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# The Impact of Luminescence in Technological Scale

Jagannathan Thirumalai

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## 1. A epigrammatic testimony of luminescence

From the prehistoric times, the term ‘luminescence’ is more fascinating towards mankind. One can simply look at the logically occurring luminescence through the aurora borealis, luminescent wood, glow worms, putrid fish and meat [1]. The effect was wearing a veil in secrecy and illustrated consequently in the Middle Ages and past. The most primitive printed report of a solid-state luminescent material originated from a Chinese text that was published in the Song dynasty (960–1279 A.D.), quite referred to a book (never recovered) from the period 140–88 B.C. It narrates a painting picture of a cow munch grass in an outside field. In the darkness, the cow would be seen repose within a shelter [1–3]. Perhaps, the first man-made ink was exploited using a persistent phosphor material. Harvey [3] dispenses a tremendous description of these untimely interpretations far beyond the purview of the current reassess. In general, the name phosphorus is mentioned only for the chemical element, whereas specific micro-crystalline luminescent materials are referred as phosphors. The first artificial phosphor exemplified in Western literature dates from 1603. Then, the Italian alchemist and shoemaker Vincenzo Cascariolo’s phosphor (1870) manifest was the earliest commercially available phosphor, referred to as “Balmain’s paint,” a barium sulphide preparation. Phosphors (light-bearing materials) are optical transducers that yield luminescence when the material is suitably excited. The idiom ‘luminescence’ (the Greek translation of *lucifer*, means light bearer) was first initiated by the German physicist, Eilhardt Wiedemann, in 1888, to facilitate the discrimination among the emission of light (luminescence) from thermally excited substances/ molecules under suitable excitation devoid of escalating their average kinetic energy.

After 1900, the modern period luminescence experimentations were started on the inspirations of promising quantum mechanics approaches [4–6]. During the antediluvian 1900s, the progress of quantum theory bestowed a concrete evidence on theoretical groundwork about the enormous accretion of spectroscopical facts. A comprehensive understanding of luminescent emission led from quantum theory, which voluntarily elucidating prior inter-

pretation and consenting predictions of innovative occurrence. Subsequently, during the period of 1920–1930, theoretical concepts of luminescence are very well implicit among researchers, and it was documented to facilitate luminescence spectroscopy is intrinsically added novel perceptive than absorption spectroscopy. A minimum of five independent luminescence properties are able to be estimated which are the features of a testing sample module [4–6]:

1. Emission intensity by monitoring the excitation wavelength.
2. Excitation intensity by monitoring the emission wavelength.
3. Decay time of the excited state.
4. Emission of polarization.
5. Quantum yield.
6. Anisotropy.

As an assessment, the merely alternative variable calculated using absorption spectroscopy is the transmission spectra (Beer-Lambert law). However, most studies concern the activity of luminescence concepts in the prediction of innovative occurrences as summarized in **Table 1**.

Type	Examples	Applications
Fluorescence	Lignum nephriticum ('kidneywood'), aragonite, and so on (in all the below cited luminescence types) [7]	Display devices, fluorescent hydrogels, biomarkers
Phosphorescence	Eu <sup>2+</sup> -doped strontium silicate-aluminate and so on (in all the below cited luminescence types) [8]	Traffic signals, phosphorescent paint ('Leuchtgelb')
Photoluminescence	Halophosphate (fluoro-or chloro-apatite): Ca <sub>5</sub> (PO <sub>4</sub> ) <sub>3</sub> (F,Cl):Sb <sup>3+</sup> , Mn <sup>2+</sup> [9]	Fluorescent lamp
Radioluminescence	Paint with radium, gaseous tritium light source (GTLs) [10]	Wristwatch faces, gun sights, nuclear reactors and radioisotopes
Cathodoluminescence	Ca <sub>3</sub> Gd <sub>7</sub> (PO <sub>4</sub> ) <sub>4</sub> (SiO <sub>4</sub> ) <sub>5</sub> O <sub>2</sub> : Ce <sup>3+</sup> , Tb <sup>3+</sup> and Mn <sup>2+</sup> [11]	Cathode ray tube, monitors, field emission device
Electroluminescence	Zn(S,Se): Cu <sup>+</sup> , ZnS: Cu <sup>+</sup> [12]	LED, EL displays
Thermoluminescence	ZnS: Mn <sup>2+</sup> , Radioactive irradiation, quartz [13, 14]	Archaeology, dating of burnt flint, pressure gauge temperature
Chemiluminescence	Oxidation of luminol, fluorescein, rhodamines, coumarins, oxazines [15]	Analytical chemistry
Bioluminescence	Green fluorescent protein [16]	Cell tracking, fast-acting biocides
Candoluminescence/ Pyroluminescence	Zinc oxide and cerium oxide or thorium dioxide, trimethyl borate, alkali metals and alkali earth metals [17, 18]	Gas mantles or limelight
Galvanoluminescence	Electrolysis of sodium bromide (NaBr) [19]	Fabrication of electrolytic cell
Sonoluminescence	Collapse of gas-filled bubbles in a liquid [20]	Bomb-resistant baggage container for wide body aircraft

Type	Examples	Applications
Mechanoluminescence/ Mechanochromic luminescence	CaZnOS:Mn <sup>2+</sup> and CaZr(PO <sub>4</sub> ) <sub>2</sub> :Eu <sup>2+</sup> [21]	Mechanical stress in industrial plants, structures and living bodies
Triboluminescence/ Fractoluminescence	ZnS:Mn <sup>2+</sup> [22, 23]	Diamond, quartz, emission of electromagnetic radiation (EMR)— sensors/smart materials
Crystaloluminescence	NaCl [24]	Image intensification techniques (spatial, temporal and spectral)
Injection luminescence	LED [25]	Basic research
Negative luminescence	InSb, (Hg,Cd)Te, Ge and InAs [26]	Electronic device

**Table 1.** Different types of luminescence, with material examples, and field of applications.

Luminescence is a process having a wide range of applications in everyday life, starting from the conventional fluorescent lighting they extend to digital radiography in the field of magnetic resonance imaging (MRI) [27], electronic portal imaging device (EPID) [28], light-emitting diodes (LEDs) [29, 30], solid-state lasers [31], luminescent solar concentrators [32] and many/ much other electrical and electronic equipment employ luminescent materials. Recently, electroluminescent display that shows promise for making flexible electroluminescent flat panel display (FEL-FPD) technology [33] is emerging worldwide; it also provides an excellent platform for a foundation for a no-compromise hang-on-the wall TV. In the field of biochemistry and biophysics, the fluorescence spectroscopy and time-resolved fluorescence are deemed as the first and foremost research equipment and this prominence has transformed and expanded nowadays with modern spectroscophical equipment. Currently, fluorescence as one of the foremost tactics was meticulously utilized in dissimilar areas of biochemistry, cell and molecular biology, genetics, bioinformatics, microbiology, biometrics, forensics, flow cytometry, medical diagnostics, nanomaterials, DNA sequencing, etc. The usage of fluorescence proves a dramatic growth in cellular and molecular imaging. Fluorescence imaging should be able to disclose the localized analysis of intra-cellular molecules, every so often at the stage of the detection of single molecule [34].

## 2. Technological advancements in the science of luminescence spectroscopy

All and sundry is having numerous astonishing moments to have a high regard for the spectacular engagement in recreation of luminosity, the consequence and the good organization of the assistance offered through optical devices to expand our prospect, in addition to reward for its ensnared defects to make ourselves with optical illusions. The well-equipped spectroscophical techniques possess broad accessibility by means of ease procedure, selectivity, sensitivity, accuracy, speed and precision [6, 9, 34]. The novel applications of fluorescence have proffered innovative technological advancements over few decades and these technological features were rapidly implemented for ground-breaking research. It is pointed out that

two-photon or multi-photon excitation and multi-photon microscopy is one of the important technologies by employing the fluorescence mechanism [35–38]. By two-photon absorption process fluorophores can be excited by means of femtosecond pump-pulse lasers with regular pulse width. These lasers have turned out to be simple to utilize and are equipped with microscopes in the recent days. **Table 2** summarizes some major innovative technological advancement associated with the science of luminescence activities in a broad spectrum.

Instrumentation	References
Time-resolved fluorescence spectroscopy	[6]
Transient-absorption spectroscopy (flash spectroscopy)	[39]
Time-resolved infrared spectroscopy	[40]
Time-resolved two-photon photoelectron (2PPE) spectroscopy (or) time-resolved photoemission spectroscopy (or) laser-based angle-resolved photoemission spectroscopy	[41–44]
Fluorescence lifetime imaging spectroscopy	[45]
Fluorescence correlation spectroscopy	[46, 47]
Single-molecule fluorescence spectroscopy	[48]
Fluorescence microscopy (epi-fluorescence, confocal)	[49]
Two-photon excitation fluorescence microscopy	[50]
Near-field scanning optical microscopy (or) optical stethoscopy	[51]

**Table 2.** Different types of luminescence spectroscopical instrumentation.

In fluorescence microscopy, the controlled excitation from the phenomenon of two-photon excitation has created a prevalent employability. Only through the focal plane of a microscope the image processing could be achieved through multi-photon excitation process [49]. This is a major benefit, since fluorescence images may get deformed from fluorescence process from top and bottom of the focal plane. There is no definite phase fluorescence so as to reduce the dissimilarity in non-confocal fluorescence microscopy; as a result, the images are obtained with good resolution. Such images are currently being achieved in numerous research laboratories.

Recently, a variety of scientific themes in association to the perspective of analytical advancements in luminescence spectroscopy and luminescence-based imaging in the field of earth sciences and related disciplines were discussed in detail [52]. Cathodoluminescence (CL) spectroscopy can be employed to detect and differentiate diverse generation of minerals or mineral by its variable CL colours or as an efficient technique on behalf of spatially resolved analysis of point/lattice defects (e.g. radiation-induced defects or vacancies, or broken bonds induced from electron defects) in solids by using the CL spectral measurements [53]. A new approach where fluorescence methods combined with modern chemo-metric approaches, such as bio-specific and other sensors, shows significant potential in the detection of cultural heritage and its degradation, explosives, residues and their components using time-resolved photoluminescence spectroscopy (TRPL) and fluorescence lifetime imaging (FLIM) [54]. Similarly, the total reflection x-ray fluorescence (TXRF) spectrometry is an energy-dispersive

x-ray method that is employed for determining the elemental and chemical analysis (in stainless steel metal release) and is also suitable for small-sample analyses like airborne silver nanoparticles (NPs) from fabrics [55].

Thus, the invention of modern luminescence technology-oriented spectroscopical tools employed with multi-photon excitation/emission is one of the most important mechanisms that encompasses with radiative energy transfer, energy transfer by resonant exchange, energy transfer by spatial process, energy exchange by spin coupling, energy transfer by non-resonant processes and so on, which involved during photophysical processes even in a molecular level. As a result, the up-to-date activity in luminescence-based spectroscopical instrumentation has been correlated to expand our prospects towards new ideas in the field of biological science, physical chemistry, food science, pharmacology, nanotechnology, photovoltaics/solar cells, LEDs and displays, environmental science and so on.

In connection to the aforementioned aspects, the proper evaluation of environmental risks pertinent to recent experimental standards with reference to technological perspectives based on the growth inhibition caused by the chemical substances require necessary qualitative assessment such as the assessment of mechanism articulating toxicity. Therefore, it is affirmed that this assessment is need to be developed for building improvement towards ecological preservation and to deep evasion against human health.

### 3. Conclusion

As discussed above, luminescence is not only well conceived, but a pioneer across the globe with innovative scientific developments; however, facts also demonstrate that it has been and will prolong to be imperative towards ground-breaking research against novel applications for the societal cause. The most important worldwide challenges amongst the major noteworthy progress are in diverse fields of biochemistry, cell, molecular biology, genetics, bioinformatics, microbiology, bioinformatics, biometrics, forensics, flow cytometry, medical diagnostics and the addition of nanotechnology. The dispute of novel spectroscopical/microscopical innovation comprises interdisciplinary areas that must continue to be improved for these innovative global developments in spectral imaging, fluorescence lifetime, time-correlated single-photon counting, kinetic chemical reaction rates, singlet-triplet dynamics, visual implants, non-invasive optical biopsy and neurology. Thus, studies on inimitable luminescence technological surroundings might provide an insights about atoms/molecules that may perhaps turn out to be the future harbingers of green energy in the upcoming scenario.

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## Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

## Author details

Jagannathan Thirumalai

Address all correspondence to: thirumalaijg@gmail.com; jthirumalai@bsauniv.ac.in

Department of Physics, B. S. Abdur Rahman University, Vandalur, Chennai, Tamil Nadu, India

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