Introduction

Hydrogen economy:
- H_2 = 75% of Universe
- H_2 produced by
  - reform NG
  - electrolysis
  - sunlight, plasma discharge,
  - micro-organisms (change DNA in bacteries, etc.)
- HC to H_2 → burn H only
- NG : H_2 = 8 : 1 density
  - 60% : 100% energy of gas state
  - 7 : 1 volume when H_2 at 700 bar
- H_2 to electricity (fuel cell) 50-70%
- gasoline to electricity ~ 25%

Obstacles for hydrogen economy:
1) not developed yet
   - get from: NG (50%), oil (30%), coal (20%), electrolysis (4%)
   - used: NH_4 (50%), hydro cracking (40%)
   - low losses during transportation
   - used for oil refining

2) H_2 is too dangerous

- all fuels are hazardous
- very light (goes up)
- no smoke
- hard to make explode
- gasoline: fume concentration required to burn
- 22 times less explosive power

liquid hydrogen more dangerous than gas hydrogen, because it has no freedom to diffuse.

3) H_2 production costs too much energy

25% well-to-wheel efficiency with a fuel cell

3) H_2 production cost too much energy
   - conversion always cost energy
   - conversion efficiencies
     - well to gas station: 73-81%
     - fossil fuel to electricity: 25-35%
     - NG reformers: 72-85%
     - electrolysis

4) H_2 distribution costs too much
   - decentralized reforming
   - NG pipes already exist
   - Use spare capacity, peak power (is very expensi
     ↳ produce when spare or gas is available

5) H_2 distribution needs new pipelines
   - adding polymer-composite liners + Hydrogen blocking metallic coating
   - stadsgas - Hytane
   - gasunie studies mixing 10-20%

6) No practical ways to run cars on H_2
   - Hybrid cars (serial) are electrical cars
   - replace combustion engine by fuel cell
   - generator ~ 20 $/kW
   - fuel cell ~ 500 $/kW

7) Lack of safe affordable way to store H_2
   - 700 bar carbon fiber reinforced tanks with aluminized bladder (TÜV)
   - volume ratio gasoline : H_2 = 1:7

- mass ration gasoline : H_2 = 1:3
- hypercar effectively < 10% additional mass
  ↳ large batteries + tubes

8) Compressing H_2 takes too much energy
- energy loss 10% using intercooler (use heat)
- compression energy $\sim V_2/V_0$
- same for 1→10 than for 10→100 bar

9) H_2 is too expensive
- fuel cells requires 99,995% purity = 18-22 $/kg
- Japan: cells for 98,5% < 2 $/kg

10) Need distribution network before cars can use it.
- gas refiners at the gas stations.
- compressors are cheaper than new pumps (?)

11) There will be not enough H_2
- global production ~ 50MT/y
- growth: 6%/y
- use of wind energy for production

www.rmi.org
issues by comparing: distance, distribution, cost

Introduction

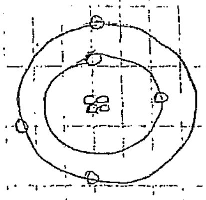
- Energy = Capacity for doing work   [E] → [J]
- Work = Force × Displacement   [W] → [J]
  Force ↓ F; Displacement ↳ along direction of the force

- Conservation of energy:
  Energy will not disappear or appear
  Energy can be transformed

- Chemical energy
  Energy out of the capacity of atoms to evolve heat as they combine or separate
  $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

  H–C(H)(H)–H + 2x O=O → O=C=O + 2x H–O–H

- Electrical energy
  Energy out of the capacity of moving electrons to evolve heat or electromagnetic radiation and magnetic fields.



- Kinetic energy
  Energy of motion : $E = \frac{1}{2} m v^2$

- Potential energy
  Energy an object possesses as the result of elevati in a gravitational field : $E_{pot} = m.g.h$

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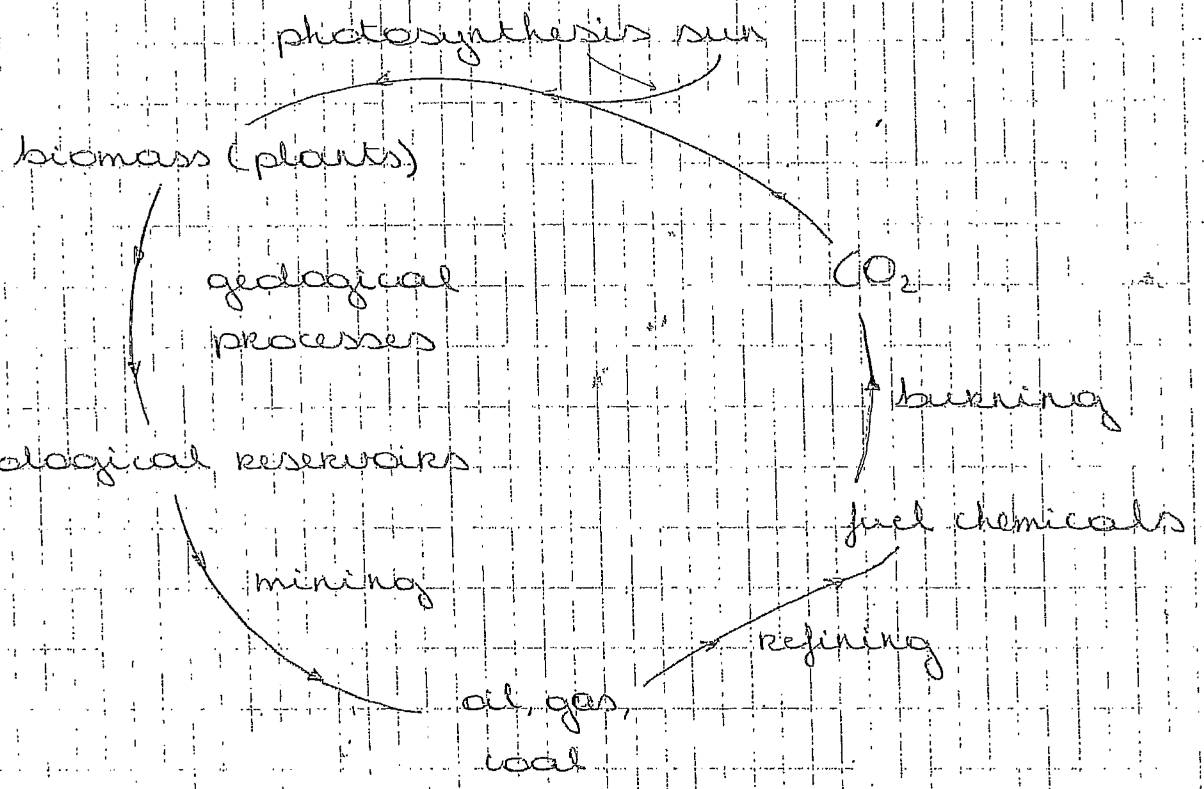
Definition renewable energy

Energy from regenerative or virtually inexhaustible sources of energy in a natural environment passing through the environment irrespective of man made devices intercepting and using it. e.g: sun, wind.

Petro - chemical carbon cycle:



Non - renewable energy

Energy obtained from static sources bound unless released by human interception

e.g. oil, gas, coal.

More formally: $E_{pot} = \int_{h_{ref}}^{h} \underline{F} \cdot d\underline{r}$, with:

$$\underline{F} = -\frac{G \cdot m \cdot M}{r^2}$$

- <u>Heat energy</u> or <u>Thermal energy</u>

The kinetic energy of molecules, or sensible and latent forms of internal energy.

- Heat content: $C_p \cdot T$

- <u>Radiant energy</u> (or light)

Energy in transit through space, emitted by electrons as they change energy and by atomic

- electron to higher energy state (higher orbit) → add energy
- electron to lower energy state (lower orbit) → release energy → light

nuclei during fusion or fission.

- <u>Nuclear (mass) energy</u>

Energy arises out of elimination of mass of atomic particles

Special theory of relativity: $E_n = \Delta m c^2$

- <u>Transformation of energy</u> from one type to anoth

from \ to	chemical	electrical	heat	light	mechanic
chemical	$CH_4 \to H_2$, food, cracking	battery, fuel cell, power plant	combustion	fire, fire flies	combustion
electrical	battery, electrolysis, electroplating	transforming AC-DC	light bulbs	light bulbs	electro mot
heat	cooking, gasification, healing tissue	thermocouple (battery)	central heating, heat exchanger	fire	gas turbi, steam eng
light	photosynthesis, bronzing, camera	solar panel	radiant solar plant	laser	solar sail
mechanical	combustion	generator	friction brake	flint spark	bike, sail, gear box

Total Primary Energy Supply : TPES
Million tonnes of oil equivalent : Mtoe
International Energy Agency (www.iea.org)

	1973	2003
Coal	24,8 %	24,4 %
oil	45,0 %	34,4 %
natural gas	16,2 %	21,2 %
nuclear	0,9 %	6,5 %
hydro	1,8 %	2,2 %
combustable renewables	11,2 %	10,8 %
other: - geothermal - sun - wind	0,1 %	0,5 %
	6034 Mtoe	10579 Mtoe

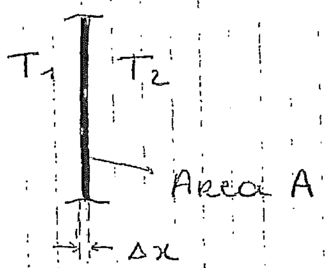
Heat transfer mechanisms

- Heat : form of energy that can be transferred from one system to another as a result of a temperature difference.
  ↳ driving force for heat transfer:
  * Conduction
  * Convection
  * Radiation

Conduction: transfer of energy from more energy particles to less energetic particles in a substance (gas, fluid, solid)

Fourier's law of heat conduction:
There is heat conduction when there is a ΔT

$$\dot{Q} = -k \cdot A \cdot \frac{\Delta T}{\Delta x}$$, k = thermal conductivity



$\Rightarrow \Delta T = T_2 - T_1$, $T_2 < T_1$

$\Rightarrow \frac{\Delta T}{\Delta x} < 0$

$k = k_0 \left(1 + \beta (T - T_0)\right)$, β = characteristics of the substance.

$k_0 = k$ @ $T = T_0$

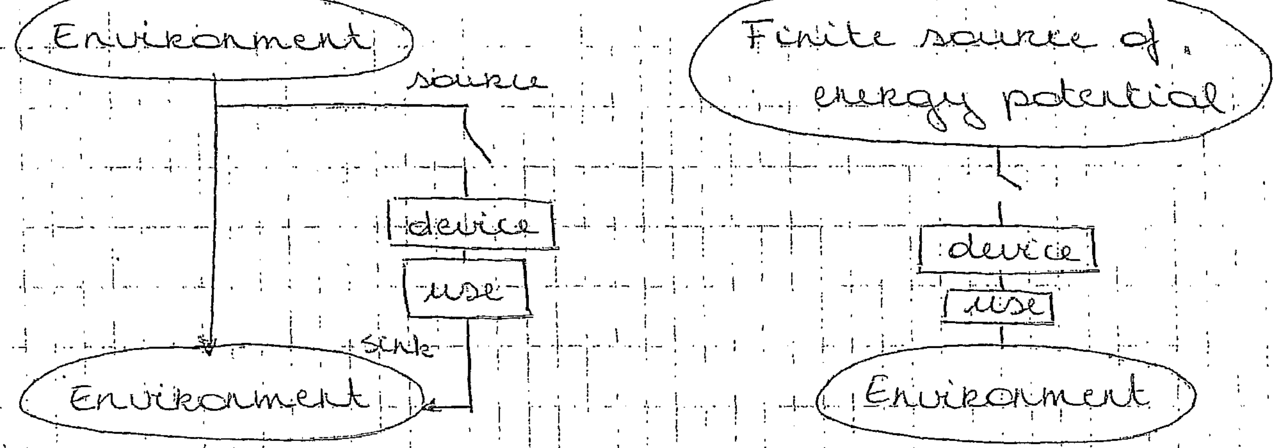
In general:
- gas: $\beta > 0$, when $T\uparrow$, $k\uparrow$
- solids & liquids: $\beta < 0$, when $T\uparrow$, $k\downarrow$

Example 1:
Plane wall in an aircraft:
$t = 0{,}001$ m
Al: $k = 204$ W/mK
OAT = $-55°C$
cabin T = $21°C$
~~ts~~ heat conduction per m^2?

$$\frac{\dot{Q}}{A} = -k \cdot \frac{\Delta T}{\Delta x}$$, $\Delta T = -55 - 21 = -76$ K
$\Delta x = 0{,}001$ m

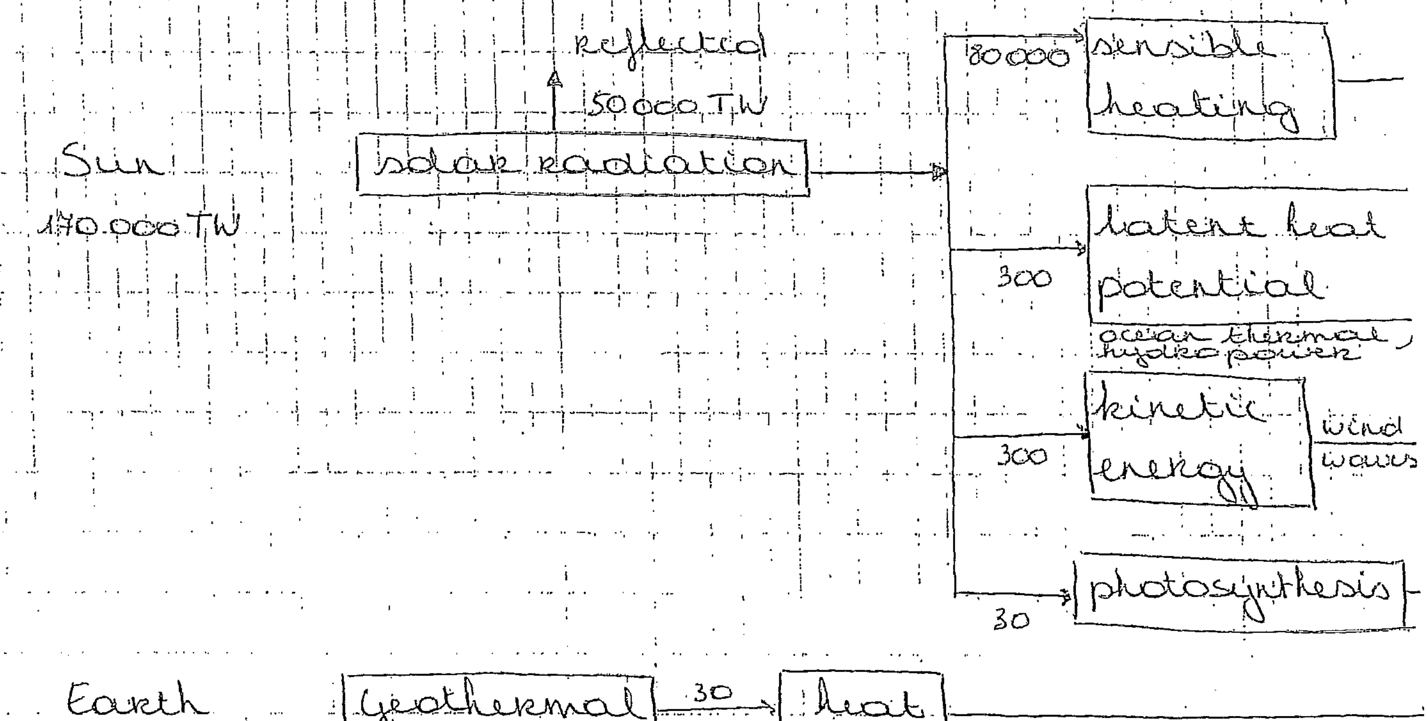
$$= -204 \cdot \frac{-76}{0{,}001} = 15{,}5 \cdot 10^6 \text{ W/m}^2$$

Renewable energy ⟷ Non-renewable energy

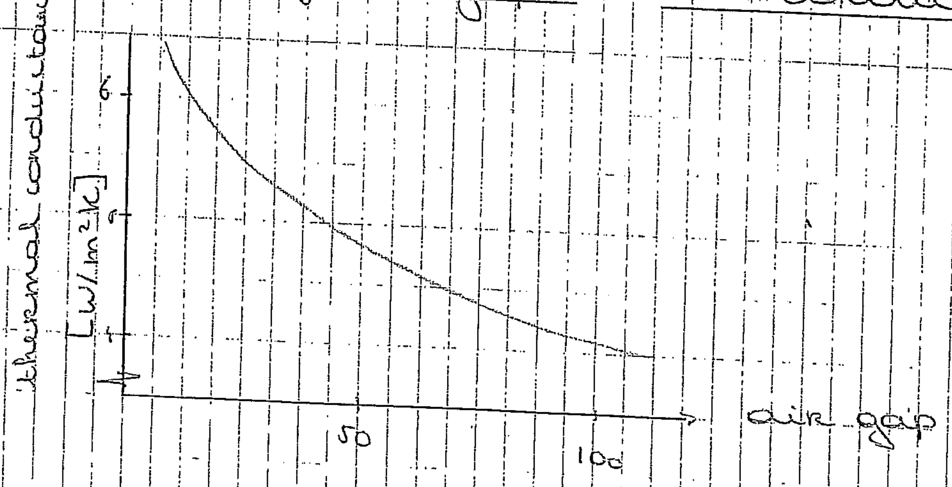


Energy sources

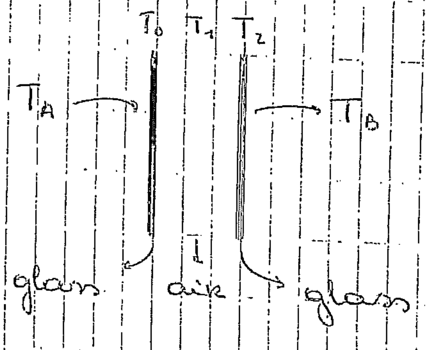
a) Sun
b) Geothermal energy
c) Motion and gravitational potential of the planet (tidal waves → tidal energy)
d) Nuclear energy
e) Chemical reactions (reversable reactions)
f) Fossil fuels



Influence of air gaps - air conductance



air gap	C
25	5,2
50	4,8
75	4,6
100	4,5



$$\dot{q} = U(T_A - T_B)$$

$$U = \left[\frac{1}{h_A} + \frac{t_1}{k_1} + \frac{1}{C} + \frac{t_2}{k_2} + \frac{1}{h_B}\right]^{-1}$$

$$U = \left[\frac{1}{h_A} + \sum_{i=1}^{n} \frac{t_i}{k_i} + \sum_{i=1} \frac{1}{C_i} + \frac{1}{h_B}\right]^{-1}$$

Example

air gap = 25 mm

perspex : $k = 0{,}20$

$\Delta T = 76\,K$

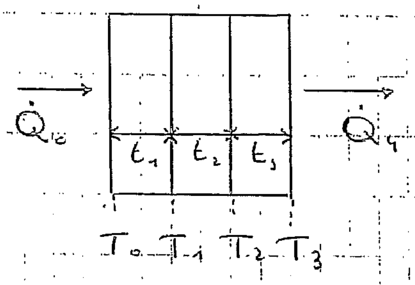
$h_A = 9{,}5$

$h_B = 5{,}7$

$t = 0{,}004$

$$\Rightarrow \dot{q} = \left[\frac{1}{9{,}5} + 2 \cdot \frac{0{,}004}{0{,}20} + \frac{1}{5{,}2} + \frac{1}{5{,}7}\right]^{-1} \cdot 76\,K = 148\ W/m^2$$

How compensate this energy loss?
- composite walls:



for continuity reasons:
$\dot{Q}_0 = \dot{Q}_4$

$$\dot{Q}_0 = \frac{-Ak(T_1 - T_0)}{t_1} = \frac{-Ak(T_2 - T_1)}{t_2} = \frac{-Ak(T_3 - T_2)}{t_3}$$

Heat resistance:

$$R_1 = \frac{t_1}{k_1}, \quad R_2 = \frac{t_2}{k_2}, \quad R_3 = \frac{t_3}{k_3}$$

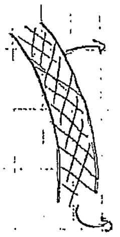
Total resistance:

$$R_{tot} = R_1 + R_2 + R_3$$

$$\Rightarrow \dot{Q} = -A\,\frac{(T_3 - T_0)}{R_{tot}}$$

$$\frac{\dot{Q}}{A} = \dot{q} = -\frac{T_3 - T_0}{R_{tot}}$$

<u>Example 2:</u>
Same data as in example 1, but composite wall



→ 1 mm Al

↳ 10 cm glass wool : $k = 0{,}038\ \mathrm{W/mK}$

$$R_{tot} = R_1 + R_2 = \frac{t_1}{k_1} + \frac{t_2}{k_2} = \frac{0{,}001}{204} + \frac{0{,}10}{0{,}038} = 2{,}63\ \frac{m^2K}{W}$$

$$\Rightarrow \dot{q} = \frac{76}{2{,}63} = 28{,}9\ \mathrm{W/m^2}$$

Convection: transfer of heat from one part of a fluid /gas to another part at lower temp. by means of mixing particles.

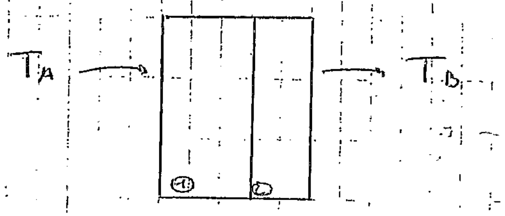
* free convection: temperature differences cause density differences ⇒ floating

* forced convection: fluid motion from external forces (independent of temperature differences) (e.g. ventilation system)

Both free and forced convection can occur simultaneously.

$\dot{Q} = h \cdot A \cdot \Delta T$, h = local heat transfer coeff. = f(fluid flow, thermo-physical parameters, geometry, ...)

Example:



Radiation:

Transfer from a body with a higher temperature to another body with a lower temperature by means of electromagnetic waves ($\lambda = 0{,}1 - 100\ \mu m$)
infrared = infrared light (behaves like light)

radiation can be : absorbed
reflected
transmitted

ρ' : reflectivity
α' : absorptivity
τ : transmissivity

$$\left.\right\} \rho' + \alpha' + \tau = 1$$

black body : $\alpha' = 1$, $\rho' = \tau = 0$

opaque surface : $\tau = 0$, $\alpha' + \rho' = 1$

white body : $\rho' = 1$, $\alpha' = \tau = 0$ (perfect mirror)

Conservation of energy

Bernoulli's equation

- no compressibility
- no viscosity - no friction
- only along a streamline

potential energy lost + work done by pressure forces = gain in kinetic energy + heat due to frictio

$$mg(z_1 - z_2) + [(p_1 . A_1).(u_1 \Delta t) - (p_2 . A_2)(u_2 \Delta t)]$$

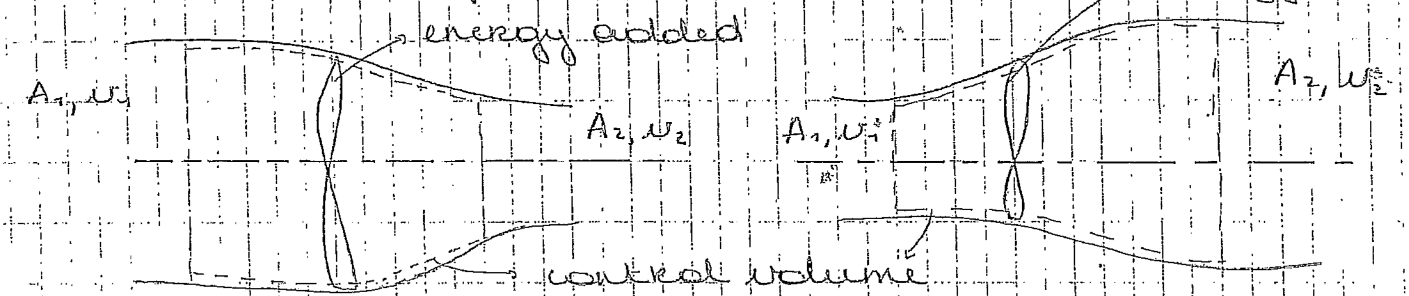
$$= \frac{1}{2} m (u_2^2 - u_1^2)$$

$$\Rightarrow p_1 + \rho g z_1 + \frac{1}{2}\rho u_1^2 = p_2 + \rho g z_2 + \frac{1}{2}\rho u_2^2$$

or : $\underbrace{\frac{p}{\rho}}_{\text{pressure energy}} + \underbrace{g.z}_{\text{potential energy}} + \underbrace{\frac{1}{2}u^2}_{\text{kinetic energy}} = \text{constant}$

pressure energy, potential energy, kinetic energy } per unit of mass

Conservation of momentum



At any instand in a steady flow the resultant force acting on the moving ~~flow~~ fluid within a fixed volume (= control volume) equals the nett rate of outflow of momentum from the closed volume

$$\frac{(A_1 u_1 \Delta t)\rho u_1 \tau}{\Delta t} = \rho A_1 u_1^2 \tau$$

! Always certain distance between wind turbines to make them effective

Solar energy

Sun = sphere of gaseous matter
- D = $1,39 \cdot 10^9$ m ≈ 14 million km
- distance from the earth : $1,5 \cdot 10^{11}$ m (= 1 AU)
- equivalent black body temperature : 5777K

- Nuclear fusion reactor

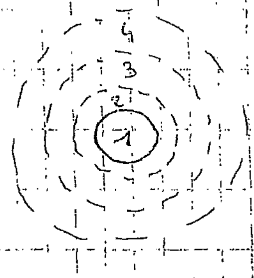
$$4H \longrightarrow He + 26,7 \text{ MeV}$$

1 proton — 2 protons, 2 neutrons

relative atomic mass : $4 \times H \Rightarrow 4 \times 1,00797$
$= 4,03188$
$1 \times He \Rightarrow 4,0026$

$E = \Delta m c^2$

$1 \text{ eV} = 1,6021765 \cdot 10^{-19}$ J.



1 : core :
- 90% of energy
- 40% of mass
- 1,2 % of volume
- R = 0,25 R

2 :
- T ≈ 0,8 - 40 $\cdot 10^6$ K
- $\rho = 10^5$ kg/m^3
- 0,70R

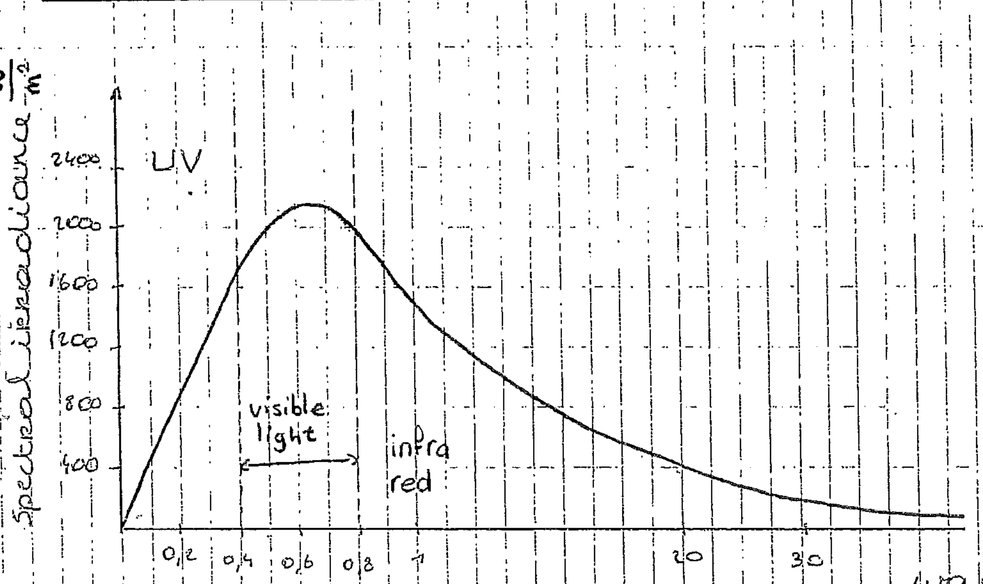
3 : Convection zone (R)
- T = $1,3 \cdot 10^5$ K
- ρ = 70 kg/m^3

4 : Renewing layer (R)

5 : Chromosphere
- T = 5000K

6 : Corona
- ρ = very low
- T = 10^6 K

Solar spectrum



Spectral irradiance ($W/m^2 \mu m$)

Maximum spectral intensity @ 0,48 µm (green light)

6,4 % of energy in the UV-range (λ - 0,38 µm)
48 % " " " " visible " (0,38 µm < λ < 0,78 µm)
45,6 % " " " " IR " (> 0,78 µm)

Stefan - Boltzmann law

$E = \varepsilon \sigma T^4$

T = surface temperature
σ = Stefan-Boltzmann constant
= 5,67051 . 10^{-8} W/m^2K^4
ε = emissivity factor of the surface
$\varepsilon = 1$: black body radiato

Planck radiation law

$$E_{\lambda b} = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{\exp\left(\frac{hc}{\lambda kT}\right) - 1}$$

$E_{\lambda b}$ = intensity of the radiation emitted by a black body
c = speed of light
h = Planck's constant
$= 6{,}62607 \cdot 10^{-34}$ J.s
k = Boltzmann constant
$= 1{,}38066 \cdot 10^{-23}$ J/K
T = temperature

Integration of $E_{\lambda b}$ over the full lambda range result in the total energy emitted

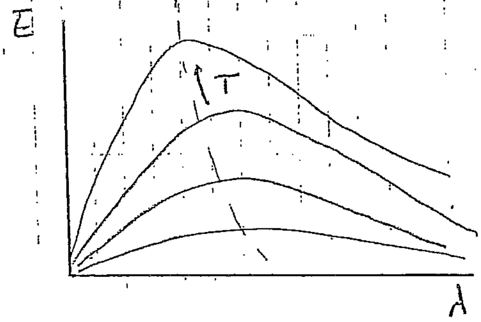
$$E_{0-\lambda,b} = \int_0^{\lambda} E_{\lambda b} \, d\lambda$$

When $\lambda \to \infty \Rightarrow E = \varepsilon \sigma T^4$

Point of maximum radiation

$$\lambda_{max} = \frac{\partial E_{\lambda,b}}{\partial \lambda} = 0$$

$$\lambda_{max} * T = 2{,}8976 \cdot 10^{-3} \text{ mK}$$



Wein's displacement law

Example:

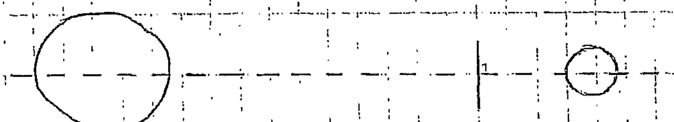
Sun: $T = 6000\,K$

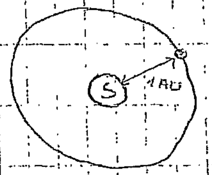
$$\lambda_{max} = \frac{2{,}8976 \cdot 10^{-3}}{6000} = 0{,}48\,\mu m \quad \text{(visible range)}$$

Earth: $T = 288\,K$

$$\lambda_{max} = \frac{2{,}8976 \cdot 10^{-3}}{288} = 10{,}06\,\mu m \quad \text{(IR range, heat radiation)}$$

Extraterrestrial solar radiation





Sun   Earth   ~~atmosphere~~: ~~O_2, CO_2, O_3, H_2O~~ ~~CO, N_2, dust~~

Distance Sun → Earth is nearly constant:
$\pm 1{,}7\,\%$ → eccentricity

⇒ energy flux received is also nearly constant:
Solar constant: $I_{sc} = 1367\,W/m^2$

Small variation in extraterrestrial radiation in a plane normal to the radiation

$$I_{et} = I_{sc}\left(1 \pm 0{,}033 \cos\frac{360 \cdot n}{365}\right), \quad n = \text{day of the year}$$

$I_{max} = 1411\,W/m^2$
$I_{min} = 1322\,W/m^2$

Example:

Determine the temperature of the Sun based on measurements in June:

$I_{et} = 1410\,W/m^2$

mean distance between Sun & Earth: $1{,}5 \cdot 10^{11}\,m$

$\sigma = 5{,}67 \cdot 10^{-8}\,W/m^2K^4$

Total radiation emitted? ($D_{sun} = 1,39 \cdot 10^9\,m$)

$= \sigma T^4 4\pi R_{sun}^2$

$I_{et} = 4\pi L_{sr}^2 = \sigma T^4 4\pi R_{sun}^2$

$\Rightarrow T_{sun} = \left(\dfrac{I_{et} \cdot 4\pi L_{sr}^2}{\sigma 4\pi R_{sun}^2}\right)^{1/4} = 5834\,K$

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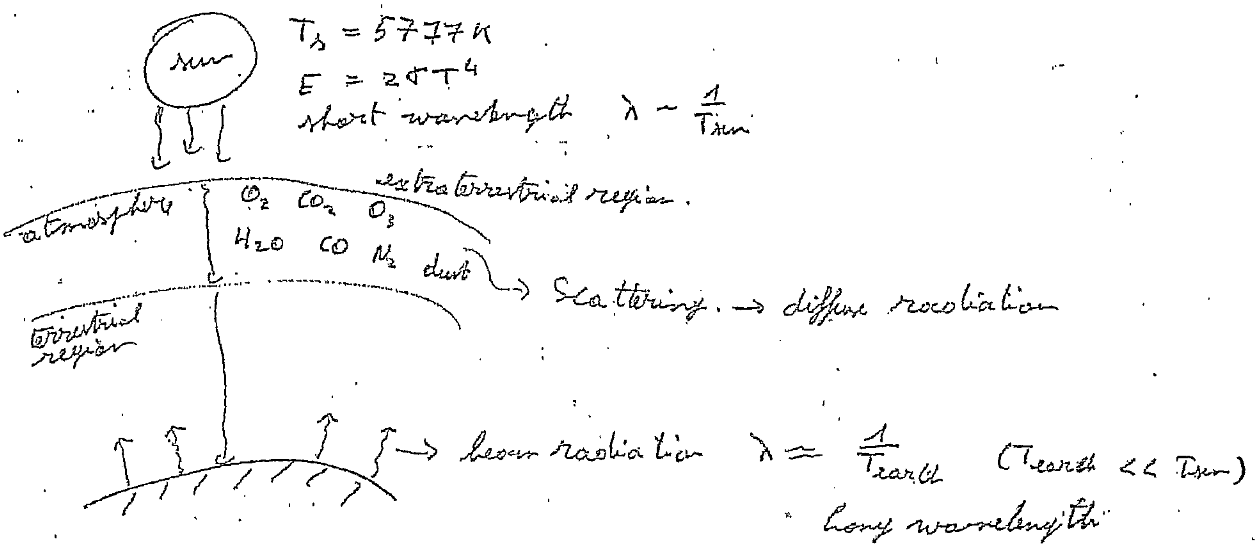
$$I_{ext} * 4\pi L_{SE}^2 = \sigma T^4 4\pi R_{sun}^2$$

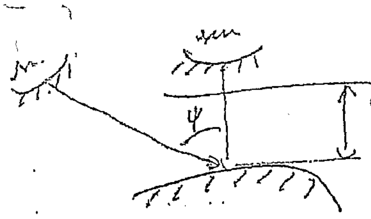
$$\Rightarrow T = \left[\frac{I_{ext}\, 4\pi\, L_{SE}^2}{\sigma\, 4\pi\, R_{sun}^2}\right]^{\frac{1}{4}}$$

Terrestrial regions and extraterrestrial regions
→ Solar energy enters the earth's atmosphere
  → absortion and scattering.
  → reflection (albedo).

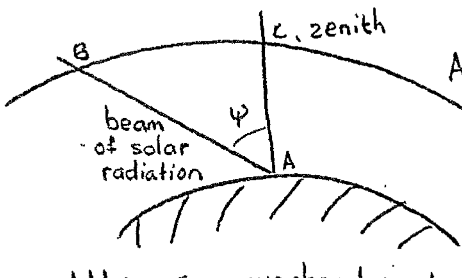


Absorbtion due to all the molecules in the atmosphere } - beam radiation
Scattering from air molecules and dust particles } - diffuse radiation

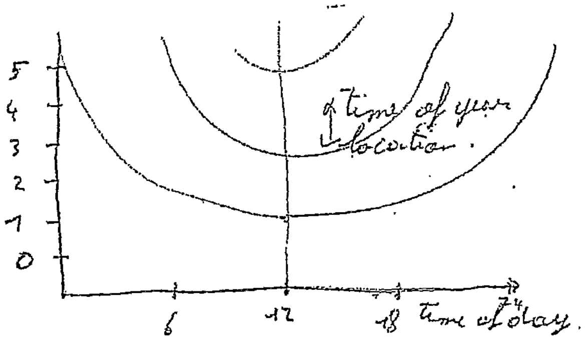
$$\text{Air mass} = \frac{\text{optical thickness of the atmosphere through which the radiation beam passes}}{\text{optical thickness when the sun is at the highest point (zenith)}}$$



$$AM = \frac{1}{\cos\psi} = \sec\psi$$

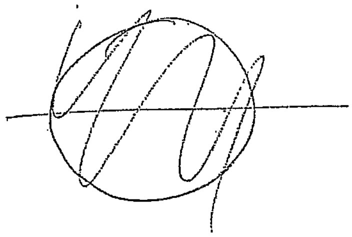


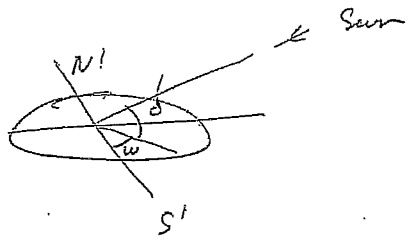
$$\text{Air mass} = \frac{AB}{AC} = \frac{1}{\cos\psi} = \sec\psi$$



AM: sun overhead : 1
in space : 0
on earth : 1,5

Equatorial plane





N'–S' = projection of the meridian of the observer on the equatorial plane.

δ = declination = angle between the lines joining the center of the sun and earth with the projected line on the equatorial plane.

$\delta = 23{,}45^\circ$ on june 21st

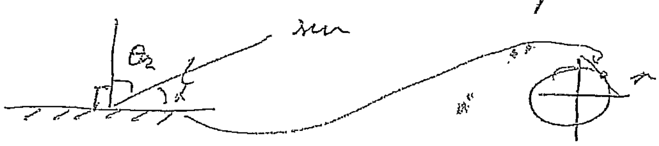
$= -23{,}45$ on december 21st.

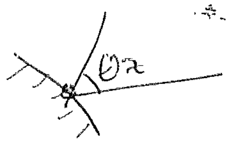
$$\delta = 23{,}45 \cdot \sin\left[\frac{360}{365}(284+n)\right]$$

↳ day of year.

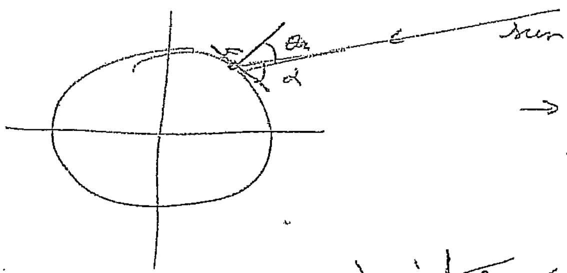
Now lets focus on the position of the observer

Zenith (θ_z) = angle between the sunray and the perpendicular line to the horizontal plane.

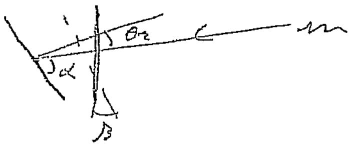


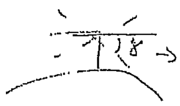


Altitude (α) = angle between the surface and the sunray.



→ We should tilt the solar panel so that the sun comes in perpendicular.





→ position of panel

β = Slope of panel
angle between the plane and the horizontal
β > 0 for pos surfaces sloping towards the south

γ = surface azimuth angle = angle in horizontal plane between the line due south and the projection of the normal to the surface on the horizontal plane.

γ_s = solar azimuth angle = angle of the projection of the solar beam on the horizontal [illegible] [illegible] beam radiation = I_b = solar radiation propagating along a line joining the receiving surface (earth, solar panel) and the sun

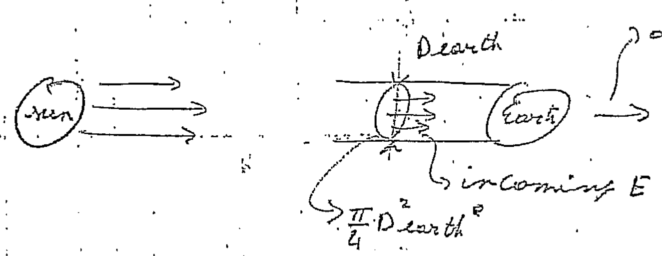
diffuse radiation = I_d = solar radiation scattered by aerosols, ... this does not have a unique direction.

albedo = reflected energy (±30% of the total radiation)

Example: calculate the average temp of the earth in the absence of the greenhouse effect.

Solar radiation in extraterrestrial region $I_{ext} = 1367 \frac{W}{m^2}$

$D_{earth} = 12,75 \cdot 10^6 m \quad \sigma = 5,672 \cdot 10^{-8} \frac{W}{m^2 K}$



$\rightarrow E_{out} = \sigma \underset{1}{\varepsilon} T^4 \pi D_{earth}^2$

We assume equilibrium: $\frac{\pi}{4} D_{earth}^2 I_{ext} = 1,745 \cdot 10^{17} W$

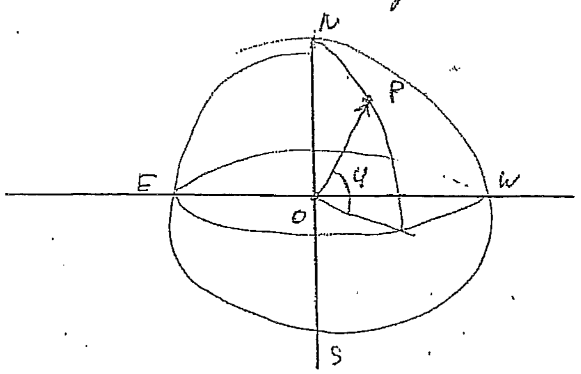
$\pi D_{earth}^2 \sigma T_E^4 \Rightarrow T_E = 278,6 K$
$= 5,5°C$

this didn't include albedo.

$\Rightarrow E_{in} = 0,70 \cdot 1,745 \cdot 10^{17} W$

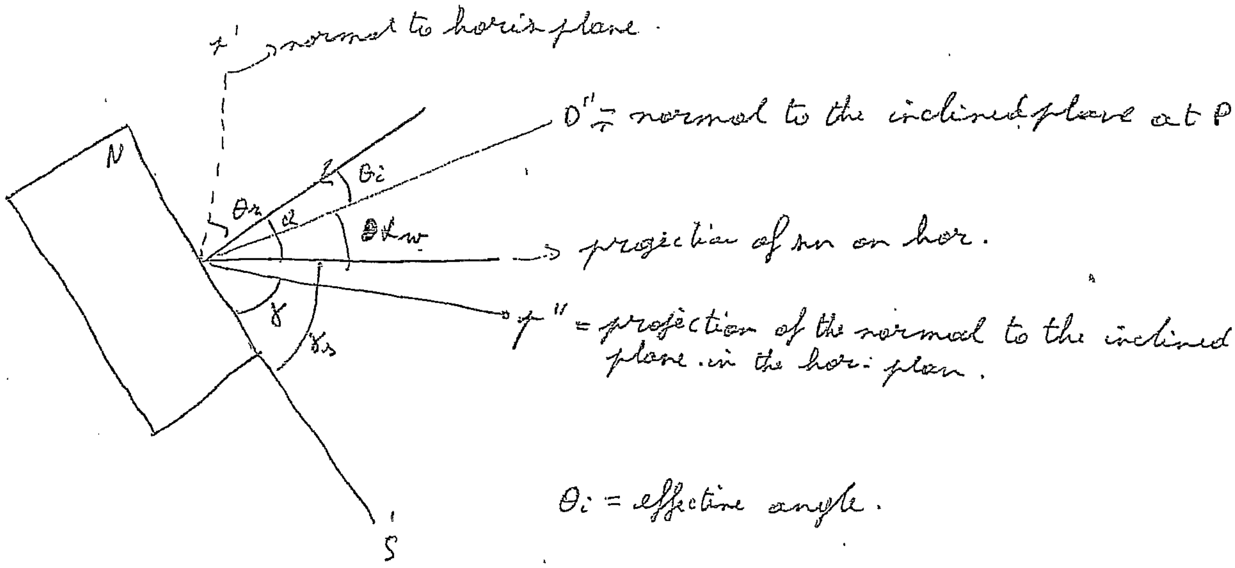
$\Rightarrow T_E = 254,8 K = -18,3°C$ (in real life ±15°C)

Sun - Earth angles.



φ = latitude
P = observer pos. P = observer position

Latitude: angle made by the radial line joining the given location to the center of the earth and its projection on the equatorial plane.



θ_i = effective angle.

α_w = solar wall angle = angle between the normal to the inclined plane and the projection of the sunbeam in the horizontal plane.

θ_i = angle of incidence = angle between beam radiation on the surface and the normal to the surface

$$\cos\theta_i = (\cos\varphi \cdot \cos\beta + \sin\varphi \sin\beta \cos\gamma)\cos\delta\cos\omega + \cos\delta \sin\omega \sin\beta \sin\gamma + \sin\delta(\sin\varphi\cos\beta - \cos\varphi\sin\beta\cos\gamma)$$

Possible simplifications

* surface facing due south ($\gamma = 0$)

$$\Rightarrow \cos\theta_i = \cos(\varphi - \beta)\cos\delta\cos\omega + \sin\delta\sin(\varphi - \beta)$$

* horizontal plane facing south ($\gamma = 0$, $\beta = 0$, $\theta_i = \theta_z$)

$$\cos\theta_i = \cos\theta_z = \cos(\varphi)\cos\delta\cos\omega + \sin\delta\sin\varphi$$

* vertical plane facing due south ($\gamma = 0$, $\beta = 90°$)

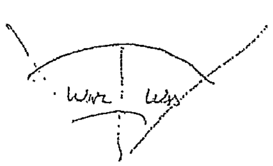
$$\cos\theta_i = -\sin\delta\cos\varphi + \cos\delta\cos\omega\sin\varphi$$

<u>Example</u>: Find number of sunshine hours for given location on earth.

- sunset: moment when zenith = 90°

$$\underset{0}{\underset{\parallel}{\cos\theta_z}} = \cos\varphi\cos\delta\cos\omega_s + \sin\delta\sin\varphi$$

$$\Rightarrow \cos\omega_s = -\frac{\sin\delta\sin\varphi}{\cos\delta\cos\varphi} = -\tan\delta\tan\varphi$$

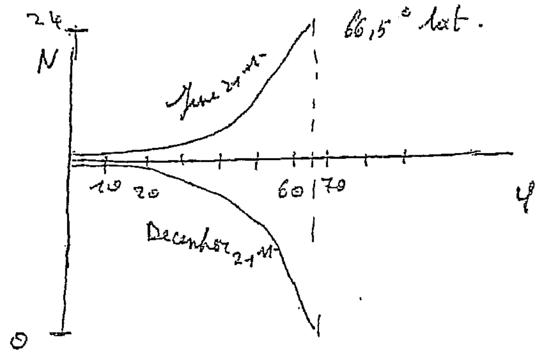


$$\Rightarrow \omega_s = 2 \cdot \mathrm{Arccos}[-\tan\delta\tan\varphi]$$

The earth rotates 360° in 24 hours.

$\Rightarrow 15 /hr$

number of hours $= N = \dfrac{2 \text{ acos}(-\tan\delta \tan\varphi)}{15}$



Delft : $\varphi = 52°$

$$N = \frac{2}{15} \text{ acos}(-\tan\delta \tan\varphi)$$

$$\delta = 23{,}45 \cdot \sin\left(\frac{360}{365}\cdot(284+n)\right)$$

mid summer : $n = 172 \Rightarrow \delta = \quad \rightarrow N = 14{,}69$

mid winter : $n = 356 \Rightarrow \delta = \quad \rightarrow N = 7{,}50$

zenith : June 21st : $\cos\theta_z = \cos 52° \cos 23{,}45° + \sin 23{,}45° \cdot \sin 52°$

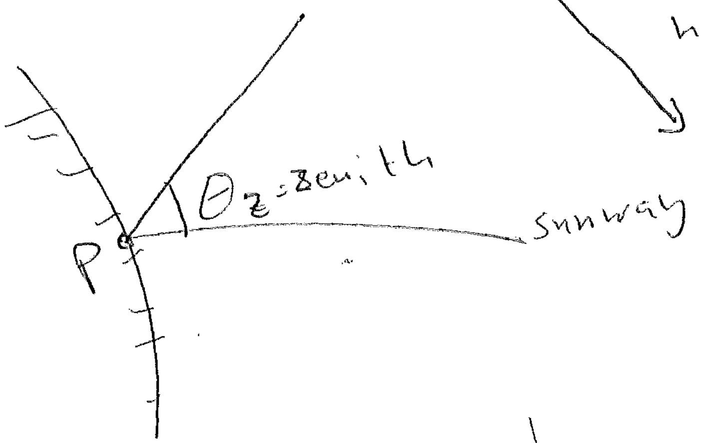
$\Rightarrow \cancel{75{,}31}\ 28{,}5°$

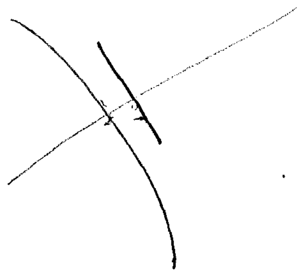
December 21st : $\theta_z = \cancel{28}\ 75{,}5°$

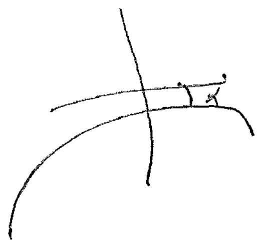
* $\boxed{\text{See 3 pages back}}$
* Lets go back to the observer site ; assume parrallel Radiation

Define following angles :- → zenith ; angle between sunray and a prependicular line to the horizontal plane

→ β : slope

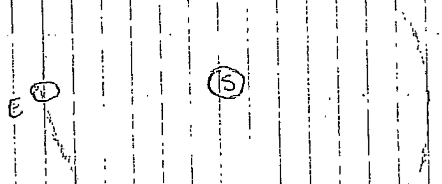


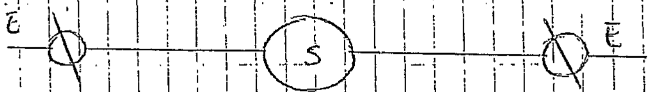


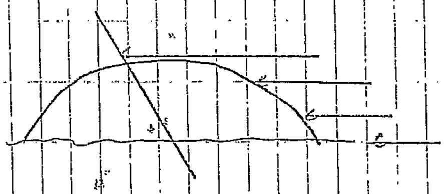


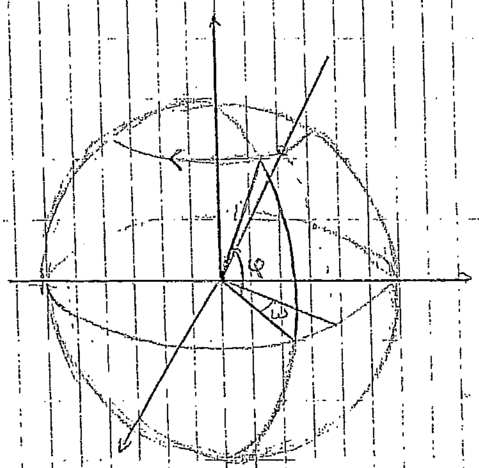
Relevant Sun-Earth angles

δ = declination
φ = lattitude
ω = sun angle
$\left.\begin{array}{l}\beta \\ \gamma\end{array}\right\}$ orientation of the solar panel w.r.t the Earth





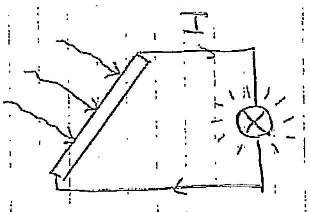




Photovoltaic systems & semiconductors

* Photovoltaic power generation: hole
radiation (light) separates positive and
negative charge carriers in a certain
lectrons material.
→ semiconductors

when there is an electric field these charges can generate an electric current which we can use in an external electric circuit.



The majority of photovoltaic cells are silicon semiconductors or junction devices.

Semiconductors are solids

- solids : $\sigma < 10^{-6} / \Omega m$
- insulators $10^{-8}/\Omega m < \sigma < 10^{4}/\Omega m$
- semiconductors
- conductors (metals): $\sigma > 10^{4}/\Omega m$

→ σ = electric conductivity

Materials can have two states:
- conducting state.
- non-conducting state.

* Concept of energy band

2 energy levels : E_c conducting band

E_g = energy gap

E_v valence band
(non-conductive state)

band diagram

When the electrons are in the conducting band, the material is conducting.
When the electrons are in the valence band, the material is not conducting.

Metals: $E_c = E_v$

Insulators: E_c

E_g very large

E_v

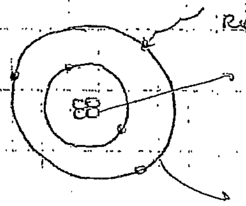
Semiconductors: E_c

E_g is small   Si : $E_g \approx 1,1\ eV$

E_v

Energy band diagram : plot of the allowed electron energy state in a material as a function the position along a prescribed direction.

Bohr's atomic model.



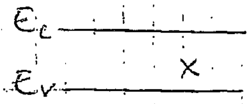
radiation (light) → raise energy level.

nucleus

shell

quantums

Energy of the electrons is increased in steps (quantums) → this goes in steps, not smoothly



electron is or in E_c or in E_v level, the zone in between is forbidden. If the radiation is not enough to put an electron in a higher energy level it will stay in the lower energy level

size of energy steps : $h \cdot \nu$

h = Planck's consta
ν = frequency

size of energy gaps : $E_g(T) = E_g(0) - \frac{aT^2}{T+b}$

silicon : $E_g(0) = 1{,}16$ eV
$a = 4 \cdot 10^{-4}$ eV/K
$b = 1100$ K

gallium arsenide : $E_g(0) = 1{,}52$ eV
$a = 5{,}8 \cdot 10^{-4}$ eV/K
$b = 300$ K

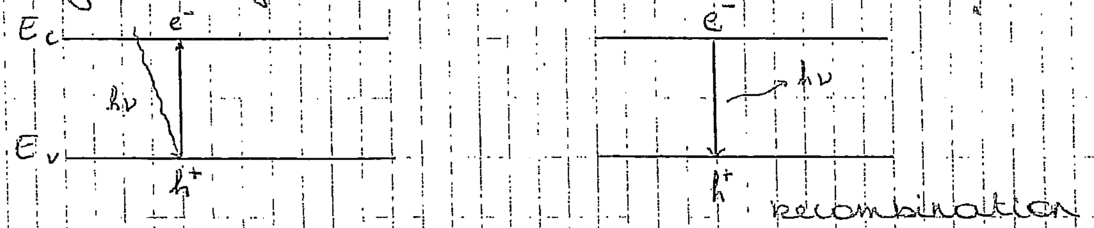
Example : $T = 40°C \rightarrow E_{g_{Si}} = 1{,}16 - \frac{4 \cdot 10^{-4} (313{,}15)^2}{313 + 1100}$

$= 1{,}11$ eV

$E_{g_{GaAs}} = 1{,}52 - \frac{5{,}8 \cdot 10^{-4} \cdot 313{,}15^2}{313{,}15 + 300}$

$= 1{,}43$ eV

When an electron gets enough energy to cross the band gap, it leaves behind a hole which is positively charged.



The closer the electrons to the nucleus, the more stabel the atom. After a certain amount of time the e^- which is brought to a higher energy level (instabel) will fall back to its lower energy level (energy comes free).

recombination time: $\tau \approx 1s$.

There a 2 categories of semiconductors:
- intrinsic
- extrinsic

Intrinsic (pure) semiconductors have a <u>Fermi-le</u> in the middle of the conduction and valence band which means that the number of free electrons in the conduction band = number of holes in the valence band.

$n = p = n_i$

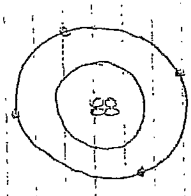
<u>Fermi-level</u> = apparent energy level within the (forbidden) band gap from which the <u>majority carriers</u> are excited by radiation to become charge carriers.

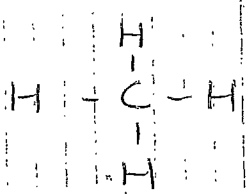
<u>Majority carrier:</u>
- electron - in n-type material
- hole - in p-type material

In order to increase the conductivity of intrinsi semiconductors, controlled quantities of specific impurities are added to this semiconductor
→ DOPING

Impurity ions of valency less than the semicondu enter the lattice and become electron acceptors that trap the free electrons.

Valency of an atom = number of connections an atom can make. This is determined by the number of electrons in the outer shell.





→ CH_4

shells	K	L	M	N	O	P	Q
number (n)	1	2	3	4	5	6	7
number of e^- in shell	2	8	18	32	50	72	98

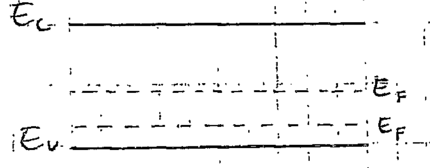
→ $2 \cdot n^2$

Silicon : atomic number : 14
shell 1 : 2 remaining : 12
2 : 8 : 4 → valency

Boron : atomic number : 5
shell 1 : 2 remaining : 3 → valency

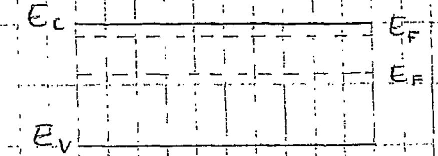
Phosphorus: atomic number : 15
shell 1 : 2 remaining : 13
2 : 8 : 5 → valency

. The traps have an energy level which is different and is located within the band gap near the valency band.



The absence of free electrons results in positively charged state → surplus of holes
→ p-type materials

Impurity ions of valency greater than the intrinsi[c] material → n-type material



p & n-type semiconductors have higher electric conductivity than the basic intrinsic semiconduc[tor]

n-type: $E_F = E_c + kT \ln \frac{N_D}{N_c}$

N_D: donor concentration
N_c: effective density of state[s] in the conduction ban[d]

p-type: $E_F = E_v - kT \ln \frac{N_A}{N_v}$

N_A: acceptor ion concentrat[ion]
N_v: effective density of state[s] in the valency band
k: Boltzmann constant
$= 1,38 \cdot 10^{-23}$ J/K

Example:

Silicon, doped by a material with a concentratic of $10^5/cm^3$ ($= N_D$).

$N_c = 2{,}82 \cdot 10^{+19}/cm^3$

$T = 27°C$ $\qquad\qquad$ $1\,eV = 1{,}6 \cdot 10^{-19}\,J$

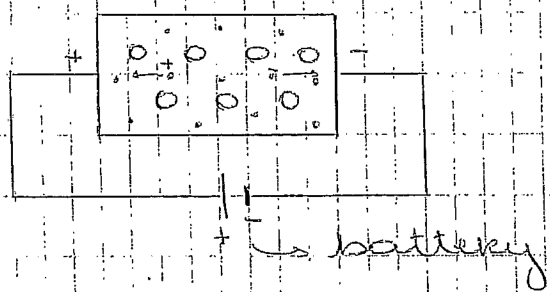
$E_F = E_C + kT \ln \frac{N_D}{N_C}$

$\Rightarrow E_F = E_C + 1{,}38 \cdot 10^{-23}\,J/K \cdot 300K \ln \frac{10^5}{2{,}82 \cdot 10^{-19}}$

$= E_C + 0{,}26\,eV$

28.02.'06 $\qquad\qquad$ AE3 - T11

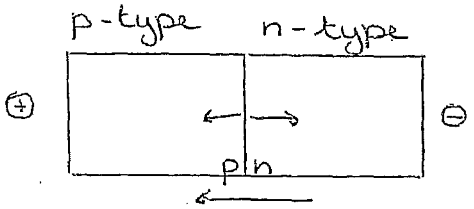
Intrinsic semiconductors



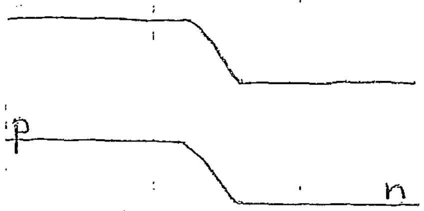
There is an electric current from electrons which have been freed from their lattice into the conduction band.

Extrinsic semiconductors

- n-type: dopants contribute to extra free electrons $\Rightarrow$ dramatical increase in conductivity.
- p-type: dopants contribute to free holes $\Rightarrow$ dramatic increase in conductivity

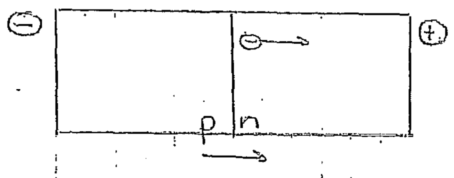


Force on an electron from the externally applied voltage → helps crossing the barrier

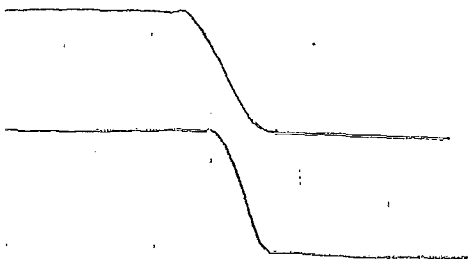


shift easy to cross
flow
↳ a diode is created.

→ forward bias situation

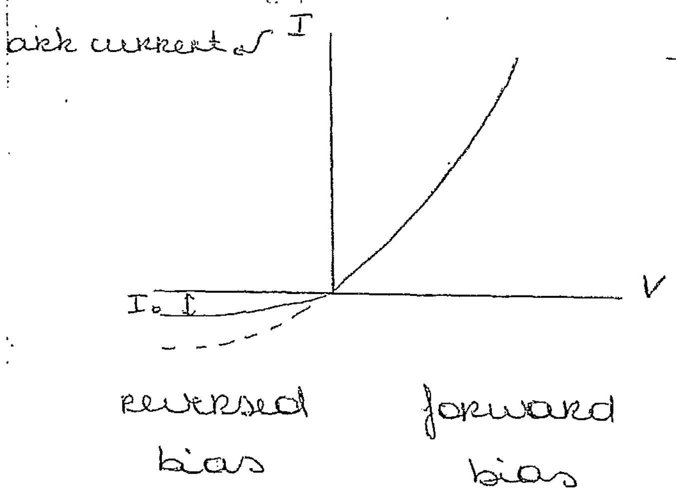


Force on the free electrons from the voltage which makes crossing of the barrier more difficult.



→ larger difference
→ difficult to cross!

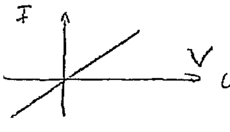
→ insulating
reverse bias



→ behaviour of a solar cell in the dark

non-linear relationship

|I₀| goes up with increasing temperature.



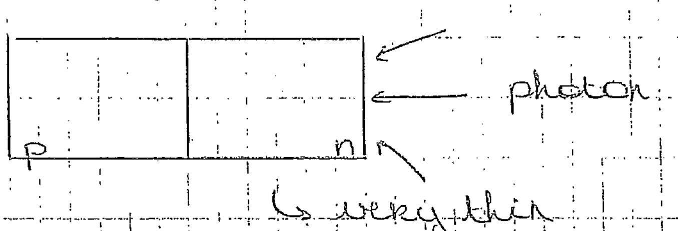
Ohm's law conduction

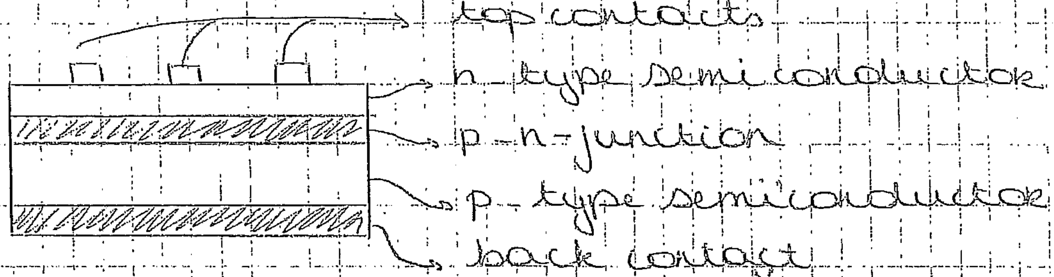
Photovoltaics

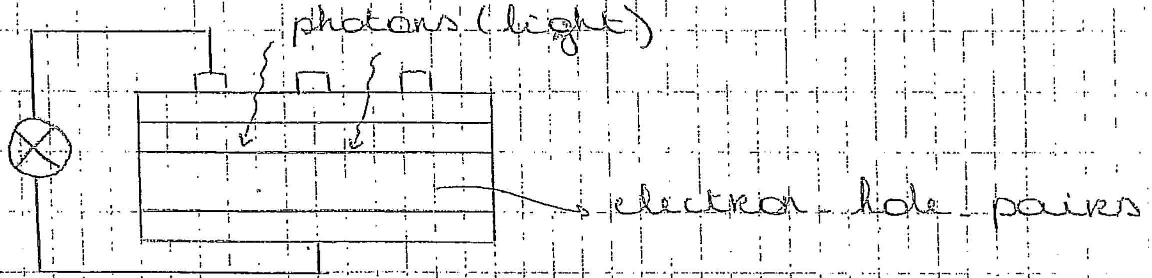
When a p-n junction is illuminated, electron-hole-pairs are generated and they feel an internal electric field

→ photo current (I_L)

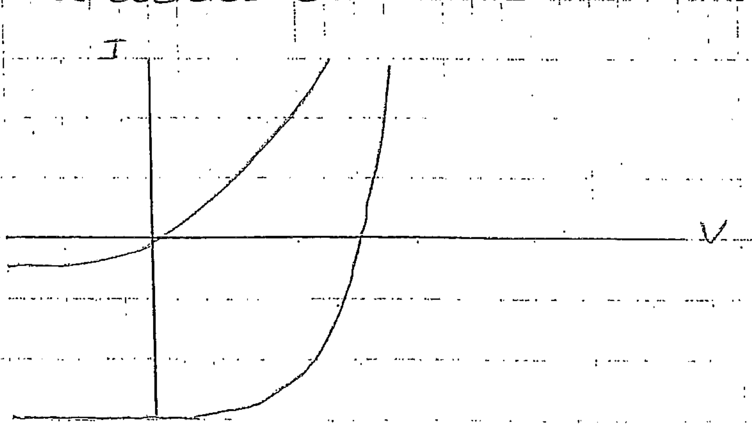
I_L flows in an opposite direction to the forward biased I_d

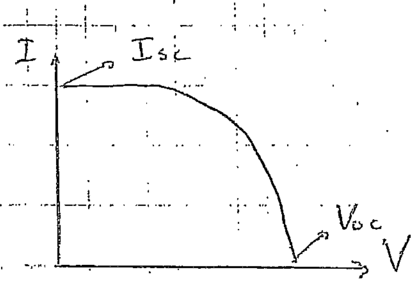






When the free electrons have enough energy to cross the junction we get a current.



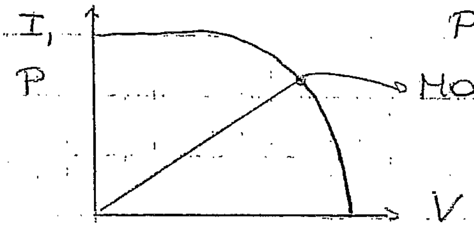


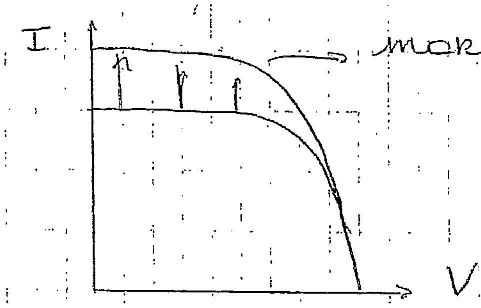
I_{sc}: short circuit current

V_{oc}: open circuit voltage

Maximise power output:

$P = I \cdot V$





ff = fill factor $= \dfrac{P_{max}}{V_{oc} \cdot I_{sc}}$

for Si: $ff_{max} = 0{,}88$

<u>Solar cell efficiency</u>: $\eta = \dfrac{P_{max}}{P_{in}} = \dfrac{ff \cdot I_{sc} \cdot V_{oc}}{P_{in}}$

P_{in} = incident solar radiation (W/m^2) x area of the solar cell (m^2)

<u>Example:</u>

$V_{oc} = 0{,}2\,V$, $I_{sc} = 5{,}5\,mA$

$V_{mpp} = 0{,}125\,V$, $I_{mpp} = 3\,mA$

$ff = \dfrac{0{,}125 \cdot 3}{0{,}2 \cdot 5{,}5} = 0{,}34$

$I_{in} = 200\,W/m^2$ $V_{oc} = 0{,}24\,V$, $I_{sc} = 8\,mA$

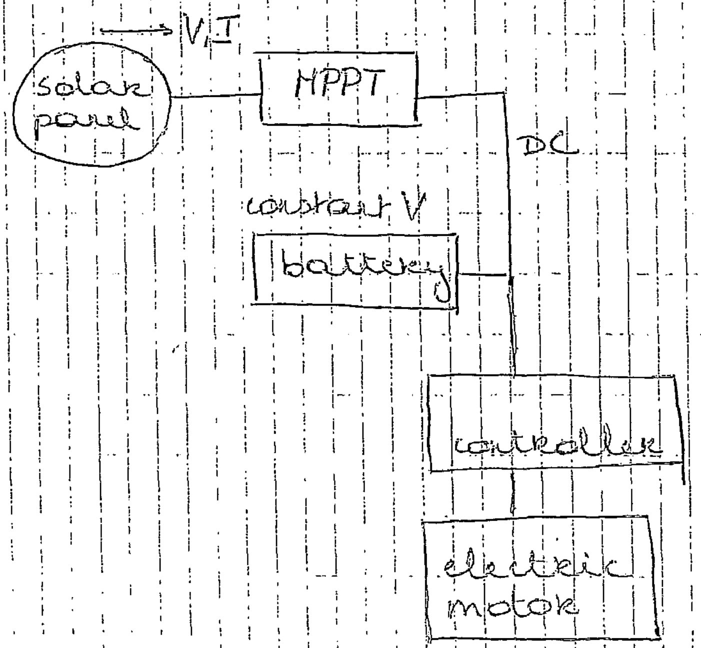
$V_{mpp} = 0{,}14\,V$, $I_{mpp} = 6\,mA$

$A = 4\,cm^2 = 4 \cdot 10^{-4}\,m^2$

$\Rightarrow \eta = \dfrac{0{,}14 \cdot 6 \cdot 10^{-3}}{200 \cdot 4 \cdot 10^{-4}} = 0{,}0105 = 1{,}05\,\%$

Presentation on NUNA solar panel design!

slides on BB



direct current (DC)
panel voltage $<$ battery voltage ⇒ boost

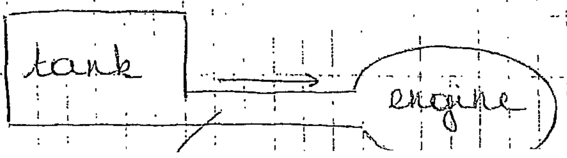
Biomass & biofuels

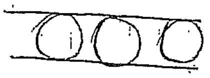
fuel = material (l.g.s) that releas heat when being burned

Conventional fuels contain C atoms & H atoms:
hydrocarbons: $C_n H_m$

most common types
- natural gas → methane CH_4
- LPG → propane C_3H_8
- gasoline → octane C_8H_{18}

aviation gasoline (AVGAS) 100LL (low lead)
↳ > 5000m height → vapour lock





↳ vapour blocks the engine
= vapour lock

- diesel / kerosene - $C_{12}H_{26}$ / $C_{13}H_{28}$
  diesel doesn't work at low temperature (thus high altitudes) → flakes
  Typical burning process
  - Kerosene: $C_{13}H_{28}$
  - Air: O_2 (21%), N_2 (78%)

$$\Rightarrow C_xH_y + a \cdot O_2 + b \cdot S + d \cdot N_2 \rightarrow$$

burning 1 kg kerosene → 3,16 kg CO_2
1,25 kg H_2O
11-18 g (NO, NO_2) = NO_x
acid rain ← 3-6 g SO_x
4-80 g CO ↷ especially during approach & idle
1-80 g VOC ↶ (volatile organic components)
$PM_{2,5}$ / $PM_{1,0}$: particle matter (fijn stof) size < 2,5 µm / 1,0 µm

PM = aerosols, soot, smoke, fumes, dust, ash, pollen
aerosols: solid & liquid particles suspended in air

biomass = material with combustible organic matter.

- wood
- agricultural crop
- animal waste
- aquatic plants
- municipal & industrial waste

(- fossil fuels)

In principle bio mass is renewable (= stored solar energy)

* Origin of bio mass: the photo synthesis process

basic chemical reaction:

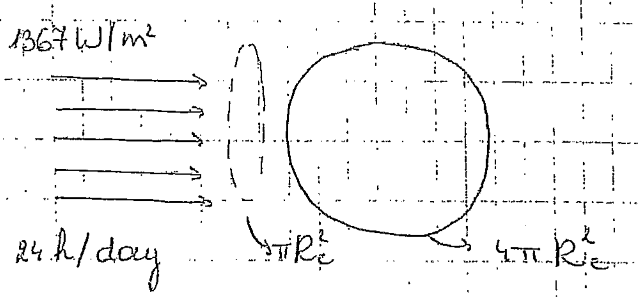
$$6\,CO_2 + 6\,H_2O \longrightarrow \underbrace{C_6H_{12}O_6}_{\text{glucose}} + 6\,O_2$$

light (= energy)

↳ requires 2,8 MJ/mole glucose

efficiency of the process is low: $\eta << 10\%$

* Example: Calculate the bio mass production on earth per m² per year



on earth: $\frac{1}{4} \times 1367 = 342\ W/m$

Energy content of light: $E = h \cdot \nu$ (photon energy)

$\lambda = 400\ nm$, $h = 6{,}63 \cdot 10^{-34}\ Js$, $c = 3 \cdot 10^8\ m/s$, $1\ eV = 1{,}6 \cdot 10^{-19}\ J$

$\Rightarrow E = 2{,}84 \cdot 10^{-19}\ J = 1{,}78\ eV$

Assume the overall efficiency = 0,7%

→ 1 mole of glucose = $6{,}022 \cdot 10^{23}$ molecules (Avogadro's number)

glucose : $C_6H_{12}O_6$

C : carbon : atomic mass : 12 ⇒ 12 × 6 = 72

H : hydrogen : : 1 ⇒ 1 × 12 = 12

O : oxygen : : 16 ⇒ 16 × 6 = 96

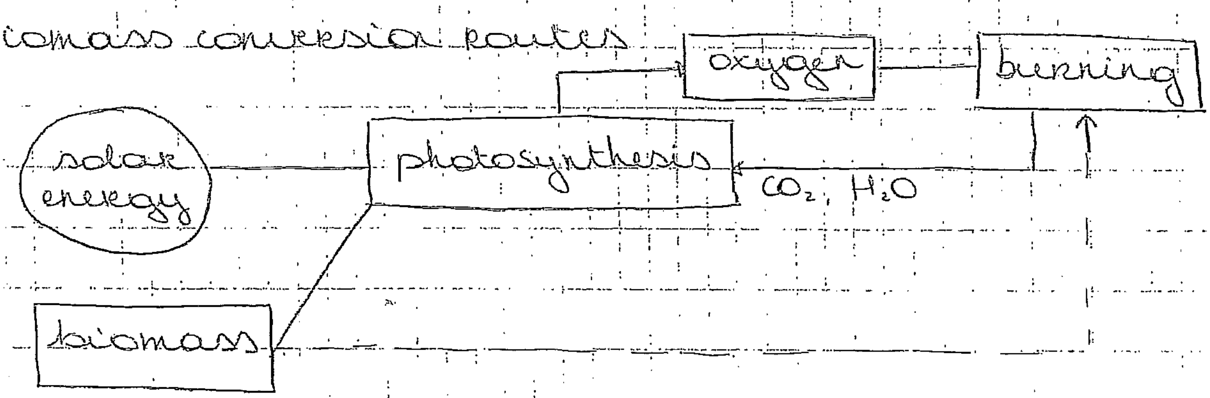
⇒ 180 g/mole 180

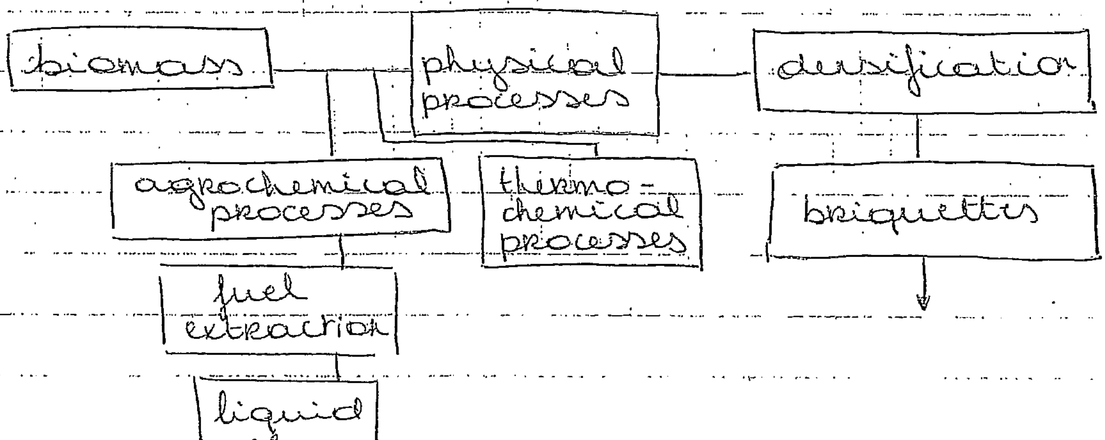
nett production = solar radiation + overall efficien

$$\frac{281 \cdot MJ/mole}{180\ g/mole} = 15{,}61\ J/g$$

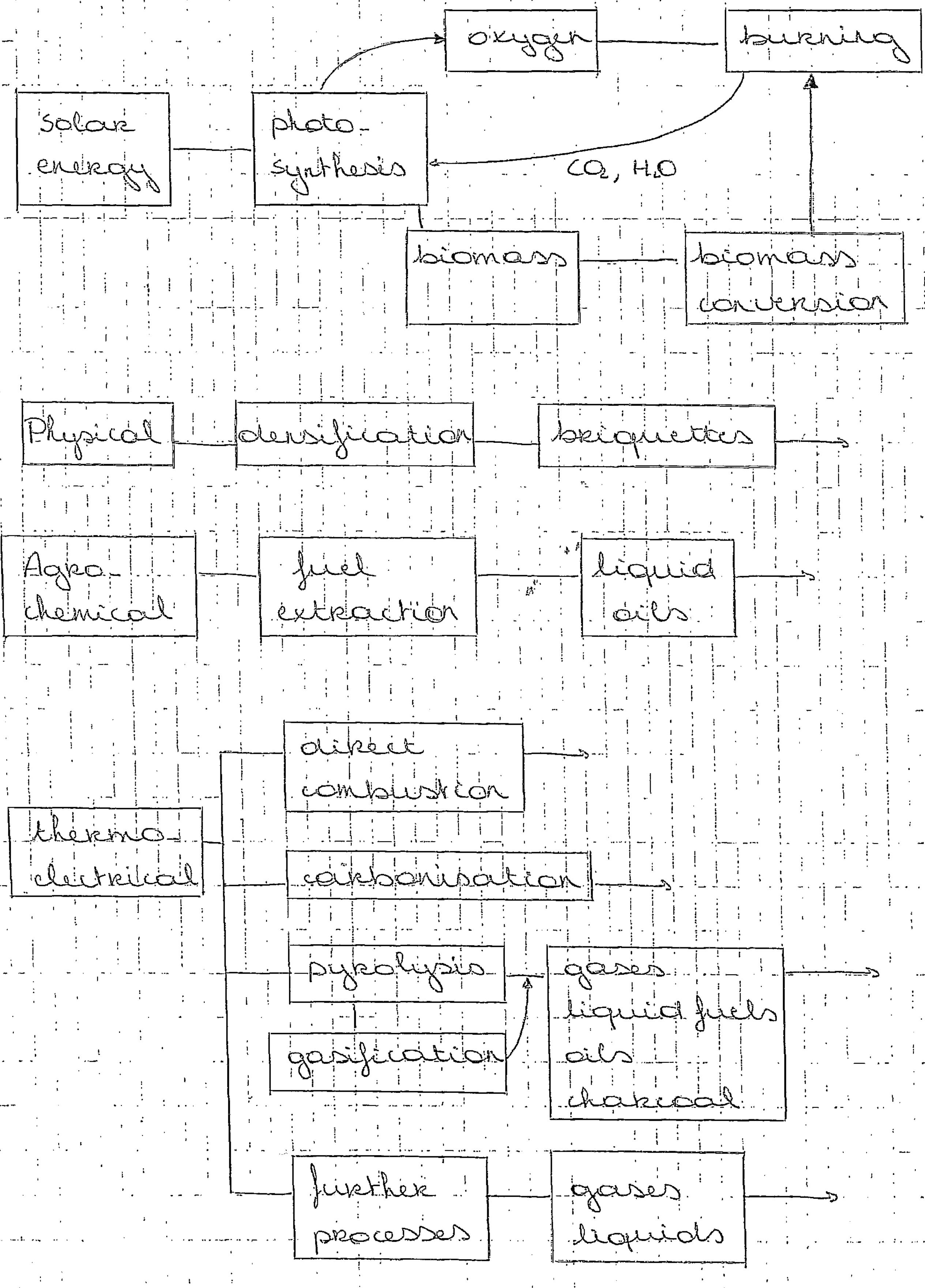
$$\text{production} : \frac{1{,}078 \cdot 10^{10}\ J/year}{15{,}61\ J/g} \cdot 0{,}007 = 4{,}836\ g/year = 4{,}836\ kg/year$$

* Biomass conversion routes





Biomass conversion routes



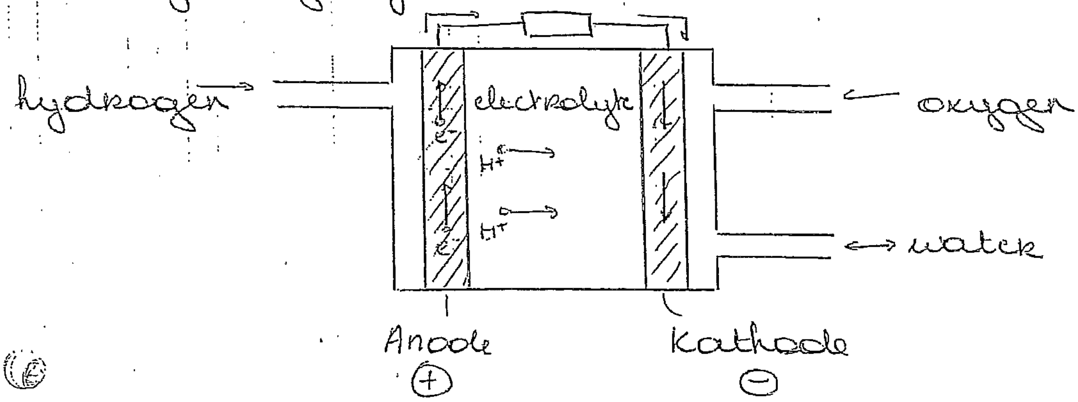
biochemical
- alcoholic fermentation → ethanol →
- anaerobic digestion → biogas (methane) →
- bio-electrolysis → hydrogen →

When valuable in economics?
- vegetable oil → biodiesel, rape seed oil, sun flower oil
- hydrogen → ~ $200
- bio-ethanol → sugar, corn grain
  ~ $20
- bio-gas (methane) → ~ $50-60

- Carbonization:

- Electrolysis:

Fuel cell principles
(Hydrogen fuel cells)



Basic chemical reaction:

$$2H_2 + O_2 \rightarrow 2H_2O + \text{heat} + \text{electric current}$$

Intermediate steps:

1) at anode: $2H_2 \rightarrow 4H^+ + 4e^-$
2) at cathode: $O_2 + 4e^- \rightarrow 2O^{2-}$
3) at cathode: $2O^{2-} + 2H_2O \rightarrow 4OH^-$
4) at cathode: $4OH^- + 4H^+ \rightarrow 4H_2O$

(electric field is needed, current cannot created by itself. Thus battery is connected to the system.)

Theoretical output: 1,23 V / cell
efficiency: 40 - 50 %
Practical output: 0,6 V / cell

In real life you need higher voltage V;
(high) current I;

Higher V → fuel cells in series } stack
Higher I → fuel cells in parallel } stack

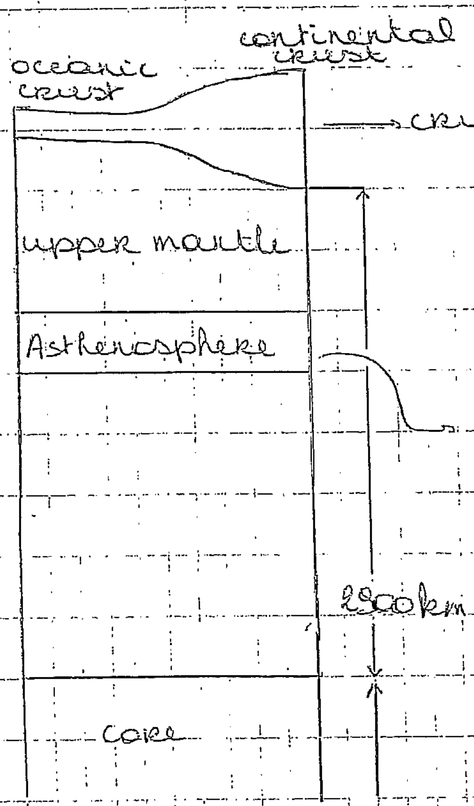
Geothermal energy: energy which is contained in the Earth's interior
→ displayed in geysers, vulcanoes, hot springs, boiling mud.

practical use is limited because it is unevenly spread over the Earth and often too deep to be exploited economically.

Origin: molten core of the Earth (± 4000°C)

heat provided by the radio active decay of long lived radio active elements
average heat flow: 0,04 - 0,09 W/m^2

Earth's structure:



crust + upper mantle = lithosphere
± 70 km oceanic
± 100 - 125 km continental
relatively rigid & brittle

low velocity zone (seismic waves are relatively slow), higher T, more plasticity

6370 - 5600 : inner core
T = 4000°C
5600 - 2900 : outer core
2900 - 700 : lower mantle
700 - 400 : asthenosphere
400 - 160 : uppermantle
160 - 0 km : crust

The heat of the Earth

Most important heat producers:
^{40}K, ^{232}Th, ^{235}U, ^{238}U
potassium thorium uranium

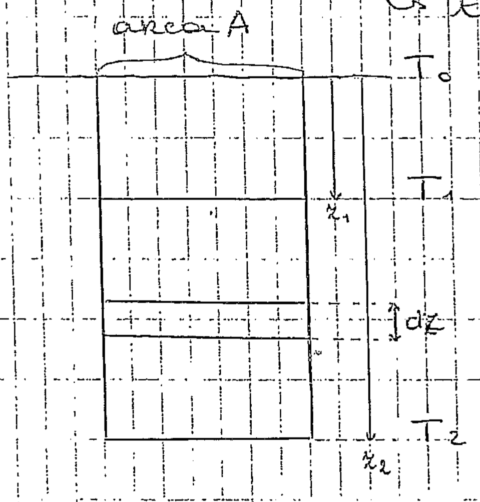
heat flow : 57 mW/ m² on continental crust
58 mW/m² on oceanic crust
82 mW/m² on average

summation over the Earth:
$4{,}7 \cdot 10^{13}$ W > 4 times the world's energy consumption.

Temperature gradient : 30° C / km
ancient continental crusts : 10°C / km
active crusts (volcanoes) : > 100°C / km

Classification of sources based on enthalpy :
low enthalpy source : $T < 100°C$
medium : $100°C < T < 200°C$
high : $> 200°C$

Hot rocks & aquifers
↳ thin layers with water



$$T_1 = T_0 + \frac{dT}{dz} z_1 = T_0 + G z$$

$$G = \frac{dT}{dz} = \text{constant}$$

ρ_r = density
C_r = specific heat capacity

Useful energy content δE at $T > T_1$ in an element with thickness dz :

$$\delta E = \rho_r A \, dz * C_r (T - T_1) = \rho_r A \, dz \, C_r G (z - z_1)$$

Total useful energy by integrating:

$$E_0 = \int_{z_1}^{z_2} \rho_r A\, c_r G (z - z_1)\, dz$$

$$= \rho_r A c_r G \left(\tfrac{1}{2} z^2 - z_1 . z \right) \Big|_{z_1}^{z_2}$$

$$= \rho_r A c_r G \left(\frac{(z_2 - z_1)^2}{2} \right)$$

Now set Θ = average temperature of the rock to depth z_2:

$$\Theta = \frac{T_2 - T_1}{2} = G \frac{z_2 - z_1}{2}$$

Assume: C_r = thermal heat capacity of the roc[k] between z_1 and z_2

$$= \rho_r A c_r (z_2 - z_1)$$

$$\Rightarrow \quad E_0 = C_r . \Theta$$

Now assume I want to get heat out by a constant stream of water: $\dot{V}$, ρ_w, c_w

Heat extraction is proportional to the temperatu[re] difference. $\sim T > T_1$

In perfect conditions the water will be heated through a temperature difference $\Delta T = \Theta$.

$$\dot{V} \rho_w c_w \Theta = - C_r \frac{d\Theta}{dt}$$

$$\frac{d\Theta}{\Theta} = \frac{-\dot{V} \rho_w c_w}{C_r} dt = - \frac{dt}{\tau}$$

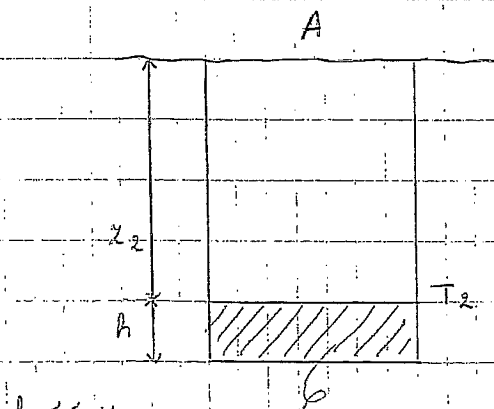
$$\tau = \frac{C_r}{\dot{V} \rho_w c_w} = \frac{\rho_r c_r A (z_2 - z_1)}{\dot{V} \rho_w c_w}$$

$$\Rightarrow \Theta(t) = \Theta_0 e^{-t/\tau}$$

Useful heat content is:

$$E = C_r \Theta = C_r \Theta_0 e^{-t/\tau} = E_0 e^{-t/\tau}$$

Hot aquifers



fraction of water in the aquifer is p. minimum useful temperat T.

$h \ll z_2$

$T = T_2$ = constant in aquifer

$$T_2 = T_0 + \frac{dT}{dz} z_2 = T_0 + G \cdot z_2$$

$$E_0 = \rho_r A C_r G \frac{(z_2 - z_1)^2}{2} = \rho_r A C_r (z_2 - z_1)\Theta$$

or: $$\frac{E_0}{A} = \rho_r C_r (z_2 - z_1)\Theta$$

In case of aquifer: $\rho C_r = p'\rho_w C_w + (1-p')\rho_r C$

$$\frac{E_0}{A} = \left[p'\rho_w C_w + (1-p')\rho_r C_r\right] h\Theta$$

$$= C_a \Theta$$

heat removal at $\dot{V}$: $\dot{V}\rho_w C_w \Theta = -C_a \frac{d\Theta}{dt}$

$E = E_0 e^{-t/\tau_a}$, with $\tau_a = \frac{C_a}{\dot{V}\rho_w C_w}$

Example:

Aquifer: $h = 0{,}5$ km @ 3 km

$T_0 = 10°C$, porosity $p' = 0{,}05$ (5%), $\rho_r = 2700\ kg/m^3$

$c_w = 4700\ J/kgK$, $\frac{dT}{dz} = 30°C/km$, $c_r = 840\ J/kgK$

a) Initial temperature in the aquifer:

$$T_z = T_0 + \frac{dT}{dz} \cdot z$$

$$= 10°C + 30°C/km \cdot 3\,km = 100°C$$

b) $C_a = [p' c_w \rho_w + (1 - p') \rho_r c_r]\, h$

$= [0{,}05 \cdot 4700 \cdot 1000 + (1 - 0{,}05)\, 2700 \cdot 840]\ 0{,}5$

$= 1{,}182 \cdot 10^9\ J/Km^2$

$= 1{,}182 \cdot 10^{15}\ J/K\,km^2$

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c) Calculate the time constant τ_a:

$$\tau_a = \frac{C_a}{\dot{V} \rho_w c_w}, \quad \dot{V} = 100\ l/s\,km^2$$

$$= \frac{1{,}182 \cdot 10^{15}\ J/K\,km^2}{100\ l/s\,km^2 \cdot 1000\ kg/m^3 \cdot 4200\ J/K\,kg}$$

$$= 2{,}814 \cdot 10^9\ s$$

$$= \frac{2{,}814 \cdot 10^9}{365 \cdot 24 \cdot 60 \cdot 60} = 89{,}2\ year$$

d) Thermal power extracted initially ($t = 0$)

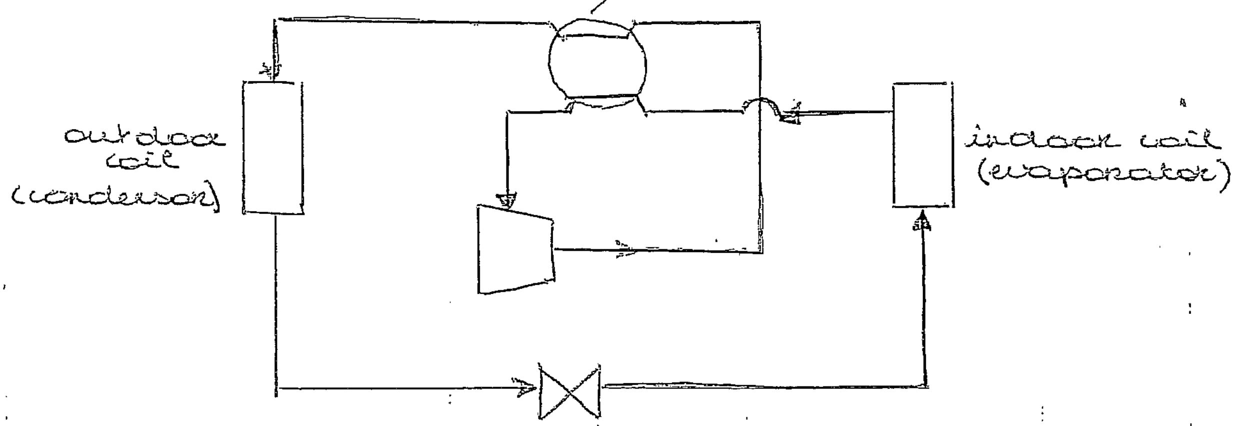
after 10 years

$$\left|\left(\frac{dE}{dt}\right)_{t=0}\right| = \frac{d}{dt}\left(E_0 e^{-t/\tau_a}\right) = -\frac{E_0}{\tau_a} e^{-t/\tau_a}$$

$$t = 0: \quad \frac{E_0}{\tau_a} = \frac{7{,}1 \cdot 10^{16}\ J/km^2}{89{,}2\ year} = \frac{7{,}1 \cdot 10^{16}\ J/km^2}{2{,}814 \cdot 10^9\ s}$$

$$= 25{,}2\ MW/km^2$$

Cooling mode:



Example: A heat pump is used for heating a house:

$T_{outdoor} = -1°C$, $T_{indoor} = 20°C$

heat loss $= 40\,000$ kJ/hr.

Coefficient of Performance (COP) $= \dfrac{\text{desired outpu}}{\text{required input}}$

$= \dfrac{\dot{Q}_H}{W_{net,in}}$

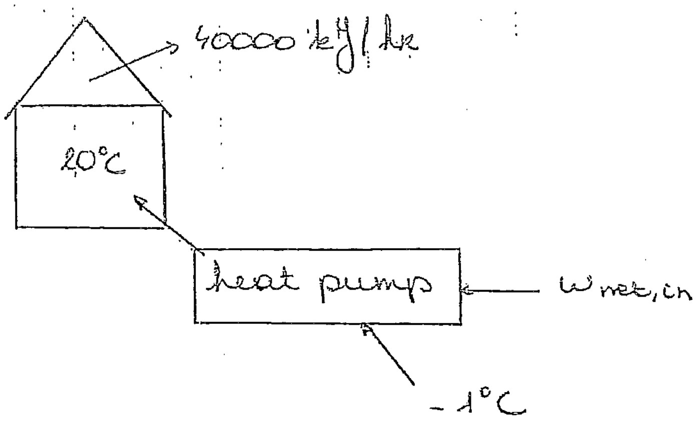
$\dot{Q}_H$ → heat flow

$W_{net,in}$ → work do by the compres

$COP = 2,5$

→ Determine the power needed by the heat pum

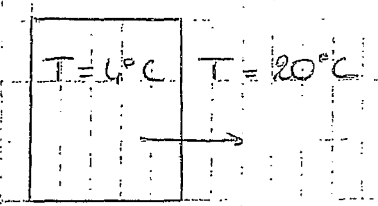
$$W_{net,in} = \frac{\dot{Q}_H}{COP} = \frac{40000 \text{ kJ/hr.}}{2,5} = 16600 \text{ kJ/hr}$$
$$= 4,45 \text{ kW}$$



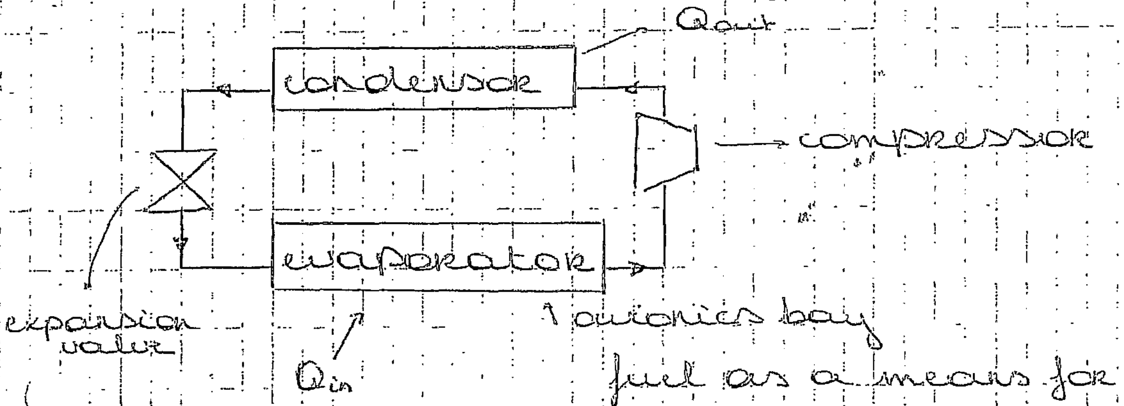
$t = 10 : \frac{E_0}{\tau_a} \cdot e^{-t/\tau_a} = 22,5 \text{ MW}$

Heat pumps : device that transfers heat from a low temperature medium to a high temperature medium.

Most widely known heat pump: refridgerator

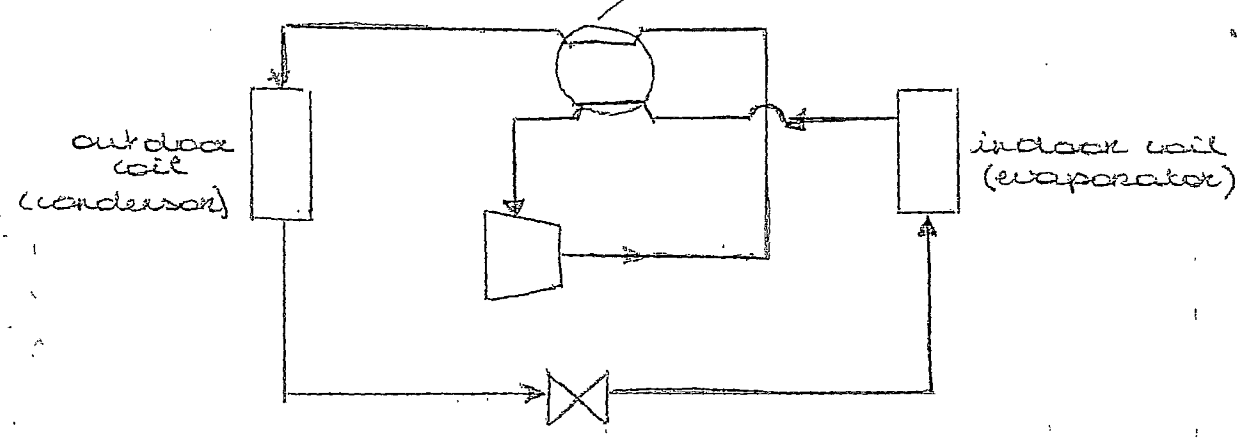


Vapour compression cycle :



↑ avionics bay
fuel as a means for cooling (fighters)

Cooling mode:



Example: A heat pump is used for heating a house:

$T_{outdoor} = -1°C$, $T_{indoor} = 20°C$

heat loss = 40 000 kJ/hr.

$$\text{Coefficient of Performance (COP)} = \frac{\text{desired output}}{\text{required input}} = \frac{\dot{Q}_H}{W_{net,in}}$$

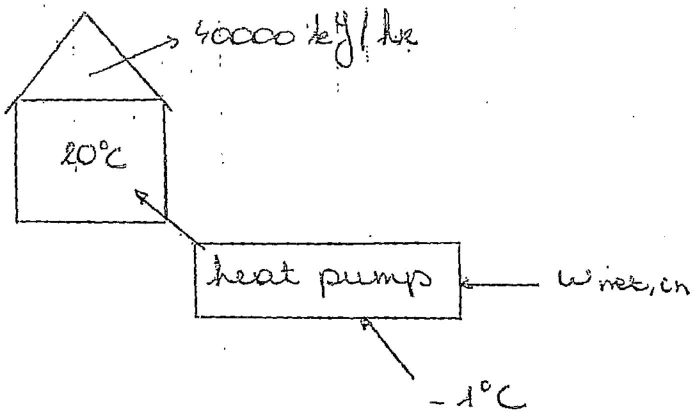
$\dot{Q}_H$ → heat flow

$W_{net,in}$ → work done by the compressor

COP = 2,5

→ Determine the power needed by the heat pump:

$$W_{net,in} = \frac{\dot{Q}_H}{COP} = \frac{40000 \text{ kJ/hr.}}{2,5} = 16600 \text{ kJ/hr} = 4,45 \text{ kW}$$

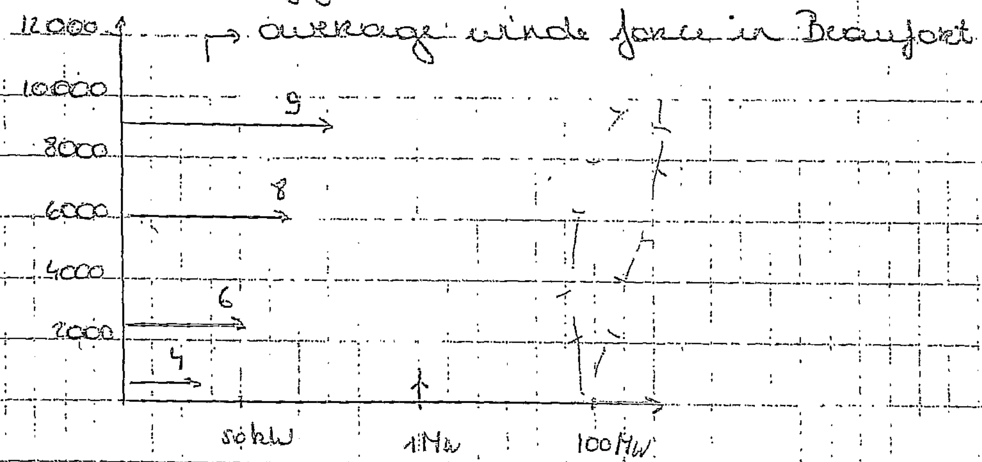


Theoretical limit :

$$COP = \frac{T_{indoor}}{T_{indoor} - T_{outdoor}} = \frac{293K}{293K - 272K} = 13,9$$

↳ in real life : COP = 2–6

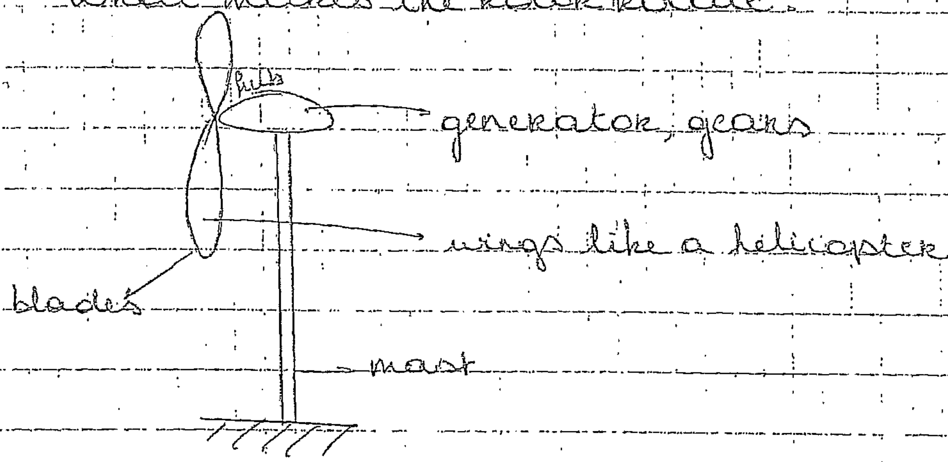
Wind energy



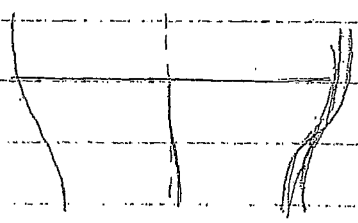
$$C_{p_{max}} = \frac{16}{27}$$

Basics of wind turbines

What makes the rotor rotate?



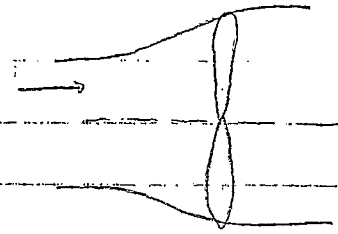
helicopter :



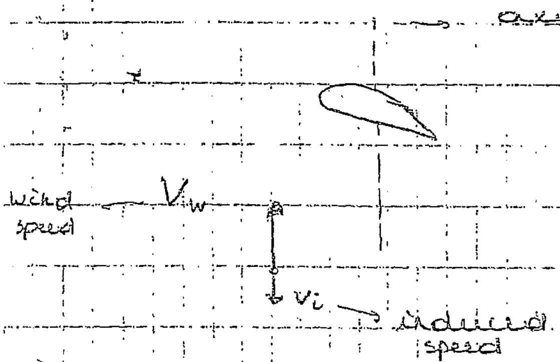
contraction in the wake

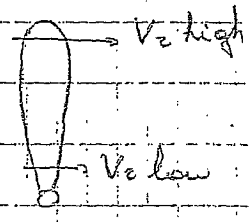
acceleration of the flow

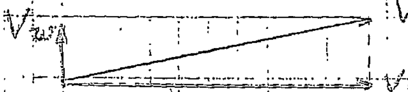
energy in



- decelleration of the flo
energy out

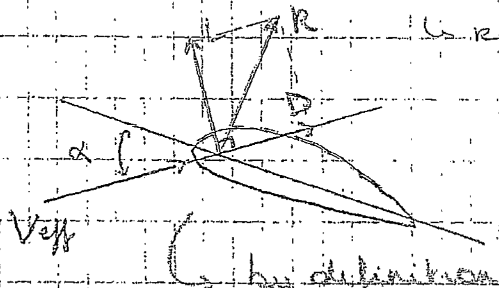


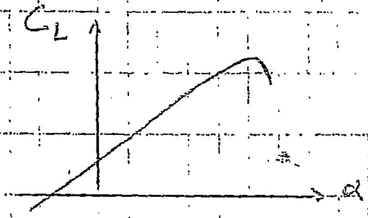




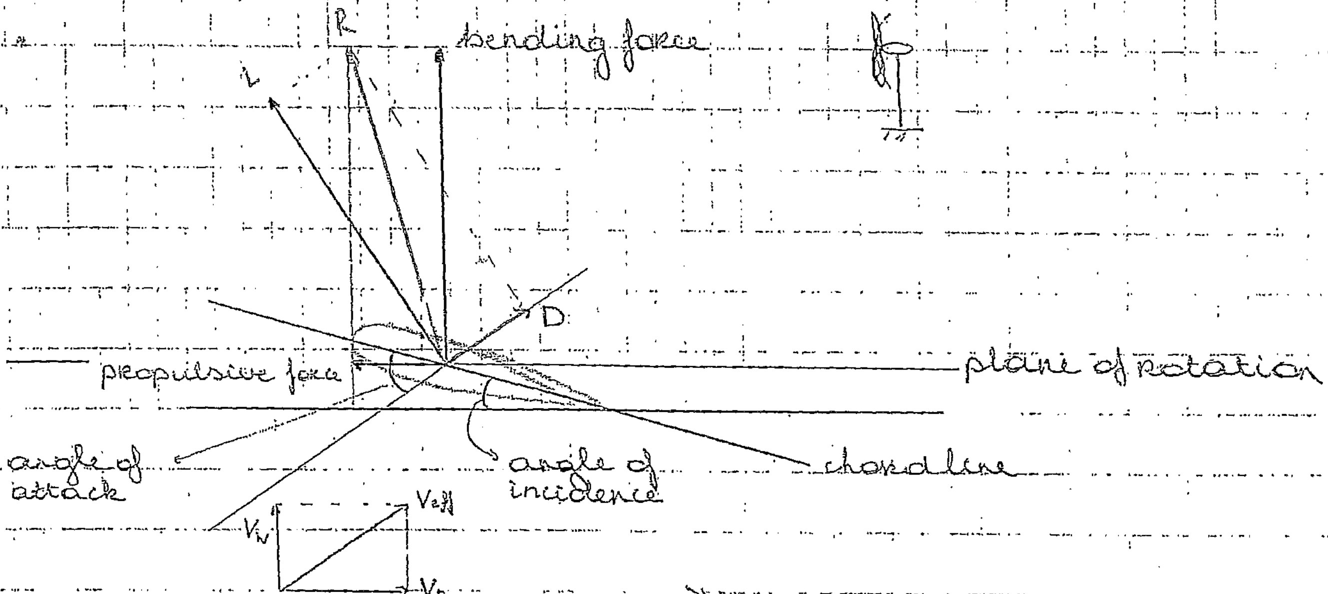
V_{eff} → effective speed, speed airfoil will 'see'

↳ rotational speed



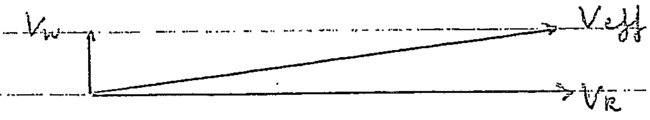


$L >> D \rightarrow \frac{L}{D} \approx 15 \; 20$

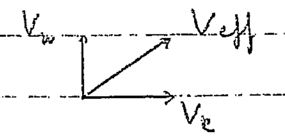


⇒ BLADE ELEMENT APPROACH

tip:



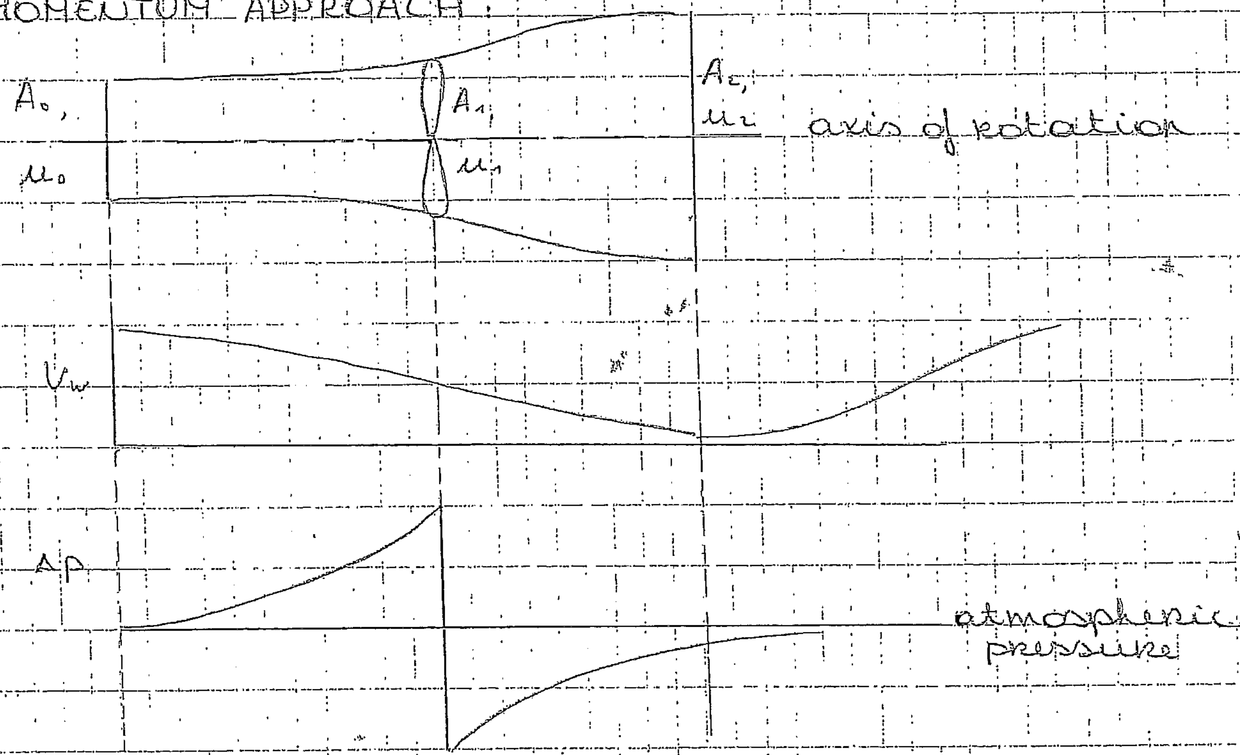
root:



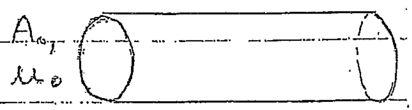
at the root : high α_i , low V_{eff}
at the tip : low α_i , high V_{eff}

$$l_{blade\ element} = c_l \frac{1}{2} \rho V_{eff}^2 \, c$$

* MOMENTUM APPROACH :



Kinetic energy per unit of time (= power available in the wind)



(5/13)

$$\frac{E_{kin}}{\Delta t} = \frac{\frac{1}{2} m u_0^2}{\Delta t} \quad , \; m = \rho A u_0 \Delta t$$

$$\Rightarrow \frac{E_{kin}}{\Delta t} = \frac{\frac{1}{2}\rho A_0 u_0 u_0^2 \Delta t}{\Delta t} = \frac{1}{2}\rho A_0 u_0^3 \Rightarrow P_0$$

P_0/m^2 : 10 m/s : $P_0 = 612{,}5\ W/m^2$

25 m/s : $P_0 = 9{,}570\ W/m^2$

↳ highly dependent on wind speed!

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Force = change in momentum

$F = \dot{m}u_0 - \dot{m}u_2$

$P_{extracted} = Fu_1 = (\dot{m}u_0 - \dot{m}u_2)u_1$

⇒ must be equal to the loss of in kinetic energy (= conservation of energy)

$$\frac{\Delta E_{kin}}{\Delta t} = \frac{1}{2}\dot{m}(u_0^2 - u_2^2) = P_{wind} = P_{extracted}$$

$$(u_0 - u_2)u_1 = \frac{1}{2}(u_0^2 - u_2^2) = \frac{1}{2}(u_0 - u_2)(u_0 + u_2)$$

$\Rightarrow u_1 = \frac{1}{2}(u_0 + u_2)$ ⇒ average speed over the stream tube

$\Rightarrow u_2 = 2u_1 - u_0$

$\dot{m} = \rho A_1 u_1$

$$\begin{aligned} P_{extr.} = \dot{m}u_1(u_0 - u_2) &= \rho A_1 u_1^2 (u_0 - u_2) \\ &= \rho A_1 u_1^2 (u_0 - 2u_1 + u_0) \\ &= 2\rho A_1 u_1^2 (u_0 - u_1) \end{aligned}$$

Now we introduce a new factor:

a = interference factor = fractional decrease of wind speed at the rotor

$$\boxed{a = \frac{u_0 - u_1}{u_0} \Rightarrow u_1 = (1-a)\,u_0}$$

(Sometimes $b = \frac{u_2}{u_0}$ is used)

$$\Rightarrow a = \frac{u_0 - \frac{u_0 + u_2}{2}}{u_0} = \frac{u_0 - u_2}{2u_0}$$

$$\Rightarrow P_{extr} = 2\rho A_1 (1-a^2)^2 u_0^2 \left[u_0 - (1-a)u_0\right]$$

$$= \frac{1}{2} \cdot 2 \cdot 2\rho A_1 (1-a^2)^2 u_0^2 \left[u_0 (1 - 1 + a)\right]$$

$$= \underbrace{\frac{1}{2}\rho A_1 u_0^3}_{= P_0} \underbrace{\left[(1-a)^2 \, 4a\right]}_{= C_p}$$

Maximise C_p:

$$\frac{\partial C_p}{\partial a} = 0 \Rightarrow \frac{\partial C_p}{\partial a} = 4(3a^2 - 4a + 1) = 0$$

$$\Rightarrow a = 1 \quad \text{or} \quad a = \frac{1}{3}$$

$a = 1$: $C_p = 0$ $\rightarrow$ not relevant

When $a = 0{,}5 \Rightarrow u_2 = 0$

Theoretical limit: $C_p = 0{,}593$

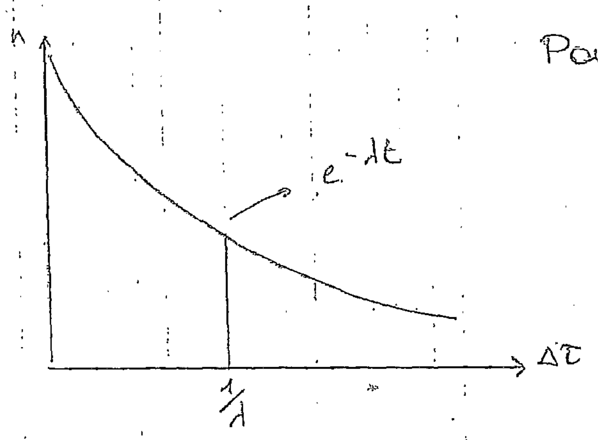
In real life $C_p \simeq 0{,}40 - 0{,}45$

Two main sources of losses: - swirl
- viscosity

<u>Kernenergie</u> → sheets on BB!

* ^3H = tritium → very poisoning, radioactive

* Tussen p^+: electromagnetic force
(= Coulombs force)
works on large distance
between quarks



Poison statistics

* Example: ^{226}Ra, $T_{1/2} = 1600$ jaar

15-03-'06 AE3-T11

Klimaatveranderingen → BB!

Exam 2

1) Long term effects: Milankovitch theory
Continental drift

Short term effects: Solar flares
Vulcanoes
El Niño

year rings trees, ice layers, isotopes in water, ocean sediments, geology (fossiles), documents (thermometers).

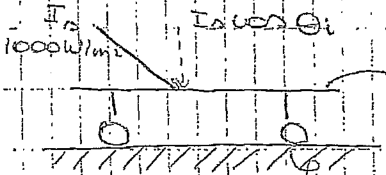
2) Declination: $\delta = 23{,}45° \sin\left(\frac{360}{365}(284+n)\right) = 6{,}377°$

21/2 $n = 31+28+31+7 = 97$ (7^{th} april)

$\cos\theta_i = \cos\theta_z = \cos\varphi \cos\delta \cos\underline{\omega} + \sin\delta \sin\varphi$ (sun angle)

↳ lattitude

sun set, when sun is in zenith: 1 full rotation in 24 hr → 360° ⇒ 15°/hr

3) 

→ $A = 10\,m^2$, $m = 350\,kg$

rolling friction, $D_r = \mu W$

33

ISA: $\rho = 1{,}225\ kg/m^3$

$D = C_D \frac{1}{2}\rho V^2 S = C_w \frac{1}{2}\rho V^2 S_f$

$\underbrace{0{,}20}_{\varepsilon_{overall}} \times I_s \cos\theta_i \times A = P_{in} = 1748\ W$

$P_r = P_a$

$DV = (\mu W + C_w \frac{1}{2}\rho V^2 S_f)V = 171{,}6V + 0{,}0228V^3 = 1748\ W$

$$\Rightarrow 0{,}0229\,V^3 + 171{,}6\,V - 1748 = 0$$

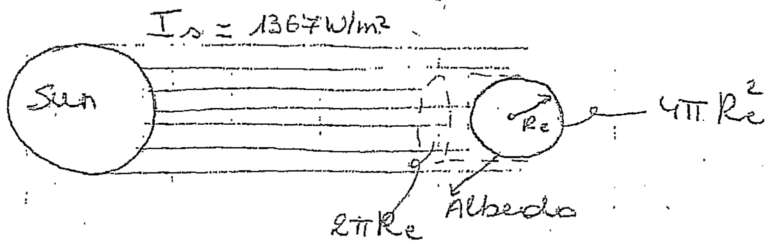
Newton - Raphson approach

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

$$f'(V) = 0{,}0687\,V^2 + 171{,}6$$

$$x_0 = 25\ m/s \Rightarrow x_1 = 11{,}48 \longrightarrow x_2 = 10{,}05$$

4) a)

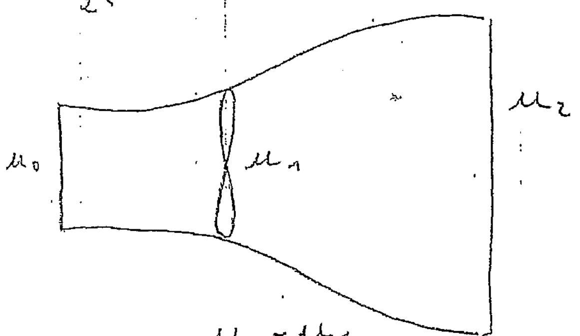


Incoming: $0{,}7 \cdot 1367\ W/m^2$
(Albedo effect included)

$C_6H_{12}O_6$: C : $12 \times 6 = 72$
H : $1 \times 12 = 12$
O : $16 \times 6 = 96$

180 g/mole
↳ biomass

5) $P_0 = \frac{1}{2}\rho\, u_0 v^3$



$$a = \frac{u_0 - u_1}{u_1}$$

$C_p = f(a)$, $\frac{\partial C_p}{\partial a} \Rightarrow$ 2nd order equation

$a_1 = 0$, $a_2 = 1/3$

$\Rightarrow C_p = \frac{16}{27}$

$$P_{max} = \frac{\pi D_e^2}{4}\,\frac{1}{2}\,\rho\, u_0^3$$

Exam 1

1) Myth #3 → H_2 production costs too much energy
Well to Wheels efficiency?

(energy density is problem in aircraft)

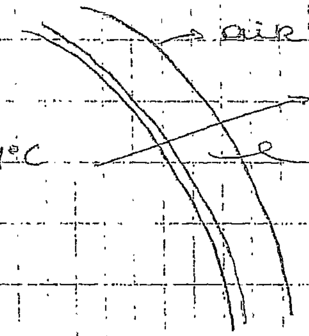
2) exponentional decay law: $N(t) = N(0)\,e^{-\lambda t}$ → number of radio nuclei

halveringstijd $\boxed{T_{1/2} = \frac{\ln(2)}{\lambda}}$

hazard: nuclear radiation
nuclear bombs

(Benefits??)

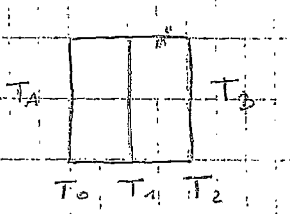
3) 14/03



→ aircraft skin heat loss?

→ -55°C

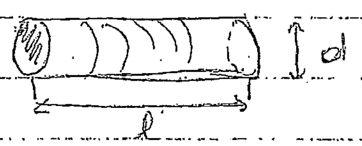
21°C ← insulation material



$R_{tot} = R_A + R_1 + R_2 + R_B$
↳ thermal resistance

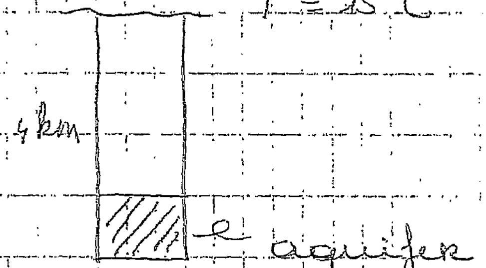
$= \frac{1}{h_a} + \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{1}{h_b}$

$\dot{Q}\,[W/m^2] = A\,\frac{(T_B - T_A)}{R_{tot}}$



4)
connection to electric field
free holes & free electrons
one way direction (diode)
conducting & nonconducting
dopants, p & n layer
energy levels: E_c, E_v
two layers
depletion region

5) E03



$T = 15°C$, $\frac{dT}{dx} = 35°C/km$

$T_{initial} = 15 + 4 \times 35$
$= 155$

$C_a = [\underbrace{p'}_{\text{porosity}} \rho_w c_w + (1-p')\rho_r c_r]\, \underbrace{h}_{500m}$

$\frac{E_0}{A} = C_a \underbrace{\Theta}_{155-50}$ → heat content per square meter

time constant: $\tau_a = \frac{C_a}{\underbrace{\dot{V}}_{\text{volume flow}} \rho_w c_w}$

$\left| \frac{dE}{dt} \right| = \frac{E_0}{\tau} e^{-\overbrace{t}^{=0}/\tau_a}$