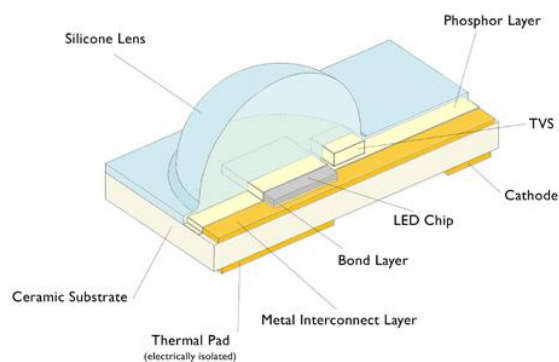


# Making White Light with Blue LEDs

**LEDs** or Light Emitting Diodes are monochromatic solid state lighting (SSL) sources that emit light in one color. There are no white LED chips; “white” light is created using multiple colors and a phenomenon known as **metamerism**. Understanding metamerism forms the basis for an appreciation of how different white LED color temperatures (or **CCTs**) are created and why white LEDs with different CCTs have different **efficacies**.

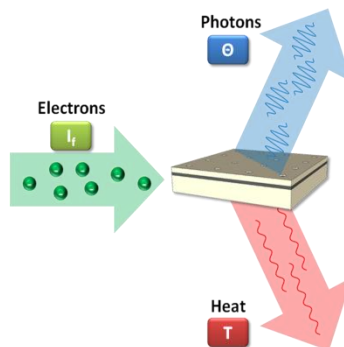
## The packaged LED device and how it creates light

LEDs as we typically recognize them are packaged devices<sup>1</sup> consisting of various components. See *Figure 1*.



*Figure 1. Cross-section of a LUXEON® Rebel LED.  
Illustration courtesy of Philips Lumileds Lighting Company.*

At the heart of the packaged LED device is the LED chip or LED die<sup>2</sup>. LEDs are a unique type of diode. They directly convert incoming electrons (electricity) into photons or visible light – hence the name LED. See *Figure 2*.



*Figure 2. How an LED creates light (and heat).  
Illustration courtesy of Philips Lumileds Lighting Company.*

Since LEDs are not 100% efficient, this conversion also creates heat. For a more thorough explanation of how this heat is mitigated in LED luminaires, see the Information Brief *LED Thermal Management*.

Diodes (the prefix “di-” means two) are made of two different materials, a positive p-type and a negative n-type. When a **forward voltage** ( $V_f$ , in DC volts) is applied across the LED **forward current** ( $I_f$ , in DC milliamps) flows. At the molecular level, holes in the p-type material and electrons in the n-type material flow toward the p-n junction<sup>3</sup> where the materials meet. The higher energy electrons “fall” into the lower energy holes. See *Figure 3*.

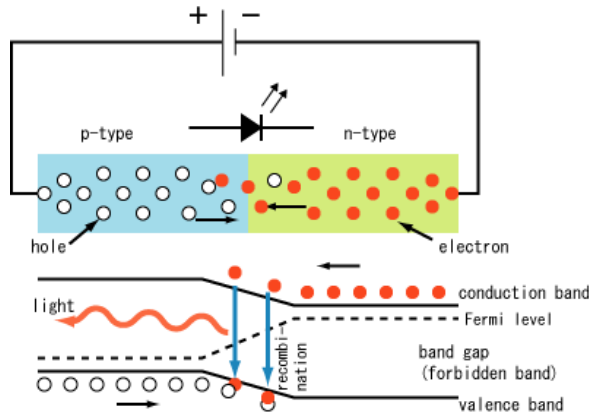


Figure 3. Falling electrons result in light emission.

According to the First Law of Thermodynamics, or the Law of Conservation, energy can neither be created nor destroyed – it can only change form. Therefore, to retain the energy balance, when electrons fall into holes they give off energy in the form of **photons**<sup>4</sup> that we see as visible light. For more on LEDs, see IESNA TM-16-05 *IESNA Technical Memorandum on Light Emitting Diode (LED) Sources and Systems* and IESNA G-2-10 *Guideline for the Application of General Illumination (“White”) Light-Emitting Diode (LED) Technologies* available at [www.iesna.org](http://www.iesna.org).

**Blue + yellow = white light**

LED chips are nearly **monochromatic** where the color emitted is dependent upon the material, which is wavelength specific; thus, we see essentially one color. The terms AlInGaP and InGaN refer to the materials or **elements** used to create the LED chip. For longer wavelength red, orange or yellow light, combinations of Aluminum (Al), Indium (In), Gallium (Ga) and Phosphorous (P) are typically chosen. Philips Lumileds also creates amber with a blue chip and phosphor plates; AlInGaP is not the only way to create amber. For shorter wavelength green or blue light, combinations of Indium (In), Gallium (Ga) and Nitrogen (N) are chosen. See *Figure 4*.

Periodic Table of the Elements

1 H 1.007																	2 He 4.00
3 Li 6.94	4 Be 9.01											5 B 10.8	6 C 12.0	7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.5											13 Al 27.0	14 Si 28.0	15 P 31.0			
19 K 39.1	20 Ca 40.1	21 Sc 45.0	22 Ti 47.9	23 V 50.9	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 58.9	28 Ni 58.7	29 Cu 63.5	30 Zn 65.4	31 Ga 69.7	32 Ge 72.6	33 As 74.9	34 Se 78.9	35 Br 79.9	36 Kr 83.8
37 Rb 85.5	38 Sr 87.6	39 Y 88.9	40 Zr 91.2	41 Nb 92.9	42 Mo 95.9	43 Tc 99.0	44 Ru 101.1	45 Rh 101.1	46 Pd 106.4	47 Ag 107.9	48 In 115	49 Sn 119	50 Sb 122	51 Te 128	52 I 127	53 Xe 131	
55 Cs 133	56 Ba 137	57-71 See Below	72 Hf 179	73 Ta 181	74 W 181	75 Re 186	76 Os 190	77 Ir 187	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 209	84 Po 209	85 At 210	86 Rn 222
87 Fr 223	88 Ra 226	89-103 See Below	104 Rf 261	105 Db 262	106 Sg 263	107 Bh 262	108 Hs 265	109 Mt 266	110 Ds 271	111 Rg 272							
57 La 139	58 Ce 140	59 Pr 141	60 Nd 144	61 Pm 147	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 163	67 Ho 165	68 Er 167	69 Tm 169	70 Yb 173	71 Lu 175			
88 Ac 227	89 Th 232	90 Pa 231	91 U 238	92 Np 237	93 Pu 242	94 Am 243	95 Cm 247	96 Bk 245	97 Cf 251	98 Es 254	99 Fm 253	100 Md 256	101 No 259	102 Lr 260			

Aluminum  
13

Gallium  
31

Indium  
49

Phosphorus  
15

AlInGaP

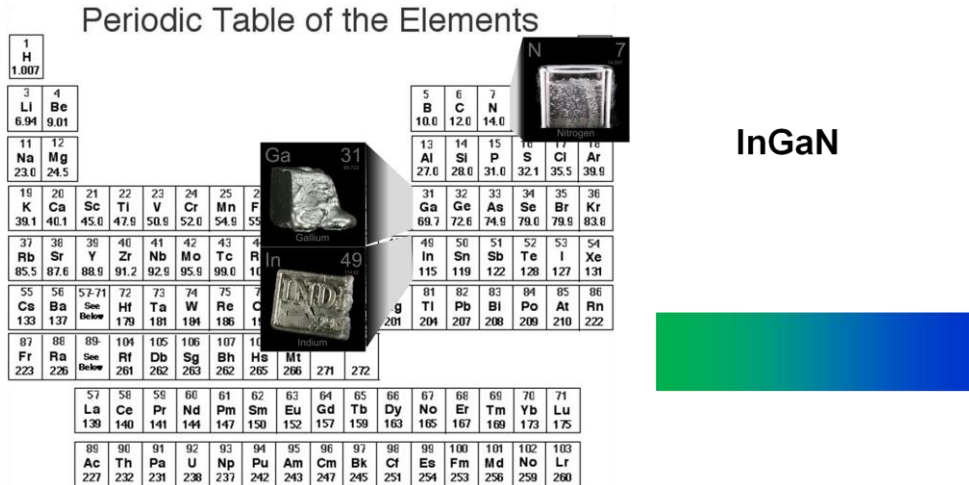


Figure 4. Wavelength or color is determined by the elements used.  
 Illustrations courtesy of Philips Lumileds Lighting Company.

Did you know there is no such thing as a white LED chip? “White” LEDs (packaged devices) start with a blue LED chip, also referred to in the LED industry as a blue “pump”. Then a yellow-based phosphor is applied over the blue chip – refer back to *Figure 1*. This combination of colors makes use of a phenomenon known as **metamerism**<sup>5</sup> which occurs when our eyes and brain perceive two different but complementary colors as “mixing” to “create” a third complementary color. When the blue light shines through the yellow phosphor it is down-converted into what we see as white light. Blue LED chip + yellow-based phosphor = white light.

**Different phosphors yield different CCTs**

See *Figure 5* which is a CIE gamut chromaticity (or color) chart with the **Planckian locus or blackbody curve**<sup>6</sup> superimposed on it. This curve represents the various Correlated Color Temperatures or **CCTs** of white light.

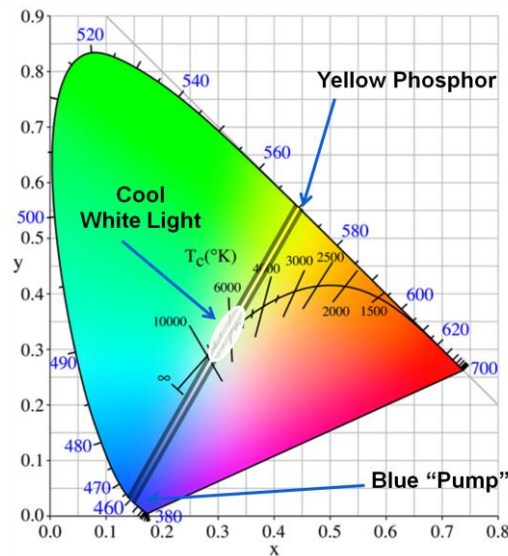


Figure 5. Blue pump with yellow phosphor produces cool white light.  
 Illustrations courtesy of Philips Lumileds Lighting Company.

Notice how the blue “pump” and the yellow phosphor are on the same line – mixing these two complementary colors results in a third complementary color, which we see as cool white light. The addition of the yellow phosphor means the packaged device’s white light output will be less efficient than the pump’s blue light. This loss, combined with other losses due to factors such as heat and the protective lens, lowers the **efficacy**<sup>7</sup> of the resulting white light. Efficacy is a measure of how effectively the LED converts the incoming electricity into visible light, and it is measured in lumens per watt (or **LPW**).

Now see *Figure 6*. If we add red phosphor, the light is down-converted further to warm white light. This additional phosphor leads to additional losses; thus, warm white LEDs have lower efficacies than cool white ones.

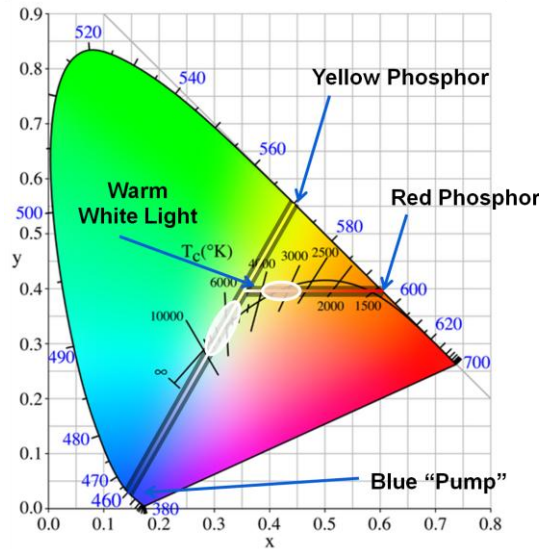


Figure 6. Blue pump with yellow + red phosphors produces warm white light. Illustrations courtesy of Philips Lumileds Lighting Company.

## References

1. The IES Nomenclature Committee and American National Standards Institute, *Nomenclature and Definitions for Illuminating Engineering*, ANSI / IES RP-16-10, New York: Illuminating Engineering Society of North America, 2010.

2. Ibid.

3. Ibid.

4. Ibid.

5. Ibid.

6. Ibid.

7. Ibid.

For more information go to [www.hadco.com](http://www.hadco.com).

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