# L'Oreal Art and Science of Color Prize

# Phosphorescent Pigments As A Significant New Material In Art

**by Anders Knutsson**
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Art is an amalgam of conquering new territory, breaking down the old rules, while incorporating its historical foundation. The materials that I have been working with for the past 20 years epitomize the concept of conquering new artistic territory – and merging science and art.

The unique material, whose properties I have been exploring are full spectrum *luminous* pigments. This exciting phosphorescent material has been studied scientifically to understand its process of emitting photons but has *little known history in art* I believe that the handful of artists, of whom I am one, determined enough to work with this difficult pigment, are truly explorers in artistic territory still to be charted. Further, the phosphorescent pigment is the only new pigment to be introduced into the history of art since the late-19th Century.

This paper will discuss the theory of luminescence as well as the unique qualities and attributes that this pigment possess and how I have incorporated these attributes into my art.

## History of the Phosphorescent Pigment and the Theory of Luminescence

Phosphorescent minerals were first discovered in the Renaissance (1603). However, it was not until the mid-19th century that luminescence was subjected to systematic study. Historically, the first law of luminescence was formulated by Stokes in 1852. It is known as **Stokes' Rule** and states that the wavelength of luminescence excited by radiation is greater than the wavelength of the exciting radiation. At about the same time, Antoin Becquerel (1852-1908) laid the foundation for the experimental investigation of the emission spectrum, the efficiency of excitation and the duration of luminescence afterglow (phosphorescence).

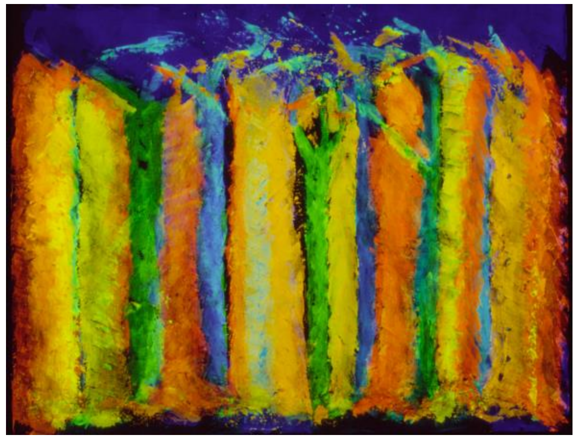
Luminescence is broken down into two separate phenomena called **Fluorescence** and **Phosphorescence.** This differentiation is made because of two different emission processes which produce two very different phenomena**.** For the human, the observed difference between these two processes involves the aspect of time. The area that applies to my work is Phosphorescence (specifically, photoluminescence). Table 1 in the attached shows a breakdown of the Types of Luminescence. Table 2 shows the electromagnetic spectrum.

Fluorescence occurs very quickly after light has been absorbed whereas Phosphorescence occurs less quickly . To the human eye, fluorescence appears to be no more than reflected light, since fluorescent phenomena stops after the light source is taken away, whereas phosphorescence emits light even after the light source is taken away. Phosphorescence is, therefore, the process which produces the afterglow seen in my luminous paintings.

From the works of past physicists we know that Electromagnetic radiation exhibits both a particle-like (or quantum) behavior and a wave-like behavior. Thus, visible light (see Table 2) is said to have a wavelength ($\lambda$) and a frequency ($\nu$). The wavelength and frequency are related to the velocity of light (c) (see Table 3, Planck's Laws).

Luminescence is a varied phenomenon and all attempts at a theoretical explanation of its properties on the basis of classical theories were inevitably unsuccessful. It was only after the advent of **quantum mechanics** and **quantum electrodynamics** that a realistic basis became available for the understanding of the many aspects of luminescence.

Quantum Theory is a method of explaining the nature of matter at the atomic and molecular level. The probabilistic interpretations generated by use of mathematics and statistics indicate that <u>reality is subject to random events and is dependent upon the observer</u>. When I began working with these pigments, one of the ways I used to explain its relationship was through quantum theory. My luminous paintings have a duality, which I will explain in greater detail, and which is defined by a random, individual experience. Thus, my luminous painting become, in this regard, an illustration and metaphor for quantum theory. (See Schedule 1 for an explanation of Quantum Theory)



## <u>Application of Phosphorescence to my art</u>

There are a number of factors influencing phosphorescent intensity that I needed to understand in order to work with them in my art:

1. **Power of excitation source**: the greater the intensity of the excitation source, the greater the excitation of luminophors (material which produces luminescence) to the Singlet (Fluorescent) or Triplet (Phosphorescent) States (see Schedule 1 for detailed explanation of these States)
2. **Duration of Exposure** – the longer the luminescent material (luminophor) is exposed to the excitation source (e.g. light bulb), the greater the amount of conversions of the Singlet (fluorescent) State to the Triplet (phosphorescent) State will occur.
3. **Intensity of Afterglow** – The intensity of Afterglow (phosphorescent emission) begins to immediately decrease once the excitation source has been removed. Each color has a different rate of intensity decrease. The challenge is to create an artwork where images shift and change with time taking into consideration the afterglow properties of each color.
4. **Apparent Intensity –** the "apparent" intensity of the afterglow, to the human observer, will increase for a period of time once the "lights have been turned out". This is due to the initial desensitization of the human eye to the dark. After the lights have been turned out, the eyes gradually become more light sensitive. Initially, both the rods and cones of the eyes' light-sensitive cells are fully functioning. As the intensity of light in the painting fades, the cones, which are only sensitive to colored light, cease to function and the night-seeing rods, which are sensitive to light (shades of gray) take over. However, the rods, due to their placement on the retina, cannot focus sharply – therefore, only indirect vision is experienced.

When I first began to work with phosphorescent pigments, I was both startled and very excited by the results! I was intrigued by four visually striking things that, when the light was turned off, happened at once.

- Light came *out* of the painting
- The image I had just seen with the light on was now *different*
- The image I was now looking at was slowly *changing*
- The painting, the object, had disappeared and was now *immaterial light!*

When I paint the daylight image, my interest focuses on a holistic experience of painted color, its emotional content and affect on the viewer. By day, the luminous pigments provide an opportunity to explore a different chromatic range with their off-whites, light greens and yellows and near-grays. They evoke a delicate, airy translucency and bring more pure reflected light into the painting. However, the most spectacular and exciting moment to me is to see, by night, colored light radiating or emitting out of the paint itself. **This opens up a new interpretation and expression of light in painting, for it deals with emitted light from paint rather than reflected light from the paint surface.** It is important to note that I do not paint "in the dark". Rather, my extensive experience allows me to work in "two tracks" while painting.

When you look at one of my luminous works you will observe that the daylight appearance of the painting is independent of the night appearance and vice versa. Yet they are physically the same painting. These two entities complement and contain each other like the Yin and the Yang, still they are not be perceived as two sides of the same coin. **This metaphor of two separates that are yet one (e.g. day and night make a 24-hour period) has never before been possible to express with painterly means.** The inclusion of luminous pigments in the vocabulary of painting permits an expansion of its expression and can be used in many creative ways. (Schedule 3 lists the historical and current applications in art.)

The passage of time that these pigments provide is real and direct – a unique occurrence **<u>having no parallel in traditional painting.</u>** The light from the paint fades at different rates of time for different colors, ranging from one minute to many hours.

Painters have been fascinated by light for centuries. It defines and reveals the world of things and materials around us through our visual system. Furthermore, light has been used in painting to suggest the existence of another force – a non-material world, an inner reality we all know exists and whose presence is of vital importance to painting as art, regardless of style and time. I see luminous painting as a powerful and direct manifestation of this universal force of light and energy. The pigments soak up light, store it and emit it – all at the same time. To a keen eye, the luminous glow can even be seen in daylight or artificial light – but its full force and magic are best seen in total darkness.

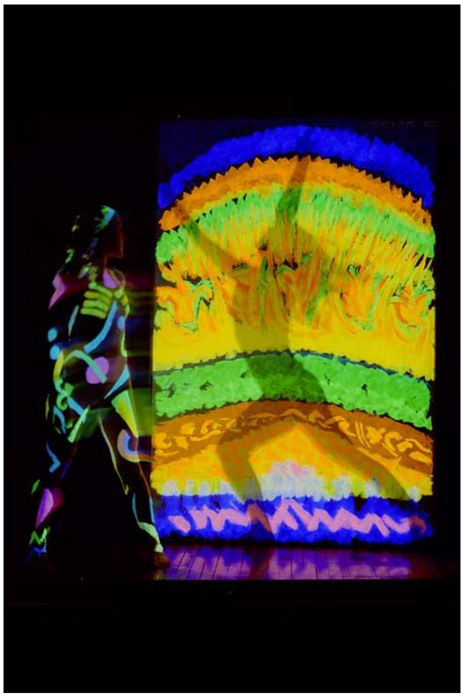
<u>Phosphorescent pigments – an artistic methodology</u>

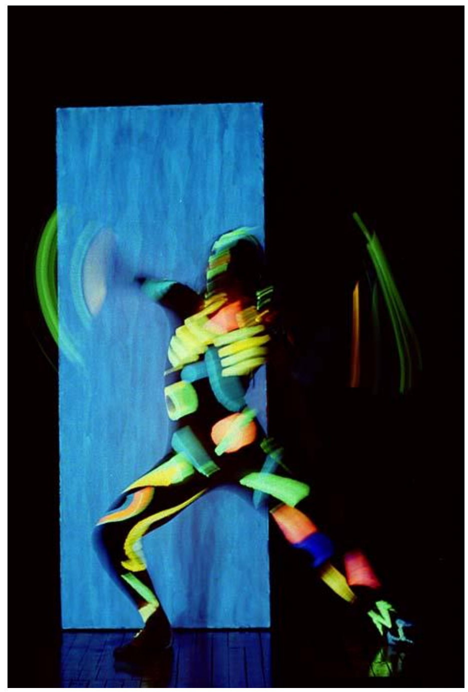
The material that I use is a synthetic material created in laboratories in America, Europe and Japan (see Schedule 2). The development of the full spectrum and long afterglow pigments in the last 10 years have created tremendous artistic potential. However, the full spectrum pigments are hard to find, expensive, and difficult to work with – it's alchemical secrets yield only to those persistent in unlocking its secrets.

I work mixing phosphorescent pigments with traditional ground color pigments and oil/wax or acrylic medium. The paintings are meant to be viewed in the dark as well as under traditional gallery lights. In the light, the paintings are light filled and luminous. In the dark, each color changes in tone and intensity at a different rate of speed – the storm of photons that come into one's eyes are powerful and very sensory. It presents an immediate surprise that some have called the "wow" moment. I create my images with an understanding of the properties of each pigment and color. The images on the CD provided show a "moment in time". (See Schedule 4). The real experience is to sit in front of a painting and experience it's transformation.

Performance

It was always obvious to me that movement and time were an integral part of this experience – that intrinsic to the experience of this work was *movement of light*. What started as improvisatory light "performances" using an ordinary camera flash at my exhibitions, developed into a performance concept. In 1999, I began to work with musicians and dancers to develop a performance concept that is improvisatory and experimental in nature. The performance has three equal components: sound, movement, and light - color is freed from the canvas, music from the instrument and movement from the body.





The artistic explorers of art – Kandinsky, Duchamp, Jackson Pollock – each changed the paradigm of art. In my mysteriously complex and changing paintings, light is emitted from within, rather than reflected from the surface and *this difference is the source of a new expression of light.* I believe that Luminous painting is part of this tradition of questioning established definitions in order to expand our visual work and to experience our physical and spiritual selves differently – and will introduce a change in the existing paradigm of art.

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## TABLES

Table 1 shows the entire range of electromagnetic emissions which include all forms of radiation, visible light, ultra-violet light, radio waves, gamma rays, micro waves, etc. The area that applies to my artwork is Photoluminescence.

### TABLE 1: Types of Luminescence

| TYPE of LUMINESCENCE | MEANS of INDUCING LUMINESCENCE |
|---|---|
| Photoluminescence | Ultraviolet or visible light of short wavelengths |
| Cathodoluminescence | High velocity electron bombardment (cathode ray tube) |
| Radioluminescence | Excitation by radioactive substances (watch faces) |
| Bioluminescence | Luminescence generated by living organisms (fireflys) |
| Electroluminescence | Electrical excitation (LED Displays) |
| Chemiluminescence & Electrochemical Luminescence | Chemical and electrochemical reactions such as those used in a glowstick |
| Triboluminescence | Pressure or intense friction |

Table 2 illustrates the breakdown of the Electromagnetic Spectrum. The critical areas for our purposes in the discussion of Photoluminescence is the ultra-violet and visible light spectrum.

### TABLE 2: Electromagnetic Spectrum

| NAME | WAVELENGTH (meters) |
|---|---|
| Radio Waves | $10^{6} – 10^{-1}$ |
| Microwaves | $10^{-1} – 10^{-3}$ |
| Infrared | $10^{-3} – 10^{-6}$ |
| Visible | $10^{-6} – 10^{-7}$ |
| Ultraviolet | $10^{-7} – 10^{-8}$ |
| X-rays | $10^{-8} – 10^{-11}$ |
| Gamma Rays | $10^{-11} – 10^{-14}$ |

### TABLE 3: Relationship of Wavelength, Frequency and Color (Planck's Law)

The wavelength and frequency are related to the velocity of light (c) which, in any given medium, is a constant (the speed of light in a vacuum is 3.00 x $10^{8}$ meters/sec or 1.86 x $10^{5}$ miles/sec). **Thus: $c = \lambda\nu$.** The energy which a photon (or one particle) of light has is dependent on its specific frequency as given by Max Planck in **Planck's Law: $E=hv = hc/\lambda$** where h is Planck's constant = 6.63 x $10^{-34}$ joule-sec.

| COLOR | WAVELENTH RANGE (Angstroms)* |
|---|---|
| Violet | 4000 – 4500 |
| Blue | 4500 – 5000 |
| Green | 5000 – 5500 |
| Yellow | 5500 – 5580 |
| Orange | 5580 – 6300 |
| Red | 6300 – 7000 |

* typically the units for wavelength ($\lambda$) are expressed in Angstroms (A) which are $10^{-10}$ meters. Frequency is expressed in $sec^{-1}$ and energy is expressed in joules.

## Schedule 1

### QUANTUM THEORY AS IT RELATES TO PHOSPHORESCENCE

In Quantum Theory, electrons exist at different energy "states"; the energy levels which the electrons can exist at are "discrete" (meaning there are no in-betweens). Since the electrons exist at discrete energy levels, to move from one energy level to another the electron must absorb or emit energy of a certain "discrete" amount. When an electron becomes excited by a photon of light (as happens in photoluminescence), the photon which does the exciting has to have a specific energy which is equal to the energy difference between the original level (or state) and the higher level (or state). When energy is absorbed by an electron, the extra energy causes some reorientation of the delicate balance between the other electrons and the nuclei. This can subtly change the energy level values for the electrons due to changes in vibrational or rotational energy components.

As an atom becomes excited, this becomes a non-stable condition and the atom wants to get rid of the energy in some manner. There are many different ways in which the energy can be either gotten rid of or partitioned to other forms. These include: internal conversion, fluorescence, intersystem crossing and phosphorescence. The different processes responsible for fluorescent and phosphorescent emissions are based on the spin of electrons when they become excited. Conserving the spin leads to an electron which will emit energy for fluorescent phenomena while reversing its spin leads to an electron which will emit as phosphorescent phenomena.

Singlet and Triplet States

A term used to describe an atom which has been excited but has had the "spin" of the excited electron reversed, is the "Triplet State" (or phosphorescence) while excitation without "spin" reversal is called the "Singlet State" (or fluorescence). Normally, it is rare that an electron will be excited to the Triplet State directly from the "Ground State", but as the lowest Triplet state is of lower energy than the lowest Singlet State, the Triplet State is reached by first being excited to the Singlet State and then, through a mechanism called intersystem crossing, the electron passes into the Triplet State, from which emission occurs. Since the Triplet state is less energetic than the original Singlet State to which the electron was excited, the photon emitted will have less energy and, due to Planck's law, will be of lower frequency and thus of higher wavelength.

## Schedule 2

## LUMINOVA PIGMENT – HISTORY AND PRODUCT SPECIFICATION

***LumiNova®*** is the name of a newly developed phosphorescent (glow-in-the-dark) pigment which is based on a metal oxide chemistry, drastically different from conventional phosphorescent pigments which are either based on the Zinc Sulfide or on radioisotopes for the self-luminous properties.

*LumiNova*® was invented and developed by Nemoto & Co. Ltd., of Tokyo, Japan, which has been in the luminous pigment business since 1941 and is one of the leading phosphorescent pigment manufacturers in the world. The development of *LumiNova*® was necessitated by the demands placed upon Nemoto & Co. Ltd. By the Japanese watch and clock manufacturers which did not want to use radioactive luminous dials in their products. Like any new product, it soon found out that the application possibilities are almost endless.

*LumiNova*® glows practically all night long without the aid of any radioactive substances was awarded the Most Innovative Product in Japan in 1993.

<u>Commercial Applications</u>

- Clock & watch dials
- Electronic instrument dial pads
- Home appliances
- Lighting apparatus and switches
- Exit sign boards
- Emergency signage and low level lighting escape systems
- Aircraft and automobile dials and instrument panels
- Firemen's equipment
- Religious objects (rosaries, etc)
- Children's toys
- Traffic signs
- Fishing equipment
- Military applications
- Outdoor path marking
- Camping equipment
- Textile printing
- Flooring
- Writing & printing inks
- Luminous tape (3M)
- Other applications where a long afterglow and/or light fastness is needed

<u>Comparison of a typical *LumiNova*® pigment with a conventional Phosphorescent Pigment</u>

| | *LumiNova*® | Conventional Phosphorescent Pigment |
|---|---|---|
| Chemical Identity | Compound oxide | ZnS:Cu |
| Body Color | Light Yellowish Green | Yellowish Green |
| Average Particle Size | 10-40 μm (6) | 20-40 μm |
| Excitation Energy | 200-450 nm | 200-450 nm |
| Emission Wave Length (Peak) | 520 nm | 530 nm |
| Afterglow Brightness (1) | ~ 300 mcd/m² | 20-30 mcd/m² |
| Afterglow Extinction (2) | > 2,000 minutes. | 200 minutes |
| Excitation Time (3) | ~ 30 minutes | ~ 4 minutes |
| Light Fastness (4) | > 1,000 hours | 10-24 hours |
| Chemical Stability | Excellent (except water) | Poor to good |
| Specific Gravity (5) | 3.6 | 4.1 |

Footnotes:

(1) Brightness after 20 minutes, excitation with a $D_{65}$ illuminant for 4 minutes at 200 lx.
(2) Time span necessary for afterglow brightness to diminish to 0.32 mcd/m² (100 times the human eye perception limit)
(3) Time required for saturation with standard $D_{65}$ illuminant at 200 lx.
(4) Time required for initial afterglow to drop by 20% after irradiation with 300W high pressure mercury lamp (accelerated light fastness test).
(5) In powder form
(6) Depends on type of *LumiNova*®

## Schedule 3

### KNOWN HISTORICAL APPLICATIONS IN ART

| Artist | Work |
|---|---|
| Loïs Fuller (1890-1910) | Performance: Phosphorescent dance |
| Kandinsky | Pigments included in paint medium |
| Lucio Fontana (1949) | Temporary environmental installations (1949) |
| Performance 1940's | Phosphorescent Ballet |

### ARTISTS CURRENTLY WORKING WITH PHOSPHORESCENCE

| Artist | Work |
|---|---|
| Tom Bacher (U.S.) | Painting |
| Pierre Bruneau (Canada) | Painting, Installation, performance |
| Marc Eggar (Swiss) | Painting, sculpture |
| Nancy Haynes (U.S.) | Painting |
| Anders Knutsson (U.S./Sweden) | Painting, Installation, performance, sculpture |
| Sheila Moss (U.S.) | Installation |

(Note: these artists are part of a luminous group show curated by Doris Schultz and Lilly Wei that will be touring North American museums and universities in 2004-2006.)

## Schedule 4

**LIST OF IMAGES ON CD (submitted separately)**

Due to its size, Schedule 4 submitted as a separate email file.