Building Block

- Radiation balance
- Energy balance
- Environmental effects of energy fluxes

Significance of Radiation

- Primary energy sources for the generation of organic material! Photosynthesis creates compounds in the form of chemical energy (glucose, starch, cellulose, etc.) A maximum of 1% of global solar radiation is used in this way – beginning of the food chain!
- Earth's heat and water cycle regulation (radiation, energy and water balances). Further, radiation is responsible for defining local climates (fulfilling the vital requirements of organisms)

Radiant energy:

...the energy through which electromagnetic waves are transported. The transported energy depends on the wavelength and the amplitude of the radiation. The shorter the wavelength is, the higher the frequency and the more energy can be transported on one wavelength.

Relationship between wavelength, frequency, and energy content

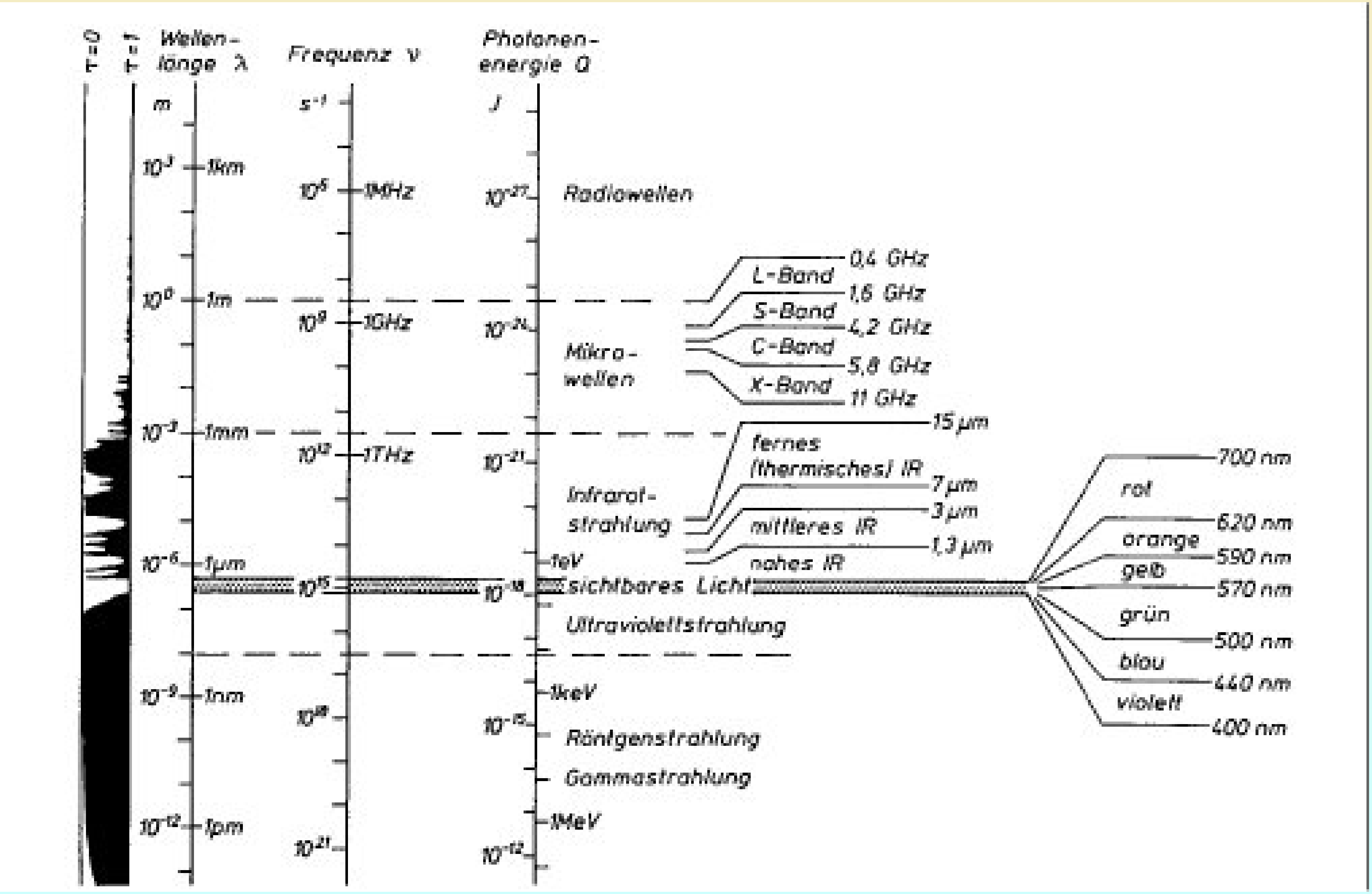
Wellenlänge λ [m]
Frequenz ν [Hz]
Photonenenergie E [J]

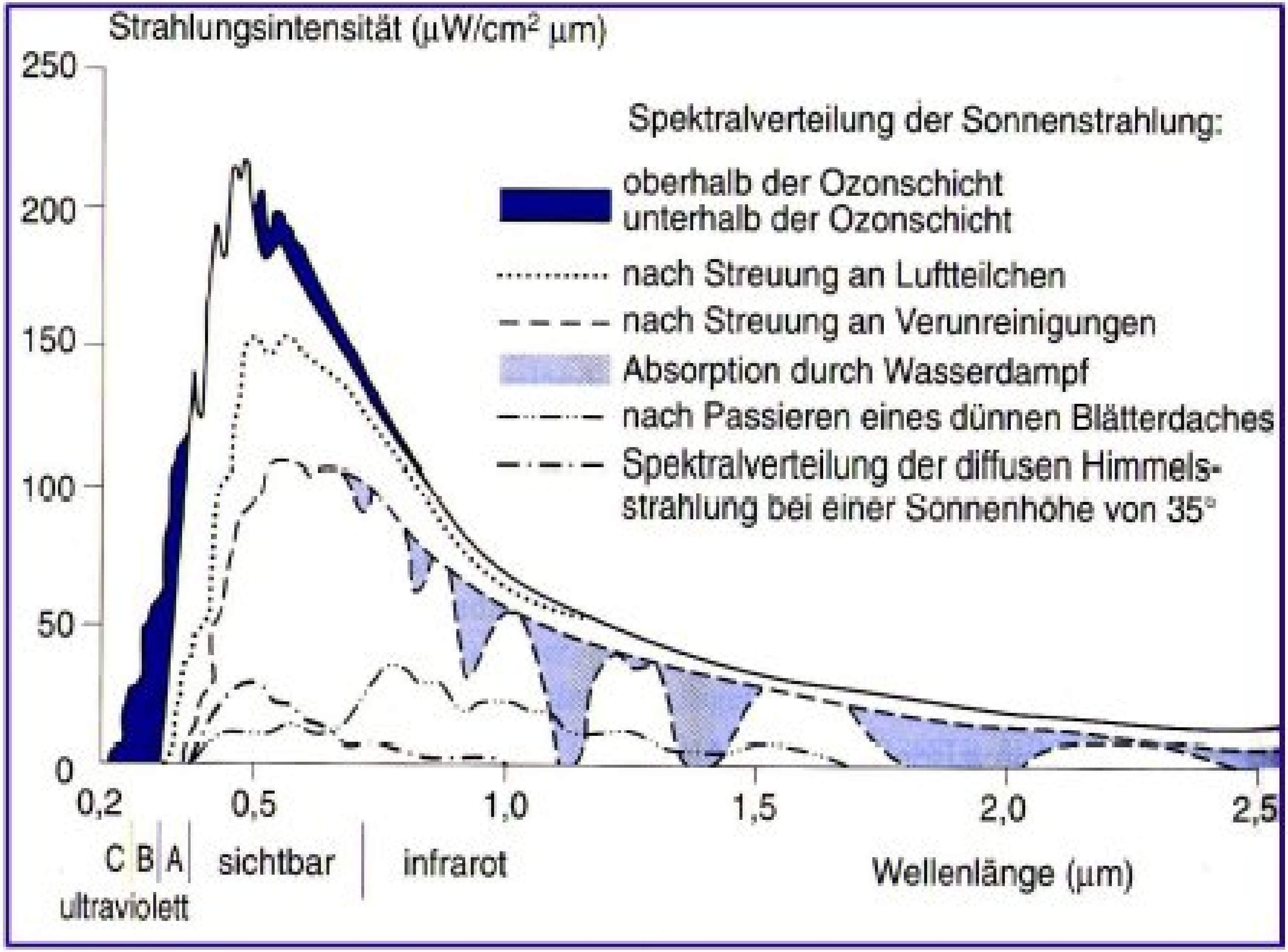
$$c = \nu \cdot \lambda$$

$$E = h \cdot \nu$$

$c = 3 \cdot 10^{8}\ m\ s^{-1}$ ... Lichtgeschwindigkeit
$h = 6{,}626 \cdot 10^{-34}\ J\ s$ ... Planck´sches Wirkungsquantum

The electromagnetic spectrum





Schönwiese, 2003

Wavelength range: Short waves

Global radiation :

(0.3 ... 3.0µm, maximum of 0.5µm): unit: W/m^2

Radiation source is the sun with 6000 degrees K

- **UV** (UVC: 0.01-0.28 µm, UVB: 0.28-0.31 µm, UVA: 0.31-0.38 µm)
- **Visible light**: 0.38-0.75 µm: The kind of radiation that plants use for photosynthesis, PAR (**Photosynthetic Active Radiation**) (makes up around 30% of global radiation)
- **Near infrared**: - around 3.0 µm

Wavelength range: Thermal or long waves

(3.0 ... 100µm, maximum of 10µm):
Radiation source is the Earth with around 287K

Unit: W/m^2

(known as irradiance)

- **Solar constant** :

Solar radiation intensity on the surface of the atmosphere

(on a plane normal for solar beams):

1369W/m²

Radiation fluxes

Short wave radiation:

+ Direct solar radiation

+ Diffuse radiation

- Reflected radiation

Long wave radiation:

- Emitted by the Earth

+ Downward terrestrial radiation

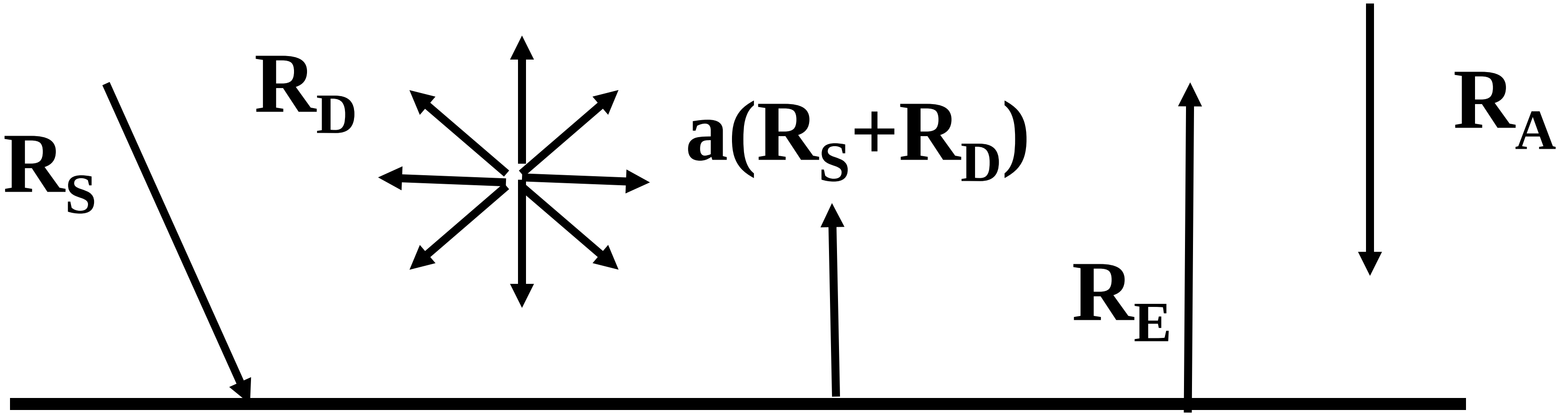
Radiation balance

Typical albedo values (%)

- Aluminium foil 90
- Dry concrete 17-35
- Black bitumen 10
- Red clay tiles 30
- New galvanised iron 45
- Rusty iron 10
- Thatched roof 15-20
- Window negligible
- Fresh white paint 75
- Red, brown, green paint 30
- Clean white car 54
- Dirty black car 10
- Caucasian human skin 40
- Negro skin 18

- Snow 80*
- Wet soil 10
- Dry sand, desert 40
- Rainforest 13
- Eucalypt forest 18
- Pine forest 13
- Grassland, vegetation 22
- Water with Sun above 3.5
- Water, Sun at 45° elevation 6
- Water, Sun at 25° 9
- Water, Sun at 10° 38

- Linacre (1992: 307)



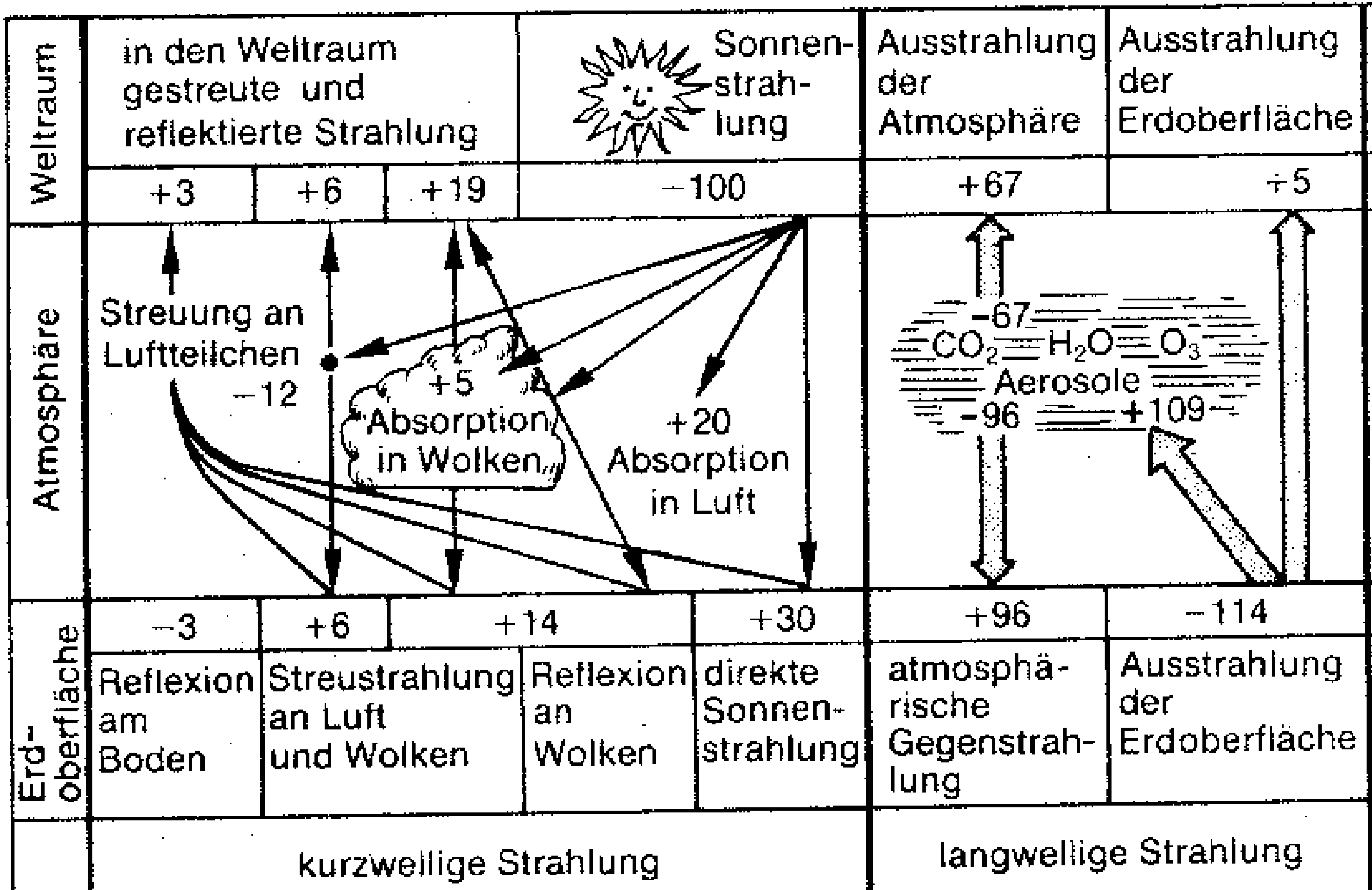
$$Rn = R_S + R_D - a(R_S + R_D) - R_E + R_A$$

short wave (solar) radiation 0.3 – 3 µm

long wave (terrestrial) radiation 3 – 50 µm

- Rn = Radiation balance
- R_S = Direct solar radiation
- R_D = Diffuse sky radiation
- a = Albedo
- R_A = Atmospheric radiation
- R_E = Radiation emitted by the Earth

Radiation balance



Diurnal variations of radiation fluxes during cloudy weather

$G = R_s + R_d$

$R = a(R_s + R_d)$

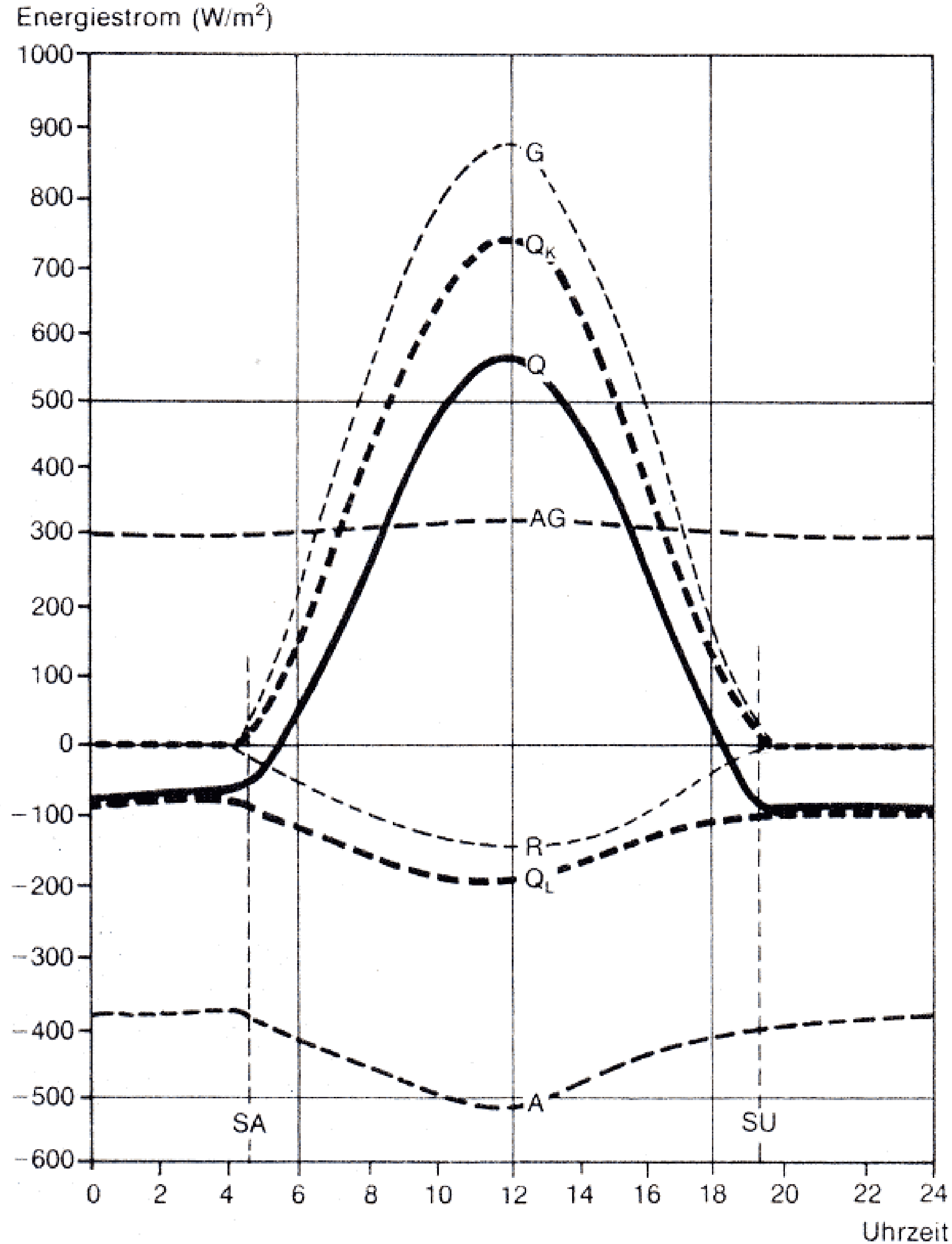
$Q_k = R_k$

$A = R_E$

$A_G = R_A$

$Q_L = R_L$

$Q = Rn$ (Radiation balance)



Energy balance as driving force of the water cycle

$0 = Rn - G - H - L.E\ (- \Delta S)$

Rn = Radiation balance
G = Soil heat flux
H = Sensible heat flux
L.E = Latent heat flux (evaporation)
L = Vaporization heat ($2.45 \cdot 10^6$ J/kg)
E = Amount of evaporated water
ΔS = Energy bound in biomass
Units : $MJ.m^{-2}\ d^{-1}$ od. $W.m^{-2}$

Energy balance

$0 = N - L.E - A - \Delta Sw + K - D$

N = Precipitation
L.E = Evaporation
A = Effluent
ΔS_W = Storage
K = Capillary suction, D = Drainage

Water balance

Effects of radiation on plants

- Energy source (photo-energetic effect)
- Development regulating impulse : Gives signal for germination, direction of growth, morphology (e.g. Elongated growth)
- Stress and damaging factor: (Photo-destructive effect, e.g. UV radiation)

Spectral range and effect of radiation on plants

			Wirkung			
Spektralbereich	Wellenlänge (nm)	eingestrahlte Sonnenenergie (%)	photosynthetisch	photomorpho-genetisch	photodestruktiv	thermisch
UV	<280–380	0–4	unbedeutend	gering	wirksam	unbedeutend
photosynthetisch aktiver Bereich (PhAR)	380–710	21–46	wirksam	wirksam	gering	wirksam
nahes Infrarot	710–4000	50–79	unbedeutend	wirksam	unbedeutend	wirksam
langwellige Strahlung	>3000	0	unbedeutend	unbedeutend	unbedeutend	wirksam

Larcher 2001

Radiative transfer (in plant cover) consists of ...

Diffusion :

Diffuse deflection of radiation quanta without changing the inherent energy

and **Reflection (Index: Albedo):**

A portion of the radiation that “bounces” back

Absorption:

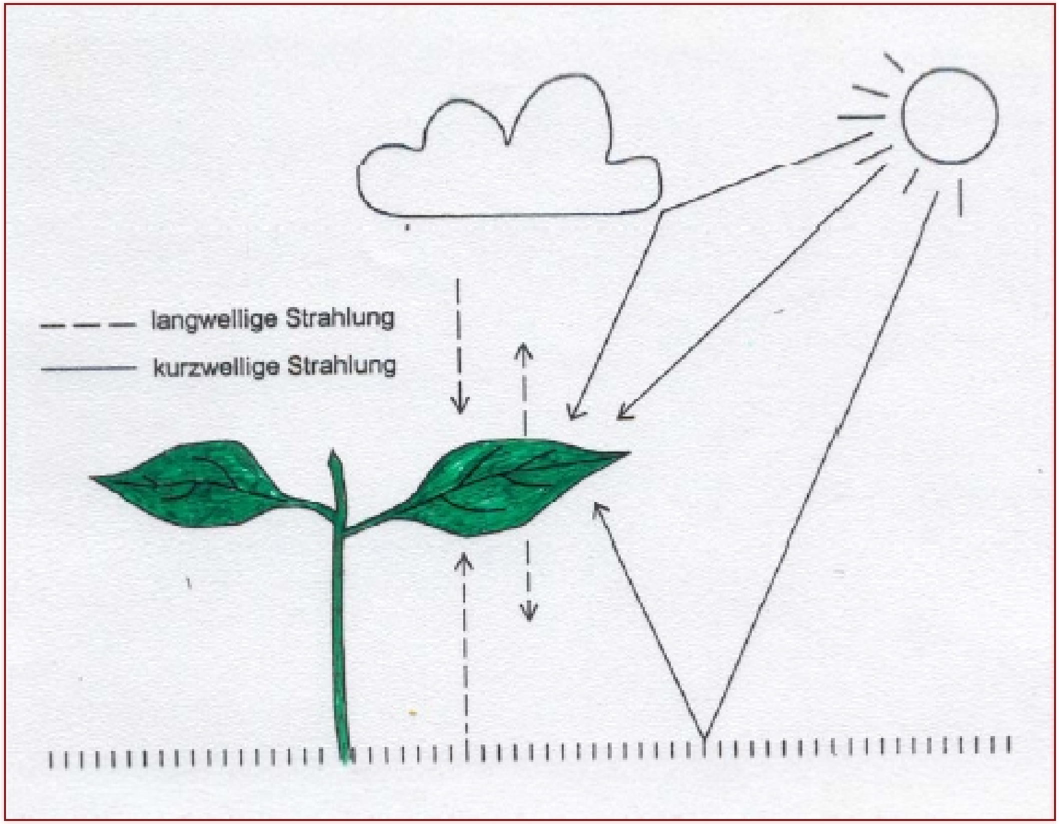
Energy uptake, absorption of “light quanta” excites chlorophyll molecules into an “animated” state. Chlorophyll molecules transferred to a higher energy level. Important for photosynthesis **!!**

Absorption by receptors: Chlorophyll a, b + Carotenoids (Location: Chloroplasts)

Transmission:

Portion of the radiation transmitted radiation (similar to reflection)

Individual plants in the field of radiation

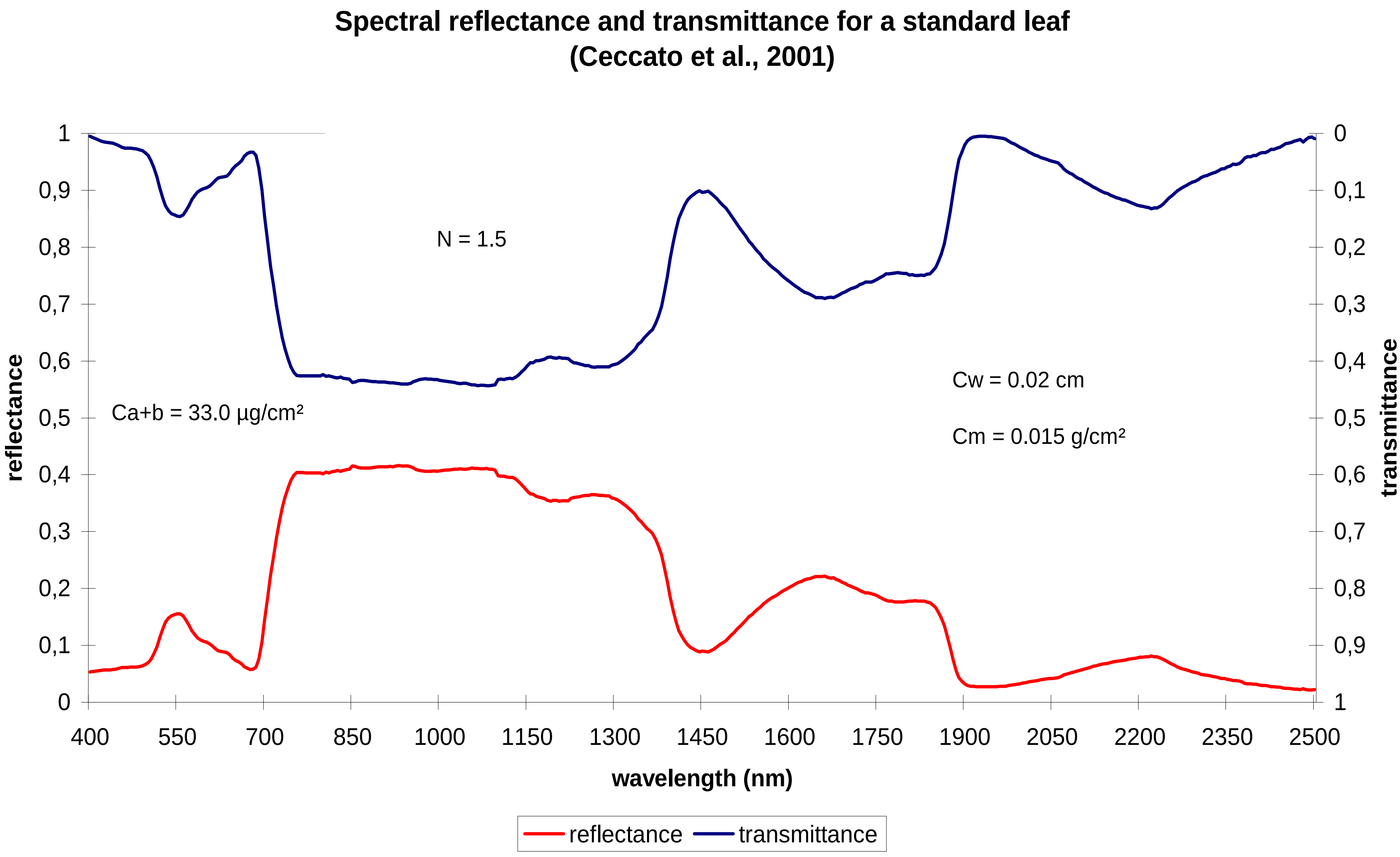


Reflexion: 6-10%

Absorption: 60-80%

Transmission: 10-20 %

Radiation processes in leaves: Dependence of transmission, reflection and absorption on wavelength



Radiation and Photosynthesis

Source of radiation (Energy source)

↓

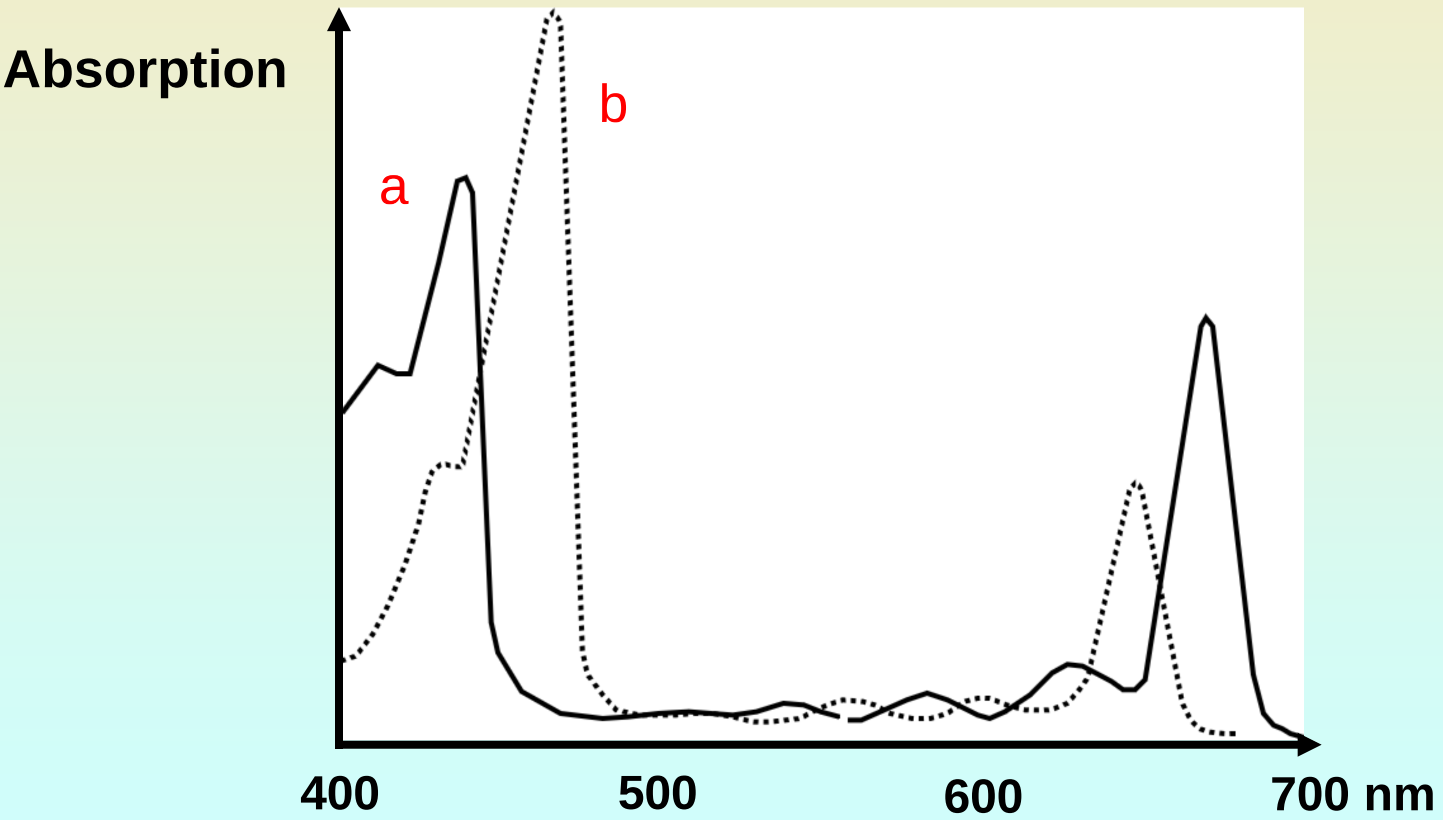
Energy uptake = **Radiation absorption of pigments**

↓

Effect = **Photosynthesis**

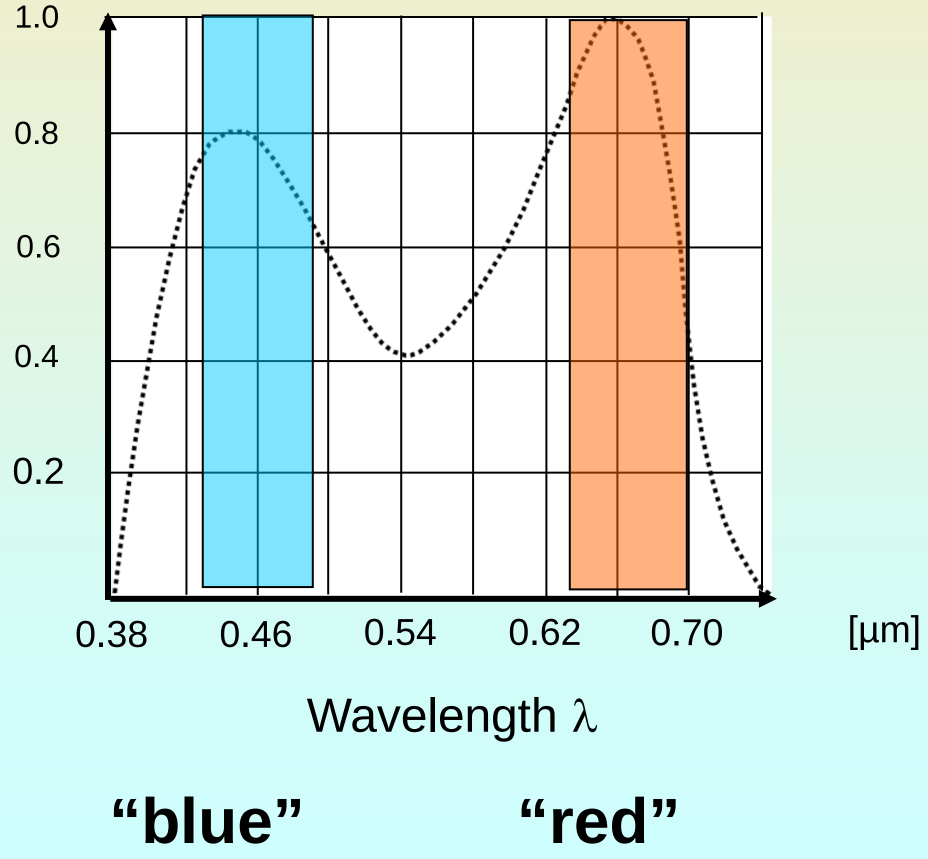
Photomorphogenesis

Absorption spectra of chlorophyll a and b



Adapted by RICHTER 1982

Two absorption maxima seen with the human eye as blue and red



- Maximum reflection of green- 0.55 µm,

(defined by photochemical behavior of Chlorophyll). This is why we see leaves as green!

- In infrared reflection increases above > 50% and transmission

(delivers important information about the state of the plant- remote sensing)

Photosynthesis in leaves and plant cover

Molecular formula of photosynthesis :

$$6CO_2 + 6H_2O + 2862\ kJ \Longleftrightarrow C_6H_{12}O_6 + 6O_2$$

Radiation

CO_2

Temperature …

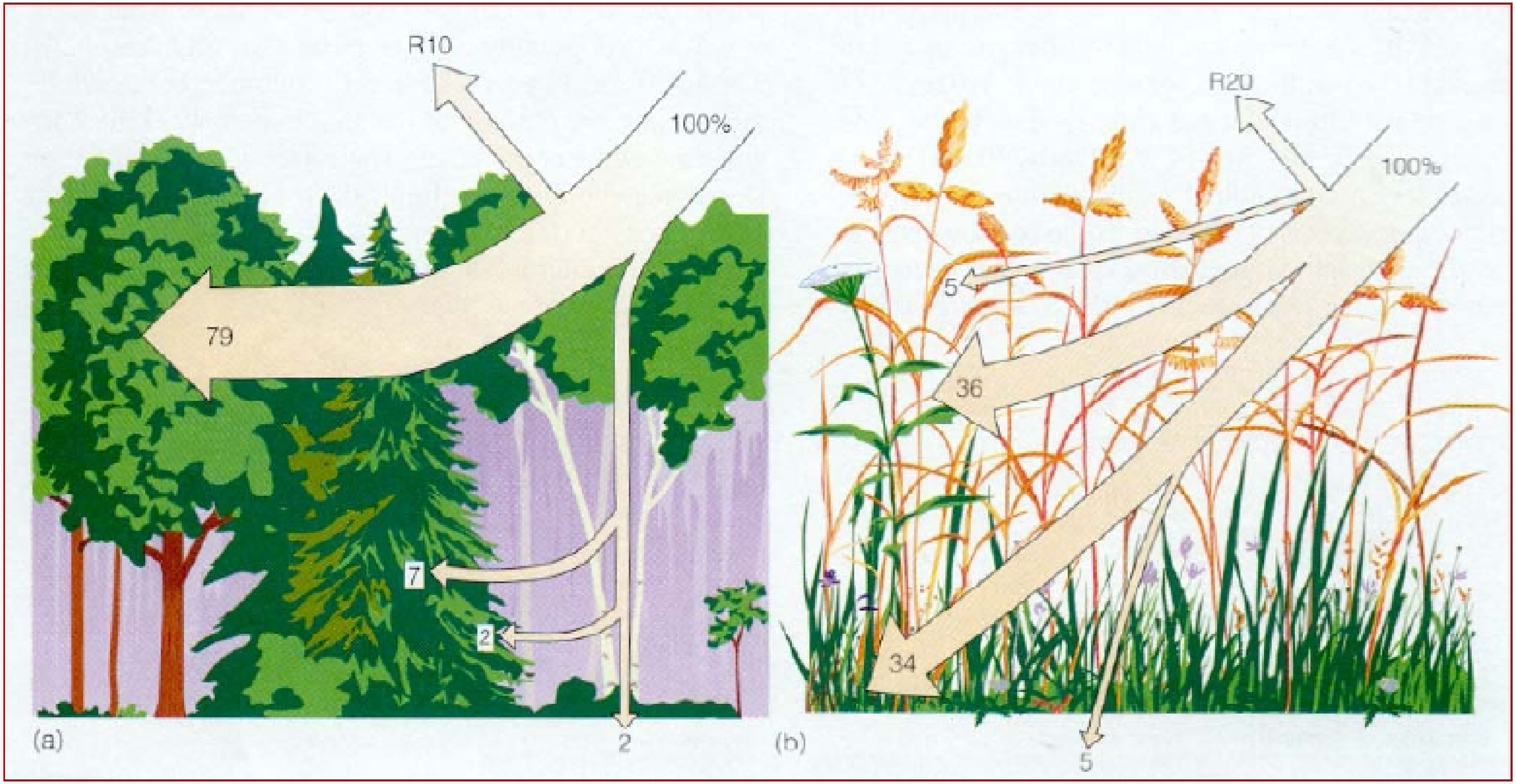
Structure of plant cover

Leaf surface

Light interception …

Photosynthesis leaf → Photosynthesis plant cover

Radiation distribution in plant cover



Form Larcher, 2001

Radiation extinction (irradiance attenuation)

…in plant covering depends on:

- **Distribution** of leaves
- **Leaf distribution** to incoming radiation
- **Foliage density** (LAI = leaf area index):

LAI [m²/m²] = $\frac{\text{Total leaf area}}{\text{Ground area}}$

(Measurement for degree of overlap)

Beer-Lambert Law

$$I = I_o * e^{-kLAI}$$

I ... Intensity of radiation at a specific distance from the top of canopy

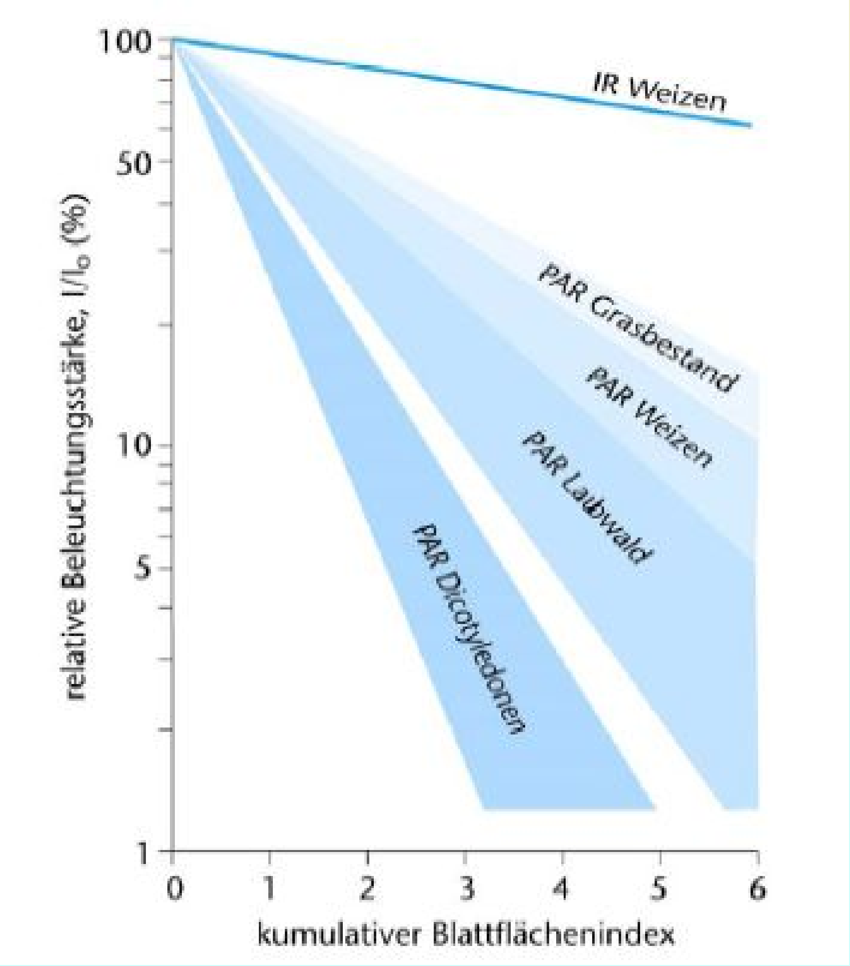
I_o ... Irradiation on the top of the canopy

k ... Attenuation coefficient

(specific for plant communities)

(e.g. grain, meadow: 0.3-0.5; forest, crop plants: 0.7-1)

LAI ... Leaf area index (m^2/m^2)



Reduction of PAR as a function of LAI