

Lecture #1

Energy & Heat Transfer



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COURSE ORGANIZATION



Fundamentals

Eight lectures and Seven Lectorials (On Campus)

- Study materials: sheets & Book :

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

Application

- Assignments in same groups
- HeatQuiz
- Lectorials

Finalizing

- Individual written exam (both calculations and understanding)

COURSE CONTENTS



Fundamentals

| | |
|---------------|--|
| 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 |
| | |
| | 7: Combined Heat Transfer |

COURSE CONTENTS



Additionally another 1 lecture:

| Lecture | |
|---------|---------|
| 8 | Summary |

Question Hours : Q&A online

There will be Q&A sessions by announcement

CANVAS

The screenshot shows a list of course items in a navigation menu:

- Energy and Heat Transfer (EHT)
 - EHT_24_25_Manual.pdf
 - HeatQuiz
 - HeatQuiz: Energy & Heat Transfer
 - [EHT] Discussion on HeatQuiz
 - Group Assignments
 - [EHT]: Group Assignment W02
19 Sep | 10 pts
 - [EHT]: Group Assignment W03
29 Sep | 10 pts

- Course Manual (Please read it carefully!)
- Information about HeatQuiz map
- Discussion on HeatQuiz
- Group assignments
- Discussion on Group Assignments

HEATQUIZ



A learning path in HeatQuiz specific to the course will be used during the course:

[**Links to an external site.**](http://167.86.98.171:3000/#/Courses/PlayMapWithKey/91)

The message "Please add a key!" will appear when playing for the first time. This has to be done by pressing the green button "Assign new key".

A box will pop up in which a key has to be entered.

This key **must be your student number**, e.g. s1234567.

GRADING



Final Grade:

- 80 % for the **final exam** (individual mark)
- 20 % for the **weekly assignments** (group mark)
- Bonus (**10%** of final grade)
 - Bonus points can be earned individually by completing the hand-in exercise during the tutorial (**submission of papers is mandatory for evaluation**).
 - –**The bonus is only valid for the 1st exam, and it is not counted for the resit exam.**

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+ Bonus**)

RESIT EXAM



- **Written Exam**
- **80% final exam** (individual)
- **20 % of Weekly assignment**(group mark)

- Bonus is not valid for Resit Exam

GROUP ARRANGEMENTS



Please contact :

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j.dacosta@utwente.nl

Why Energy and Heat Transfer?

Dutch demand for energy in five domains. Source: CBS

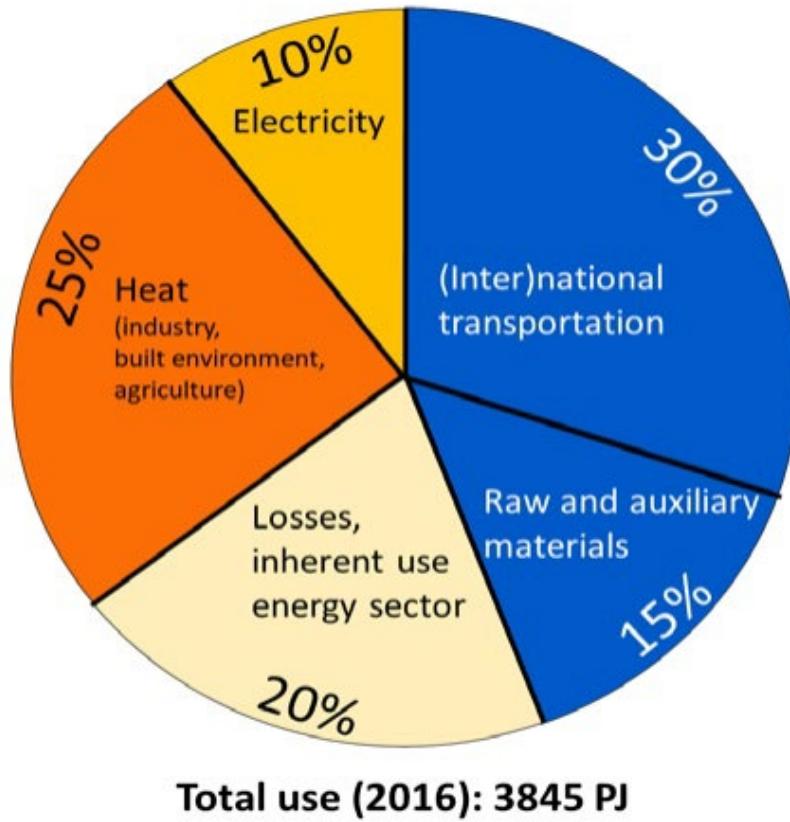
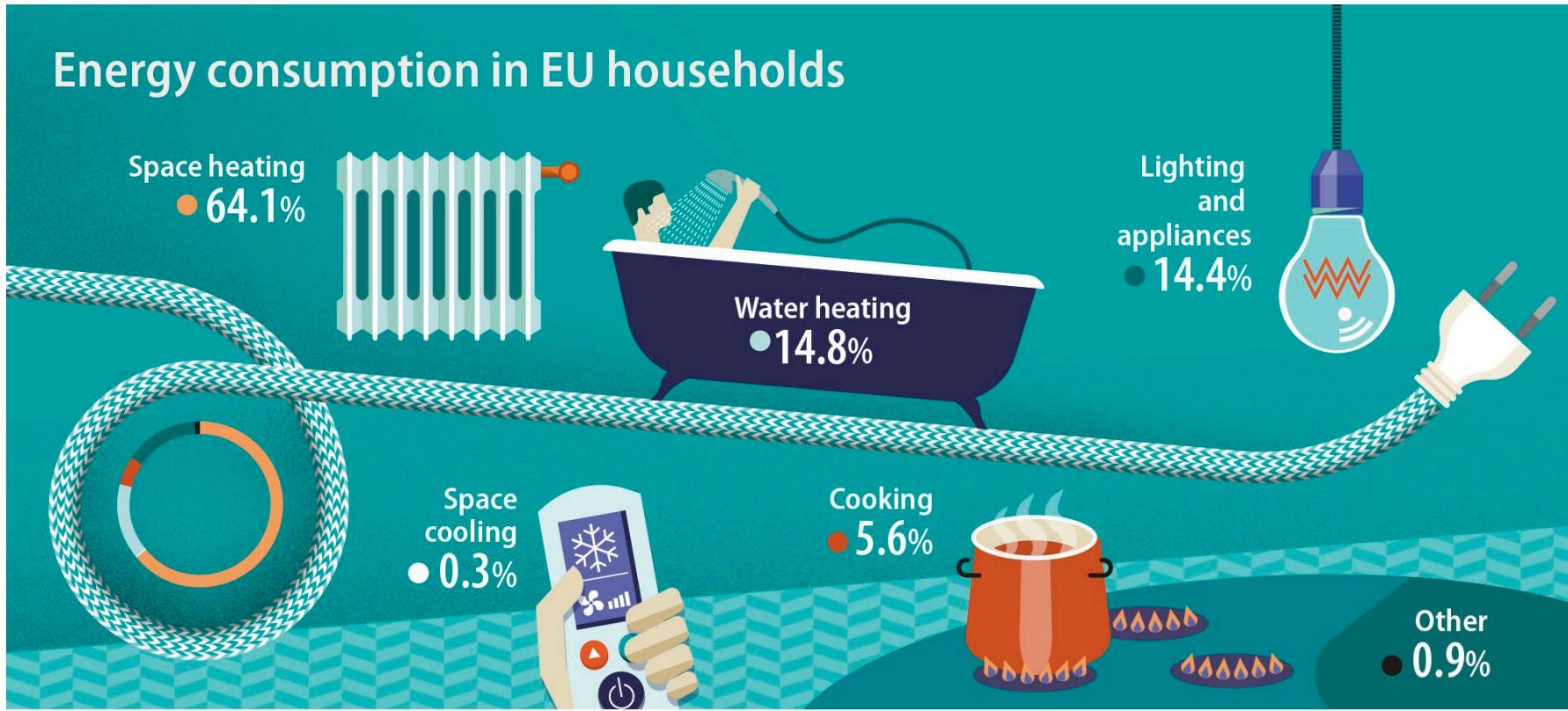


Figure 4. Dutch demand for energy in five domains.
Source: CBS [13].

Why Energy and Heat Transfer?



ec.europa.eu/eurostat

WHY ENERGY & HEAT TRANSFER?

84%

Fossil
Fuels

Electricity generation, transmission, and distribution

power plant generates electricity



transformer steps up voltage for transmission



transmission lines carry electricity long distances

distribution lines carry electricity to houses



neighborhood transformer steps down voltage

transformers on poles step down electricity before it enters houses



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

Chemical
Energy

Heat Energy

Mechanical
Energy

Electrical
Energy

Heat Energy

WHY ENERGY & HEAT TRANSFER?

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



2000W Kettle

$$P = 2000W = 2kW$$

What do you mean by an electric kettle has a power of 2000 W?
In 1 second, 2000 J of electrical energy is converted to thermal energy.

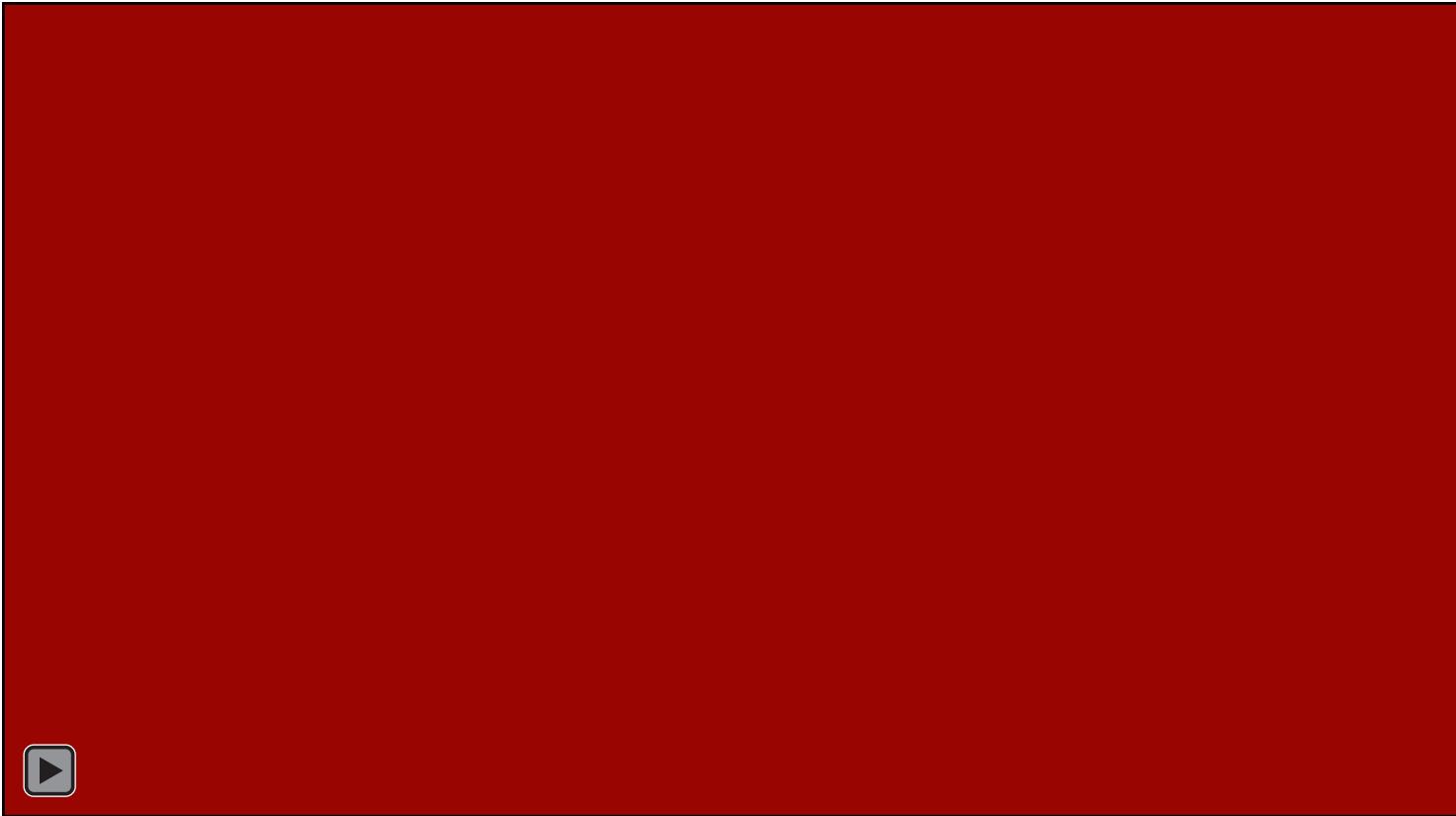
$$\left. \begin{array}{l} P = \frac{E}{t} \\ 2000W = \frac{2000}{1s} \end{array} \right\}$$

must state the main energy conversion

Why need a lid?
With the lid, thermal energy lost by convection current with the surrounding air is reduced. Hence water can boil faster.

Why plastic handle?
Plastic is a poor conductor. Hence you can hold the handle without getting burned.

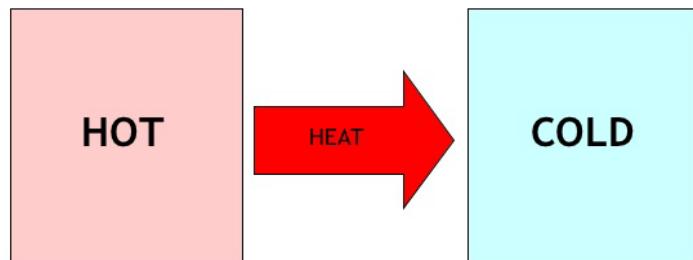
Why outer surface is silver?
Silver is a poor emitter of infra-red radiation.
Thermal energy lost from water to surrounding will be reduced.
Hence water can boil faster.



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



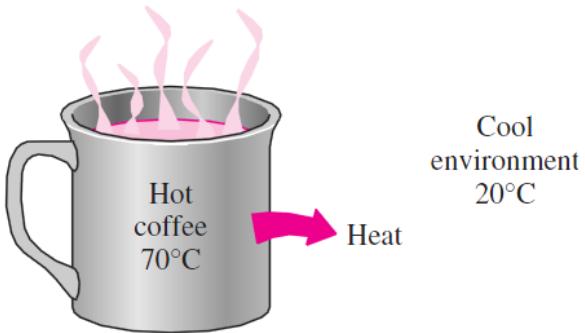
WHY ENERGY & HEAT TRANSFER?



- Heat always moves from HOT to COLD.
 $\text{hot} \rightarrow \text{cold}$

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

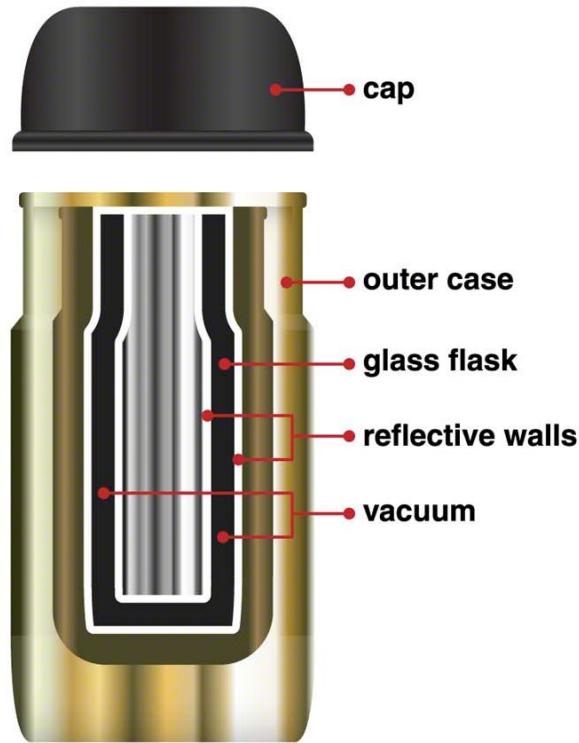
WHY ENERGY & HEAT TRANSFER?

Thermo Flask



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

WORK, ENERGY, POWER

$$W = F.d$$



50N —————→

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

5m

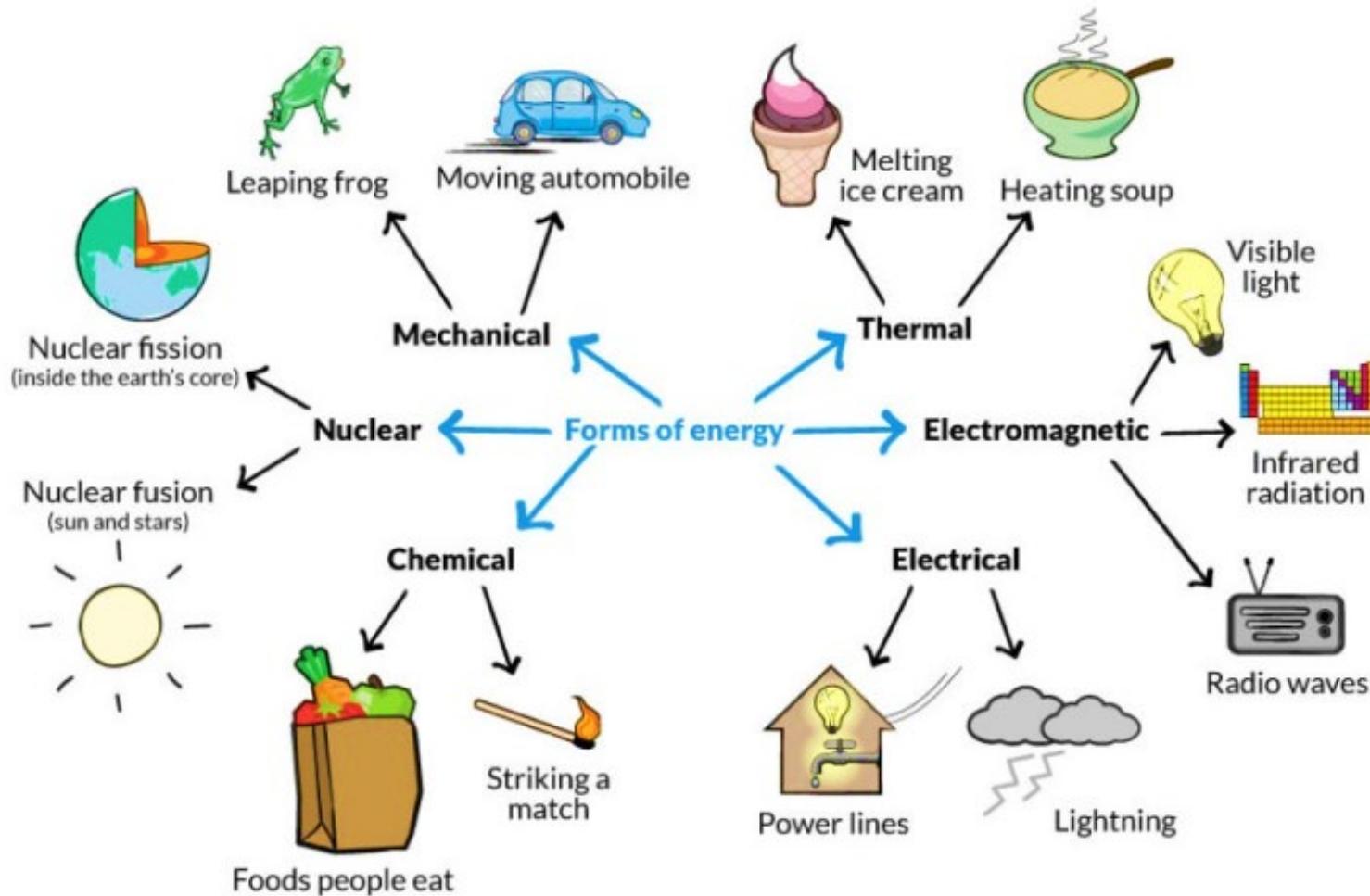


If you pull the rope and therefore the box with a force of **50 N**, while you moved it **5 m**, then we would say that you did **250 N.m** of work on the box. More commonly however, the work is expressed in units known as **Joules**.

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



- Energy is the **quantitative property** that must be transferred to an object in order to perform **work** on, or to **heat**, the object.
- Energy is a **conserved quantity**; the law of conservation of energy states that energy can be converted in form, but not created or destroyed.
- The **SI unit** of energy is the **joule**, which is the energy transferred to an object by the work of moving it for one meter against a force of 1 newton.
- 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.
- **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

WORK, ENERGY, POWER



JOULE DEFINITION

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

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

Power: The Rate of Doing Work

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

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

So: 1 Watt = 1 Joule per second

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

Watch out:
Quantity ≠ unit!

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

Wrong!

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

WORK, ENERGY, POWER

| <u>Quantity</u> | <u>Symbol</u> | <u>Unit</u> |
|-----------------|---------------|-------------|
| Work | W | J (Joule) |
| Energy | E | J (Joule) |
| Power | P | W (Watt) |



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.($g=9.81\text{m/s}^2$)

- 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.

$$F = mg = 1000 \times 9.81 = 9810 \text{ N.}$$

$$W = F.d = 9810\text{N} \times 2\text{m} = 19620 \text{ Nm} = 19620 \text{ J.}$$

$$\text{The power is } P = W/t = 19620\text{J} / 20\text{s} = 981 \text{ J/s} = 981 \text{ W}$$

LEARNING OBJECTIVES LECTURE 1



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

OTHER UNITS

Energy

J

$$\text{kJ} = 10^3 \text{ J}$$

$$\text{kW} = 10^3 \text{ W}$$

$$\text{MJ} = 10^6 \text{ J}$$

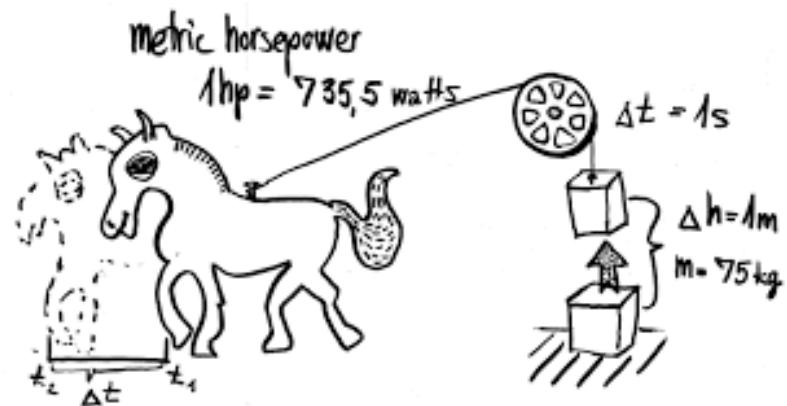
$$\text{MW} = 10^6 \text{ W}$$

$$\text{GJ} = 10^9 \text{ J}$$

Power

W

Metric Horsepower :
 $1\text{hp} = 735,5 \text{ W}$



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

TONS OF JOULE



- kWh – kilowatt-hour: no power but energy!
- 1 kWh = the energy when using 1 kW for 1 hour
- $= 1 \cdot 10^3 \text{ W} \cdot 3600 \text{ s} = 3,6 \cdot 10^6 \text{ W} \cdot \text{s}$
 $= 3,6 \cdot 10^6 \text{ J}$
 $= 3,6 \text{ MJ}$

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

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

LEARNING OBJECTIVES LECTURE 1

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

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
- 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

A horizontal line consisting of a thin black line with seven evenly spaced black circular dots. It spans the width of the slide below the title.

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

ELECTRICAL ENERGY

- Ohm's law

$$U = I \cdot R$$

- So Electrical power

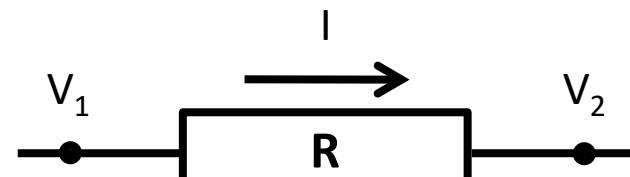
$$P = U \cdot I$$

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

- Electrical energy:

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

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



$$U = V_1 - V_2$$

$$R = \frac{U}{I}$$
$$\Omega = \frac{V}{A}$$

$1 \Omega \rightarrow 1 V$ required to cause a $1 A$ current to flow

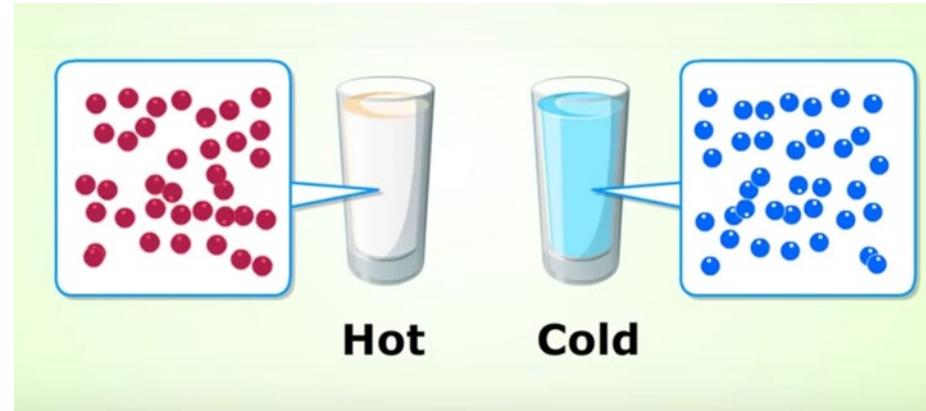
ELECTRICAL ENERGY



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



Heat Transfer: $\Delta E = Q$

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

m = mass of “system” (kg)

ΔT = temperature change of system during process (K)

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

THERMAL ENERGY

c = specific heat capacity ($\text{J} / (\text{kg} \cdot \text{K})$)

“The amount of energy required to heat 1 kg of a substance by 1 Kelvin”

→ 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”

→ Joule per Kelvin

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

Check:

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

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

$$[Q] = \text{J}$$



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

lowercase

uppercase

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 | Air | c_p $1,007 \cdot 10^3$ |
| | Methane (Steam) | c_v $2,226 \cdot 10^3$ $1,865 \cdot 10^3$ |
| | | $0,721 \cdot 10^3$ $1,708 \cdot 10^3$ $1,403 \cdot 10^3$ |

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

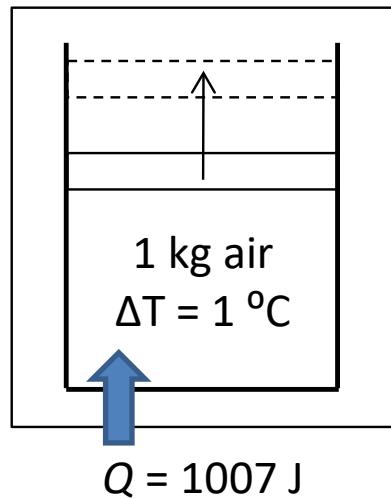
Energy required
to heat 1 kg of
water by 1 K.

Values at room temperature!

SPECIFIC HEAT FOR GASES

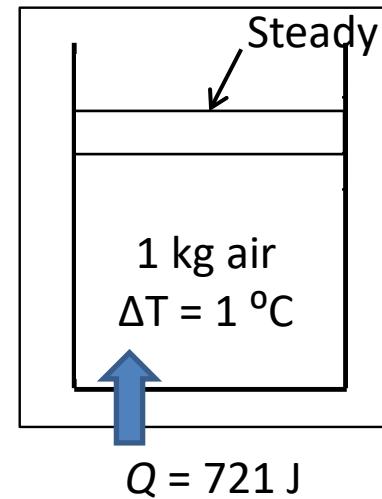
Heating in open environment

- Pressure constant
- Volume changes



Heating in a fixed volume, closed

- Volume constant
- Pressure changes



c_p

$c_p > c_v$; why?

c_v

Heating at constant pressure \rightarrow larger volume \rightarrow 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 |
| q | Specific heat transfer = heat transfer per unit mass, $q = Q/m$ | kJ/kg |
| \dot{Q} | Rate of heat transfer* | kW (= kJ/s) |

- 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 $J = N \cdot m = \frac{kg \cdot m}{s^2} \cdot m$

- Power $P = \frac{\Delta E}{\Delta t}$ 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)

HEATQUIZ



Energy & heat transfer: Learning path



Tables

Practice
Exam

Extra Practice
Material

