Measure of Backscatter for small particles of atmosphere by lasers

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Abstract. It developed a program for the atmosphere to study the backscattering for contents gas &Molecules, Aerosol, Fog, clouds and rain droplets. By using Rayleigh, Mie and geometric scattering. The aim of research Using different types of lasers from various optical region to calculate differential cross scatter section and backscatter of atmosphere component in one layer from height 10-2000m. 180° is backscattering angle using ISA standard sea level condition P=1013.25 ( kpa) at t° =15 ° C.and then calculated the density of molecules and water vapor molecules represented D in kg/m3 .Results reflected index consist of the large value of the real part and imaginary m=1.463-0.028i.this research diff. scatter cross section of different component of atmosphere layer decreased vs. wavelengths . The purpose of lider research to find backscatter from UV to IR laser within the optical range in the atmosphere and measurement of excitation and analysis of backscatter signals. Recently, the atmosphere of Iraq has become full of dust and pollution, so by knowing the differential cross scatter section and backscatter of atmosphere. Relation between total Rayleigh scatter coefficient & type of particles include fog and clouds, Aerosols and Water Droplet (-0.01, 0.025, -0.005) m-1/sr-1.

1. Introduction
Light strikes a medium, it is scattered or absorbed. Scattering is the spread of light in several directions are far away from original direction after collision with a specific particle and include several physical meanings are, Reflection, refraction, diffraction etc. All just forms of scattering.

The atmosphere interaction of importance in determine the received lidar signal elastic process Mie scattering when d)>>λ (aerosols) and Rayleigh scattering (d<<λ) when interact with some gas molecules.

Rayleigh [1] is the elastic scattering of light by particles much smaller than the wavelength of the radiation. Rayleigh scattering does not change the state of material; hence it is parametric process [2]. Whose size is similar to the wavelength such as water droplets in the atmosphere is necessary [3].

Mie scattering, make it is useful formalism when using scattered light to measure particle size Kear et., al[4] Mie theory is used in commutations applied in laser diffraction analysis. It is widely used since the 1990s and officially recommended for particles below 50 µm [5].

The various of sky colour at sunset, from red to the blue is caused by Rayleigh scattering by atmospheric gas particles which are much smaller than the wavelengths of visible light, also the ratio of grey/white colour of the clouds is caused by Mie scattering by water droplets when are of compare that size of the wavelengths of visible light [5].LIDAR is brief of light detection and ranging use light matter interaction. The LIDAR system based on the fundamental second and third harmonic emission lines of Nd: YAG laser collected the backscatter Raman return from nitrogen at visible and ultraviolet
wavelengths. In addition, the water vapor Raman–shifted backscatter return from UV laser line is used to retrieve the water vapor as a function of relative humidity [6]. During previous researches Eldlen [7], Owens [8] presented an in-depth treatment of indices of refraction at CO$_2$ in free air, pure CO$_2$ and water vapor, their opinions were provided for dependence on temp., pressure and compositions. Dr. Fouad Ismail is studied some of the atmospheric effects (aerosols and rain) on three specified laser beams (785, 850, and 1550) nm, like absorption and scattered of (Mie and Rayleigh) for the atmospheric, with horizontal propagation range between (0.01–4) km at a stander condition in a middle summer season [9]. That study of some atmosphere effect in Baghdad city to calculate the average transmittance.

2. Theory
Light interaction with matter was three kinds of scattering [10] include: Elastic scattering – the wavelength (frequency) of the scattered light is the same as the incident light (Rayleigh and Mie scattering). Inelastic scattering – the emitted radiation has a wavelength different from that of the incident radiation (Raman scattering, fluorescence) and Quasi-elastic scattering – the wavelength (frequency) of the scattered light shifts (e.g., in moving matter due to Doppler effects). Size of the diffuser is that Rayleigh (d<1) and Mie d~1 and geometric d>>1, where d is the dimensionless size parameter is given by:

$$d = \frac{2\pi r}{\lambda}$$

(1)

Where r is the particle radius of diffuser, and λ is the wavelength of incident radiation. The refractive index of the scattering particle, is commonly represented by the complex nature as:

$$m = n - ik$$

(2)

Complex refractive index, where the real part (n) no absorbing part and imaging part (k) represent the absorbing part. The scattering parameters can express for the Rayleigh and Mie solutions by using coordinate system can be seen in ‘Figure 1’.

![Figure 1. Coordinate geometry for the Rayleigh and Mie scattering [10].](image)

The Rayleigh differential scattering cross section for polarized, monochromatic light is given by [11]:

$$\frac{d\sigma_R}{d\Omega} = \left[ \frac{n^2 (n^2 - 1)^2}{N^2 \lambda^4} \right] \left[ \cos^2\Phi \cos^2\Theta + \sin^2\Phi \right]$$

(3)

where n is the index of refraction of the atmosphere, N is the density of molecules, λ is the wavelength of the optical radiation, and φ and θ are the spherical coordinate angles of the scattered polarized light referenced to the direction of the incident light. Equation (3), shorter-wavelength light (i.e., blue) is
more strongly scattered out from a propagating beam than the longer wavelengths (i.e., red), which is consistent with the preceding comments regarding the color of the sky or the sunset.

The total Rayleigh scattering cross section can be determined from Eq. (3) by integrating over $4\pi$ steradians is obtained [12]:

$$\sigma_R(\text{total}) = \left[\frac{8}{3}\right] \left[\pi^2 (n^2 - 1)^2 / N^2 \lambda^4\right]$$

(4)

The total Rayleigh scattering extinction coefficient as:

$$N\sigma_R(\text{total}) = 1.18 \times 10^{-8} \left[\frac{550(\text{nm})}{\lambda}\right]^4 \text{ cm}^{-1}$$

(5)

The molecular Rayleigh backscatter cross section for the atmosphere (r =180 $^\circ$) has been given by Collins and Russell for polarized incident light (and received scattered light of the same polarization [12]:

$$\sigma_R = 5.45 \times 10^{-20} \left[\frac{550(\text{nm})}{\lambda(\text{nm})}\right]^4 \text{ cm}^2 \text{ sr}^{-1}$$

(6)

$$\sigma_r(\lambda) = 5.45 \times 10^{-32} \left[\frac{550}{\lambda}\right]^{4.09} \text{ m}^2 \text{ sr}^{-1}$$

(7)

The efficiency to scatter light is found to be analytically in the case of spherical molecules:

$$Q_{\text{scat}} = \frac{8}{3} \left(\frac{\pi d}{\lambda}\right)^4 \left[\frac{m^2-1}{m^2+1}\right]^2$$

(8)

Where $Q_{\text{scat}}$ is the scattering efficiency. The ratio $\pi d/\lambda$ is called the size parameter, $m$ is index of refraction, $d$ is the diameter of the molecule and $\lambda$ the wavelength. The scattering coefficient due to nm spherical molecules will be:

$$\sigma_m = \frac{n_m}{n} \pi d^2 \frac{Q_{\text{ext}}}{3} \frac{32\pi^2 (m-1)^2}{3 \lambda^4} k \left(\frac{T}{\delta}\right)^{6+\delta}$$

(9)

Where $K$ is the Boltzmann’s constant, $T$ is the temperature and $P$ is the pressure; $\delta$ is a correction factor (depolarization factor) which accounts for the anisotropy of the molecules.

The efficiencies of the particles are calculated for scattering ($Q_{\text{scat}}$), backscattering ($Q_{\text{back}}$), and extinction ($Q_{\text{ext}}$). The relationships for extinction, scattering, backscattering and absorption efficiencies (which are functions of $r$, $\lambda$ and $m$) respectively [13].

3. Material and Method

A model put to measure the matter vertical distribution use differential backscatter laser technique requires the simulated emission of two laser beams, $\lambda_1 = 551.3784$ $\mu$m and $\lambda_2 = 991.4376$ $\mu$m. The light detected and ranging system includes several laser sources, optical devices to reduce the divergence, telescope to collect light scattered back. Optical analyzer system with detectors such as: interference filters or spectrometers. Input the program atmosphere some parameters such as depolarization factor 0.035, pollutant concentration ratio 0.05 and gas constant (R) in 8.314 (J/mol.K)

Use one layer of atmosphere is height from 10-20000 (m) and scattering angle degree $\theta = 180^\circ$ [10] $180^\circ$ is backscattering. Using different type lasers rang resolved measurements can be obtained using (pulsed lasers). A model put to measure the matter vertical distribution use differential backscatter laser technique requires the simulated emission of two laser beams, $\lambda_1 = 551.3784$ $\mu$m and $\lambda_2 = 991.4376$ $\mu$m. This research base of program atmosphere in one layer to be calculated .using ISA standard sea level condition $P=1013.25$ (kPa) at $t_0=15^\circ$C. and then calculated the density of molecules and water vapor molecules represented D in kg/m$^3$, can calculated by pressure of dry air $P_d$ pressure of water vapor $P_v$, to get total air pressure $P=P_d+P_v$. Where gas constant for dry air $R_d(kg*K)=287.05=\frac{R}{M_d}$ formula to determine the saturation vapor pressure [12] and vapor pressure
from relative humidity. Scattering (Rayleigh, Mie and geometric). the section of lidar system as shown as in ‘Figure 2’.

![Lidar system diagram](image)

**Figure 2.** Represent the diagram of some parts of a lidar system [13]

4. Results
Using different types of lasers from various optical region such as Ruby (\(\lambda=694\) nm), Nd:YAG (NIR \(\lambda=1064\) nm) with optical parameter oscillation (OPO Oscill) and second harmonic oscillator (SHO) by using nonlinear tech. to get lasers output with a suitable wavelength for optical communication such as (266, 355, 532) nm and NaCl Excimer laser (213 nm). Dye laser, Alexander, Ruby, diode lasers, CO and CO\(_2\) and then calculated the density of molecules and water vapor molecules represented D in kg/m\(^3\). Results reflected index consist of the large value of the real part and imaginary \(m=1.463-0.028i\) is a value contain real and imaginary parts wave number \(k=2\pi\) are function of wavelength \(\lambda\) since \(d=kr\). For all values of the total differential scattering cross section due to of laser wavelengths. When wavelengths increased vs. decreased of diff. scatter cross section of different component of atmosphere layer. Data are presented in table 1, forward and backscatter for different particle component of atmosphere by satisfy of equation (7).

| Wavelengths (nm) | total diff. scatter cross section ( m\(^2\)/molecules .sr) |
|------------------|----------------------------------------------------------|
| 213              | 0.9999683                                                |
| 266              | -9.082651E-3                                            |
| 355              | 7.8736169E-5                                            |
| 532              | -6.1117958E-7                                           |
| 694              | 4.3884187E-9                                            |
| 1064             | -2.9883885E-11                                          |
| 1550             | 2.1874425E-13                                           |
| 1600             | -1.7892321E-15                                          |
| 10600            | 1.111201E-17                                            |
The results in the table 2 showed that the components of atmosphere in one layer, the program atmosphere have given total Rayleigh scatter coefficient \((m^{-1}/sr^{-1})\) the backscatter by using equation (9) for the scattering coefficient due to nm spherical molecules as shown in table 2.

| total Rayleigh scatter coefficient \((m^{-1}/sr^{-1})\) | Types of Particles |
|------------------------------------------------------|---------------------|
| 6.5                                                  | Molecules & Gas     |
| -0.01                                                | Aerosols           |
| 0.025                                                | Fog & Clouds       |
| -0.005                                               | Water Droplet       |

5. Conclusion
In this program, all types of laser have been given Rayleigh backscattering unless Nacl Excimer \((\lambda=213\text{ nm})\), studied forward and backscatter with use Nd:YAG (opooscill) with different cross section \((6.1E^{-7} - 4.38E^{-9})m^{2}/molecules.sr\)

It is observed from values of total diff. scatter cross section that decrease by increasing the wavelengths. These values fluctuated due to the diffusion of light between the various components in the size of atmospheric component produced the complex interactions of scattered rays that results to different paths with the same scattering angle 180 degree. Note the wavelength for 213 nm and 10600nm, hence these cross-sections vary by forward and backscatter during 9 values between value and other of total Rayleigh backscatter cross section and total Rayleigh scatter coefficient is great value in gas and molecules.

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