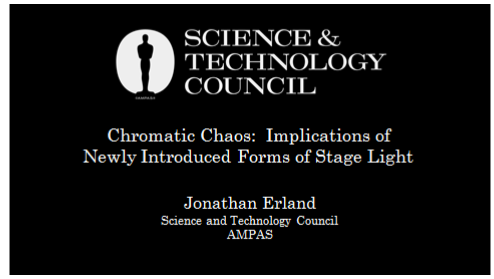
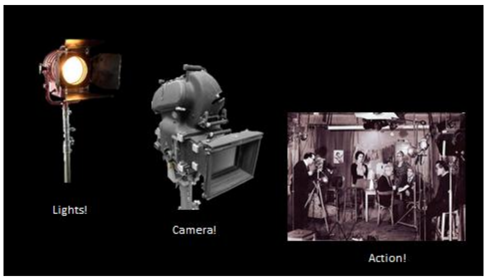
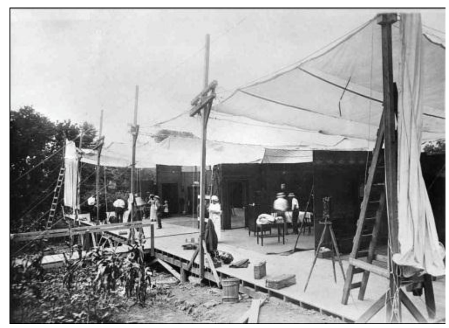
Chromatic Chaos: Implications of Newly Introduced Forms of Stage Light



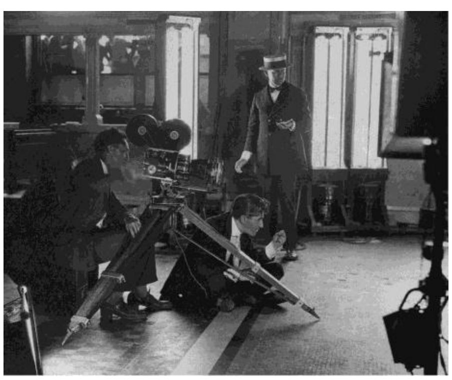
Jonathan Erland, Chair, Solid State Lighting Subcommittee
of the Science and Technology Council



Lights! Camera! Action! - by tradition, the commands that bring a stage to life and begin the filming of every shot in a motion picture. These three elements comprise the essence of storytelling in film, and the science and technology of each are at the very core of the mission of the Academy.

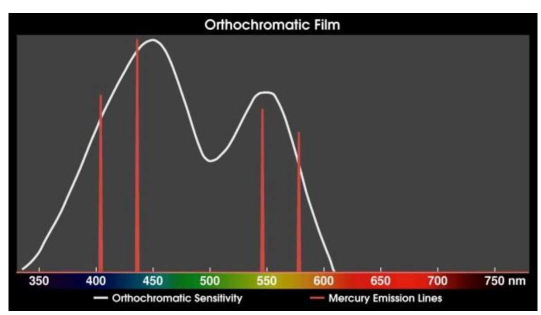


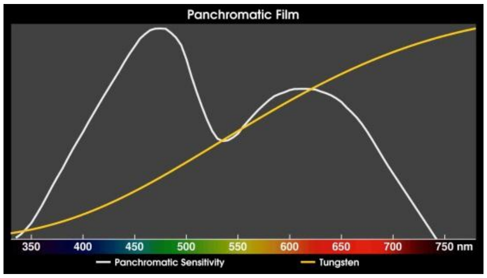
Images are made with light, and thus the quality of light is essential to the quality of the image. The earliest form of lighting for motion pictures was, of course, daylight. Even interior sets were built with their tops exposed to natural daylight, though covered with scrim to prevent harsh shadows.



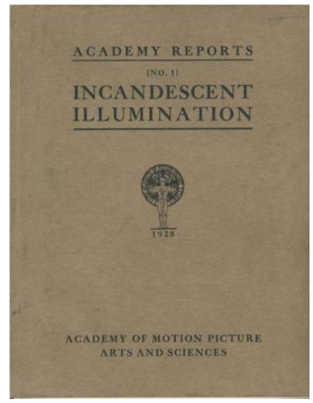
It soon became necessary to avoid the weather, and artificial light was introduced in the form of Mercury vapor lamps.

Both daylight and Mercury vapor were compatible with the orthochromatic film in use at the time, though the constrained color gamut required extensive compensations in the choice of colors and especially in make-up in order to produce anything like a natural look.

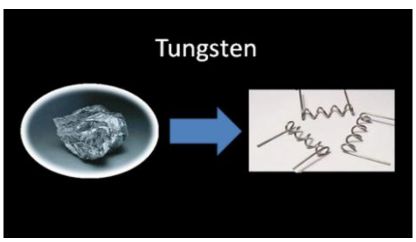




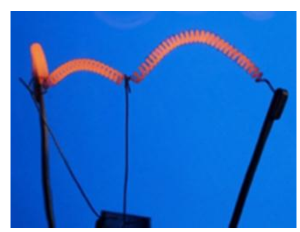
All that changed in 1927 with the introduction of panchromatic film. This wider spectral sensitivity film demanded a broader spectral power distribution light source making the then twenty year old Tungsten Incandescent the obvious candidate.

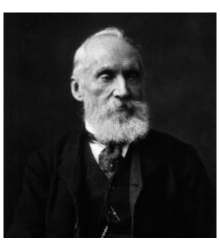


This was acknowledged in the very first engineering project undertaken by the Academy in November 1927, barely six months into the institution's first year. In July of 1928 the deliverable of that project was published as "Academy Reports, No. 1 - Incandescent Illumination" This eighty page report laid the cornerstone of incandescent lighting in motion pictures. By the way, as always, the views, conclusions and opinions I express here are entirely my own, and do not represent official positions of the Academy.

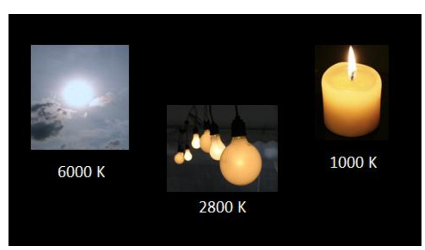


The basic concept of such a light is to take a metal, known as a "black body," such as Tungsten which has the highest melting point of any metal, draw it into a wire, enclose it in a vacuum and apply a voltage to it. The resistance the wire presents to the current causes the wire to become hot. So much so that it glows, or incandesces.



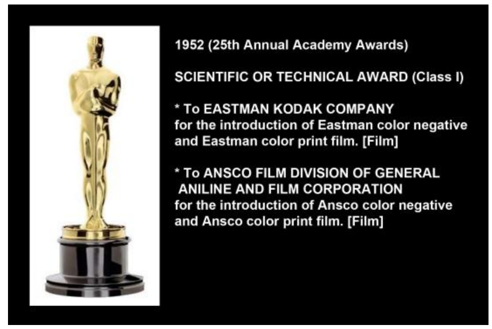


With his "Planckian Locus," Max Planck adapted a scale devised by William Thomson, Lord Kelvin whereby, the brightness and whiteness of such a light could be described by its temperature in degrees centigrade above absolute zero. This was designated kelvin or simply K. For a visual reference, consider that daylight is approximately 6000K while a candle is about 1000K. An ordinary household light



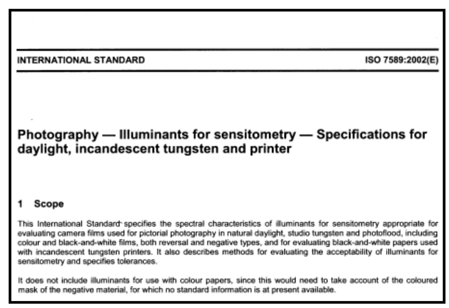
bulb, then and now, was thus about 2800K and used a relatively fine wire. The necessarily much more powerful lights needed for filming required a much larger and thicker filament which could be driven by a higher current, and this resulted in a bright white light, and a temperature of 3200K.

Then in 1950, motion picture monopak color film became available from Eastman Kodak and also Ansco. While slow by today's standards, it was fast enough to allow the use of incandescent light. And since the color balance of the color image would be dictated by the color temperature, the Kelvin, of the lights used for filming, the filmstock designers settled on 3200K as the "white" light that would yield a neutral white in the final print image.



As M.A. Hankins says in his 1966 SMPTE paper "History of Motion Picture Set Lighting Equipment:" "Since 1951, all professional color film used in the motion picture studios has been balanced for exposure with tungsten illumination." (SMPTE Journal Article reproduced on Mole.com)

The International Standards Organization (the ISO) published Studio Tungsten as a standard for photography at least as early as 1972. The current revision is ISO 7589.



INTERNATIONAL STANDARD ISO 7589:2002(E)

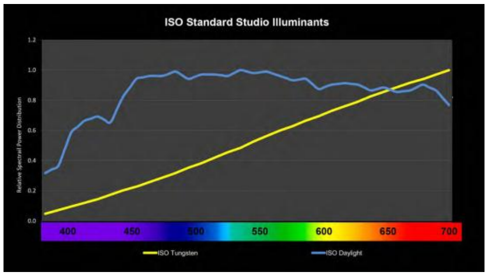
Photography — Illuminants for sensitometry — Specifications for daylight, incandescent tungsten and printer

1 Scope

This International Standard specifies the spectral characteristics of illuminants for sensitometry appropriate for evaluating camera films used for pictorial photography in natural daylight, studio tungsten and photoflood, including colour and black-and-white films, both reversal and negative types, and for evaluating black-and-white papers used with incandescent tungsten printers. It also describes methods for evaluating the acceptability of illuminants for sensitometry and specifies tolerances.

It does not include illuminants for use with colour papers, since this would need to take account of the coloured mask of the negative material, for which no standard information is at present available.

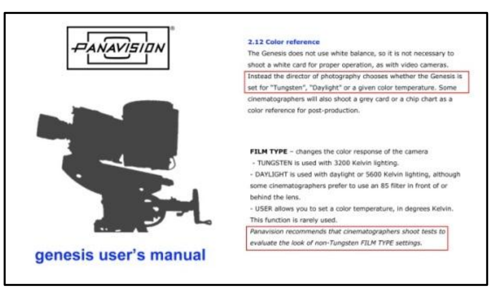
Thus the motion picture industry, and color photography generally, constructed its image- forming infrastructure around this standard, such that filmstocks, camera filters, light meters, and so forth, all assumed Studio Tungsten light as the source, unless, of course, the source was daylight which required a different color balance for the filmstock. Daylight was also standardized as Studio Daylight by the same ISO Standard.



Solid State technology has made substantial inroads into almost every aspect of the entertainment industry with imaging, sound and display already significantly impacted. Now, with the introduction of LED's, the very light from which we form our images is undergoing the same transition.

Today we are hearing the standard Studio Tungsten light being characterized as a "legacy" light, "revered" by generations of cinematographers who grew up with it. Such a characterization suggests the appeal is familiarity, habit and custom; a mere fashion that can be cast off in favor of a newer one. This is dismissive of the incredible effort that created the reliable light/film imaging infrastructure that has served us so well for some eighty years. The indifference to this infrastructure can arguably be traced to its very reliability.

Every stage light, be it Mole-Richardson, Arri or even the humble 100 W household light bulb, delivered an utterly predictable, totally reliable SPD at the flick of a switch. After eighty years, it's not surprising that it's taken so for granted that nobody remembers what a miracle it was when it was introduced.



PANAVISION

genesis user's manual

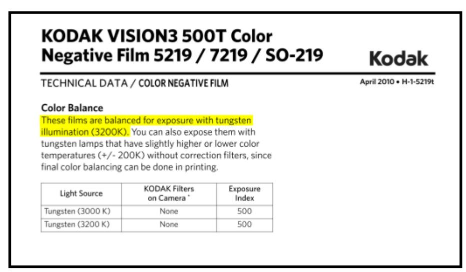
2.12 Color reference

The Genesis does not use white balance, so it is not necessary to shoot a white card for proper operation, as with video cameras. Instead the director of photography chooses whether the Genesis is set for "Tungsten", "Daylight" or a given color temperature. Some cinematographers will also shoot a grey card or a chip chart as a color reference for post-production.

FILM TYPE – changes the color response of the camera
- TUNGSTEN is used with 3200 Kelvin lighting.
- DAYLIGHT is used with daylight or 5600 Kelvin lighting, although some cinematographers prefer to use an 85 filter in front of or behind the lens.
- USER allows you to set a color temperature, in degrees Kelvin. This function is rarely used.

Panavision recommends that cinematographers shoot tests to evaluate the look of non-Tungsten FILM TYPE settings.

In most filmstock specification sheets, you can find the statement, "This film is balanced for 3200K Tungsten Incandescent light."



KODAK VISION3 500T Color Negative Film 5219 / 7219 / SO-219

Kodak

TECHNICAL DATA / COLOR NEGATIVE FILM

April 2010 • H-1-5219t

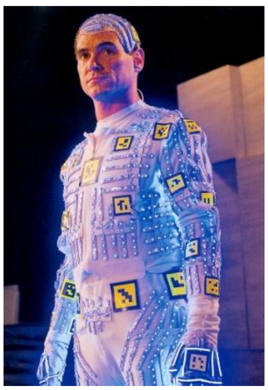
Color Balance

These films are balanced for exposure with tungsten illumination (3200K). You can also expose them with tungsten lamps that have slightly higher or lower color temperatures (+/- 200K) without correction filters, since final color balancing can be done in printing.

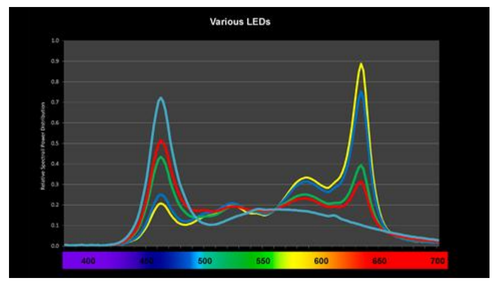
Light Source	KODAK Filters on Camera *	Exposure Index
Tungsten (3000 K)	None	500
Tungsten (3200 K)	None	500

A similar statement is to be found in most digital camera operations manuals. That term, "balanced" is not used lightly. It is, indeed, a very fine balance.

The first rule of wingwalking is: “don’t let go of something ‘til you have a firm hold of something else!” At this point, in the world of Solid State LED’s, we have little more than a tenuous grasp on the “new.”   And we are at risk of losing that very fine balance.



While there are obvious advantages to the LED in terms of economy, and it demonstrably has superb application as an “effects” light with its capacity for sophisticated controls, there are however, problems with color rendering which hinder its adoption as a “stage light” that can serve as a replacement for Tungsten, and these have surfaced in actual production. Almost immediately, in our investigations these problems were traced to discontinuity.



The history of the motion picture industry is littered with laments about the lack of understanding of such issues as continuous and discontinuous light, of spectral power and color rendering.

In their 1949 SMPE paper “Spectral Characteristics of Light Sources,” Norman Macbeth and Dorothy Nickerson, a pair of names renowned in the science of color, said (and I’ve had to condense their remarks for brevity:

> Thus, while illuminants in this report are often referred to in terms of the color-temperature scale, it should be remembered that it is not their color but only their spectral characteristics that will tell whether they are suitable for use with a given film, or to produce a specified result. (159)

and,

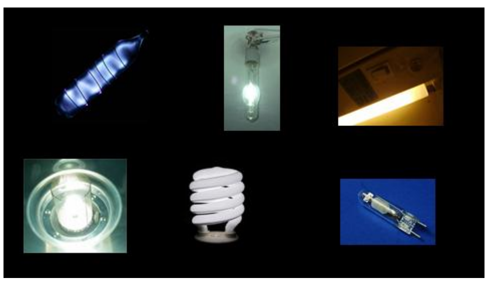
> A definition proposed by the Colour Group of the [British] Physical Society, require[s] that a source be of substantially the same spectral distribution in the visible region as a full radiator [or black body] of the same color. (158-159)

It's part of the Academy's mission and our heritage to engage such problems, as witness this passage from a 1949 SMPE paper by Crandell, Freund and Moen entitled, "Effects of Incorrect Color Temperature On Motion Picture Production":

> Different studios, using the same Technicolor process, employ sharply differing basic makeup colors. Which are correct? Which are better? It would seem that this might well be a matter for the attention of the Research Council of the Academy of Motion Picture Arts and Sciences, rather than the individual manufacturer of cosmetics. As regards camera tests of makeups, fabrics and the like, it goes without saying that the color of the illuminant should be rigorously controlled, so that it may be duplicated during production. (77)

And so the Council empaneled The Solid State Lighting Subcommittee, to assess the problem and seek solutions. We'll share some of its work with you today.

Our committee has several working groups.
We've been at work for two years, and in that time we have amassed quite a lot of knowledge



both about the nature of Solid State Light and the story of how we got to this juncture. We've not confined the study to LED's. We look at all SSL sources. We've presented a SMPTE paper, created some very powerful computer tools to assist us in studying the issue, shot a lot of photographic tests in the lab as well as simulated production footage, visited the National Institute of Standards and Technology (NIST) and embarked there on what we look forward to being a very productive relationship, built an expanding

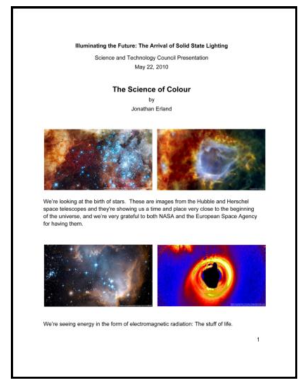
NIST

database of literature and patents, and, of course, established a website where much of this is available.

Last May we produced a Public Program with a demonstration on film, shot by Daryn Okada, ASC, called “The Experiment” and we’ll share some of that with you today.

11:45 pm	Panel commentary, Daryn introduces “THE EXPERIMENT”	
11:47 am	**“THE EXPERIMENT” – CLOSE-UPS** **Digital Cinema presentation - 1:85, M.O.S.**	**11:00**
11:58 am	Panel Discussion on makeup and cinematography	
12:03 pm	**“THE EXPERIMENT” – MEDIUM SHOTS** **Digital Cinema presentation - 1:85, M.O.S.**	**11:00**
12:14 pm	Panel Discussion on costume design and cinematography	
12:19 pm	**“THE EXPERIMENT” – Prod. Design & Set Decoration** **Digital Cinema presentation - 1:85, M.O.S.**	**9:00**

That program also contained a tutorial on “The Science of Color.” It’s available on the website.


Illuminating the Future: The Arrival of Solid State Lighting

Science and Technology Council Presentation

May 22, 2010

The Science of Colour

by

Jonathan Erland

We’re looking at the birth of stars. These are images from the Hubble and Herschel space telescopes and they’re showing us a time and place very close to the beginning of the universe, and we’re very grateful to both NASA and the European Space Agency for having them.

We’re seeing energy in the form of electromagnetic radiation: The stuff of life.

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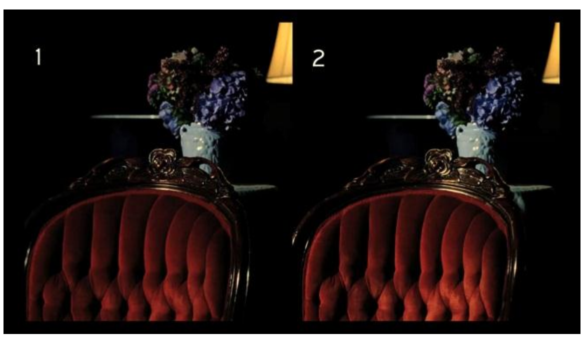
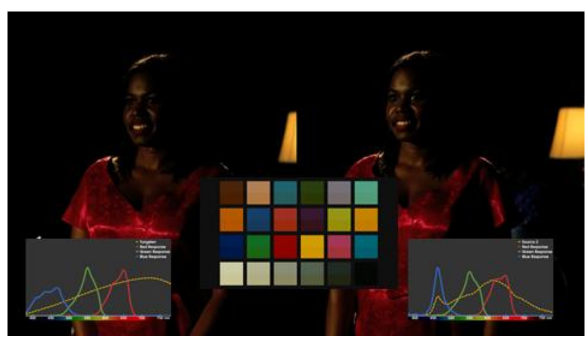
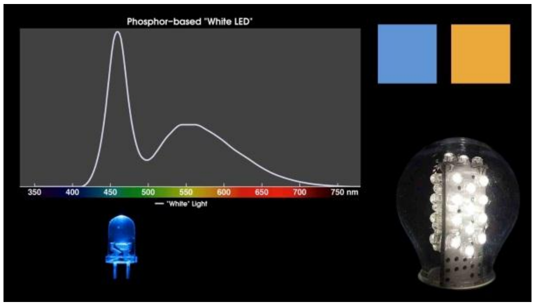


Here’s a segment from, the film “Experiment” which illustrates some of the problems we’ve observed.



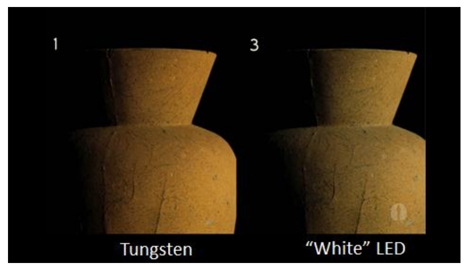
It’s necessary to understand what produced the artifacts seen in the Experiment footage.

To do that, we need a summary review of LED technology, as well as a little explanation of Spectral Power Distribution and Color Rendering.



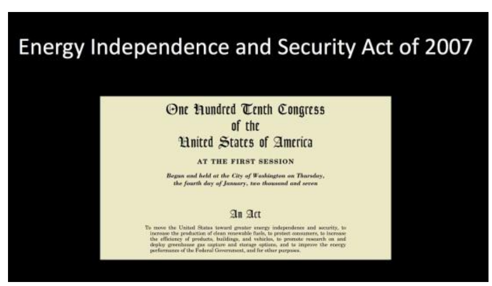
The current commercially obtainable "white" LED's are constructed along much the same lines as the fluorescent tube. Instead of a short wave ultraviolet "excitation" emission and a recipe of phosphors, the LED uses a blue emitter, with an emission at around 450 nm to excite a phosphor that, with some variations, is producing a sort of orange light. The designer hopes that the "integration" of Blue and Orange will be the equivalent of combining Red, Green and Blue and producing White. Superficially, this is demonstrably the case.

In the demonstration film "Experiment," our panelists were uniformly confounded by the fact that their onstage observations were that the light looked uniformly "white," while the screened reproduction showed it clearly was not. This shows a comparison of the Standard Studio Tungsten light to one of the LED "white" lights used in our test. The discontinuity is quite obvious: even though the light appears to be white, it is incapable of recording many subtle shifts in hue and saturation that the real colors of the world present to us, and that we, as film-makers, are under an obligation to deliver to our audience.



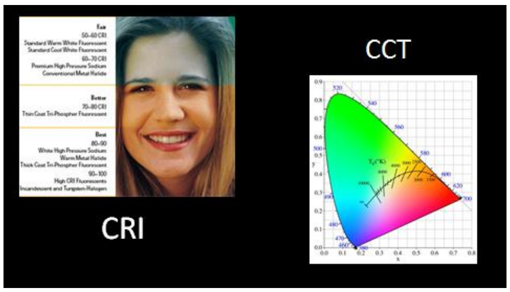
That said, human technological genius is demonstrably sufficient to solve the problem and produce a close approximation to the smooth, continuous emission that has characterized essentially all of our predecessor light sources such as candles, oil lamps, gas lights and incandescents.

However, as things stand, there is no such requirement in the proposed legislation, either here or elsewhere in the world, that will ban many incandescents by 2014.

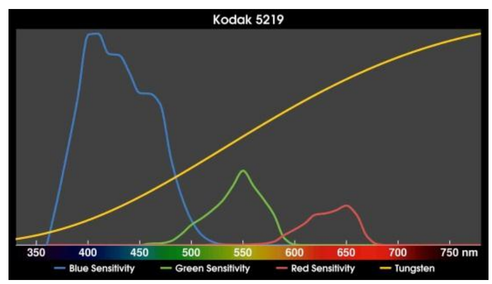


Here is what Crandell, et.al., had to say in their 1949 SMPE paper, on the issue of discontinuity:

> What we are interested in is a continuous spectrum . . . which will be recorded on film, and it is desirable that the general curve of spectral energy distribution be reasonably smooth, so that it will not show any unpleasant surprises in connection with colors having narrow absorption or reflectance bands. (72)



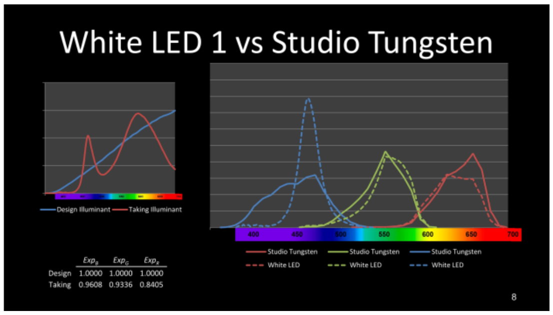
Later in this session we'll discuss the lighting industry's use of inaccurate and irrelevant indices such as Correlated Color Temperature (CCT) and Color Rendering Index (CRI) to describe their products' color rendering, but just now, let's look at the effect of the discontinuous nature of LED illumination on the spectral response curves for imaging devices, our cameras.



As we've discussed, film and digital cameras are designed to produce a specific color rendering of our world. To do this the film or camera designer creates spectral response curves. The film will record colors according to the degree of its sensitivity across the spectrum.

To achieve his goal, the designer had to first establish what would be the base line quanta of energy across the whole spectra illuminating the scene. And as we know from Mr. Hankins, "Since 1951, all professional color film used in the motion picture studios has been balanced for exposure with tungsten illumination." (SMPTE Journal Article reproduced on Mole.com)

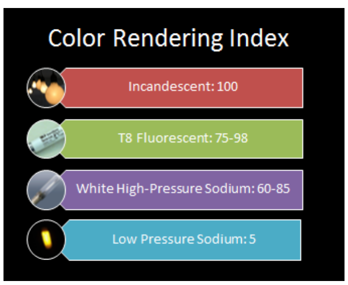
The salient point then is: if you change the illuminant from the "design" illuminant to some other, then you have overridden the filmstock design color rendering. It's that simple. Here we can see how that occurs.



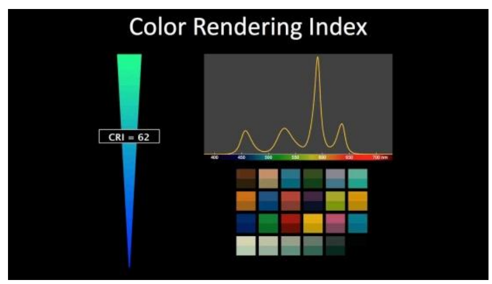
And yet, such sources may fairly lay claim to seductively attractive CCT and CRI values to the very expensive dismay of the unwary cinematographer. So, there's an immediate and quite critical need to provide a more effective index, or rather indices, to assist the cinematographer in selecting these new instruments.

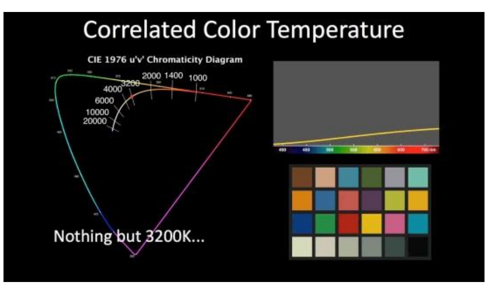
The International Commission on Illumination (the CIE), in the 4th Edition of the International Lighting Vocabulary, defines Color Rendering as

> The effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant. (CIE/IEC 17.4:1987)



The Color Rendering Index, then, is a numeric scale of from 0 to 100 with 100 indicating a perfect match between a sample light (which may, for example, be a fluorescent or an LED) and a standard reference light such as Tungsten at 2950K.





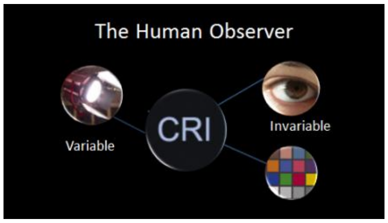
Correlated Color Temperature (CCT) designates the "approximation" of the color temperature of a sample light (such as a fluorescent) to a black body such as Tungsten.

Neither the CRI nor the CCT have any relevance to color rendering in photography.

The formal definition of the CCT by the International Commission on Illumination (CIE) is:

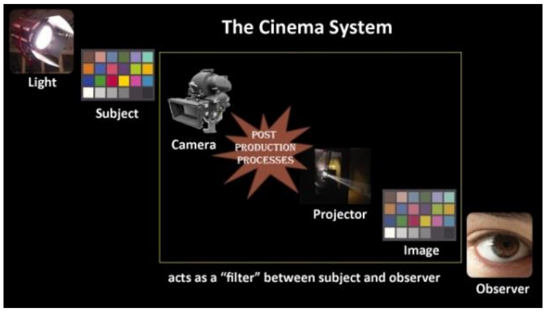
> The CCT is the temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. (CIE/IEC 17.4:1987)

The irrelevance of the CRI, or for that matter, any existing color rendering index, in color photography, is based on the fact that such indices are intended to gauge how accurately a color is matched using various illuminations of a set of standard color chips as observed by the human

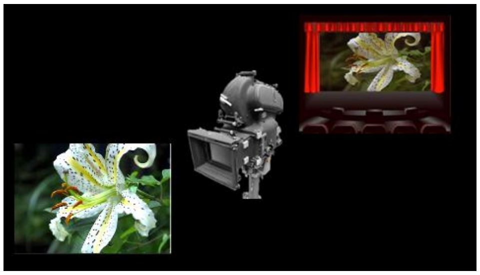


eye and compared to a standard reference illuminant.

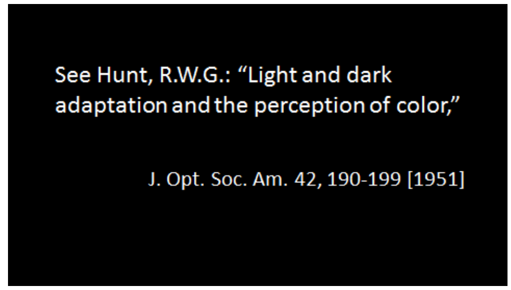
There are thus three elements: the human observer, the color chip and the light. Two, the human observer and the color chip, are invariable; while, one, the light, is variable. Various manipulations of a sample light can lead to some degree of a color match to which a numeric CRI value may be attached.



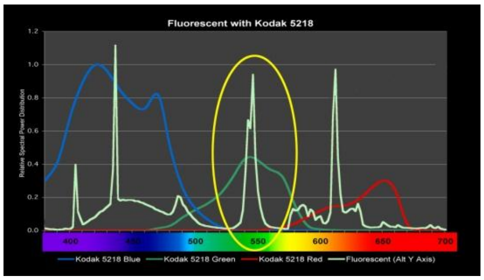
However, color reproduction in motion pictures involves a fourth element: the unique color rendering of the cinema system (comprised of film or digital camera sensors, the intermediate process and the display device), yielding the image displayed to the eventual human observer. This fourth element effectively comprises a "filter" through which the world is viewed by the audience. This "filter" is unique, and indeed it's



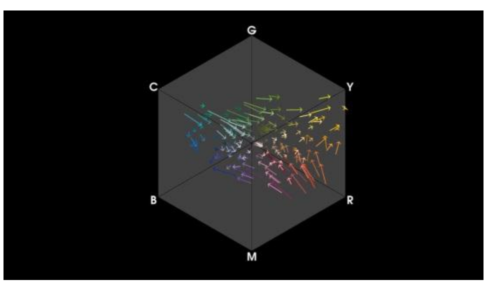
intended to be so. It is intended by its designers to yield, not necessarily an exact match to real world colors, (which it couldn't in any case) but rather a particular interpretation, the "verisimilitude" of the world. One that, within the context of the motion picture display system, "conjures" our world rather than "reproduces" it. After all, the contrast ratio and sheer luminance of light available for viewing motion pictures is a mere fraction of that prevailing in the real world. Our eyes have literally to operate in a different "gear." So, creating such an illusion of reality is a technological tour de force and the very essence of our art.



The filmstock design then is the variable, and it should be the only variable, since the interaction of more than one variable at a time can cause a sort of chromatic "phasing" resulting in "moire"-like amplification and/or cancellation effects, (e.g. the green cast from fluorescent tubes, which is the result of the coincidence of the green mercury emission spike and the peak of the filmstock green sensitivity with consequent amplification). The situation is exacerbated if still more variables are introduced in the form of yet more light sources with still more varied SPD's resulting in what I have come to call "chromatic chaos." For those who may be thinking that "power windows" provides an option here; perhaps, but consider first: is this any way to run a railroad?



Furthermore, take a look at this tri-linear plot of a discontinuous source. If the color shifts were on a single axis it would be possible to correct for them. But diverging as they do, there is little that can be done, as a correction of one condition in one direction exacerbates other conditions.



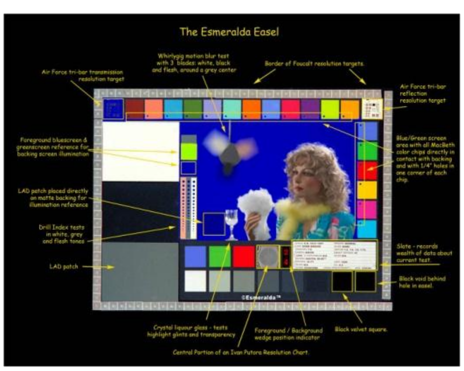
Of course, if at any time, the Director of Photography consciously and deliberately selects any of these consequences, they are immediately transformed into "art." It only remains an "artifact" if it was "imposed" by the technology.

M.A. Hankins likens us to artists who paint in oils:

> The makers of motion pictures may be likened to artists who paint in oils . . . In motion picture studio lighting great strides have been made in refining and improving the tools, but the basic materials that compare with the brushes and pigments of the artist remain the same. (SMPTE Journal Article reproduced on Mole.com)

Within that metaphor then, the combination of a Tungsten 3200K balanced filmstock and a Tungsten 3200K light source or the very close simulation thereof, the "default condition," represents the blank white gessoed canvas that an artist confronts as he begins a painting. In the course of executing the painting, he may impose all manner of changes and effects upon that canvas: that, after all, is the essence of art, but he is entitled to expect the blank pure white canvas as his starting place. A light source differing from the Standard Studio Tungsten source, especially a discontinuous one, will preemptively impose a color cast on the canvas that will be difficult, or impossible to subsequently correct.

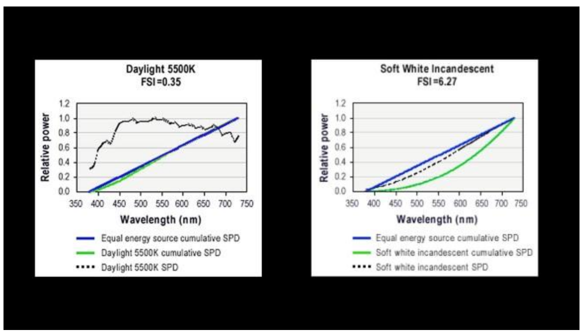
The default condition, then, will be proven by achievement of Laboratory Aim Density, visually represented by the LAD frame you see here. All these patches have the specific density values required for normal exposure and color rendering.



In the Esmeralda version, we have many more such metrics. These metrics are actually meaningful and useful in the imaging industry.

We really do need meaningful metrics. Bearing in mind, then, that the imaging industry has codified (via the ISO) standards for Daylight and Tungsten, we will need at least two Indices to replace the inappropriate and meaningless CCT and CRI: One index to reference solely the power function and still others to reference the color rendering of various devices, i.e. differing film stocks and electronic cameras.

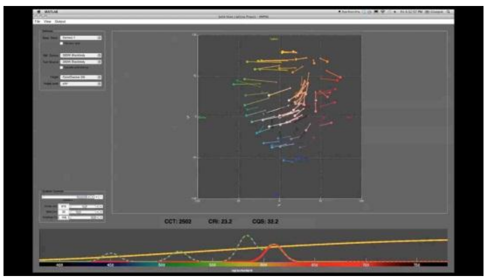
Taking the power function first, and it's by far the easiest, I am now in a position to suggest a Studio Tungsten Simulating Index (the STSI).



One possible implementation we're studying is conceptually similar to Full Spectrum Index (FSI) developed at the Lighting Research Institute at Rensselaer Polytechnic Institute. The FSI provides a reference of an artificial light source to Daylight on a scale in which 0 represents a perfect match for daylight. The STSI implementation we're studying provides a reference of an artificial light source to the Standard Studio Tungsten in the spectral range of 350 nm to 690 nm and on a scale of 1 to 100 with 100 being a perfect match. As such, it's absolutely not a color rendering index per se, but a Spectral Power Distribution index. It's only a color rendering index by inference, in that, for systems designed to yield optimal color rendering with the Black Body Standard Studio Tungsten or Daylight source, which encompasses virtually all motion picture imaging systems, an STSI of 100 would, by definition, yield the design color rendering result.

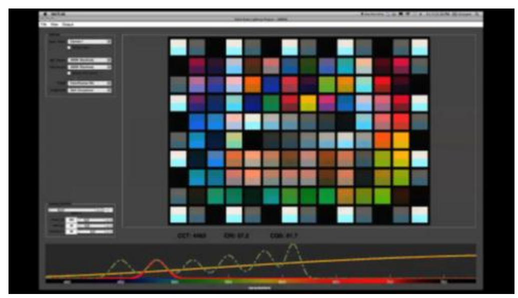
However, it is desirable to develop additional indices, based on actual color rendering, which will describe the efficacy of a light source/camera combination. A singular advantage of the STSI would be that, to the extent that all imaging devices assume Studio Tungsten as the design illuminant, a high STSI should perform equally well in all cases, whereas, color rendering indices will be source/imaging device specific. Thus the user confronted with a high STSI would not feel obliged to look for further reassurance; while a less than perfect STSI would alert the user to seek confirmation from an additional index, such as a color rendering index, or to simply test the proposed source.

To further our understanding of such indices we dispatched Council staff imaging engineer Scott Dyer to the National Institute of Standards and Technology to consult with Wendy Davis of their staff.



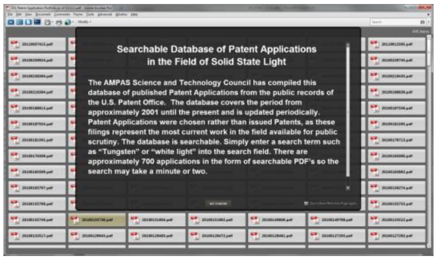
I mentioned also, powerful simulation tools we're developing. We'll explore these in more detail a little later, but let's just take a brief glimpse now.

You can see the actual color rendering changes being wrought by the alteration of the spectral power distribution in the graph below.



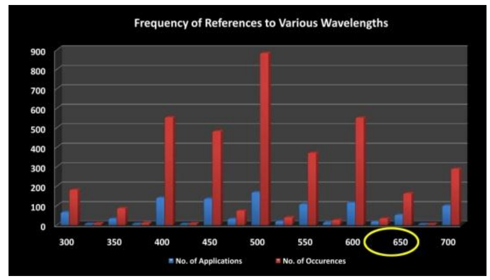
But, as helpful as such indices may be in assisting in the selection of lighting instruments, they are not the ultimate goal for our work. The ultimate goal is simply to ensure that a new technology such as LED's or Plasma or whatever may lie in our future, actually advances the art form to a new level. In short: to make it work.

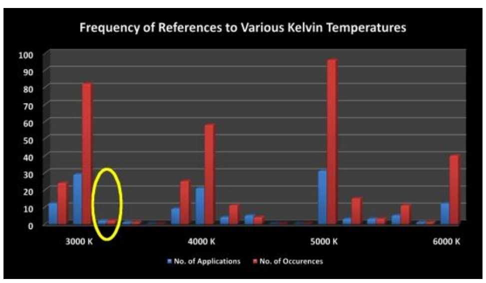
To that end, we actively research the field of Solid State Light. We increase our knowledge on a daily basis with research in the technical literature, patent application literature and hands-on research of the devices themselves.



From the patent literature, we have built a database of nearly a thousand of the most relevant applications. This allows us to do some statistical research that indicates the direction industry is taking. Here are some examples:

This graph shows the frequency of references to various wavelengths in the patent application literature. For photographic applications, the regions around 450 n.m., 550 n.m. and from 625 - 650 n.m. would be significant. There is clearly a lack of emphasis on the Red region, just as there historically was with fluorescents.





In this graph, we show the frequency of references to color temperatures where, of course, 3200K would be of interest to photography. As we can see, there's little interest in 3200K.

Though rare, there are occasional papers that show an understanding of the issues. This one by Zukauskus et. al. is such an example.

IOP Publishing — Journal of Physics D: Applied Physics

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Colour-rendition properties of solid-state lamps

A Žukauskas[1,4], R Vaicekauskas[2] and M S Shur[3]

[1] Institute of Applied Research, Vilnius University, Saulėtekio al. 9, bldg. III, Vilnius, LT-10222, Lithuania
[2] Department of Computer Science, Vilnius University, Naugarduko g. 24, Vilnius, LT-03225, Lithuania
[3] Department of Electrical, Computer, and System Engineering, Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY 12180, USA

E-mail: arturas.zukauskas@ff.vu.lt

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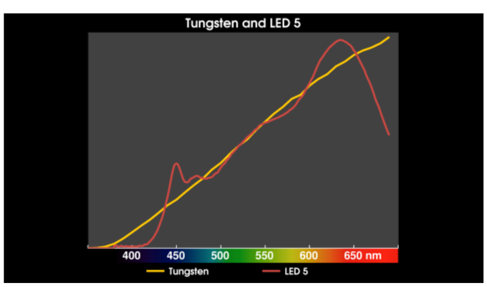
Abstract
The applicability of colour-quality metrics to solid-state light sources is validated and the results of the assessment of colour-rendition characteristics of various lamps are presented. The standard colour-rendering index metric or a refined colour-quality scale metric fails to distinguish between two principle colour-rendition properties of illumination: the ability to



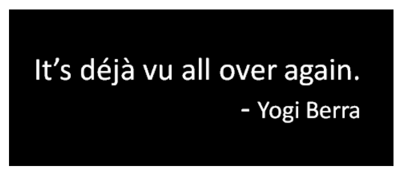
This research is encouraging in that it suggests that if sufficient effort were directed toward the production of a relatively continuous Spectral Power Distribution at 3200K, we may well get there. In fact, in the case of one newly introduced LED plus phosphor device, it's been essentially achieved, while in the direct emitter approach, it's not yet.

The research is discouraging, on the other hand, in that there really doesn't seem to be much evidence of a continuous source as a goal, versus the goal of producing as many lumens per Watt as possible from a discontinuous source, almost regardless of the color rendering properties. In part, this may be attributable to the fact that the industry's basic mandate is to encourage the conservation of energy, so it funds research to produce light sufficient to see by, though not necessarily to photograph by.

This too is a reprise of unfortunate history, as Norman Macbeth and Dorothy Nickerson remind us from their 1949 SMPE paper:

> Unfortunately, only one manufacturer has announced a fluorescent lamp employing this new phosphor in lamps . . . This is due to the fact that while this red-corrected fluorescent lamp provides a much closer approximation to the spectral-energy requirements for film and visual applications, the addition of this red phosphor lowers the overall efficiency of the fluorescent tube enough so that manufacturers at the present time are convinced that maintaining present efficiencies is more important than the color improvement which they consider to be minor. (174-175)

As Mr. Berra says, "It's déjà vu all over again."



So, the core takeaway from this presentation is that, with the Academy's mission being the "pursuit of excellence in the arts and sciences of motion pictures," which is usually most evident in our annual extravaganza known as the Oscars, it begins, as we showed all the way back in 1928, with

"Light!" The raw material of our vision.