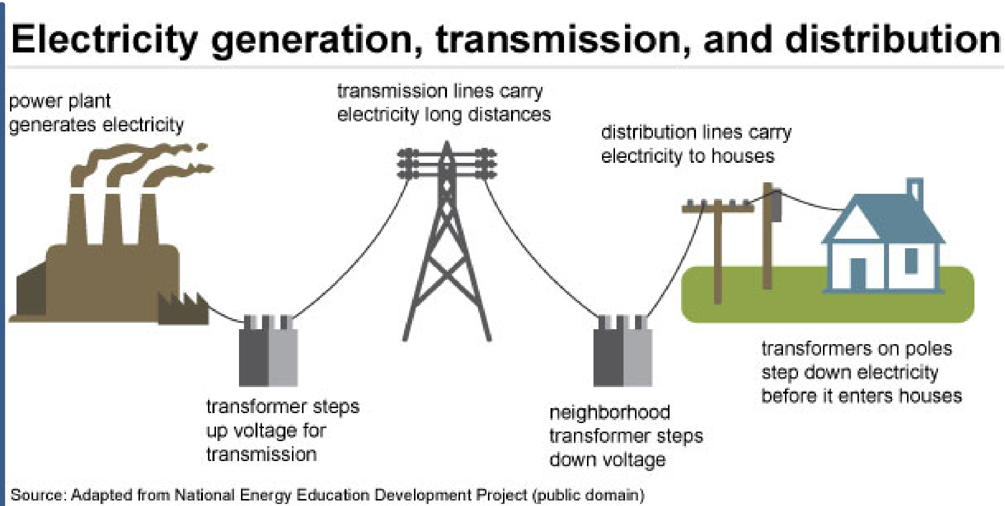

Chemical Energy

WHY ENERGY & HEAT TRANSFER?

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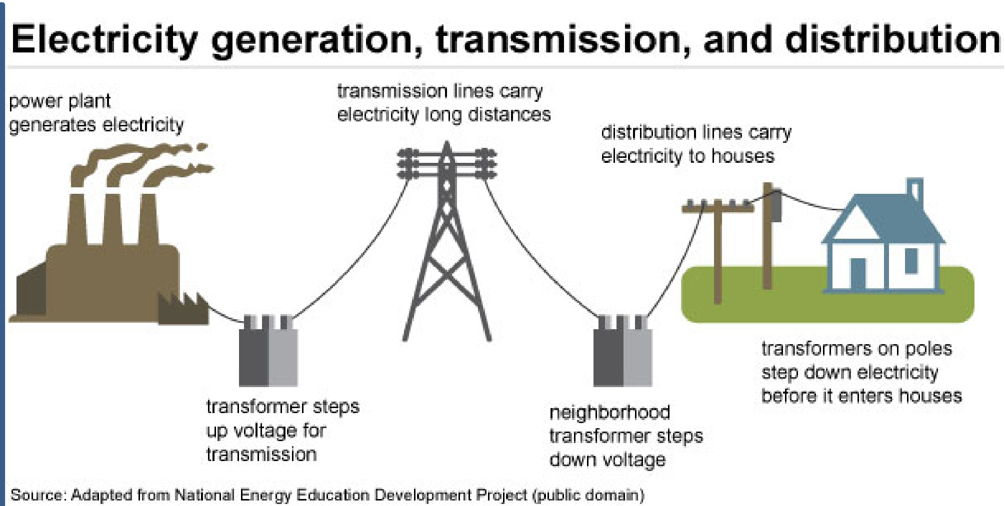

Chemical Energy

Heat Energy

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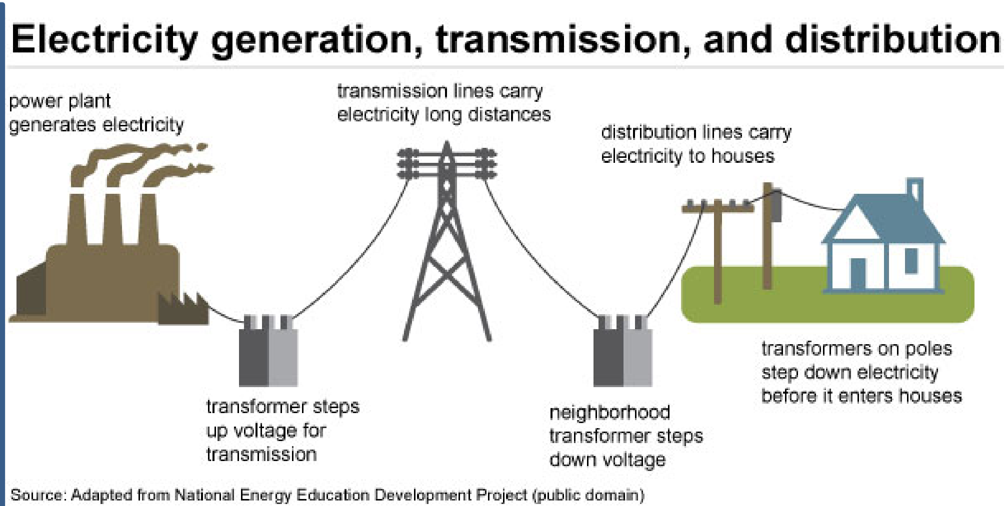

Chemical Energy → Heat Energy → Mechanical Energy →

Why Energy & Heat Transfer?

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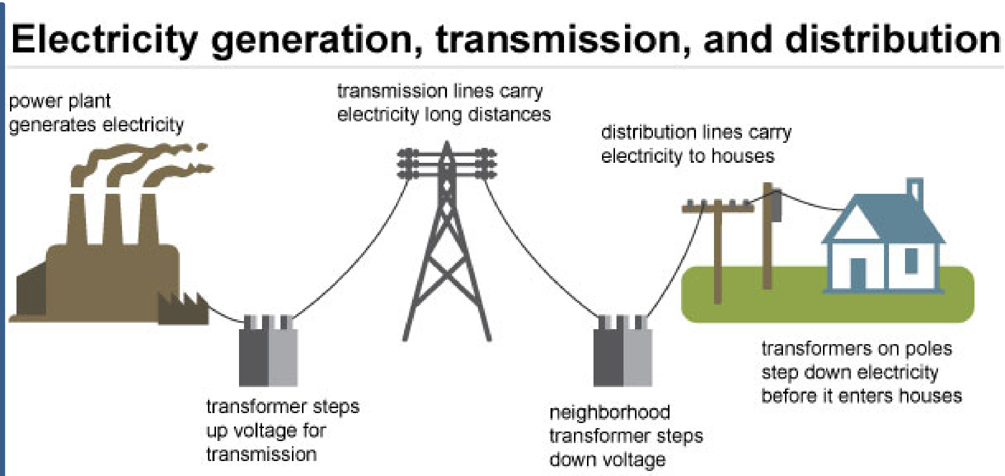

Source: Adapted from National Energy Education Development Project (public domain)

Chemical Energy → Heat Energy → Mechanical Energy → Electrical Energy →

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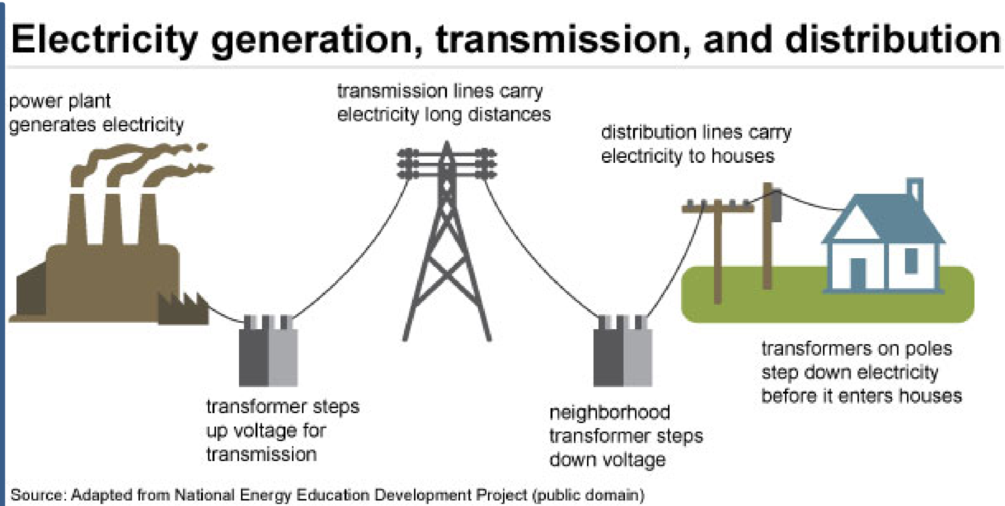

Chemical Energy → Heat Energy → Mechanical Energy → Electrical Energy → Heat Energy

Why Energy & Heat Transfer?

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What aspects are interesting for a Design Engineer to design a sustainable electric kettle? (Think about the aspects related to the heat and energy)

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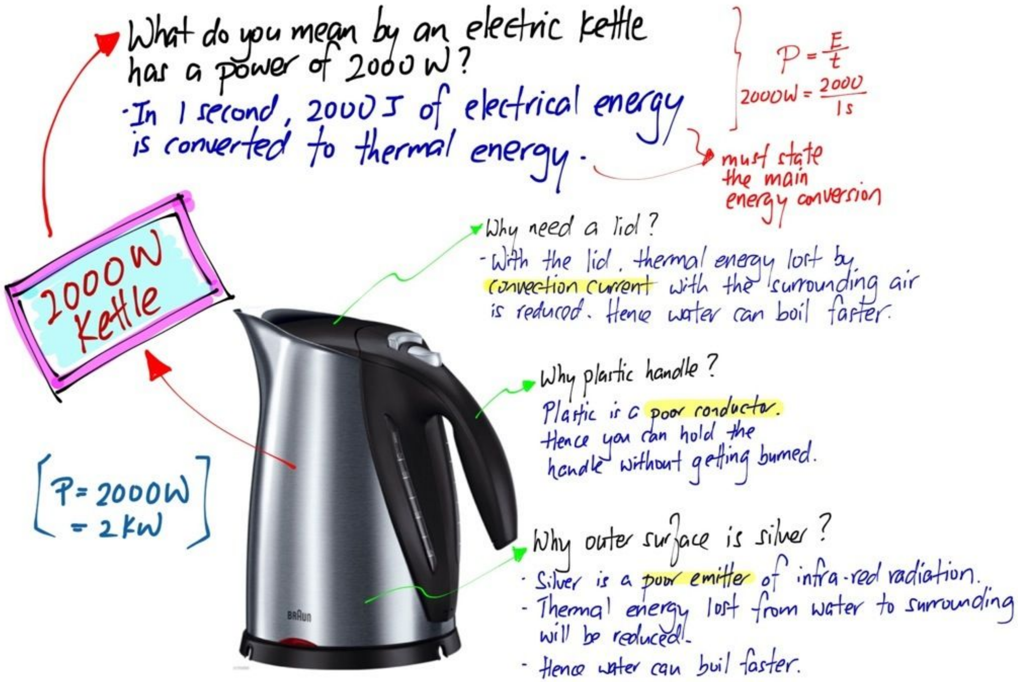
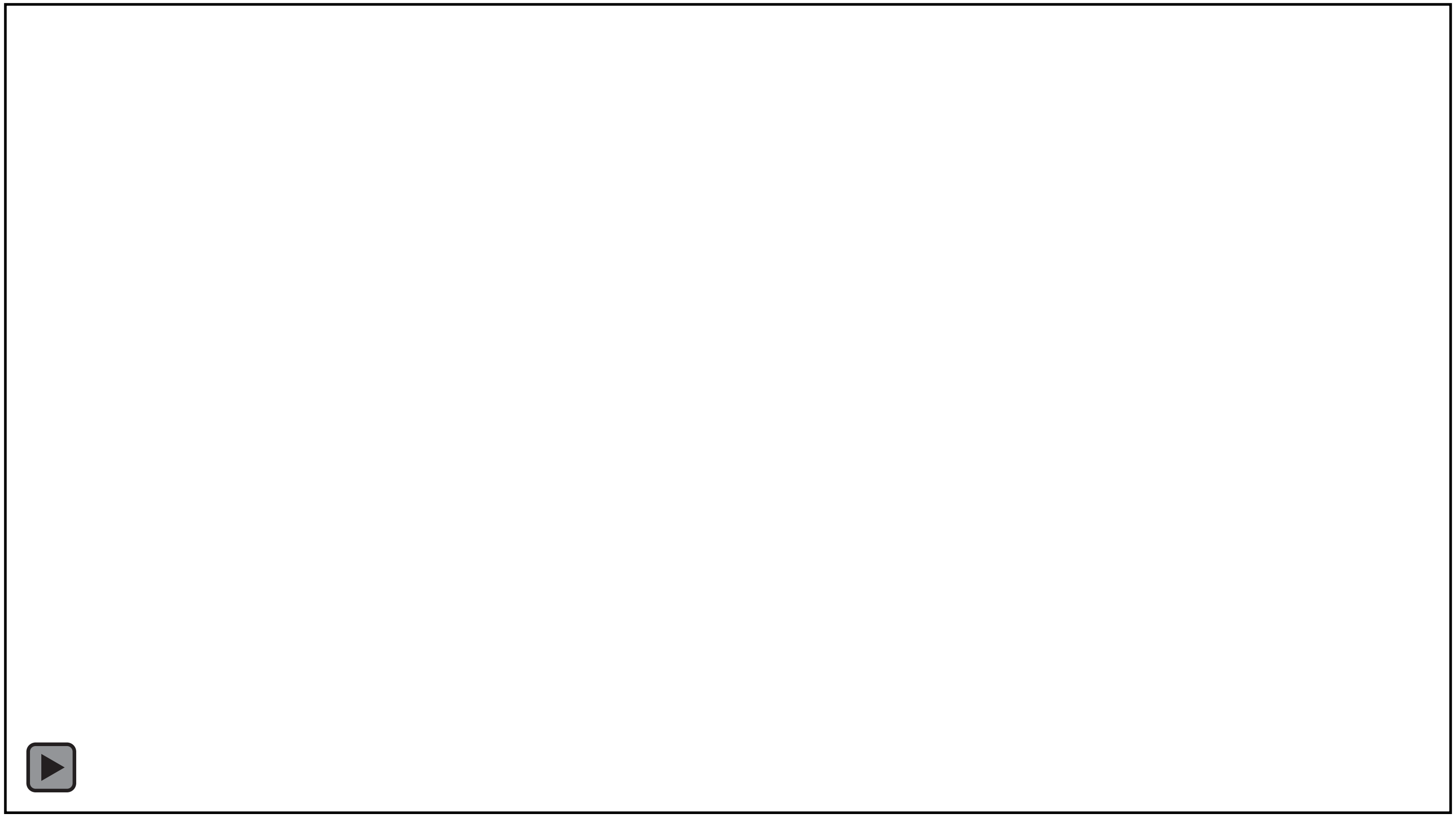
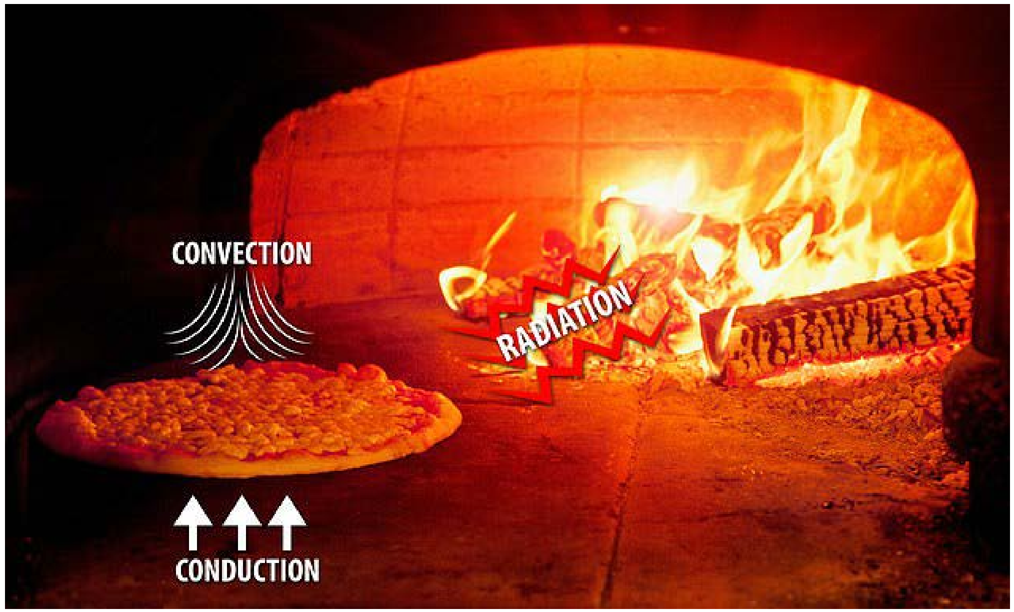
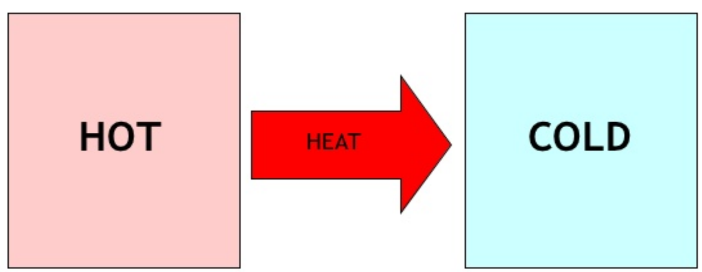




https://www.youtube.com/watch?v=2SYMgopseUk

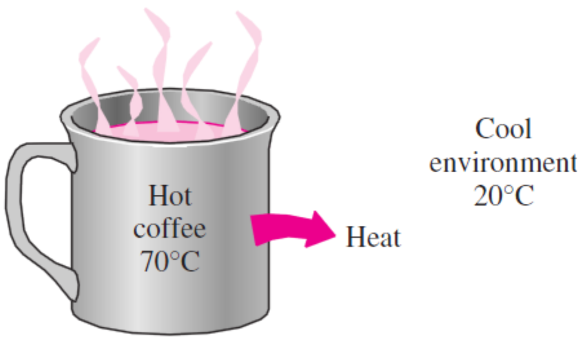
Why Energy & Heat Transfer?





- Heat always moves from HOT to COLD. hot→cold

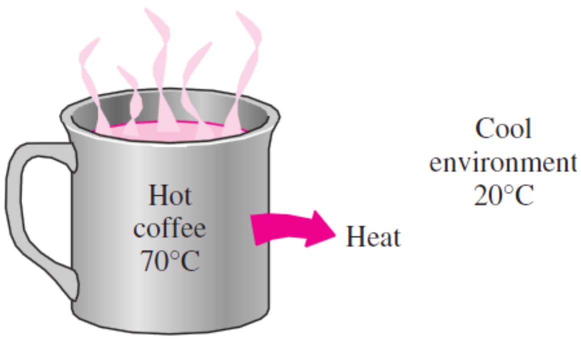
Illustration 1:Hot Coffee



Coffee mug

WHY ENERGY & HEAT TRANSFER?

Illustration 1:Hot Coffee



Coffee mug

We are normally interested in how long it takes for the hot coffee in a thermos to cool to a certain temperature, which cannot be determined from a thermodynamic analysis alone

Why Energy & Heat Transfer?

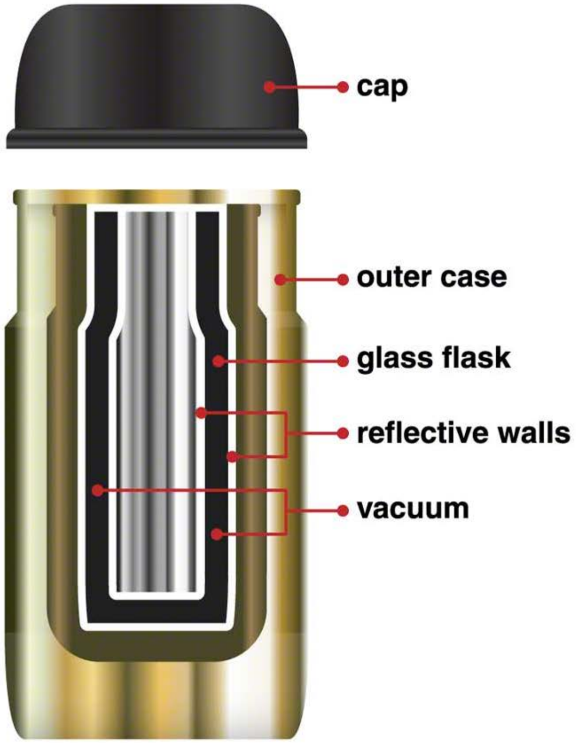
Thermo Flask

Why Energy & Heat Transfer?

Thermo Flask

Here's why the thermos or vacuum flask is such a good insulator:

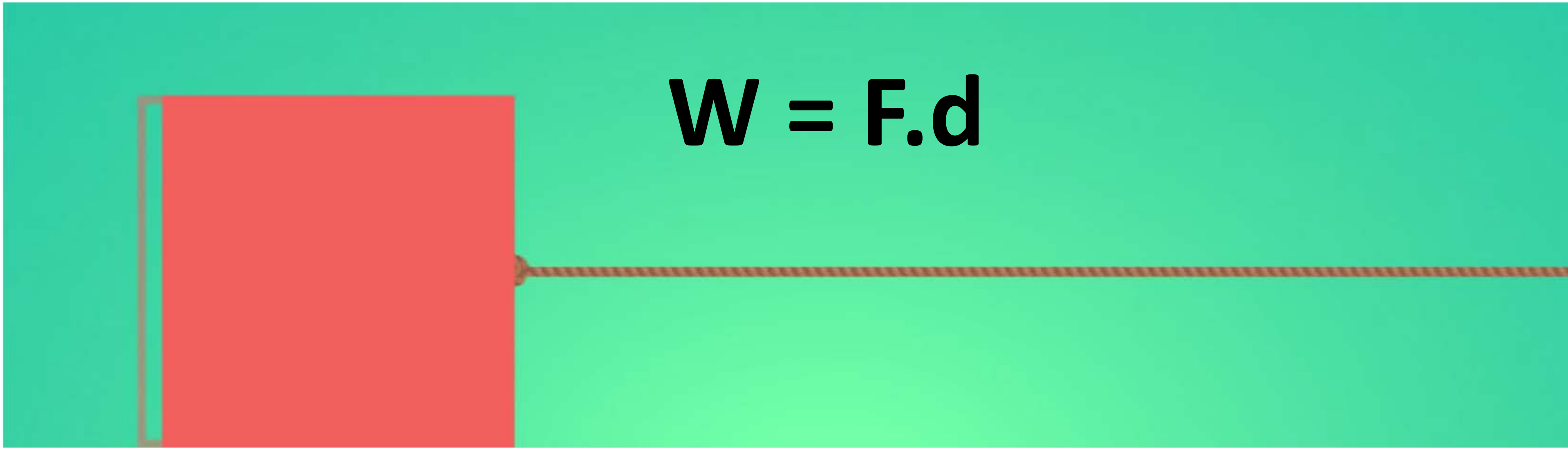
1. **Conduction** can't occur in a vacuum. It only occurs in matter, and there's no matter in a vacuum.
2. **Convection** can't occur in a vacuum. It only occurs in fluids such as air, and there's no air (or any other fluid) in a vacuum.
3. **Radiation** (electromagnetic waves) can travel through a vacuum. But electromagnetic waves bounce off the flask's reflective walls, greatly reducing heat transfer by radiation.



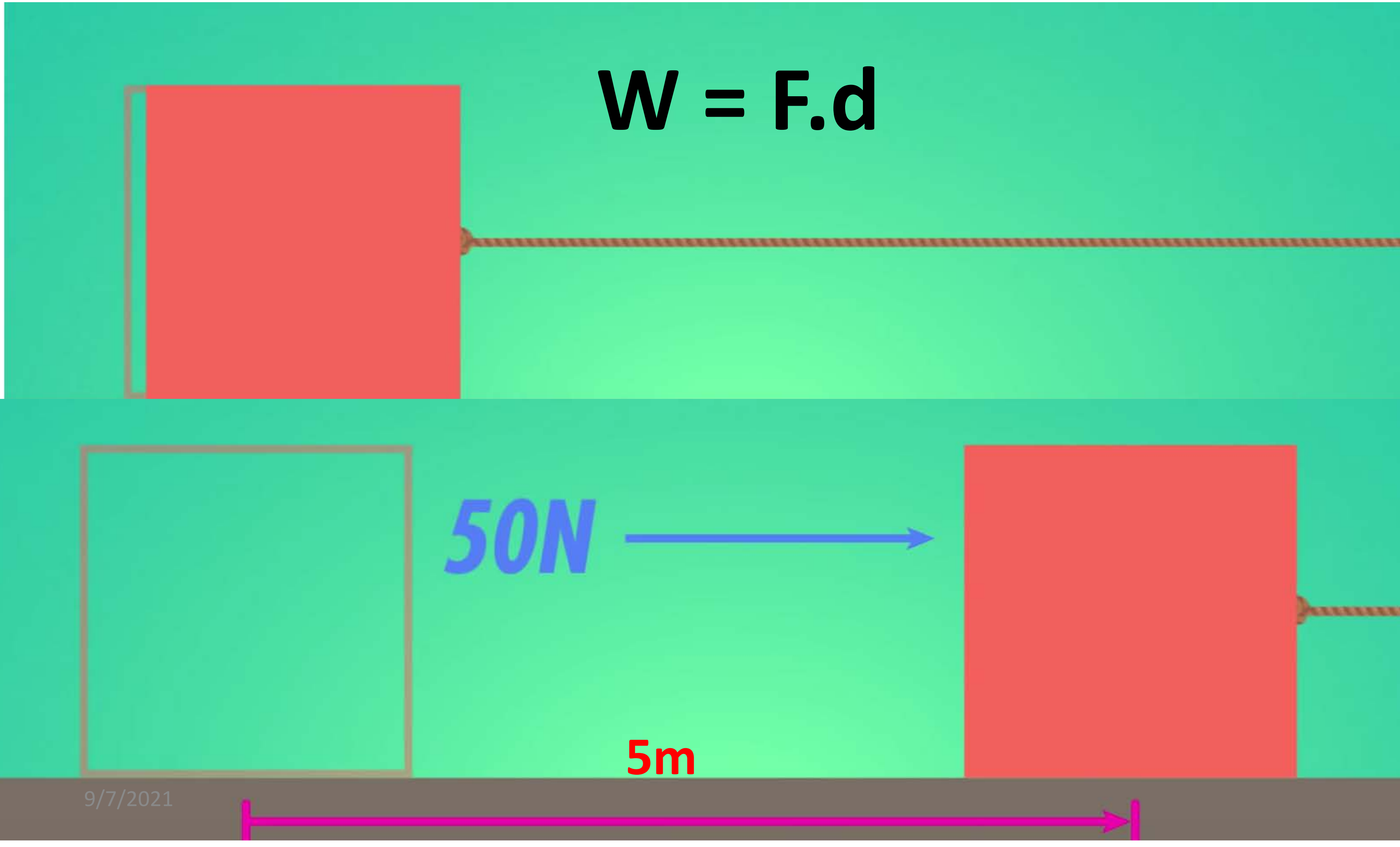
Designing requires knowledge from a physical background

Learning objectives lecture 1

- Define and distinguish work/energy/power
- Distinguish corresponding units
- Develop a sense for reasonable quantities
- Calculate energy content


W = F.d

Work, energy, power



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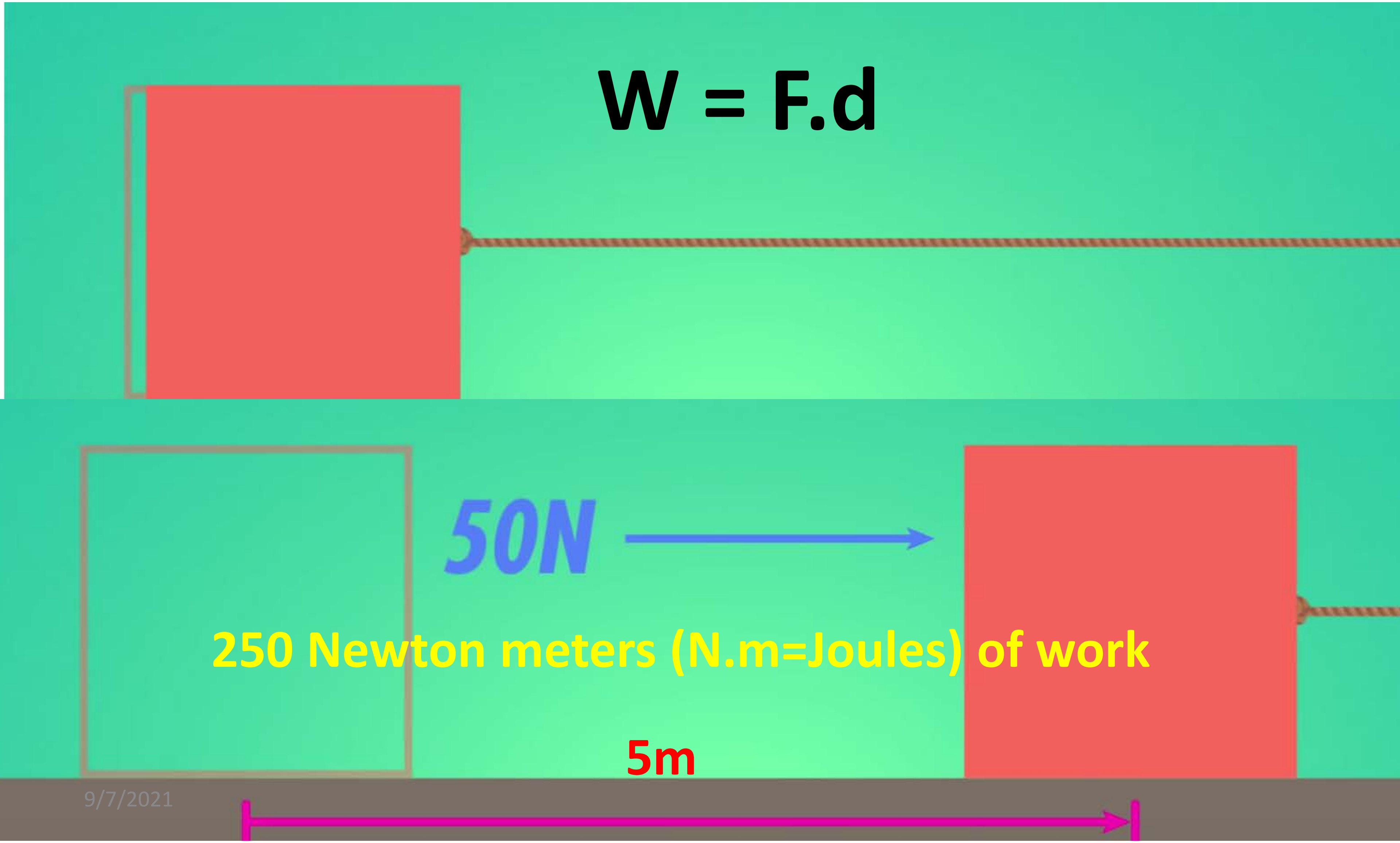

250 Newton meters (N.m=Joules) of work

If you pull the rope and therefore the box with a force of 50 N, while you moved it 5 m, then we would say that you did 250 N.m of work on the box. More commonly however, the work is expressed in unites knows as Joules.

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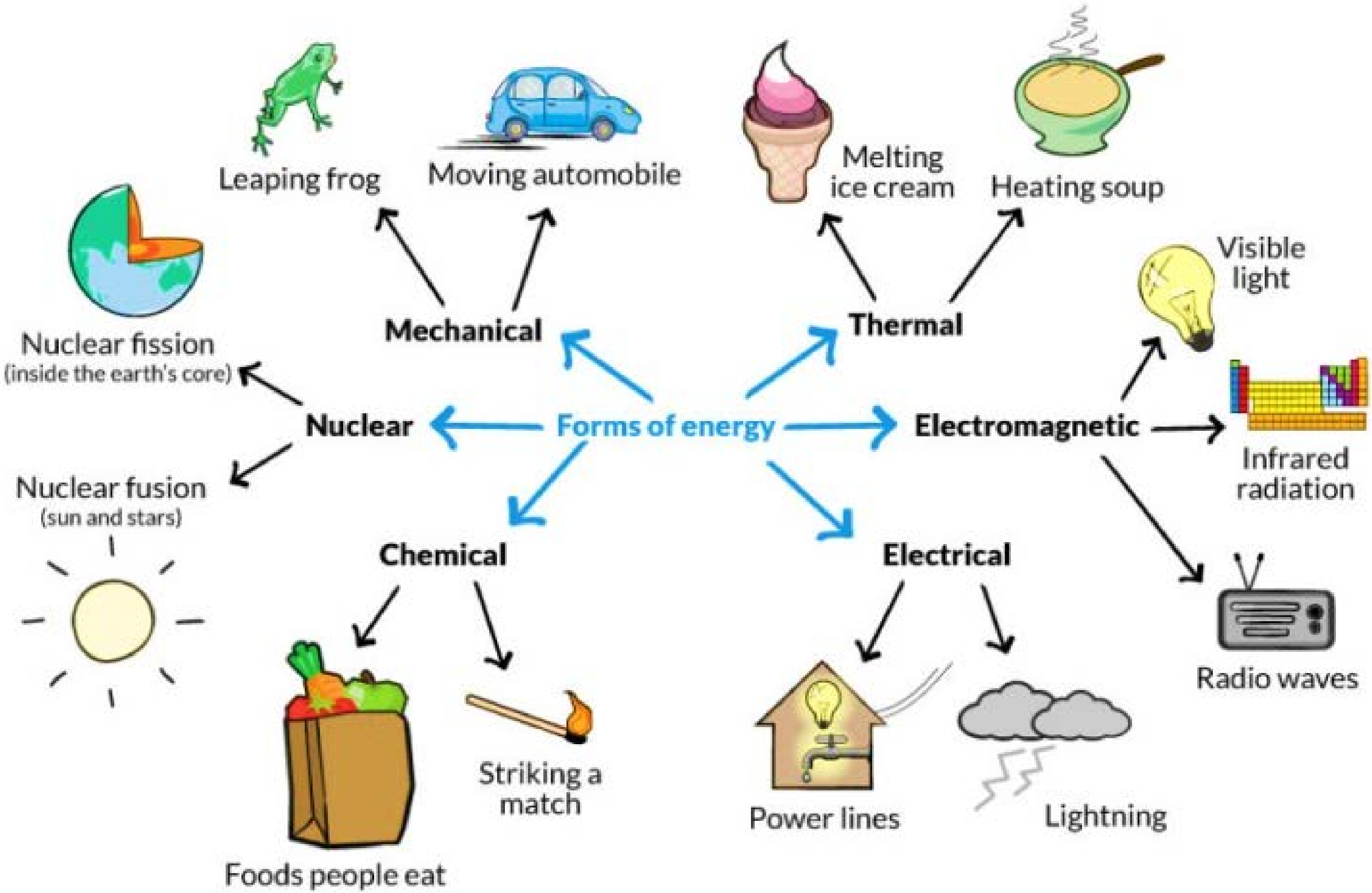
Work uses the same unit as energy because work is just a change in energy.

What happens when an external force is applied to a system and changes the energy of that system?

In fact that's one of the way to define energy! It is the ability to do work.

Different forms of Energy



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- Common forms of energy include the **kinetic energy** of a moving object, the **potential energy** stored by an object's position in a force field (**gravitational, electric** or **magnetic**), the **chemical energy** released when a fuel burns, the **radiant energy** carried by light, and the **thermal energy** due to an object's temperature.

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- **Work (electrical),** the energy transferred by a force from an electric field acting on a charge through a distance
- **Work (physics),** the energy transferred by a force acting through a distance
- **Work (thermodynamics),** the energy transferred from one system to another by macroscopic forces measurable in the surroundings

Joule Definition

- 1 Joule is the energy required to move an object 1 meter using a force of 1 Newton:

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$$\boxed{1\ \text{J} = 1\ \text{N} \cdot \text{m}}$$

Power: The Rate of Doing Work

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$$\text{Power} = \frac{\text{Change in energy}}{\text{Change in time}}$$

$$P = \frac{\Delta E}{\Delta t} \Rightarrow \text{W} = \frac{\text{J}}{\text{s}}$$

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So: 1 Watt = 1 Joule per second

Power determines how quickly we can do a certain amount of work or heat transfer
→ J/s

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Power determines how quickly we can do a certain amount of work or heat transfer → J/s

Watch out:
Quantity ≠ unit!

$$P = \frac{\Delta E}{\Delta t} = \frac{\text{J}}{\text{s}}$$

Wrong!

$$\text{Right}: P = \frac{\Delta E}{\Delta t} = \frac{100\text{J}}{20\text{s}} = 5\text{W}$$

Work, energy, power

Quantity	**Symbol**	**Unit**
Work	W	J (Joule)
Energy	E	J (Joule)
Power	P	W (Watt)

Work, energy, power

Quantity	**Symbol**	**Unit**
Work	W	J (Joule)
Energy	E	J (Joule)
Power	P	W (Watt)

Watch out!

A garage hoist steadily lifts a car up 2 meters in 20 seconds. Calculate the power delivered to the car. Use 1000 kg for the mass of the car.($g=9.81m/s^2$)

A. 985

B. 990

C. 981

D. 1050

WORK, ENERGY, POWER

Example: A garage hoist steadily lifts a car up 2 meters in 20 seconds. Calculate the power delivered to the car. Use 1000 kg for the mass of the car.
Hint: First we need to calculate the work done, which requires the force necessary to lift the car against gravity.

F = mg = 1000 x 9.81 = 9810 N.
W = Fd = 9810N x 2m = 19620 Nm = 19620 J.
The power is P = W/t = 19620J / 20s = 981 J/s = 981 W

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- Define and distinguish work/energy/power
- **Distinguish corresponding units**
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Other units

Energy

J

Power

W

Other units

Energy

J

$kJ = 10^3\ J$
$kW = 10^3\ W$
$MJ = 10^6\ J$
$MW = 10^6\ W$
$GJ = 10^9\ J$

Power

W

Other units

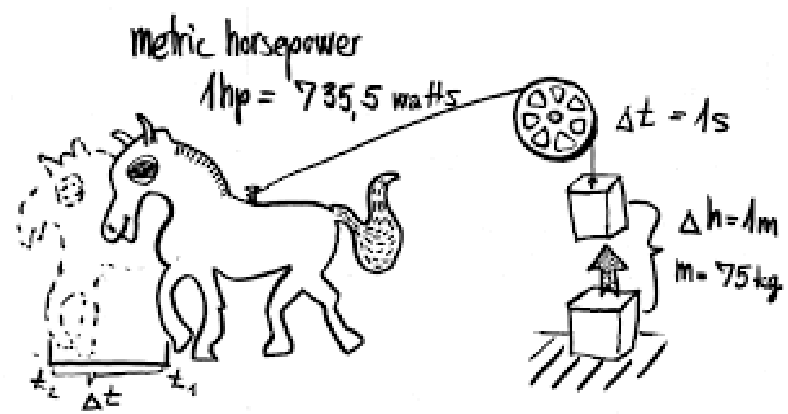
Energy

J

Power

W

kJ = 10^3 J
kW = 10^3 W
MJ = 10^6 J
MW = 10^6 W
GJ = 10^9 J



Metric Horsepower :
1hp = 735,5 W

Large units often convenient when using large amounts of energy/power

Tons of Joule

- kWh – kilowatt-hour: no power but energy!

Tons of Joule

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- 1 kWh = the energy when using 1 kW for 1 hour
- $= 1 \cdot 10^3\ W \cdot 3600\ s = 3{,}6 \cdot 10^6\ W \cdot s$

$$= 3{,}6 \cdot 10^6\ J$$

$$= 3{,}6\ MJ$$

Tons of Joule

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$$= 3{,}6 \cdot 10^6\ J$$

$$= 3{,}6\ MJ$$

$1\ kcal = 4{,}184 \cdot 10^3\ J$

- kcal – kilocalorie: the **energy** it takes to raise the temperature of 1kg of water by 1˚C.

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- Define and distinguish work/energy/power
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- **Develop a sense for reasonable quantities**
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View on energy

- **Equivalents**:
  - 1 medium Big Mac menu with fries = 835 kcal = 3494 kJ

- **Activities at home**:
  - Toasting 2 slices of bread: 216 kJ
  - Watching one hour of television: 720 kJ
  - 15 minutes of vacuum cleaning: 1440 kJ
  - One full load of laundry: 4320 kJ

- **Physical activities**:
  - 1 hour of walking (normal speed): 1440 kJ
  - 1 hour of jogging(10,5 km): 2760 kJ
  - 1 hour of cycling (15 km): 1600 kJ

Where we are

- Definitions work, energy, power
  - Work *W*: delivering a certain performance
  - Energy *E*: capacity to deliver work
  - Power *P*: change of energy per unit of time

Unit J = N · m

Unit W = J / s

$$P = \frac{\Delta E}{\Delta t}$$

- Other units
  - Energy: kJ, MJ, GJ, kWh, kcal, Calvé, ...
  - Power: kW, MW, hp, …

- Quantities / proportions of energy

  → How to calculate these?

Learning objectives lecture 1

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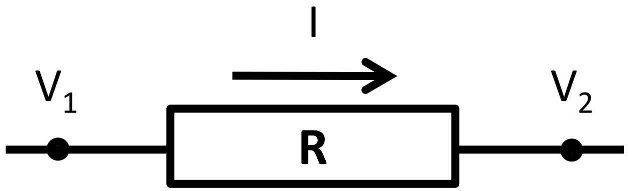
- **Calculate energy content**

Electrical energy

- Ohm's law

  $U = I \cdot R$



$U = V_1 - V_2$

Electrical energy

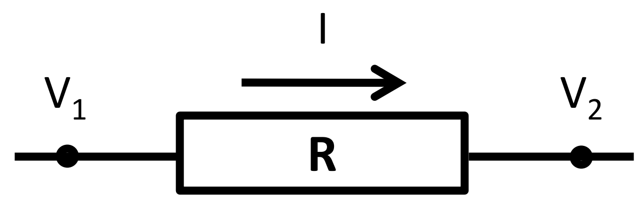
- Ohm's law

  $U = I \cdot R$

- So Electrical power

  $$P = U \cdot I$$

  $$P = (I \cdot R) \cdot I = I^2 \cdot R$$



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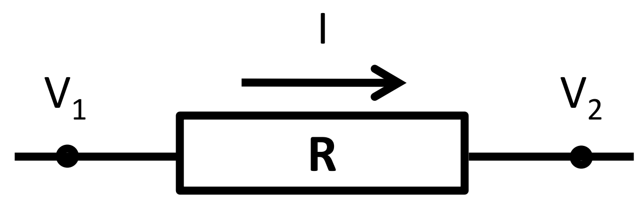
- Electrical energy:

  $$\Delta E = P \cdot \Delta t$$

  $$= U \cdot I \cdot \Delta t = I^2 \cdot R \cdot \Delta t$$



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- Electrical energy:

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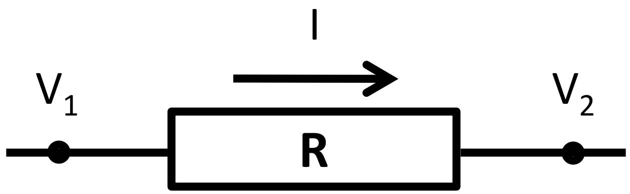

$U = V_1 - V_2$

$$R = \frac{U}{I}$$

$$\Omega = \frac{\mathrm{V}}{\mathrm{A}}$$

1 Ω → 1 V required to cause a 1 A current to flow

Electrical energy

- An **electric current** is the rate of flow of electric charge past a point.

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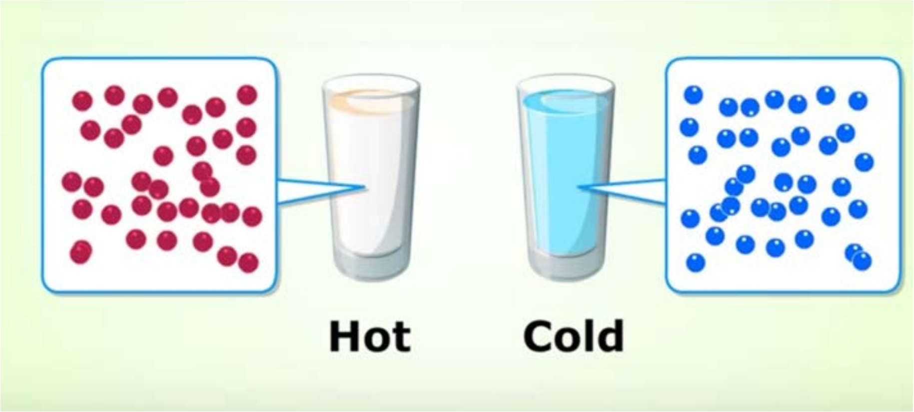
- **Ohm's law** states that the current through a conductor between two points is directly proportional to the potential difference across the two points.
- **Electric power** is the rate, per unit time, at which electrical energy is transferred by an electric circuit. The SI unit of power is the watt, one joule per second.

Thermal energy

- Thermal energy: kinetic energy of molecules and atoms.



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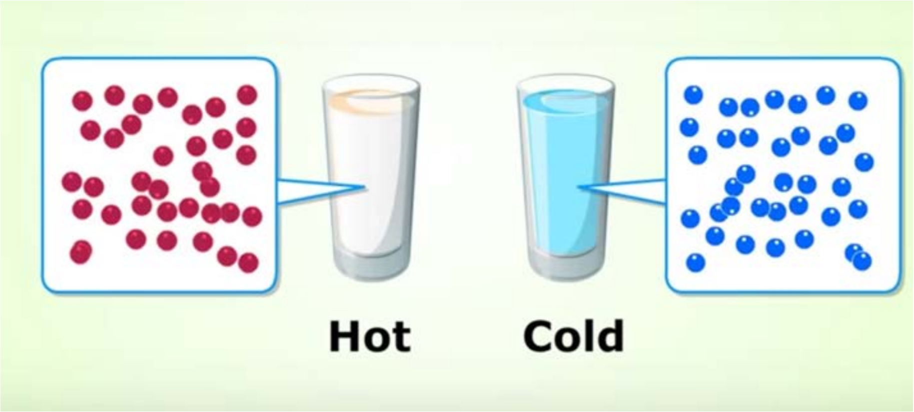

Heat Transfer: $\Delta E = Q$

$$\boxed{Q = m \cdot c \cdot \Delta T}$$

m = mass of "system" (kg)

ΔT = temperature change of system during process (K)

c = specific heat capacity (J / (kg · K))

Thermal energy

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→ Joule per kilogram per Kelvin

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⟶ Joule per kilogram per Kelvin

Alternatively:

$C = m \cdot c$ = heat capacity (J / K)

"The amount of energy required to heat a complete system by 1 Kelvin"

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$$Q = m \cdot c \cdot \Delta T = C \cdot \Delta T \quad \text{(J)}$$

lowercase

uppercase

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lowercase uppercase

$$\boldsymbol{Q = m \cdot c \cdot \Delta T}$$

Check:

$$Q = m \cdot c \cdot \Delta T$$

$$\mathrm{kg}\frac{\mathrm{J}}{\mathrm{kg} \cdot \mathrm{K}}\mathrm{K} = \mathrm{J}$$

$$[Q] = \mathrm{J}$$ ✔

Specific heat Capacity

	Substance	c (J / kg · K)	
Solids	Stainless Steel	$0{,}480 \cdot 10^3$	
	Aluminum	$0{,}903 \cdot 10^3$	
	Polyester	$1{,}170 \cdot 10^3$	
	Polypropene	$1{,}925 \cdot 10^3$	
Liquids	Water	$4{,}184 \cdot 10^3$	
	Engine oil	$1{,}900 \cdot 10^3$	
Gases		c_p	c_v
	Air	$1{,}007 \cdot 10^3$	$0{,}721 \cdot 10^3$
	Methane	$2{,}226 \cdot 10^3$	$1{,}708 \cdot 10^3$
	(Steam)	$1{,}865 \cdot 10^3$	$1{,}403 \cdot 10^3$

1 kcal = $4{,}184 \cdot 10^3$ J

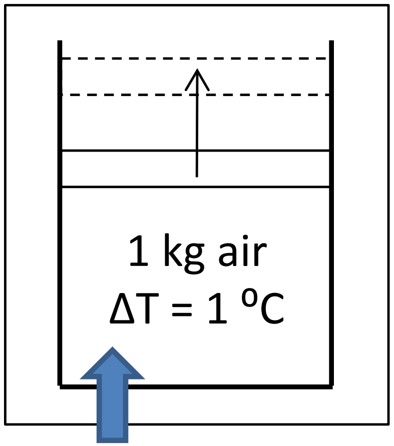
Energy required to heat 1 kg of water by 1 K.

Values at room temperature!

Specific heat for gases

SPECIFIC HEAT FOR GASES

Heating in open environment
- Pressure constant
- Volume changes



Q = 1007 J

$\boldsymbol{c_p}$

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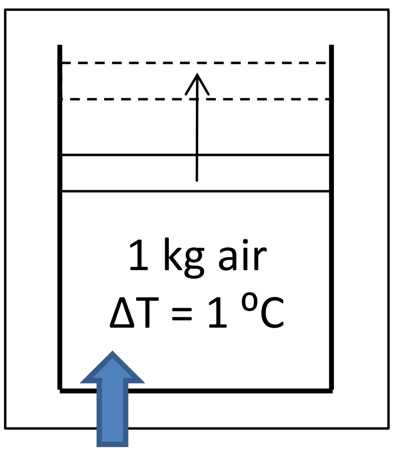

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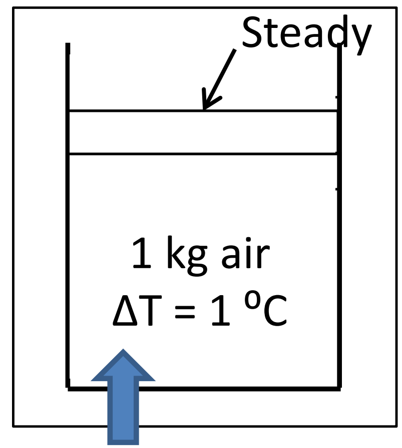
$\boldsymbol{c_p}$

Heating in a fixed volume, closed

- Volume constant
- Pressure changes



Q = 721 J

$\boldsymbol{c_v}$

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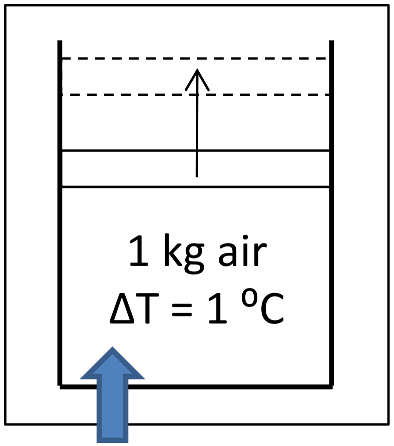

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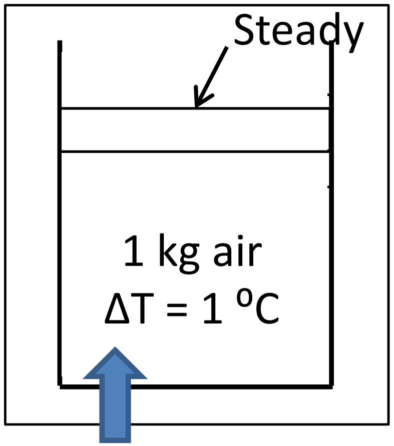

Q = 721 J

$\boldsymbol{c_p}$ $\quad$ $c_p > c_v$; why? $\quad$ $\boldsymbol{c_v}$

Specific heat for gases

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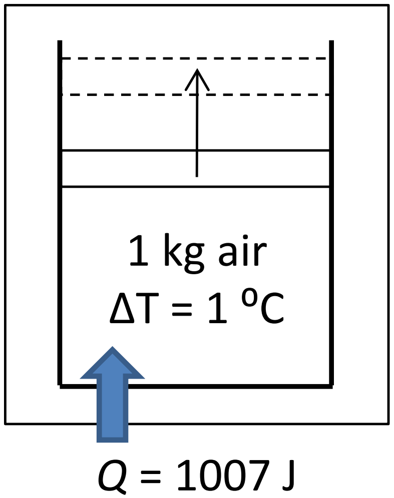

$\boldsymbol{c_p}$

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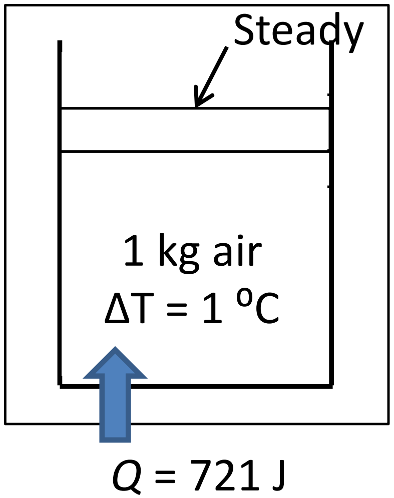

$\boldsymbol{c_v}$

$c_p > c_v$; why?

Heating at constant pressure → larger volume → mechanical work

Energy Transfer: Work and Heat

Symbol	Definition	Units
W	Work	kJ
w	Specific work = work per unit mass, w = W/m	kJ/kg
P	Power = rate of work*	kW (= kJ/s)
Q	Heat transfer	kJ
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- NOTE: Rates are denoted by a dot on top of the variable.
- However, sometimes these dots are hard to see in PowerPoint.

Quantities of energy – summarized

- Mechanical work : $W = F \cdot D$
- Thermal energy (change): $\Delta E = m \cdot c \cdot \Delta T$
- Chemical energy

Everything in Joule!

Summary (1-2)

- Work W, energy E, power P $$P = \frac{\Delta E}{\Delta t}$$
- Units J, W = J/s, kWh, hp, …
- Work *W*, Energy *E* in $\mathrm{J} = \mathrm{N} \cdot \mathrm{m} = \dfrac{\mathrm{kg} \cdot \mathrm{m}}{\mathrm{s}^2} \cdot \mathrm{m}$
- Power $P = \dfrac{\Delta E}{\Delta t}$ in W = J / s
- Units kWh, kcal, hp, ….
- Comparison / estimating / proportion

Summary (2-2)

- Mechanical work $W = F \cdot D$
- Thermal energy $Q = m \cdot c \cdot \Delta T$
  - – c is specific heat capacity in J / (kg · K)

LECTORIAL 1

- Lectorial : Friday, 10 September 2021,13:45 - 15:30

⇒ Assignments: bundle on Canvas

⇒ Deadlines: schedule on Canvas

Ready, set,

GO!...