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The Phenomenon of Luminescence and Its Applications

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Annotation: This article examines the phenomenon of luminescence — the emission of light by substances without heat — and its various types, such as photoluminescence, chemiluminescence, electroluminescence, and bioluminescence. The physical principles behind luminescence are briefly discussed, including how energy is absorbed and later emitted as visible light. The article also highlights the broad range of practical applications of luminescence in fields like medicine, electronics, biology, and environmental science. Due to its high sensitivity and efficiency, luminescence is widely used in diagnostics, display technologies, molecular research, and safety signaling.

Keywords: *Luminescence, photoluminescence, chemiluminescence, electroluminescence, bioluminescence, light emission, cold light, fluorescence, medical imaging, display technology, molecular analysis, diagnostics*.

Introduction

On Earth, the primary sources of light are highly heated objects. Such sources of light are called hot sources. However, in addition to hot sources, there are also cold sources of light, in which other forms of energy (such as chemical energy) are converted into light energy. The various phenomena in which cold light is emitted are referred to as luminescence. The term luminescence is derived from the Latin word lumen, meaning "light." The causes of luminescence are also varied. The glow of insects (such as fireflies), rotting wood, decaying meat, and similar substances has been known to humans since ancient times — these are examples of light emission at low temperatures.In such cases, the glow is caused by chemical processes, mainly oxidation reactions. For example, if a small amount of yellow crystals of uranium nitrate is placed on an anvil and struck with a hammer in a dark room, a beautiful greenish flash will be seen upon impact. This demonstrates that mechanical action can also cause the crystal to emit light while remaining cold. When the crystal is struck, the fragments that scatter around may continue to glow for a short period. It emits light continuously, which is a very characteristic feature of the luminescence phenomenon. In the past, this behavior seemed mysterious. Only modern science has been able to explain the cause of such light emission. It is related to the phenomenon known as luminescence. Luminescent radiation is emitted by a relatively small number of luminescence centers — atoms, molecules, or ions. Under the influence of external factors, these centers become excited, and when they return from the excited state to a lower energy level, they emit a quantum of luminescent radiation. When a photon from a light source hits the luminescence center of a crystal, it excites the center to one of the intermediate levels densely filled with absorption band states. Within approximately 10^{-8} seconds, the luminescence center transitions to level AA, releasing energy to the crystal lattice. As it returns to the ground state BB, it emits a quantum of light. Substances in which luminescence occurs are called luminescent materials or phosphors. One of the key characteristics of the luminescence process is the average time it takes for the luminescence center to transition from the excited state to a lower energy level. If the

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luminescent emission ceases rapidly — within about one ten-millionth of a second (10^{-8} s) — this type of luminescence is called fluorescence. This time interval represents the typical lifetime of an excited atom. If the excitation occurs in the outer electron shell, the atom usually remains in the excited state for that duration before returning to the ground state. Another type of luminescence is phosphorescence, which is characterized by the slow decay of light emission after the excitation source has been removed. In this case, the luminescence centers enter metastable states after excitation. Transition from these metastable states to lower energy levels is quantum mechanically forbidden, so the process takes significantly longer than 10^{-8} seconds to occur. One of the most important principles of luminescence is the relationship between the intensity of the exciting electromagnetic radiation and the intensity of the luminescent emission. The ratio of the energy of the emitted luminescent light (E_1) to the energy of the absorbed light (E_k) defines the energetic efficiency of luminescence:

$$B_e = \frac{E_1}{E_k}$$

The ratio of the number of emitted photons (N_1) to the number of absorbed photons (N_k) defines the quantum efficiency of luminescence:

$$Bh\nu = \frac{N}{N_k}$$

The energetic and quantum efficiencies of luminescence show what portion of the absorbed energy is converted into luminescent energy. These values are related to each other as follows:

$$B_e = \frac{E_1}{E_k} = \frac{h\nu}{h\nu_k}\frac{N_1}{N_k} = \frac{\nu_1}{\upsilon_k} = \frac{\lambda_1}{\lambda_k}$$

S. I. Vavilov studied the relationship between the energetic efficiency of luminescence and the wavelengths of the exciting radiation and formulated the following law: "When luminescence is excited by the short-wavelength part of the absorption spectrum, its energetic efficiency increases proportionally with the wavelength of the exciting light. Then, despite the increase in the excitation wavelength, the luminescence efficiency remains constant within a certain spectral range and sharply decreases in the region where the absorption and emission spectra overlap." Thus, in a certain part of the spectrum, the quantum efficiency of luminescence does not depend on the wavelength. In other words, luminescence is determined by the set of energy levels of the molecule and does not depend on which specific light quanta were involved in the excitation.In geometric optics, based on a few concepts and laws (such as the nature of light rays, and the laws of reflection and refraction), many important practical results can be obtained. When external energy is supplied to a substance, the atoms or molecules that make up the substance enter an excited state — a state with excess energy — as a result of absorbing that energy. During this time, electrons move to higher energy levels of the atom, becoming excited due to the excess energy. However, they do not remain in the excited state for long. Within a short time, they release the excess energy and attempt to return to their original, stable state. If atoms and molecules emit part of the absorbed energy not as heat but as radiation, this phenomenon is called luminescence. The intensity of luminescent radiation, within a certain concentration range of the substance being analyzed, is proportional to the concentration (C) of that substance.

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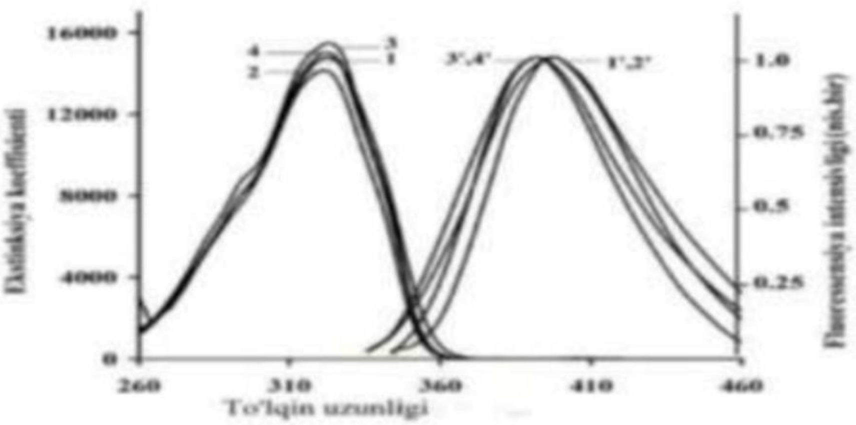

This relationship is widely used for the quantitative analysis of many substances. Ultraviolet (UV) rays are typically used to induce luminescence. The luminescent method is one of the most sensitive techniques, allowing detection of substances in very small amounts (10^{-6}–10^{-8} g/ml). Additionally, in chemical analysis, certain organic compounds with luminescent properties are valuable because they can act as indicators during titration processes. If the molecule of an organic substance has acidic or basic properties, its luminescence will change depending on the concentration of hydrogen ions in the solution. In titrimetric methods of chemical analysis, such compounds are referred to as luminescent indicators, and they play an important role in determining the quantity of substances. The luminescent analysis method is widely used in industry and agriculture. Photoluminescence refers to the luminescence of a substance when exposed to ultraviolet (UV) and visible light rays. It is a type of luminescence triggered by light or UV radiation. The optical spectra of photoluminescence (electromagnetic radiation with wavelengths from 0.1 to 103 micrometers) can be line, band, or continuous. The type of photoluminescence depends on the aggregate state of the substance (some properties may change in a non-continuous manner), as well as the conditions under which atoms and molecules are excited. Only the spectra of vapors in photoluminescence are directly dependent on the wavelength of the exciting radiation (light or ultraviolet rays). The energy of chemical reactions is another source that can excite luminescence. In the body of a firefly beetle, chemical energy is converted into light energy with a very high quantum yield, close to 100%. This is about five times more efficient than luminescent lamps. Such a type of luminescence is called chemiluminescence. This phenomenon used to seem mysterious. Only modern science has been able to explain the cause of such light emission, which is associated with a phenomenon called luminescence. Luminescent radiation is emitted from a limited number of luminescent centers—atoms, molecules, or ions. Under the influence of external factors, these centers transition to an excited state. Then, as the excited center returns to a lower energy level, it emits a quantum of luminescent radiation. Luminescence is not only used in gas-discharge lamps and cathode ray tubes, but it also finds applications in other fields. Luminescent radiation can be observed even at very low concentrations of substances. The luminescent analysis method is based on this principle.

Conclusion. Luminescence is a physical phenomenon in which certain substances emit light without being heated, as a result of absorbing energy from various sources such as ultraviolet radiation, mechanical impact, or chemical reactions. Unlike incandescence, luminescence occurs at lower temperatures and is observed in various natural and artificial environments. This phenomenon is categorized into types such as photoluminescence, chemiluminescence, fluorescence, and phosphorescence, each defined by the nature and duration of the emitted light. Luminescent materials, also called luminophores, are widely used in many fields including medicine, analytical

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chemistry, agriculture, and industry due to their high sensitivity and ability to detect substances in very low concentrations. In conclusion, luminescence is not only a fascinating scientific process but also a valuable tool in modern technologies. Its applications are growing rapidly, contributing to advancements in diagnostics, lighting, imaging, and environmental monitoring.

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