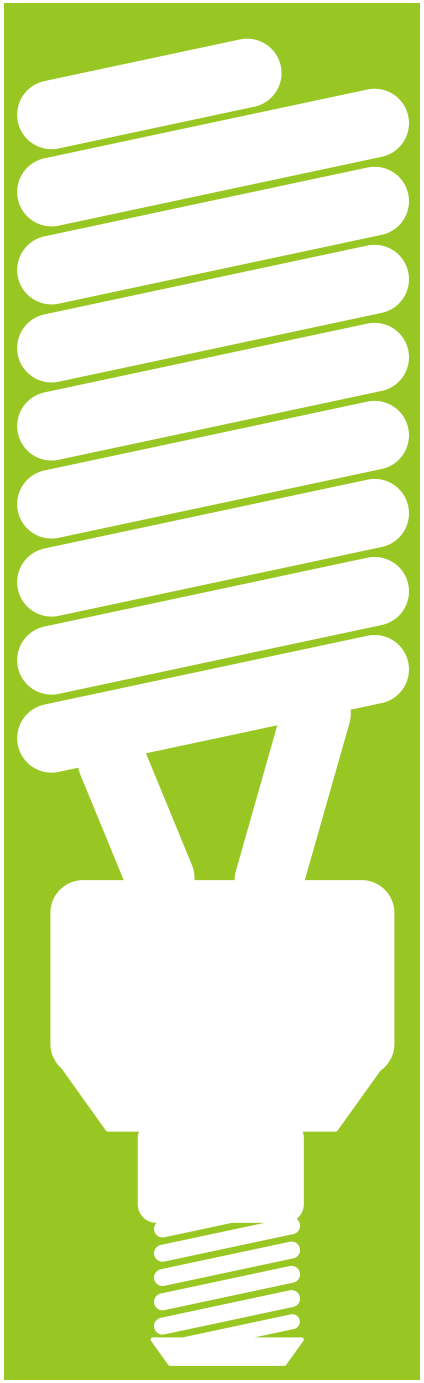
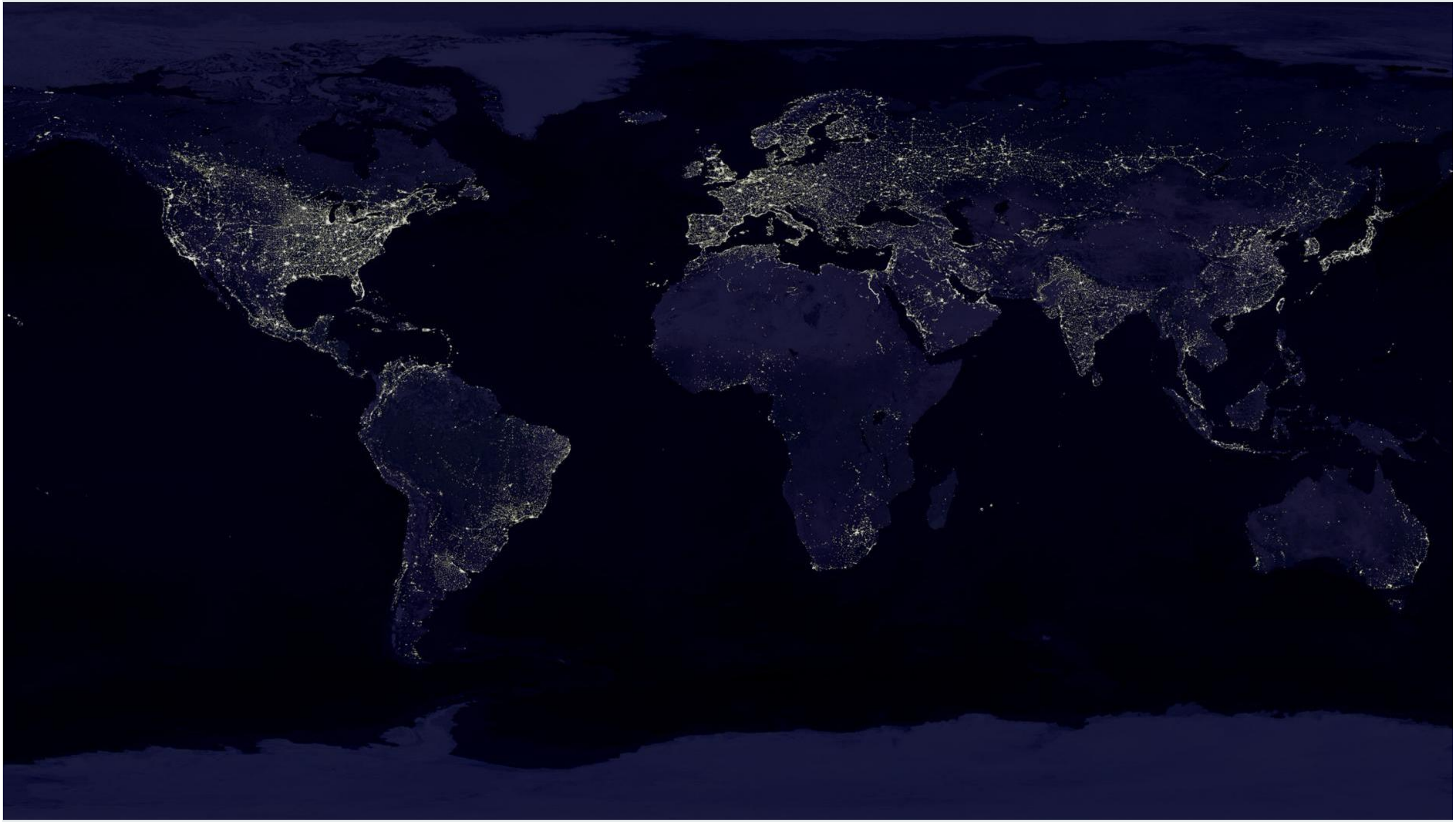
THE PAST, PRESENT, AND FUTURE OF LIGHTING



WHY CARE ABOUT LIGHTING?

Lighting Statistics

- 38% of industrial and commercial electricity use is for lighting.
- 10% to 20% of home electricity use is for lighting.



NASA, 2000

LIGHTING THROUGH THE YEARS

- 400,000 BC: Fire and torches.
- 20,000 BC: First lamps
  - Animal and vegetable grease, fiber wicks in shells
- 500 BC: Oil reservoir lamps
- 400 AD: Wax candles
- 1820 AD: Gas lighting
  - Heavy use in streets, factories, theaters
  - Coincidently (or not) between 500-1,000 theaters burn down in 19^{th} century USA and UK!
- 1850: Kerosene Lamps
  - Dominates indoor lighting
  - Still the main source of indoor lighting in much of the developing world

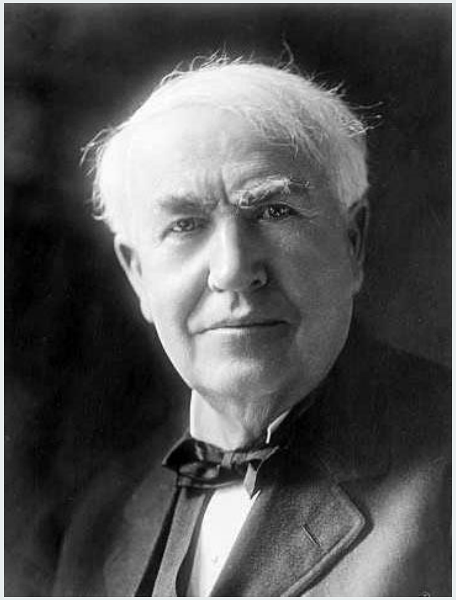
GHANA: HOMEWORK BY KEROSENE LAMP

SENEGAL: ELECTION WORKERS COUNT BALLOTS BY CANDLELIGHT AND KEROSENE LAMP (2007)

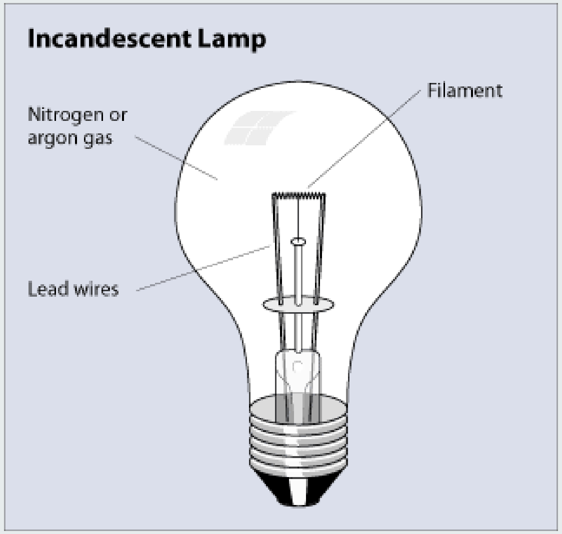
THEN, ALONG COMES THOMAS EDISON

- In September 1878, Thomas Edison announces he will introduce new form of incandescent lighting.

- October 21, 1879, Edison demonstrates light bulb.



THE EDISON BULB



- Current travels through filament, causing it to **incandesce**.
- Energy Transfer:
- Efficiency = useful energy produced / total energy used
  - Incandescent bulb efficiency is about 10-20%.
  - Only 10-20% energy used to produce light. The rest is used for heat.
- Light Intensity: “Lumen” is the unit of total visible light output from a light source.
  - If a lamp or fixture were surrounded by a transparent bubble, the total rate of light flow through the bubble is measured in lumens.
- Light efficacy: lumens per watt
  - Edison’s 1879 light bulb: 1.4 lumens per watt
  - Today’s incandescent light bulb: 17 lumens per watt

THE FUTURE OF EDISON'S BULB

THE FUTURE OF EDISON'S BULB

- US: Energy Independence and Security Act of 2007
  - Phase 1: All general purpose bulbs must be 30% more efficient by 2014.
    - California voted to enact the standards set by the energy independence and security act one year before the country

Traditional Wattage	Phase 1 Max Wattage	Phase 2 Max Wattage	Lumens	Phase 1 Implementation Date
100	72	17	1490-2600	January 1, 2011
75	53	12	1050-1489	January 1, 2012
60	43	10	750-1049	January 1, 2013
40	29	5	310-749	January 1, 2014

  - Phase 2: By 2020, all general purpose bulbs must produce 45 lumens/watt.
    - California voted to enact this standard by Jan 1 2018.

THE FUTURE OF EDISON'S BULB

- Beyond the USA:
  - European Union: All incandescent bulbs phased out by 2012.
  - Canada: No incandescent bulbs by 2012.
  - Cuba: Banned sale and import of all incandescent bulbs in 2005.

In 2007 the Cuban Government donated 2-3 million compact florescent lights to help Haiti reduce power consumption. The bulbs were distributed by Boy Scouts which went door to door to exchange incandescent bulbs for compact fluorescents.

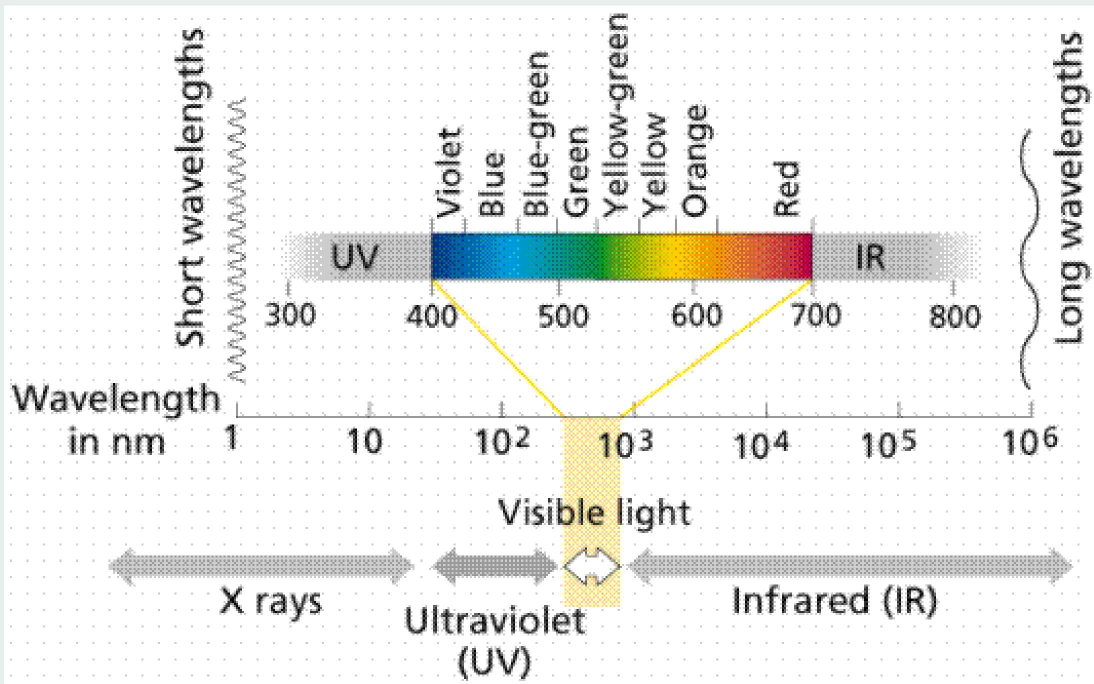
WHAT NOW? HALOGENS

- How they work
  - Types of incandescent bulbs
  - Filament gets hotter than traditional incandescent and filament evaporates
  - Halogen gas reacts with tungsten on glass and redeposits it back onto filament.
- Pros
  - Less energy than traditional incandescence (~15%)
  - Can use less expensive gases in them

- Cons
  - Very hot (known to start fires)
  - Cannot touch bulbs
  - Some need transformers
  - Shorter life time (60 W replacement .9 year at 3 hours a day)

THE COLOR OF LIGHT

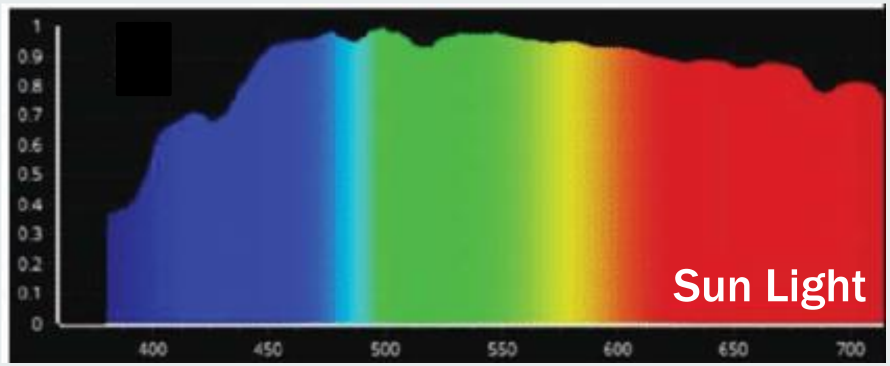
- Visible Spectrum $\left(E = \frac{hc}{\lambda}\right)$

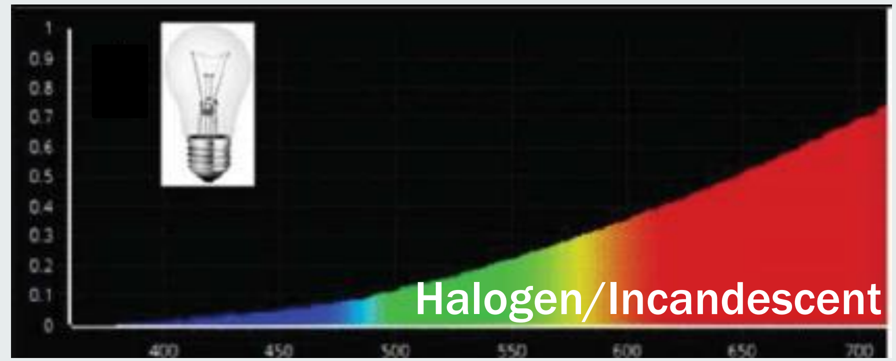


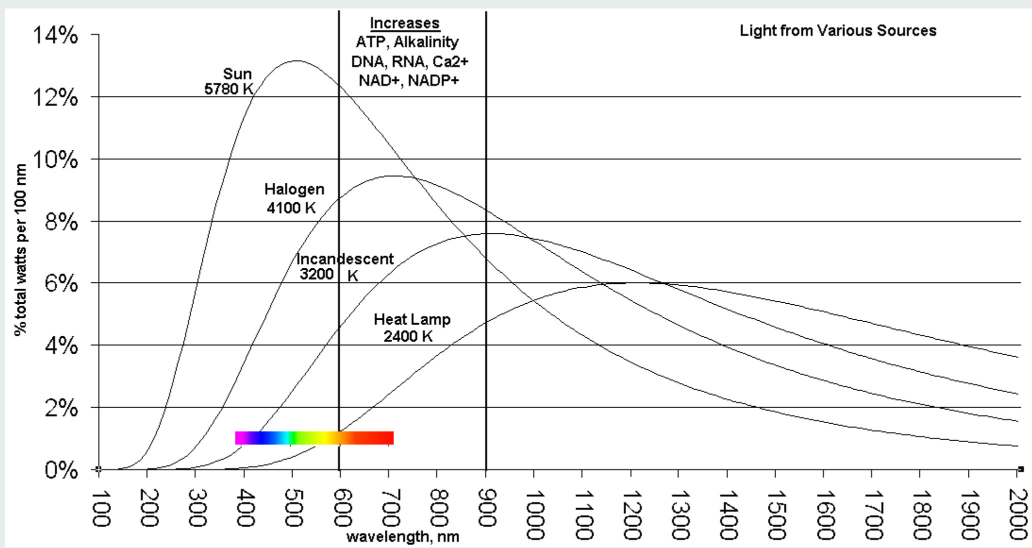
Wavelength

Energy

EMISSION SPECTRUM







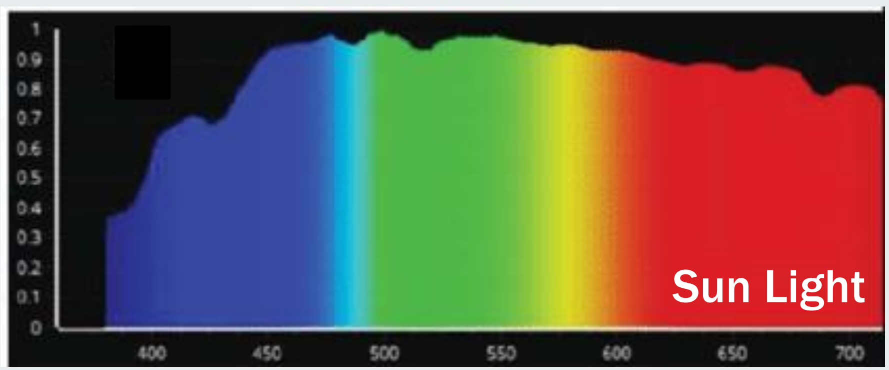
WHAT NOW? FLORESCENT / COMPACT FLORESCENT

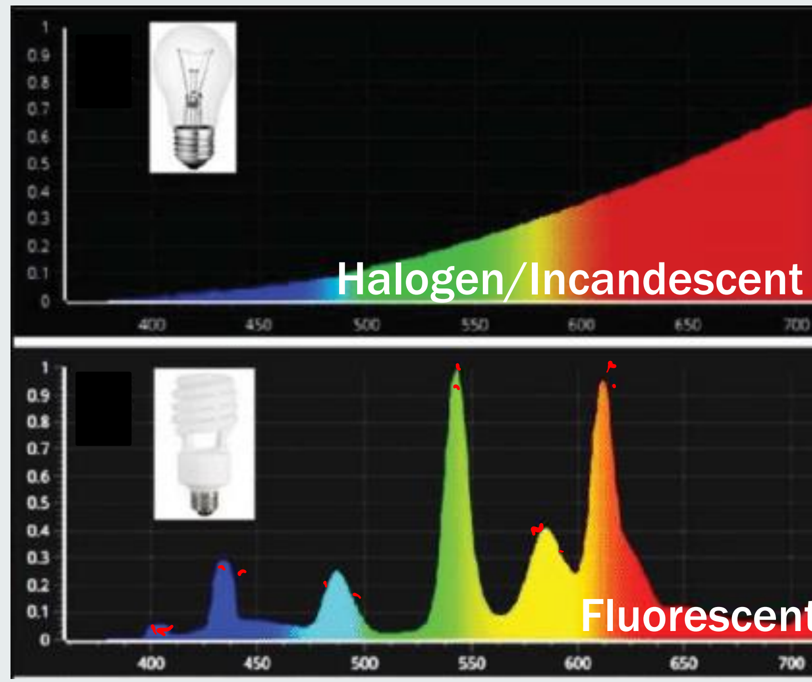
- How They Work
  - Bulb is filled with mercury gas, sealed and coated with an Ultra-Violet (UV) light-sensitive material (called a phosphor)
  - Electric current is run through a filament producing electrons
  - The electrons transfer their energy to the gas, causing the gas to emit UV radiation.
  - Phosphor absorbs UV radiation and re-emits visible, while light.

- Pros:
  - More efficient than an incandescent light bulb.
  - Last Longer

- Cons
  - Contains toxic mercury.
  - Resistance decreases as current flows through bulb. Needs either external ballast (florescent) or internal ballast (compact florescent) to control current.
  - Warm up time

EMISSION SPECTRUM



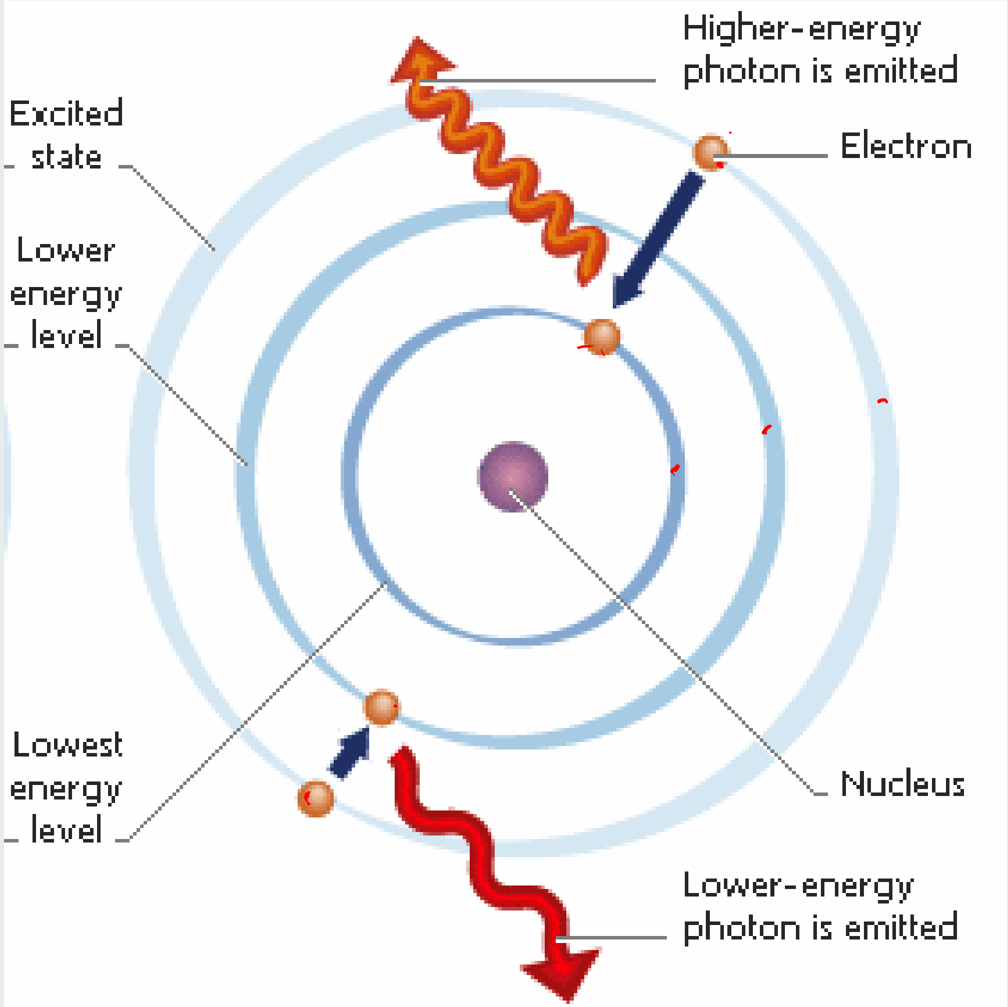


HOW IS LIGHT PRODUCED?

Any light that you see is made up of a collection of one or more photons propagating through space as electromagnetic waves.

Electrons can only be in certain energy levels around the nucleus. If energy is supplies to the atom, the electron can be moved in to a higher energy level.

Once an electron absorbs energy it is in an excited state which is unstable. After a very small period of time (<< 1 sec), the electron falls back to its ground state. During the fall, it emits a photon.

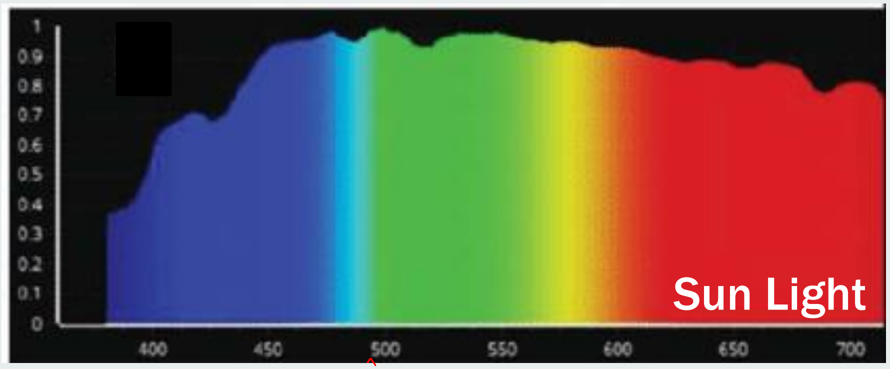


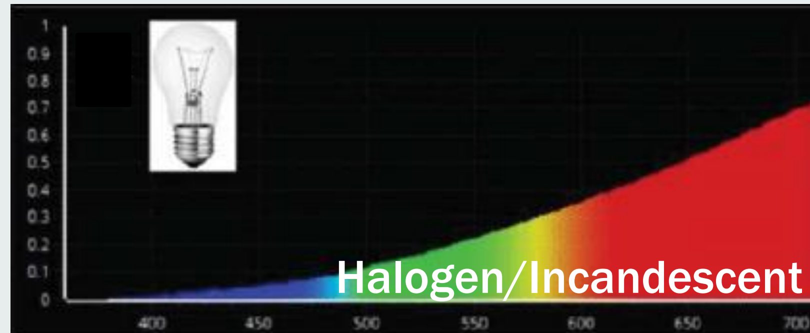
WHAT NOW? LEDS

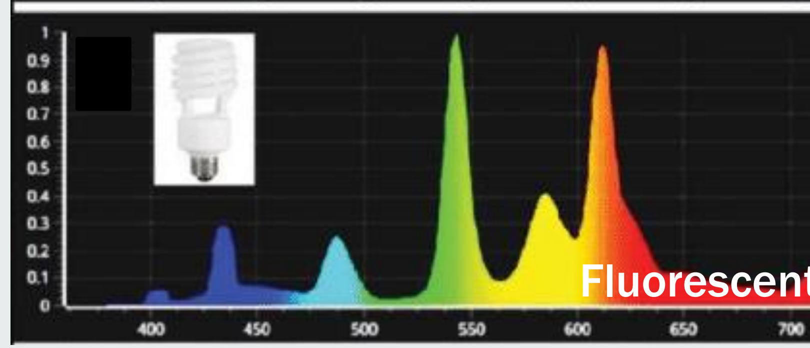
- Pros
  - Very small (5 mm is a typical size)
  - Do not catastrophically fail (gets dimmer over time)
  - Lifetime 25,000-60,000 hours (life defined as reaching 70% of original brightness)
  - 98% of power goes to light

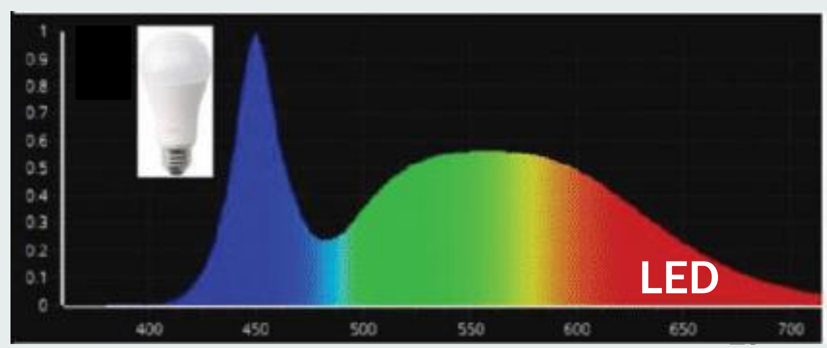
- Cons
  - Directional lighting (shines in straight line not spread out)
  - High cost
  - Heat sensitive

EMISSION SPECTRUM

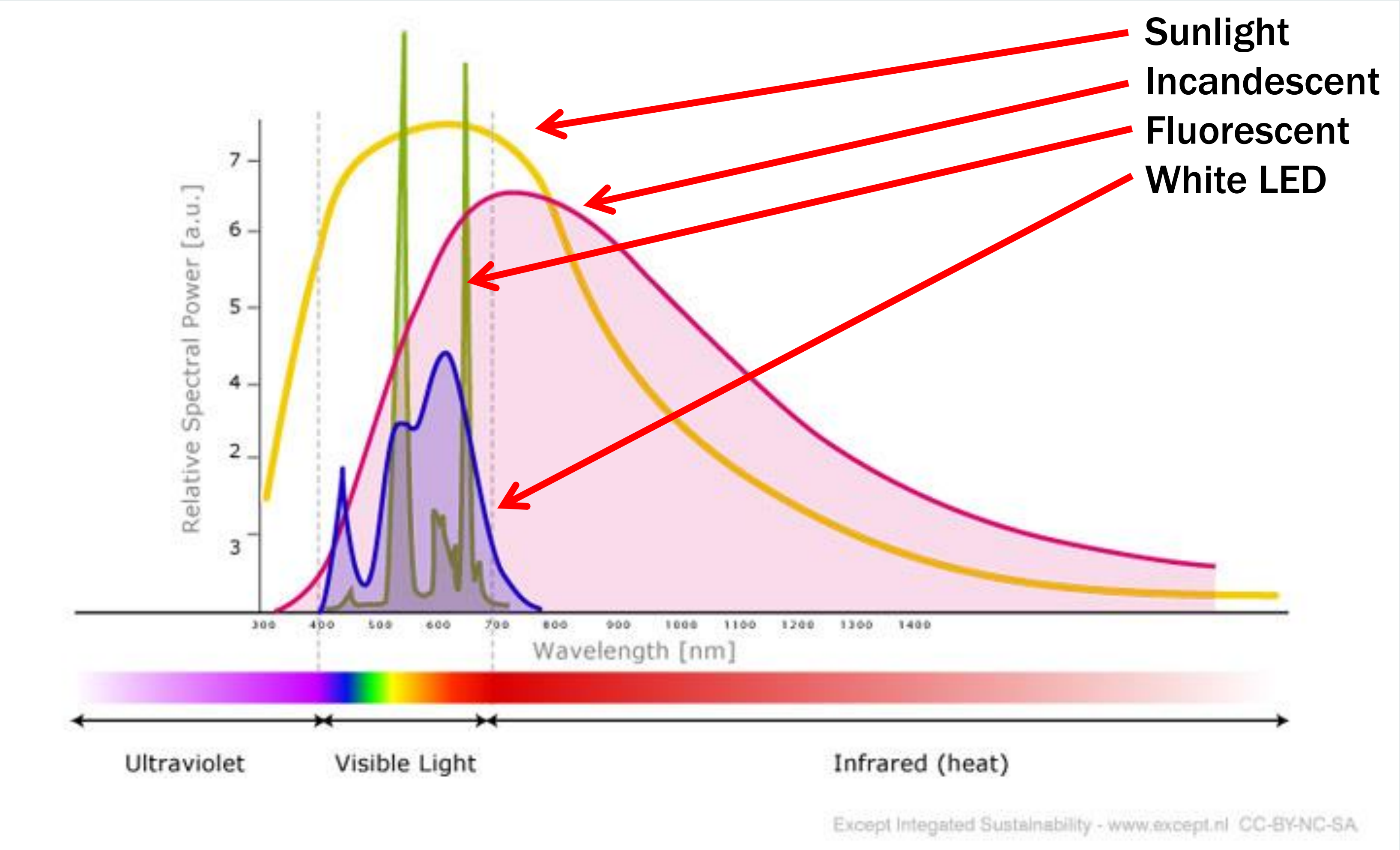






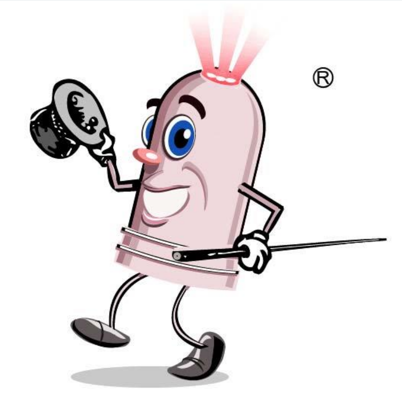


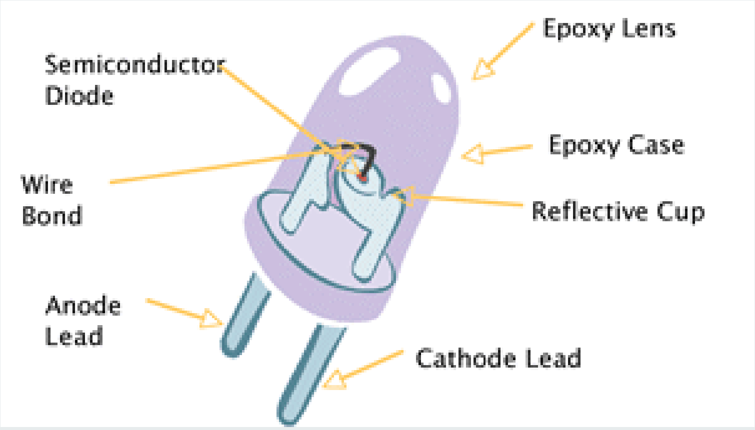
THE SPECTRA OF LIGHT SOURCES



LED

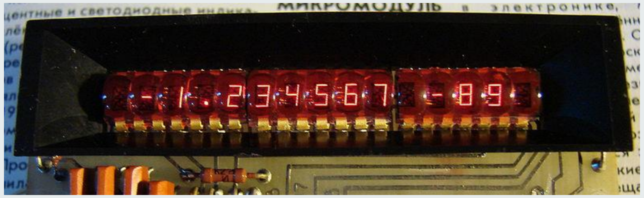
- What is a Light Emitting Diode (**LED**)?
  - An LED is a diode that produces light.



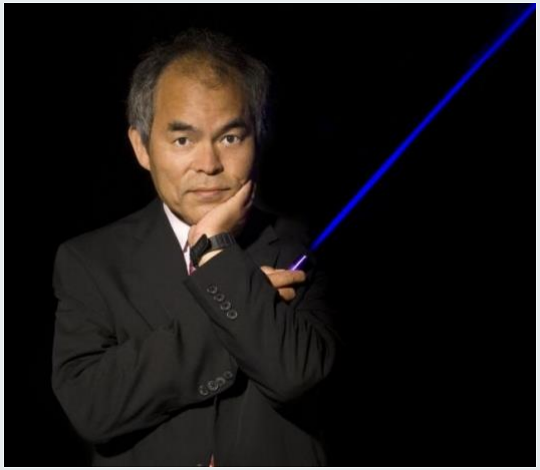


- Why is it called solid state lighting (SSL)?
  - The material that gives off the light is in a solid form. No moving parts, no glass or filament to break
  - Compare to filament lighting (incandescent), plasma (arc lamps), fluorescence, or gas (burning propane)

LED HISTORY



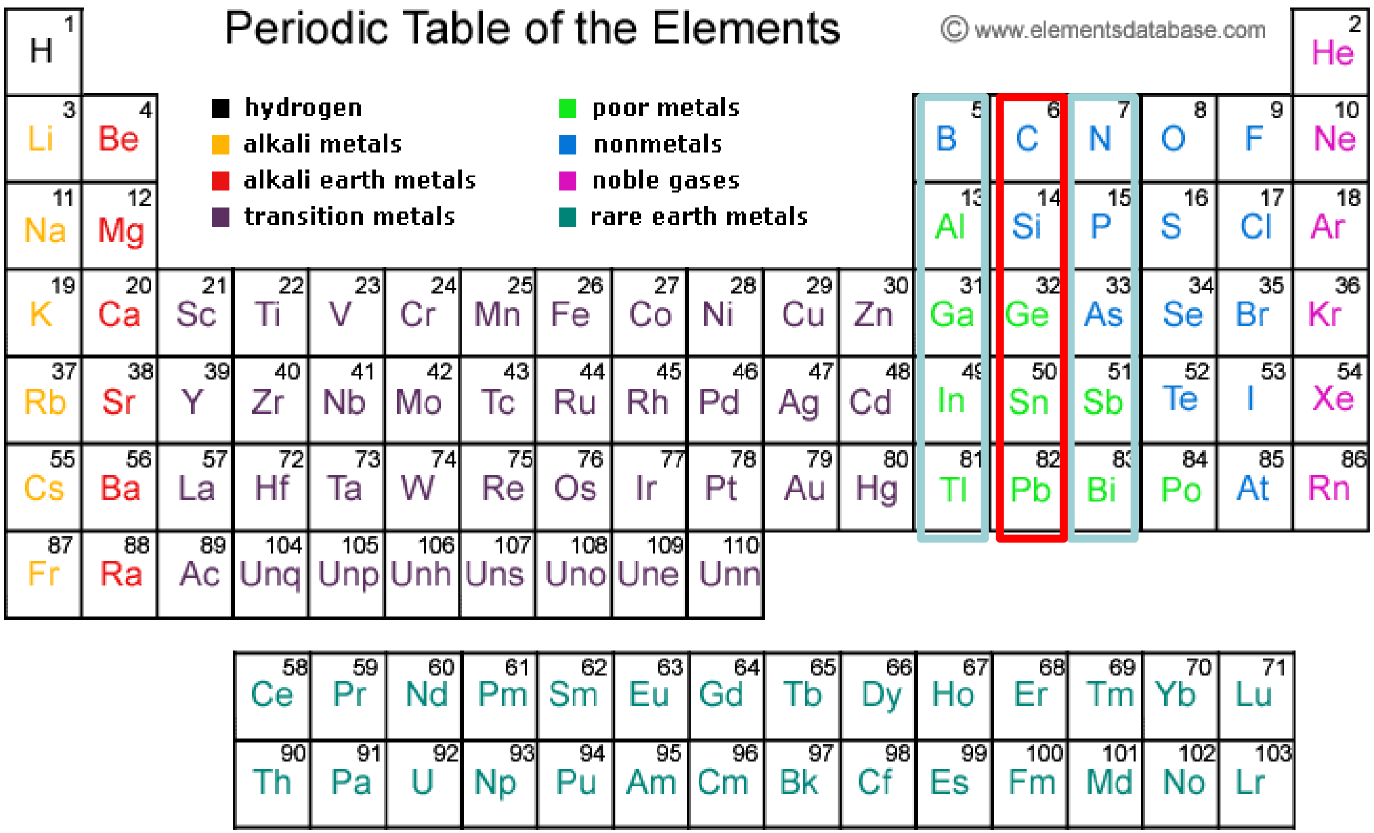
- 1962: First practical LED built by Nick Holonyak Jr. at GE.
  - It gave off dim red light.
  - Used in clocks, radios, on/off indicators, etc.
- Dim green LEDs came soon after, and also put to use as indicators.
- Research to develop something better was ongoing for another 30 years….
- On Nov 29, 1993, the world was *stunned* to hear that **Shuji Nakamura**, a little known researcher from the small Japanese chemical company Nichia, had developed and demonstrated a bright blue LED.
  - Dr. Nakamura is now a professor in the materials department here at UCSB
  - He one the Nobel prize for the blue LED in 2014



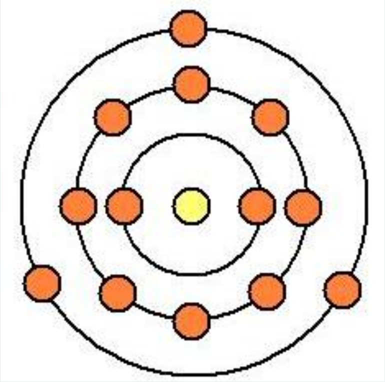
LED HISTORY

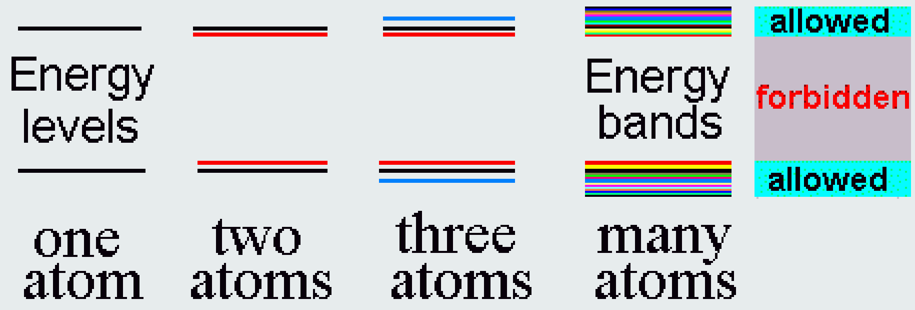
- The emergence of a bright blue LED meant that a bright white LED was also possible by either color mixing red, green, and blue or by putting a phosphorus lining on blue LEDs.
- Two years later, in 1995, Nakamura announced he had developed the world's first bright green LED and then the first white LED.
- Since then, several large companies have been competing and to get LED lighting to market by decreasing costs and further improving efficiency.
- Company names to remember: Cree (The Cree lighting unit, a spin-off of UCSB is based in Goleta), Nichia, Philips Lumileds, Osram Opto
- http://ssleec.ucsb.edu/

SEMICONDUCTOR'S



ALLOWED ENERGY LEVELS





Bands are occupied by electrons.

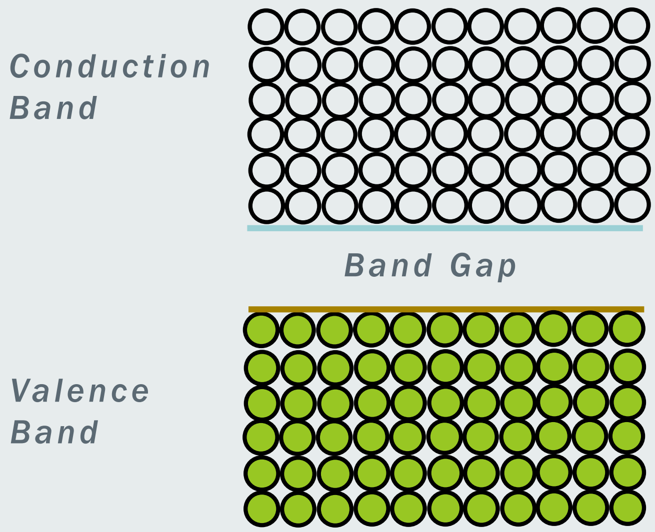
Band gaps have no electrons.

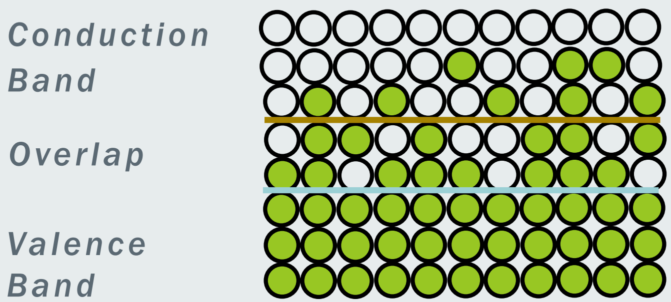
The top band is called the **conduction band**.

The bottom band is called the **valence band**.

Electric current is due to the motion of valence electrons that have been promoted to the conduction band.

CONDUCTION IN SOLIDS



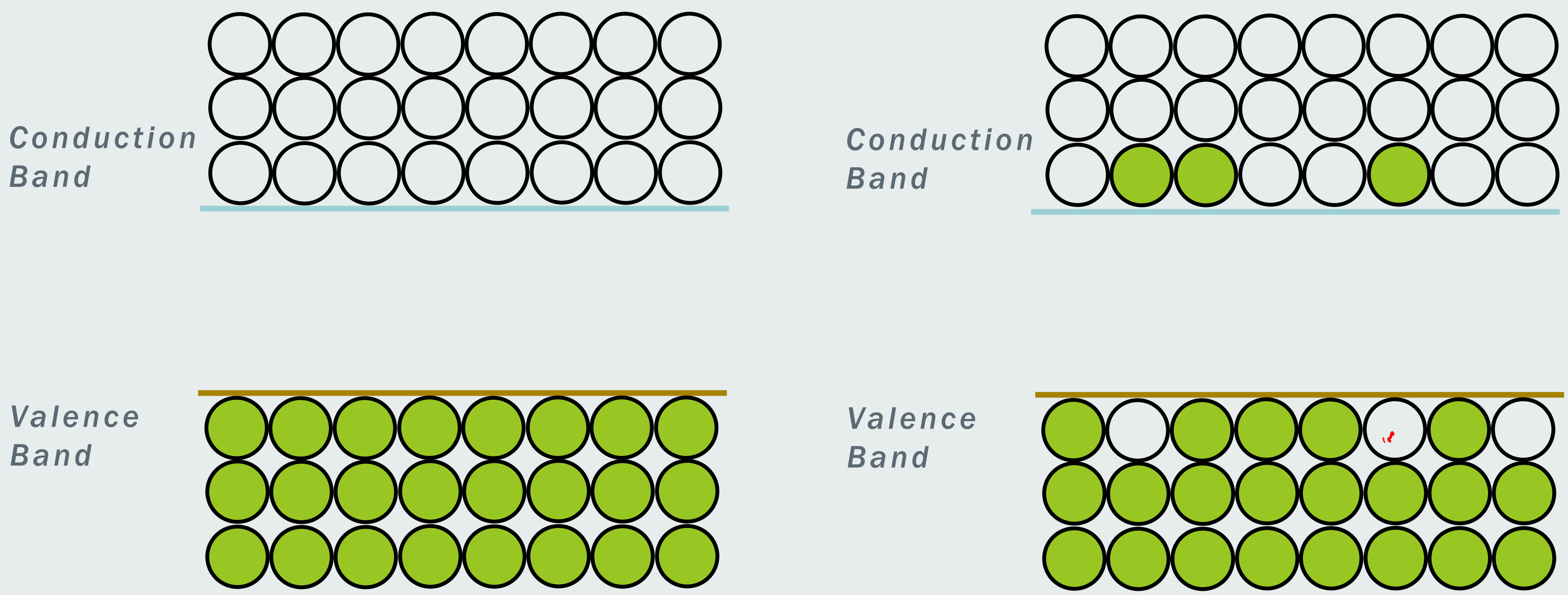


- Electrons in an **insulator** fill all available states in the valence band.
- Must jump across band gap into the empty conduction band before they can move freely.

- Electrons in a **conductor** can move freely into the conduction band without gaining extra energy.

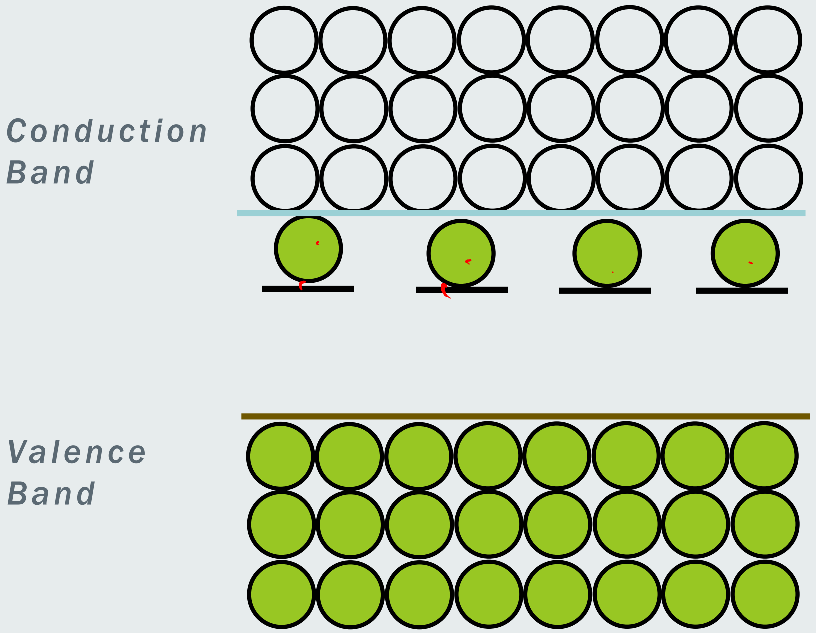
SEMICONDUCTORS

- Semiconductors have full valence shells.
- Semiconductor band gaps are small enough that electrons can be promoted from the valence to the conduction bands.
- The absence of an electron is called a hole.



DOPING (N-TYPE)

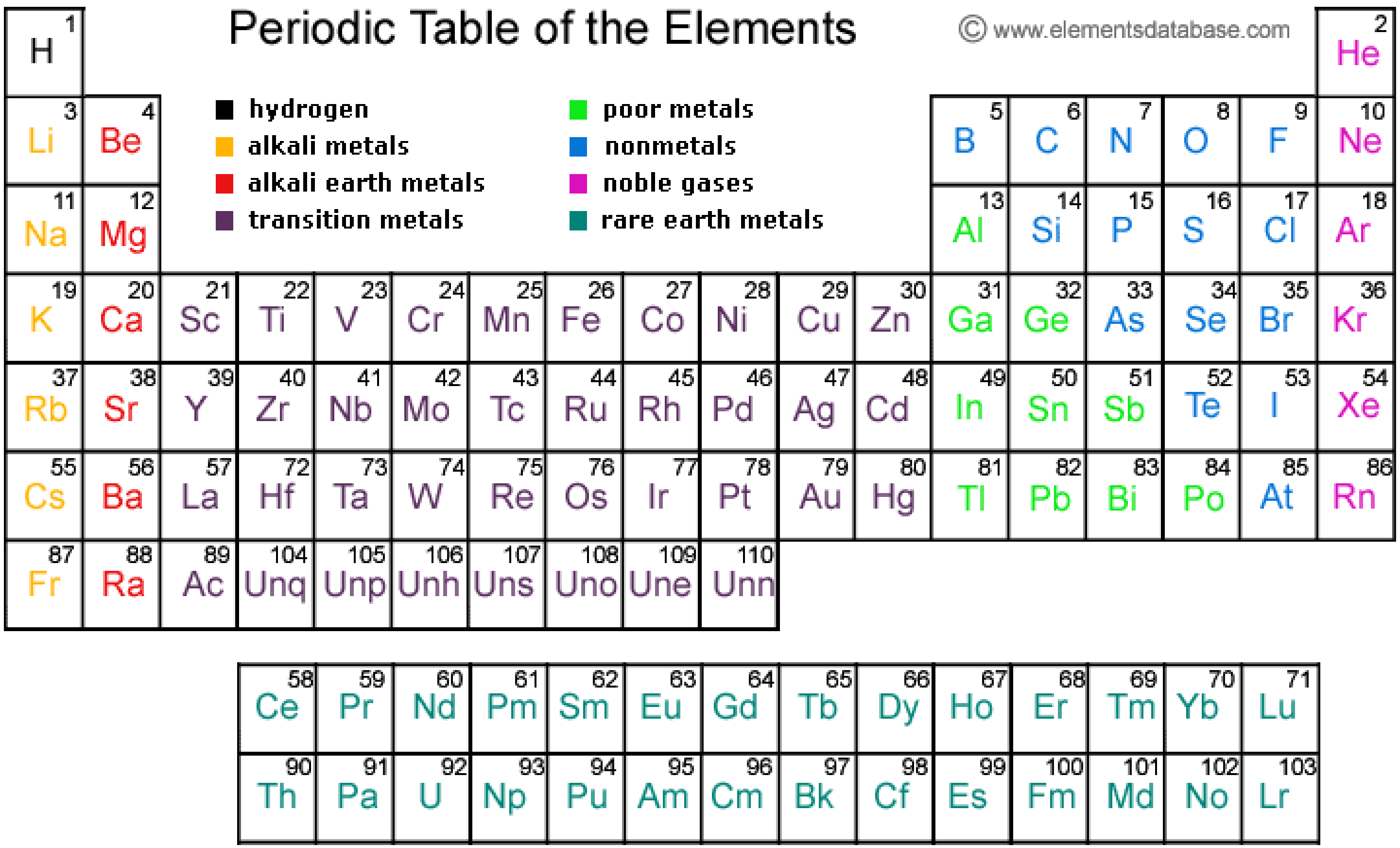
- A doped semiconductor has "impurities," atoms of a different type, scattered throughout the primary semiconductor.
- Example: Phosphorus-doped Silicon



- Replace some silicon atoms (4 valence electrons), with phosphorus atoms (5 valence electrons).
- Result: "left over” electrons.
- 5th phosphorus electron is only loosely bound since it doesn't fit in the filled valence band, but it is not quite in the conduction band.
- Much easier for the electron to jump to the conduction band and move freely.

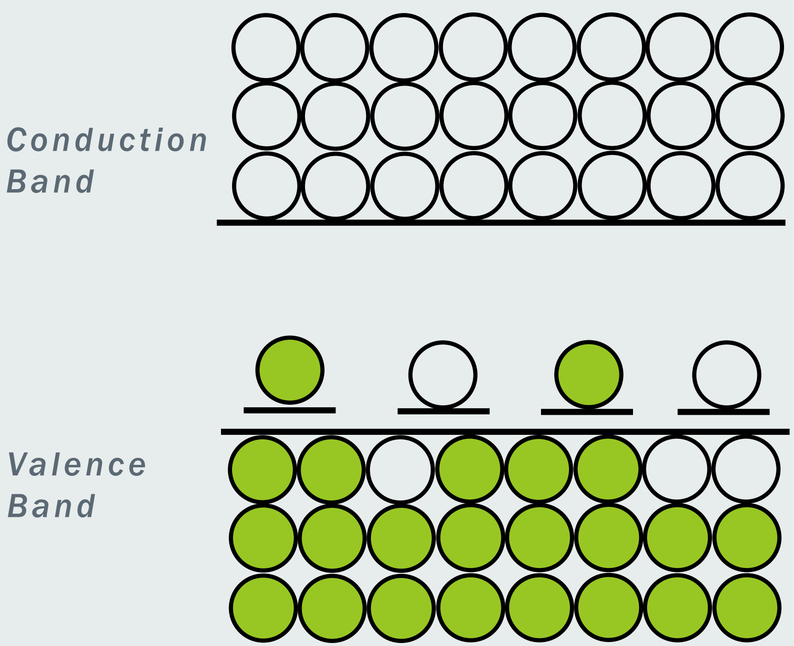
- The material is known as an n-type semiconductor.

SEMICONDUCTOR'S



DOPING (P-TYPE)

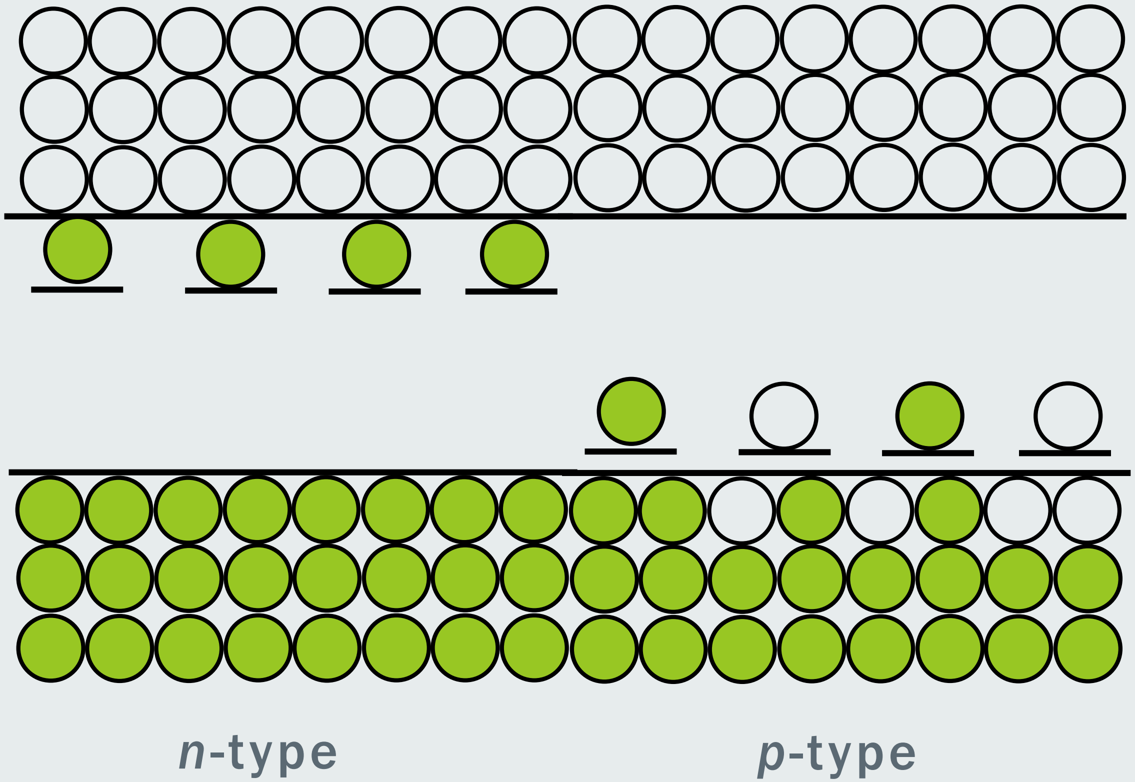
- Example: Gallium-doped Silicon



- Replace some silicon atoms (4 valence electrons), with gallium atoms (3 valence electrons).
- Result: “holes” in the valence band.
- Holes aren’t in the conduction band, not quite in the valence band either.
- Easy for the electrons in valence band to jump to the these holes outside the valence band.
- Holes in valence band can then move freely.

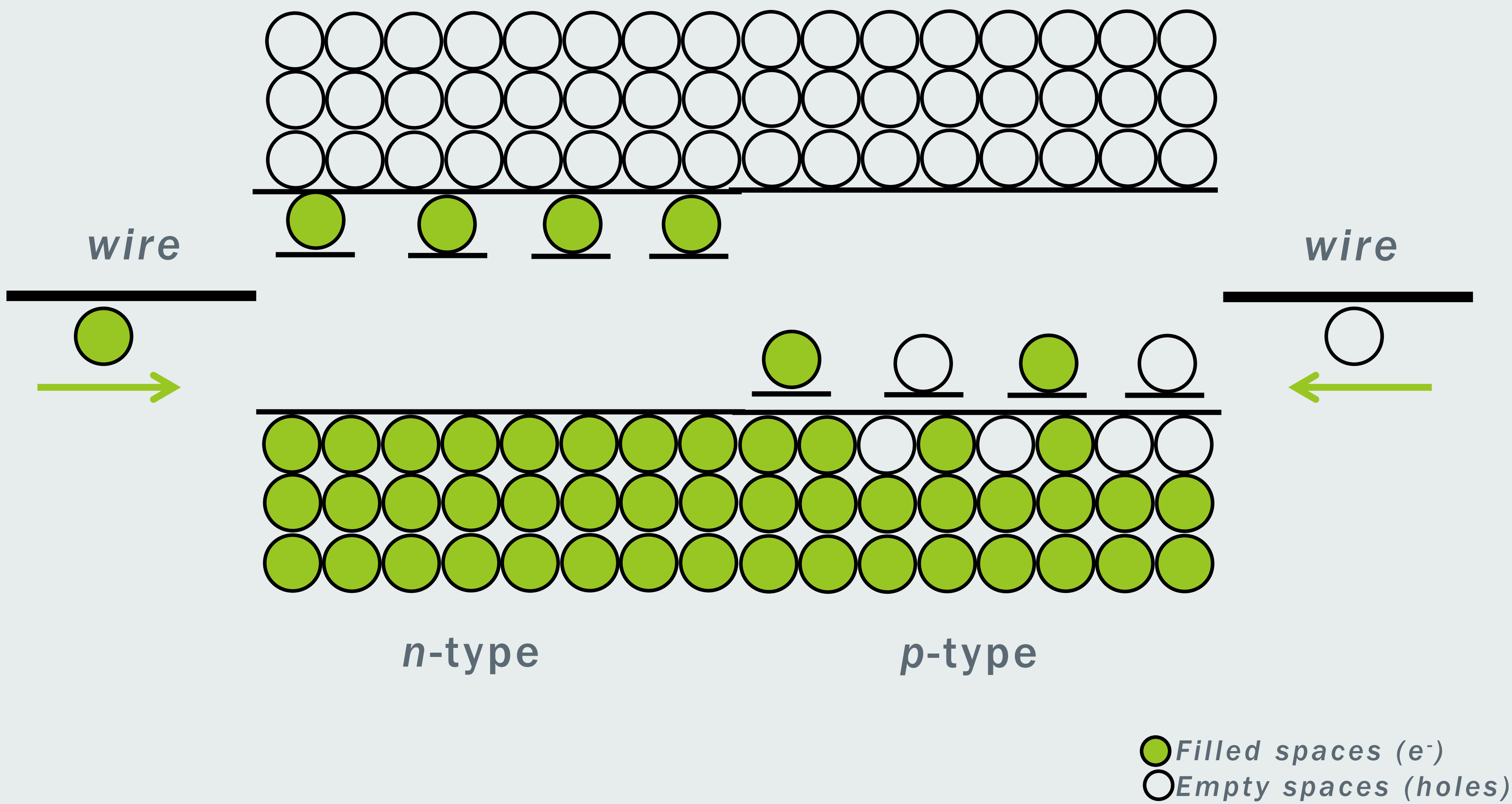
- Gallium-doped silicon is a **p-type semiconductor**

P-N JUNCTIONS



- LEDs are made by placing a piece of *n*-type semiconductor next to *p*-type semiconductor. This is referred to as a P-N junction.

HOW DO P-N JUNCTIONS PRODUCE LIGHT



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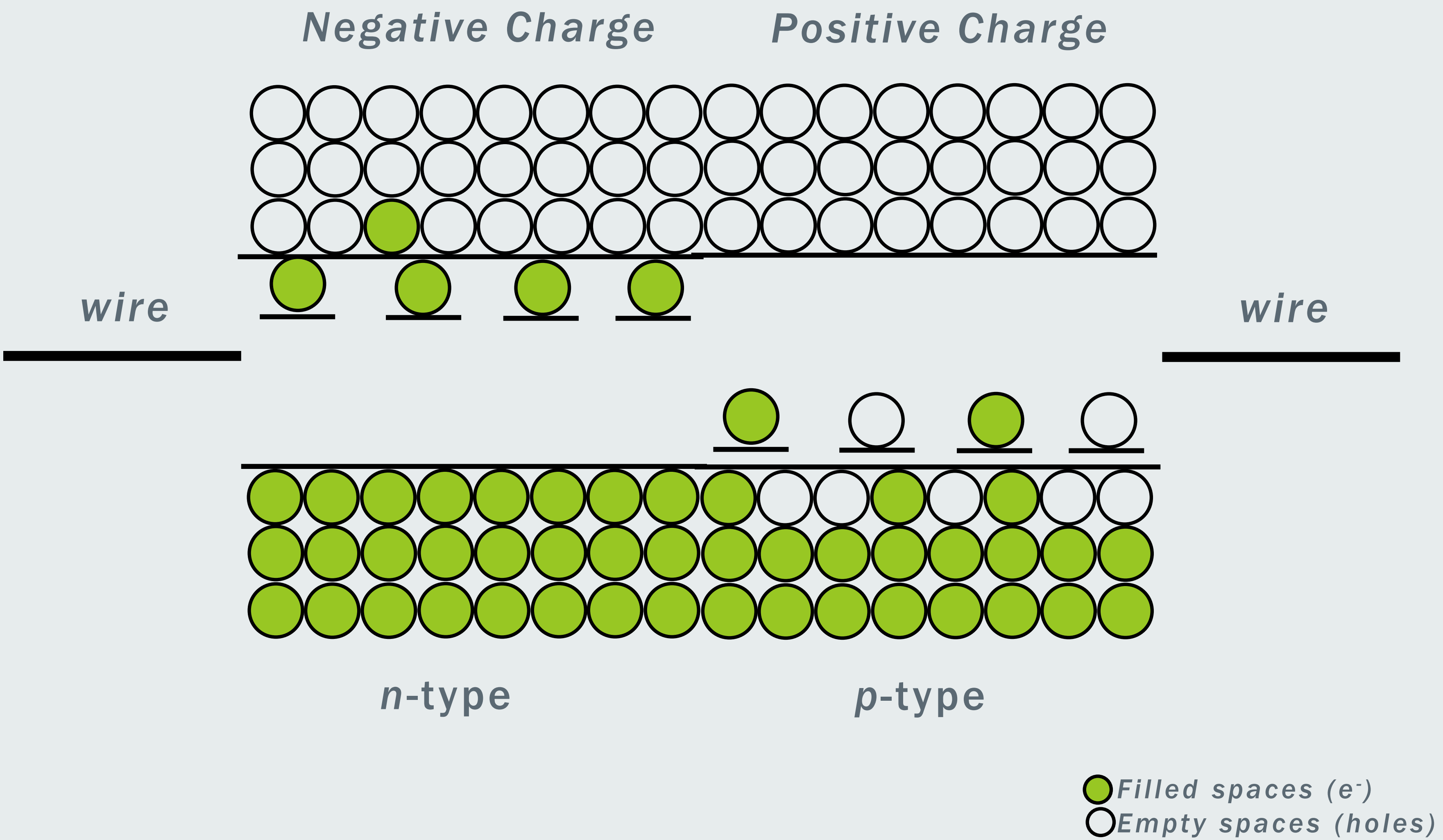

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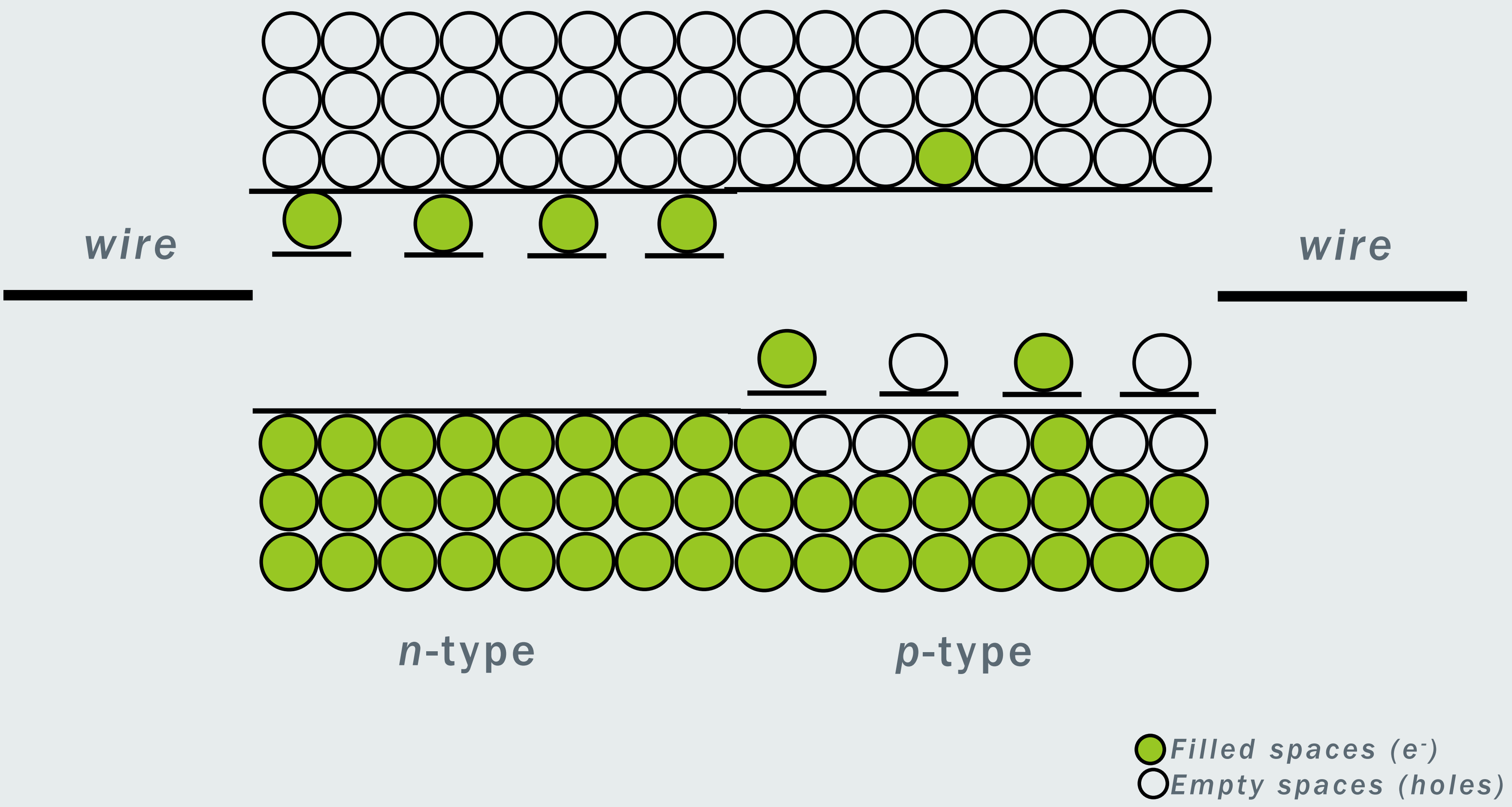
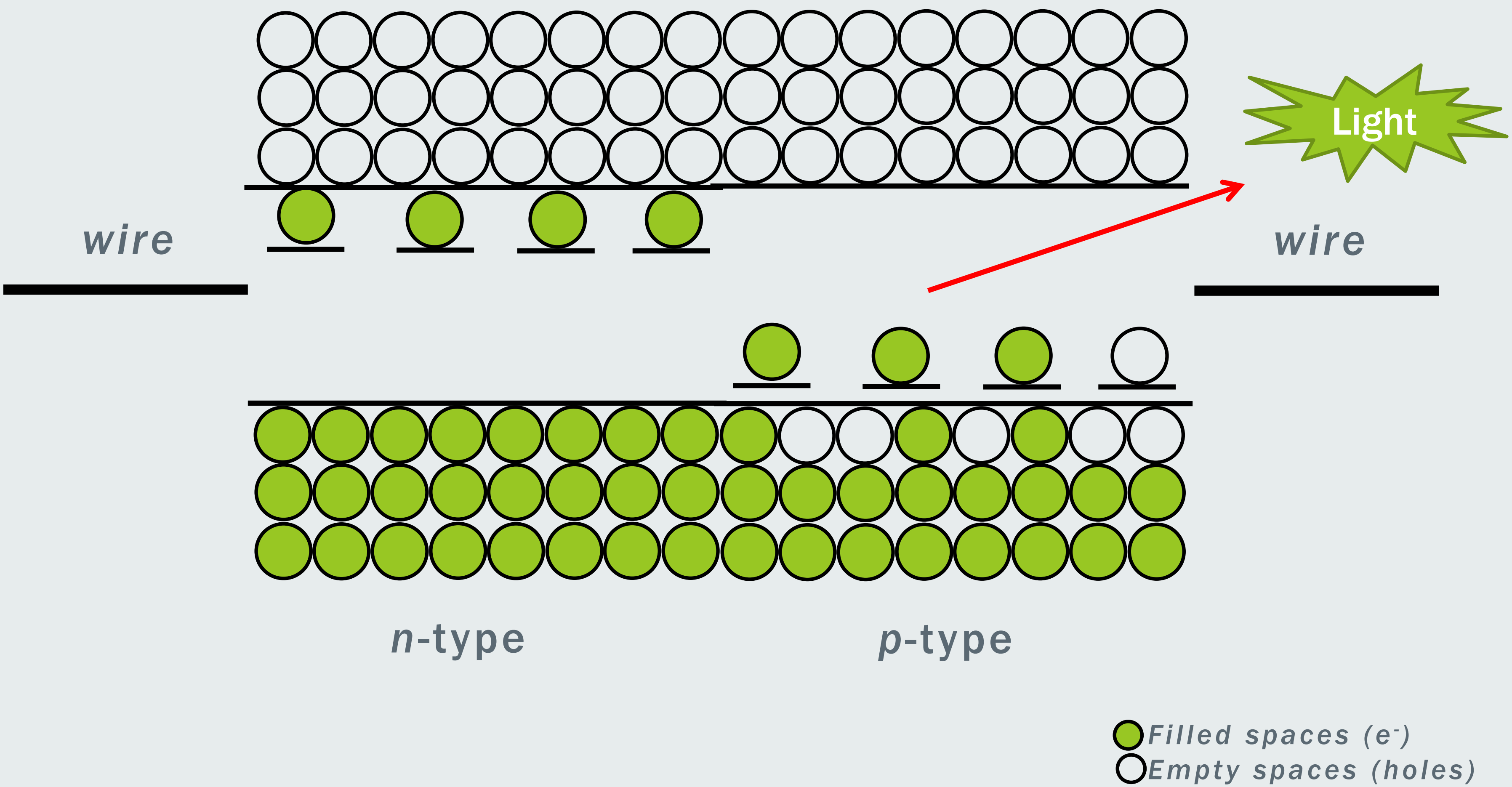
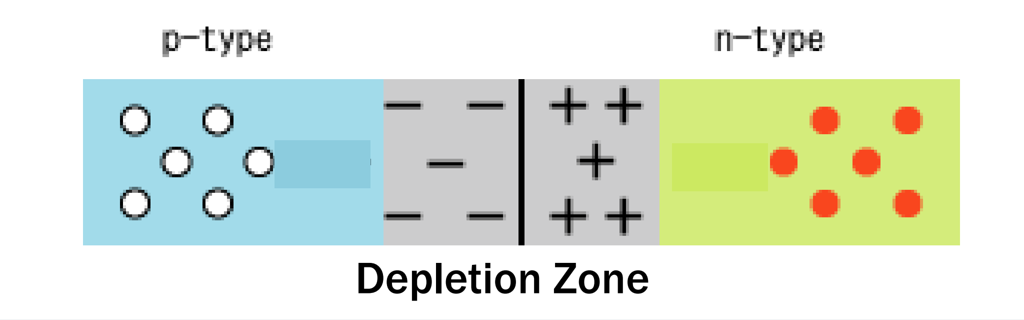


HOW DO P-N JUNCTIONS PRODUCE LIGHT

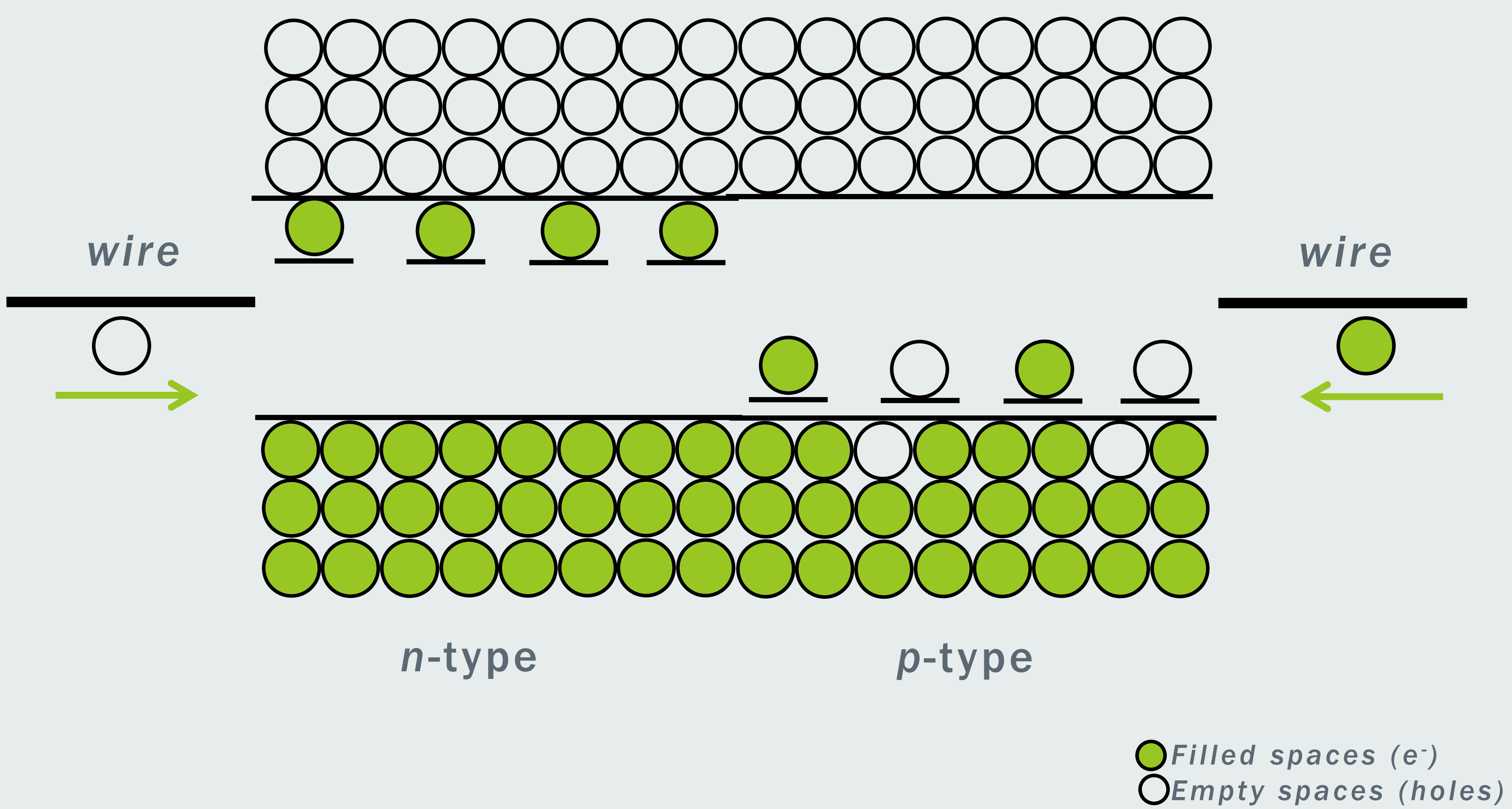


OTHER PROPERTIES OF P-N JUNCTIONS

- At the P-N junction (where the p-type and n-type materials meet) the electron in the *n*-type material combined with the holes in the *p*-type material form a depletion zone. (Similar to what happens when the voltage is applied).
- If no voltage is connected, diffusion of electrons across junction stops because electric field is created (charge is built up).



CAN LEDS RUN IN THE REVERSE DIRECTION



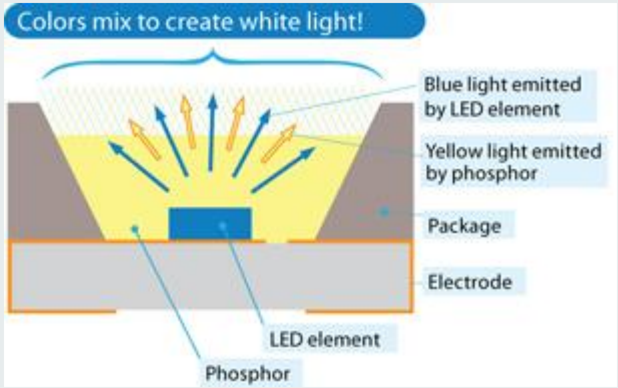
LIGHT EMITTING DIODES

Color	Wavelength	Material LED could be from:
	Infrared	Gallium arsenide (GaAs), or Aluminium gallium arsenide (AlGaAs)
	Red	Aluminium gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP), Aluminium gallium indium phosphide (AlGaInP), or Gallium(III) phosphide (GaP)
	Orange	Gallium arsenide phosphide (GaAsP), Aluminium gallium indium phosphide (AlGaInP), or Gallium(III) phosphide (GaP)
	Yellow	Gallium arsenide phosphide (GaAsP), Aluminium gallium indium phosphide (AlGaInP), or Gallium(III) phosphide(GaP)
	Green	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN), Gallium(III) phosphide (GaP), Aluminium gallium indium phosphide(AlGaInP) or Aluminium gallium phosphide (AlGaP)
	Blue	Zinc selenide (ZnSe), Indium gallium nitride (InGaN), Silicon carbide (SiC) as substrate, or Silicon (Si) as substrate – (under development)
	Violet	Indium gallium nitride (InGaN)
	Purple	Dual blue/red LEDs, blue with red phosphor or white with purple plastic
	Ultraviolet	Diamond (235 nm), Boron nitride (215 nm), Aluminium nitride (AlN) (210 nm), Aluminium gallium nitride (AlGaN), or Aluminium gallium indium nitride (AlGaInN) – (down to 210 nm)
	White	Blue/UV diode with yellow phosphor

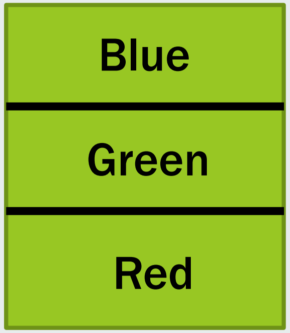
LIGHT EMITTING DIODES

How do we make white LEDs?

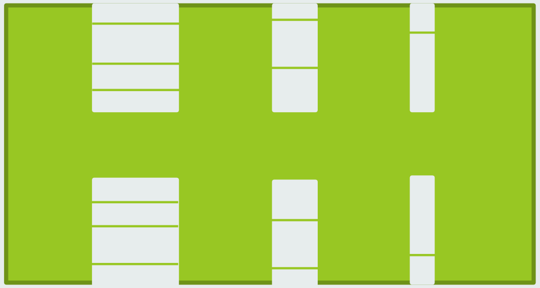
Option 1: GaN (blue)



Option 2:



Option 3: InGaN/GaN



CHOCOLATE BUNNIES

LASER LIGHTING

Currently being used in:

projectors

headlights

Advantages:

White Light

Less energy per lumen

Coherent Light

Colored Light

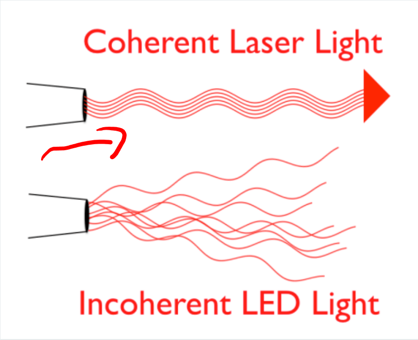
Easier to tune

Turn on/off and modulate faster

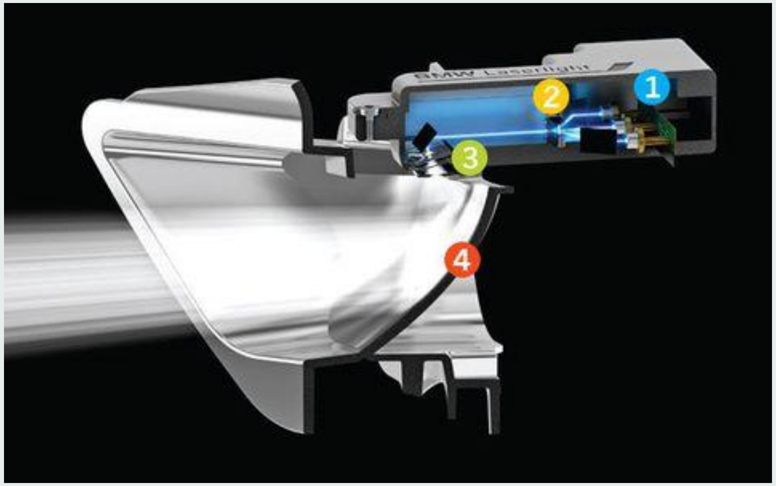
Disadvantages:

Expensive

More complex than LED.



LASER LIGHTING



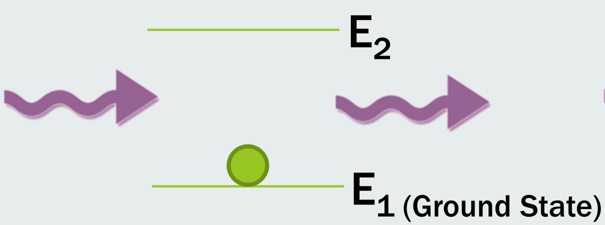
1) Laser diodes create three separate beams of blue laser light.
2) The beams are directed through a prism, merging into a single beam.
3) The concentrated beam passes through a phosphorous lens that yields a diffuse white light, which is safer for human eyes.
4) The white beam bounces off a reflector and past a clear lens onto the road.

LASER

LASER (Light Amplification by the Stimulated Emission of Radiation)

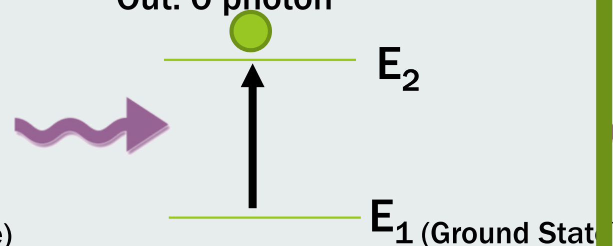
Option 1: No Interaction

In: 1 photon
Out: 1 photon



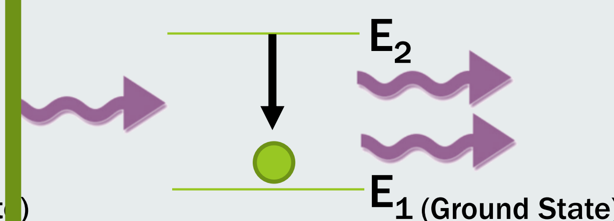
Option 2: Interaction

In: 1 photon
Out: 0 photon

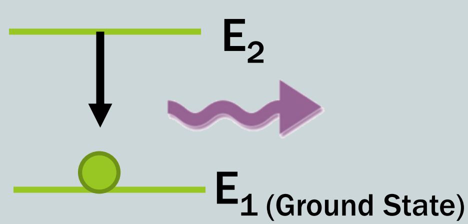


Option 3: Interaction

In: 1 photon
Out: 2 photon



Review: Spontaneous Emission

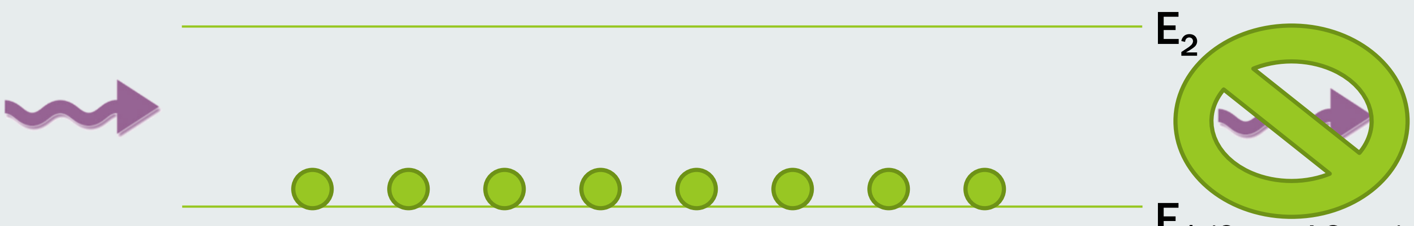


This is called Stimulated Emission and is what is Needed for Lasers

Option	In	Atom	Out
1	1	Either	1
2	1	Ground	0
3	1	Excited	2

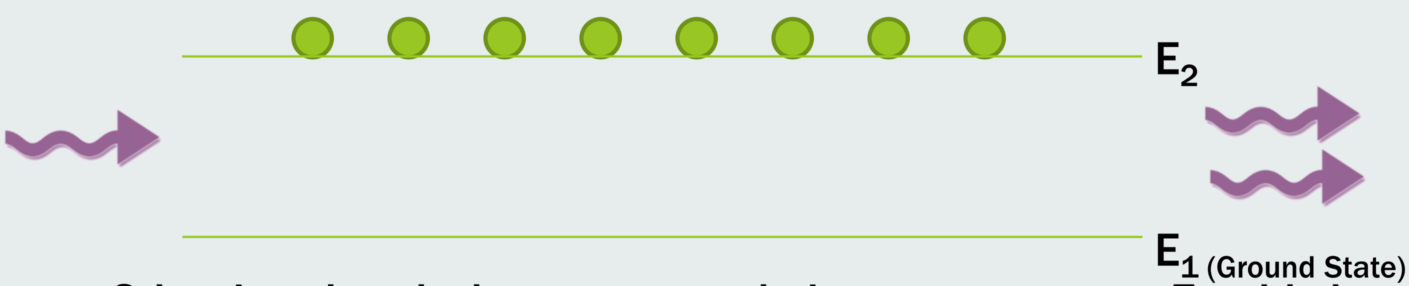
LASER

What happens?



Electron promoted to E_2 level no energy out

What happens?



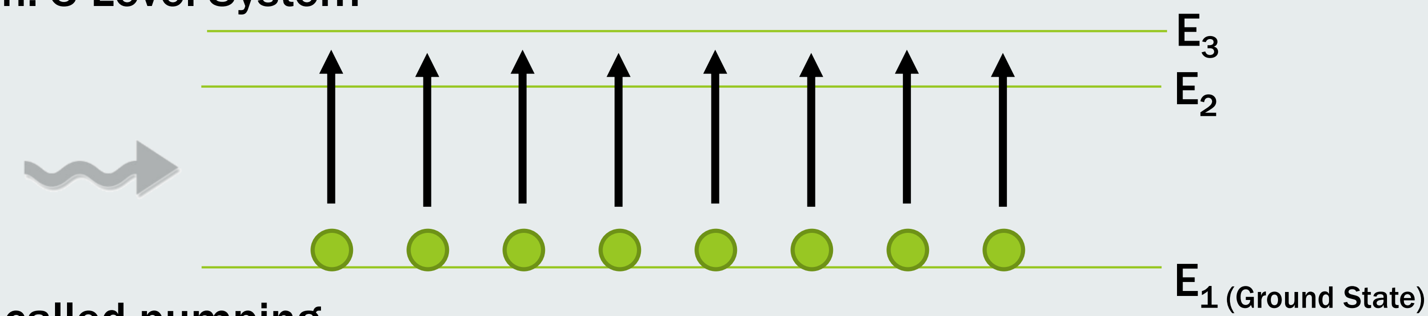
Stimulated emission occurs and electrons return to E_1 this is called a population inversion.

For lasers need more electrons in E_2 than in E_1 levels

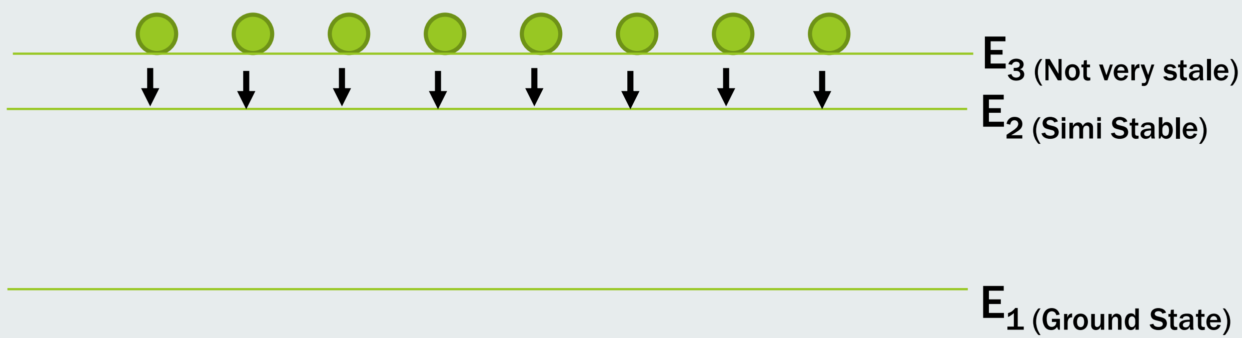
LASER

Problem: Number of electrons at E1 and E2 tend to be equal. Then the 3 photons in and 3 out.

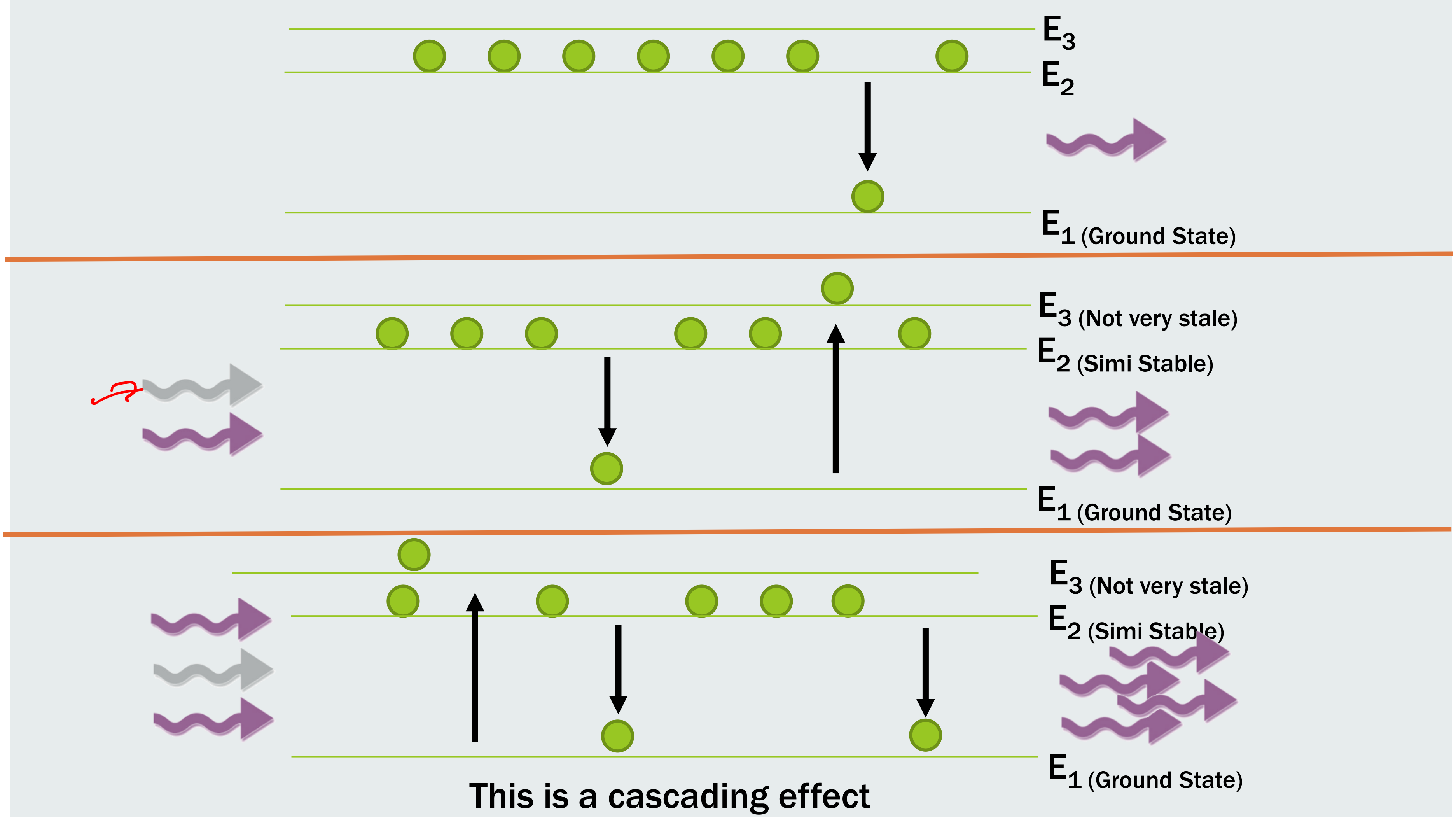
Solution: 3 Level System



This is called pumping



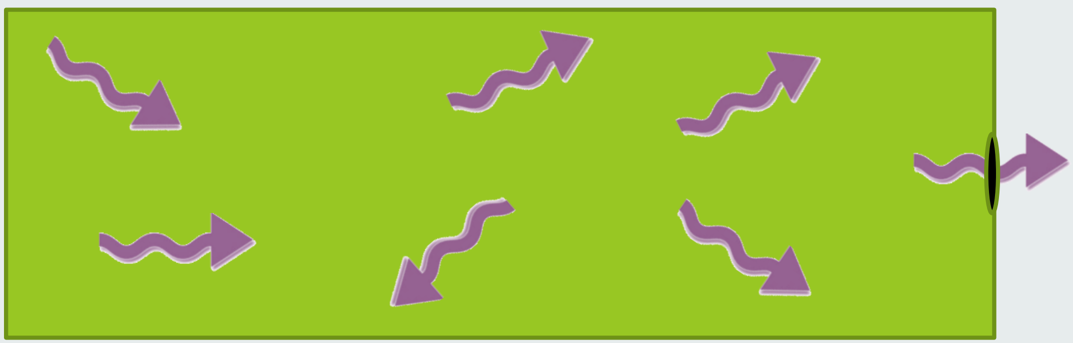
LASER



E_3
E_2
E_1 (Ground State)
E_3 (Not very stale)
E_2 (Simi Stable)
E_1 (Ground State)
E_3 (Not very stale)
E_2 (Simi Stable)
E_1 (Ground State)
This is a cascading effect

LASER

Laser Cavity



Only photons traveling correct direction will be allowed to exit the laser which causes the light to be coherent.

LASER DIODES

LASER can be made from the same materials as LEDs.

The only difference is they polish the materials so that they can get stimulated emission