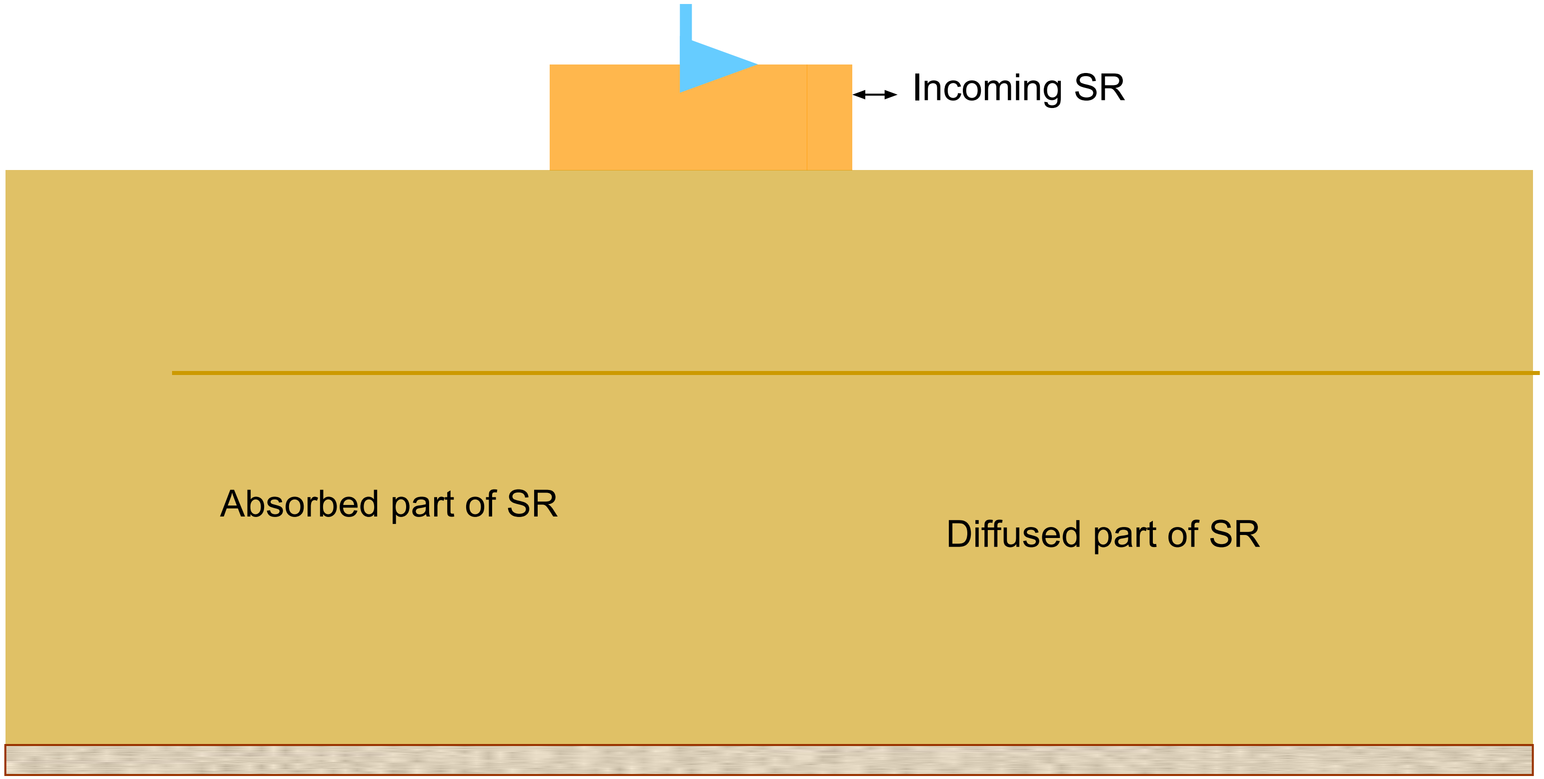
Solar radiation extinction in the atmosphere

Lecture 3

Incoming SR

When passing through the atmosphere SR undergoes significant changes

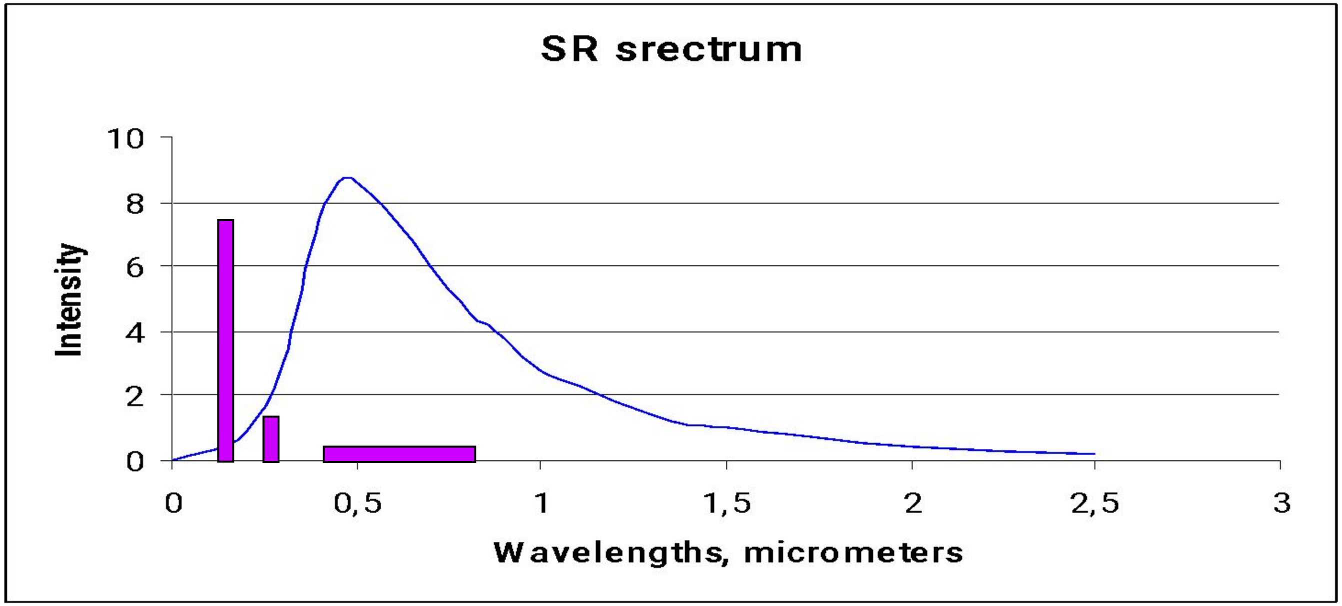


SR absorption

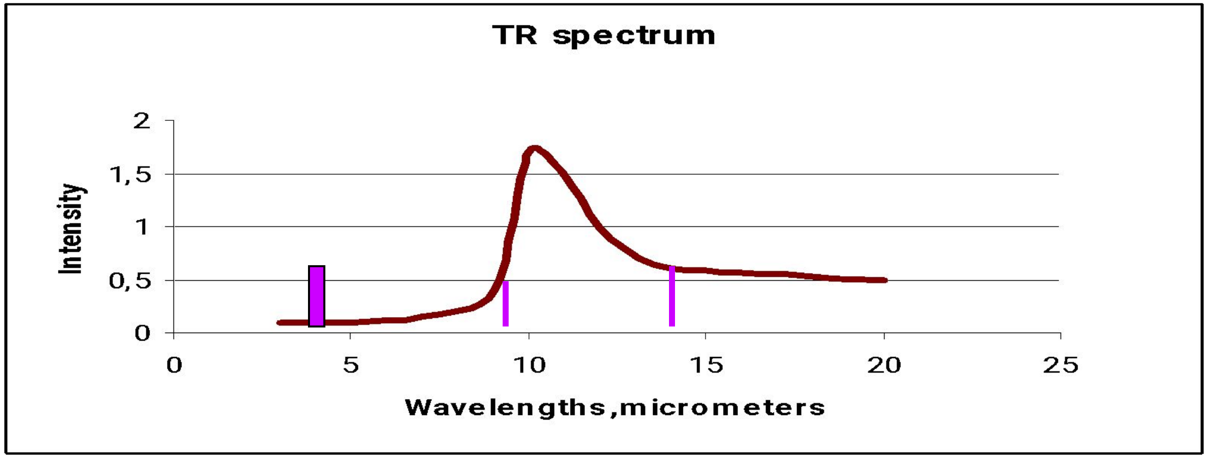
The main gases absorbing S radiation are

Ozone

Absorption bands	Volume coefficient of absorption, 1/cm	Rang of the spectrum
0,22 – 0,29	126,5	UV
0,31 – 0,36	0,79	UV
0,44 – 0,75	0,0594	Visible
4,75	<0,01	IR
9,6	<0,01	IR
14,1	<0,01	Distant IR



Ozone (O3) absorbtion



Oxygen

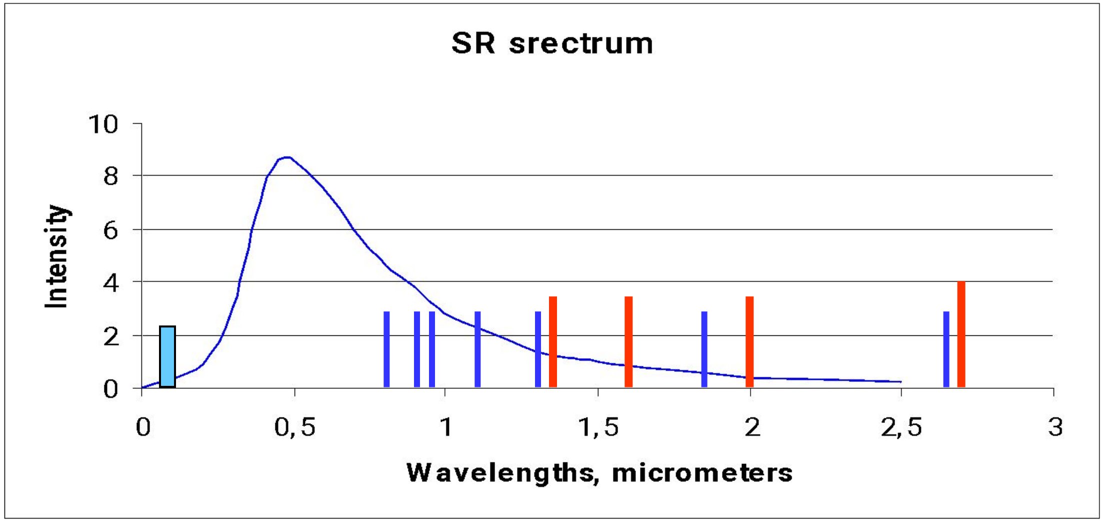
0,13 – 0,24

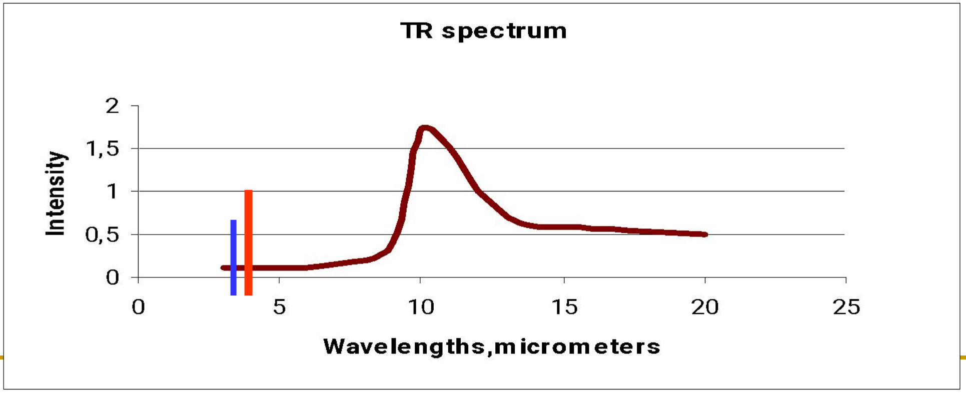
Water vapor

0,72; 0,84; 0,94; 1,14; 1,38; 1,87; 2,7; 3,2

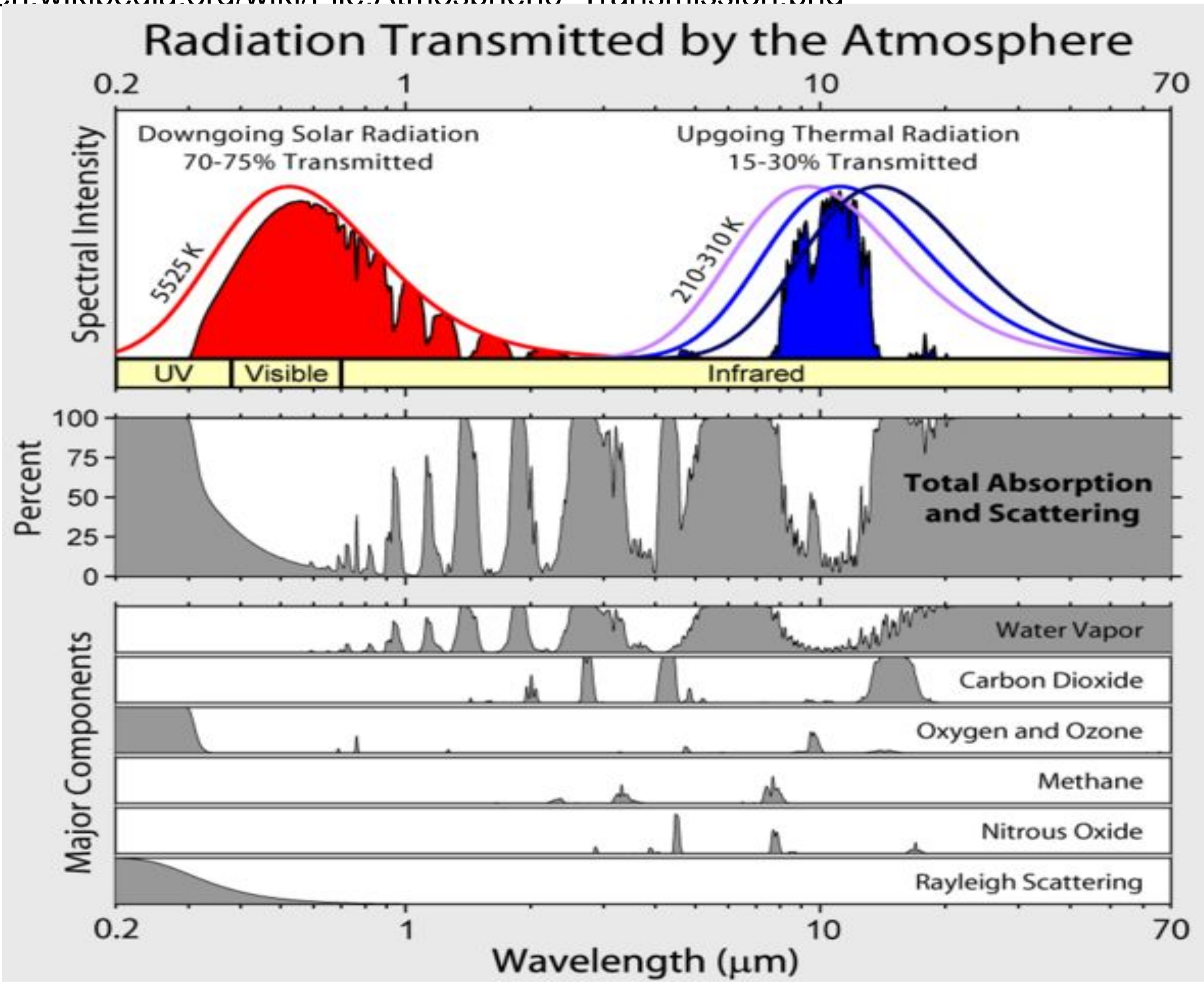
Carbon dioxide

1,44; 1,6; 2,02; 2,7; 4,31;





http://en.wikipedia.org/wiki/File:Atmospheric_Transmission.png



http://en.wikipedia.org/wiki/File:Atmospheric_Transmission.png

Water vapor transmission function

$$P(Q_v) = \sum_{i=1}^{3} b_i \cdot \exp(-\beta_i \cdot Q_v)$$

Q_v **is the mass of water vapor in a column of air with the base 1** m^2

b_i **and** β_i **are quantities empirically obtained.**

i	*b*	*β*
1	*0,077*	*5,83*
2	*0,145*	*0,145*
3	*0,778*	*0,002*

Mass of the water vapor in the atmosphere is larger than that of ozone and carbon dioxide. Hence, it absorbs the larger part of the total absorbed radiation.

Nitrogen does not absorb radiation. Solid aerosols also absorb SR. In the layer 0,3 – 8,4 km O_2 **and** CO_2 **absorb 3,8% and solid aerosols absorb 4,8% of SR.**

SR diffusion in the atmosphere

Terminology

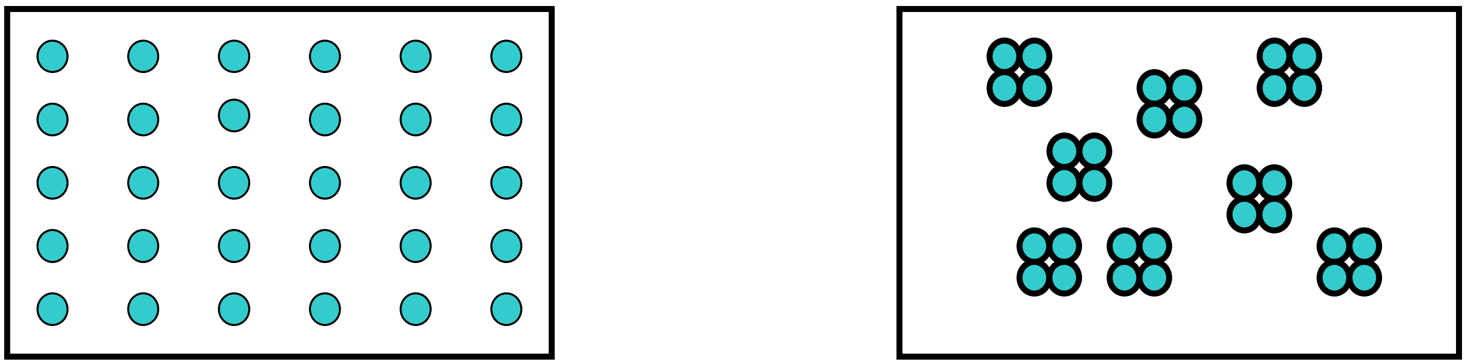
- **Diffusion** (произвольное рассеяние)
- **Scattering** (Разбрасывание в разных направлениях любых веществ, предметов и даже людей)
- **Dispersion** (синоним Scattering, в науке применяется к свету)
- **Turbidity** (мутность).

The atmosphere is *turbid* medium due to many admixtures (aerosols) suspended in the air.

Aerosols scatter and absorb solar and terrestrial radiation.

Molecular scattering or Rayleigh scattering

The atmosphere is turbid medium diffusing SR even in the absence of aerosols. In this case ***turbidity*** is ***molecular complexes.***



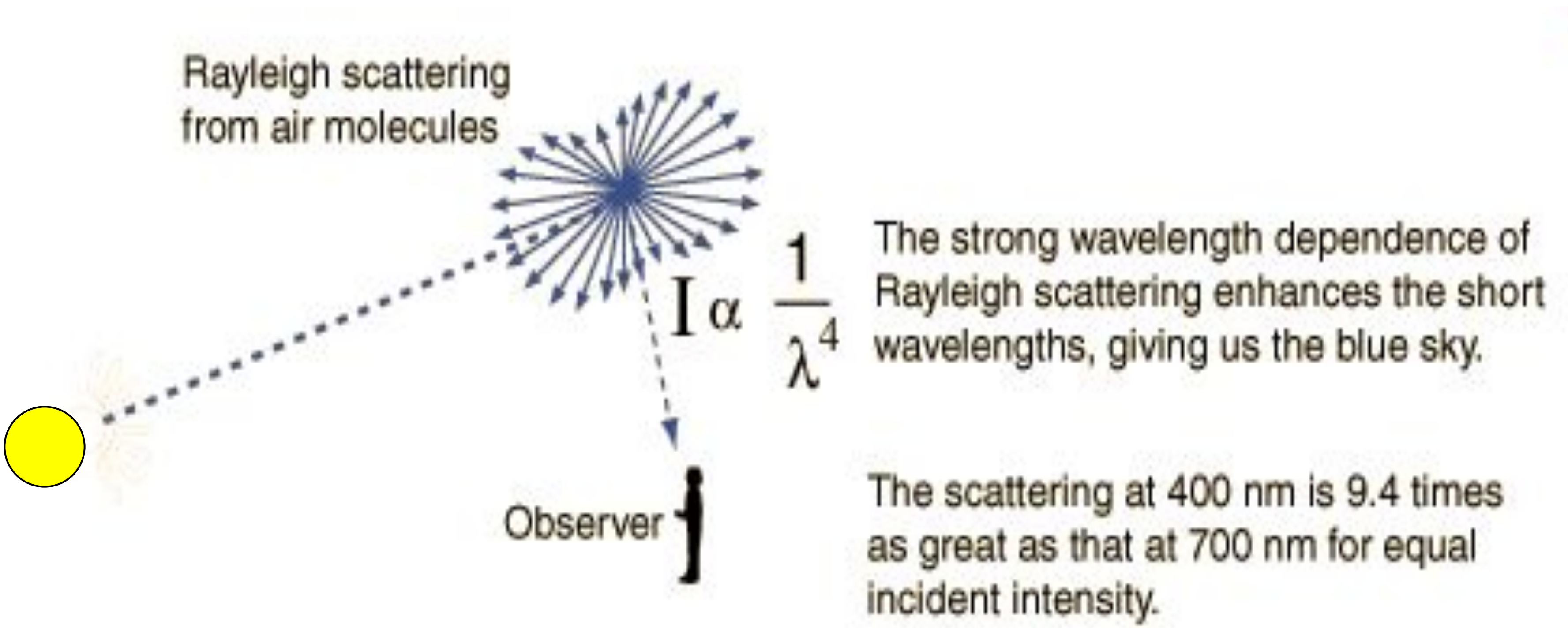
The essence of the scattering is a particular form of interaction between variable field of coming electromagnetic waves and particles in the medium. Due to this kind of interaction the particles become sources of new electromagnetic waves.

John William Strutt, third Baron Rayleigh

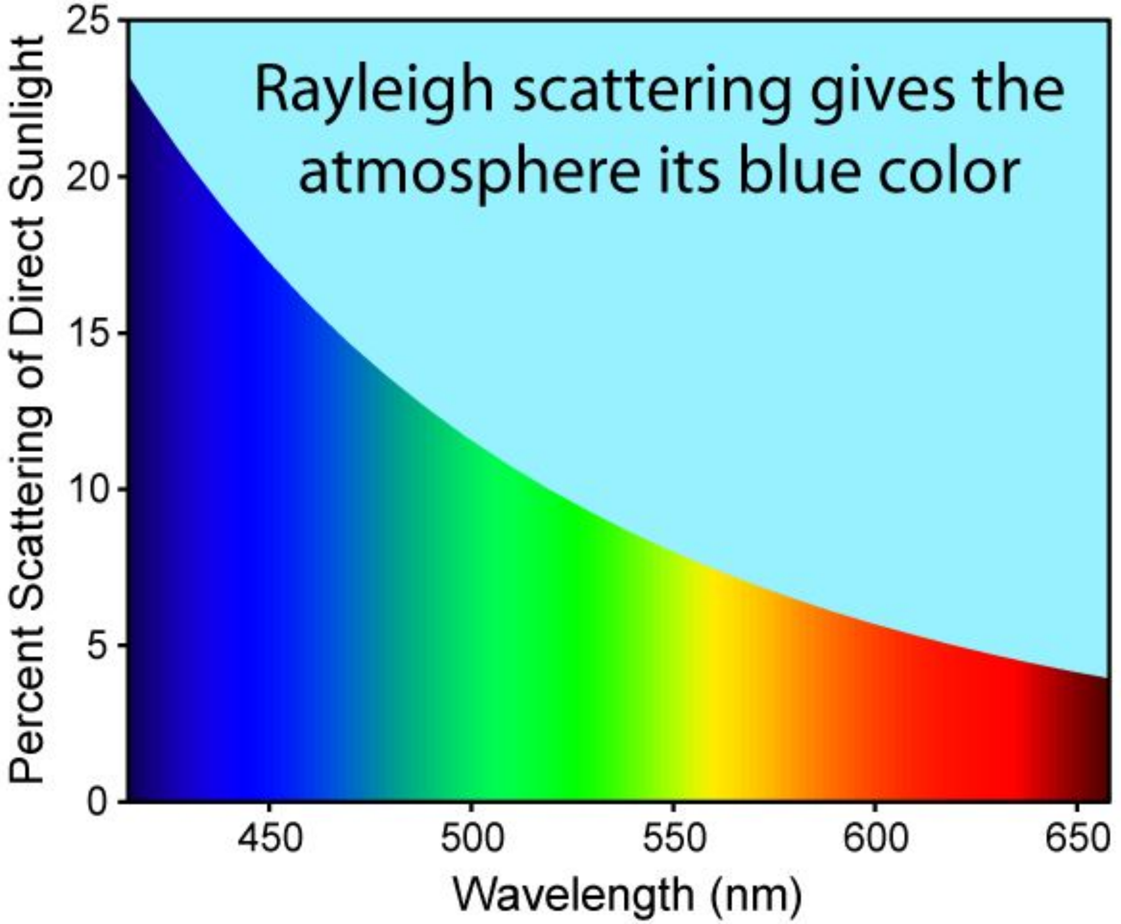
1842 - 1919

"Lord Rayleigh - Biography". Nobelprize.org. 22 Sep 2010
http://nobelprize.org/nobel_prizes/physics/laureates/1904/strutt-bio.html

Rayleigh scattering



http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html#c4


Rayleigh scattering gives the atmosphere its blue color
Percent Scattering of Direct Sunlight
0
5
10
15
20
25
450
500
550
600
650
Wavelength (nm)

Raman scattering

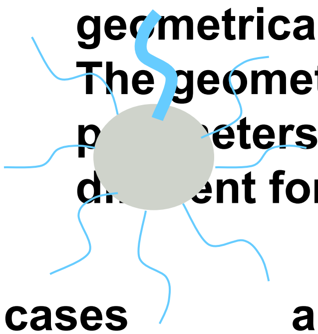
- Rayleigh scattering can be considered to be elastic scattering (the photon energies of the scattered photons is not changed)
- Scattering in which the scattered photons have either a higher or lower photon energy is called ***Raman scattering***.
- Usually this kind of scattering involves exciting some vibrational mode of the molecules, giving a lower scattered photon energy, or scattering off an excited vibrational state of a molecule which adds its vibrational energy to the incident photon.

Raman scattering

- C. V. Raman discovered the inelastic scattering phenomenon which bears his name in 1928 and for it he was awarded the Nobel Prize for Physics in 1930.

Molecular scattering (Continuation)

The incident radiation flux of a definite wavelength makes fluxes of the radiation of the same wavelength.



This process is greatly influenced by the geometrical structure and properties of the turbid medium. The geometrical structure is determined by dimensionless parameters r/λ and L/λ. The laws of scattering are quite different for the cases $r << \lambda$ and $r \geq \lambda$.

If $L/\lambda >> 1$, the particles can be regarded as independent emittants.

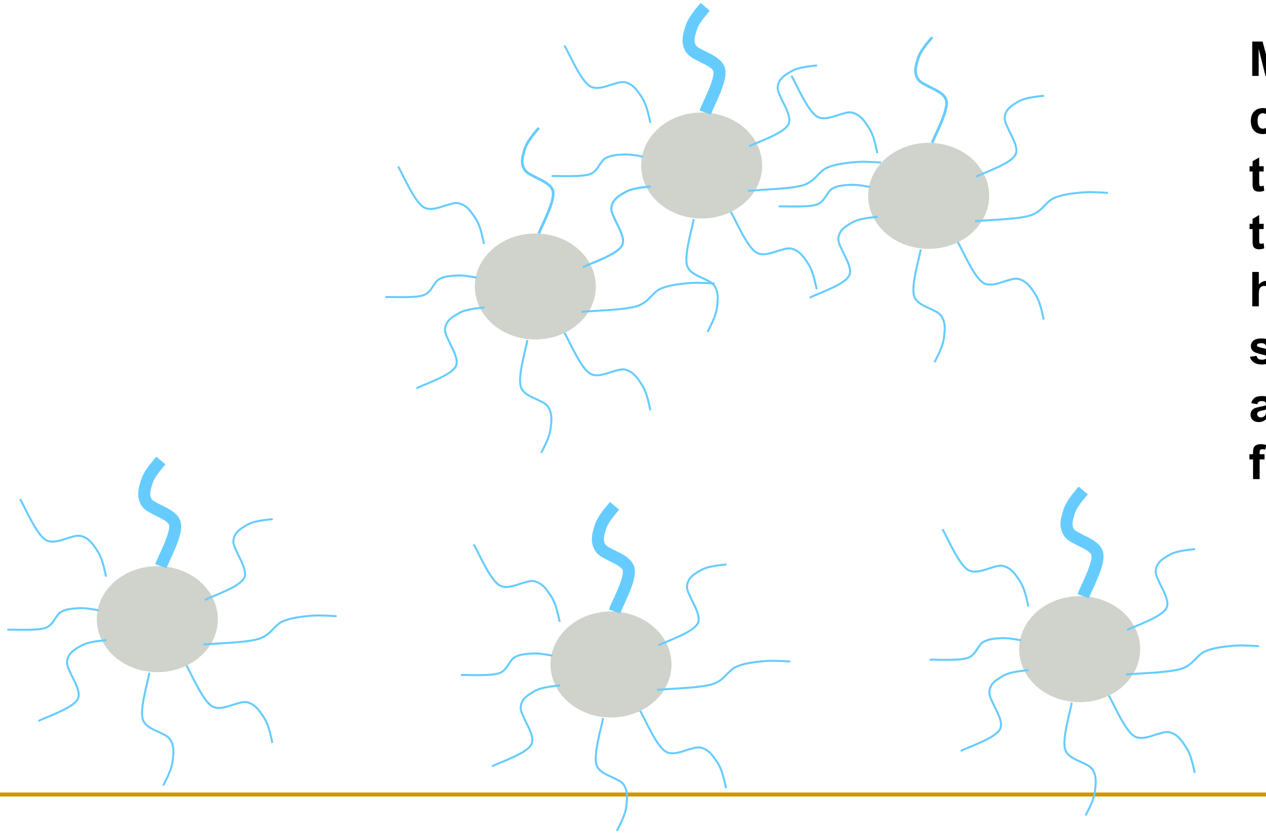
The phenomenon of interference will not be observed.

No additional fields of radiation will appear.

Instead, the intensities of the radiation will be summed up. This simplifies solution of the problem of, so called, *multiple scattering*.

Multiple scattering

Multiple scattering is the result of diffusion of the previously scattered radiation.



Multiple scattering can be neglected if the medium turbidity is not very high, i. e. the scattering particles are very distant from each other

Physical properties of the scattering fields

The main characteristics of the properties is *complex index of refraction*.

$$m = n(1 + i\chi)$$

$n = c/v$ **is absolute index of refraction**

χ **is characteristics of absorption** $4\pi\chi = k\lambda$

The theory of the molecular scattering had been developed by English scientist Rayleigh, who put in the base of the theory the following assumptions:

1. All particles have form of a ball. They are dielectrically homogeneous and *r<<λ.*
2. Particle index of refraction does not markedly differ from that of the medium: **nμ<1** and **μ=2πr/λ.**
3. The particles diffuse the light independently, I. e. **L>>λ**
4. The diffused light is observed at the distance **R>>r**

Aerosol scattering

Mie theory (also called Lorenz–Mie theory or Lorenz–Mie–Debye theory)

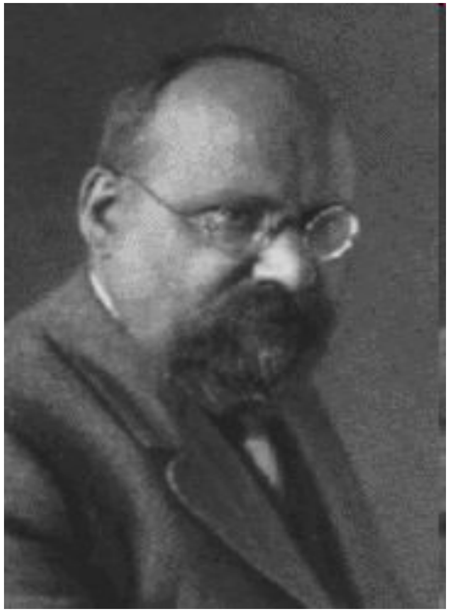
Aerosol particles are much larger than molecule complexes

There are two types of the larger particles in the atmosphere: non-transparent ones (dust, $n = \infty$), and transparent ones (water droplets).

Water droplets absorb radiation of ultraviolet and visible parts of the spectrum just slightly. Absolute index of refraction for water droplets varies not significantly. It average value *n=1,33.*

n* *is absolute index of refraction

Gustav Mie,
German physicist



1869 –1957

The volume coefficient of extinction for larger particles

$$K_\lambda = \pi r^2 K(\mu, m) N$$

$K(\mu, m)$ is a function of quantity

m - complex index of refraction, $\mu = 2\pi r / \lambda$

N is the number of particles in a unit of volume.

For very large particles (*10*<*r*<*40μ*)

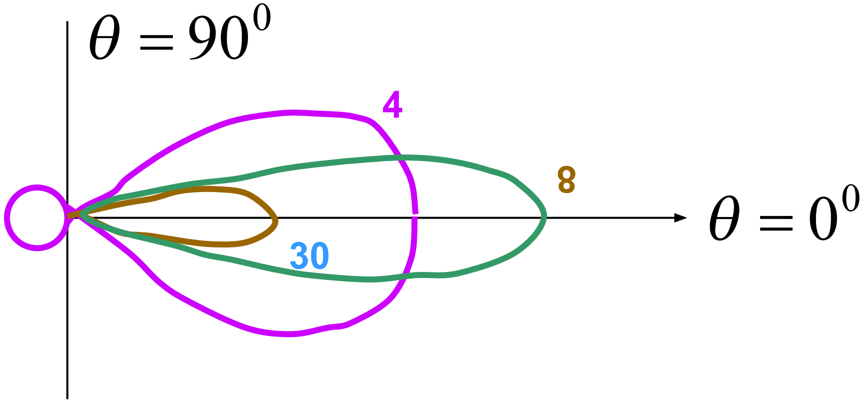
In case r>40 μ, the scattering does not depend on wavelength.

$$K_\lambda = 2\pi r^2 N$$

If many particle of this size are present in the atmosphere the sky becomes of whitish color (instead of light blue) due to the fact that the light dispersed in the same way regardless which wavelength is dispersed.

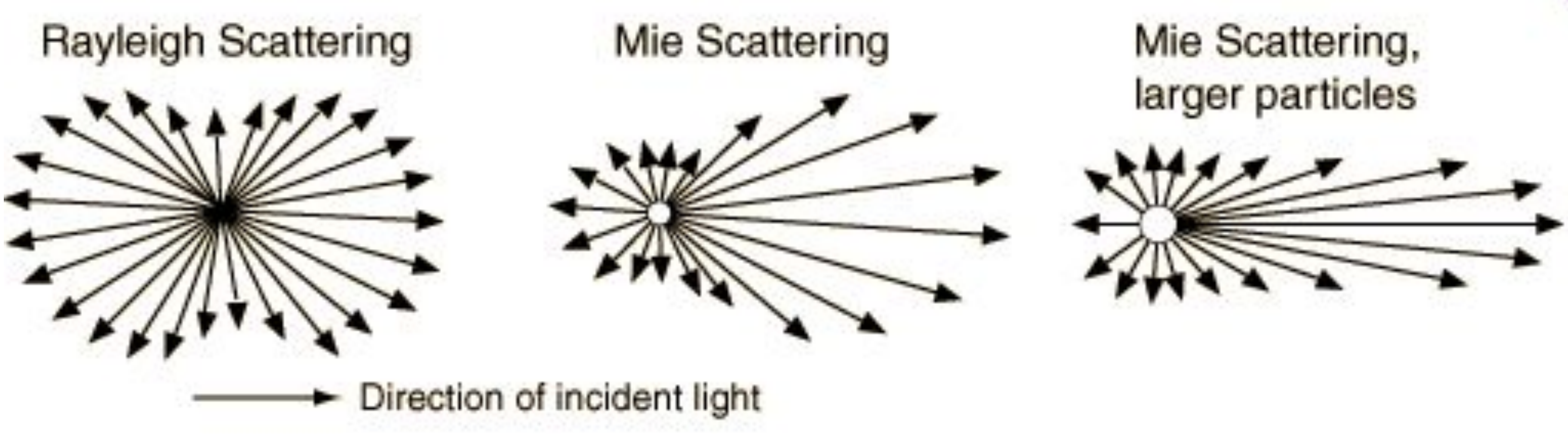
Due to the same reason, clouds and fogs have white (whitish) or gre`y color.

Scatter indicatrix for several values of parameter μ.



The larger particles mainly scatter in the direction of incident beam http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html#c4

- Scatter indicatrix is a vectoral diagram depicting dependence of scattered radiation on direction.



http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html#c4

Simultaneous molecular and aerosol scattering

Since in the atmosphere some kind of aerosols always exists, both molecular and aerosol scattering goes on simultaneously.

It makes difficult to estimate real scattering quantitatively from the theoretically obtained equations. Instead some empirical or semi-empirical relations are used for the purpose. It was learnt that regularities of the scattering *<u>strongly depends</u>* upon the sizes of the particles, and, first of all, on the *<u>water droplet</u>* sizes.

Very important characteristics is so called *scattering index K_λ.*

$$K_\lambda(z) = K_{\lambda,m}(z) + K_{\lambda,a}(z)$$

Prevails above 3 – 4 km ← **Molecular scattering index** ($K_{\lambda,m}$)

Aerosol scattering index ($K_{\lambda,a}$) → **Prevails up to 3 – 4 km**

$$K_\lambda = \alpha_\lambda \rho$$

$$\rho = \rho(z)$$

$$\frac{\partial \rho}{\partial z} < 0 \Rightarrow \frac{\partial K_\lambda}{\partial z} < 0$$

$K_{\lambda,a}$ *depends on* ***turbidity***

$$S_m = S_m(K_\lambda)$$

$S_m(visibility)$ *depend on* ***turbidity*** *too*

Optical depth of the atmosphere

The volume extinction index summed up through the whole atmosphere is termed *optical depth of the atmosphere.*

$$\tau_\lambda = \int_0^\infty K_\lambda(z)\,dz$$

λ, μ	0,30	0,34	0,45	0,60	0,80
$\tau_{\lambda,m}$	1,22	0,72	0,22	0,07	0,02
τ_λ	1,97	1,05	0,46	0,30	0,19

$\tau_{\lambda,m}$ is the optical depth caused by molecular scattering, and τ_λ is that caused by the total scattering.

In the ultraviolet area (λ<40μ) the molecular scattering makes the larger contribution in the total scattering, at λ=0,45 both contribution are almost equal, at λ>0,45 aerosol scattering contribution prevails.

What is the type of scattering below?

The beam of a 5 mW green laser pointer is visible at night due to Rayleigh scattering and airborne dust.

http://en.wikipedia.org/wiki/Rayleigh_scattering

Which type of scattering is presented?

Рерих Н.К. "Величайшая и Святейшая Тангла "

Beijing's sky