Solid State Lightning and LEDs

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Development of Lighting Technology

FIRE

Torches		**Thousands of centuries before written history**

OIL LAMPS

Terra-cotta lamps	Mesopotamian plains	**8000-7000 BC**
Copper and Bronze lamps	Egypt, Persia	**2700 BC**
Wick	vegetable fiber in vessel of olive or nut oil	**1000 BC**
Horn lantern	Rome	**100 BC**
Da Vinci oil lamp	cylindrical glass chimney	**1490 AD**

GAS LIGHT

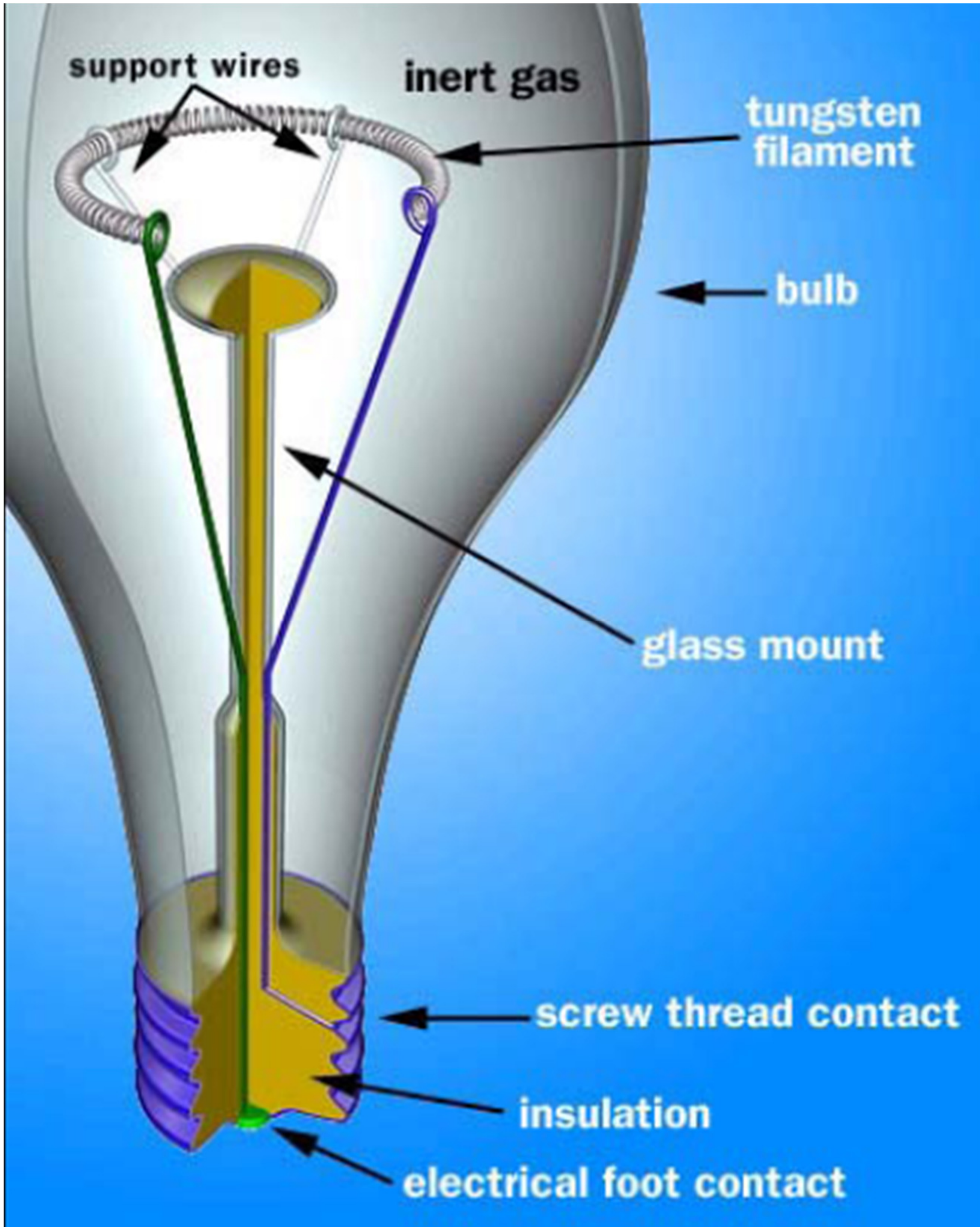
Natural gas	China (long before), England	**1664 AD**

CANDLES

Spermaceti candles	Whaling industry	**1700 AD**

ARC LAMPS

Electric arc between electrodes	France, Russia	**1800 AD**



Incandescent Lamp

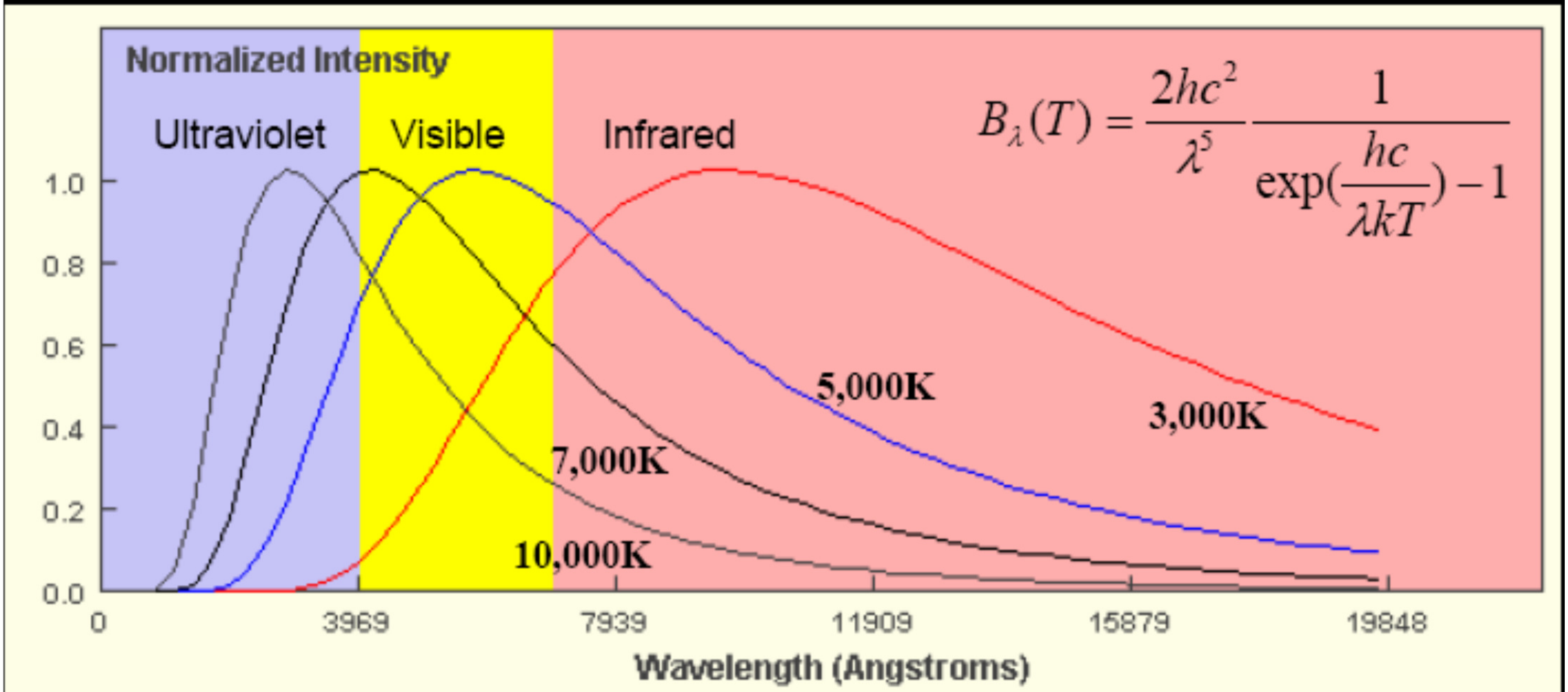
Thomas Edison
1870

Tungsten filaments
early 1900s
Lifetime > 1000 hours

Tungsten-halogen lamp
1970s
a small amount of Hg reduces migration of W,
allows operation at higher T,
produces whiter light

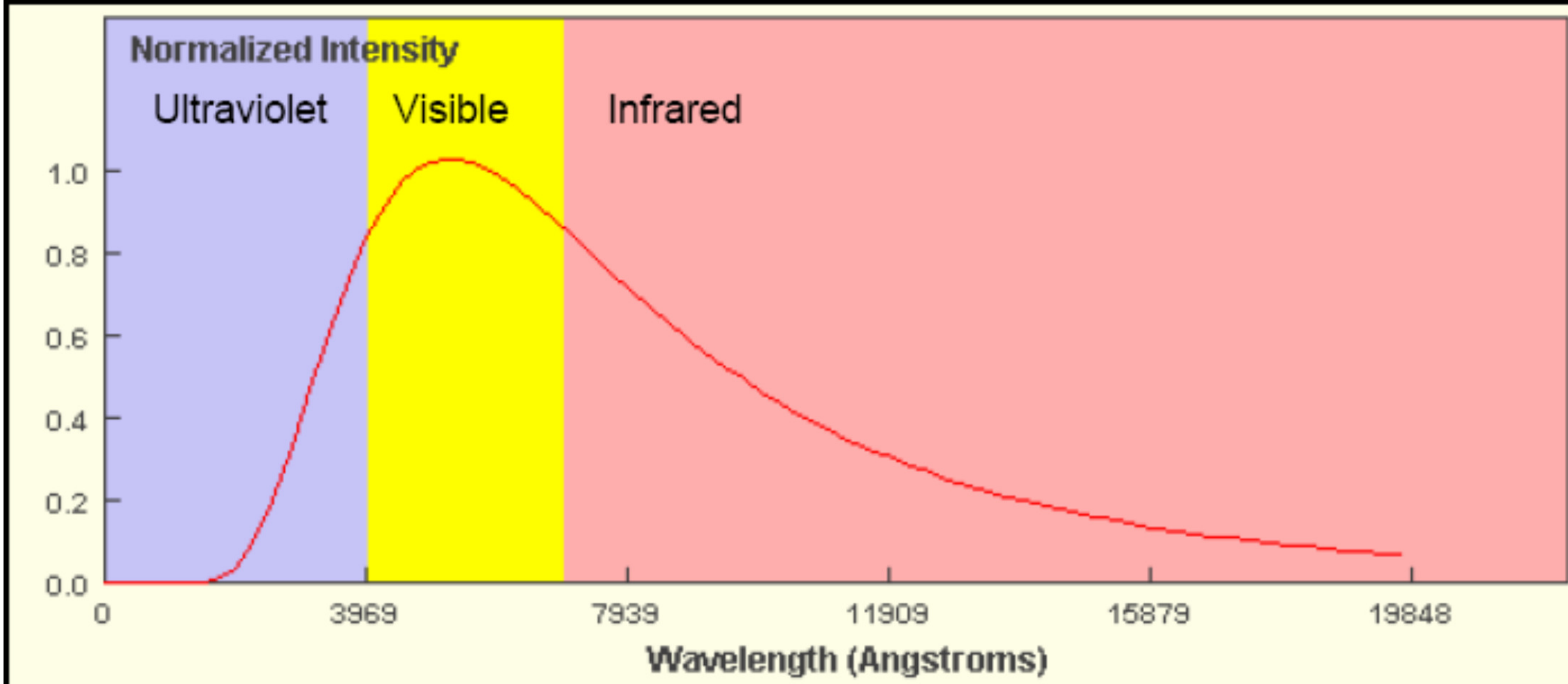
http://science.howstuffworks.com/incandesent-lamp2.htm

Black Body Radiation



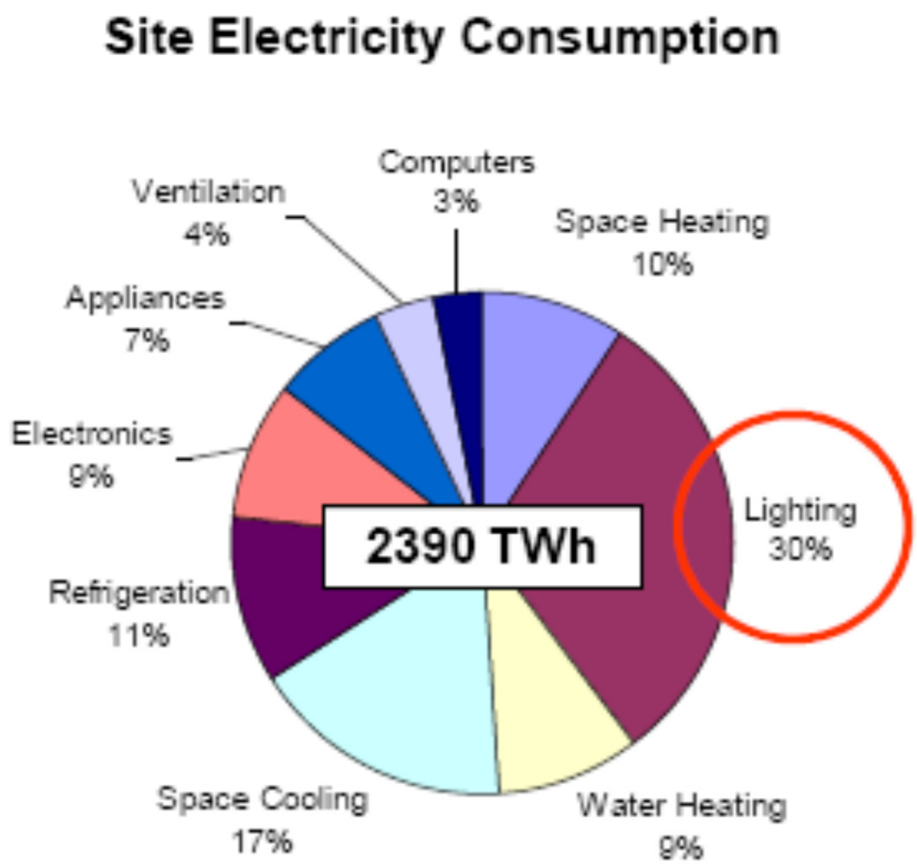
Incandescent lamps follow the black-body radiation characteristics.
Their color and brightness depends on the temperature of the filament

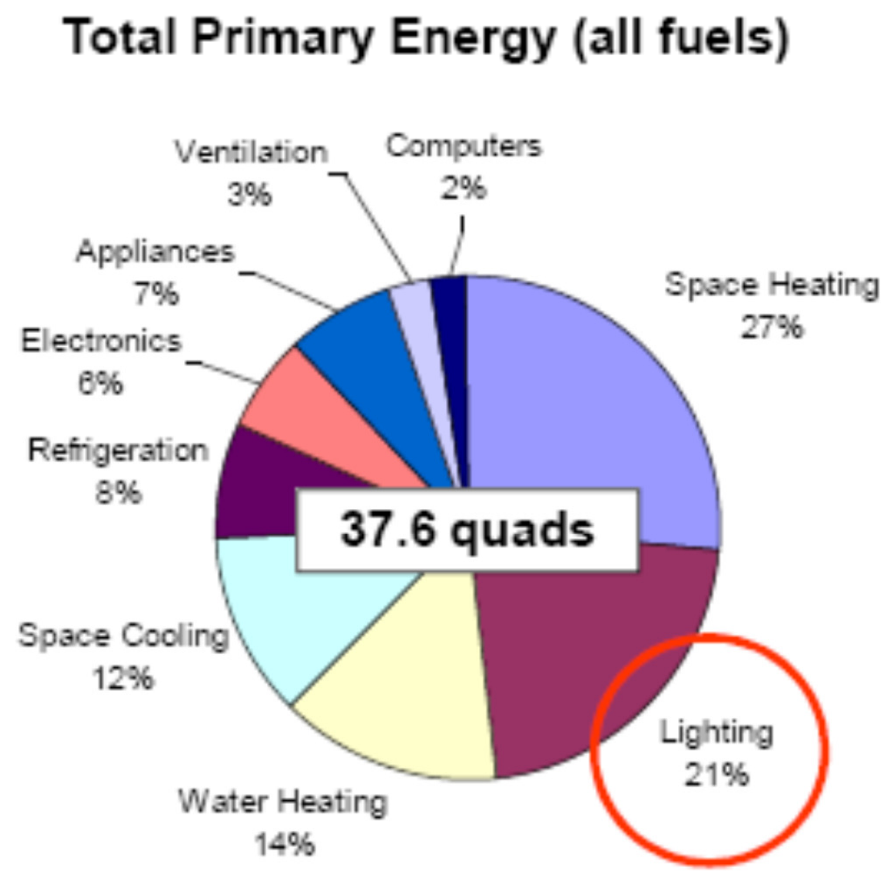
White Light: T= 5500K



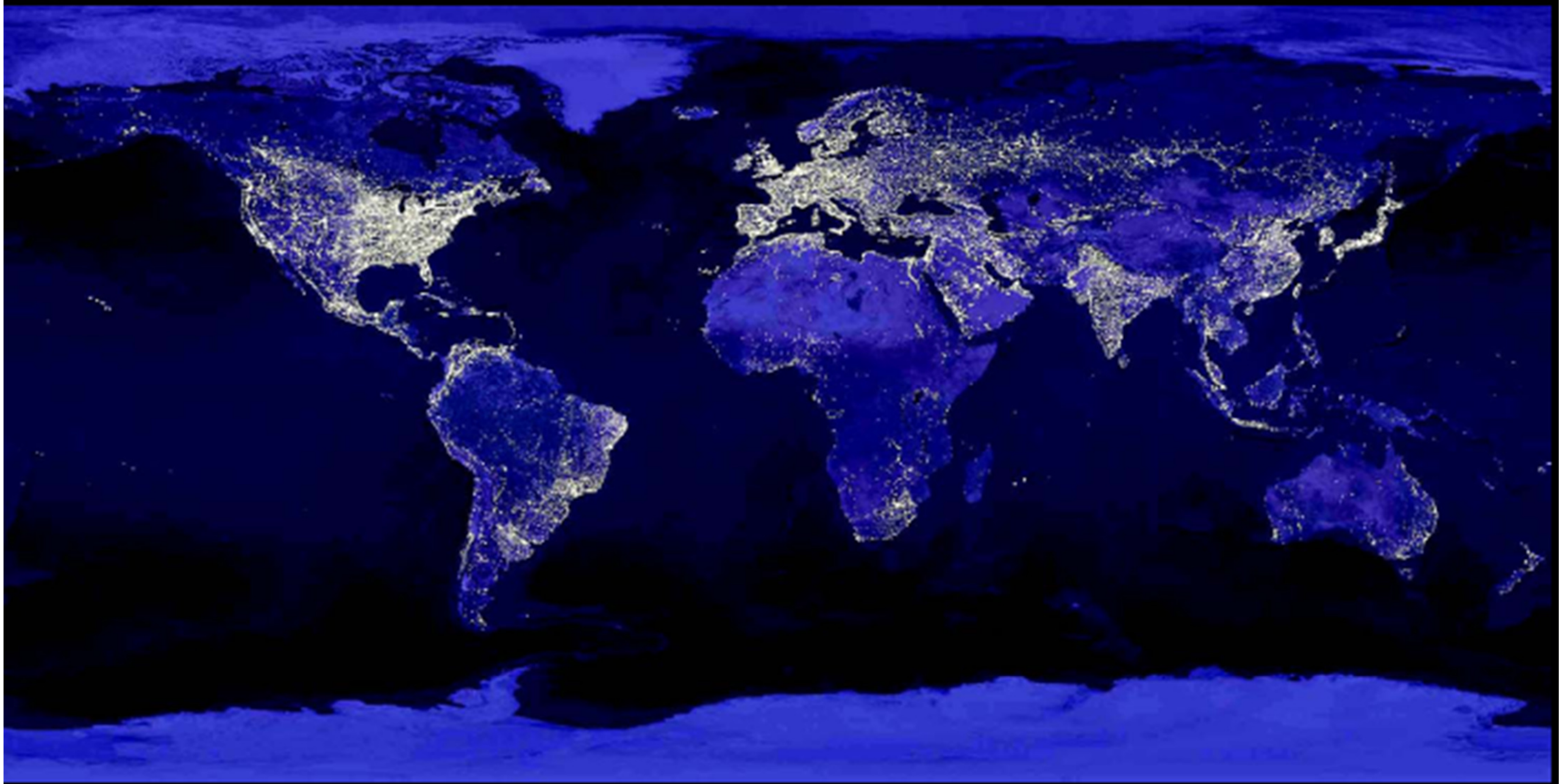
The spectrum of *white light* is that of solar radiation, corresponding to black body radiation at 5500K

U.S. Buildings Energy End-Use Breakdown, 2001





Earth at Night

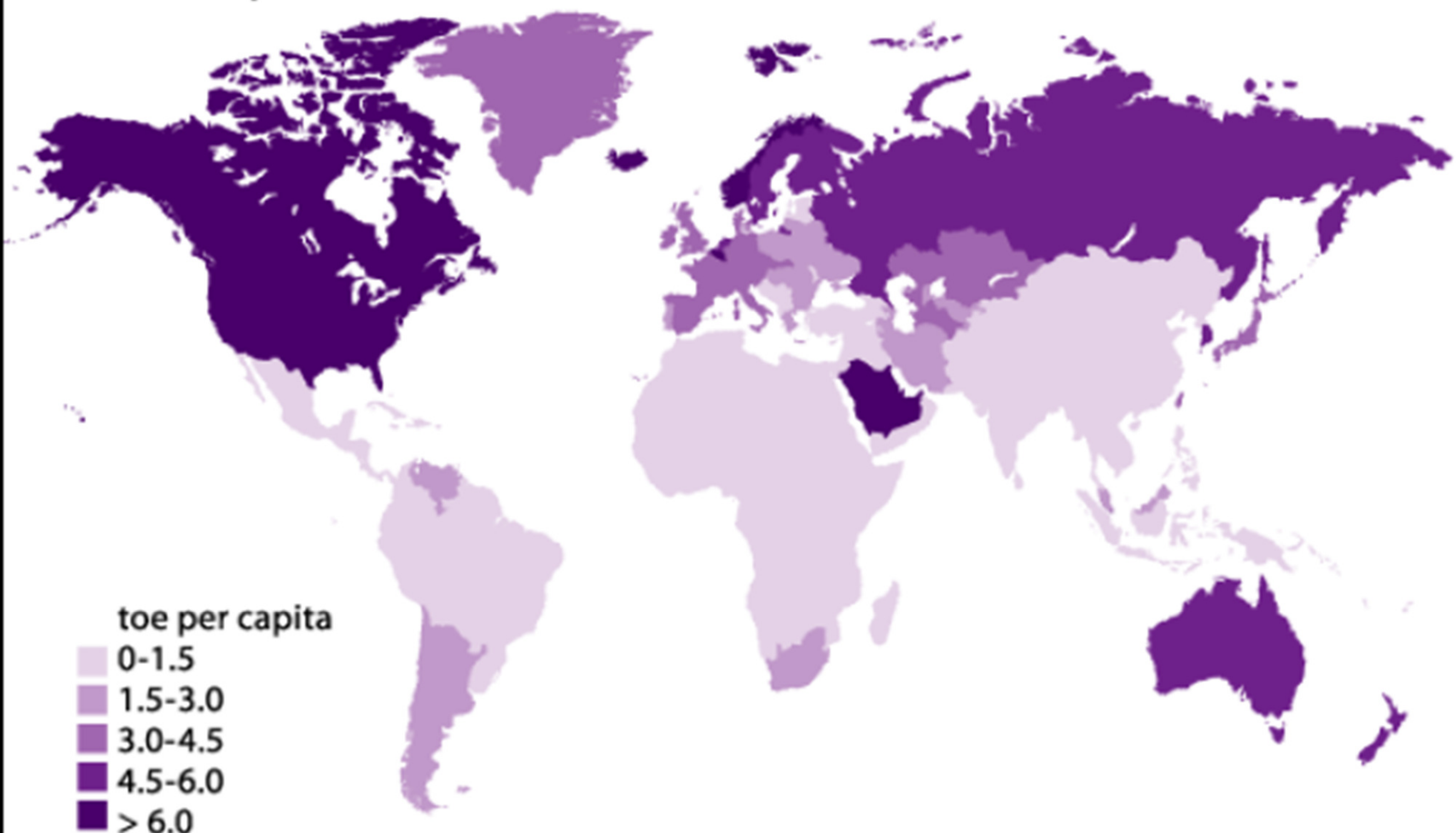


Acquired by NASA, Nov 2001
Physics Today, April 2002 Issue

Night-time satellite image of the world.
The use of light at night appears to be directly related to wealth and prosperity.
The lights also reflect trends in population and energy consumption.

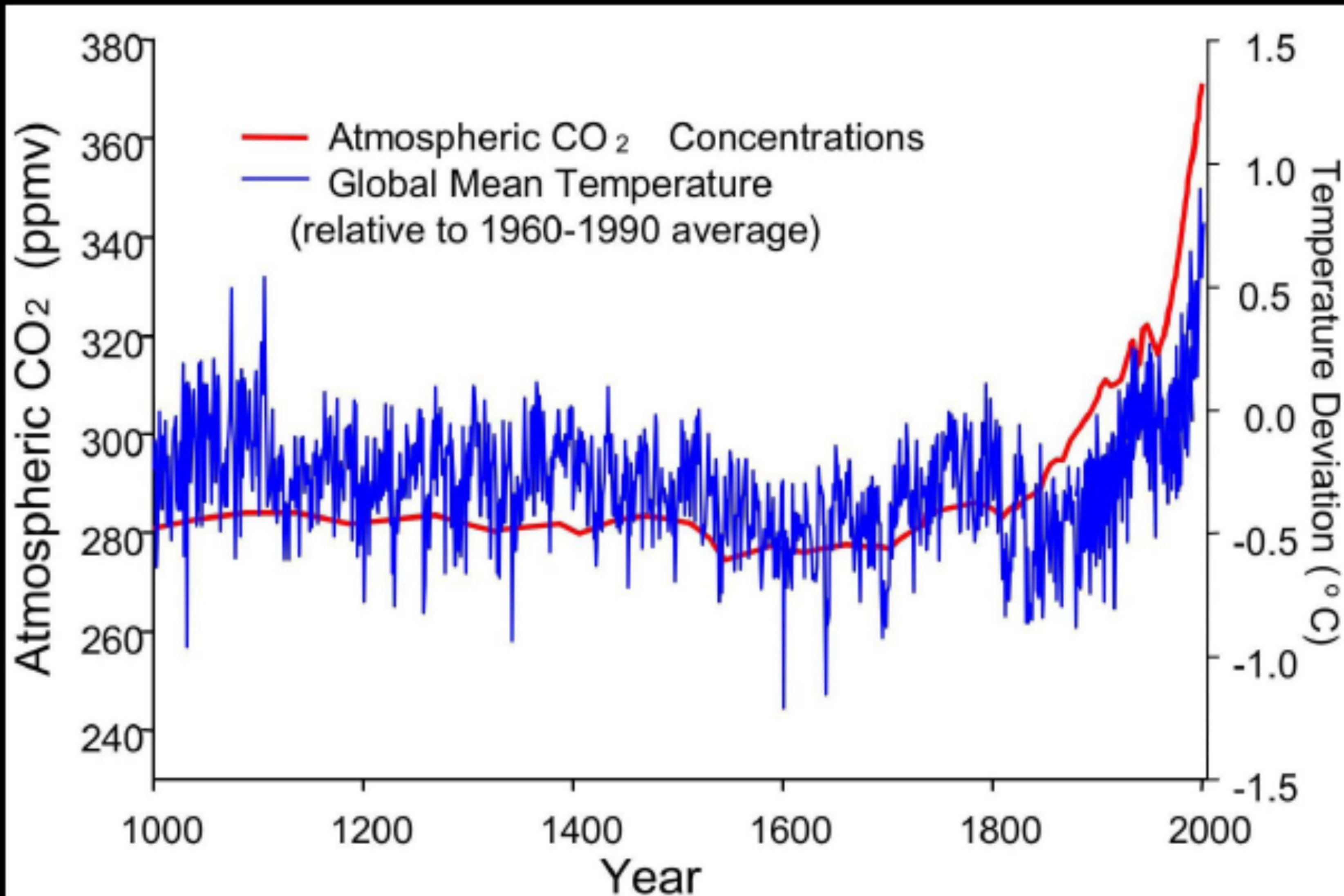
Primary energy consumption per capita

Tonnes oil equivalent



Source: British Petroleum 2005

Concentration of CO_2 and Global Mean Temperature



Source: DOE/BES Workshop on "Basic Research Needs for the Hydrogen Economy"

Great Challenges for the 21st Century

1. Energy consumption

   Oil → nuclear, wind, and solar

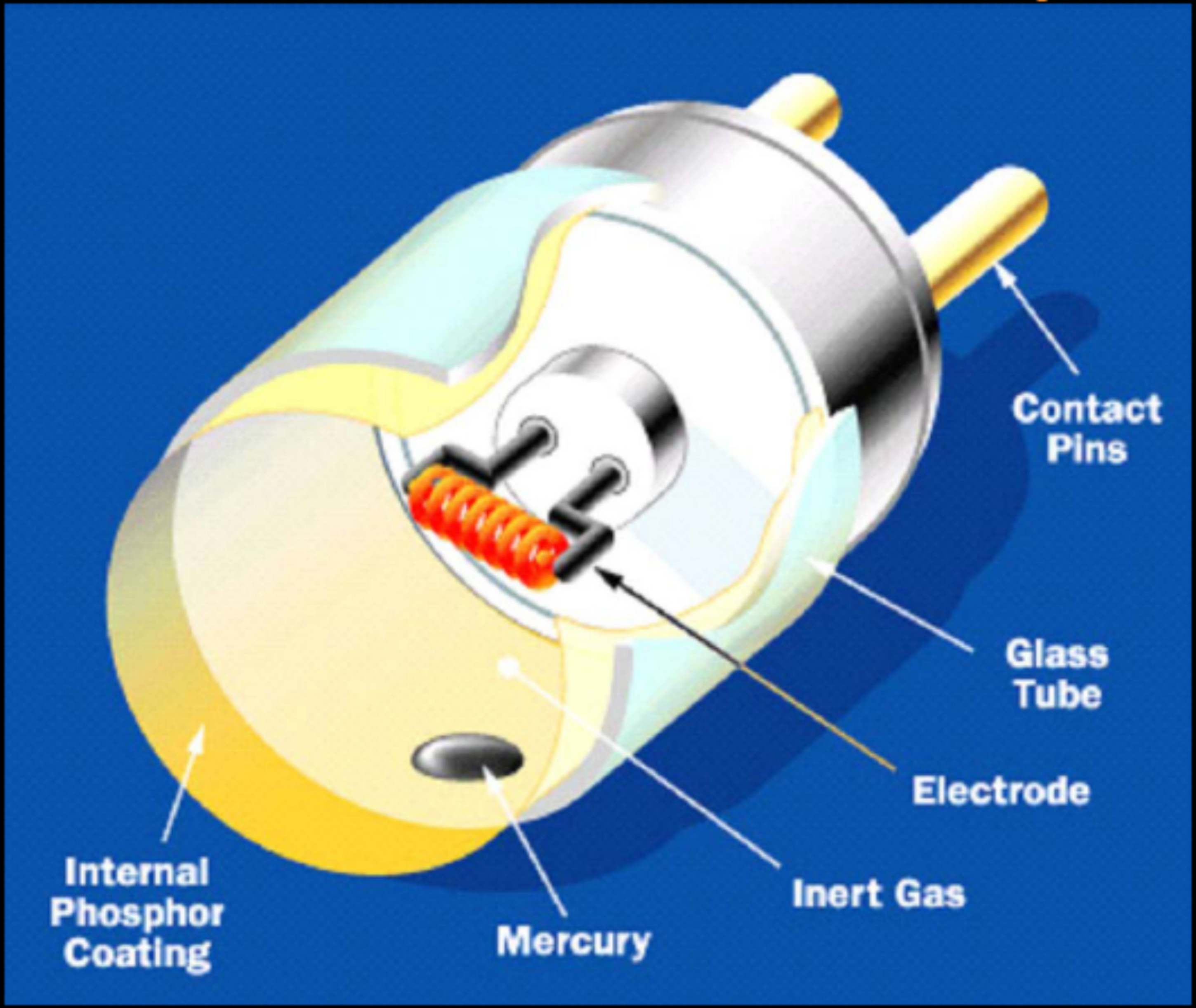
2. Climate change

   Global heating
   Melting of the poles,
   Possible new ice age

- Both are closely linked.
- We must be concious of the problem.
- It is essential to take drastic steps to reduce the use of hydrocarbons, and the destruction of our forests.
- Kyoto Protocol (199y)
- The oil industry questions scientific findings about global climate change.

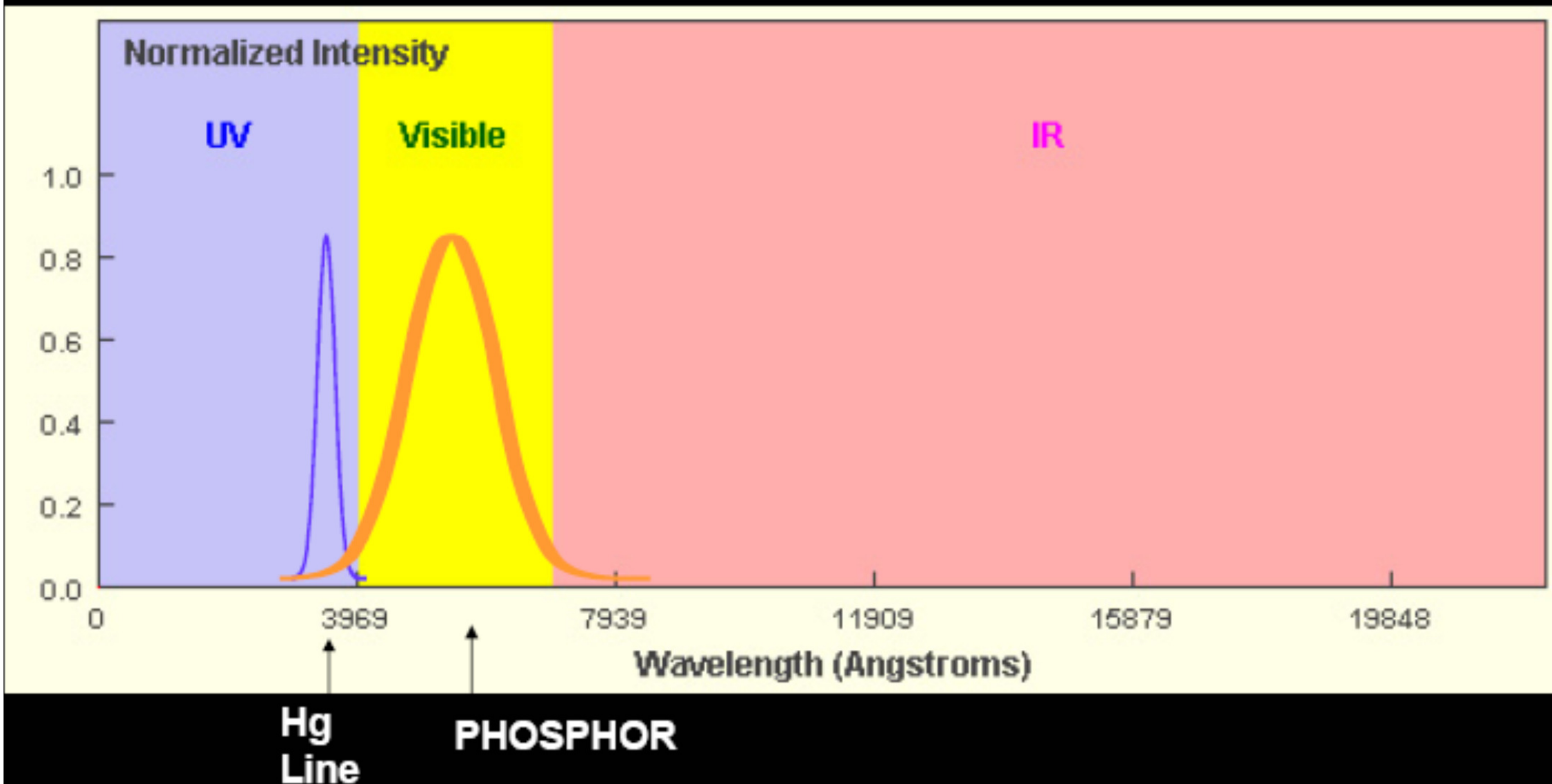
- “Solid State Lighting is the most disruptive technology to hit the lighting industry in 50 years…”

The Fluorescent Lamp

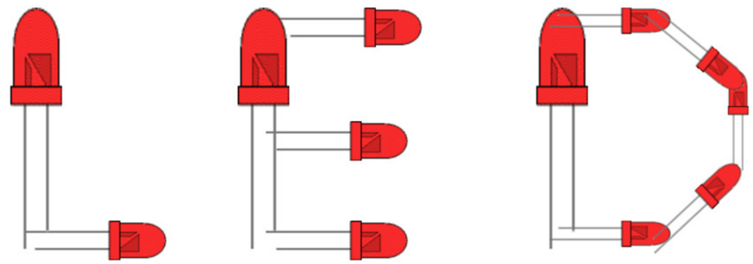


http://science.howstuffworks.com/fluorescent-lamp2.

Fluorescent Lamps



The ultraviolet radiation of mercury is converted into visible by phosphor deposited inside the glass-tube envelope

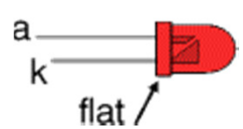


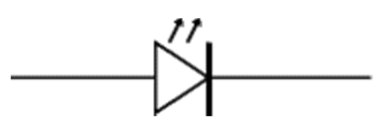
LIGHT EMITTING DIODES

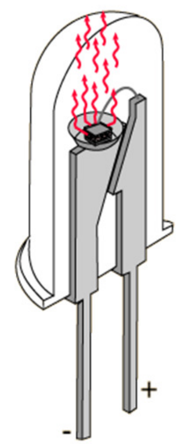
Solid State Lightning

A light emitting diode (LED) is essentially a PN junction opto-semiconductor that emits a monochromatic (single color) light when operated in a forward biased direction.

LEDs convert electrical energy into light energy. They are frequently used as "pilot" lights in electronic appliances to indicate whether the circuit is closed or not.

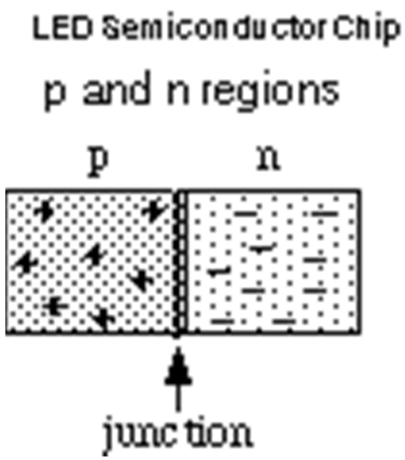


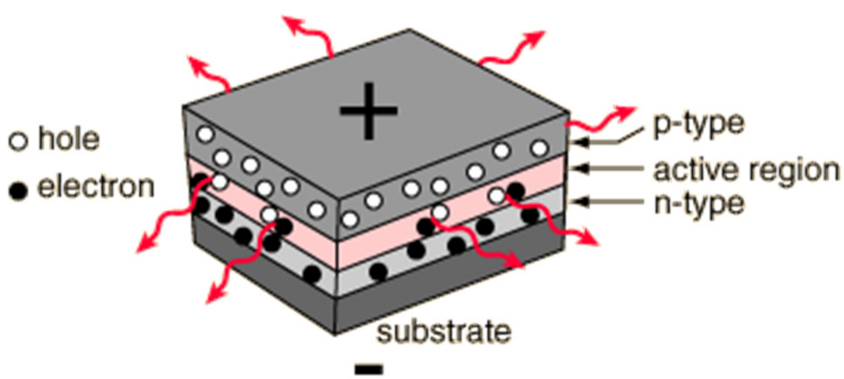




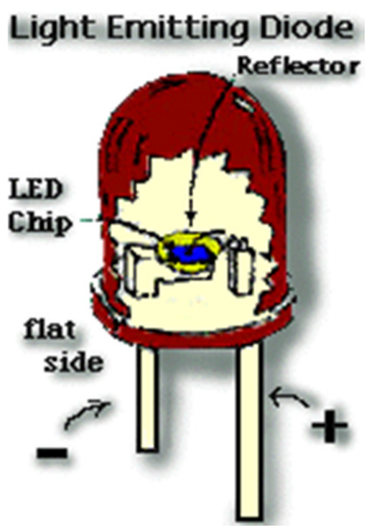
About LEDs (1/2)

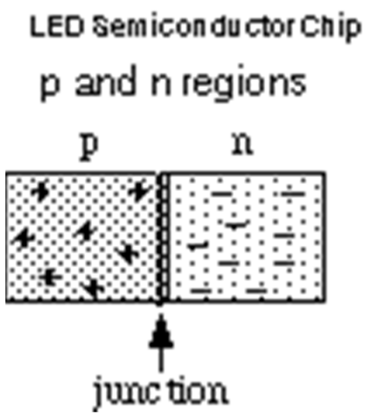
The most important part of a *light emitting diode (LED)* is the semi-conductor chip located in the center of the bulb as shown at the right. The chip has two regions separated by a *junction.* The *p region* is dominated by positive electric charges, and the *n region* is dominated by negative electric charges. The *junction* acts as a barrier to the flow of electrons between the *p* and the *n regions.* Only when sufficient voltage is applied to the semi-conductor chip, can the current flow, and the electrons cross the junction into the *p region.*





How Does A LED Work? (1/2)



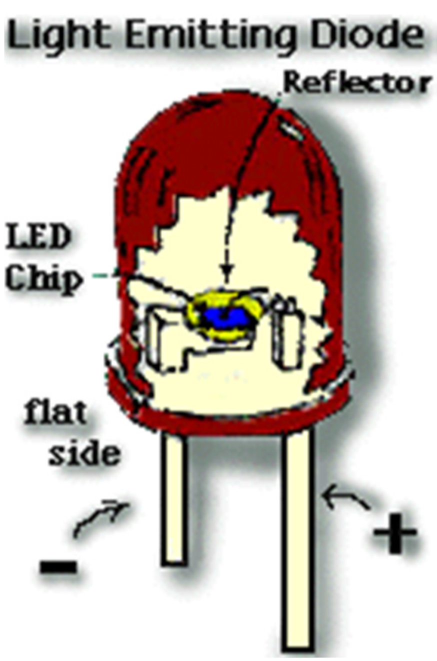


When sufficient voltage is applied to the <u>chip</u> across the <u>leads</u> of the LED, electrons can move easily in only one direction across the *junction* between the *p* and *n* regions.

In the *p region* there are many more positive than negative charges.

When a voltage is applied and the current starts to flow, electrons in the *n region* have sufficient energy to move across the junction into the *p region.*

How Does A LED Work? (2/2)



Each time an electron *recombines* with a positive charge, <u>electric potential energy is converted into electromagnetic energy</u>.

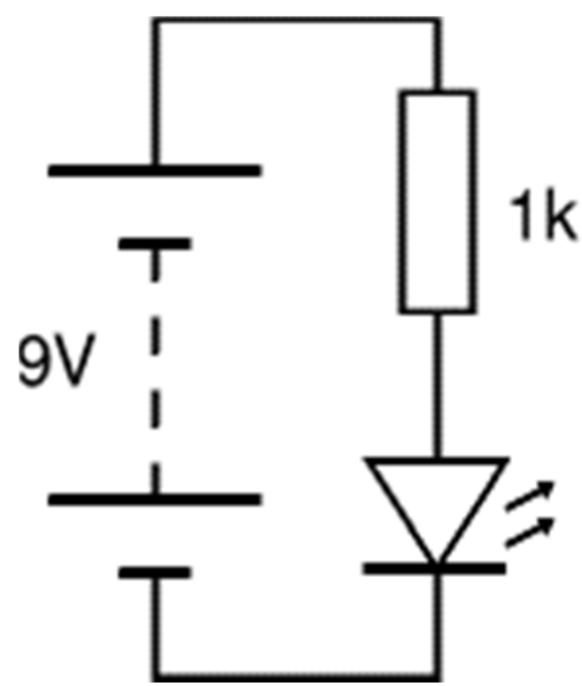
For each recombination of a negative and a positive charge, a <u>quantum</u> of electromagnetic energy is emitted in the form of a <u>photon</u> of light with a frequency characteristic of the semi-conductor material (usually a combination of the chemical elements gallium, arsenic and phosphorus)..

Testing LEDs

Never connect an LED directly to a battery or power supply! It will be destroyed almost instantly because too much current will pass through and burn it out.

LEDs must have a resistor in series to limit the current to a safe value, for quick testing purposes a 1k resistor is suitable for most LEDs if your supply voltage is 12V or less.

Remember to connect the LED the correct way round!



How Much Energy Does an LED Emit?

The energy (*E*) of the light emitted by an LED is related to the electric charge (*q*) of an electron and the voltage (*V*) required to light the LED by the expression: $E = qV$ Joules.

This expression simply says that the voltage is proportional to the electric energy, and is a general statement which applies to any circuit, as well as to LED's. The constant *q* is the electric charge of a single electron, -1.6×10^{-19} *Coulomb*.

Finding the Energy from the Voltage

Suppose you measured the voltage across the leads of an LED, and you wished to find the corresponding energy required to light the LED. Let us say that you have a red LED, and the voltage measured between the leads of is 1.71 Volts. So the Energy required to light the LED is

$E = qV$ or $E = -1.6 \times 10^{-19}$ (1.71) Joule,

since a Coulomb-Volt is a Joule. Multiplication of these numbers then gives

$E = 2.74 \times 10^{-19}$ Joule.

Applications

- Sensor Applications
- Mobile Applications
- Sign Applications
- Automative Uses
- LED Signals
- Illuminations
- Indicators

Sensor Applications

- Medical Instrumentation
- Bar Code Readers
- Color & Money Sensors
- Encoders
- Optical Switches
- Fiber Optic Communication

Mobile Applications

- Mobile Phone
- PDA's
- Digital Cameras
- Lap Tops
- General Backlighting

Sign Applications

- Full Color Video
- Monochrome Message Boards
- Traffic/VMS
- Transportation - Passenger Information

Automative Applications

- Interior Lighting - Instrument Panels & Switches, Courtesy Lighting
- Exterior Lighting - CHMSL, Rear Stop/Turn/Tail
- Truck/Bus Lighting - Retrofits, New Turn/Tail/Marker Lights

Signal Appications

- Traffic
- Rail
- Aviation
- Tower Lights
- Runway Lights
- Emergency/Police Vehicle Lighting

LEDs offer enormous benefits over traditional incandescent lamps including:

- Energy savings (up to 85% less power than incandescent)
- Reduction in maintenance costs
- Increased visibility in daylight and adverse weather conditions

Illumination (1/2)

- Architectural Lighting
- Signage (Channel Letters)
- Machine Vision
- Retail Displays
- Emergency Lighting (Exit Signs)
- Neon Replacement
- Bulb Replacements
- Flashlights
- Outdoor Accent Lighting - Pathway, Marker Lights

Illumination (2/2)

LEDs not only consume far less electricity than traditional forms of illumination, resulting in reduced energy costs, but require less maintenance and repair. Studies have shown that the use of LEDs in illumination applications can offer:

- Greater visual appeal
- Reduced energy costs
- Increased attention capture
- Savings in maintenance and lighting replacements

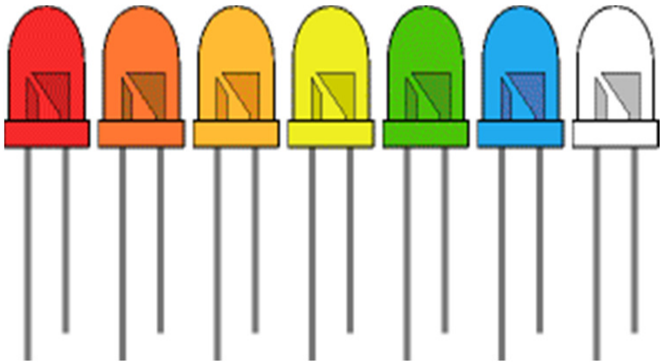
As white LED technology continues to improve, the use of LEDs for general illumination applications will become more prevalent in the industry.

Indication

- Household appliances
- VCR/ DVD/ Stereo and other audio and video devices
- Toys/Games
- Instrumentation
- Security Equipment
- Switches

Colours of LEDs (1/3)

LEDs are made from gallium-based crystals that contain one or more additional materials such as phosphorous to produce a distinct color. Different LED chip technologies emit light in specific regions of the visible light spectrum and produce different intensity levels.



LEDs are available in red, orange, amber, yellow, green, blue and white. Blue and white LEDs are much more expensive than the other colours. The colour of an LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body). LEDs of all colours are available in uncoloured packages which may be diffused (milky) or clear (often described as 'water clear'). The coloured packages are also available as diffused (the standard type) or transparent.

Colours of LEDs (2/3)

Tri-colour LEDs

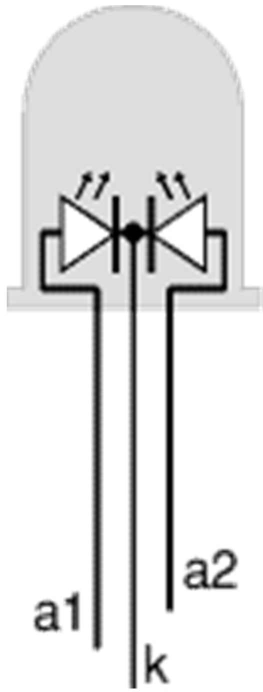
The most popular type of tri-colour LED has a red and a green LED combined in one package with three leads. They are called tri-colour because mixed red and green light appears to be yellow and this is produced when both the red and green LEDs are on.

The diagram shows the construction of a tri - colour LED. Note the different lengths of the three leads. The centre lead (k) is the common cathode for both LEDs, the outer leads (a1 and a2) are the anodes to the LEDs allowing each one to be lit separately, or both together to give the third colour.

Colours of LEDs (3/3)

Bi-colour LEDs

A bi-colour LED has two LEDs wired in 'inverse parallel' (one forwards, one backwards) combined in one package with two leads. Only one of the LEDs can be lit at one time and they are less useful than the tri-colour LEDs described above.



Comparison Of Chip Technologies For Wide-Angle, Non-Diffused LEDs

LED Color	*Standard Brightness*				*High Brightness*			
	Chip Material	Ipk (NM)	Iv (mcd)	Viewing Angle	Chip Material	Ipk (NM)	Iv^3 (mcd)	Viewing Angle
Red	GaAsP/GaP	635	120	35	AS AlInGaP	635	900	30
Orange	GaAsP/Gap	605	90	30	AS AlInGaP	609	1,300	30
Amber	GaAsP/Gap	583	100	35	AS AlInGaP	592	1,300	30
Yellow	Gap	570	160	30	--	--	--	--
Green	Gap	565	140	24	GaN	520	1,200	45
Turquoise	--	--	--	--	GaN	495	2,000	30
Blue	--	--	--	--	GaN	465	325	45

LED Performance (1/8)

LED performance is based on a few primary characteristics:

- Color
- White light
- Intensity
- Eye safety information
- Visibility
- Operating Life
- Voltage/Design Current

LED Performance (2/8)

Colour

Peak wavelength is a function of the LED chip material. Although process variations are ±10 NM, the 565 to 600 NM wavelength spectral region is where the sensitivity level of the human eye is highest. Therefore, it is easier to perceive color variations in yellow and amber LEDs than other colors.

LED Performance (3/8)

White Light

When light from all parts of the visible spectrum overlap one another, the additive mixture of colors appears white. However, the eye does not require a mixture of all the colors of the spectrum to perceive white light. Primary colors from the upper, middle, and lower parts of the spectrum (red, green, and blue), when combined, appear white.

LED Performance (4/8)

<u>Intensity</u>

LED light output varies with the type of chip, encapsulation, efficiency of individual wafer lots and other variables. Several LED manufacturers use terms such as "super-bright," and "ultra-bright" to describe LED intensity. Such terminology is entirely subjective, as there is no industry standard for LED brightness.

LED Performance (5/8)

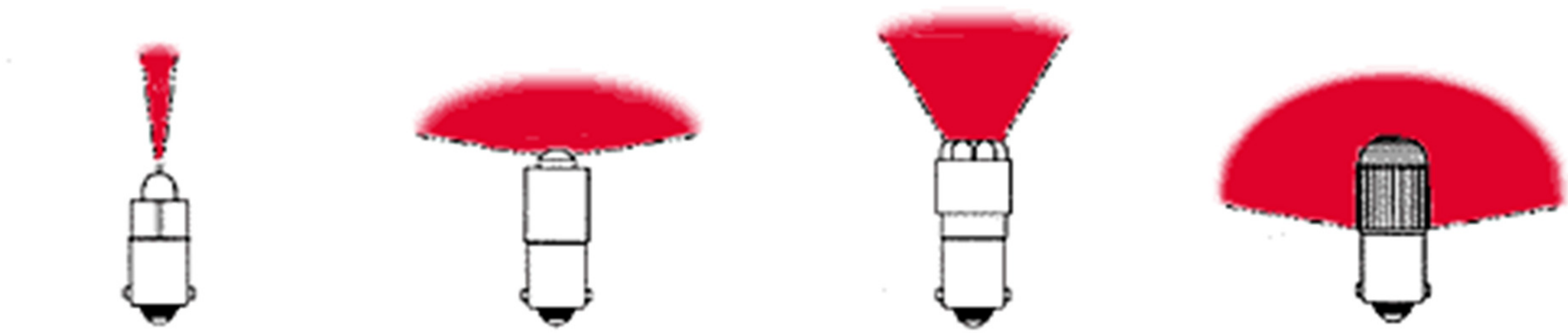
Eye Safety

The need to place eye safety labeling on LED products is dependent upon the product design and the application. Only a few LEDs produce sufficient intensity to require eye safety labeling. However, for eye safety, do not stare into the light beam of any LED at close range

LED Performance (6/8)

Visibility

Luminous intensity (Iv) does not represent the total light output from an LED. Both the luminous intensity and the spatial radiation pattern (viewing angle) must be taken into account. If two LEDs have the same luminous intensity value, the lamp with the larger viewing angle will have the higher total light output.



Single-Chip LED (6,500 mcd, 6°) | 6-Chip LED (58 mcd, 160°) | 7-LED Cluster (7 LEDs × 80 mcd/30° each) | Lensed LED Cluster (3 LEDs × 340 mcd/45° each)

LED Performance (7/8)

Operating Life

Because LEDs are solid-state devices they are not subject to catastrophic failure when operated within design parameters. DDP® LEDs are designed to operate upwards of 100,000 hours at 25°C ambient temperature. Operating life is characterized by the degradation of LED intensity over time. When the LED degrades to half of its original intensity after 100,000 hours it is at the end of its useful life although the LED will continue to operate as output diminishes. Unlike standard incandescent bulbs, DDP® LEDs resist shock and vibration and can be cycled on and off without excessive degradation.

LED Performance (8/8)

Voltage/Design Current

LEDs are current-driven devices, not voltage driven. Although drive current and light output are directly related, exceeding the maximum current rating will produce excessive heat within the LED chip due to excessive power dissipation. The result will be reduced light output and reduced operating life.

LEDs that are designed to operate at a specific voltage contain a built-in current-limiting resistor. Additional circuitry may include a protection diode for AC operation or full-bridge rectifier for bipolar operation. The operating current for a particular voltage is designed to maintain LED reliability over its operating life.

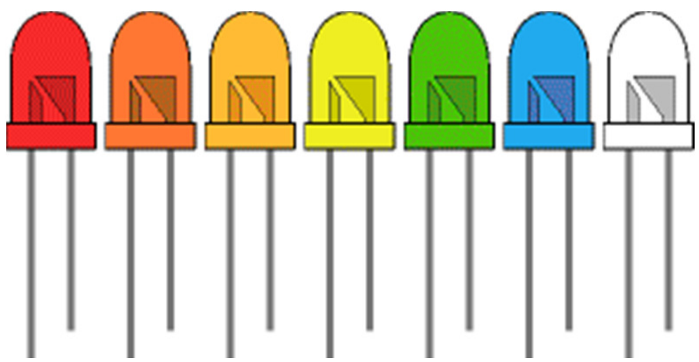
Some Types of LEDs

Bargraph

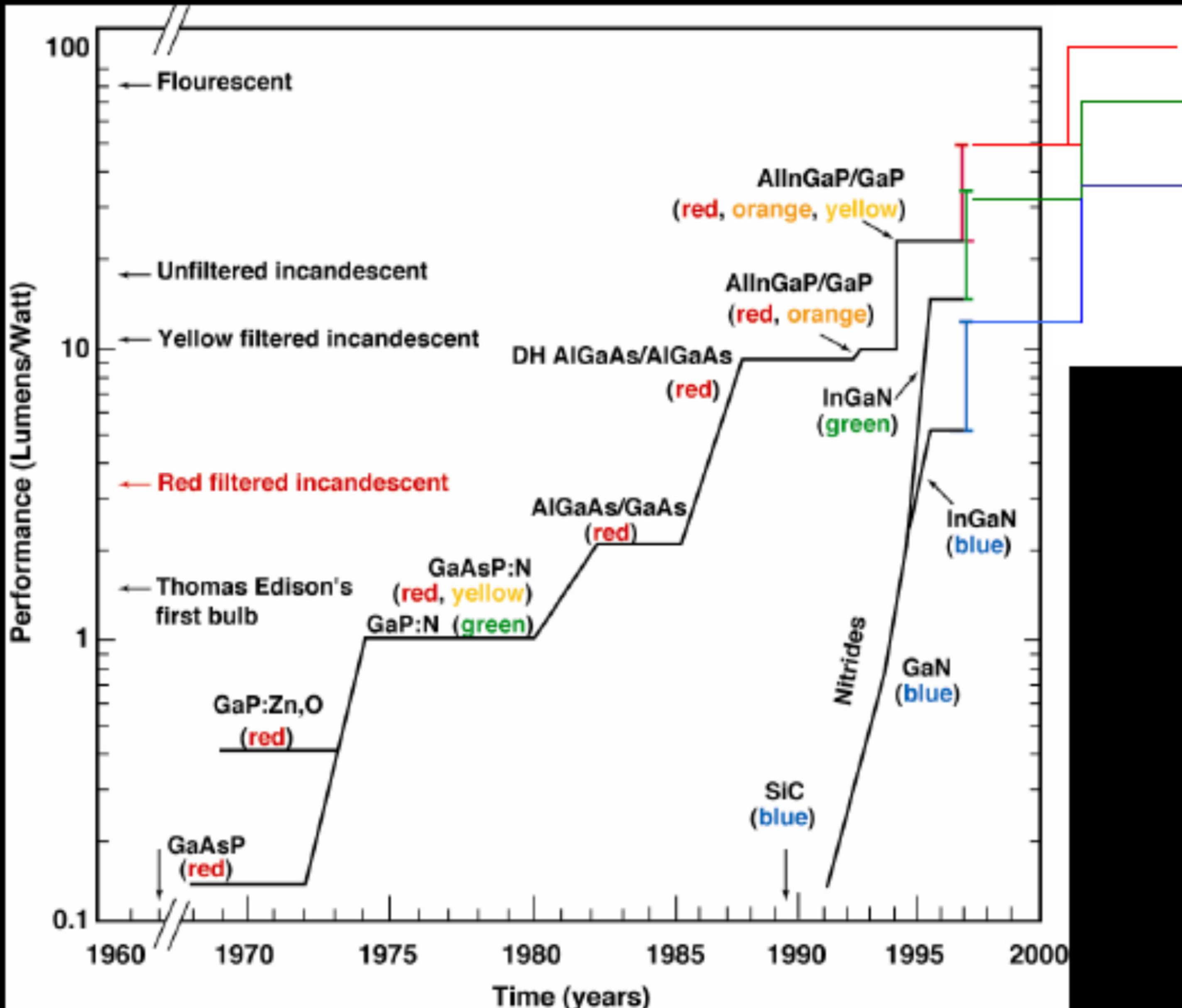
7-segment

Starburst

Dot matrix



Evolution of Visible LEDs



F. A. Ponce and D. P. Bour, Nature 386, 351 (1997)

What do LEDs look like?

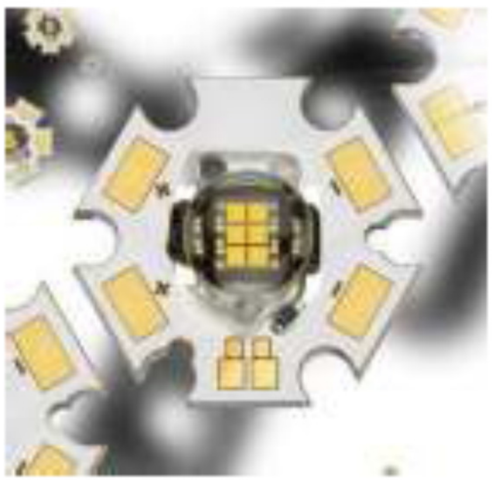
Cree XLamp

Philips Lumileds K2

GE Lumination Vio

LED Devices

What do LEDs look like?



Osram OSTAR

Lamina Titan

LED Packages or Light Engines

What do LEDs look like?

Mule Lighting

Lighting Sciences Group

Enlux

LED Drop-in Replacements

What do LEDs look like?

Lighting Services Inc LumeLEX

Color Kinetics iW Blast

Integrated LED Systems

Preferences

- http://www.marktechopto.com/
- http://acept.la.asu.edu/courses/phs110/expmts/exp13a.html
- http://www.kpsec.freeuk.com/components/led.htm
- http://www.fiber-optics.info/articles/LEDs.htm
- http://www.theledlight.com/technical1.html
- http://hyperphysics.phy-astr.gsu.edu/hbase/electronic/leds.html
- www.kpsec.freeuk.com/components/led.htm

P.S : You can download this presentation from,

http://www.eee.metu.edu.tr/~eekmekci

Myth #1:

LEDs create no heat

Myth #2:

LEDs last 100,000 hours

(or forever depending on whom you ask!)

Myth #3:

LEDs are “White Light” Sources

Myth #4:

LEDs are more efficient than Fluorescent

Power Conversion for "White" Light Sources

	Incandescent† (60W)	Fluorescent† (Typical linear CW)	Metal Halide‡	LED
Visible Light	8 %	21 %	27 %	15-25 %
Infrared	73 %	37 %	17 %	~ 0 %
Ultraviolet	0 %	0 %	19 %	0 %
Total Radiant Energy	81 %	58 %	63 %	15-25 %
Heat (Conduction + Convection)	19 %	42 %	37 %	75-85 %
Total	100 %	100 %	100 %	100 %

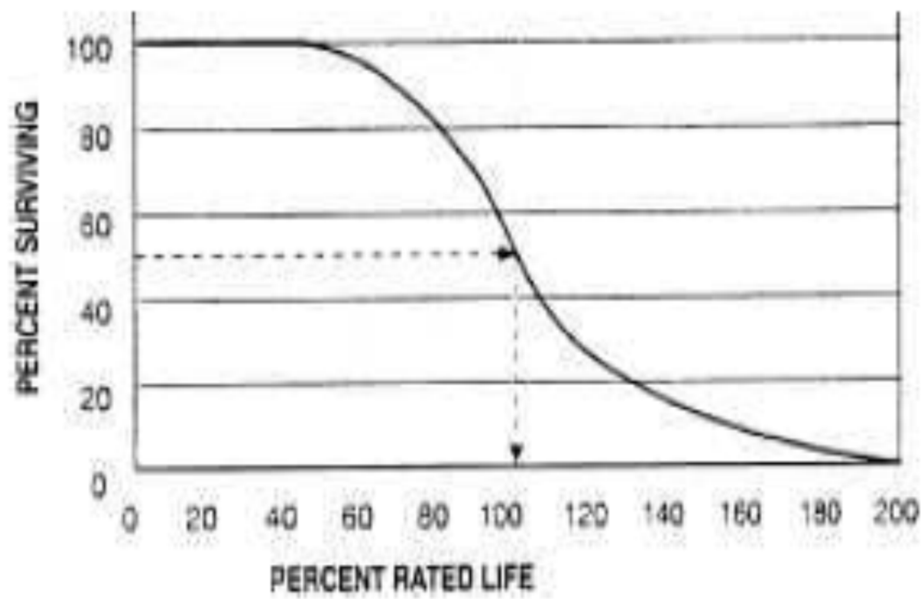
† IESNA Lighting Handbook – 9th Ed.

‡ Osram Sylvania

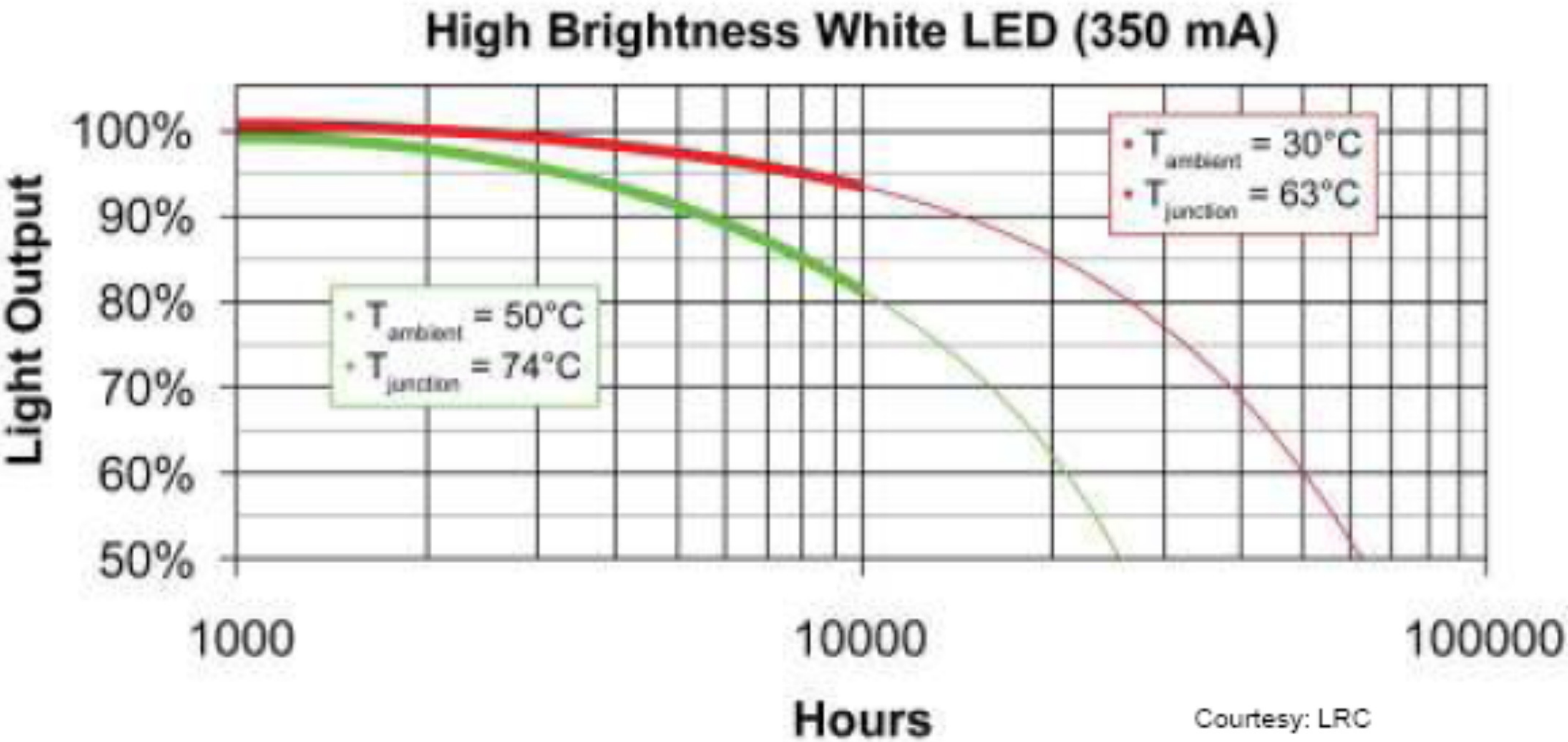
Traditional Lamp Life Rating

- Lumen depreciation vs. failure
- LED life definition
  - L_{70} for general illumination
- IESNA LM-80 test procedure in process

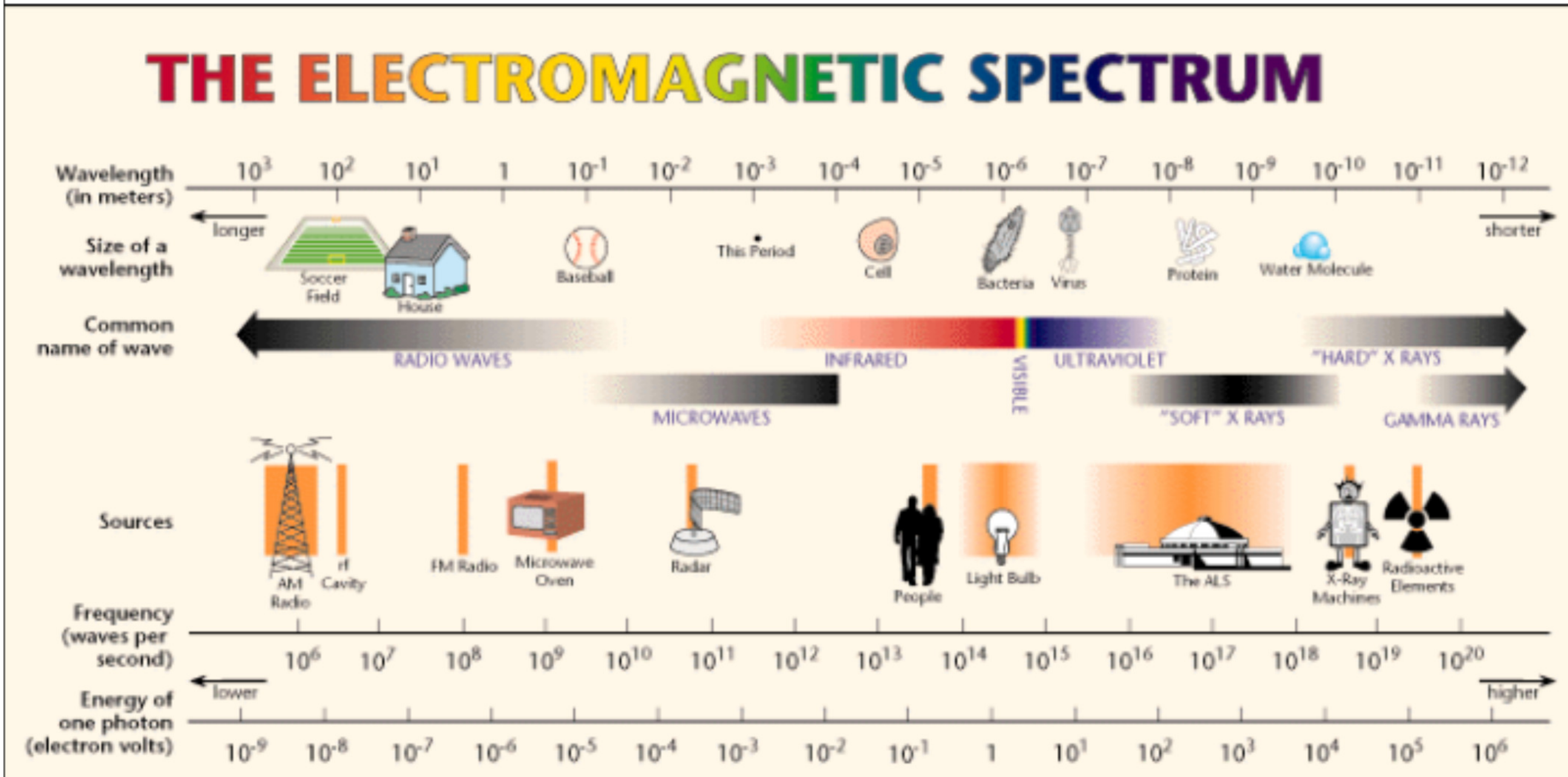
Typical lamp mortality curve

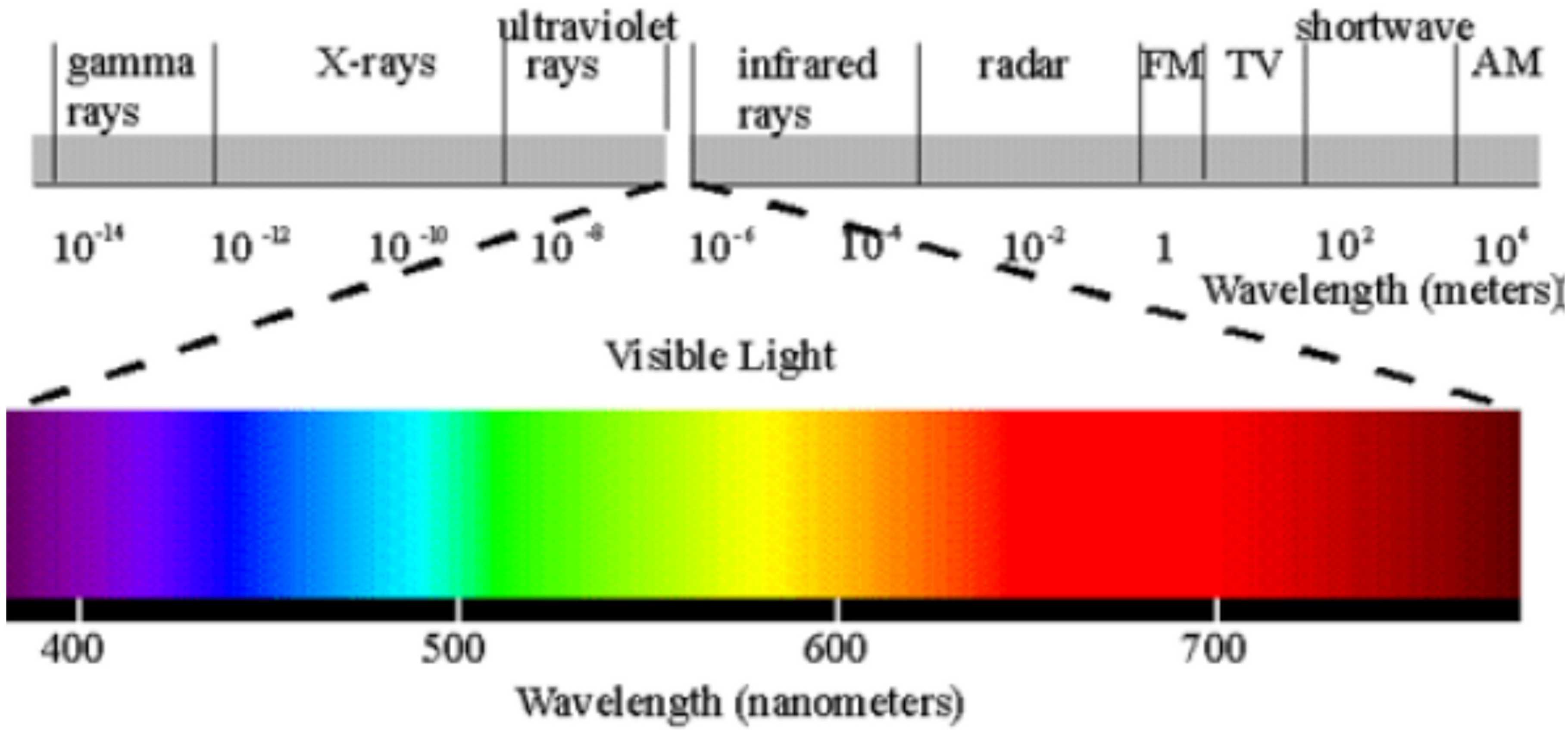


Light Output over Time

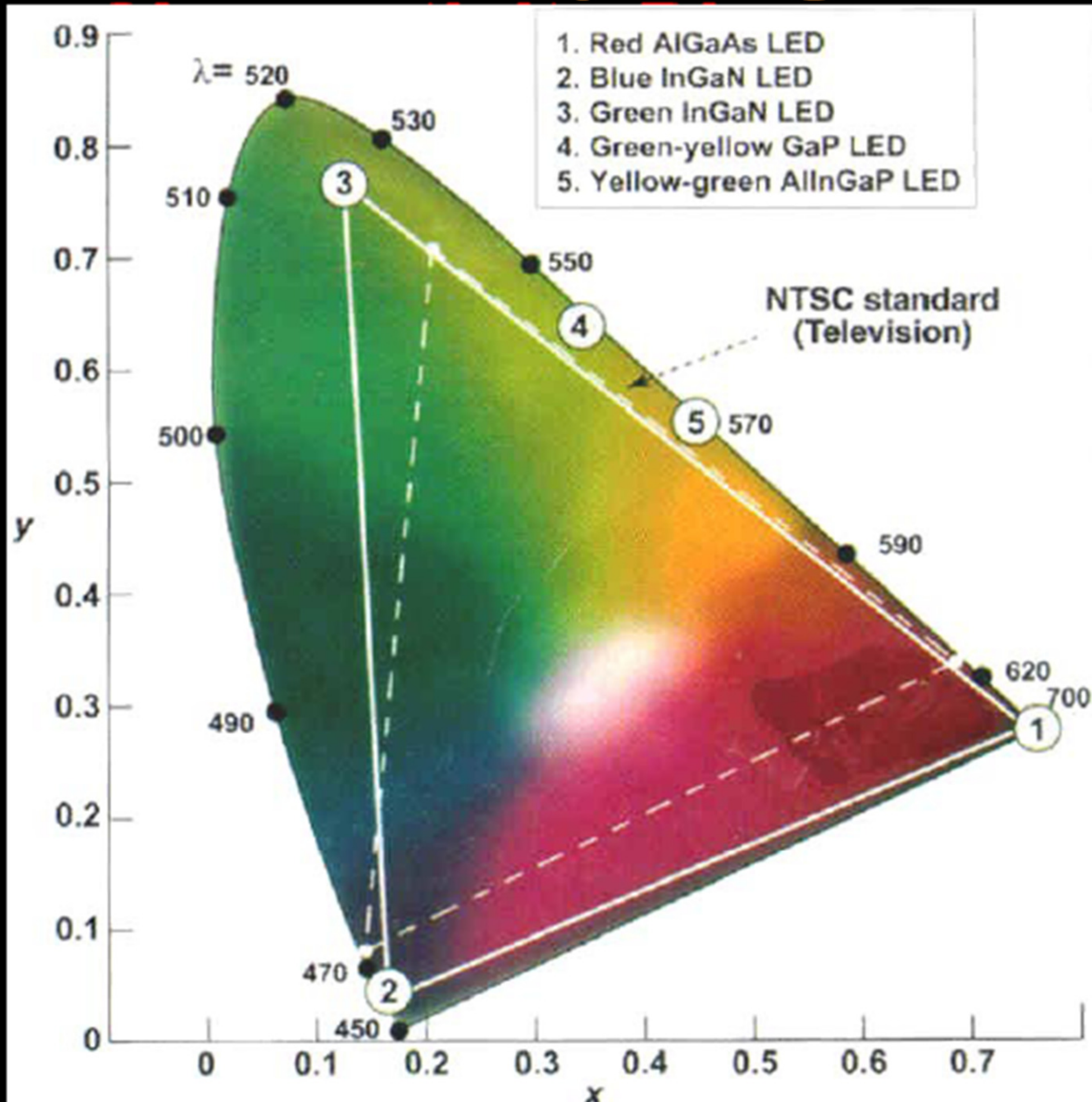


Are LEDs Emitting White Light?



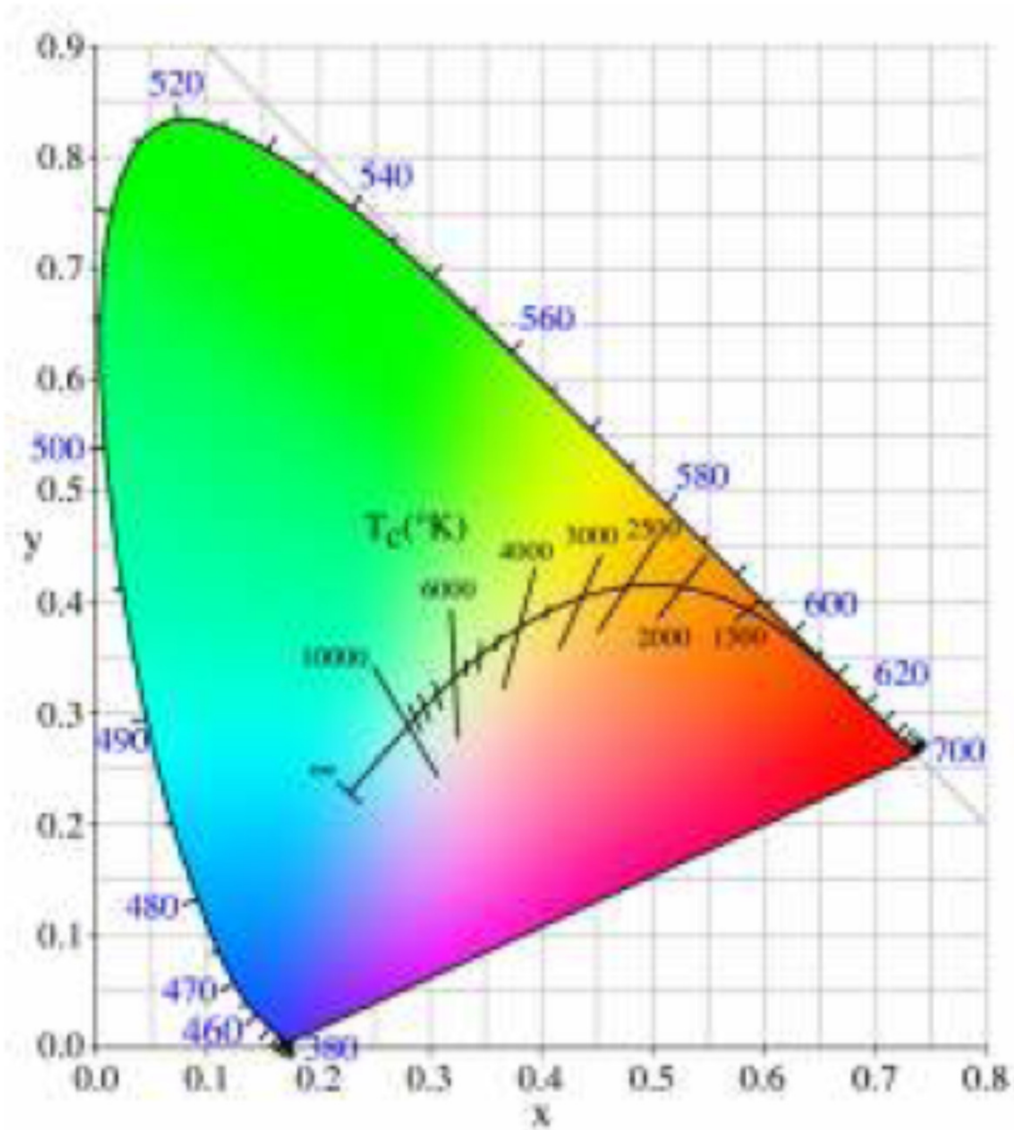

gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^-14
10^-12
10^-10
10^-8
10^-6
10^-4
10^-2
1
10^2
10^4
Wavelength (meters)
Visible Light
400
500
600
700
Wavelength (nanometers)

Chromaticity Diagram

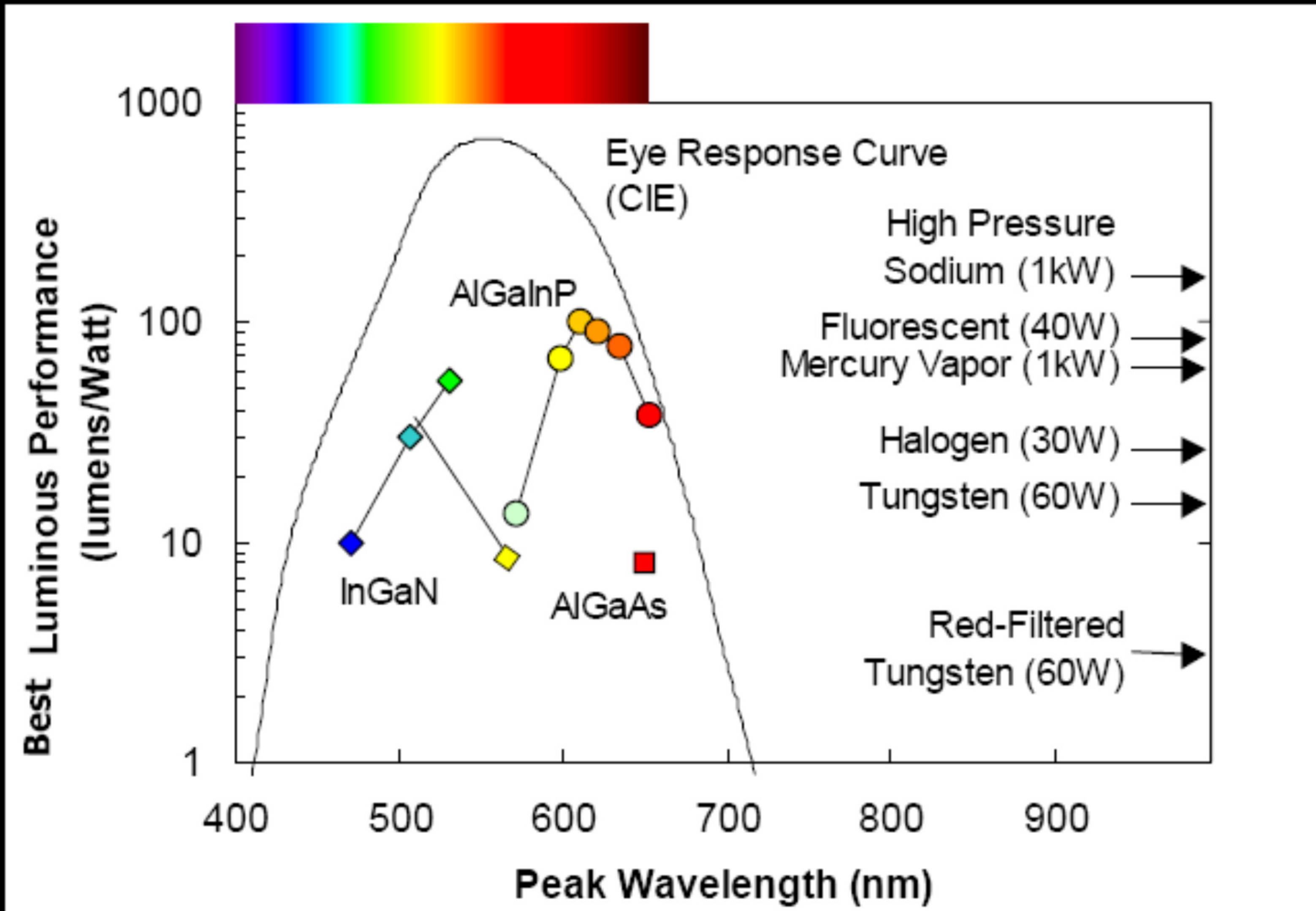


F. A. Ponce and D. P. Bour, Nature 386, 351 (1997)

CIE 1931 x,y Diagram

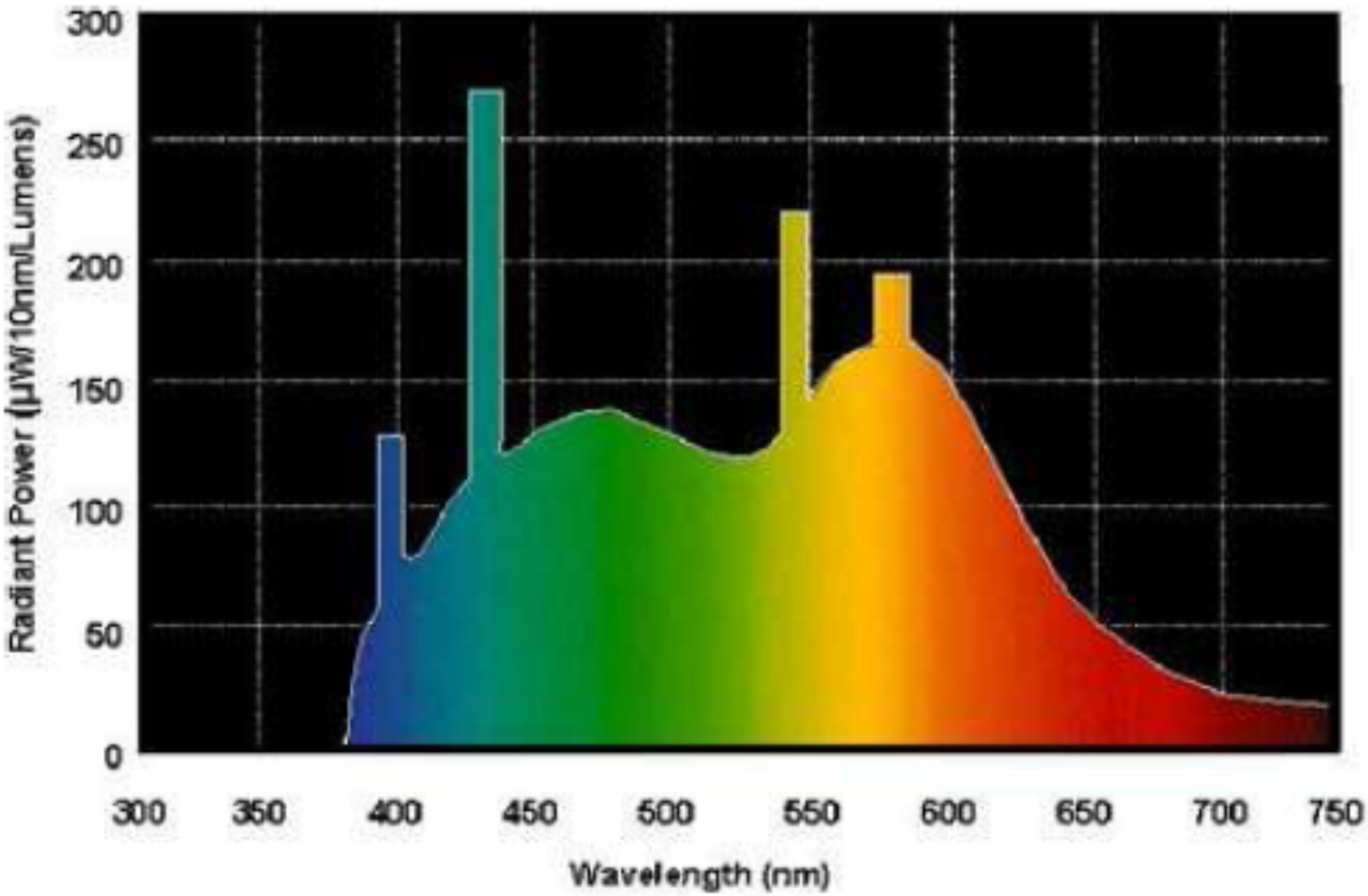


Luminous efficiency

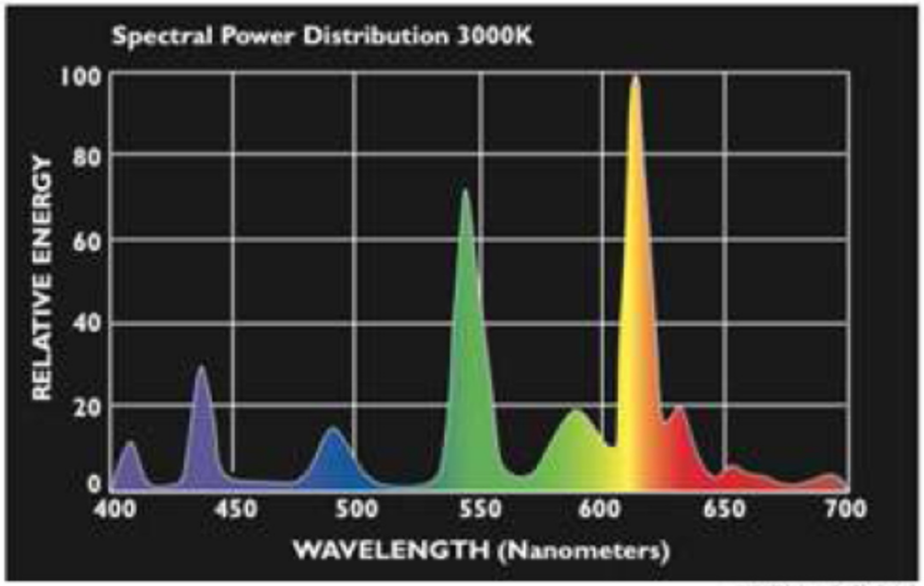


Courtesy of D. P. Bour,

Daylight Spectra

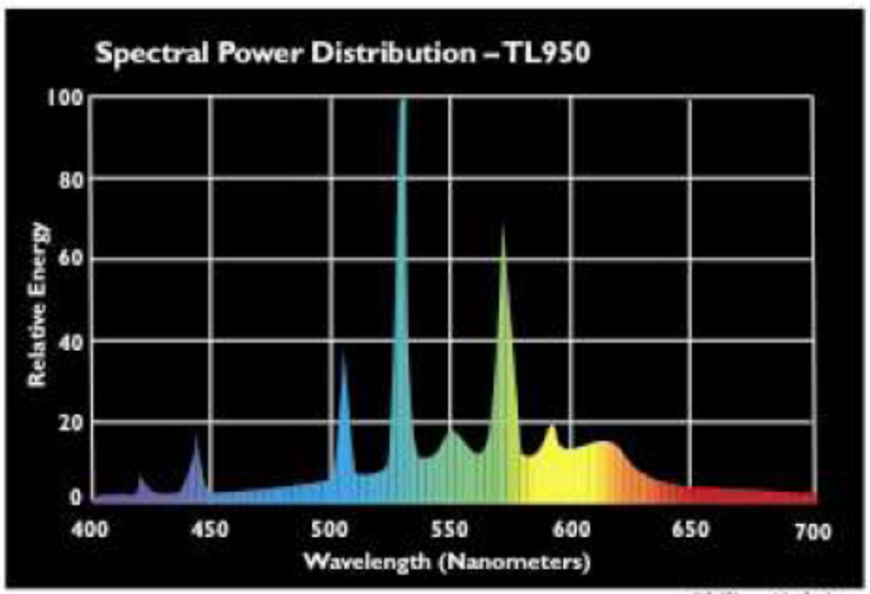


3000K Fluorescent Spectra



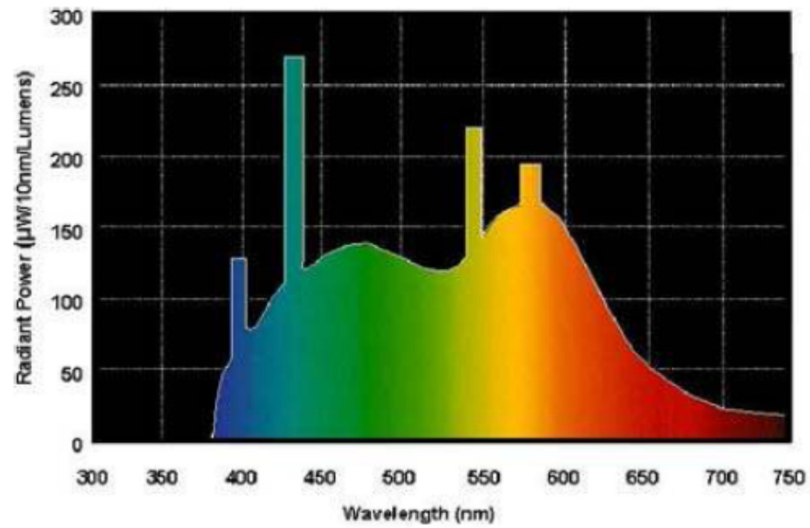
Philips Lighting

5000K Fluorescent Spectra



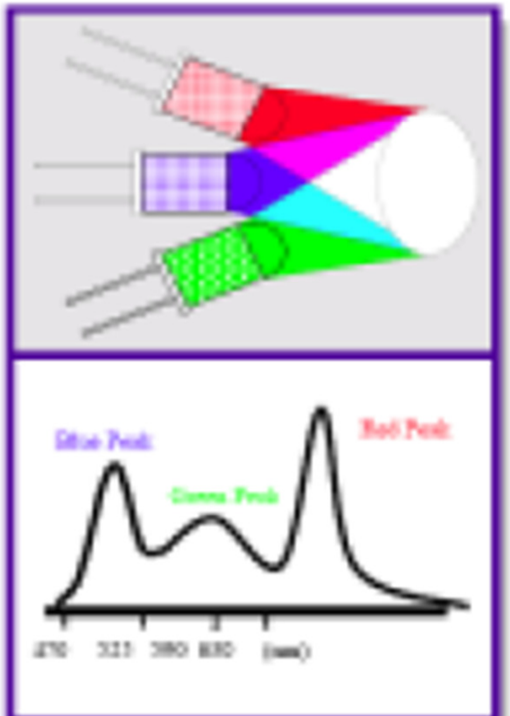
Philips Lighting

Daylight Spectra



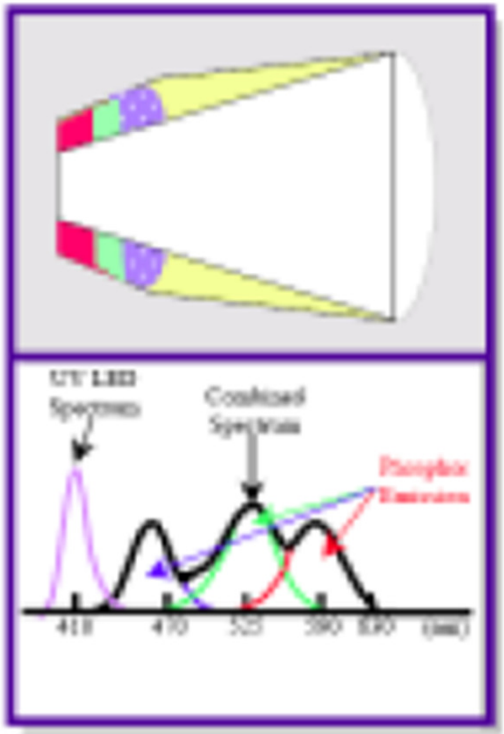
How do LEDs make white light?

Red + Green + Blue LEDs



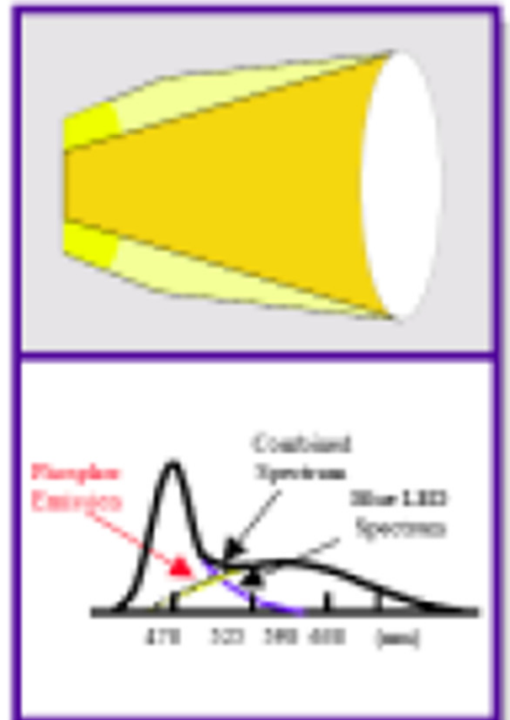
- Dynamic color tuning
- Excellent color rendering
- Large color gamut

UV LED + RGB Phosphor



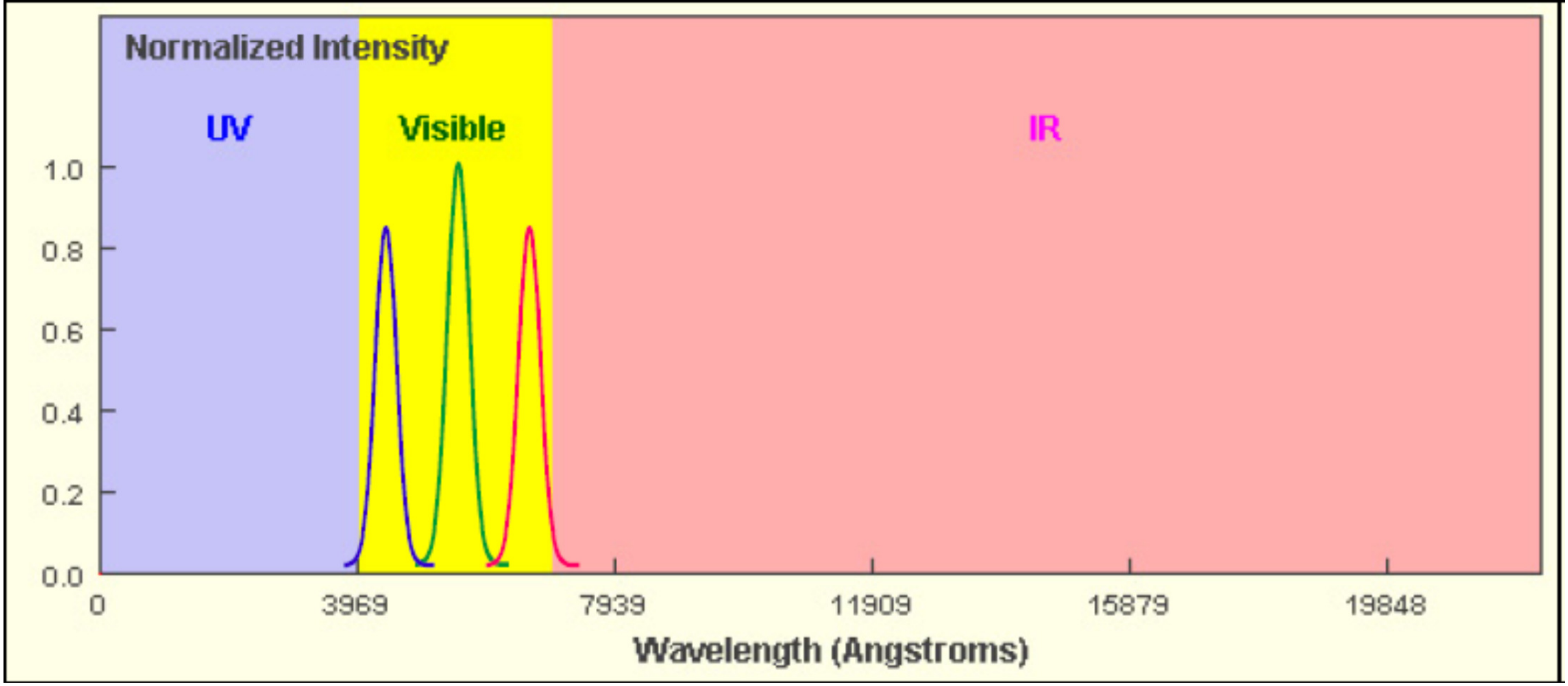
- White point tunable by phosphors
- Excellent color rendering
- Simple to create white

Blue LED + Yellow Phosphor

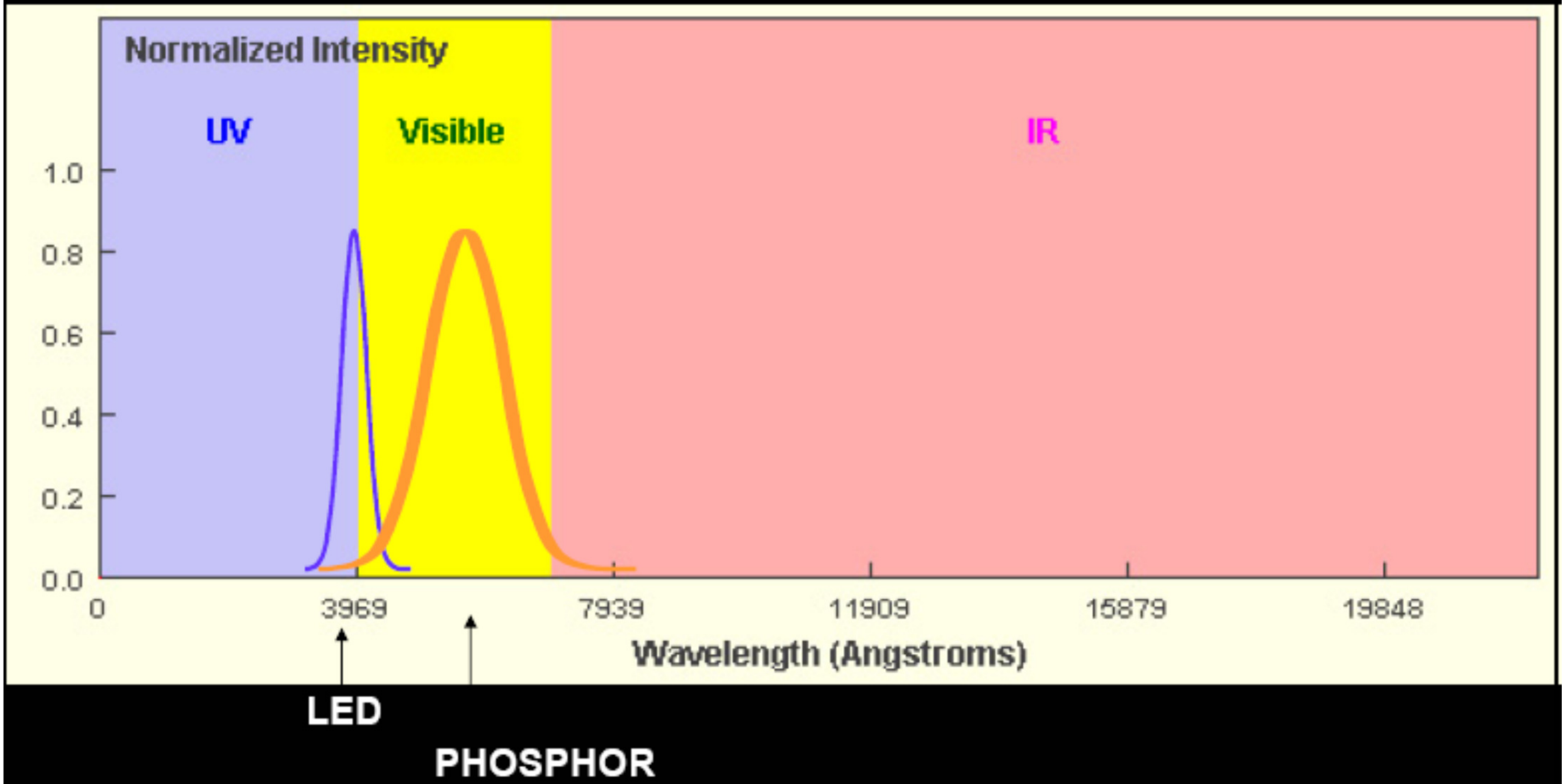


- Simple to create white
- Good color rendering

White Light: 3 LEDs

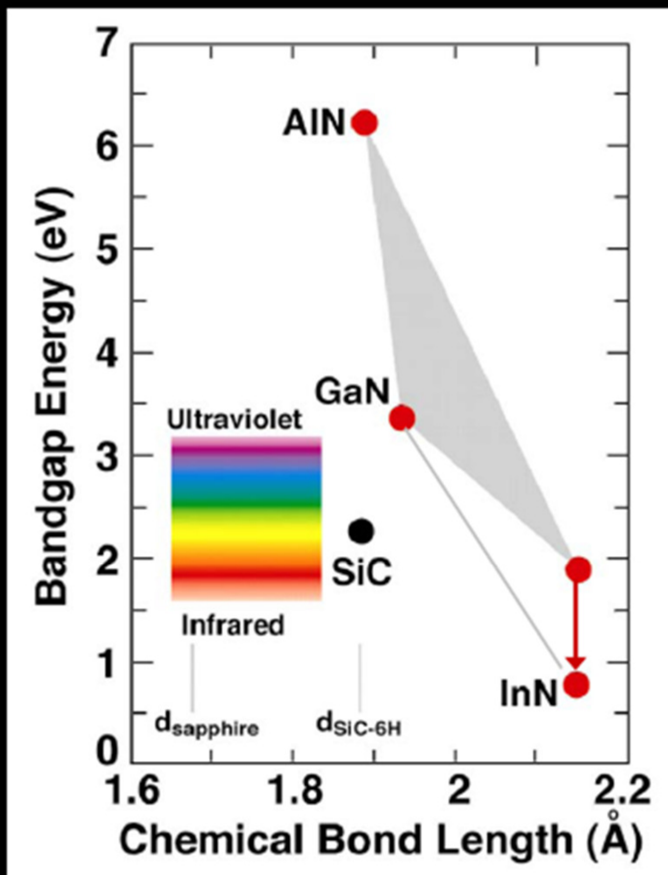


White Light: Purple + Phosphor



Research Today

InGaN Alloys



GaN 3.4 eV (UV)

InN 0.8 eV (IR)

$\mathbf{In_xGa_{1-x}N}$ Visible + UV

$$E_g(x) = xE_g^{InN} + (1\text{-}x)E_g^{GaN} - bx(1\text{-}x)$$

	a	*c*
GaN	*3.189*	*5.185*
InN	*3.545*	*5.703*

11% lattice mismatch

Compositional inhomogeneities
phase separation for $x \geq 0.06$