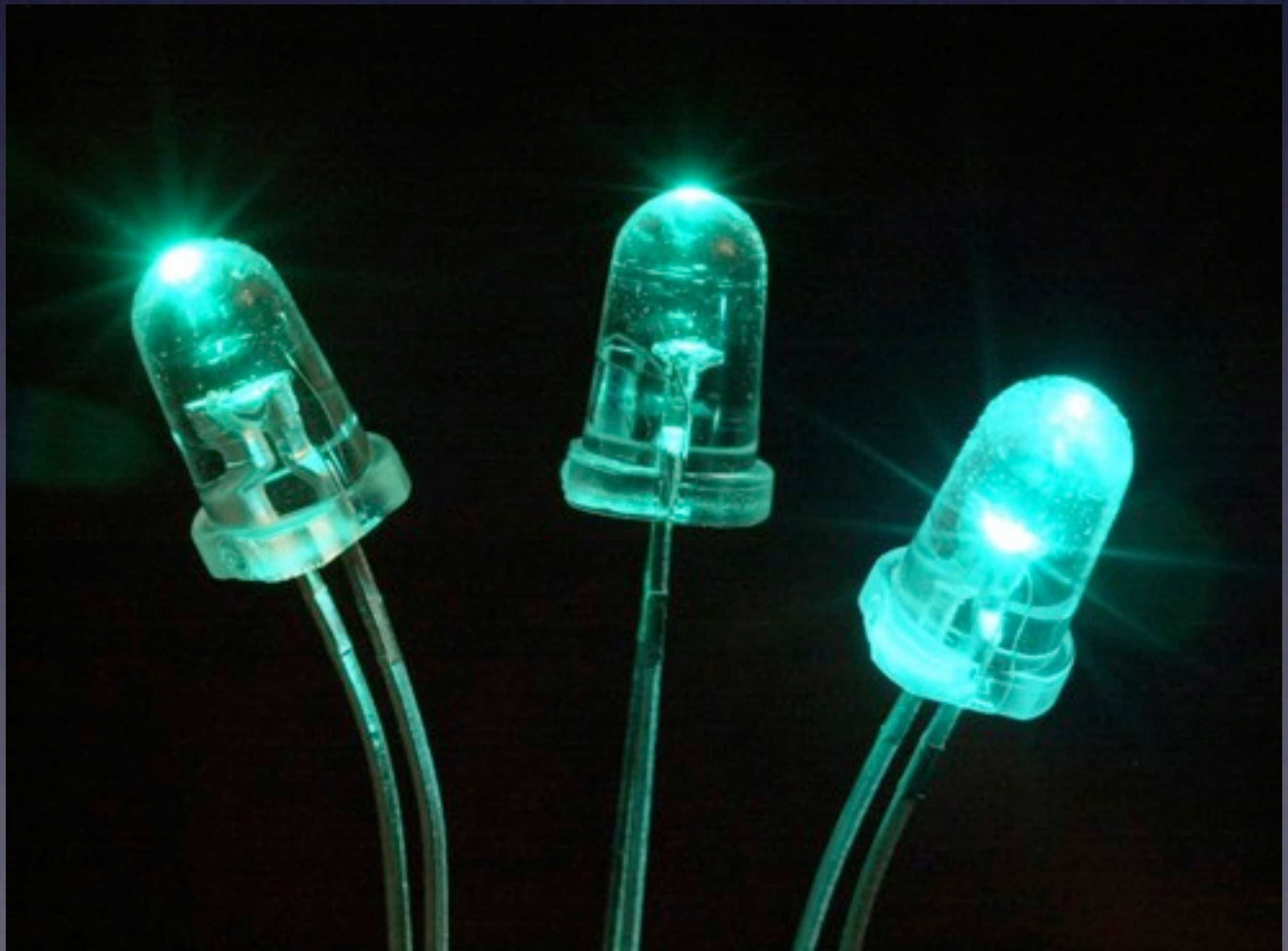
More than you ever wanted to know about LEDs



LED:
Light Emitting Diode

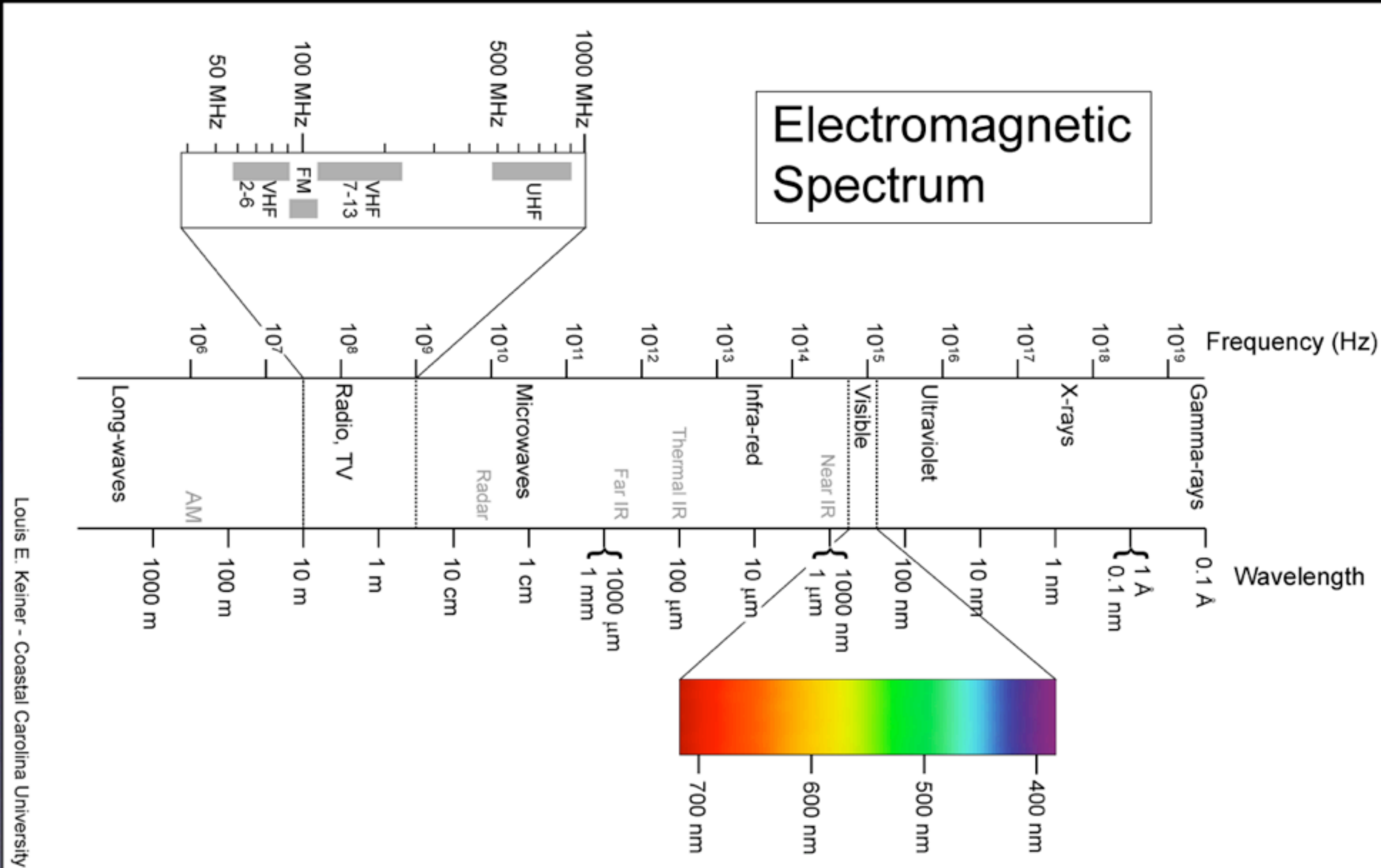
- What is light?
- What is a diode?
- How does a diode emit light?

What is light?

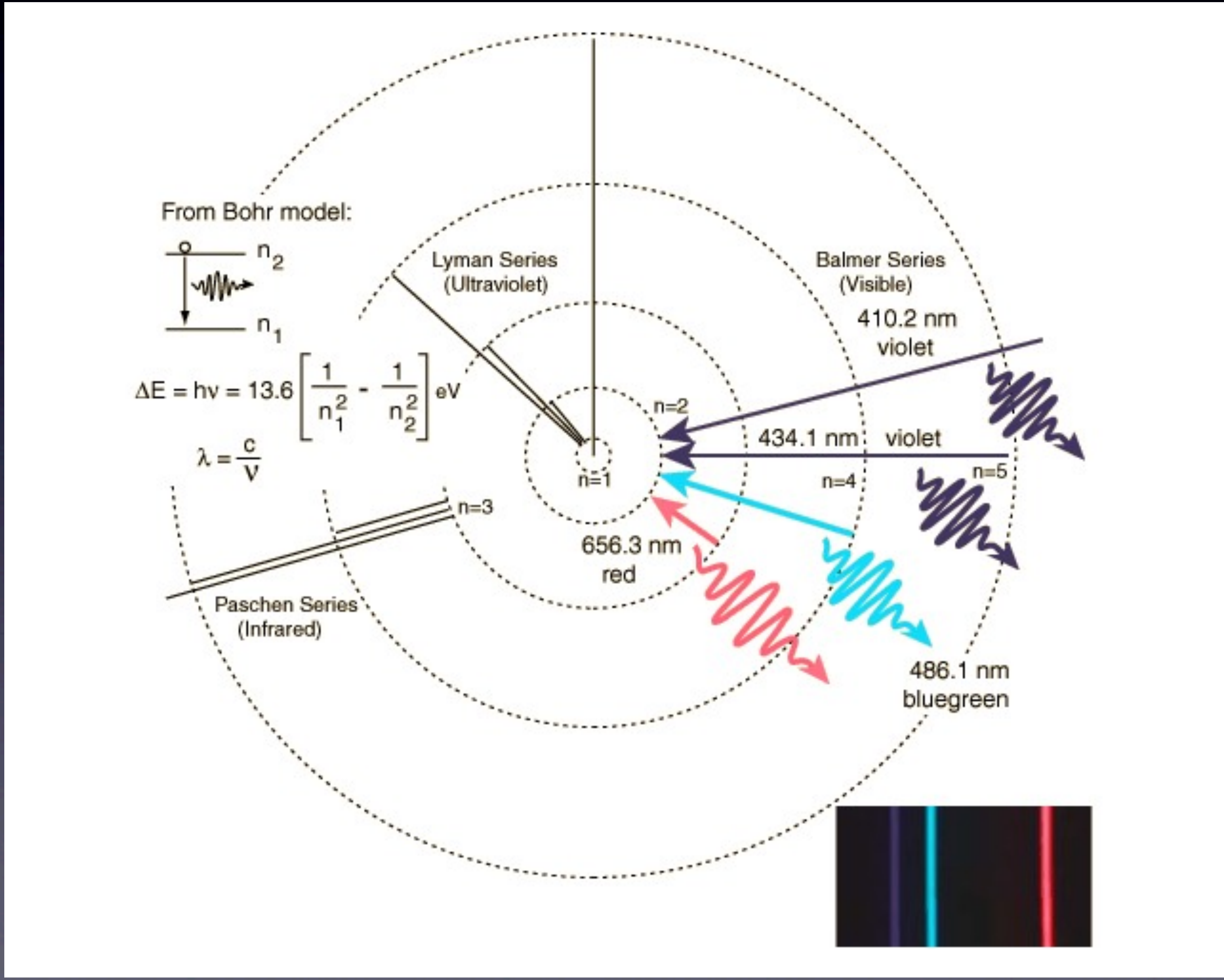
- 1921 Nobel prize in physics to one A. Einstein,

  "*On a Heuristic Viewpoint Concerning the Production and Transformation of Light*"

- Quanta of light are called "photons"
- Photons are electromagnetic radiation
- Photons have different levels of energy; level of energy equals electromagnetic frequency


Electromagnetic Spectrum
50 MHz
100 MHz
500 MHz
1000 MHz
VHF 2-6
FM
VHF 7-13
UHF
Frequency (Hz)
10^6
10^7
10^8
10^9
10^10
10^11
10^12
10^13
10^14
10^15
10^16
10^17
10^18
10^19
Long-waves
AM
Radio, TV
Microwaves
Radar
Far IR
Thermal IR
Infra-red
Near IR
Visible
Ultraviolet
X-rays
Gamma-rays
Wavelength
1000 m
100 m
10 m
1 m
10 cm
1 cm
1000 µm
1 mm
100 µm
10 µm
1000 nm
1 µm
100 nm
10 nm
1 nm
1 Å
0.1 nm
0.1 Å
700 nm
600 nm
500 nm
400 nm
Louis E. Keiner - Coastal Carolina University

Photons and electron energy levels



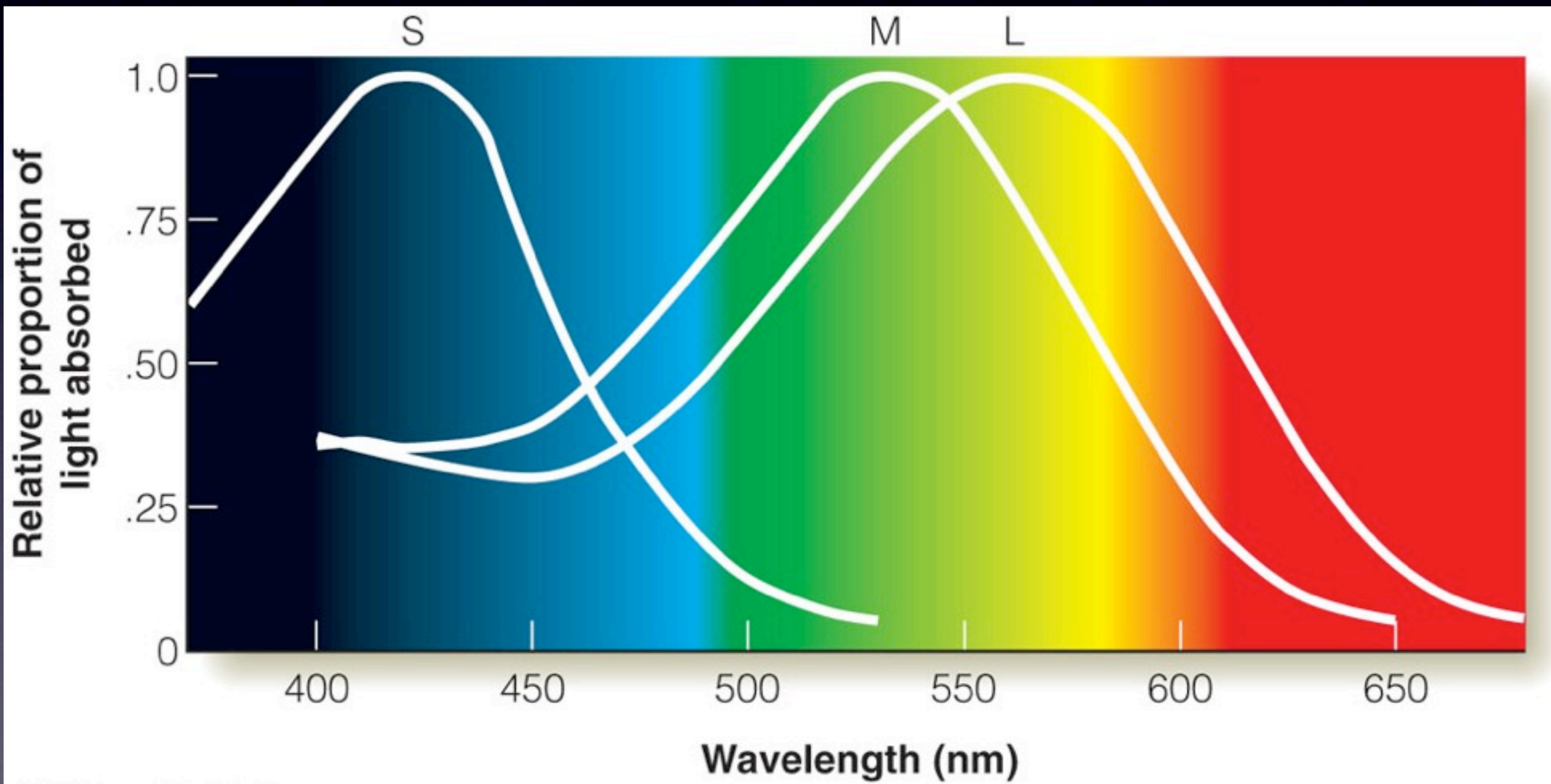
Light and humans

- Humans are generally equipped with a pair of specialized photon-detecting organs called “eyes”
- Eyes contain cells which generate electrical signals when struck by photons (Einstein’s photoelectric effect in action)
- Brain integrates sensations of photon impingement into a perception of light

Components of light

- Brightness: rate at which photons strike photoreceptors
- Hue: which photoreceptors respond most strongly to the arriving wavelengths
- Saturation: how divergent are the responses of the different photoreceptors

Absorption spectrum



Color is an illusion

- We cannot perceive EM wavelengths directly
- Brain creates sensation of a single color based on sampling of differently-sensitive photoreceptors
- We can exploit this illusion... more later

What is a diode?

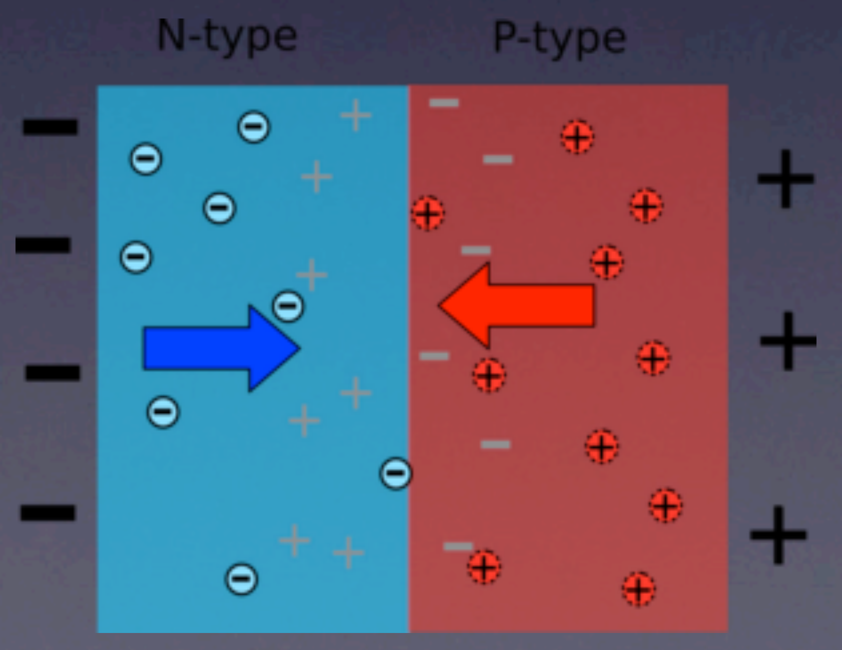
- Like a ratchet, for electricity
- Simplest type of semiconductor
- Junction of N-type and P-type silicon layers

Semiconductors

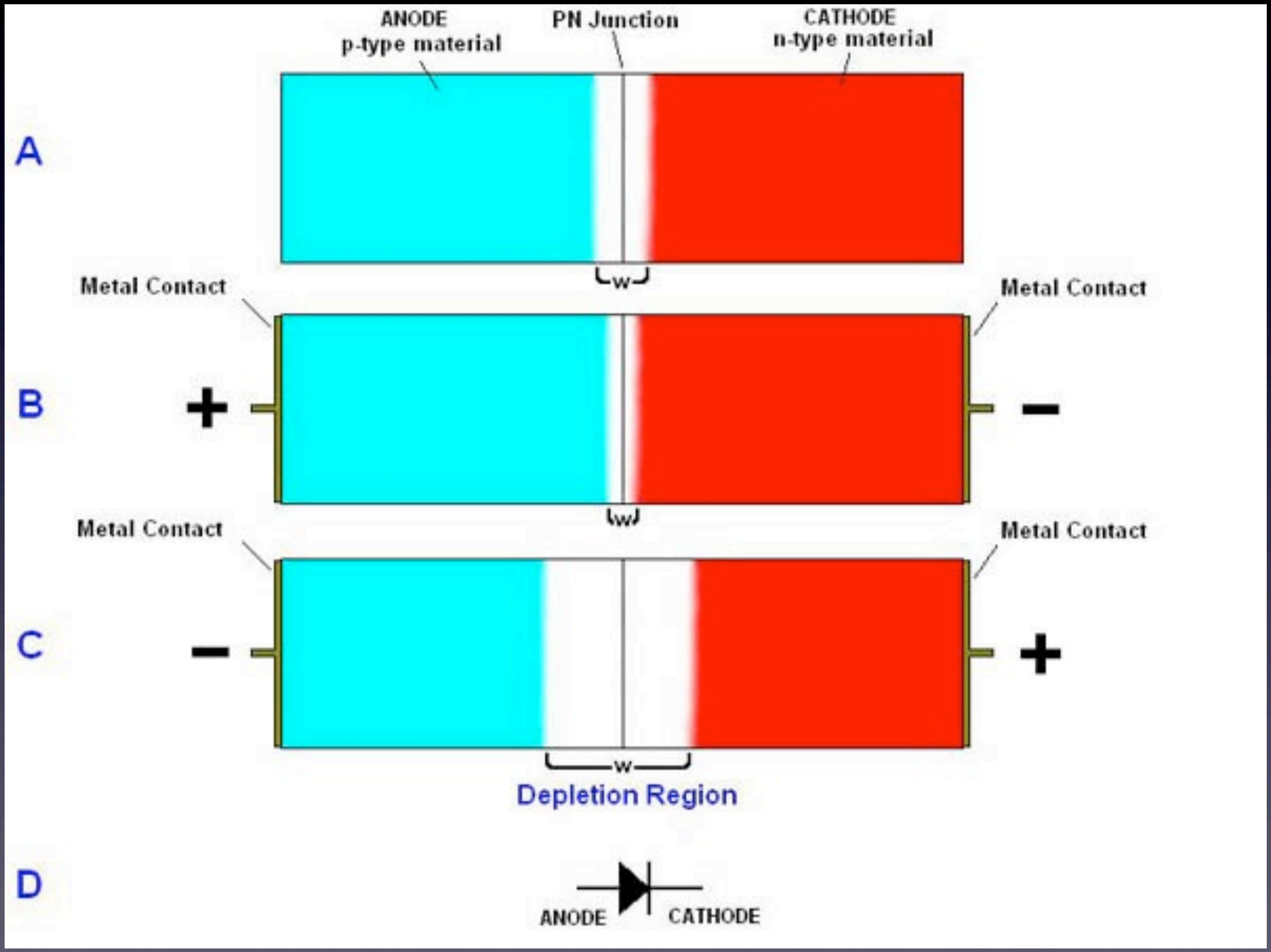
- Silicon: non-conductor, aka “insulator”
- Silicon mixed with phosphorus or arsenic: surplus electrons, negative charge, “N-type” conductor
- Silicon mixed with boron or gallium: missing electrons, positive charge, “P-type” conductor

Layered silicon

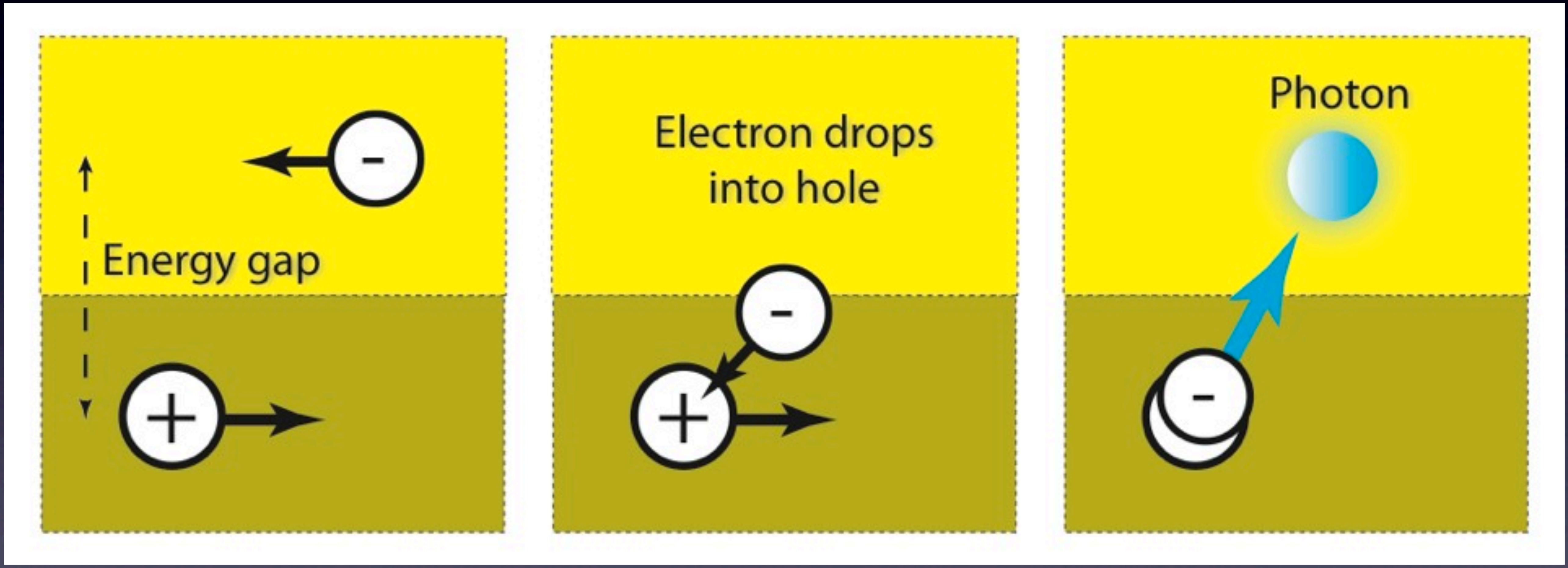
- A semiconductor is a sandwich of both types
- Surplus electrons in the N-type layer migrate to the holes in the P-type layer
- Non-conducting zone between the layers



Electrical ratchet

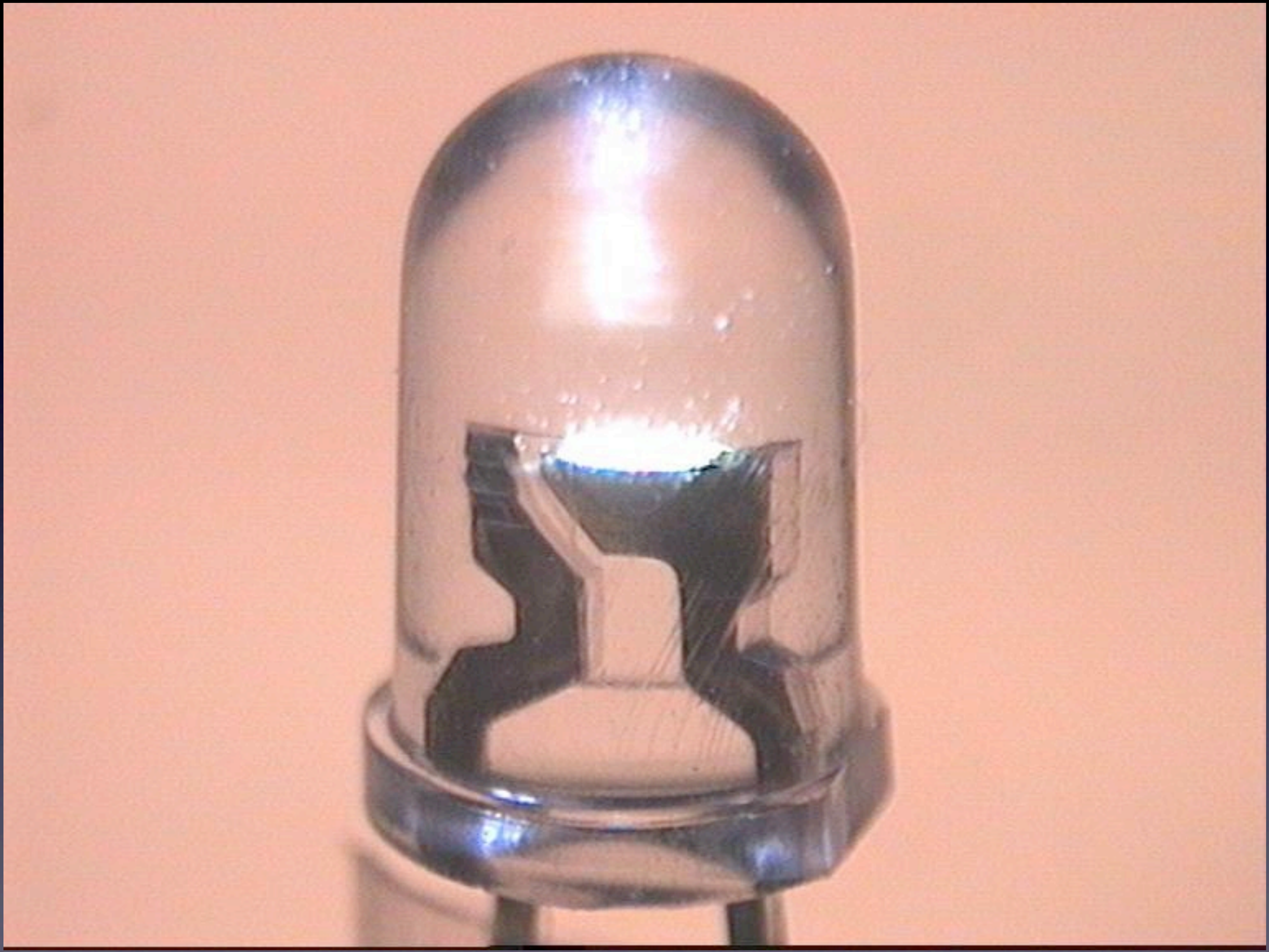


Emitting light



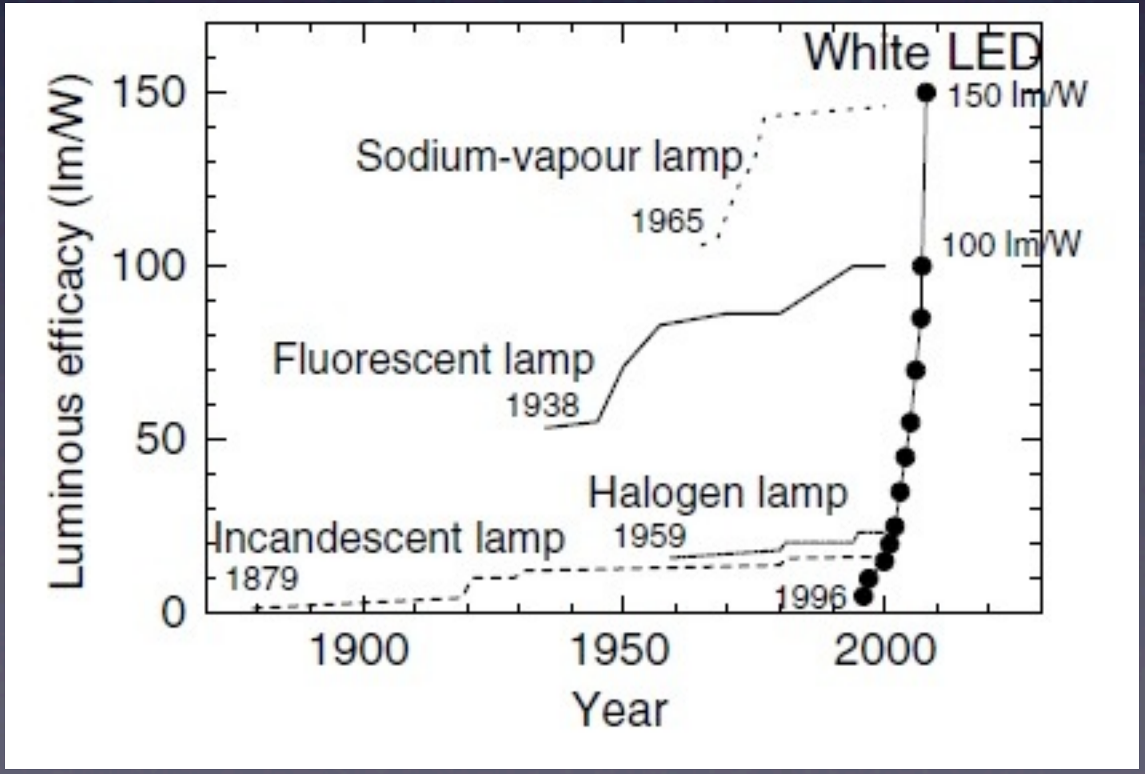
Making it visible

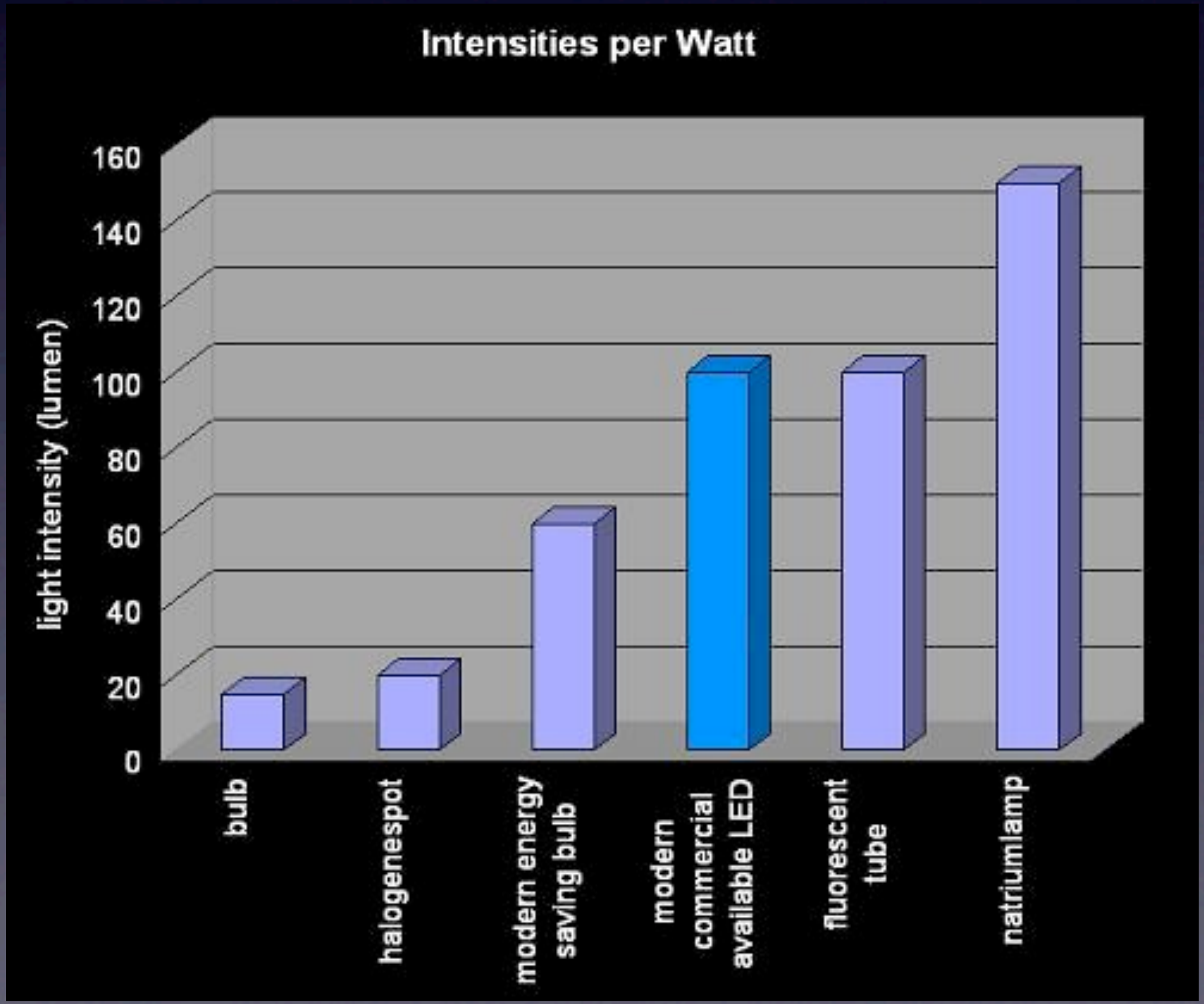
- All diodes emit photons
- The photons all come from the semiconductor’s junction layer
- Most absorbed as heat!
- LED is a diode which is transparent to the photons it emits



Why are LEDs cool?

- Efficiency: lumens per watt
- Highest efficiency at low voltage
- Efficiency is climbing fast



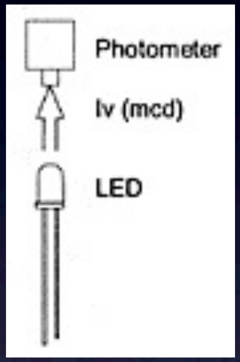


The Future

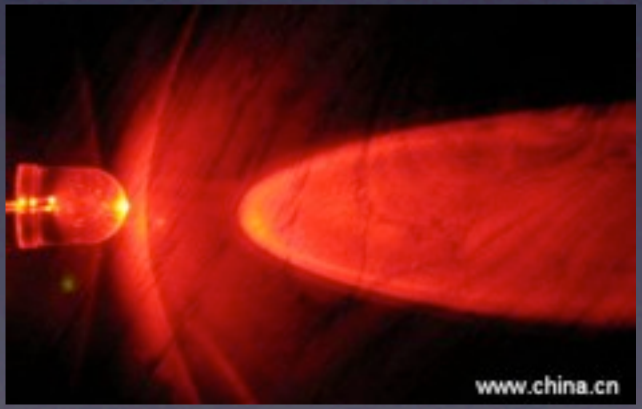
- LEDs universal in low-voltage applications
- LEDs crush incandescents and will match CFLs in terms of lumens/watt
- Not yet cost-competitive for mid-to-high brightness applications
- Solid state means long life: low long-term operating costs

Calculating efficiency

- LEDs rated for amperage and voltage; light production is measured in millicandelas



- lumens = $2\pi(1-\cos(\text{angle}/2))$*candelas
- watts = amps * volts
- efficiency = lumens / watts

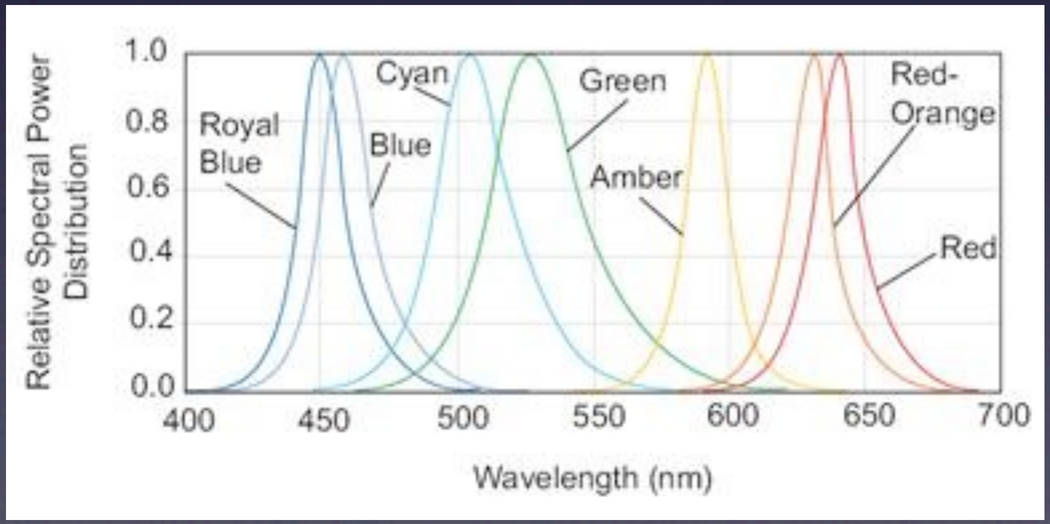


Typical LED brightness

- Narrower beam provides more brightness
- “superbright”, “ultrabright” all subjective
- Typical LEDs have 20° beam width, produce single-digit candelas
- More lumens means more current means lower resistance: use better chemistry or wire more LEDs in parallel

What's not so cool?

- Limited high end: have to use lots of chips
- Expensive: competing with decades of production
- Limited color range
- Less familiar!



Color is chemistry

- GaAsP / GaAs: 660 nm (red)
- InGaAlP: 600 nm (orange)
- GaAsP / GaP: 590 nm (yellow)
- GaAlP: 565 nm (green)
- InGaN: 470 nm (blue)
- Only about a dozen formulas known

What is “white”?

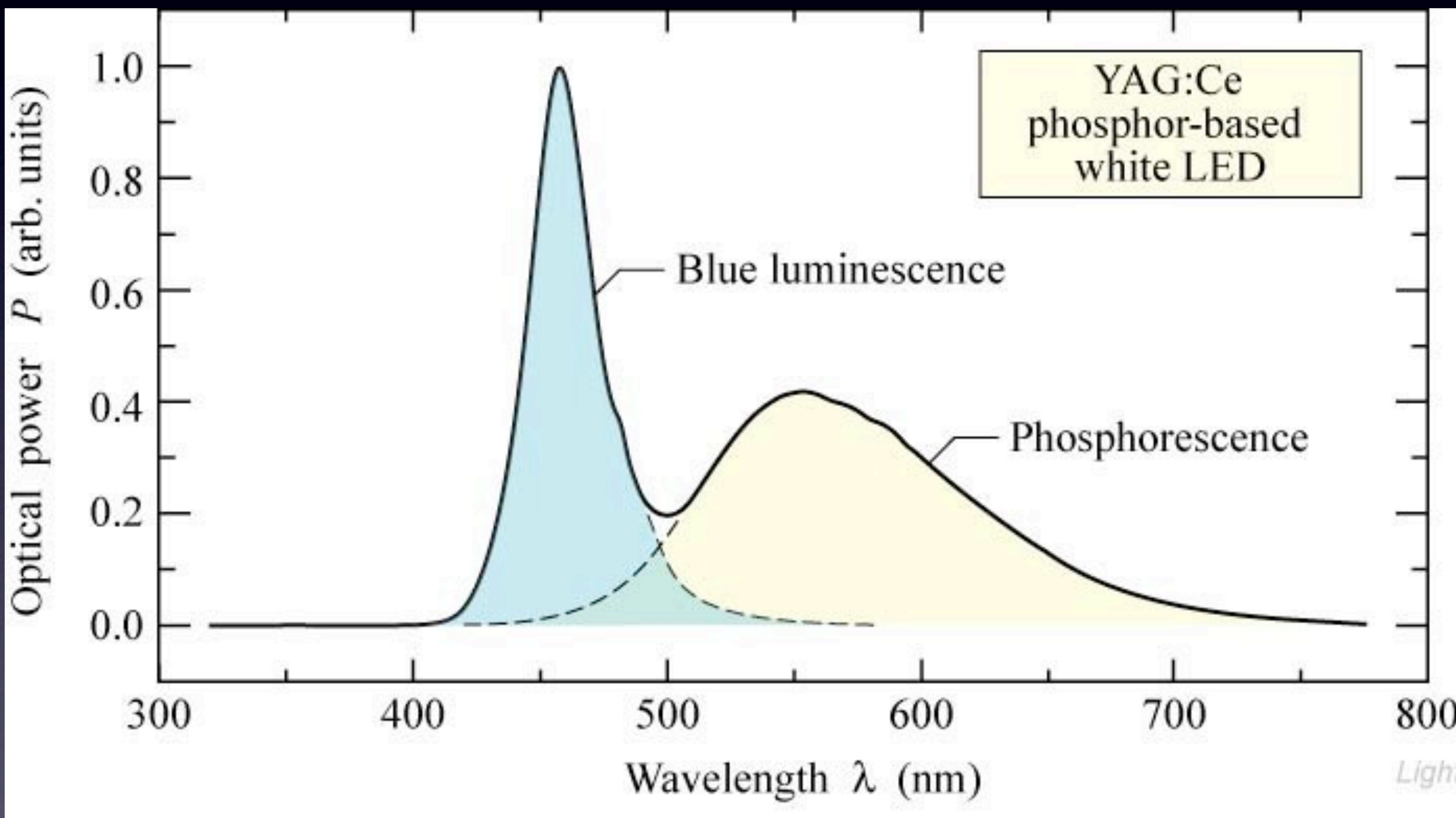
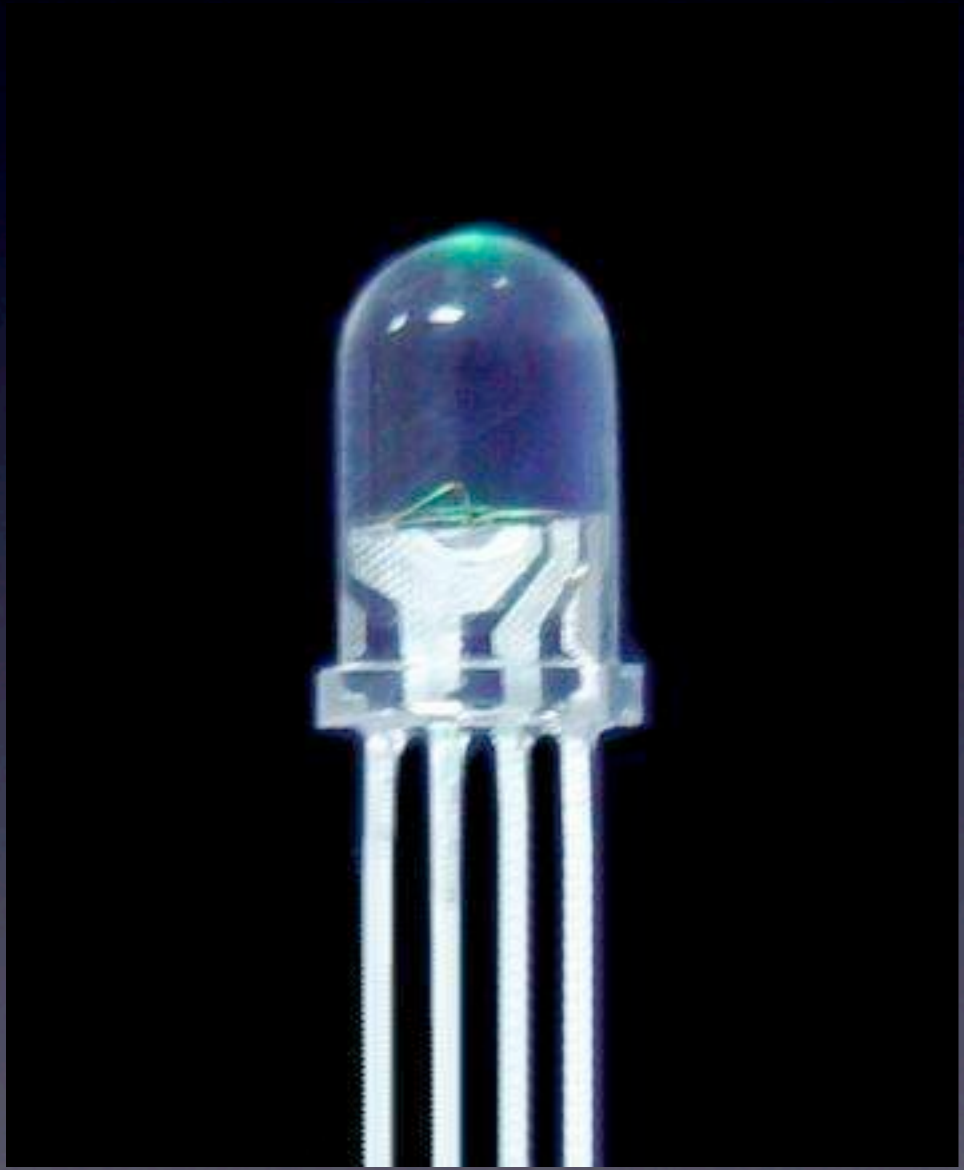


Fig. 21.8. Emission spectrum of a phophor-based white LED manufactured by Nichia Corporation (Anan, Tokushima, Japan).

E. F. Schubert
Light-Emitting Diodes (Cambridge Univ. Press)
www.LightEmittingDiodes.org

Color mixing

- RGB LED is just three LEDs in one package
- 2.0V red, 3.2V green and blue
- Both common-positive and common-negative types exist



Electricity in a nutshell

- Atoms prefer a fixed number of electrons
- Atoms with surplus electrons tend to shed them; atoms with a deficit attract them
- Strength of attraction proportional to size of charge difference
- When strength of attraction exceeds resistance of medium, current flows

Basic units

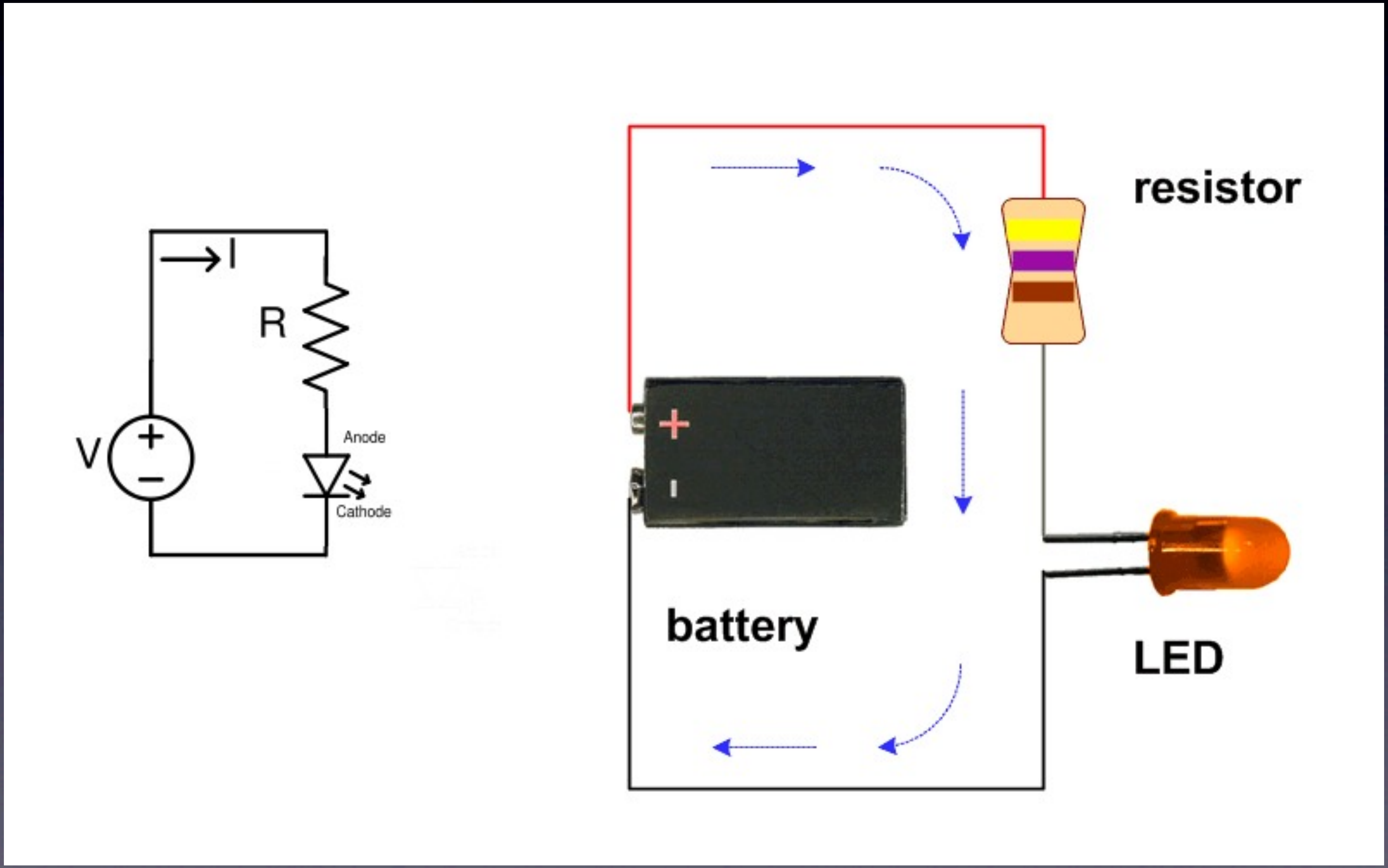
- Pressure (volts): magnitude of the difference in charge between two points
- Resistance (ohms): friction impeding flow of electrons along some connection
- Current (amps): rate of electron flow per second past some point

Basic math: Ohm's law

- Defines the relationship between current, pressure, and resistance
- Current = Pressure / Resistance

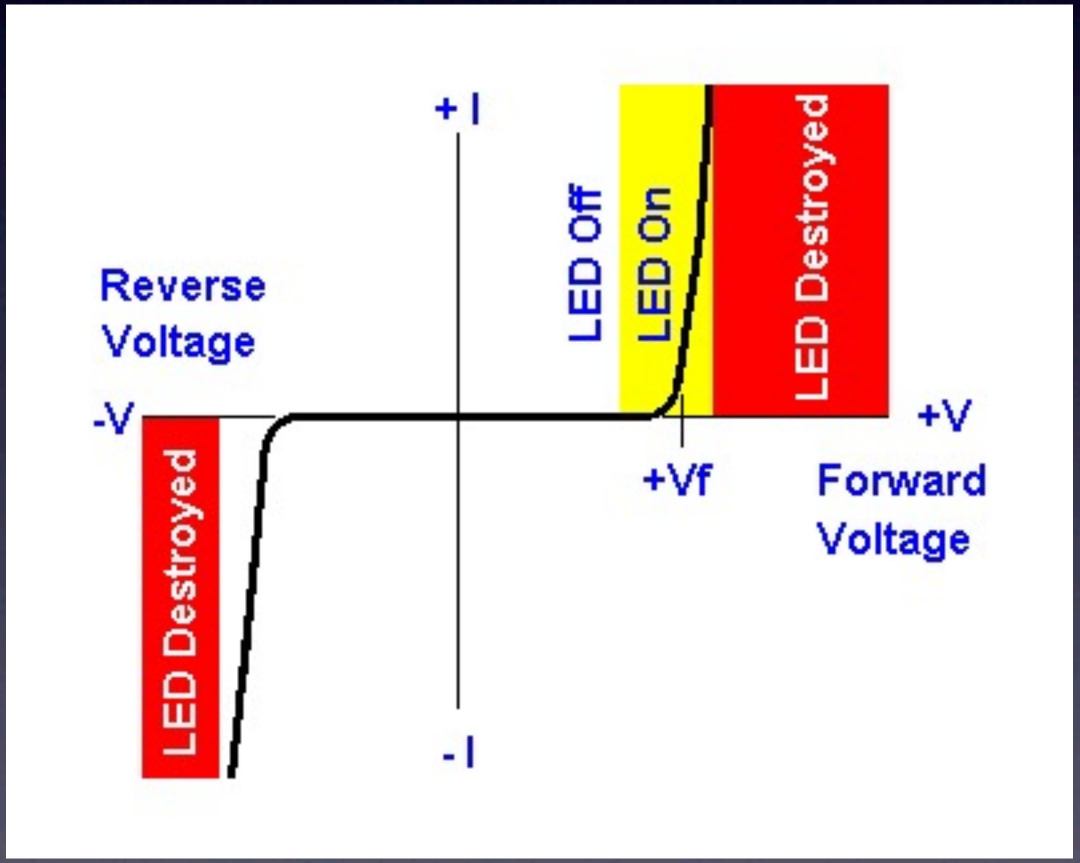
  Amps = Volts / Ohms
- Source of voltage and a circuit to flow through creates current; amount of voltage and resistance of the circuit determine rate of current flow.

Light up an LED!



Current-limiting resistor

- LEDs have a steep conduction curve
- Current proportional to ratio of voltage and resistance
- Solution: add resistance to reduce current



Calculating resistance

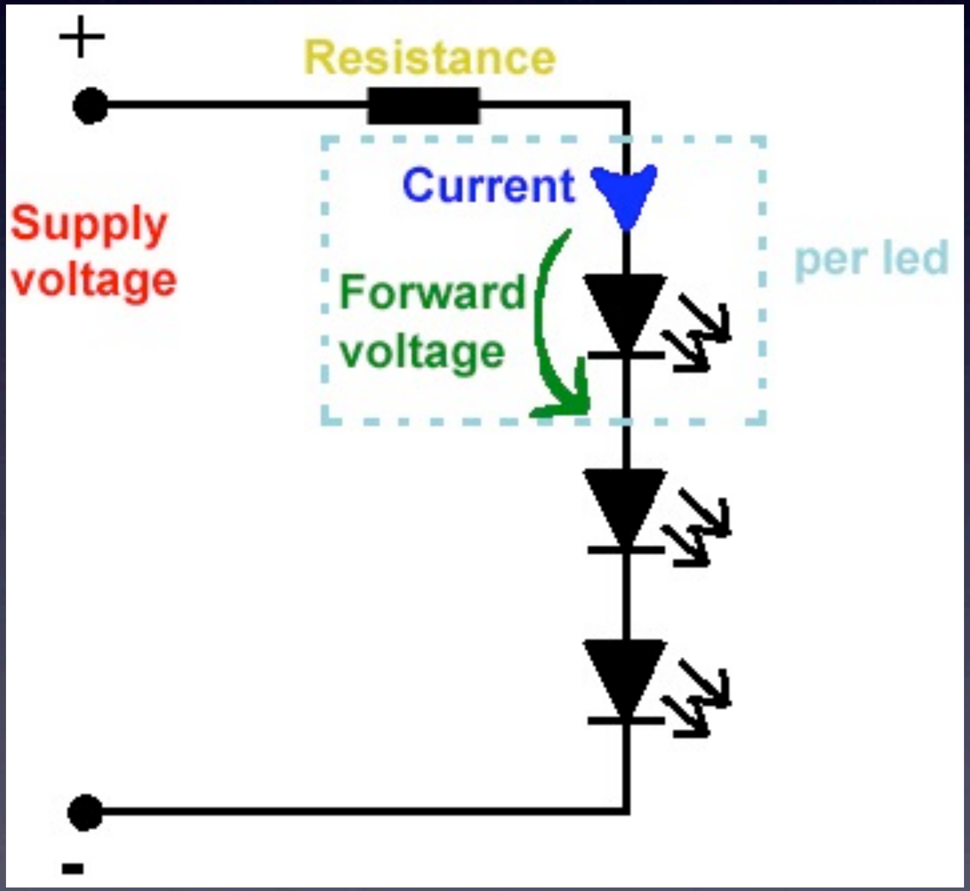
- Resistance = (Supply voltage - LED voltage) / LED current
- LED voltage is determined by chemistry: 1.9-2.1 for AlGaInP, 3.1-3.5 for InGaAn, etc.
- Current determined by resistance of semiconductor; limited ability to shed heat
- Common LEDs are designed for 20 mA

Common examples

- Red/orange/yellow LED, 9V battery: (9V - 2V) / 20 mA = 350 ohms
- Blue LED, 9V battery: (9V - 3.3V) / 20 mA = 285 ohms =~ 330 ohms
- Red LED, two AA batteries: (3V - 2V) / 20 mA = 50 ohms =~ 56 ohms
- http://led.linear1.org/

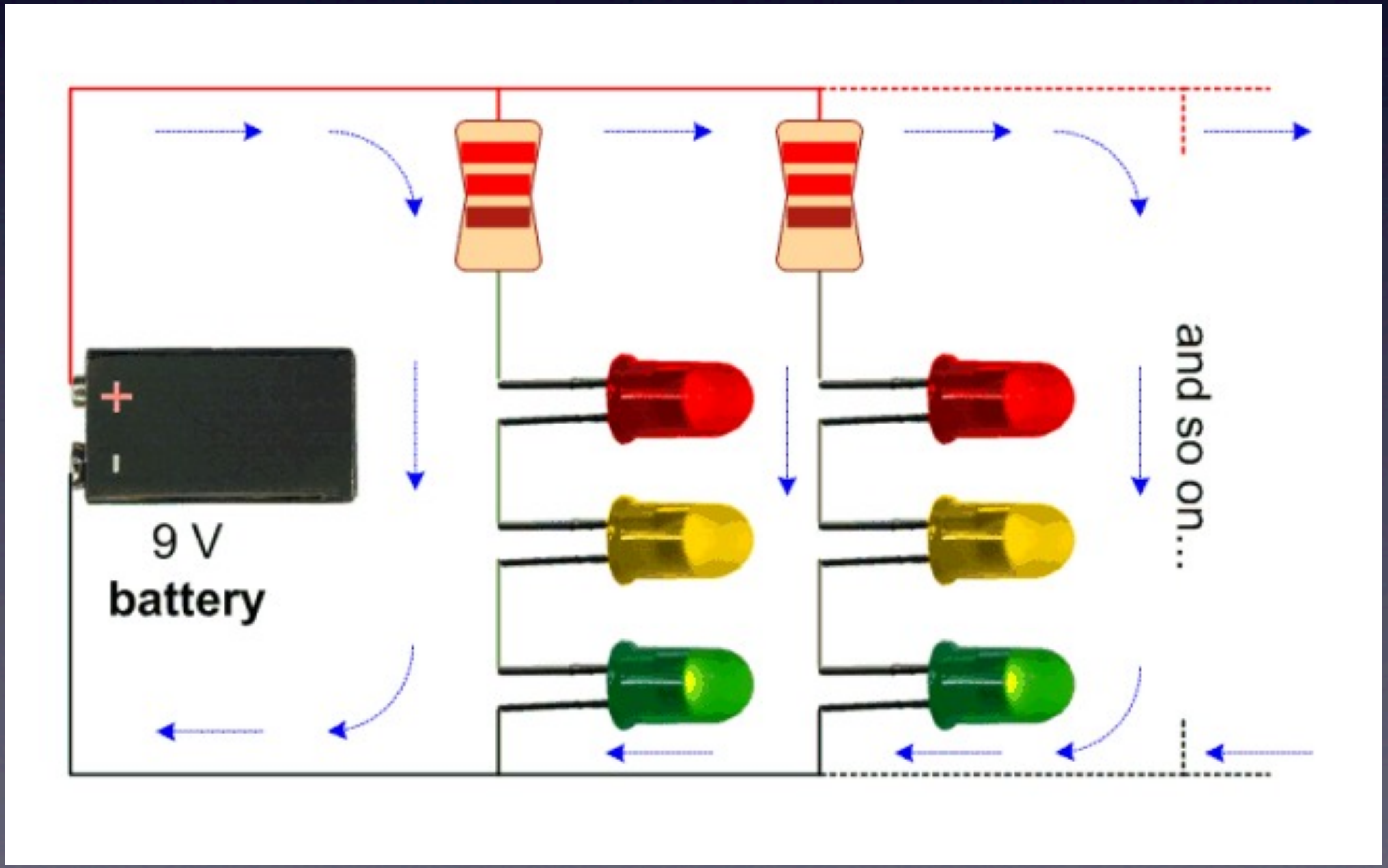
Multiple-LED circuits

- Daisy-chain LEDs in series, negative to positive: add their voltages to calculate resistor value
- Resistor can go anywhere in the chain



Even bigger circuits

- Make new circuits in parallel with the original one - each chain gets a resistor

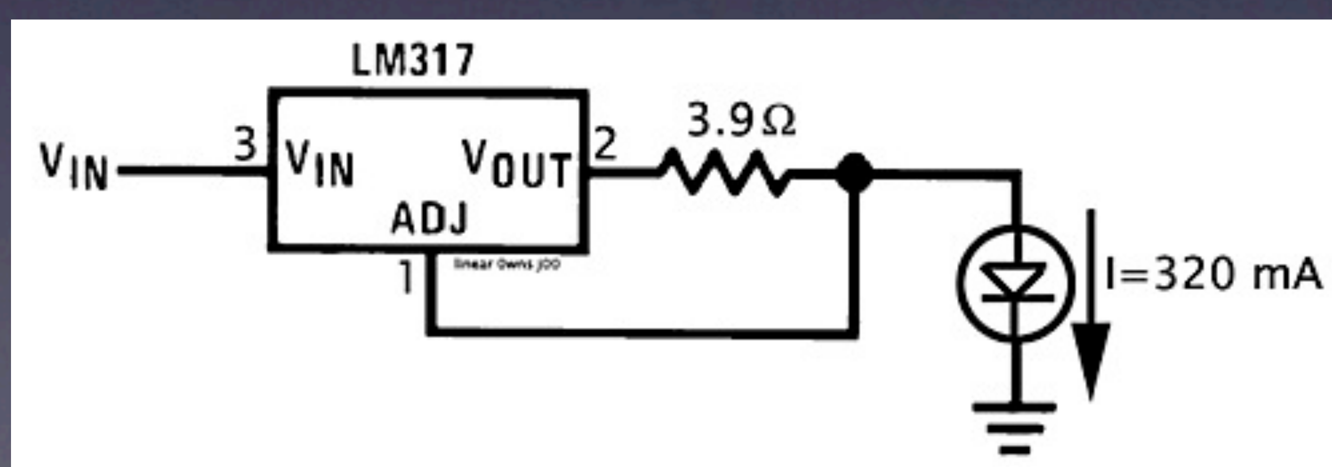


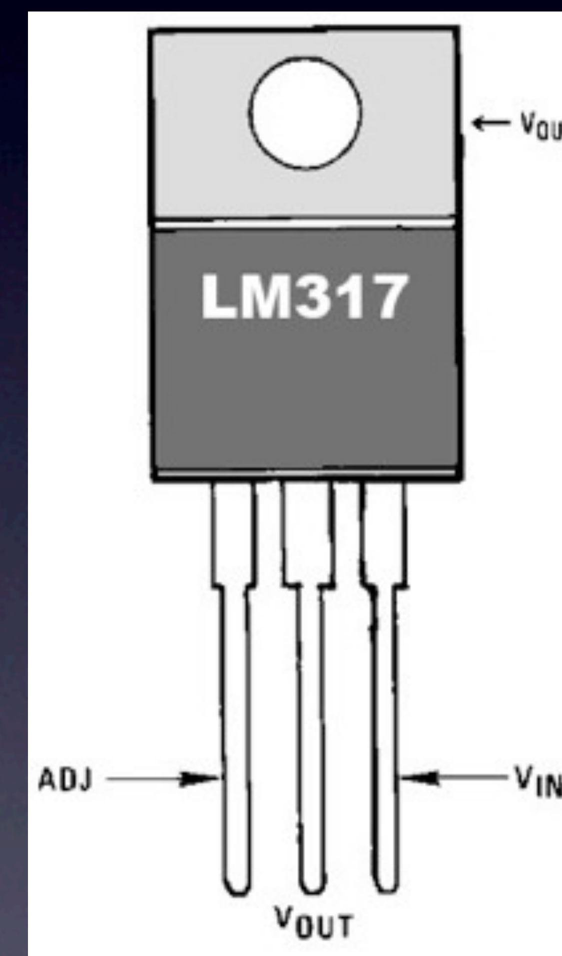
High-power LEDs

- Still all about the chemistry
- Higher currents but tighter tolerances
- Electrical principles are the same

Simple regulator

- Linear regulator controls current by varying its own resistance
- Excess power burned off as heat
- Cheap, easy, not efficient





Designing for a regulator

- Adding LEDs in series does not change the current through each LED
- Each series needs its own regulator
- For LM317, resistance = 1.25V / current
- http://www.digikey.com/

Sophisticated regulator

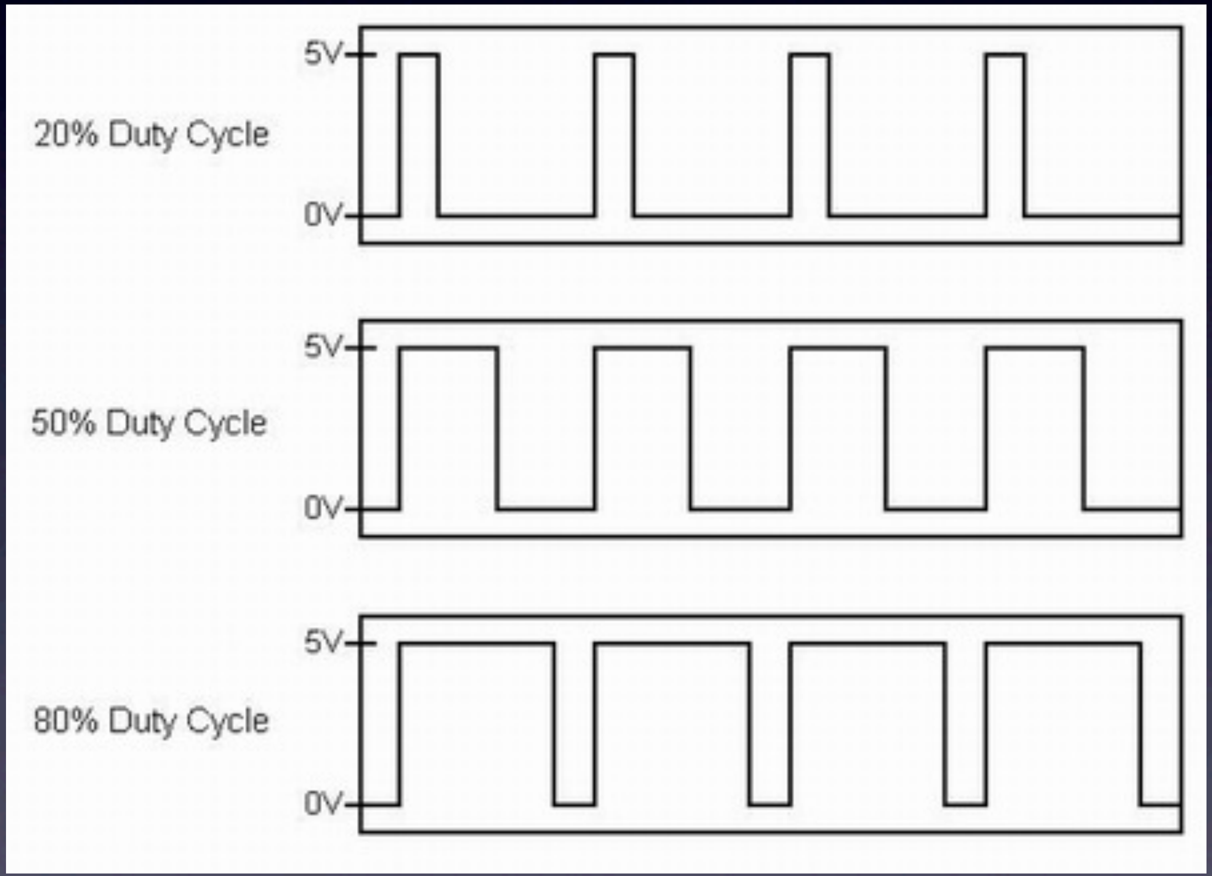
- Switching regulators don’t just burn off the power
- Available for a variety of currents: look in your LED’s datasheet
- too much to get into in this presentation

Let’s make illusions

- LEDs produce light at a fixed rate
- Eyes count photons over unit time
- Brightness control equals time control
- Limits: faster than human vision, slower than controller’s ability to drive LED circuit

Pulse-width modulation

- Flicker-fusion rate approximately 60 Hz
- Talbot-Plateau law: subjectively indistinguishable from steady light



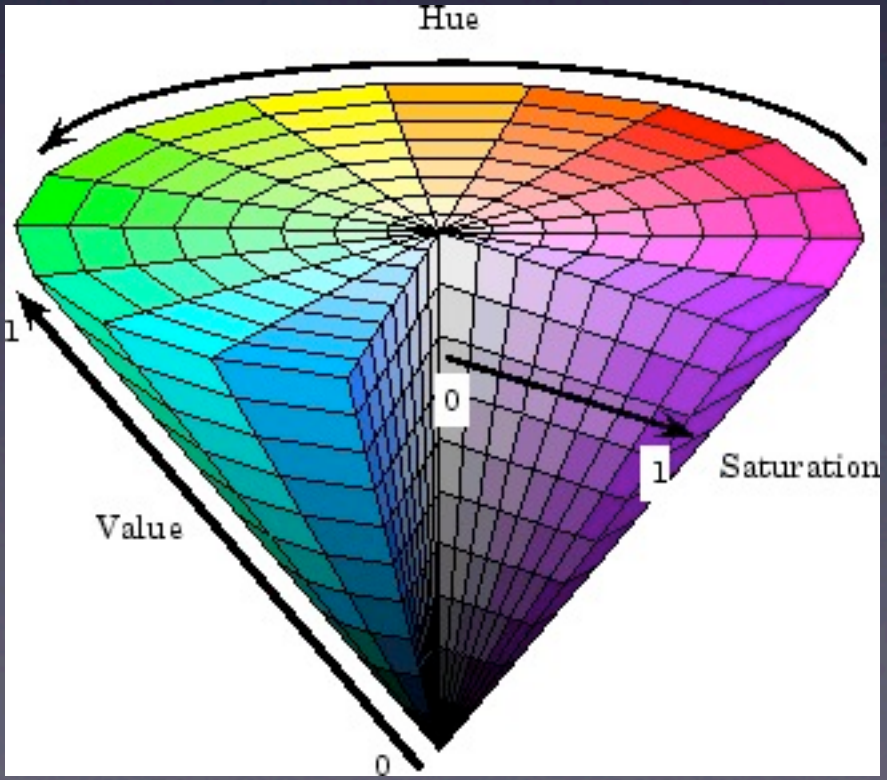
Nonlinear brightness

- Human senses respond on a log scale
- Gamma correction:

  luminance = brightness ^ 2.5
- Interesting engineering challenge due to large difference between lengths of brightest and dimmest pulses

HSV color space

- Often a more useful way to represent human perceptions of color
- Many implementations of the conversion
- http://en.wikipedia.org/wiki/HSL_and_HSV

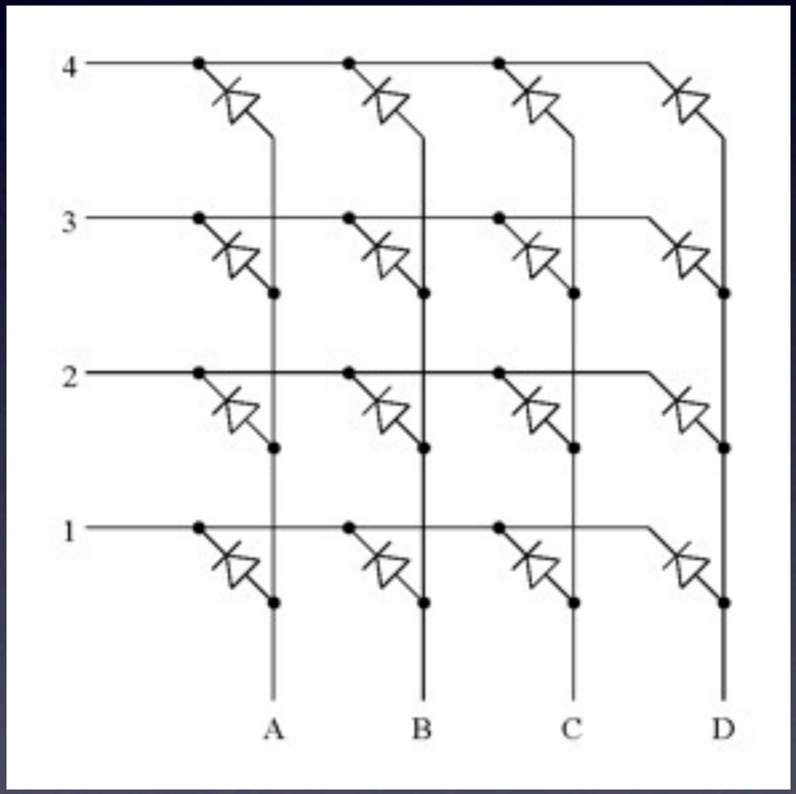


Arduino!

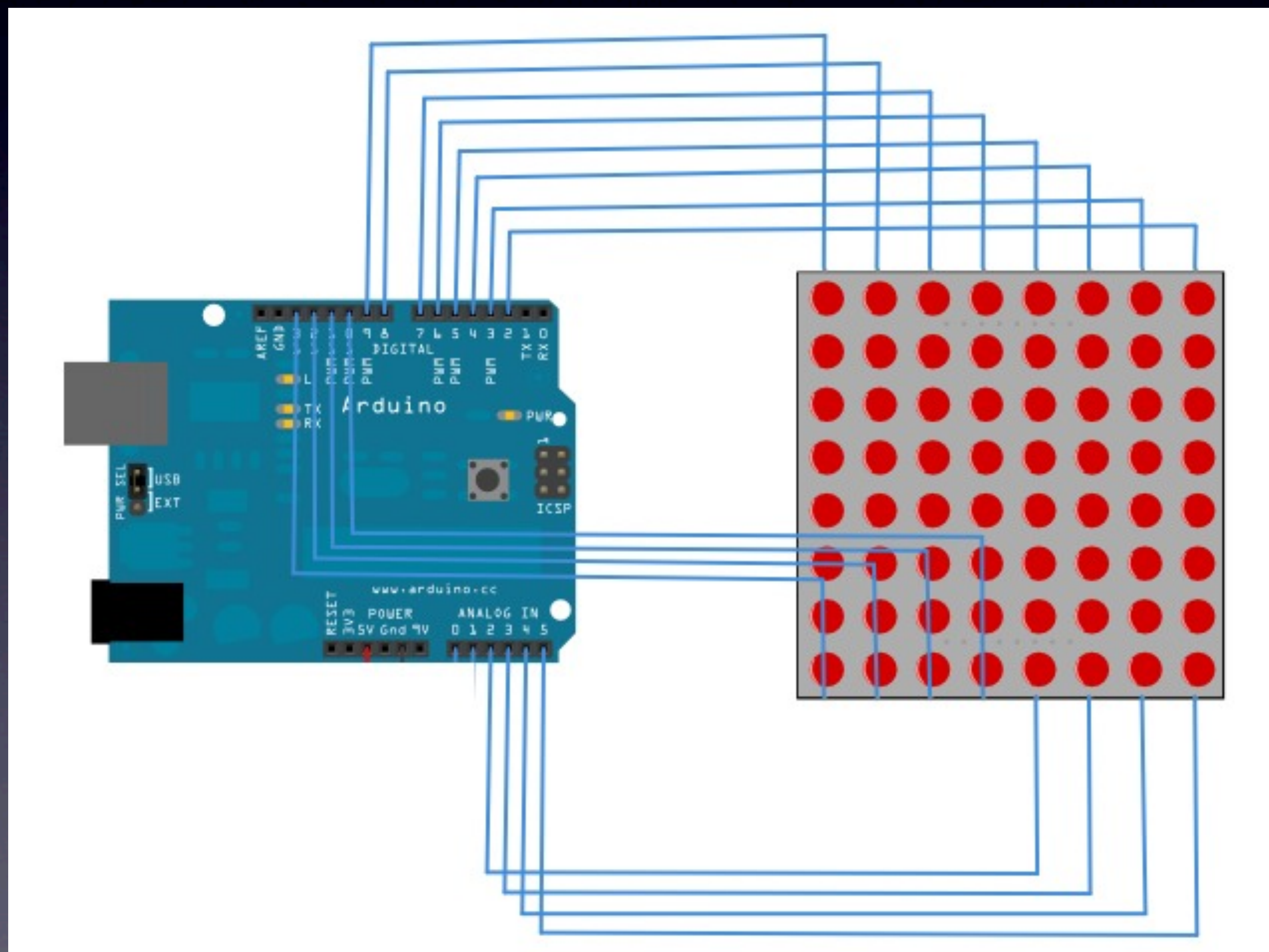
- Six pins can produce PWM signals using the built in analogWrite() command
- http://www.arduino.cc/
- TLC5940: 16-channel LED PWM controller chip, 10-bit resolution, can be daisy-chained
- http://combee.net/rgbshield/

Pixel matrix circuit

- Just like raster scanning: one row at a time
- Humans don't notice the flicker if you scan fast enough
- One IO port per row and column, not per pixel
- One resistor per column



Wiring example, 8x8



That’s it

- Questions?