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Research Article

STUDYING THE PHYSICAL PROPERTIES OF INELASTIC SCATTERING OF LIGHT FROM MEDIA

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ABSTRACT

This work is devoted to the study of physical properties of inelastic scattering of light from different media as a result of intermolecular interaction. Intermolecular interaction plays a major role in studying the basic properties and physical nature of substances. In order to study the nature and mechanism of the intermolecular interaction of liquids, the process of formation of the combined scattering spectra of light, which is the most effective among various optical methods, and the optical properties were studied.

KEYWORDS

Inelastic, antistokes, stokes, dipole, polarization, frequency, satellite, monochromatic, concentration, incoherent.

INTRODUCTION

Nowadays, studying the nature of intermolecular interaction is one of the main tasks of modern molecular physics. Intermolecular interaction plays a major role in studying the basic properties and physical nature of substances. The properties of substances depend on what molecules it is made of and how these molecules are arranged among themselves. Solving many fundamental problems in the field of physics, chemistry and biology requires the amount of molecules in matter, their structure and other properties in a wide range of temperature, pressure and concentration and in different aggregate states. In this respect, applying the achievements of all sciences to production is one of the urgent problems of today. Despite the fact that some progress has been made in creating the statistical theory of fluids in recent years, many difficulties are encountered. Due to the widespread use of liquids in practice and their use in several fields of chemistry, biology and physics, the demand for knowledge of the structure and properties of liquids and the environment is increasing, and as a result, further development of the theory of liquids is required. Therefore, the most effective among various optical methods for studying the nature and mechanism of intermolecular interaction of liquids is the method of studying light combinatory scattering spectra. Optically, the condition of homogeneity means that the refractive indices of different parts of the medium have the same value. When the refractive index of such a medium is constant in the entire volume, it is concluded that light refraction phenomena do not occur. The use of different techniques to obtain information on intermolecular interactions using combinational scattering spectra has been researched for many years and several works have been done in this field. Many researchers in this field have explained the occurrence of various effects observed in these molecules through various interactions. It should be noted that the results of scientific research conducted in this work will further expand our understanding of liquid environments, contribute to the rapidly developing field of biotechnology and the development of molecular spectroscopy.In relay scattering, the frequency of the scattered light corresponds to the frequency of the incident light. Since Rayleigh was the first to identify this type of scattering, it is called Rayleigh scattering. This scattering occurs coherently. Therefore, Rayleigh scattering is a coherent scattering of light (Fig.1). However, careful investigations have shown that in the spectrum of scattered light, in addition to the lines characterizing the incident light, there are additional lines (satellites), which are known to stand next to each line of incident light. ldi (Fig.1)[1,2].

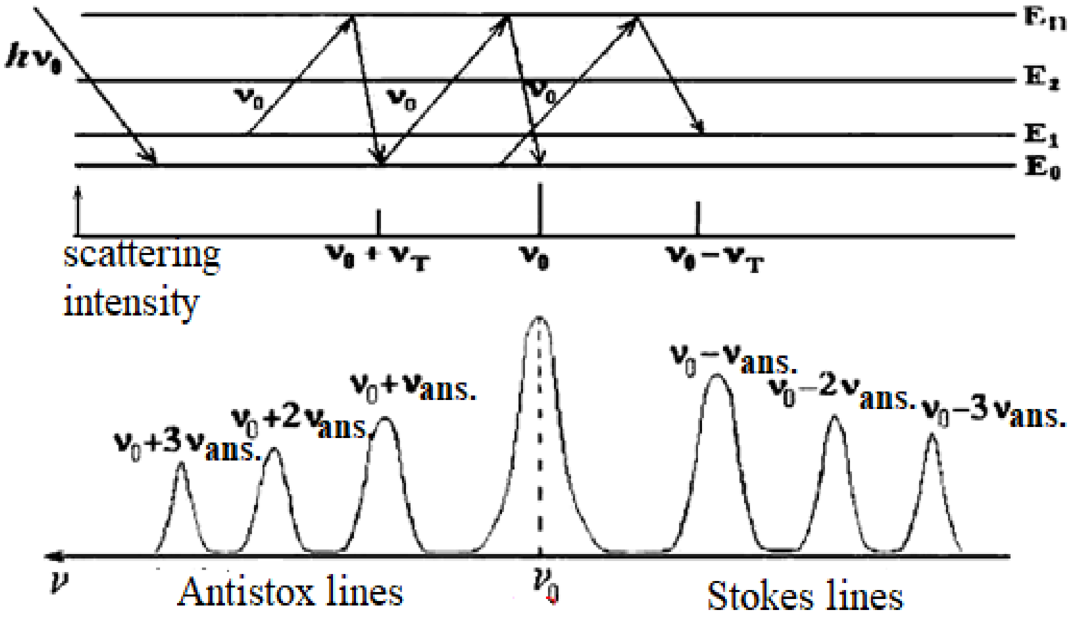

Figure 1. Transitions between energy levels leading to Rayleigh (ν_0) and combinatorial (ν_0-ν_{ans} or ν_0+ν_{ans}) scattering spectra

Since satellites appear near any spectral line of incident light, the question arises as to what conditions these satellites can be observed. In order for satellites to be visible, the incident light spectrum must not be a continuous spectrum, but a set of separate lines (monochromatic lines).

The following laws of this phenomenon have been found from experience.

- Satellites are near each line of incident light.
- The difference between the frequency of the spectral line of the exciting (falling) light and the frequencies of each of the lines from the satellites ν', ν'', ν''' ....,is characteristic for the scattering substance and is equal to the specific vibrational frequencies of its molecules $\left(\nu^i\right)$:

$$\Delta\nu_1 = \nu_0 - \nu' = \nu_1^i,\ \ \Delta\nu_2 = \nu_0 - \nu'' = \nu_2^i,\ \ \Delta\nu_3 = \nu_0 -$$

- Satellites consist of two systems of lines lying symmetrically on both sides of the wake line, (Fig.1) i.e.

$$\nu_0 - \nu_r = \nu_\upsilon - \nu_{0.}$$

Here, on the left a re the frequencies of the satellites on the longer wavelength side than the excitation frequencies, and on the right are the frequencies of the satellites on the other side of the excitation frequencies.The first satellites, which are located near the red part of the spectrum and are therefore called "red" satellites, are much more intense than "violet" satellites (Fig.1) [1,3,4].

- When the temperature rises, the intensity of "purple" satellites increases rapidly.

Combined scattering was first discovered by G.S. Landsberg and L.I. Mandelstam and Indian scientists Raman and Krishnan. Indian scientists won the Nobel Prize. In foreign literature, this process is also called the Raman effect. This scattering is commonly called combinatorial scattering.

Classical theory of combinatorial scattering of light

The phenomenon of combinatorial scattering is explained in terms of classical theory as follows. The reasons for the appearance of satellites in this phenomenon can be explained by the modulation by low-frequency vibrations of the atoms of the molecules of the light wave scattering medium. Polarization of a molecule generally depends on the location of the atoms that make it up. When atoms vibrate, the polarization α_0- oscillates around the average value, which can be explained as follows:

The frequency of these vibrations is 10^{12}-10^{13} Hz and corresponds to the infrared spectrum of the electromagnetic wave scale. In other words, the magnitude change of $\alpha(t)$ changes more slowly compared to the fluctuation of the $\left(\approx 10^{15} Gr\right)$ electric field of the incident light. For this reason, the change in the dipole moment of the molecule in the monochromatic field of the incident light wave

$$p(t)=\alpha\cdot E=[\alpha_0+F(t)]E_0\cos\omega t$$

occurs according to the law, that is, it consists of amplitude modulated oscillation. Here is the $E=E_0\cos\omega t$ - variable electric field of the light wave, E_0 is the amplitude of the electric field intensity of the light wave, is the angular frequency $\omega=2\pi\nu$ -of the incident light, α - is the polarizability of the molecule, which depends only on its structure and properties l is a constant. In this process, the oscillation of the scattered light field strength is also modulated. The carrier frequency ω - of these vibrations is equal ω_i -to the frequency of the incident light wave, and the modulation occurs at - frequencies (vibration frequency of the atoms in the molecule of the scattering substance). The spectrum of such amplitude-modulated oscillations $\omega\pm\omega_i$ -along with the frequency carrier frequency, combined oscillations with a frequency are formed. In other words, the spectrum of the scattered light gives information about this molecule. By studying and analyzing this spectrum, we will be able to know the structure and structure of the molecule[4,5].

According to the classical law $\omega=2\pi\nu$ of electrodynamics, the intensity of a dipole oscillating at a frequency

$$I_v=\frac{16\pi^4 v^4}{3c^2}\alpha^2 E_0^2 \qquad (1)$$

emits monochromatic light equal to $\alpha\neq const$ for example, that is, if the polarizability of the molecule of the scattering medium changes, then the dipole moment of the molecule also changes over time. In general, the polarizability of a molecule should vary due to the participation of the nuclear vibration in dipole vibrations. Due to the interconnectedness of electrons and the nucleus, the electrons oscillating at a forced frequency cause the nucleus to vibrate as well.

However, since the mass of the nucleus is very large compared to the mass of the electron, the vibration of the nucleus is very weak. This causes the polarity of the molecule to change. As a result, the frequency of the scattered light changes and the displacement becomes incoherent .

Thus, classical electrodynamics correctly explains the appearance of lines - satellites symmetrically shifted by a distance i on both sides of the unshifted line (ν) in the spectrum ν_i - of scattered light, and their intensity

$$I_{S,A} = \frac{4\pi^4}{3c^2}\left(\nu_R^{S,A}\right)^4 \alpha^4 E_0^2 = \frac{4\pi^4}{3c^2}\left(\nu_0 \mp \nu_i\right)^4 \alpha^4 E_0^2 \qquad (2)$$

is calculated by the formula. In this $\nu_R^{S,A}$ - the Raman frequency (for Stokes and anti-Stokes lines). From the point of view of classical electrodynamics, it follows that the intensity of Stokes and anti-Stokes lines is equal. It is known from the results of the experiment that the intensity of these lines (satellites) is not equal, including that the intensity of red satellites-Stokes lines is higher than the intensity of purple satellites. Classical physics could not explain this quantitative difference between the intensities of red and violet satellites. The quantitative problem of intensities in combinatorial scattering of light can be correctly explained only on the basis of quantum concepts.

Quantum theory of combinatorial scattering of light

Using a simplified view of light quanta, it is possible to understand the essence of the phenomenon of combinatorial scattering. According to quantum views, light with a frequency is scattered in the form ν_0 of certain fractions (quanta), the amount $h\nu_0$ of which is equal to where $h = 6{,}62 \cdot 10^{-34}$ J.s (s - Planck is a universal constant. Therefore, an atom with frequency oscillations has a reserve of energy. This energy can be emitted by the atom in the form $h\nu_0$ of light with such a frequency. From this point of view, the scattering of light in molecules by light quanta ((that is, photons) collide with molecules. As a result of this collision, the photons change their direction. Collisions between photons and molecules are elastic and inelastic. The collision is an elastic collision. in the case of collision, the energy of the molecule and the frequency of the photon do not change, which corresponds to Rayleigh scattering (Fig.1). That is why Rayleigh scattering is also called elastic scattering[5].

If the collision is inelastic, the energy of the photon changes by the amount of the oscillating quantum. If light interacts with a molecule that is not in a vibrational state, the light gives the molecule the appropriate part of its energy, according to the equation $h\nu' = h\nu_0 - h\nu_i$ or $\nu' = \nu_0 - \nu_i$ turns into a low-frequency light (red satellite, Stokes line), where the frequency ν_0 of the excitation light is the frequency ν_i of the molecule's vibrations. If light affects a molecule in a state of vibration, i.e., $h\nu_i$ -a molecule with energy, then the light absorbs this energy from the molecule, $h\nu' = h\nu_0 + h\nu_i$ or $\nu' = \nu_0 + \nu_i$, according to the equation, to high-frequency light (Violet satellite, anti-Stokes line becomes).This can be easily understood from Figure 1 above. Based on the above, combinatorial scattering can be defined as follows: The frequency of the scattered light is composed of the combination v_0 of the frequency of the incident light and the frequency v_i of vibrations inside the molecules. Therefore, this scattering is called combinatorial scattering.The number of molecules in a state of vibration is much less than the number of unexcited molecules, so the intensity of the violet satellite must be incomparably less than the intensity of the red satellite; the same is true in experience. As the temperature rises, the number of excited molecules increases rapidly, so the intensity of purple satellites should increase rapidly; this is also confirmed in experience.In fact, the intensity of the combinational line with a frequency is determined by how much the α polarizability of the molecule changes when the molecule vibrates corresponding to this frequency. The change of the electric moment with the change of polarity can be expressed in different ways in different oscillations[5,6].

Vibrations that are active in the infrared spectrum are not active in the combined scattering spectrum and vice versa. In SO_2 a different vibration (Fig.2,v), the polarity does not change, because when one of the oxygen atoms approaches the carbon, the other moves away and vice versa; however, the electric moment (O) of the molecule changes during these vibrations.Therefore, in the first type of oscillation (Fig.2b), a combinatorial scattering line appears, the frequency (O) of this line can be determined from the combinatorial scattering spectrum;

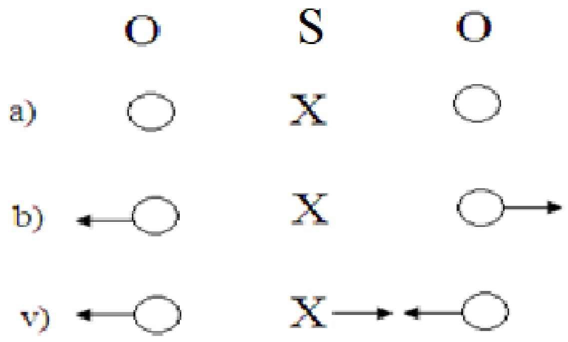

Figure 2. Types of atomic vibration in the SO2 molecule. initial situation of a-atoms; b-polarization changing vibration; v-electric torquechanging vibration.

In the second type of vibration (Fig.2b), the frequency can be found depending on the position of the infrared absorption band.The combinational scattering method is an important method for studying the molecular structure of a substance[2,4,6]. The specific frequencies of molecular vibrations are easily determined using this method; this method allows us to think about the nature of molecular symmetry, the magnitude of the forces acting inside the molecules, and the specific aspects of molecular dynamics in general.In many cases, this method is studied together with the infrared absorption method, which allows for a complete study of the molecule. Combination scattering spectra are so characteristic of molecules that complex molecular mixtures can be analyzed with the help of these spectra, especially mixtures of organic molecules that are difficult or even impossible to analyze by chemical means. For example, the composition of gasoline, which is a very complex mixture of hydrocarbons, is effectively analyzed using the combinatorial scattering method. Above, we talked about combinatorial scattering, which occurs during the interaction of primary radiation with molecules of the environment. A similar phenomenon occurs when light is scattered by atoms or ions. In order to understand the essence of the matter, it is necessary to recall the results of the study of absorption and dispersion of light in atomic gases. An atom can be thought of as a set of oscillators; the specific frequencies of these oscillators are determined by the difference between the energies of two arbitrary quantum states of the atom. Therefore, the difference between atoms and molecules is only in the nature of oscillators: oscillators in the form of molecules describe the movement of nuclei, and in the case of atoms, oscillators describe the movement of electrons. Given this similarity, the above considerations can be applied to atoms from the point of view of the classical modulation picture and from the point of view of the simplified quantum scheme.Inelastic scattering of photons was predicted theoretically based on their interaction with atoms (A. Smekal 1923). However, this phenomenon was found experimentally long after molecular combinatorial scattering.The phenomenon of combinatorial scattering of light can be explained within the framework of classical physics, but its quantum interpretation essentially confirms the quantum nature of light. The combinatorial scattering method is of great practical importance in the study of the structure of molecules, internal molecular and intermolecular forces, the analysis of complex mixtures and the identification (separation) of certain compounds [3,5,6].

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