

Sustainable Development for Aerospace Engineers

Sustainable development = development that meets the needs of the present without compromising the ability of future generations to meet their own needs

Reach new equilibrium

- loads posed on the environment
- rich and the poor
- present and the future

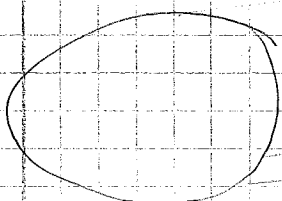
Precautionary principle = moral and political principle which states that if an action/policy might cause severe or irreversible harm to the public, in the absence of any scientific consensus that harm would not ensue, the burden of proof falls on those who would advocate taking action

Greenhouse effect
Climate change
Global warming } three different effects

Solar energy: $S_0 = 1372 \frac{W}{m^2}$

Reflection (albedo) $\alpha = 30\%$

70% of the solar energy reaches the earth



$\frac{1}{4}$ on average received

Remember the 1:4 ratio

$$\frac{1}{4} \cdot 0.7 \cdot 1372 = 240 \frac{\text{W}}{\text{m}^2}$$

Incoming energy

$$E_{in} = (1 - \alpha) \cdot S_0 \cdot \pi \cdot R^2$$

Outgoing energy

$$E_{out} = \sigma T^4 \cdot 4 \cdot \pi \cdot R^2$$

Balance:

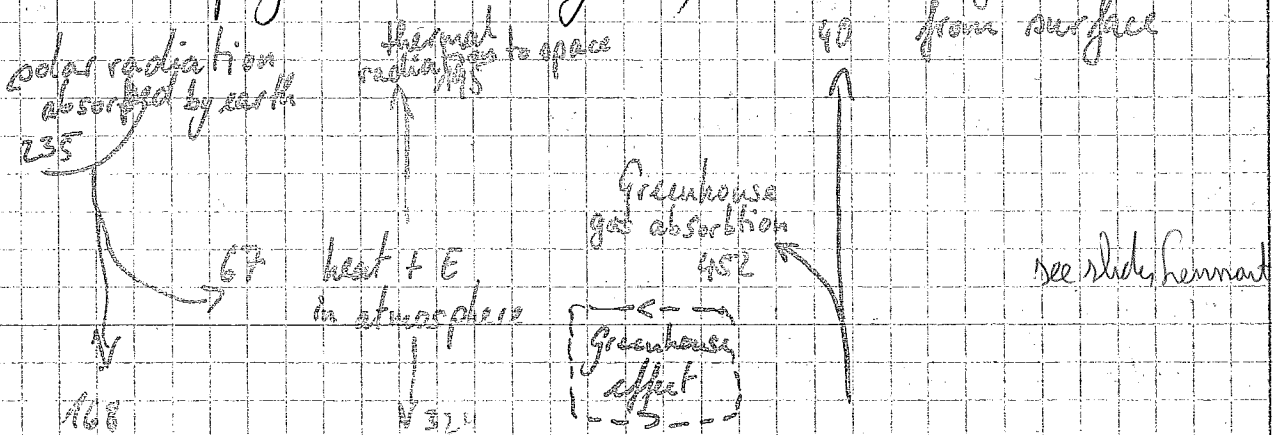
$$E_{in} = E_{out} \Rightarrow T = -18^\circ\text{C} \quad (255\text{K})$$

Average temperature is $+15^\circ\text{C}$ (Greenhouse effect)

Without the greenhouse effect it would be very cold

Greenhouse effect

- natural (naturally occurring)
- Anthropogenic (emitted gases)



Receiving energy: Sun

Outgoing energy: Albedo, radiation

Atmosphere is transparent to visible light but absorbes at the wavelengths of infrared radiation

Radiative forcing ('man-made' greenhouse effect)

- Equivalent additional energy
- Components: CO_2 , CH_4 , Ozone, Albedo, Aerosols, solar irradiance

Climate change \Rightarrow long term effects, variation in the earth's global climate over time

Global warming \Rightarrow component of climate change

IPCC = Intergovernmental Panel On Climate Change

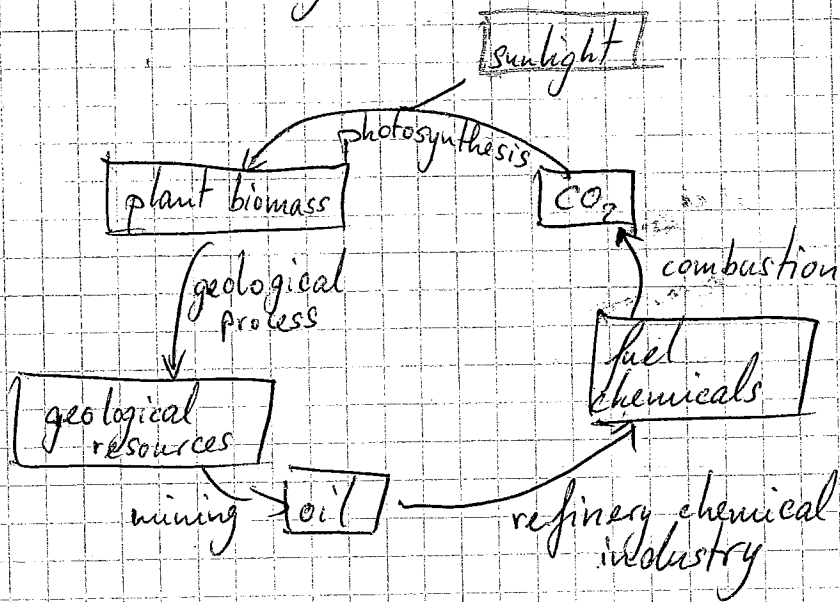
- Scientific body tasked to evaluate the risk of climate change caused by human activities (no research, only review)

Renewable energy = energy from regenerative of virtually unexhaustible sources of energy in a natural environment irrespective of man-made devices

Non-renewable energy = energy obtained from static sources that remain bound unless released by human action

Fossil Fuels: (lecture 2)

The carbon cycle:



- Coal
- Natural gas
- (Crude) oil

Coal

- Fossilized, condensed carbon-rich fuel

- 10 times reserves of oil/gas

- lasts 200 years

- types:

- 1) lignite / brown coal
- 2) sub-bituminous
- 3) bituminous
- 4) anthracite

- energy loss 1) 65% in power plants

2) 10% loss due to transmission / transport

- 24% of world's energy from coal

- we consume at a rate of 600 000 times the creation rate

Natural gas

Advantages

- Cleaner to burn (half CO_2 of Coal)
- More efficient (10% of energy loss)

Disadvantages

- 60 year supply @ current rate

Danger of linear predictions

- Account for increasing consumption
 - ↳ Growth in world population
 - ↳ growth in wealth

Crude oil

- buried organic matter rich with hydrocarbons
- fractions of different compositions

1) Gasoline (mogas): chains of 5 to 12 carbon atoms
Can be used in aviation

Disadvantage \Rightarrow vapour lock = "short chains" evaporate easily at high altitudes. Bubbles are formed which can block the fuel tubes. This stops engines

2) Aviation gasoline (Avgas): higher octane, less volatile

3) Diesel: chains of 10 to 15 carbon atoms

4) Kerosene: chains of 12 to 15 carbon atoms

- limited resources

Carter - doctrine = every attempt of a power outside the Persian Gulf region that tries to take control of oil will be considered an attempt or attack on the vital interest of the USA and by any means, including military force is allowed to stop this

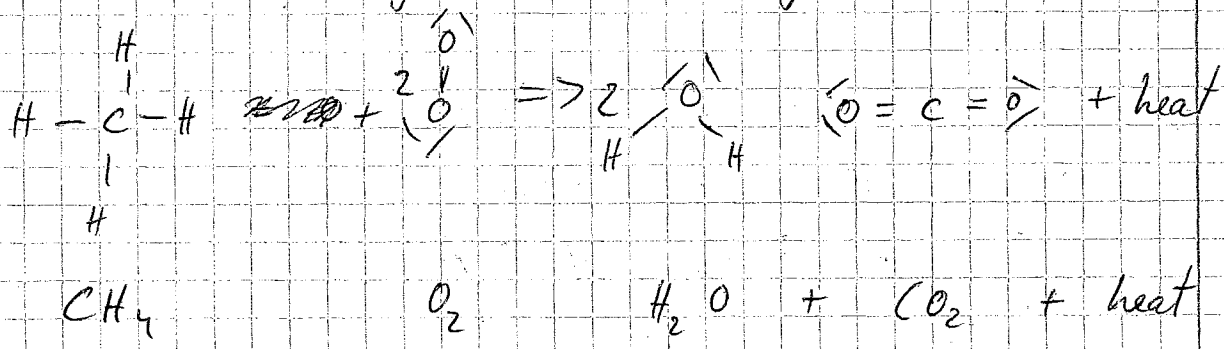
Basics

- Energy \equiv Capacity for doing work
- Work \equiv Force \times displacement along the direction of the force

Energy (E, U) } Unit Joule = (N.m)
 Work (W) }

Power = energy per unit of time \rightarrow unit $J/s = \text{Watt}$

Conservation of energy
 - chemical energy = comes out of the capacity of atoms to generate heat as they combine or separate



- Electrical energy
- Kinetic energy
- Potential energy
- Heat energy
- Radiant energy (= energy in transit through space)

from \ to	Chemical	Electrical	Heat	Light	Mechanical
chemical	////	battery fuel cell	oxidation burning	burning candle	muscles
electrical	battery electrolysis	////	toaster electric heating	light bulb	electric motor
Heat	vaporization gasification	thermal couple peltier element	////	fric	gas turbine starting motor
Light	photosynthesis photo camera	solar cells	solar collector	////	photo electric door opener solar wind
Mechanical (kinetic)	heat cell	generator	friction brake	friction flintspark	////

a lot of energy is lost due to loss of heat, which is not used

Heat transfer

form of energy? \rightarrow can be transferred from A to B
as a result of temperature difference

3 types of heat transfer

- conduction
- convection
- radiation

Conduction: = transfer of energy from more energetic particles in a substance to less energetic particles

- Fourier's law of heat conduction

heat conduction through a wall with a thickness of Δx and area A :

$$\dot{Q} = -k \cdot A \frac{\Delta T}{\Delta x} \quad \Rightarrow \text{steady state solution}$$

o $\frac{\Delta T}{\Delta x}$ = gradient = driving force of heat conduction

o k = material property (thermal conductivity)

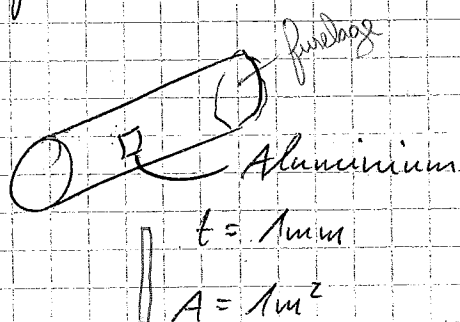
$$k = k_0 (1 + \beta (T - T_0))$$

In General:

gases: $\beta > 0$; when $T \uparrow \Rightarrow k \uparrow$

solid/liquids $\beta < 0$; when $T \uparrow \Rightarrow k \downarrow$

Example calculations:



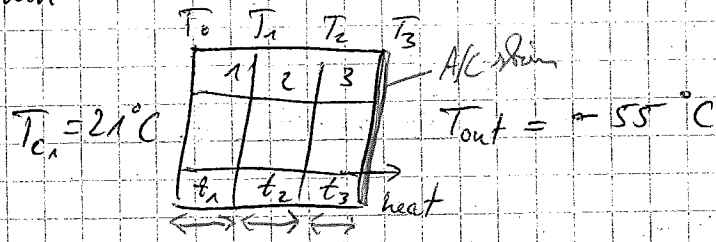
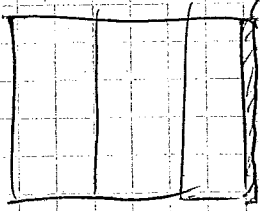
$$\left. \begin{array}{l} \text{OAT} = -55^\circ\text{C} \\ \text{on board} = 21^\circ\text{C} \end{array} \right\} \Delta T = 76\text{K}$$

$$k = 204 \text{ W/mK}$$

$$\dot{Q} = 2 = 15.5 \text{ MW}$$

$q = 15.5 \text{ MW/m}^2$
= incredibly much! due to conductivity of aluminium

Insulation is the solution, since the calculated value would make it impossible to fly
Aircraft skin



$$\begin{aligned} \dot{Q}_1 &= \frac{A k_1 (\Delta T_1)}{t_1} \\ \dot{Q}_2 &= \frac{A k_2 (\Delta T_2)}{t_2} \\ \dot{Q}_3 &= \frac{A k_3 (\Delta T_3)}{t_3} \end{aligned} \quad \left. \begin{array}{l} \\ \\ \end{array} \right\} \dot{Q}_1 = \dot{Q}_2 = \dot{Q}_3$$

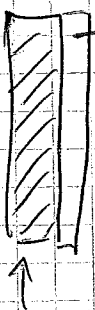
$|\Delta T_1| = T_1 - T_0$

R = thermal resistance

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

$$\dot{Q} = \frac{A \cdot \Delta T_{tot}}{R_{tot}} \quad \longleftrightarrow \quad \dot{q} = \frac{\dot{Q}}{A} = \frac{T_0 - T_3}{R_{tot}}$$

Example 2:



$$t = 0.001 \text{ m}$$

$$k = 204 \text{ W/mK}$$

$$|\Delta T| = 76 \text{ K}$$

$$R_{tot} = \frac{t_1}{k_1} + \frac{t_2}{k_2} = \frac{0.1}{0.038} + \frac{0.001}{204} = 2.63 \frac{\text{m}^2 \text{K}}{\text{W}}$$

$$\dot{q} = \frac{76 \text{ K}}{2.63 \frac{\text{m}^2 \text{K}}{\text{W}}} = 28.9 \frac{\text{W}}{\text{m}^2}$$

Not a huge difference!

insulation glasswool

$$\sim 10 \text{ cm}; \quad k = 0.038 \text{ W/mK}$$

• convection: = transfer of heat from one part of a fluid gas to another part with a lower temperature Done by mixing of particles

- free convection: example of a hot rod. Temperature differences cause density differences \rightarrow buoyancy effect only with gravity

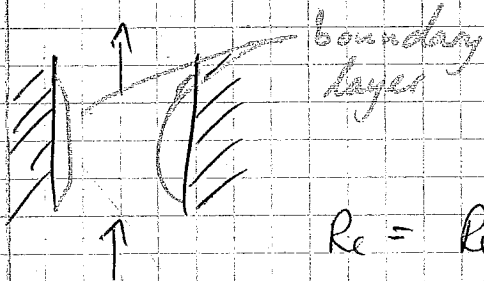
- forced convection: fluid motion caused by external forces: e.g. fan

free and forced convection ^{can} occur simultaneously

$$\dot{Q} = h \cdot A \cdot \Delta T$$

\hookrightarrow local heat transfer coefficient which depends on material and geometry $h = f(Re, Pr, Nu, Gr)$

More convection when boundary layer is turbulent



$$so \ h = f(Re, Pr, Nu, Gr)$$

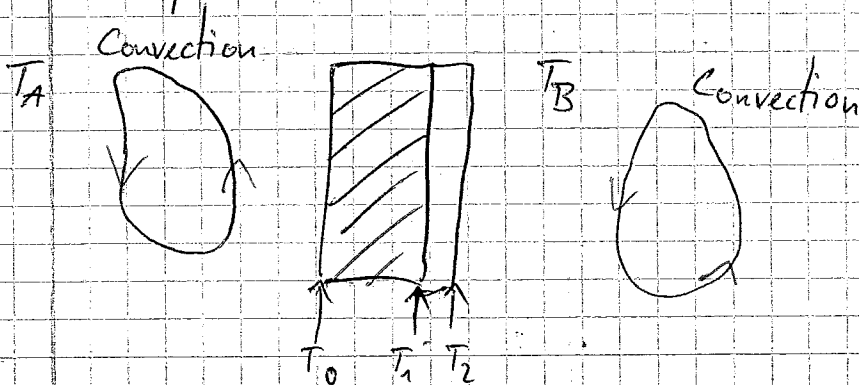
$Re =$ Reynolds nr

$Pr =$ Prandtl nr

$Nu =$ Nusselt nr

$Gr =$ Gractz nr

Exempl



equivalent thermal resistance

$$R_1 = \frac{t_1}{K_1} \quad R_2 = \frac{t_2}{K_2}$$

$$Q = h_A A \Delta T_A = \frac{A h_A (T_0 - T_1)}{t_1} = \frac{A h_2 (T_1 - T_2)}{t_2} = h_B A \Delta T_B$$

note $\Delta T_A = T_1 - T_0$

$\Delta T_B = T_2 - T_1$

$$R_A = \frac{1}{h_A} ; R_B = \frac{1}{h_B}$$

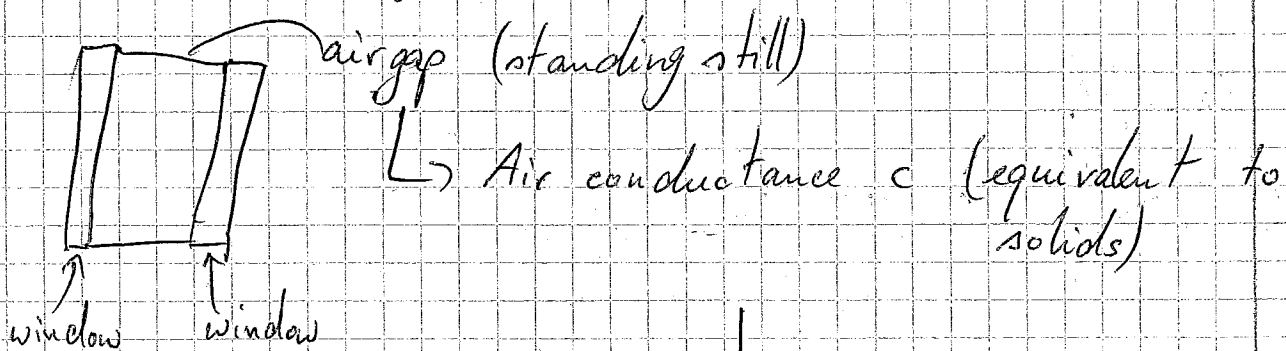
$$R_{\text{tot, equivalent}} = \sum_{i=1}^n \frac{t_i}{k_i} + \sum_{i=1}^m \frac{1}{h_i} = \frac{1}{h_A} + \frac{t_1}{k_1} + \frac{t_2}{k_2} + \frac{1}{h_B}$$

$$h_A = 9.5 \frac{W}{m^2 K} ; h_B = 5.7 \frac{W}{m^2 K}$$

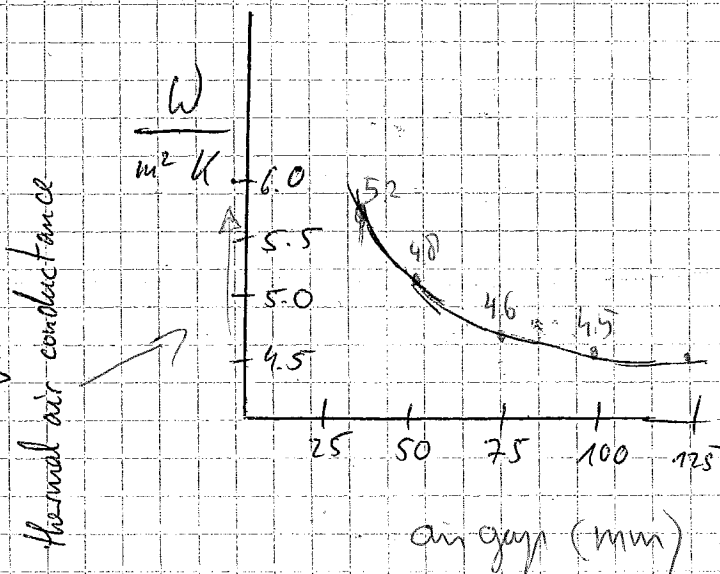
$$R_{\text{tot}} = \frac{1}{9.5} + \frac{1}{5.7} + \frac{0.10}{0.038} + \frac{0.001}{204} = 2.91 \frac{m^2 K}{W}$$

$$q = \frac{76}{2.91} = 26 \frac{W}{m^2}$$

What is the effect of windows ???

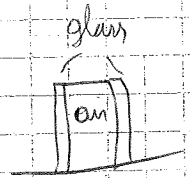


Airgap in [cm]	C
25	5.2
50	4.8
75	4.6
100	4.5
150	...



$$\dot{q} = U \cdot \Delta T; \quad U = \frac{1}{\frac{1}{h_A} + \frac{t_1}{k_1} + \frac{1}{c} + \frac{t_2}{k_2} + \frac{1}{h_B}}$$

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



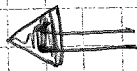
2 layers of perspex each $t = 4 \text{ mm}$; $k = 0.2$

1 layer of air 25 cm

h_A and h_B remains unchanged

$$U = \left[\frac{1}{9.5} + 2 \frac{0.004}{0.20} + \frac{1}{5.2} + \frac{1}{5.7} \right]^{-1} = 1.95$$

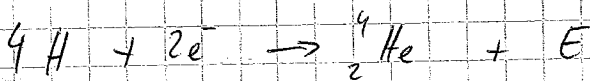
$$\dot{q} = 1.95 \cdot 76 = 148 \frac{\text{W}}{\text{m}^2}$$



Sustainable development for Aerospace engineers

Solar Energy

Sun = nuclear fusion reactor



↓
Hydrogen atoms
- 1 electron

- 8 protons

- relative atomic mass

4×1007.97
 $= 4.03188$

Helium atoms

- 2 neutrons

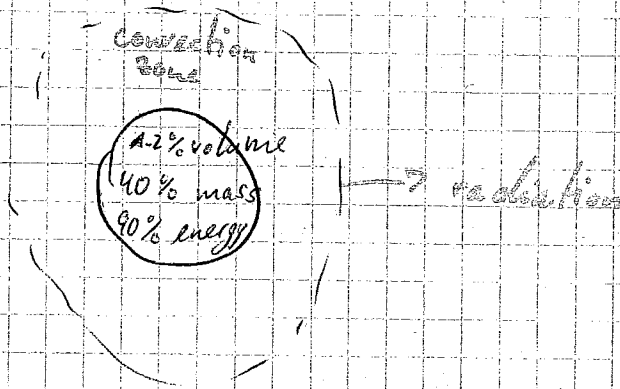
- 2 protons

- relative atomic mass

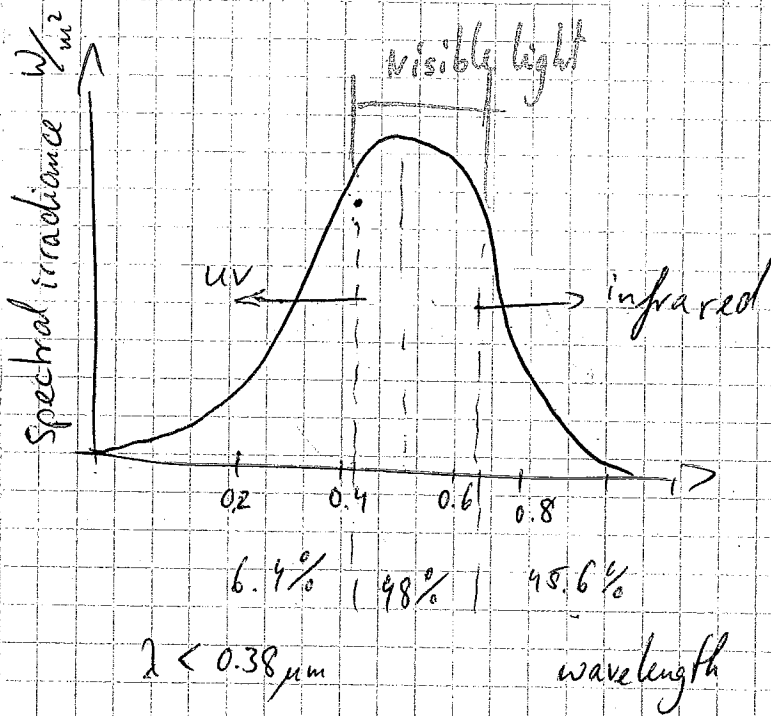
$$= 4.0026$$

$$E = mc^2$$

Sun build-up



Equivalent black body radiator: $T_{eq} = 5777 K$



- Energy of the Sun travels through space via radiation
- law of Stefan Boltzmann

$$E \sim T^4 \Rightarrow E = \sigma T^4$$

↳ Stefan-Boltzmann constant $5.67051 \cdot 10^{-8} \frac{W}{m^2 K^4}$
 ↳ emissivity of the surface: ideal case (black body radiation) $\rightarrow \epsilon = 1$

- Planck's radiation law

$$E_{\lambda b}(\lambda, T) = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

Intensity of radiation emitted per unit of area as a function of wavelength

h = Planck's constant = $6.6207 \cdot 10^{-34}$ Js

k = Boltzmann constant = $1.38066 \cdot 10^{-23}$ J/K

- Total energy emitted is found by integrating over the whole range of wavelengths λ :

$$E_{0-\lambda} = \int_0^{\lambda} E_{\lambda b}(\lambda, T) d\lambda = \text{Stefan-Boltzmann law}$$

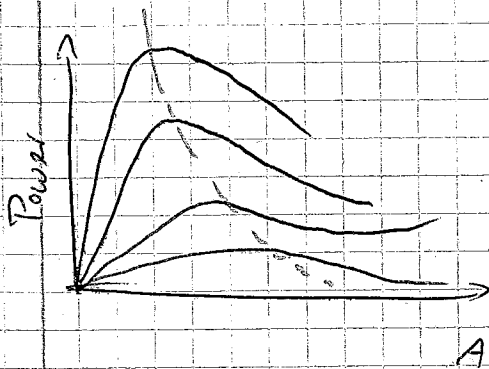
- Point of maximum radiation

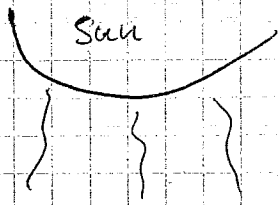
$$\lambda_{\text{max rad}} \cdot \frac{dE_{\lambda b}}{d\lambda} = 0 \Rightarrow \lambda_{\text{max}} T = \text{constant} = 2897.6 \cdot 10^{-3} \text{ m K}$$

\Rightarrow Wien's displacement law

Sun $T = 6000 \text{ K} \Rightarrow \lambda_{\text{max}} = 483 \text{ nm} (0.48 \mu\text{m})$

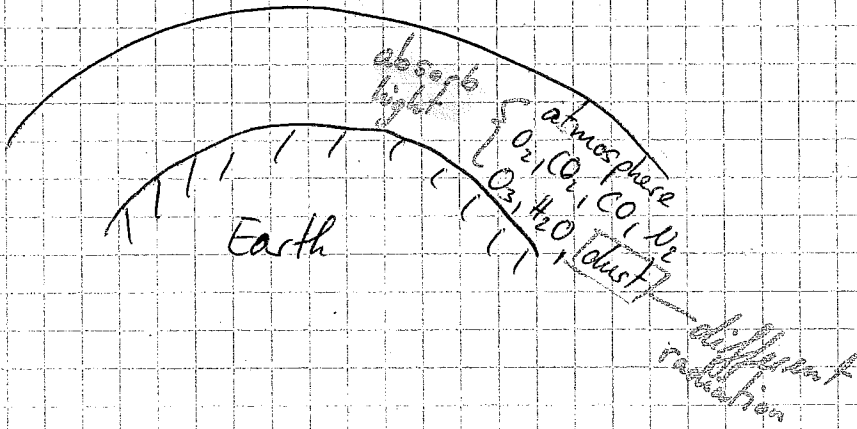
Earth $T = 288 \text{ K} \Rightarrow \lambda_{\text{max}} = 1006 \text{ nm} (\text{infrared})$





- UV is blocked by O_3
- X-rays absorbed by the atmosphere
- extreme UV absorbed by the ionosphere

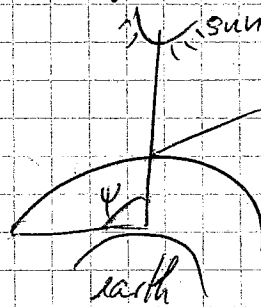
Space



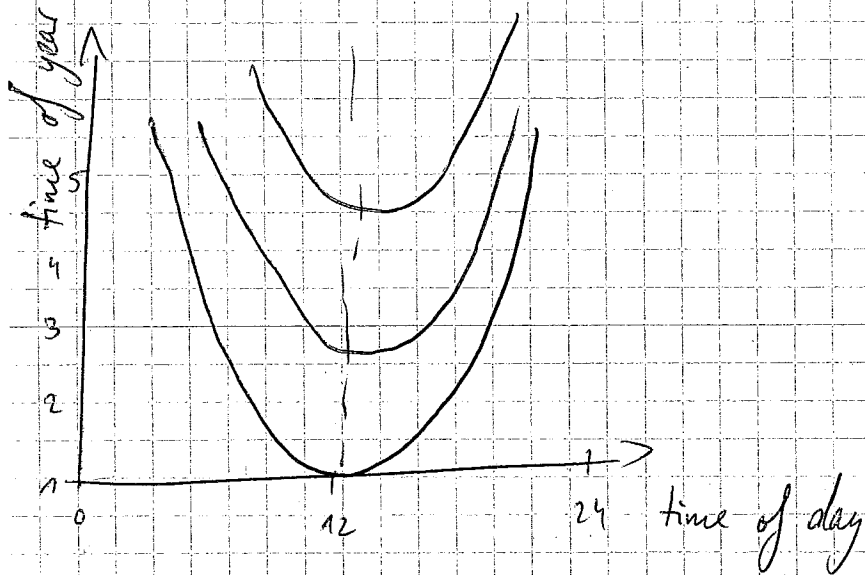
Air mass = optical thickness of the atmosphere through which the radiation passes

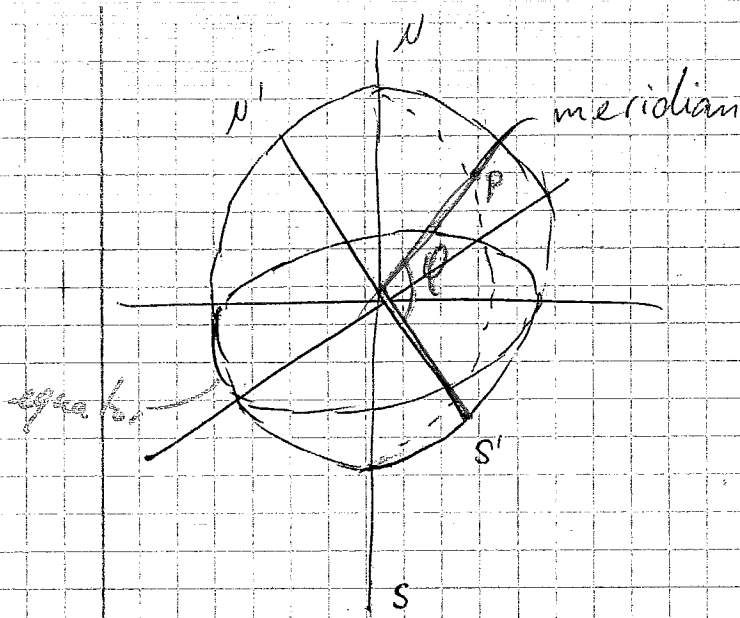
Optical thickness if the sun is in zenith

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



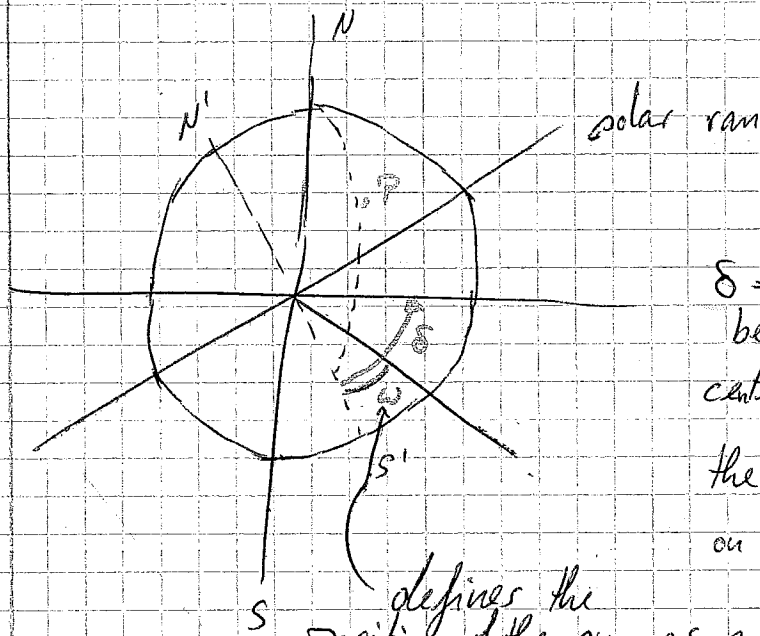
sun is in zenith $A_m = 1.0$
in space $A_m = 0$





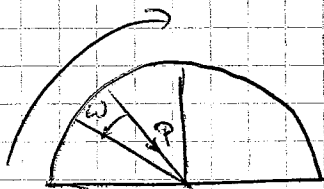
P = position of observer

φ = latitude



δ = declination = angle between the lines joining the center of the sun & center of the earth and its projection on the equator plane

defines the position of the sun as a function of time of day
midday $\omega = 0$



$$\delta = 23.45^\circ \sin\left(\frac{360}{365}(284 + n)\right)$$

n = day of the year

example δ (feb 1st): jan 31 days; feb 1 day

$$n = 32 \text{ days}$$

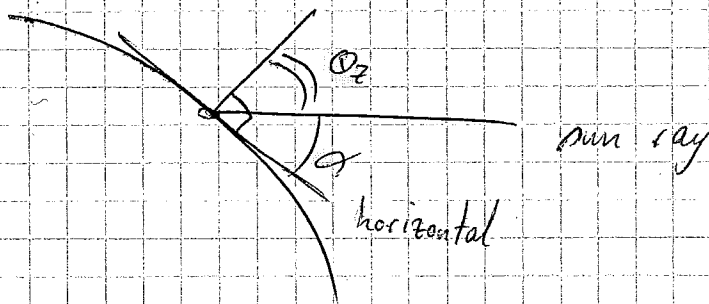
$$\Rightarrow \delta = -17.5^\circ$$

(degree)

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

altitude (α) = angle between sunray and the horizontal plane

$$\alpha = 90^\circ - \theta_z$$



Solar panel attitude;

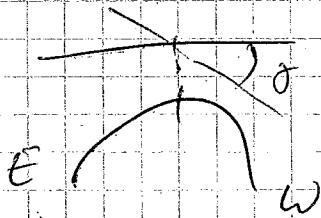
β = slope of the solar panel

↳ angle between the plane surface (solar panel) and the local horizontal;



γ = surface azimuth angle

↳ angle in the horizontal plane between the line due south & projection of the normal on the to the surface



northern hemisphere

$\gamma < 0$ when projection is east of south

$\gamma > 0$ when projection is west of south

$\theta_z =$ angle of incidence

In general, 5 relevant angles: $\delta, \varphi, \omega, \beta, \gamma$

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

Question:

Find out the number of days light hours (sunshine) for a given location (φ) on earth

• Sunset: when zenith is $90^\circ \Rightarrow \omega = \omega_s$

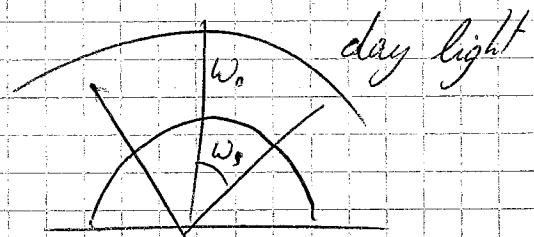
\rightarrow use Formulas for horizontal plane facing due south

$$\cos \theta_z = \cos \varphi \cos \delta \cos \omega_s + \sin \delta \sin \varphi$$

$$\downarrow$$

$$0 \Rightarrow \cos \omega_s = -\frac{\sin \delta \cdot \sin \varphi}{\cos \delta \cdot \cos \varphi} = -\tan \delta \cdot \tan \varphi$$

(angle when the sun sets)



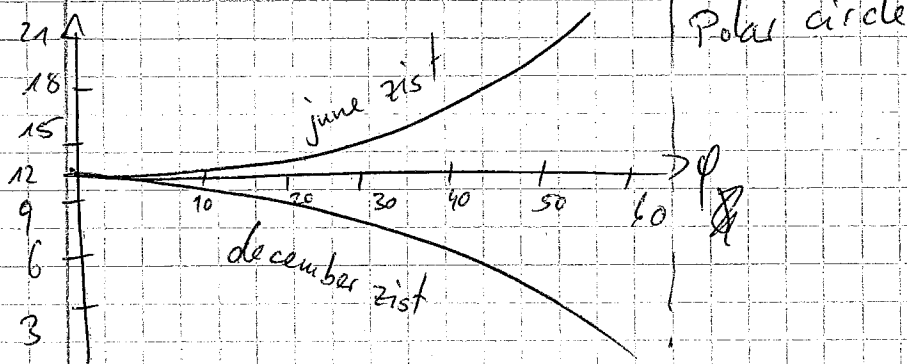
We need to know $2\omega_s$

$$2 \cos^{-1} (-\tan \delta \tan \varphi)$$

one full rotation of the earth in 24 hours

$$\frac{360^\circ}{24^\circ} = 15^\circ/\text{hr}$$

$$N = \frac{2}{15} \cos^{-1} (-\tan \delta \tan \varphi)$$



Sunlight

$$\text{June } 21^{\text{st}} = 172$$

$$\varphi = 52^\circ$$

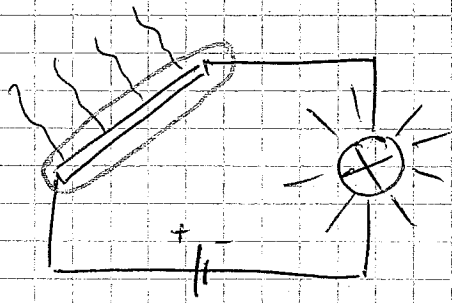
$$\text{December } 21^{\text{st}} = 356$$

$$\delta = 23.45 \sin\left(\frac{360}{365}(284 + n)\right) = \begin{matrix} / \\ \backslash \end{matrix}$$

$$\text{June } 21^{\text{st}} \Rightarrow N = 16 \text{ hr } 29 \text{ min } 49 \text{ sec}$$

$$\text{Dec } 21^{\text{st}} \Rightarrow N = 7 \text{ hr } 30 \text{ min } 11 \text{ sec}$$

Photovoltaic systems



The majority of photovoltaic cells are silicon semiconductors or junction devices

semiconductors

σ = electric conductivity

solids can be divided into 3 categories

- insulators (e.g. plastics) $\sigma < 10^{-8} / \Omega m$

- conductor (e.g. metals) $\sigma > 10^9 / \Omega m$

- semiconductor $10^{-8} < \sigma < 10^9 \Omega m$

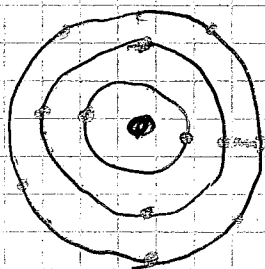
~~semi~~ semiconductors can have two states

- conducting

- non-conducting

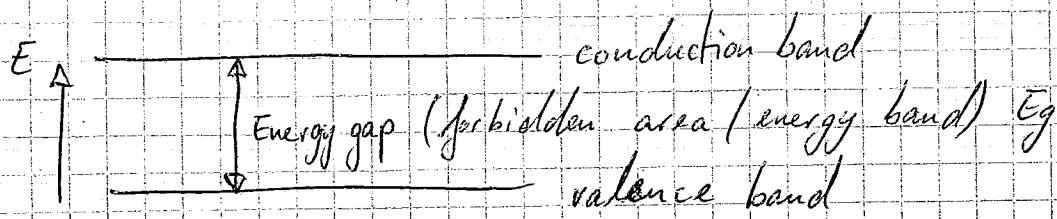
Energy band diagram

plot of the allowed electron energy states in a material



specific quantity of energy makes the electron to not be shell

"quantum theory"



increasing energy of electrons (potential energy)

conductors $E_g = 0$

insulators $E_g \approx$ very large

semiconductors E_g has limited size

quantum of energy = steps of energy

given by $h\nu$ — frequency
Planck's constant

Energy gap is a function of T

$$E_g(T) = E_g(0) - \frac{aT^2}{T+b}$$

a, b are material properties

Silicon $E_g(0) = 1.16 \text{ eV}$

$$a = 7 \cdot 10^{-4} \text{ eV/K} \quad b = 1100 \text{ K}$$

Gallium - Arsenide $E_g(0) = 1.52 \text{ eV}$

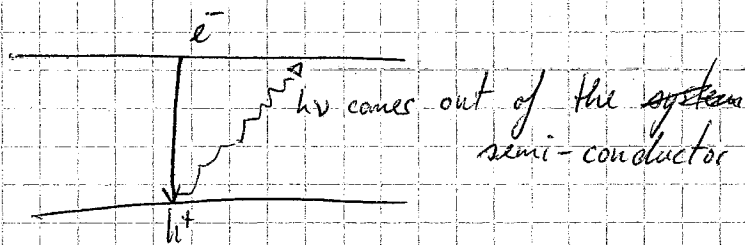
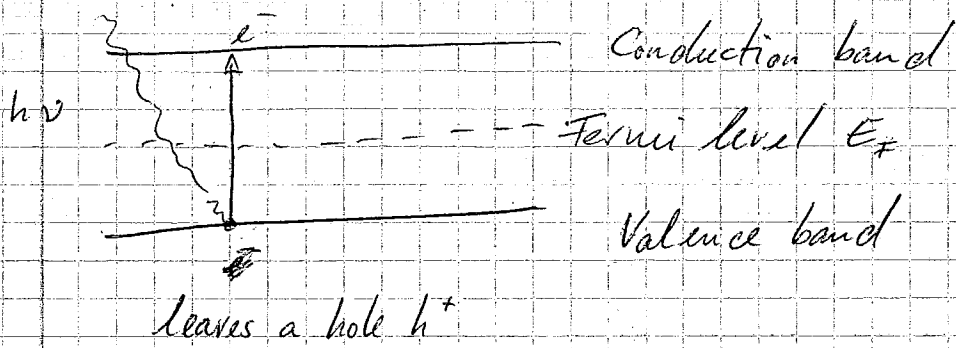
$$a = 5.8 \text{ eV/K} \quad b = 300 \text{ K}$$

multiple junction: combination of the above

What is the size of the energy gap @ 40°C

$$\text{Si: } 1.16 - \frac{7 \cdot 10^{-4} (273.15 + 40)^2}{40 + 273.15 + 1100 \text{ K}} = 1.11 \text{ eV}$$

$$\text{GaAs} \Rightarrow 1.43 \text{ eV}$$



electron-hole-recombination

2 categories of semiconductors

intrinsic - pure semiconductors have a so-called Fermi level in the middle of the conduction & valence band
 \Rightarrow this means that the number of free electrons in the conduction band = number of free holes in the valence band

Fermi level = apparent energy level within the forbidden energy gap from which the majority carriers are excited to become charge carriers

majority carriers = electrons - n-type semiconductor
 holes - p-type semiconductor

number of free electrons = n

number of free holes = p

$$n = p = (n_i)$$

We want to increase the conductivity of the intrinsic semiconductors

\Rightarrow add controlled quantities of specific impurities \Rightarrow doping

Impurities ion of valency less than that of the semiconductor \Rightarrow become electron acceptors
 \Rightarrow trap free electrons

These traps have an energy level within the bandgap

\Rightarrow create a situation where the electrons are trapped \Rightarrow resulting positive charge
 \Rightarrow p-type semiconductor

Impurity of valence higher than that of the semiconductor
 \Rightarrow trap free holes
 \Rightarrow n-type semiconductor

n-type : electrons - majority carrier
holes - minority carrier

p-type : holes - majority carrier
electrons - minority carrier

\Rightarrow We have created extrinsic semiconductors

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

E_c = conduction energy

k = Boltzmann constant $1.38 \cdot 10^{-23} \text{ J/K}$

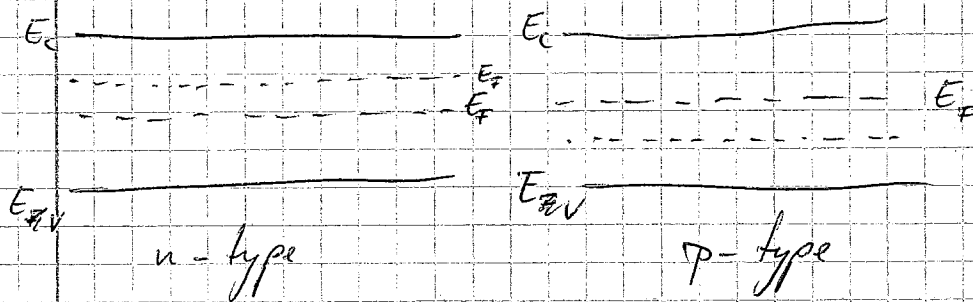
N_D = donor concentration

N_c = effective density of states in the conduction band
 $= f(T) \approx 10^{19} / \text{cm}^3$

p-type material $E_F = E_V - kT \ln \frac{N_A}{N_V}$
 ↓
 valence energy level

N_A - acceptor ion concentration

N_V - effective density of states in valence band $\approx 10^{19}/\text{cm}^3$



Calculate the shift in Fermi-level in a silicon semiconductor doped with Vanadium group of impurities with a concentration of $10^{15}/\text{cm}^3$

given $N_D = 2.82 \cdot 10^{19}/\text{cm}^3$

$E_g = 1.1 \text{ eV}$

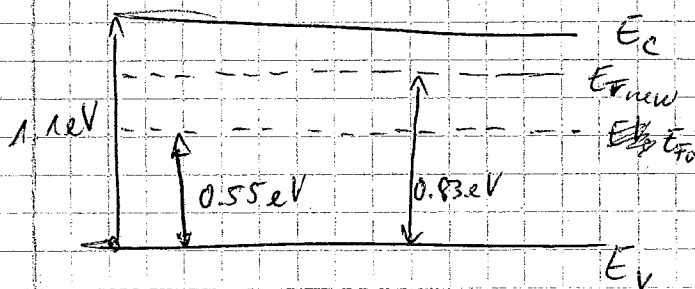
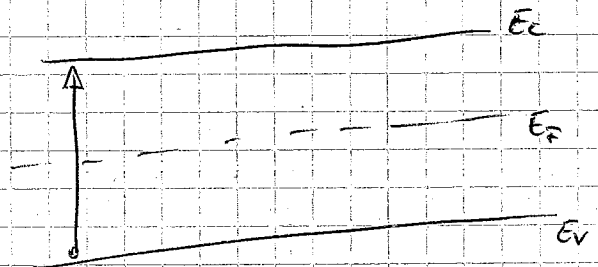
$T = 27^\circ\text{C}$

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

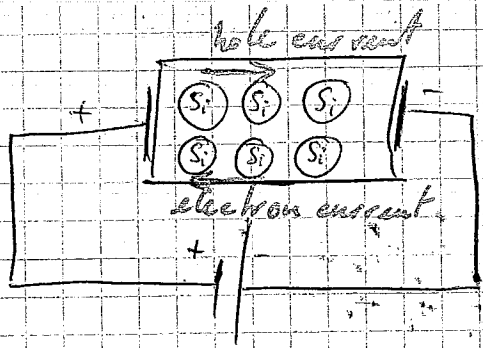
$= 1.1 \text{ eV} + \frac{1.38 \cdot 10^{-23} \text{ J/K}}{1.6 \cdot 10^{-19} \text{ J/eV}} \cdot 300 \text{ K} \cdot \ln \frac{10^{15}}{2.8 \cdot 10^{19}}$

$= 1.1 \text{ eV} - 0.26 \text{ eV} = 0.83 \text{ eV}$

≈ 0.82



shift $\Delta E_F = 0.83 \text{ eV} - 0.55 \text{ eV} = 0.28 \text{ eV}$



Extrinsic semiconductors

n-type: dopant contributes to extra electrons

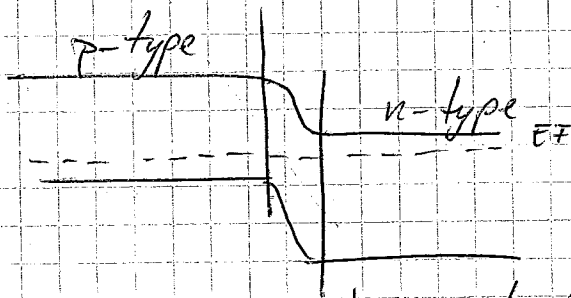
p-type: " " " " holes

⇒ dramatic increase in conductivity

Combination of a p-type & n-type semiconductor



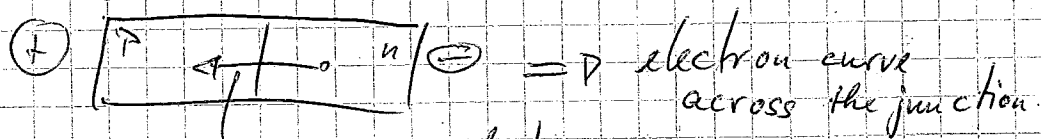
p-n-junction



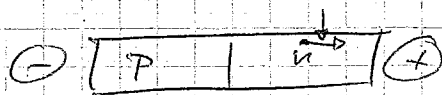
junction = depletion zone

in the depletion zone the free holes & free electrons recombine

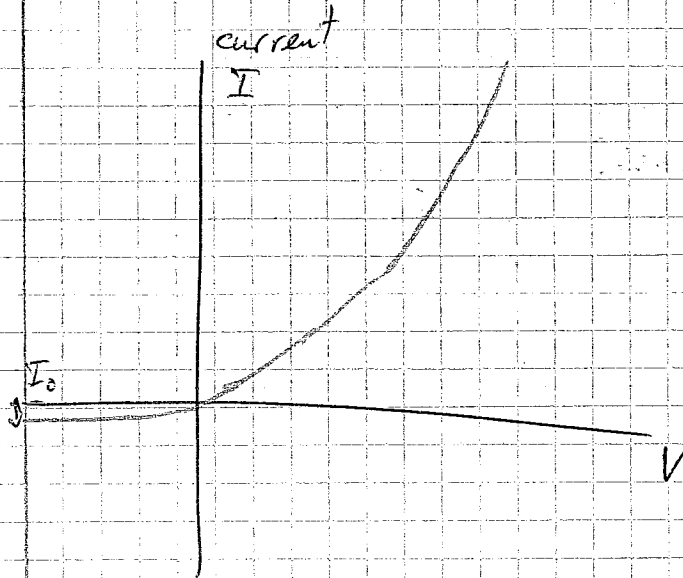
Now apply a voltage across the junction



force on an electron because of the applied voltage



→ no current across the junction



current-voltage characteristic

diode (dark solar cell)

for good quality solar cells $I_0 = 10^{-8} \text{ A/m}^2$

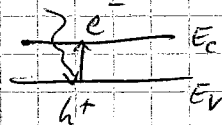
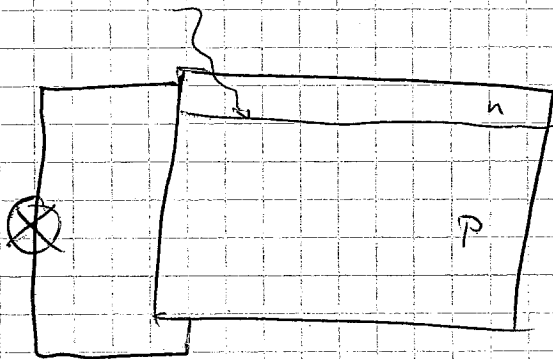
$$I_0 = f(T)$$

$$I_0 = A T^3 e^{-\frac{E_g}{kT}}$$

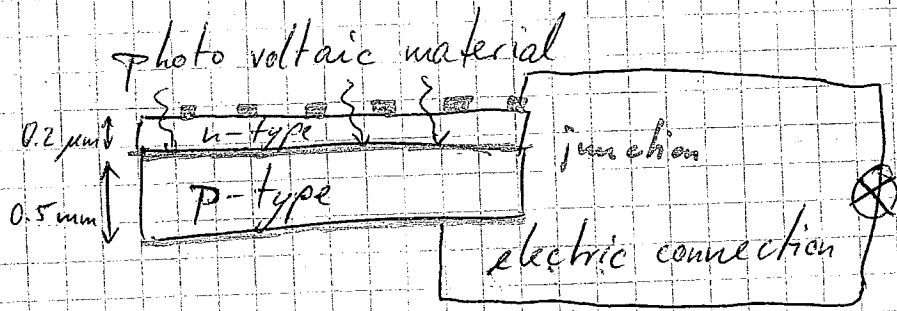
non-ideally factor band gap

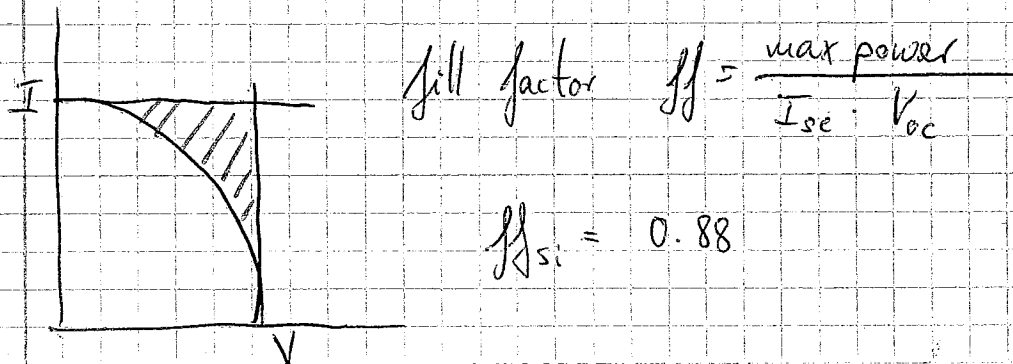
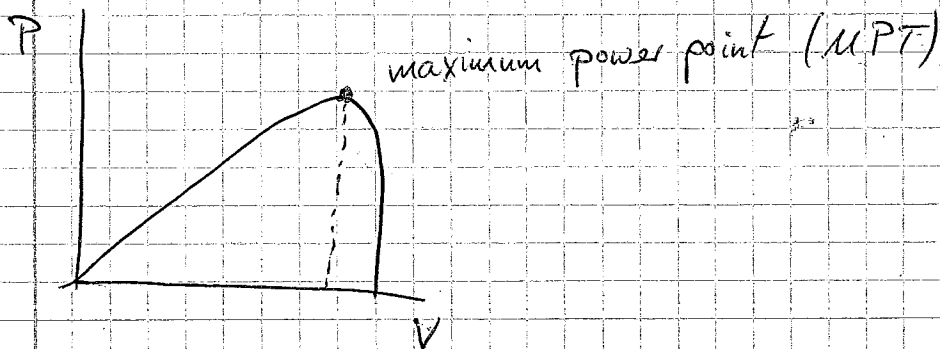
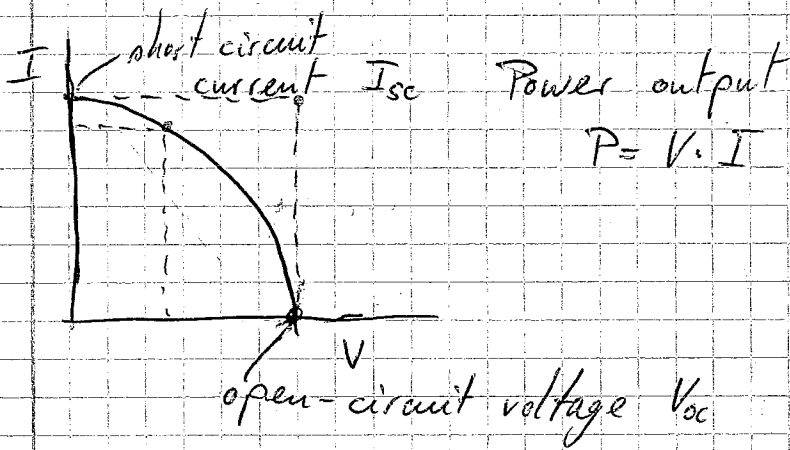
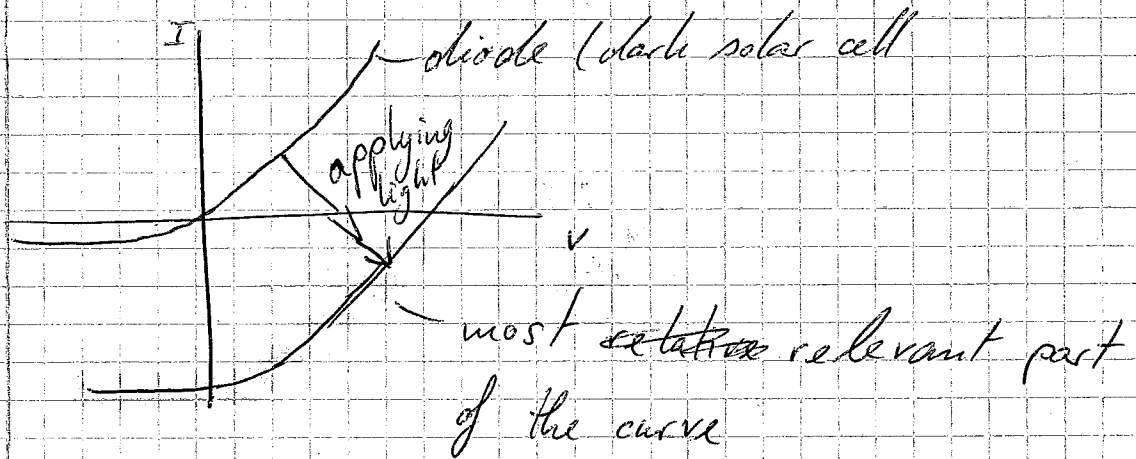
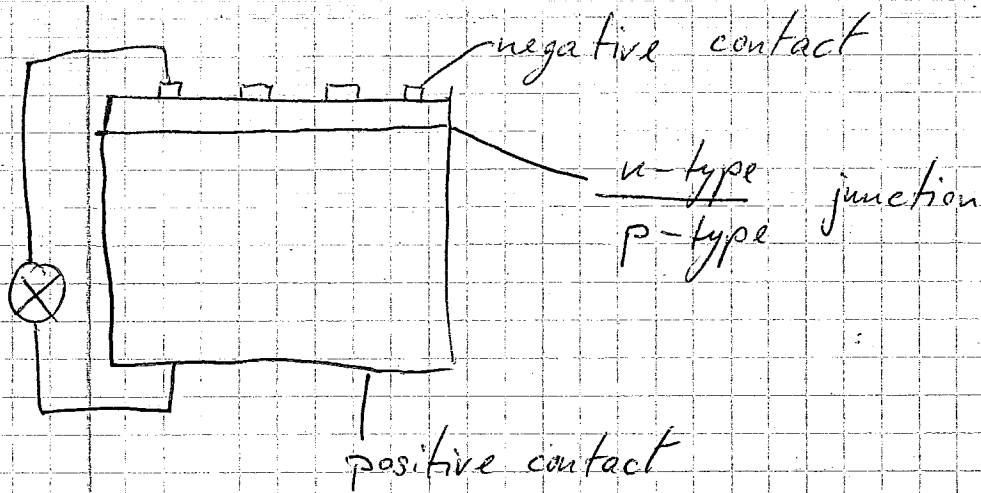
Photo voltaic effect

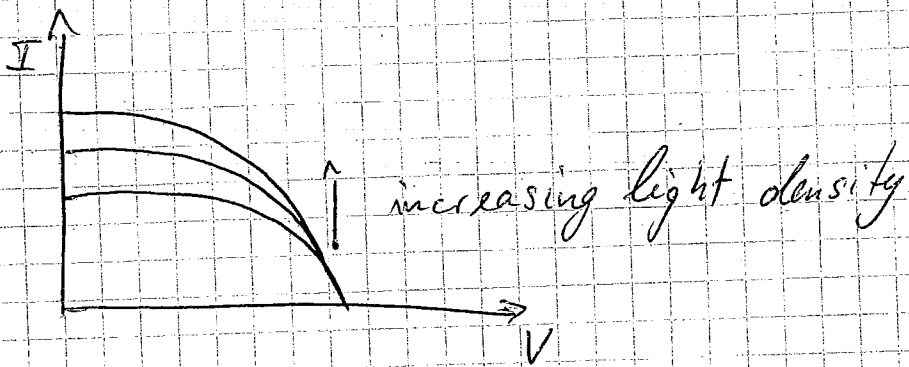
When a p-n-junction is illuminated electron-hole pairs are generated and can be used in an electric circuit if we "catch" them before they combine



\Rightarrow resulting photo current I_c



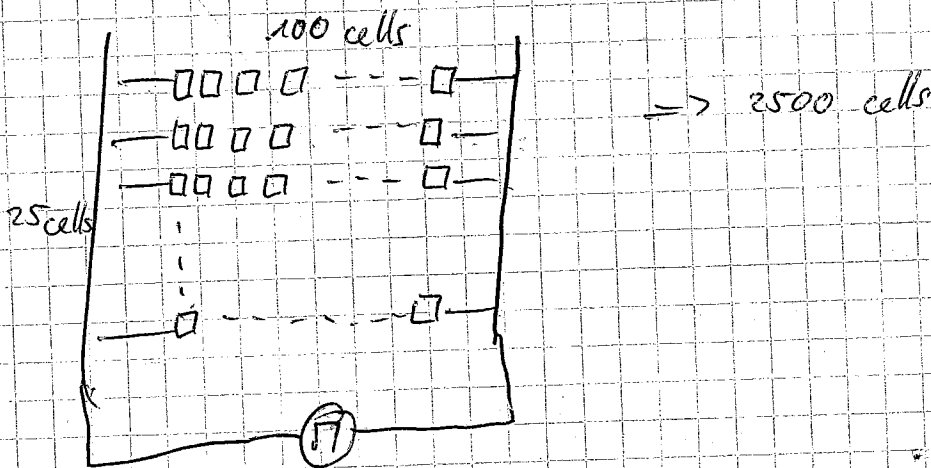




more voltage \Rightarrow connect cells in series
 more current \Rightarrow connect cells in parallel

1 cell max. V at V } 0.60V
 1 need to V } $\frac{60}{0.60} \rightarrow$ number of cells
 in series = 100

e.g. 50 A motor } $\frac{50}{2} = 25$ cells in parallel
 2 A per cell }



Units

kWh \rightarrow 5 kWh is 5 kW for 1 hour
Wh/kg \rightarrow 5 Wh/kg is 5 W for 1 hour per kg

C rating \rightarrow 12 V 45 Ah

12 V 45 A \Rightarrow costs for 1 hr

$I = 45 \text{ A} \Rightarrow$ 1C rating (1 hr)

$I = 90 \text{ A} \Rightarrow$ 2C rating ($\frac{1}{2}$ hr)

$I = 22.5 \text{ A} \Rightarrow$ 0.5C rating (2 hrs)

normally ($\frac{C}{20}$)

Shadow testing: helps deciding which MPPT to connect to which panel

Energy sources:

- Fossil
- Biomass
- Sun/wind/water/geo
- nuclear

Secondary energy carriers:

- Gasoline/diesel/LPG
- Methane
- Liquid biofuels
- Hydrogene
- Electricity

Final energy transformer

- Conventional and hybrid vehicles
- Fuel cell vehicles
- Battery electric vehicles

Biomass = material with combustible organic matters

+ wood

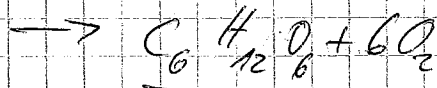
+ agricultural crop

+ animal waste (incl. manure)

+ aquatic plants

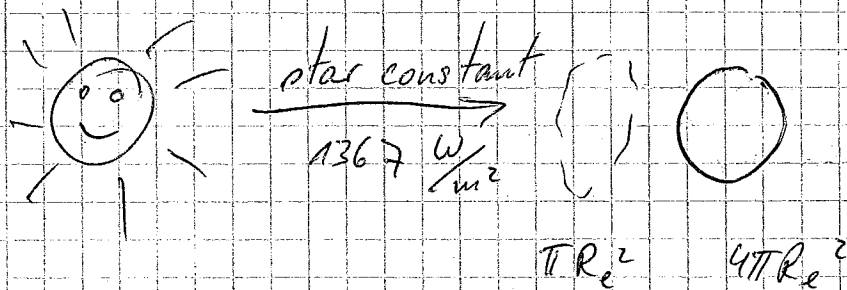
+ fossil fuel

Basic chemical reaction $6\text{CO}_2 + 6\text{H}_2\text{O}$



$\rightarrow 2.81 \text{ MJ/mole glucose}$

Example calculation: Calculate the biomass production on earth per m^2 per year.



- on average we get $\frac{1367}{4} \frac{\text{W}}{\text{m}^2} \cdot 0.7 = 240 \frac{\text{W}}{\text{m}^2}$
- albedo = 0.7

• Now assume that the efficiency of a plant is 0.7%

• 1 mole of glucose $\rightarrow 6.022 \cdot 10^{23}$ molecules

$C_6H_{12}O_6$: Carbon atoms: atomic mass
 $= 12 \cdot 6 = 72$

Hydrogen atoms: atomic mass $1 \cdot 12 = 12$

Oxygen atoms: $16 \cdot 6 = 96$

180 g/mole

net production $\frac{2.81 \text{ MJ/mol}}{180 \text{ g/mol}} = 15.6 \text{ MJ/kg}$

• $240 \frac{\text{W}}{\text{m}^2} \cdot 365 \cdot 24 \cdot 3600 \text{ sec} = 7.56864 \frac{\text{GJ}}{\text{m}^2 \text{ year}}$

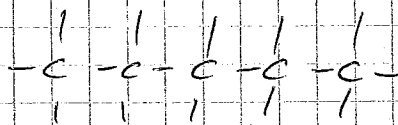
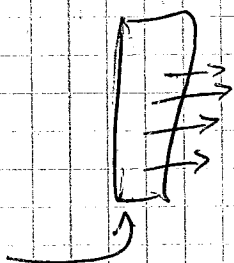
$\frac{7.56864 \cdot 10^9 \frac{\text{J}}{\text{m}^2 \text{ year}}}{15.6 \cdot 10^6 \frac{\text{J}}{\text{kg}}} \approx 0.007 = 3.4 \text{ kg/m}^2 \text{ year}$
 efficiency

Kerosene characteristics

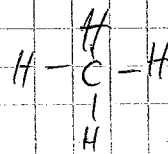
- good cold flow (viscosity, freeze point)
- clean combustion
- good energy density
- good thermal stability

wide-cut

refinery \rightarrow crude oil



$C_9 - C_{10}$ blend



Kerosene as aviation fuel

Secure supplies

Future fuel challenges

Reduce env. impact

Reduce cost

Better thermal stability of fuel would allow engines to run hotter → increase in specific fuel consumption

- insufficient thermal stability results in formation of deposits and even blockages in the fuel system
- improvements by processing fuel and adding additives

Secure supplies

- Aviation fuel vs diesel
- current automotive biofuels are oxygenates - either ethanol or fare (vegetable oil) → downsides
 - lower energy density
 - added oxygen leads to heavy molecules
 - oil depends on vegetable type
- hydro treating vegetable oil → removing oxygen (better energy density)