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# A Literature Review on the Fluorescence and phosphorescent

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**Abstract**
The present literature explains Fluorescence and phosphorescent in chemical compounds , fluorescence has types practical uses and applications, containing mineralogy, medicine, chemical sensors (fluorescence technique), fluorescent labeling , dyes compounds , medical detectors and most commonly, fluorescent lamps.

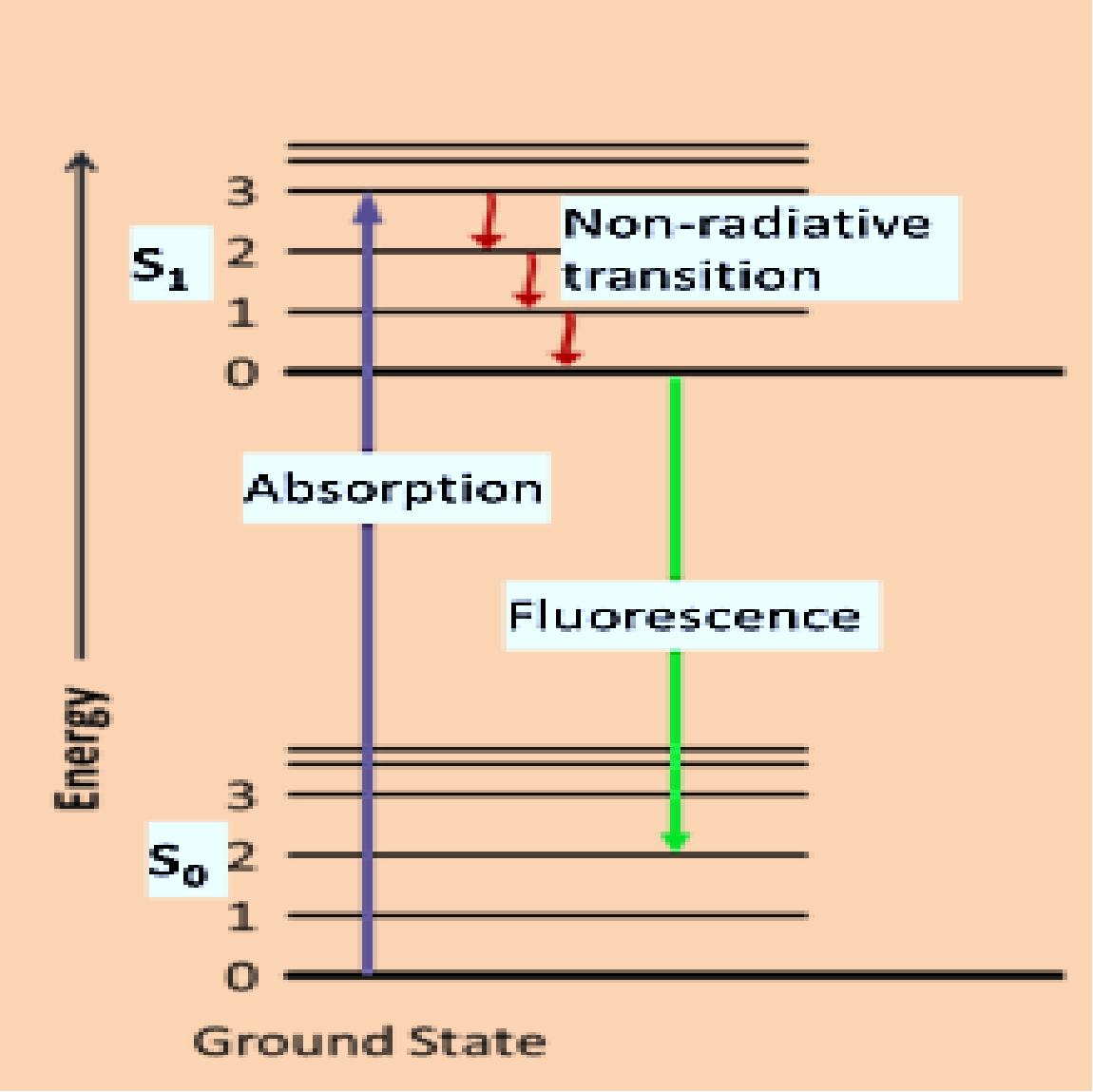
**Introduction**

Bernardino de Sahagún observed and described fluorescence in 1560 by then in 1565 by Nicolás Monardes in the infusion known as ( lignum nephriticum). It was derived from the wood of two components, Pterocarpusindicus and Eysenhardtiapolystachya.[1-4] The chemical component responsible for the fluorescence is matlaline, that is the oxidation product for one of the flavonoids component in this wood.[5]

In 1819, Edward D. Clarke[6] and in 1822 René Just Haüy[7] described fluorescence in fluorites, David Brewster explained the phenomenon for chlorophyll in 1833[8] and John Herschel did the same for quinine in 1845[9].

In 1852 described the "Refrangibility" (wavelength change) of light, George Gabriel Stokesdescribed the ability of fluorspar and uranium glass to change invisible light beyond the violet end of the visible spectrum into blue light. He named this phenomenon fluorescence : "I am almost inclined to coin a word, and call the appearance fluorescence, from fluor-spar [10] The name was derived from the mineral fluorite (calcium difluoride), which contain traces of divalent europium, which serves as the fluorescent activator to emit blue light. In a key experiment which is used a prism to isolate ultraviolet radiation from sunlight and observed colored light - blue light emitted by an ethanol solution of quinine exposed by it.

Excitation can result in the compound reaching any of the vibrational sub-levels associated with every electronic state. Since the energy is absorbed as discrete quanta, this should result in a series of giving absorption bands. However, the simple diagram above neglects the rotational levels associated with both vibrational level and that normally increase the many of possible absorption bands to such an extent that it becomes impossible to resolve individual transitions. Therefore, some components have broad absorption spectra except for those where rotational levels are restricted (like, planar, aromatic compounds). Having absorbed energy and reached one of the higher vibrational levels of an excited state, the compound rapidly loses its excess of vibrational energy through collision and falls to the lowest vibrational level of the excited state. In addition, almost all compounds occupying an electronic state higher than the second undergo internal conversion and pass from the lowest vibrational level of the upper state to a higher vibrational level of a lower excited state which has the same energy. From there the compound lose energy until the lowest vibrational level of the first excited state is reached. From this level, the compound can return to any of the vibrational levels of the ground state, emitting its energy in the form of fluorescence. If this process takes place for all the compounds that absorbed light, then the efficiency of the solution will be in a maximum data. If, however, any other route is followed, the quantum efficiency will be less than one and may even be almost zero.




**Rules of Fluorescence Technique :**

There are many general rules that deal with fluorescence. In the following rules has exceptions while they are useful guidelines for supplement information this technique fluorescence (these rules do not necessarily use two-photon absorption):

**A- Kasha's Rule**

Kasha's rule dictates that the quantum yield of luminescence is independent of the wavelength of exciting radiation.[20] This occurs because excited compound usually decay to the lowest vibrational level of the excited state before fluorescence emission takes place. The Kasha–Vavilov rule does not always use and is violated severely in many simple unit of compounds. A somewhat more reliable statement, although still with exceptions, would be that the fluorescence spectrum appear very little dependence on the wavelength of exciting radiation.

**B- Mirror Image Rule**

For many fluorophoresthe absorption spectrum is a mirror image of the emission spectrum.[21] Which is known as the mirror image rule and is related to the Franck–Condon principle which states that electronic transitions are vertical, that is energy changes without distance changing as can act a vertical line in Jablonski diagram. That

means the nucleus does not move and the vibration levels of the excited state resemble the vibration levels of the ground state.

### C- Stokes Shift

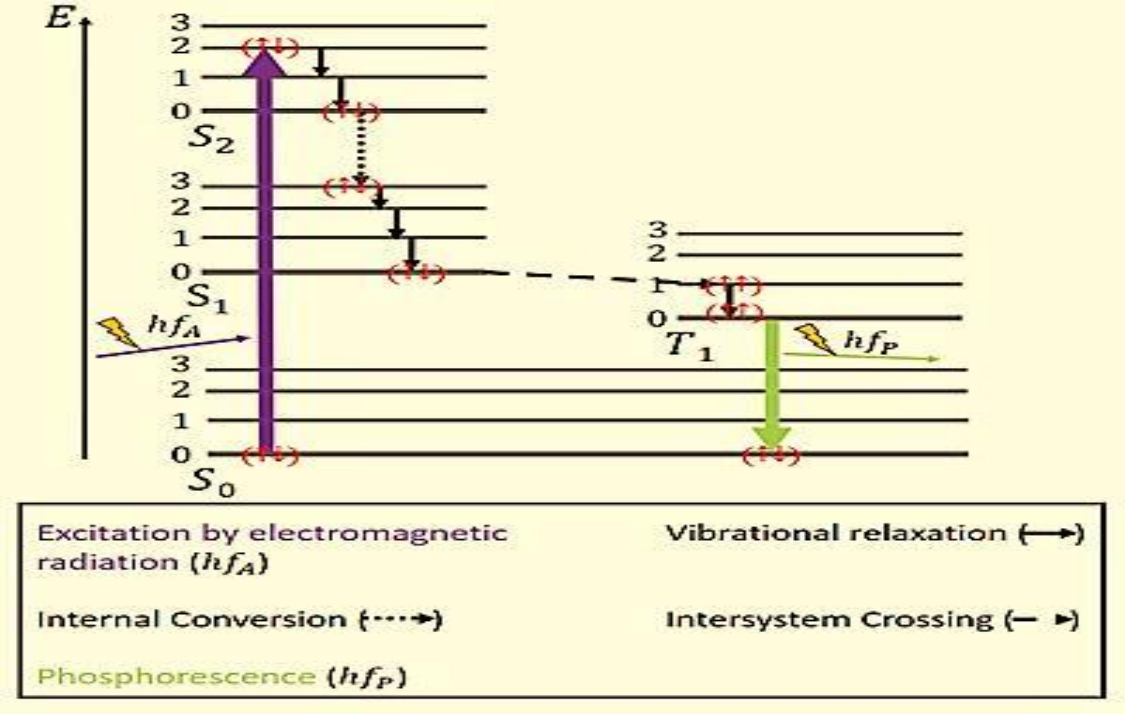
In general, emitted fluorescence light has a longer wavelength and lower energy than the absorbed light.[22] This phenomenon, known as Stokes shift, is a result to energy loss between the time a photon is absorbed and when a new one is emitted. The reasons and magnitude of Stokes shift can be complex and are dependent on the fluorophoreand its environment. However, there are many common reasons. It is frequently resulted non-radiativedecay to the lowest vibrational energy level of the excited state. Another reason is that the emission of fluorescence frequently leaves a fluorophorein a higher vibrational level of the ground state.

There are many natural compounds that exhibit fluorescence, and they have many of uses and applications. Many deep-sea animals, such as the greeneye, use fluorescence.

**Biofluorescence vs. bioluminescence vs. biophosphorescence**

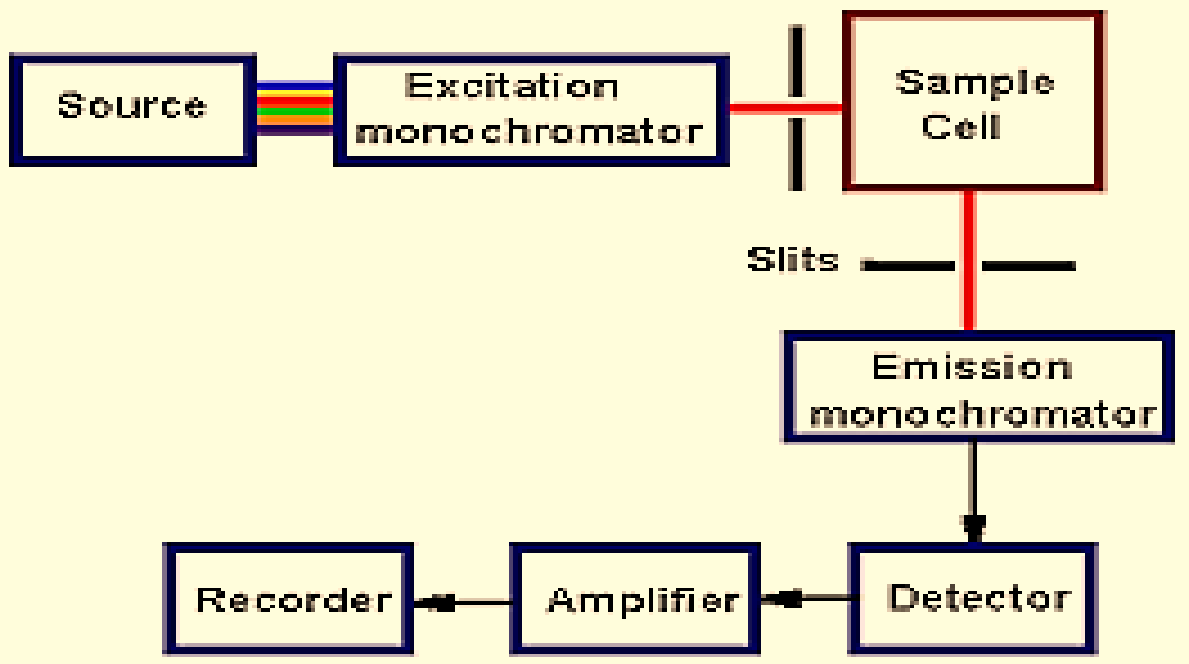
**Biofluorescence**

Biofluorescence is the absorption of electromagnetic wavelengths from the visible light spectrum by fluorescent proteins in a living organism, and the emission of light at a lower energy level. This causes the light that is emitted to be a different color than the light that is absorbed. Stimulating light excites an electron, raising energy to an unstable level. This instability is unfavorable, so the energized electron is returned to a stable state almost as immediately as it becomes unstable. This return to stability corresponds with the release of excess energy in the form of fluorescence light. This emission of light is only observable when the stimulant light is still providing light to the organism/object and is typically (yellow, pink, orange, red, green, or purple). Biofluorescence is often confused with the following forms of biotic light, bioluminescence and biophosphorescence.[17-23]



**Bioluminescence**

Bioluminescence differs from biofluorescence in that it is the natural production of light through chemical reactions within an organism, whereas biofluorescence is the absorption and reemission of light from the environment.[24]




**Biophosphorescence**

Biophosphorescence is similar to biofluorescence in its requirement of light wavelengths as a provider of excitation energy. The difference here lies in the relative stability of the energized electron. Unlike with biofluorescence, the electron retains stability, emitting light that continues to "glow-in-the-dark" even long after the stimulating light source has been removed.[23]

**Mechanisms of biofluorescence**

**Epidermal chromatophores**

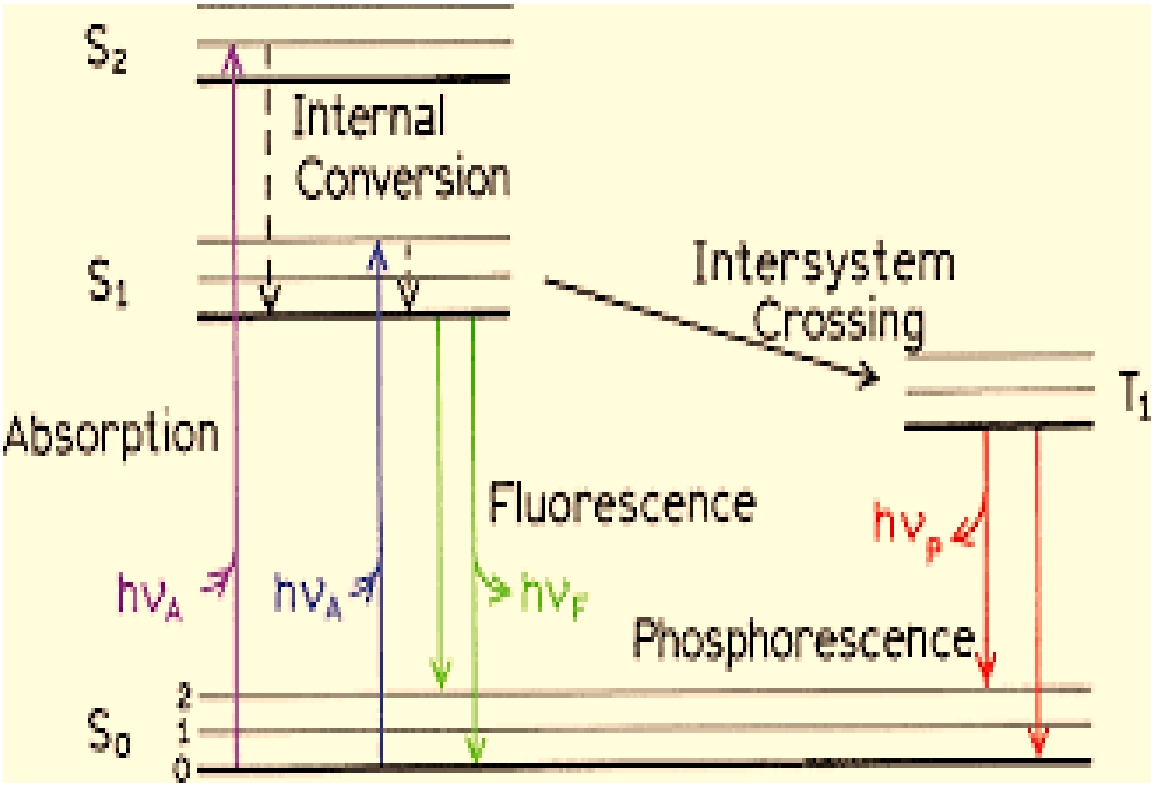
Pigment cells that appear fluorescence are named fluorescent chromatophores and function somatically similar to regular chromatophores. These cells are dendritic, and contain pigments named fluorosomes. These pigments contain fluorescent proteins that are activated through (potassium) ions, and it is their movement, aggregation, and dispersion within the fluorescent chromatophore that cause directed fluorescence patterning.[26-35] Fluorescent cells are innervated the same as other chromatphores, like melanophores, pigment cells that contain melanin. Short term fluorescent patterning and signaling is controlled through the nervous system.[37]Fluorescent chromatophores can be found in the ( skin such as in fish) just below the epidermis, amongst other chromatophores.

Epidermal fluorescent cells in ( fish ) respond to hormonal stimuli through the (α–MSH)hormones much the same as melanophores. That suggests that fluorescent cells may have color changes throughout the day that coincide with their circadian rhythm.[28] Fish may be sensitive to cortisol induced stress responses to environmental stimuli, such as interaction with a predator or engaging in a mating ritual.[36-48]

Fluorescence in minerals is caused through a wide range of activators. In most cases, the concentration of the activator must be restricted to below a certain level, to prevent quenching of the fluorescent emission. Furthermore, the mineral must be free of impurities like ( iron or copper ) – ion , to prevent quenching of possible fluorescence. Divalent manganese, in concentrations of up to several percent, is responsible for the red or orange fluorescence

of calcite, the green fluorescence of willemite, the yellow fluorescence of esperite, and the orange fluorescence of wollastonite and clinohedrite.. When present together in solid solution, energy is transferred from the higher-energy tungsten to the lower-energy molybdenum, such that fairly low levels of molybdenum are sufficient to cause a yellow emission for scheelite, instead of blue. Divalent europium is the source of the blue fluorescence, when seen in the mineral fluorite. Trivalent lanthanides such as terbium and dysprosium are the principal activators of the creamy yellow fluorescence exhibited by the yttrofluorite variety of the mineral fluorite, and contribute to the orange fluorescence of zircon. Powellite (calcium molybdate) and scheelite (Ca- tungstate) fluoresce intrinsically in yellow and blue, respectively. Low-iron sphalerite (Zinc sulfide), fluoresces[56-60] and phosphoresces in a spectrum of colors, influenced by the presence of many trace impurities.

Crude oil (petroleum) fluoresces in a spectrum of colors, from dull-brown for heavy oils and tars through to bright-yellowish and bluish-white for very light oils and condensates. This phenomenon is used in oil exploration drilling to identify very small amounts of oil in drill cuttings and core samples.



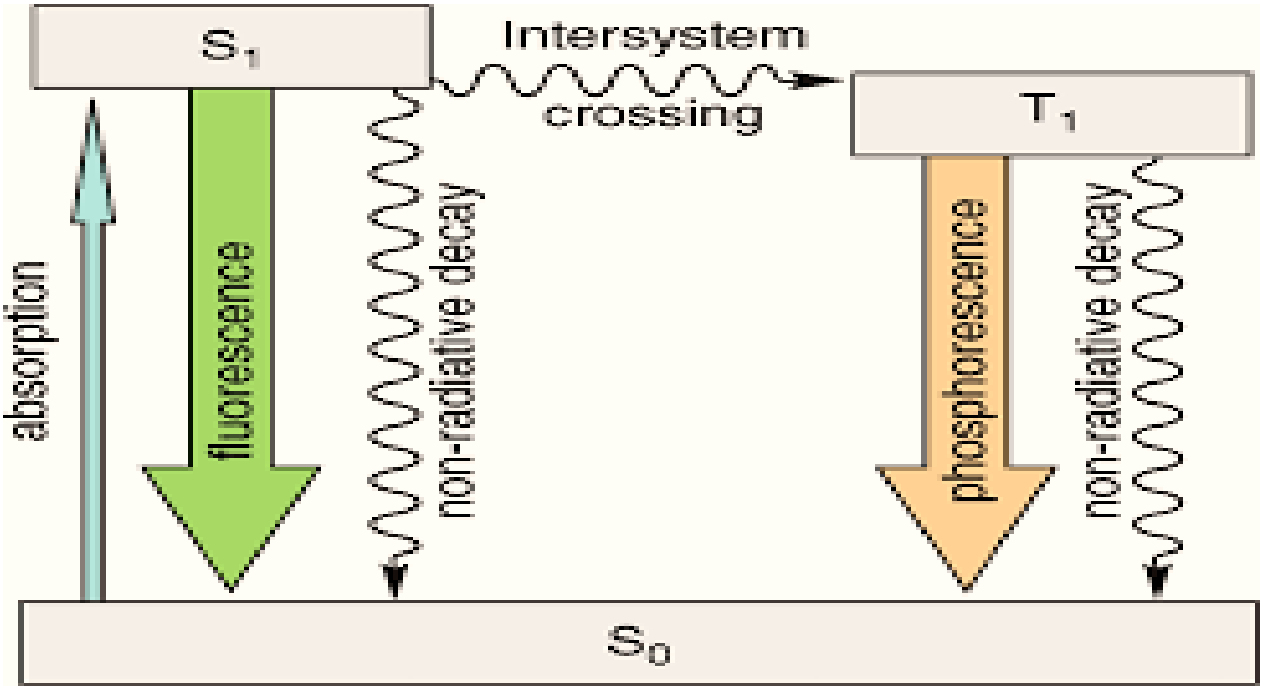

Fluorescent paint, or black light paint, glows in ultraviolet light. This is an indicator of photoluminescence. Phosphorescent paints also emit light when it excited through visible or ultraviolet light, but do so over extended periods. This long-lasting effect of phosphorescents also allows kids to enjoy "glow-in-the-dark" adhesive stars on the ceilings of their rooms.

Common phosphorescents involve petroleum jelly, glow-in-the-dark paints, the quinine in tonic water, and some detergents. Clocks and watches have their faces or numbers and hands coated with phosphorescent paints.

**Phosphorescence**

In the production of excited states via promotion of an electron into a higher orbital, the direction of the spin of the electron is preserved. Since most compounds have an even number of electrons and these are normally arranged in pairs of opposite spin, the promotion of an electron does not disturb this parity. However, it is possible for the spin of the promoted electron to be reversed so that it is no longer paired and the compound has two independent electrons of the same spin in different orbitals. Quantum theory predicts that same compound can exist in three forms of very slightly differing, but normally indistinguishable energy, and the molecule[49-55] is said to exist in a

triplet state. The indirect process of conversion from the excited state produced by absorption of energy, the singlet state, to a triplet state, is known as intersystem crossing and can occur in many substances when the lowest vibrational level of the excited singlet state, S1, has the same energy level as an upper vibrational level of the triplet state. Direct transition from the ground state, usually a singlet state, for a compound with an even number of electrons, to an excited triplet state is theoretically forbidden, which means that the reverse transition from triplet to ground state will be difficult. Thus, while the transition from an excited singlet state, for example, S1, to the ground state with the emission of fluorescence can take place easily and within ((10-9 - 10-6 )) seconds, the transition from an excited (triplet state to the ground state) with the emission of phosphorescence requires at least (10-4 seconds ) and may take as long as (102) seconds.




This delay was once used as the characterization of phosphorescence, but a more precise definition requires that phosphorescence be derived from transitions directly from the triplet state to the ground state.

**References:**


1. Acuña, A. Ulises; Amat-Guerri, Francisco; Morcillo, Purificación; Liras, Marta; Rodríguez, Benjamín (2009). "Structure and Formation of the Fluorescent Compound of Lignum nephriticum". Organic Letters. 11 (14): 3020–3023. doi:10.1021/ol901022g.
2. Safford, William Edwin *(1916). "Lignum nephriticum".* Annual report of the Board of Regents of the Smithsonian Institution . *Washington: Government Printing Office. pp. 271–298.*
3. *Valeur, B.; Berberan-Santos, M. R. N. (2011). "A Brief History of Fluorescence and Phosphorescence before the Emergence of Quantum Theory". Journal of Chemical Education.* ***88*** *(6): 731–738.* Bibcode*:*2011JChEd..88..731V. doi*:*10.1021/ed100182h.
4. *Muyskens, M.; Ed Vitz (2006). "The Fluorescence of Lignum nephriticum: A Flash Back to the Past and a Simple Demonstration of Natural Substance Fluorescence". Journal of Chemical Education.* ***83*** *(5): 765.* Bibcode*:*2006JChEd..83..765M. doi*:*10.1021/ed083p765.
5. *Herschel, John (1845).* "On a case of superficial colour presented by a homogeneous liquid internally colourless". *Philosophical Transactions of the Royal Society of London.* ***135****: 143–145.* doi*:*10.1098/rstl.1845.0004. Archived *from the original on 24 December 2016.*
6. *Herschel, John (1845).* "On the epipŏlic dispersion of light, being a supplement to a paper entitled, "On a case of superficial colour presented by a homogeneous liquid internally colourless"". *Philosophical*

*Transactions of the Royal Society of London.* ***135****: 147–153*. doi:10.1098/rstl.1845.0005. Archived *from the original on 17 January 2017.*

**7.** Holler, F. James; Skoog, Douglas A. and Crouch, Stanley R. (2006) Principles Of Instrumental Analysis. Cengage Learning. ISBN 0495012017

**8.** Valeur, Bernard, Berberan-Santos, Mario (2012). Molecular Fluorescence: Principles and Applications. Wiley-VCH. ISBN 978-3-527-32837-6. p. 64

**9.** "Animation for the Principle of Fluorescence and UV-Visible Absorbance"Archived 9 June 2013 at the Wayback Machine.. PharmaXChange.info.

**10.** Valeur, Bernard, Berberan-Santos, Mario (2012). Molecular Fluorescence: Principles and Applications. Wiley-VCH. ISBN 978-3-527-32837-6. p. 186

**11.** *Schieber, Frank (October 2001). "Modeling the Appearance of Fluorescent Colors". Proceedings of the Human Factors and Ergonomics Society Annual Meeting.* ***45*** *(18): 1324–1327.* doi:10.1177/154193120104501802.

**12.** Kasha–Vavilov rule – Compendium of Chemical Terminology, 2nd ed. (the "Gold Book") Archived 21 March 2012 at the Wayback Machine.. Compiled by McNaught, A.D. and Wilkinson, A. Blackwell Scientific Publications, Oxford, 1997.

**13.** "Fluorescence in marine organisms". *Gestalt Switch Expeditions. Archived from* the original *on 21 February 2015.*

**14.** *Wucherer, M. F.; Michiels, N. K. (2012).* "A Fluorescent Chromatophore Changes the Level of Fluorescence in a Reef Fish". *PLoS ONE.* ***7*** *(6): e37913.* Bibcode:2012PLoSO...737913W. doi:10.1371/journal.pone.0037913. PMC 3368913. PMID 22701587.

**15.** *Fujii, R (2000). "The regulation of motile activity in fish chromatophores". Pigment Cell Research.* ***13*** *(5): 300–19.* doi:10.1034/j.1600-0749.2000.130502.x. PMID 11041206.

**16.** *Abbott, F. S. (1973). "Endocrine Regulation of Pigmentation in Fish". Integrative and Comparative Biology.* ***13*** *(3): 885–894.* doi:10.1093/icb/13.3.885.

**17.** *Beyer, Steffen.* "Biology of underwater fluorescence". *Fluopedia.org.*

**18.** *Sparks, J. S.; Schelly, R. C.; Smith, W. L.; Davis, M. P.; Tchernov, D.; Pieribone, V. A.; Gruber, D. F. (2014). Fontaneto, Diego, ed.* "The Covert World of Fish Biofluorescence: A Phylogenetically Widespread and Phenotypically Variable Phenomenon". *PLoS ONE.* ***9*** *(1): e83259.* Bibcode:2014PLoSO...983259S. doi:10.1371/journal.pone.0083259. PMC 3885428. PMID 24421880.

**19.** *Matz, M.* "Fluorescence: The Secret Color of the Deep". *Office of Ocean Exploration and Research, U.S. National Oceanic and Atmospheric Administration.* Archived *from the original on 31 October 2014.*

**20.** Jump up to:[a] [b] *Heinermann, P (2014-03-10). "Yellow intraocular filters in fishes". Experimental Biology.* ***43*** *(2): 127–147.* PMID 6398222.

**21.** *Michiels, N. K.; Anthes, N.; Hart, N. S.; Herler, J. R.; Meixner, A. J.; Schleifenbaum, F.; Schulte, G.; Siebeck, U. E.; Sprenger, D.; Wucherer, M. F. (2008).* "Red fluorescence in reef fish: A novel signalling mechanism?". *BMC Ecology.* ***8****: 16.* doi:10.1186/1472-6785-8-16. PMC 2567963. PMID 18796150.

**22.** *Gerlach, T; Sprenger, D; Michiels, N. K. (2014).* "Fairy wrasses perceive and respond to their deep red fluorescent coloration". *Proceedings of the Royal Society B: Biological Sciences.* ***281*** *(1787): 20140787.* doi:10.1098/rspb.2014.0787. PMC 4071555. PMID 24870049.

**23.** *Salih, A.; Larkum, A.; Cox, G.; Kühl, M.; Hoegh-Guldberg, O. (2000).* "Fluorescent pigments in corals are photoprotective". *Nature.* ***408*** *(6814): 850–3.* Bibcode:2000Natur.408..850S. doi:10.1038/35048564. PMID 11130722. Archived *from the original on 22 December 2015.*

**24.** *Roth, M. S.; Latz, M. I.; Goericke, R.; Deheyn, D. D. (2010). "Green fluorescent protein regulation in the coral Acroporayongei during photoacclimation". Journal of Experimental Biology.* ***213*** *(21): 3644-3655.* doi:10.1242/jeb.040881. PMID 20952612.

**25.** *Bou-Abdallah, F.; Chasteen, N. D.; Lesser, M. P. (2006).* "Quenching of superoxide radicals by green fluorescent protein". *Biochimica et BiophysicaActa (BBA) - General Subjects.* ***1760*** *(11): 1690–1695.* doi:10.1016/j.bbagen.2006.08.014. PMC 1764454. PMID 17023114.

**26.** *Field, S. F.; Bulina, M. Y.; Kelmanson, I. V.; Bielawski, J. P.; Matz, M. V. (2006). "Adaptive Evolution of Multicolored Fluorescent Proteins in Reef-Building Corals". Journal of Molecular Evolution.* ***62*** *(3): 332–339.* Bibcode:2006JMolE..62..332F. doi:10.1007/s00239-005-0129-9. PMID 16474984.

**27.** *Mäthger, L. M.;* Denton, E. J. *(2001).* "Reflective properties of iridophores and fluorescent 'eyespots' in the loliginid squid Alloteuthissubulata and Loligo vulgaris". *The Journal of Experimental Biology.* ***204*** *(Pt 12): 2103–18.* PMID 11441052. Archived *from the original on 4 March 2016.*

**28.** *Tsien, R. Y. (1998). "The Green Fluorescent Protein". Annual Review of Biochemistry.* ***67****: 509–544.* doi:10.1146/annurev.biochem.67.1.509. PMID 9759496.

**29.** *Mazel, C. H. (2004). "Fluorescent Enhancement of Signaling in a Mantis Shrimp". Science.* ***303*** *(5654): 51.* doi:10.1126/science.1089803. PMID 14615546.

**30.** *Bou-Abdallah, F.; Chasteen, N. D.; Lesser, M. P. (2006).* "Quenching of superoxide radicals by green fluorescent protein". *Biochimica et BiophysicaActa (BBA) - General Subjects.* ***1760*** *(11): 1690–1695.* doi:10.1016/j.bbagen.2006.08.014. PMC 1764454. PMID 17023114.

**31.** *Douglas, R. H.; Partridge, J. C.; Dulai, K.; Hunt, D.; Mullineaux, C. W.; Tauber, A. Y.; Hynninen, P. H. (1998). "Dragon fish see using chlorophyll". Nature.* ***393*** *(6684): 423–424.* Bibcode:1998Natur.393..423D. doi:10.1038/30871.

**32.** *Wong, Sam (13 March 2017).* "Luminous frog is the first known naturally fluorescent amphibian". Archived *from the original on 20 March 2017*. Retrieved 22 March 2017.

**33.** *King, Anthony (13 March 2017).* "Fluorescent frog first down to new molecule". Archived *from the original on 22 March 2017*. Retrieved 22 March 2017.

**34.** *Vukusic, P; Hooper, I (2005). "Directionally controlled fluorescence emission in butterflies". Science.* ***310*** *(5751): 1151.* doi:10.1126/science.1116612. PMID 16293753.

**35.** *Arnold, K. E. (2002).* "Fluorescent Signaling in Parrots". *Science.* ***295*** *(5552): 92.* doi:10.1126/science.295.5552.92. PMID 11778040.[permanent dead link]

**36.** *Andrews, K; Reed, S. M.; Masta, S. E. (2007).* "Spiders fluoresce variably across many taxa". *Biology Letters.* ***3*** *(3): 265–7.* doi:10.1098/rsbl.2007.0016. PMC 2104643. PMID 17412670.

**37.** *Stachel, S. J.; Stockwell, S. A.; Van Vranken, D. L. (1999). "The fluorescence of scorpions and cataractogenesis". Chemistry & Biology.* ***6*** *(8): 531–539.* doi:10.1016/S1074-5521(99)80085-4. PMID 10421760.

**38.** *Iriel, A. A.; Lagorio, M. A. G. (2010). "Is the flower fluorescence relevant in biocommunication?". Naturwissenschaften.* ***97*** *(10): 915–924.* Bibcode:2010NW.....97..915I. doi:10.1007/s00114-010-0709-4. PMID 20811871.

**39.** *McDonald, Maurice S. (2 June 2003).* Photobiology of Higher Plants. *John Wiley & Sons.* ISBN 9780470855232. Archived *from the original on 21 December 2017.*

**40.** *Gilmore, F. R.; Laher, R. R.; Espy, P. J. (1992).* "Franck–Condon Factors, r-Centroids, Electronic Transition Moments, and Einstein Coefficients for Many Nitrogen and Oxygen Band Systems". *Journal of Physical and Chemical Reference Data.* ***21*** *(5): 1005.* Bibcode:1992JPCRD..21.1005G. doi:10.1063/1.555910. Archived *from the original on 9 July 2017.*

**41.** *Harris, Tom.* "How Fluorescent Lamps Work". *HowStuffWorks. Discovery Communications.* Archived *from the original on 6 July 2010*. Retrieved 27 June2010.

**42.** *Rye, H. S.; Dabora, J. M.; Quesada, M. A.; Mathies, R. A.; Glazer, A. N. (1993). "Fluorometric Assay Using Dimeric Dyes for Double- and Single-Stranded DNA and RNA with Picogram Sensitivity". Analytical Biochemistry.* ***208*** *(1): 144–150.* doi:10.1006/abio.1993.1020. PMID 7679561.

**43.** *Harris, Daniel C. (2004).* Exploring chemical analysis. *Macmillan.* ISBN 978-0-7167-0571-0. Archived *from the original on 31 July 2016.*

**44.** *Calfon MA, Vinegoni C,* Ntziachristos V, *Jaffer FA (2010).* "Intravascular near-infrared fluorescence molecular imaging of atherosclerosis: toward coronary arterial visualization of biologically high-risk plaques". *J Biomed Opt.* ***15*** *(1): 011107.* Bibcode:2010JBO....15a1107C. doi:10.1117/1.3280282. PMC 3188610. PMID 20210433.

**45.** *Ughi GJ, Wang H, Gerbaud E, Gardecki JA, Fard AM, Hamidi E, et al. (2016).* "Clinical Characterization of Coronary Atherosclerosis With Dual-Modality OCT and Near-Infrared Autofluorescence Imaging". *JACC Cardiovasc Imaging.* ***9*** *(11): 1304–1314.* doi:10.1016/j.jcmg.2015.11.020. PMC 5010789. PMID 26971006.

**46.** *Hara T, Ughi GJ, McCarthy JR, Erdem SS, Mauskapf A, Lyon SC, et al. (2015).* "Intravascular fibrin molecular imaging improves the detection of unhealed stents assessed by optical coherence tomography in vivo". *Eur Heart J.* ***38*** *(6): 447–455.* doi:10.1093/eurheartj/ehv677. PMC 5837565. PMID 26685129.

**47.** *Shkolnikov, V; Santiago, J. G. (2013).* "A method for non-invasive full-field imaging and quantification of chemical species" (PDF). *Lab on a Chip.* ***13*** *(8): 1632–43.* doi:10.1039/c3lc41293h. PMID 23463253. Archived (PDF) *from the original on 5 March 2016.*

**48.** *Moczko, E; Mirkes, EM; Cáceres, C; Gorban, AN; Piletsky, S (2016).* "Fluorescence-based assay as a new screening tool for toxic chemicals". *Scientific Reports.* ***6****: 33922.* Bibcode:2016NatSR...633922M. doi:10.1038/srep33922. PMC 5031998. PMID 27653274.

**49.** *Smith, W. Leo; Buck, Chesney A.; Ornay, Gregory S.; Davis, Matthew P.; Martin, Rene P.; Gibson, Sarah Z.; Girard, Matthew G. (2018-08-20). "Improving Vertebrate Skeleton Images: Fluorescence and the Non-Permanent Mounting of Cleared-and-Stained Specimens". Copeia.* ***106*** *(3): 427–435.* doi:10.1643/cg-18-047. ISSN 0045-8511.

**50.** K. Arnold et al., *ChemieOberstufe* (in German), CornelsenSchulverlage, Berlin, 2015, 496-497. ISBN: 978-3-06-011179-4

**51.** Lexikon der Physik: Lumineszenz (in German), *spektrum.de*. (accessed January 25, 2017)

**52.** D. Wiechoczek, WennMineralienselberleuchten – Phosphoreszenz, Fluoreszenz und Lumineszenz (in German), *chemieunterricht.de* **2010**. (accessed January 25, 2017)

**53.** Lexikon der Physik: PhotophysikalischeProzesse (in German), *spektrum.de*. (accessed January 27, 2017)

**54.** D. Wiechoczek, Chemiemit Curry (in German), *chemieunterricht.de* **2015**. (accessed January 27, 2017)

**55.** P. W. Atkins, J. de Paula, KurzlehrbuchPhysikalischeChemie **(in German)**, Wiley-VCH, Weinheim, **2008**, 853ff., 921ff. ISBN: 978-3-527-31807-0

**56.** Kobayashi, H., Ogawa, M., Alford, R., Choyke, P.L. and Urano, Y., "New strategies for fluorescent probe design in medical diagnostic imaging," Chem Rev (2010) 110:2620–2640.

**57.** Kricka, L.J. and Fortina, P., "Analytical ancestry: "Firsts" in fluorescent labeling of nucleosides, nucleotides, and nucleic acids," ClinChem (2009) 55:670–683.

**58.** Liehr, T., Ed., Fluorescence In Situ Hybridization (FISH): Application Guide, Springer (2008).

**59.** Mason, W.T., Ed., Fluorescent and Luminescent Probes for Biological Activity, Second Edition, Academic Press (1999).

**60.** Oliver, C. and Jamur, M.C., Eds., Immunocytochemical Methods and Protocols, Third Edition (Methods in Molecular Biology, Volume 588), Humana Press (2010).