
E40M

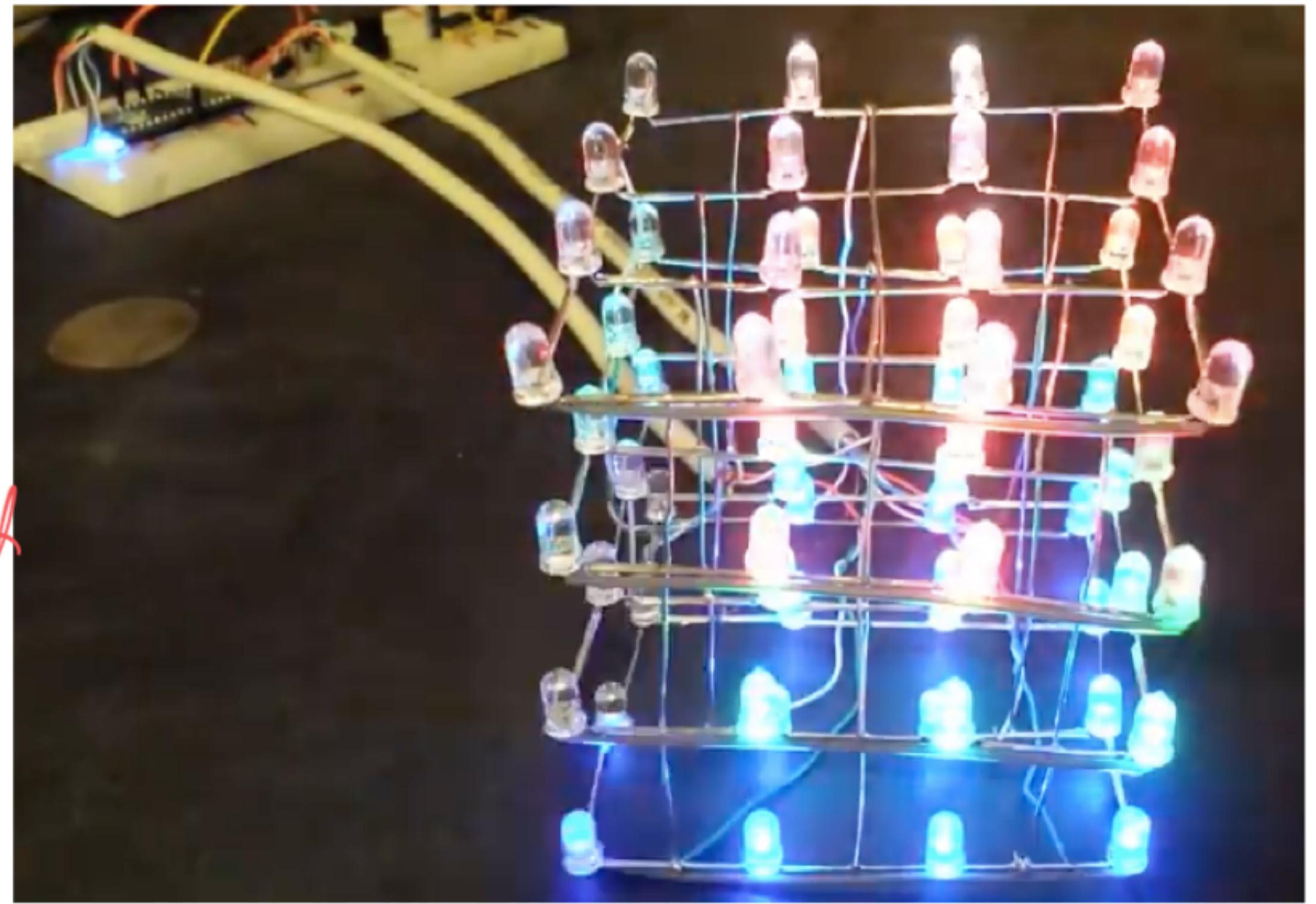
LEDs, Time Multiplexing

Reading

- Course Reader 2.6 – LEDs
- Course Reader 5.8 - Multiplexing
- LEDs
 - <https://learn.adafruit.com/all-about-leds>
 - http://dangerousprototypes.com/docs/Basic_Light_Emitting_Diode_guide
- LED Multiplexing
 - <http://www.instructables.com/id/Multiplexing-with-Arduino-and-the-74HC595/step1/What-Is-Multiplexing/>

LED Cube – Project #3

- In the next several lectures, we'll study
- Concepts
 - Coding
 - Light ✓
 - Sound — *next time*
 - Transforms/equalizers - *WTF*
- Devices
 - LEDs
 - Analog to digital converters

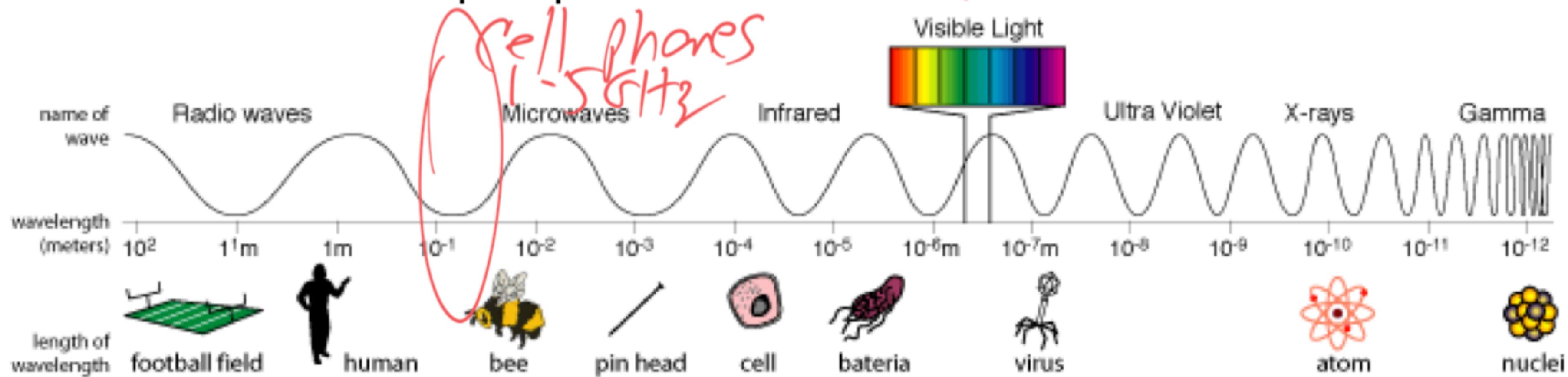


Music responsive LED Cube

<https://www.youtube.com/watch?v=FRXDTiOHFII&feature=youtu.be>

What is Light?

- It is an electromagnetic wave
 - Speed of light, $c = 3E8$ m/s
 - Frequency $= c/\lambda = Hz = \frac{1}{T}$
- Part of electromagnetic spectrum:
- All waves transport power



(<https://science.hq.nasa.gov/kids/imagers//ems/index.html>)

Quantum Mechanics - Photons

- Just when it looked like things would be simple
 - In Quantum Mechanics light not always a wave
 - It is also carried by particles called photons
- Each photon has a precise energy
 - Set by the wavelength
 - $E = hc/\lambda$; where h is Planck's constant = 6.6×10^{-34} Jsec
- It will be useful to calculate energy in eV (electron volts)
 - This is the energy needed to move one electron, one volt
 - $q * 1V = 1.6 \times 10^{-19}$ J
 - $hc = 1.24 \text{ eV} \cdot \mu\text{m}$

$$\begin{aligned}h &= (6.6 \times 10^{-34}) / (1.6 \times 10^{-19}) \\&= 4.125 \times 10^{-5} \text{ Jsec}\end{aligned}$$

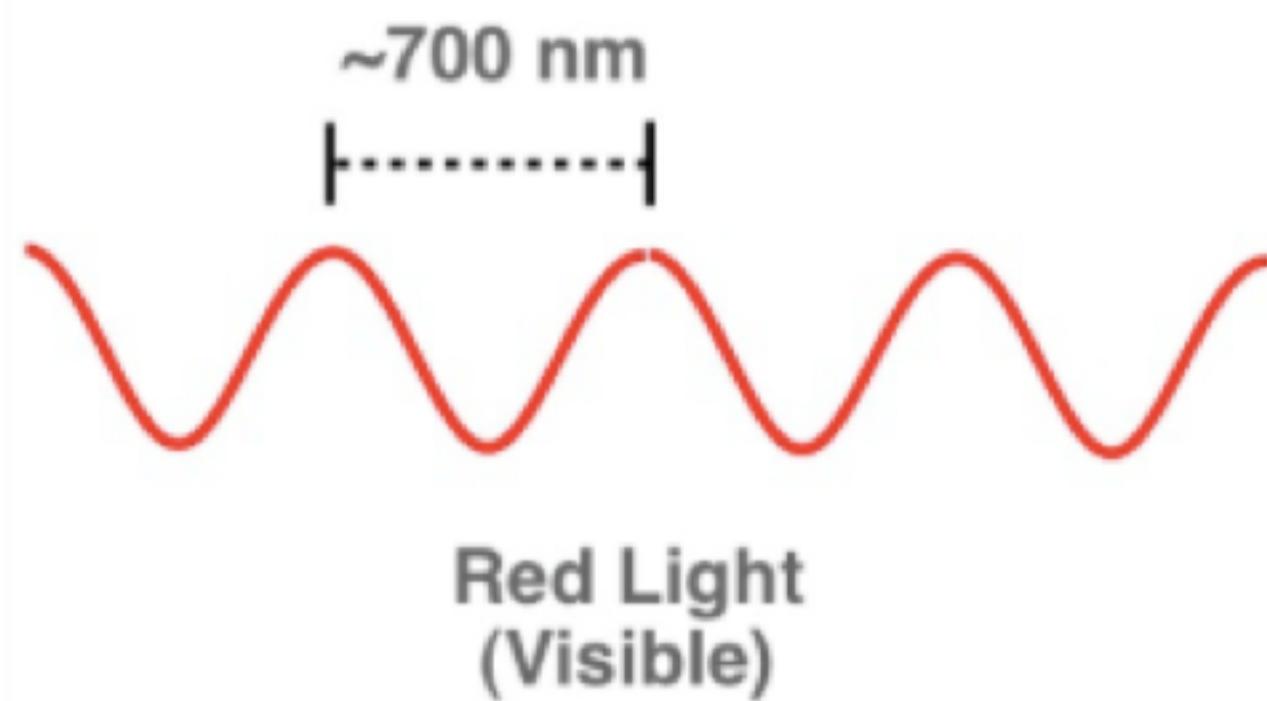
Energy of Photons

- Visible light = $0.63\mu\text{m}$ (red), $0.55\mu\text{m}$ (green), $0.47\mu\text{m}$ (blue)
 - Infrared lights, used in remotes are around $1\mu\text{m}$
- The energy of these photons range from
 - 1.2eV for infrared
 - 2.0eV for red
 - 2.3eV for green
 - 2.6 eV for blue
- We have sensors that can detect single photons
 - And light really is quantized

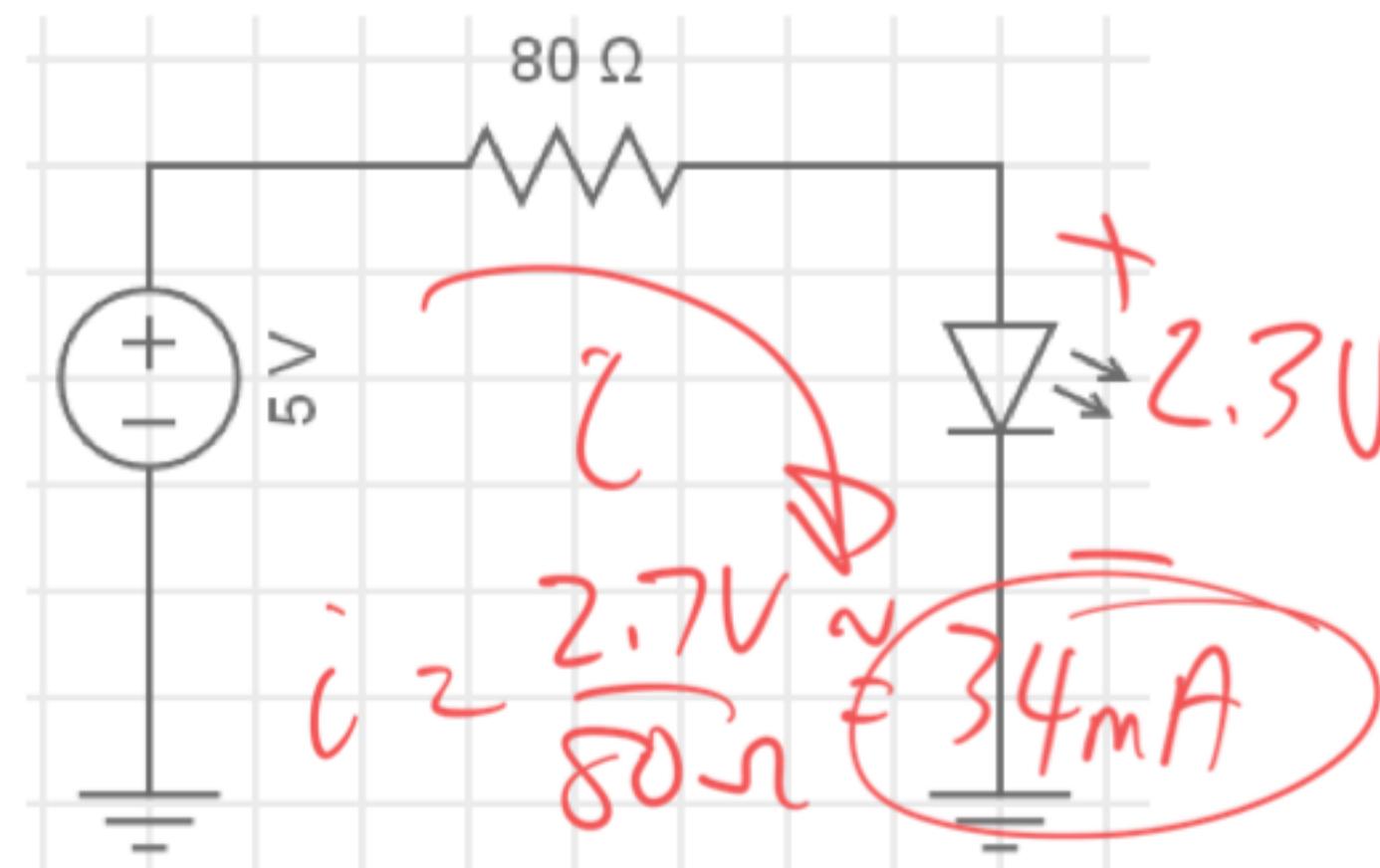
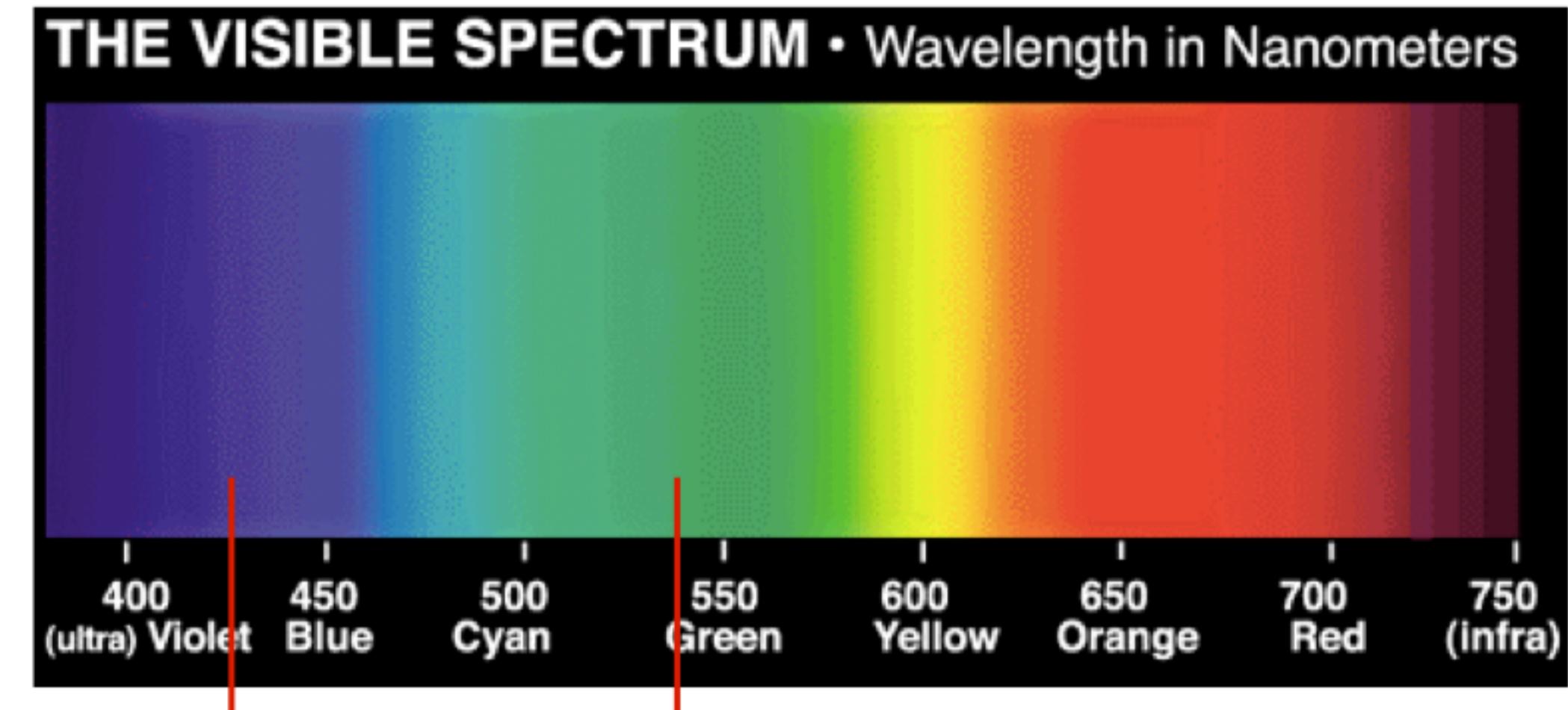
$$E = \frac{hc}{\lambda} = \frac{1.24\text{eV}\mu\text{m}}{\lambda}$$

$$\frac{1.24\text{eV}\mu\text{m}}{\lambda}$$

Energy of Photons



$$f = \frac{c}{\lambda} \quad E = \frac{hc}{\lambda} = \frac{1.24\text{eV}}{\lambda(\mu\text{m})}$$



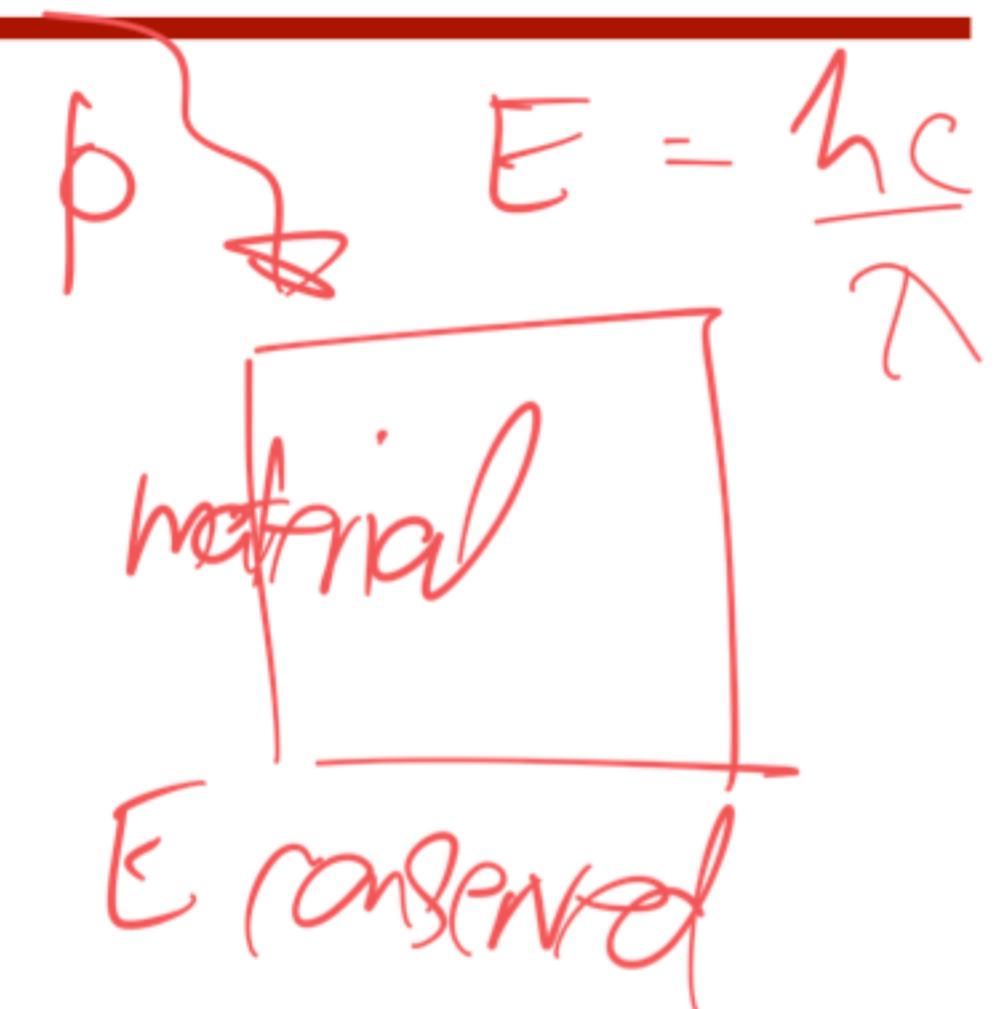
- Current drops 2.3 volts across diode and green photons are emitted.
- Green photons strike a diode, current and up to 2.3 volts can be generated.

Light Measurements

- Total light emitted is measured in lumens
 - Comparing light bulbs compares lumen output
 - 60Watt bulb is about 800 lumens
- Illumination on a surface is in lux
 - Lumens/m²
 - 300 lux - Office lighting
 - 10k lux - Full sunlight (not direct)
 - 32k – 100k lux - Direct sunlight
- At green (550nm), $680 \text{ lux} = 1 \text{ W/m}^2$
 - Other freq require less lux for 1 W/m^2

When Light is Absorbed By a Material

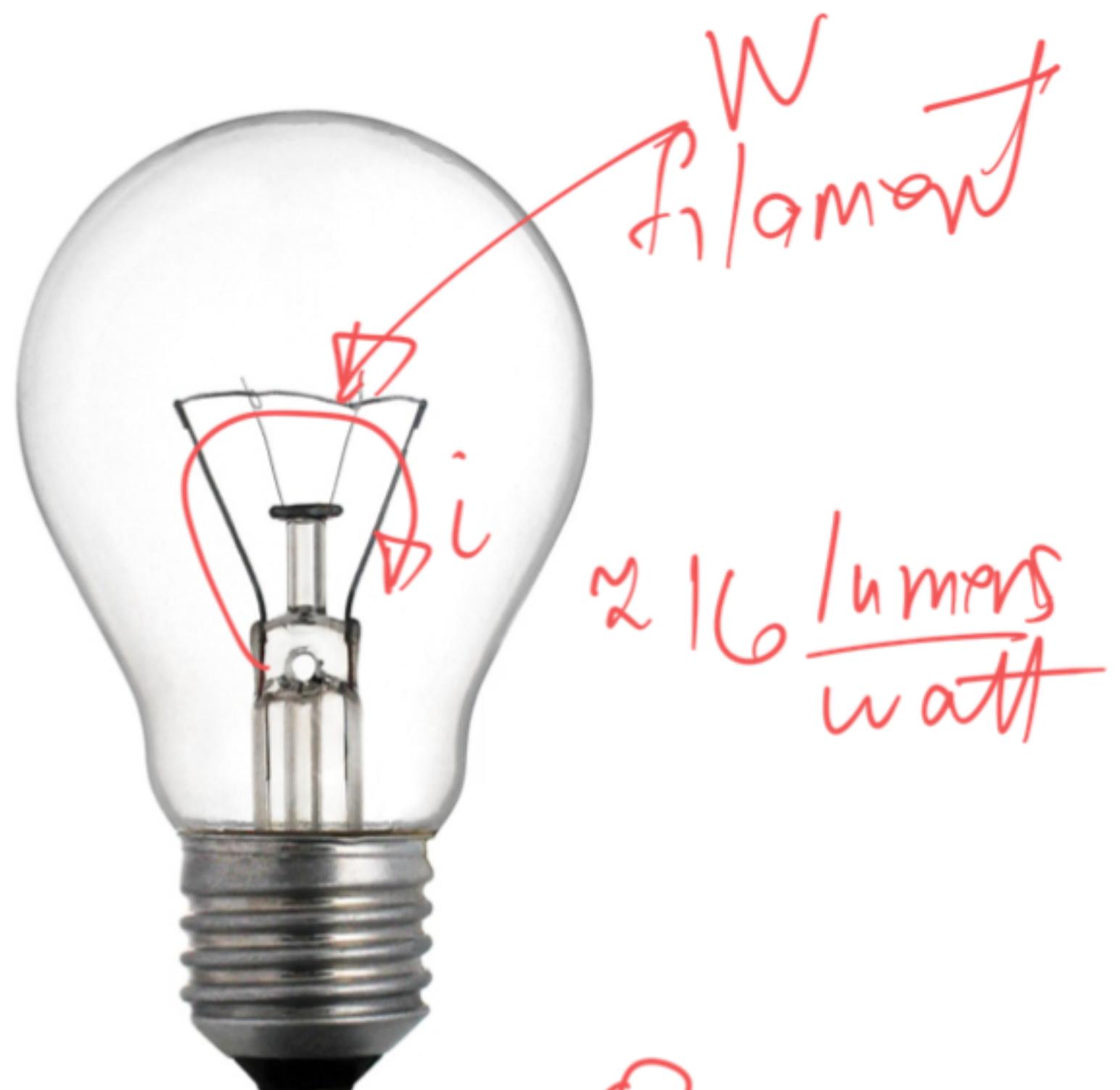
- It transfers its energy to the material
 - While the energy of each photon is small
 - The energy flux can be large
- In most cases this energy is converted to heat
 - That is why you feel warm in dark clothes
 - They absorb the sunlight and convert it into heat
 - Can generate energy this way
 - Heat rocks, boil water, generate steam, turn turbines
- In special situations (a.k.a diodes)
 - Can directly generate electricity with some of the energy



LEDs

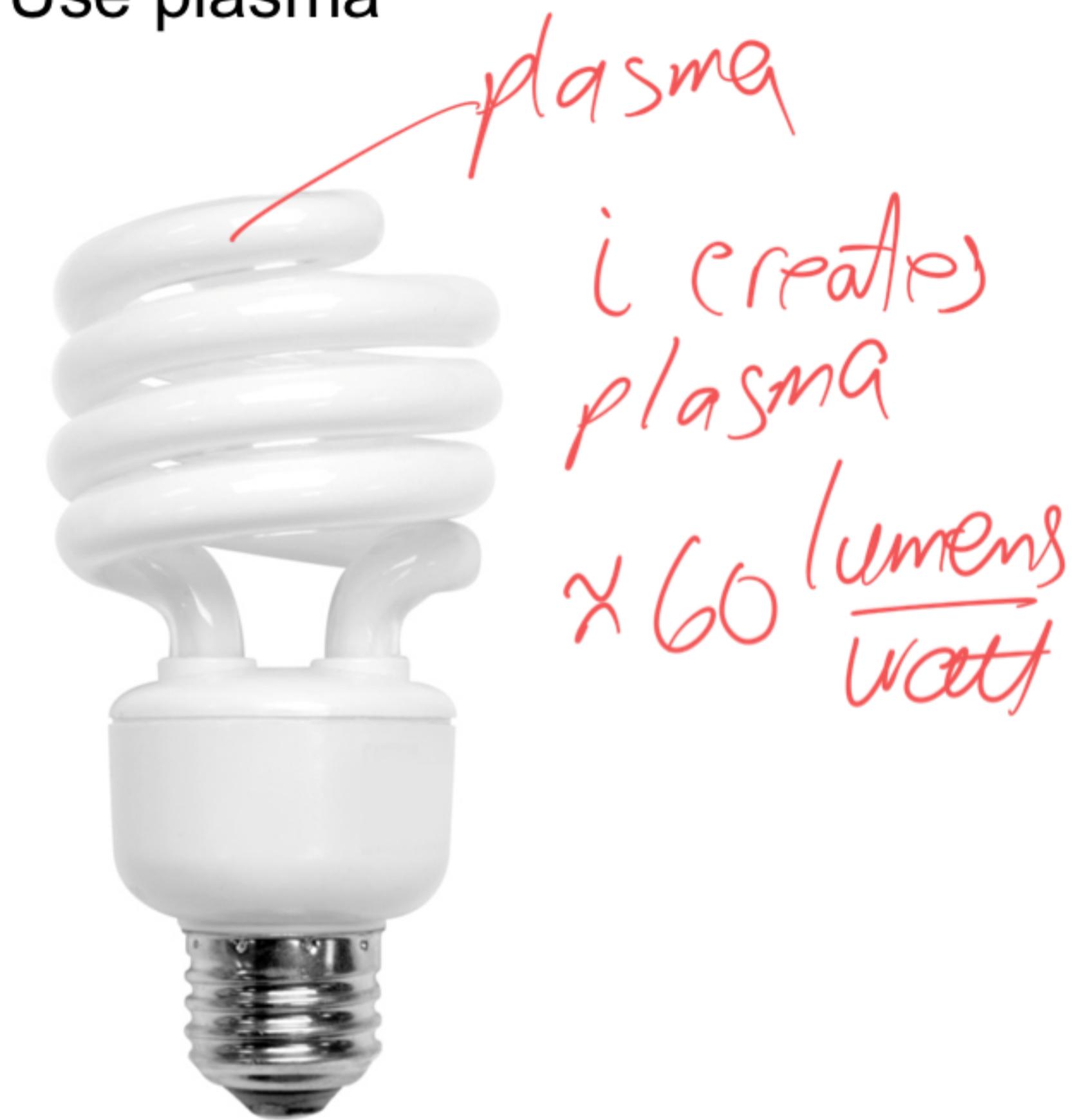
Generating Light from Electricity

- Use heat

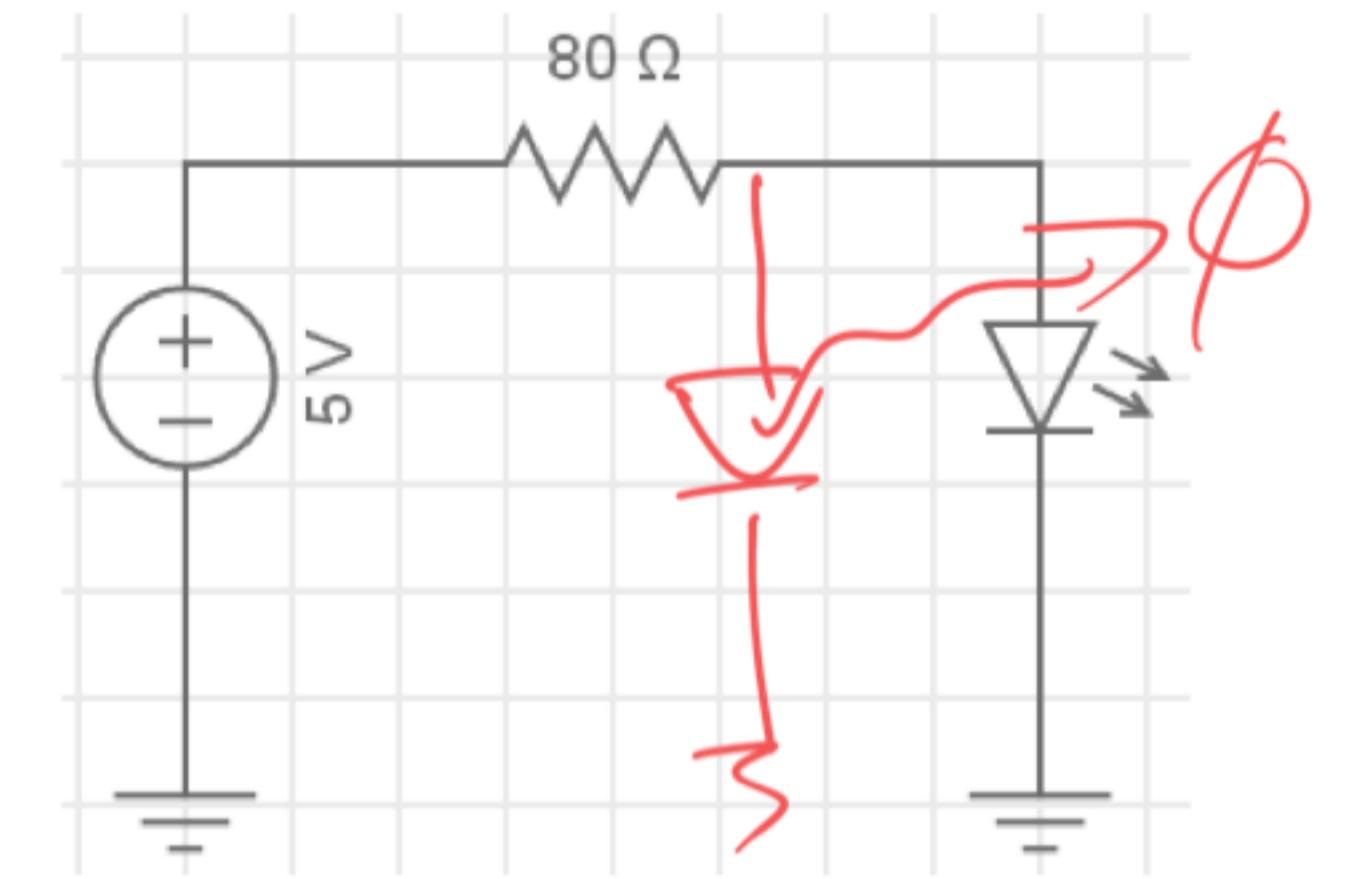
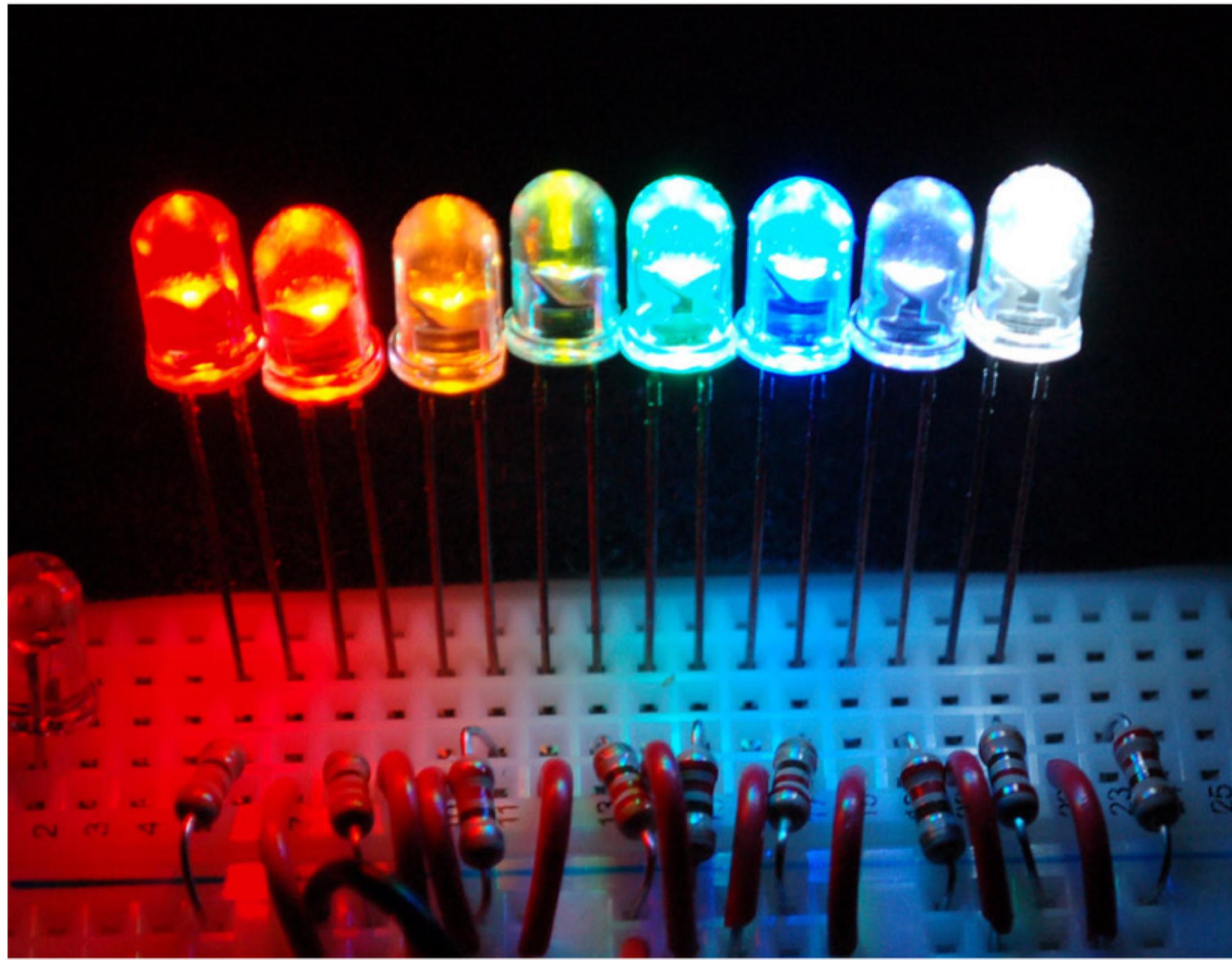


$$\eta \approx 2-5\%$$

- Use plasma



LEDs



- How do we get different colors?
- How does this relate to a solar cell which operates in reverse?

LED Operation

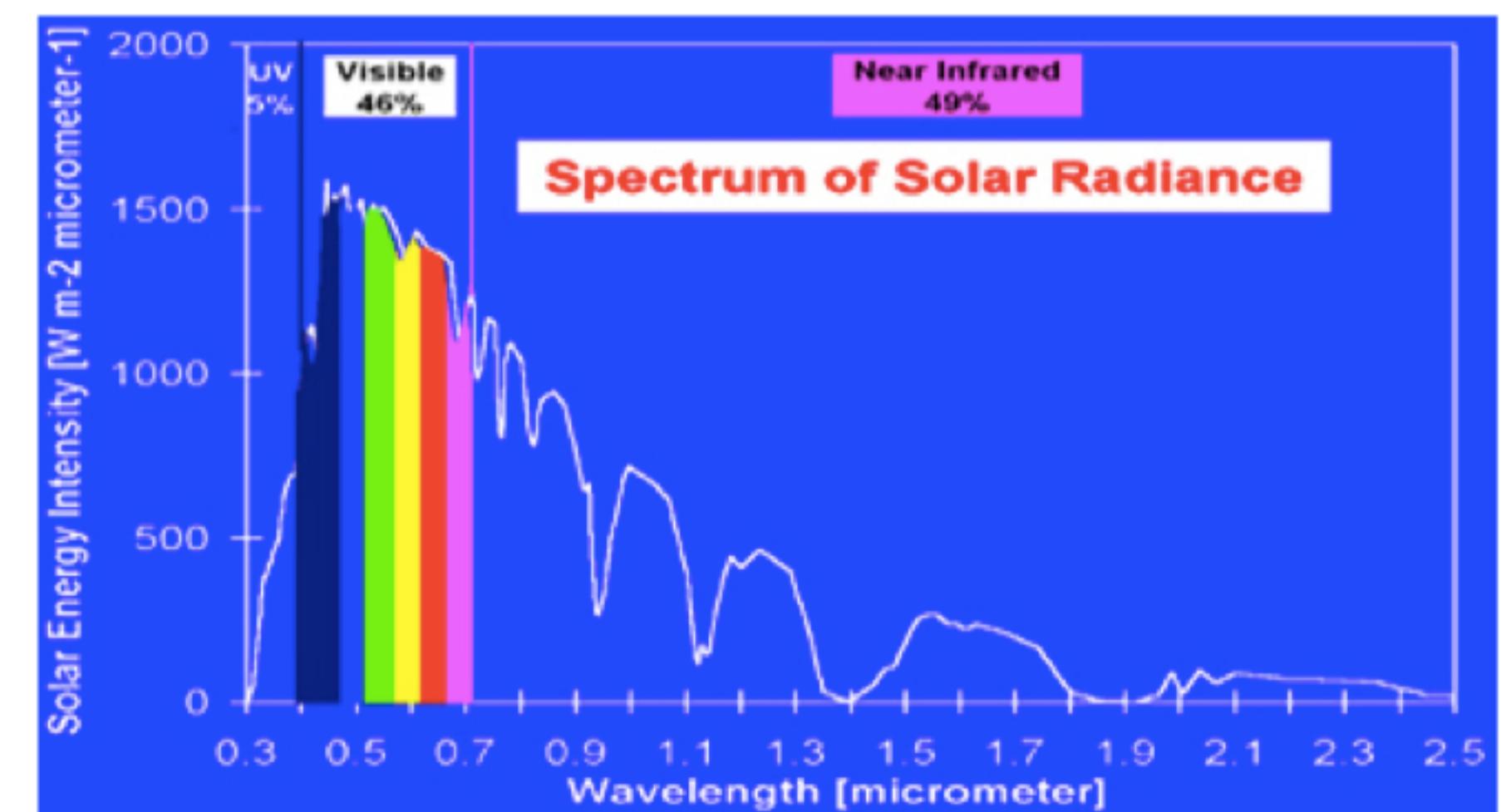
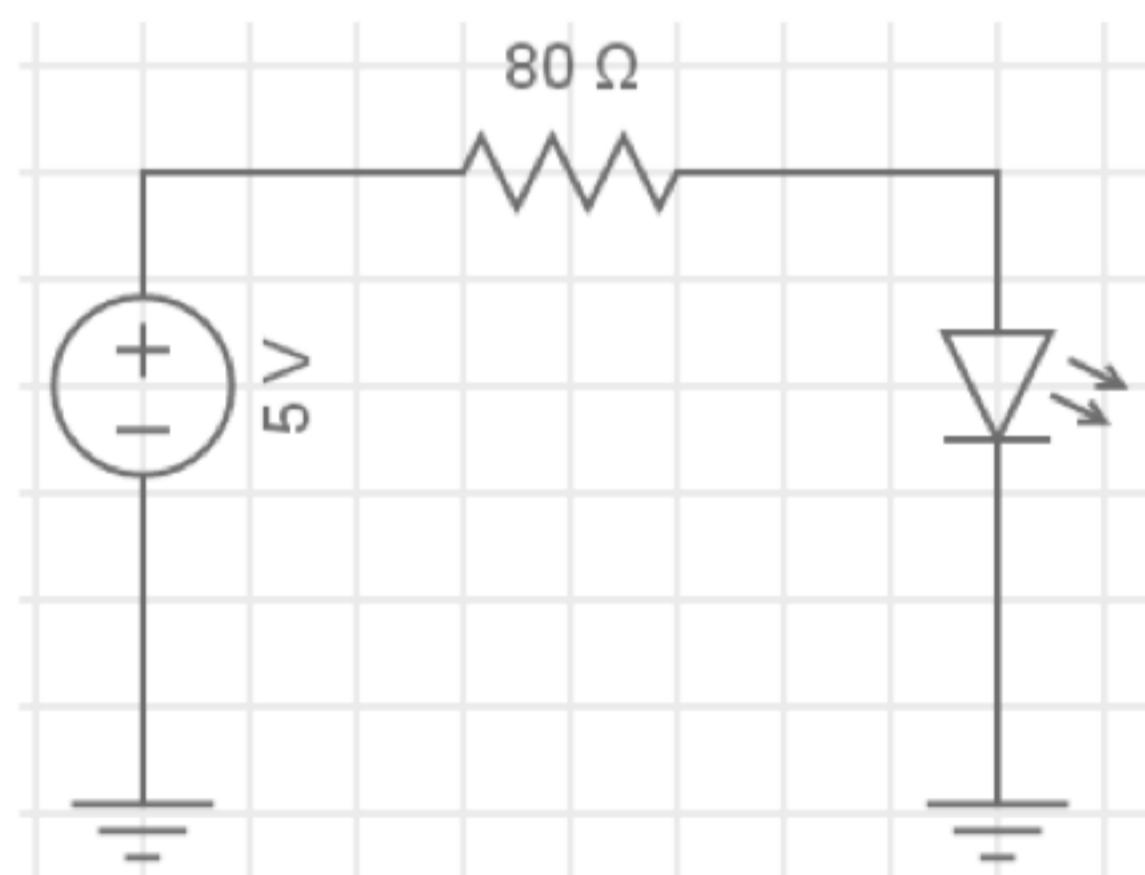
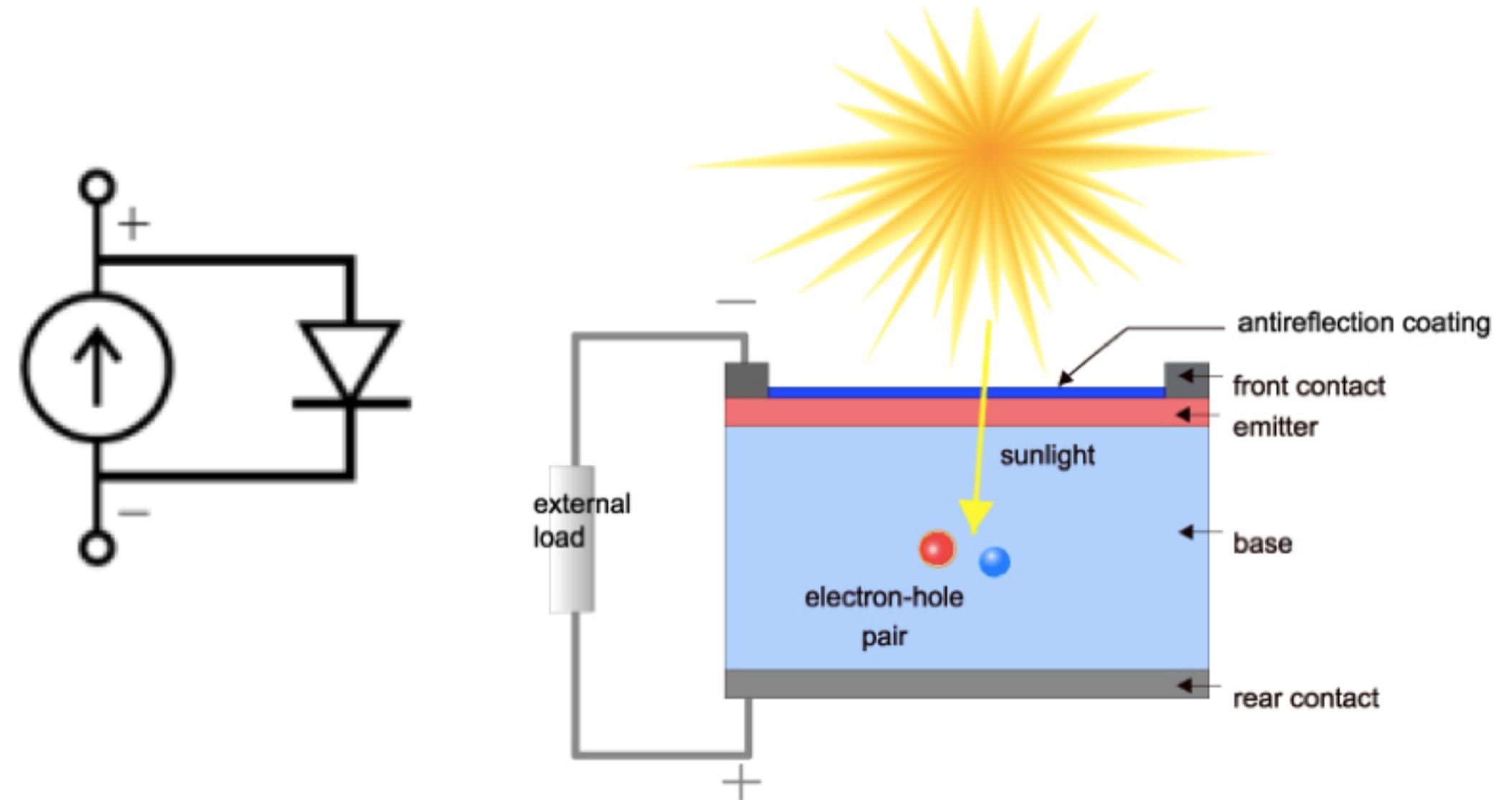
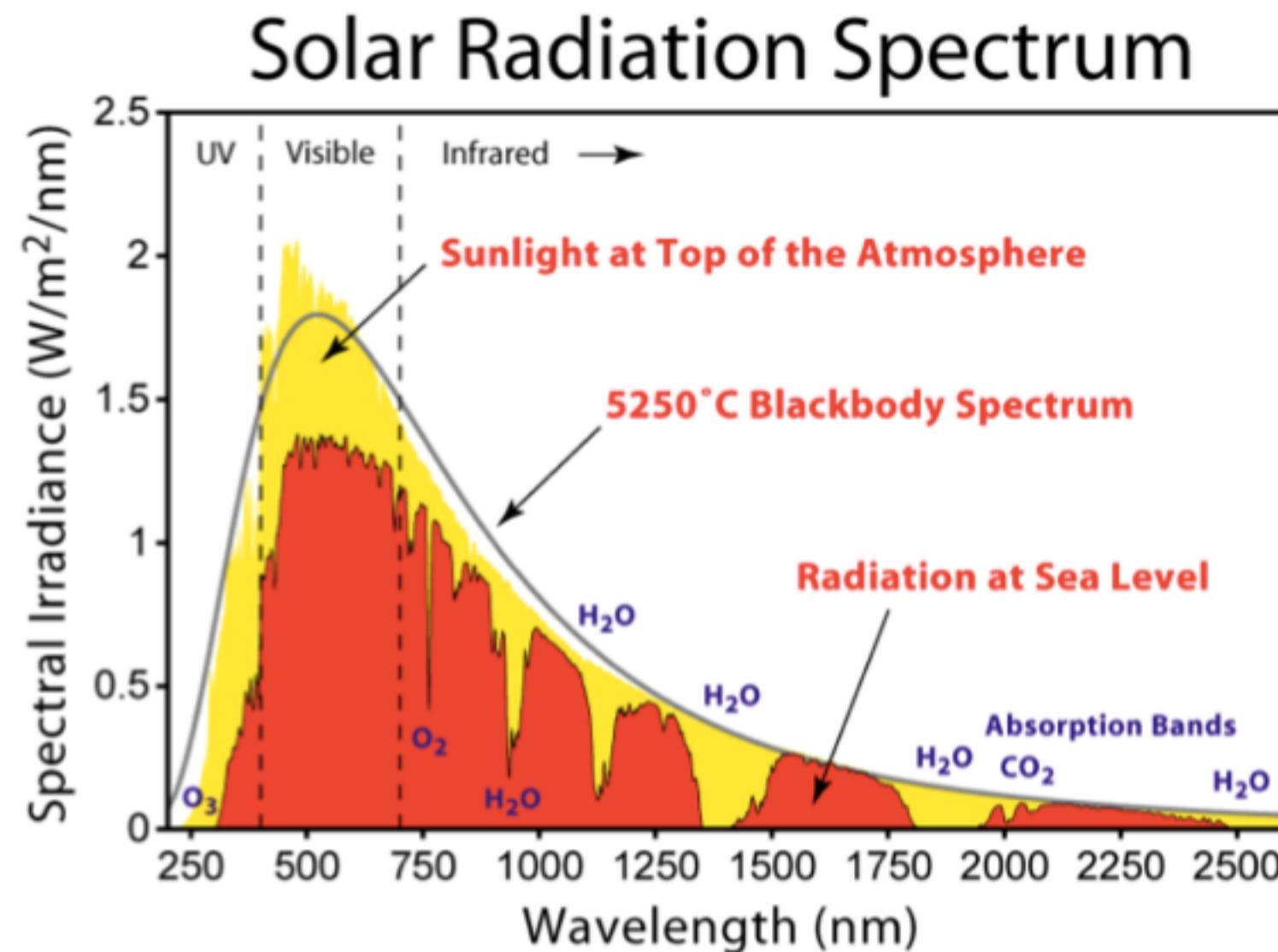
- When current flows through a diode
 - There is a voltage drop across the diode
 - This drop depends on the material
 - Device consumes energy
 - iV
- For many materials this energy is converted into heat
 - Silicon, for example
- For some materials
 - “Direct band-gap” materials
 - This energy can emit a photon

LED Voltage Drop and Color

- The color of the photon depends on energy
- The energy available depends on the voltage
 - Each electron that flows can create one photon
 - If it takes two, the two have to happen at the same time (unlikely)
 - V_f for a blue LED is larger than for a Red LED

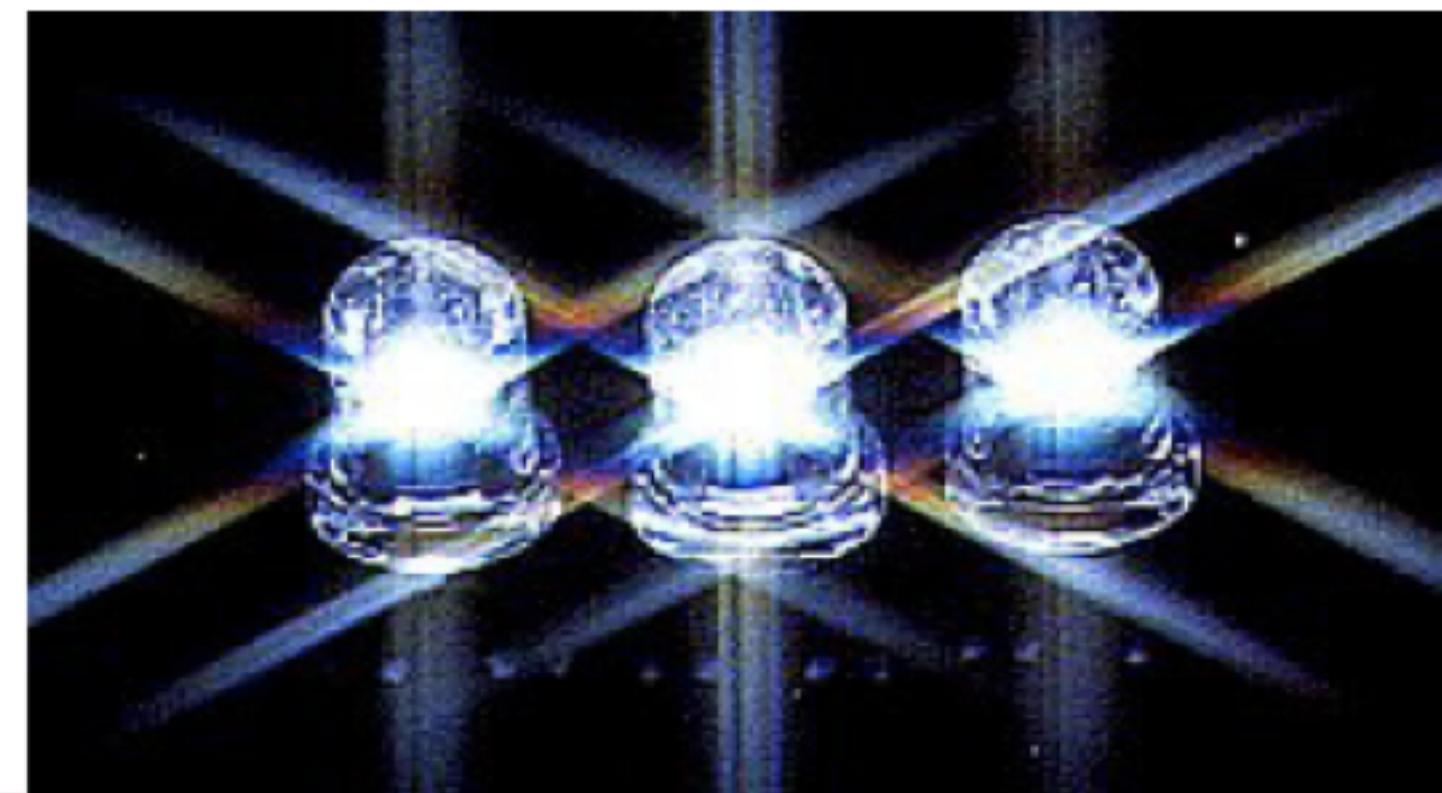
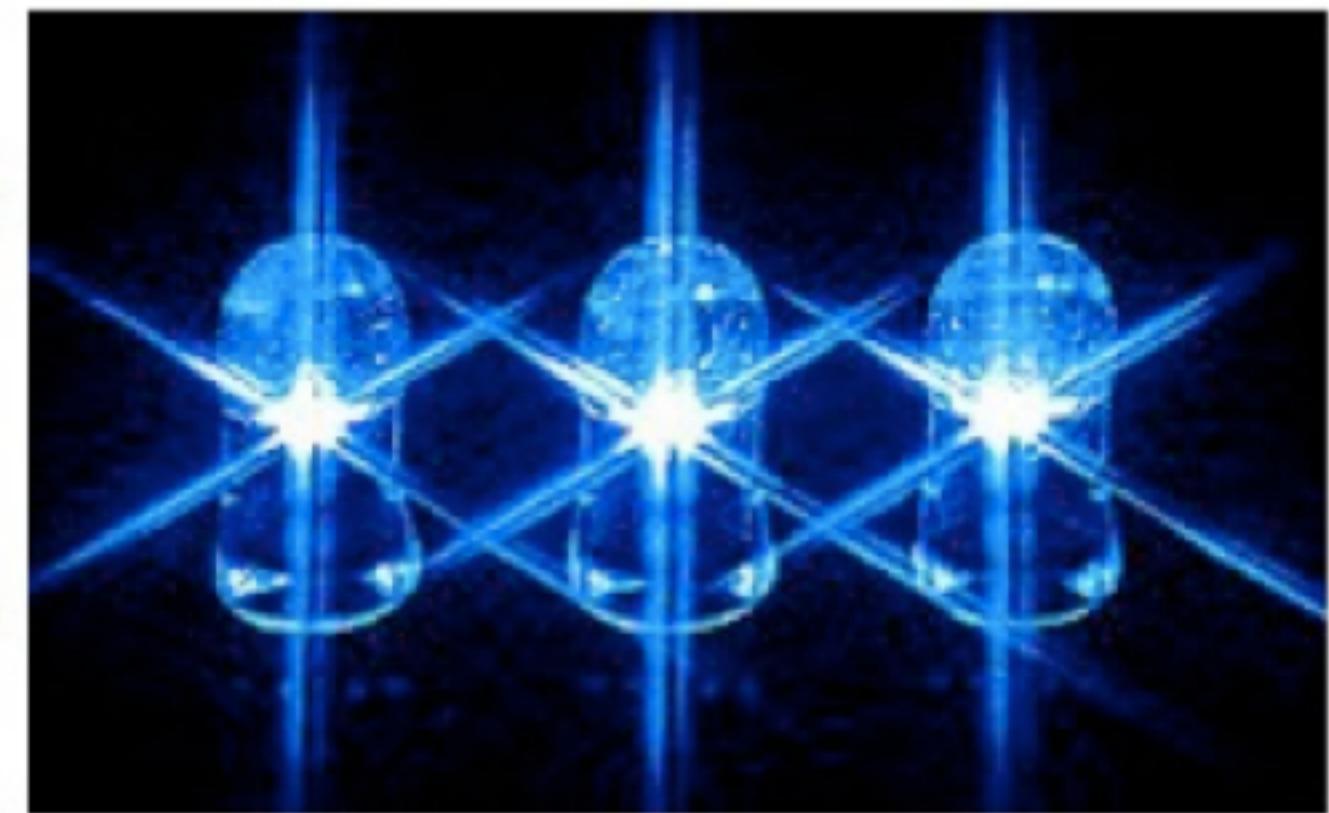
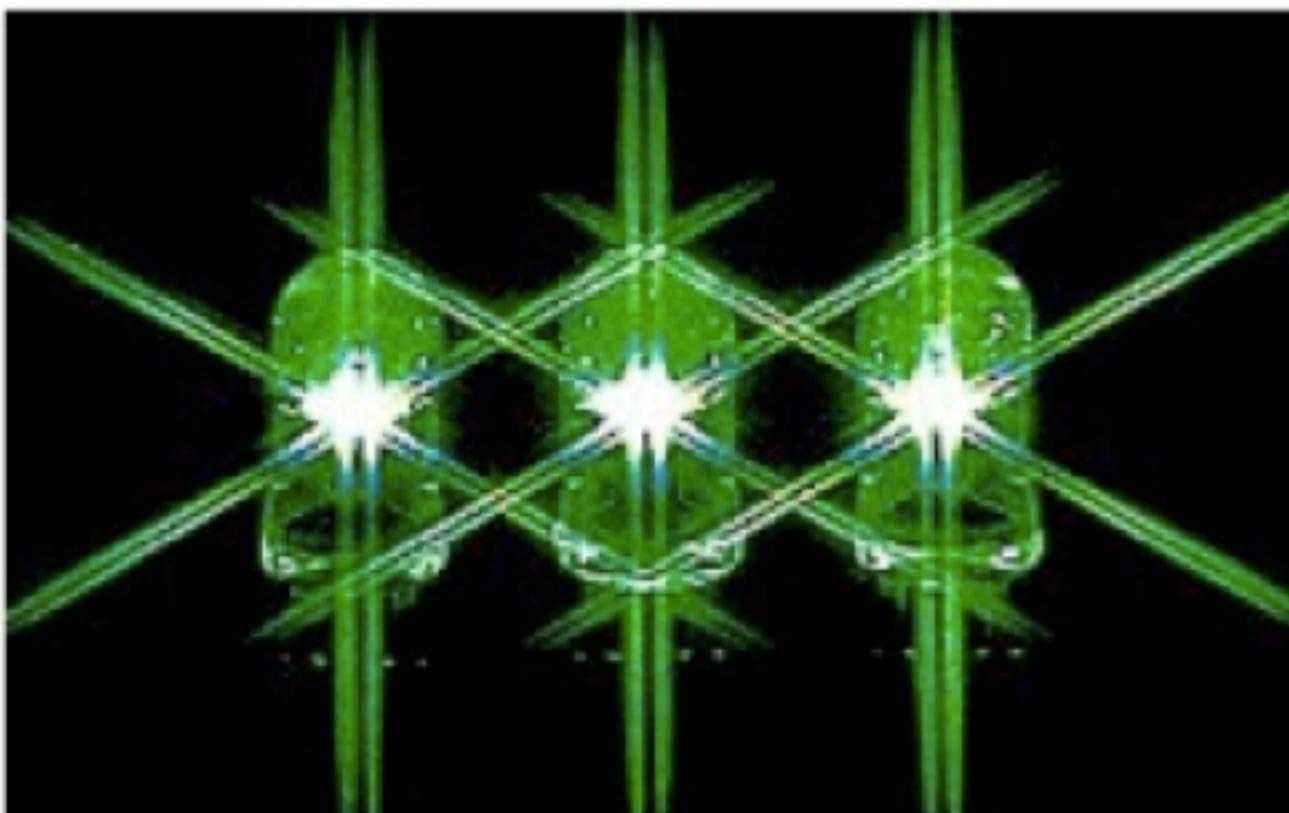
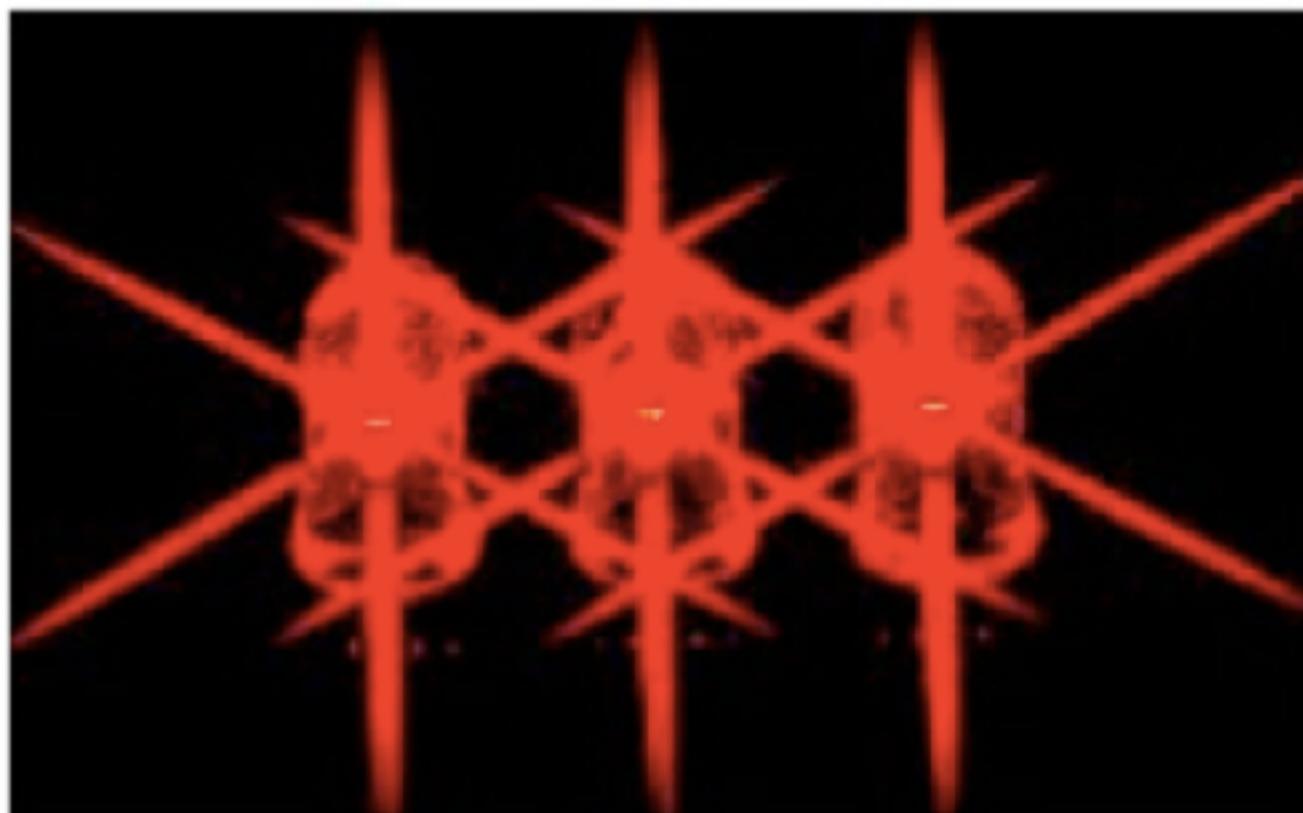
DIALIGHT PIN	EMITTED COLOR	MATERIAL	LENS COLOR	LUMINOUS INTENSITY (mcd)			DOMINANT WAVELENGTH (nm)			FORWARD VOLTAGE (V)			VIEWING ANGLE ° DEGREES	
				If = 20 mA			If = 20 mA			If = 20 mA				
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX		
598-8010-107F	RED	AlInGaP	Water Clear	30	40	80	630	635	642	1.7	2.2	2.4	140	
598-8020-107F	RED-ORANGE	AlInGaP	Water Clear	120	150	200	620	625	630	1.7	2	2.4	140	
598-8030-107F	ORANGE	AlInGaP	Water Clear	70	-	150	600	-	610	1.7	2	2.4	140	
598-8040-107F	YELLOW	AlInGaP	Water Clear	100	130	160	590	-	595	1.7	2	2.2	140	
598-8050-107F	YELLOW	AlInGaP	Water Clear	100	130	160	583	-	590	1.7	2	2.4	140	
598-8060-107F	YELLOW-GREEN	AlInGaP	Water Clear	20	40	60	570	-	575	1.8	2	2.4	140	
598-8070-107F	GREEN	GaP	Water Clear	10	20	40	562	-	570	1.8	2	2.4	140	
598-8081-107F	GREEN	InGaN	Water Clear	220	300	400	520	523	525	3	3.2	3.5	140	
598-8091-107F	BLUE	InGaN	Water Clear	90	140	160	470	473	475	2.8	3.2	3.5	140	

FYI – How Do Light Emitting Diodes and Solar Cells Actually Work?



FYI – Full Color LED Displays and Solid State Lighting (https://en.wikipedia.org/wiki/Light-emitting_diode)

- Red/orange/green LEDs have been used in small displays for 30 years. Nakamura's invention of InGaN LEDs has dramatically changed the lighting world – not only creating blue LEDs for full color displays, but creating the possibility of solid state lighting.



White LEDs utilize blue emission of GaN or InGaN to excite fluorescence in a phosphor which emits yellow light. Blue + yellow appears white to the eye. Alternatively, phosphors are used that emit green and red. Blue + green + red = white

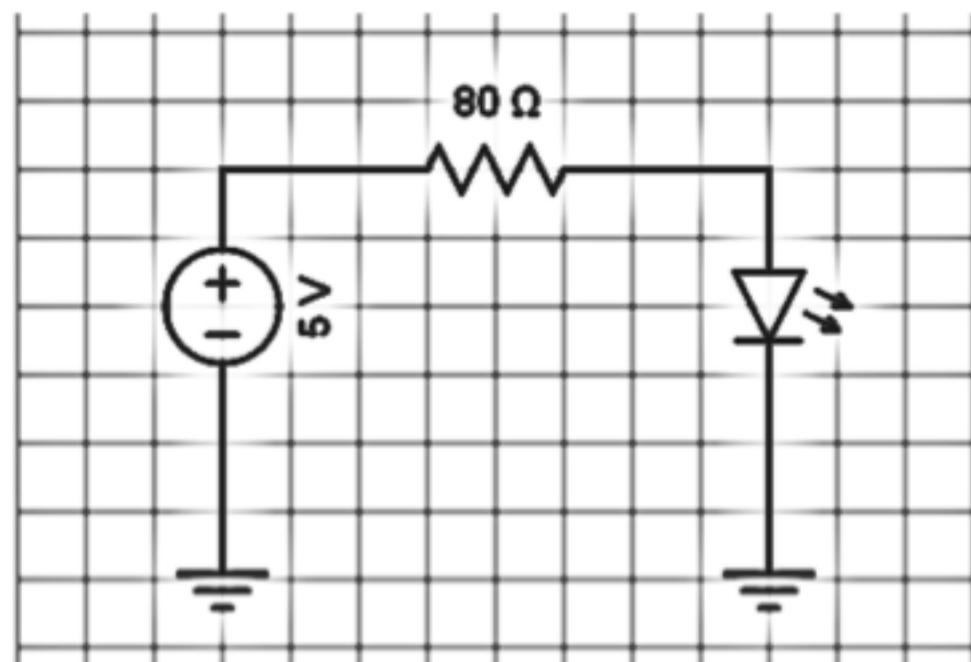
Using LEDs



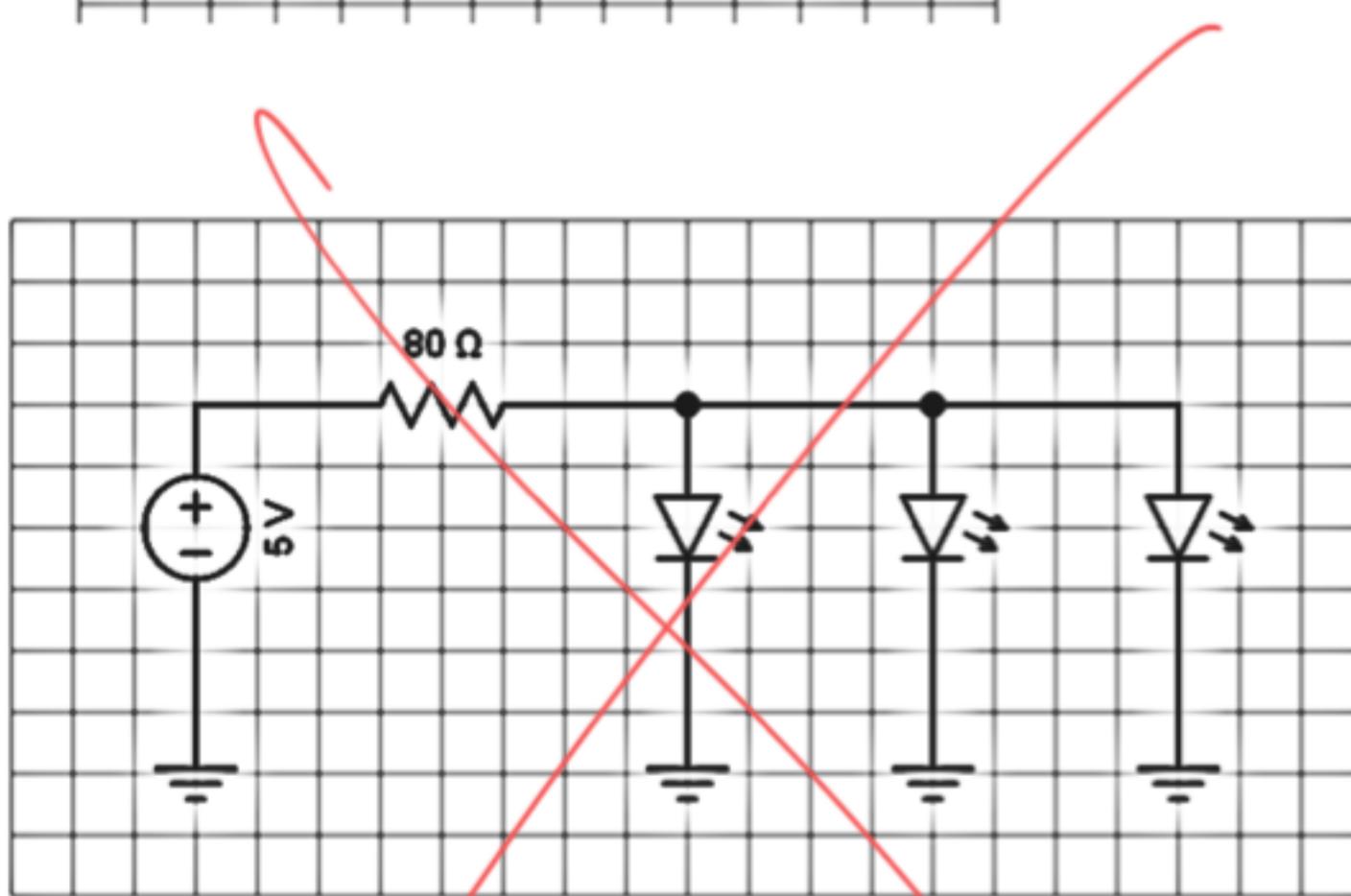
- They are diodes
 - Current only flows in one direction
 - Voltage not very sensitive to current
 - Often have an internal resistance
- You should use external resistance to limit current
 - Set current at around 20mA (30mA max)
 - Voltage drop across diode is 2-3V
 - Voltage drop across resistor is 3-2V if driven from 5V supply
 - $R = V/I = 3V/20mA = 150\Omega$; $2V/20mA = 100\Omega$
 - And the Arduino pin has a **resistance of 30Ω**



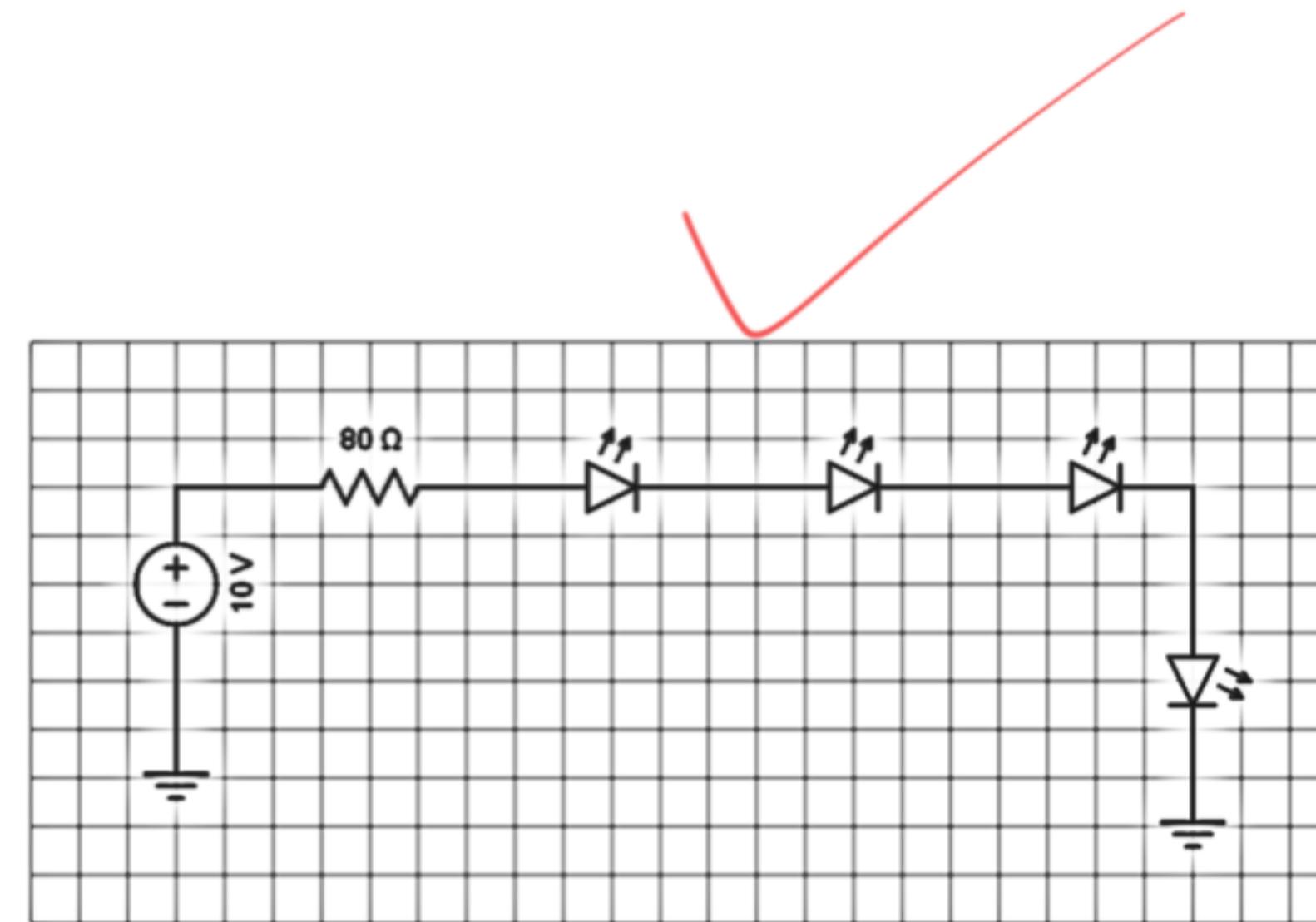
Using LEDs in Simple Circuits



- Always use a series R with an LED



- Do not wire LEDs in parallel

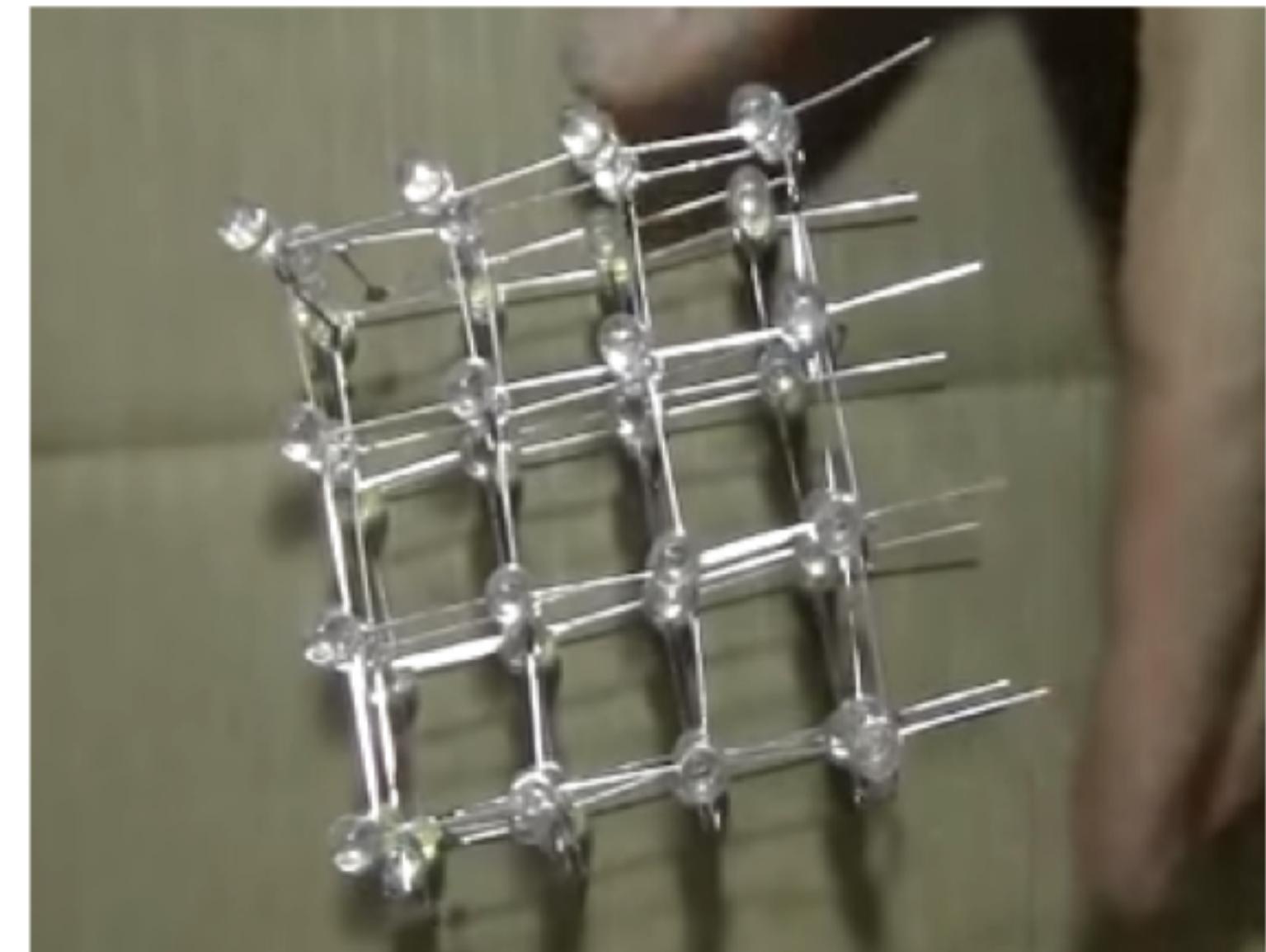


- Series connection is fine with a higher V

LED CUBE

LED Cube

- You are building a $4 \times 4 \times 4$ cube of LEDs
- You can choose
 - Red, Green, Blue, White
 - Or can mix it up
- Two challenges
 - How to control 64 lights?
 - How to build something
 - With 64 elements
 - That is a lot of soldering
 - A little planning will go a long way
- Friday's prelab lecture will discuss soldering strategies.



The Control Problem

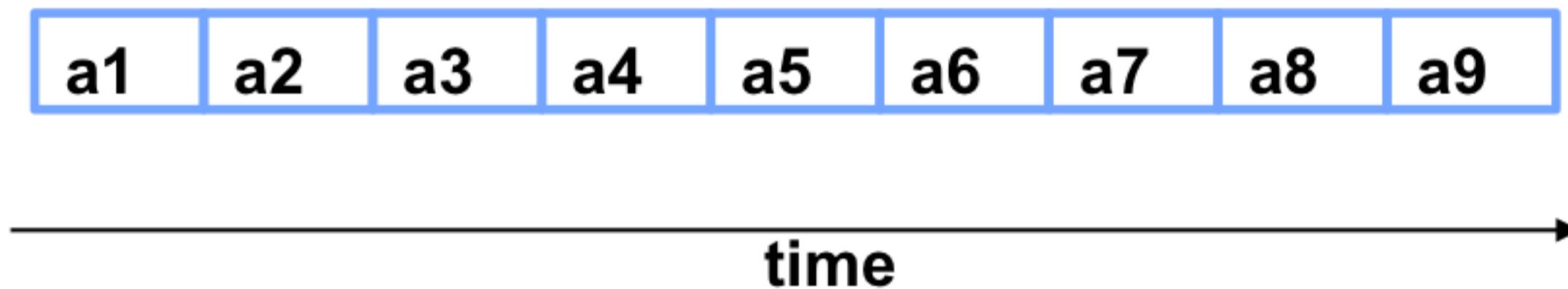
- Our cube has 64 lights
 - We would like to allow any combinations of lights to be on
 - So you can create any light pattern that you would like
 - If every light is independent
 - Need at least one bit per light (on, off)
 - State of lights is 64 bits (4x4x4 array)
- Our computer only has around 20 digital output pins
 - And 20 is less than 64.
 - Need to communicate 64 bits over 20 pins.
- How are we going to do this?

PIN MULTIPLEXING

Solving the Pin Problem

- The pin problem is very common
 - Your keyboard has many keys
 - But not that many wires that connect it to a computer
 - Your display has millions of pixels
 - And the cable has only a few wires
- Clearly need to get more than 1 bit/wire
 - The way computers do it is serial communication
 - Transmit different bits at different times

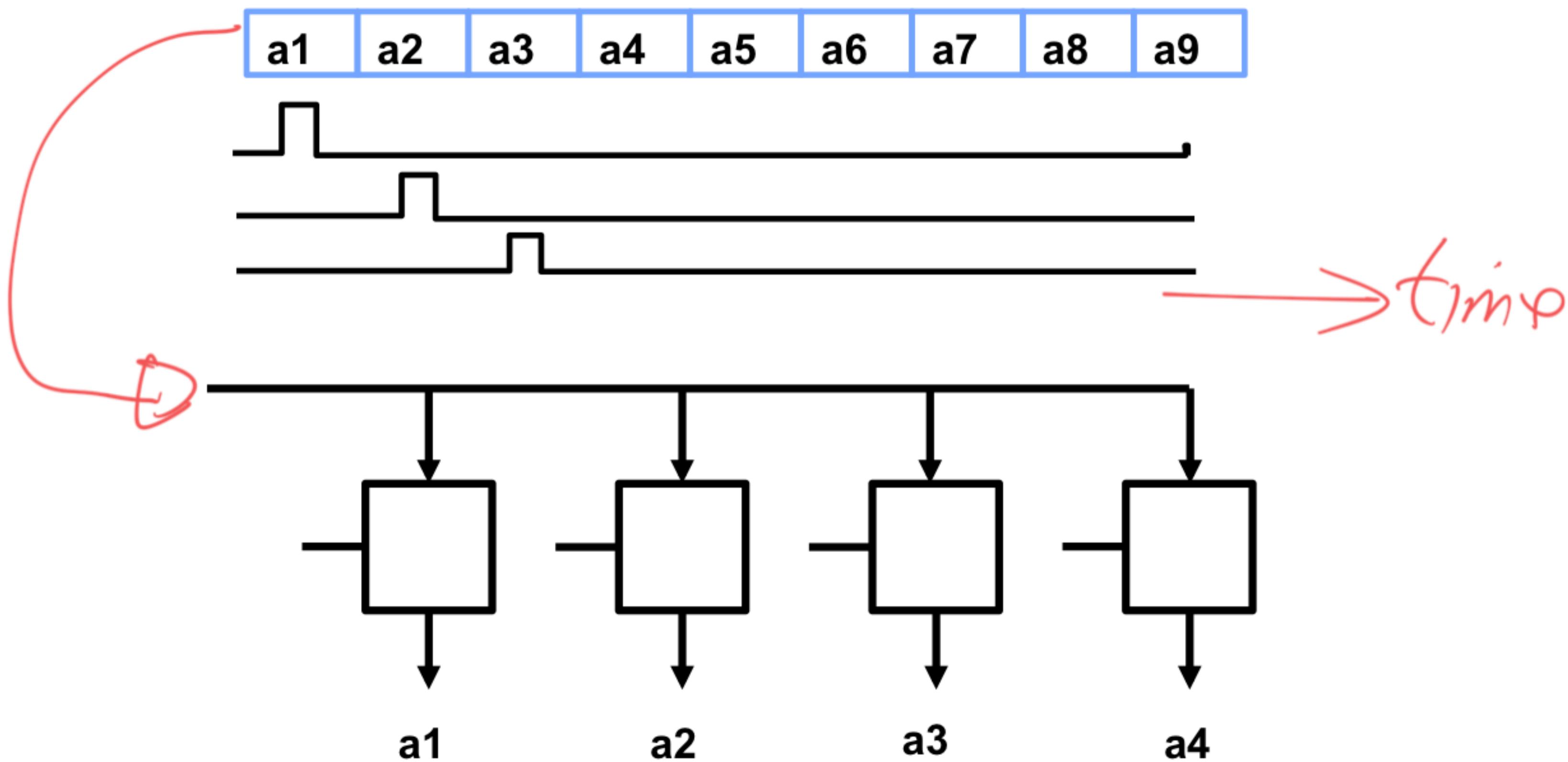
Serial Communication



- Also called
 - Time division multiplexing
 - Or just multiplexing
- Heavily used
 - Ethernet
 - Serial ports
 - USB (universal serial bus)
 - I²C, SPI, HDMI, JTAG, etc.

Serial to Parallel Converters

- If you use a string of memory cells can get all the bits
 - Load each memory cell at the “right” time

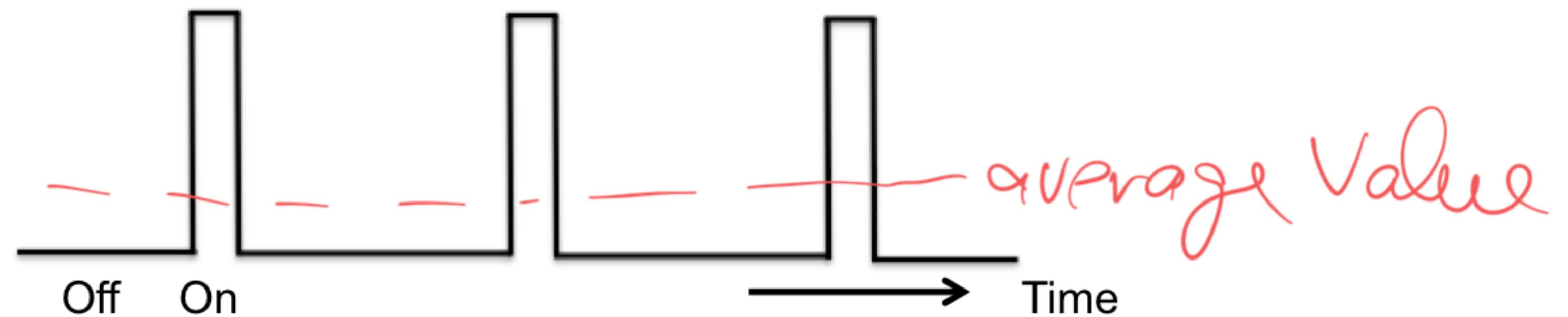


Dealing With Lights and Switches

- Serial communication works well between two chips
 - And there are some LEDs that have a chip packaged w/ them
 - But not most
- LEDs and switches don't have memory to store information
 - So simple serial communication doesn't work
- Use the fact that humans are slow (in computer time)

Optical Persistence

- We can take advantage of the fact that our eyes are “slow”
- If we turn an LED ON and OFF faster than our eyes can “see” then we will perceive a constant light intensity.
 - The flicker fusion rate is around 30Hz
 - Your eye averages the signal

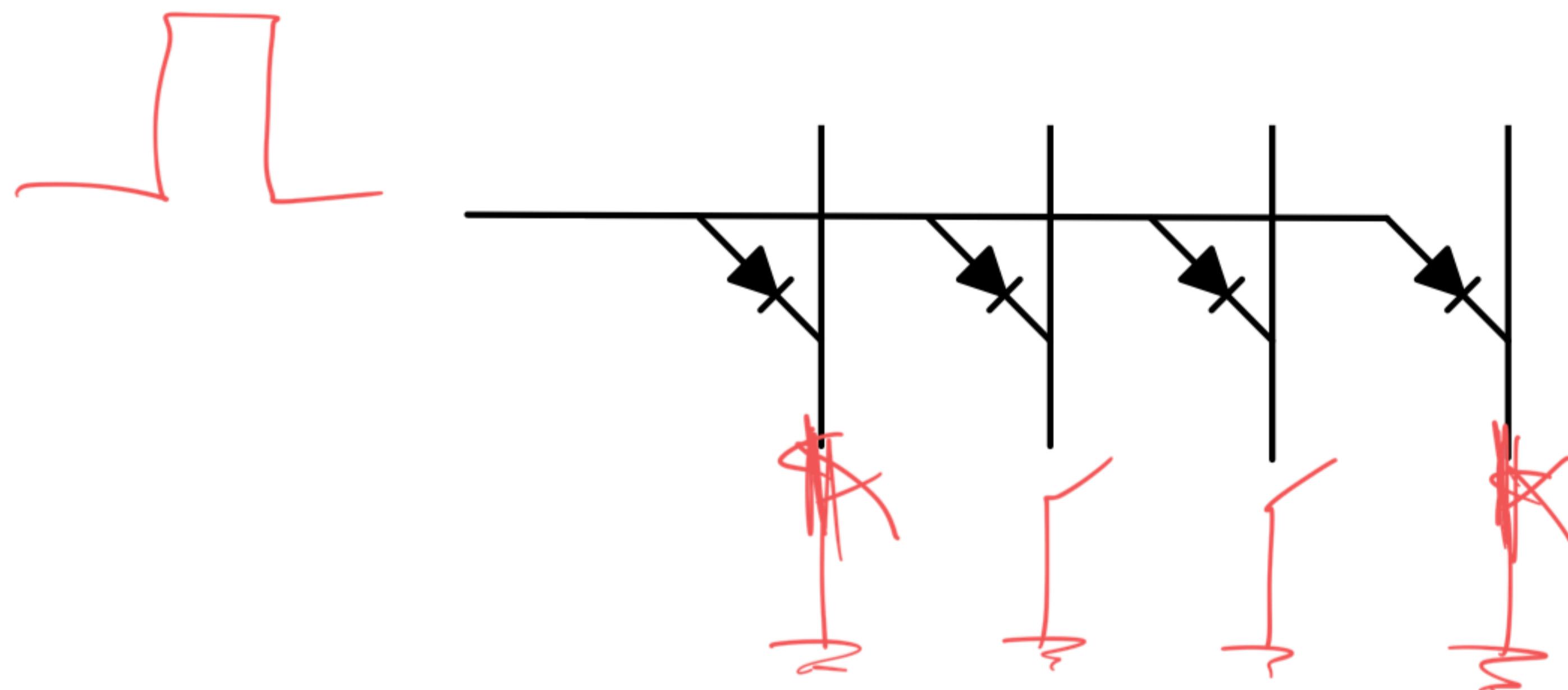


- Electronics takes advantage of the fact that your eyes are slow
 - Creates more outputs than wires
 - Creates analog light output values on digital pins

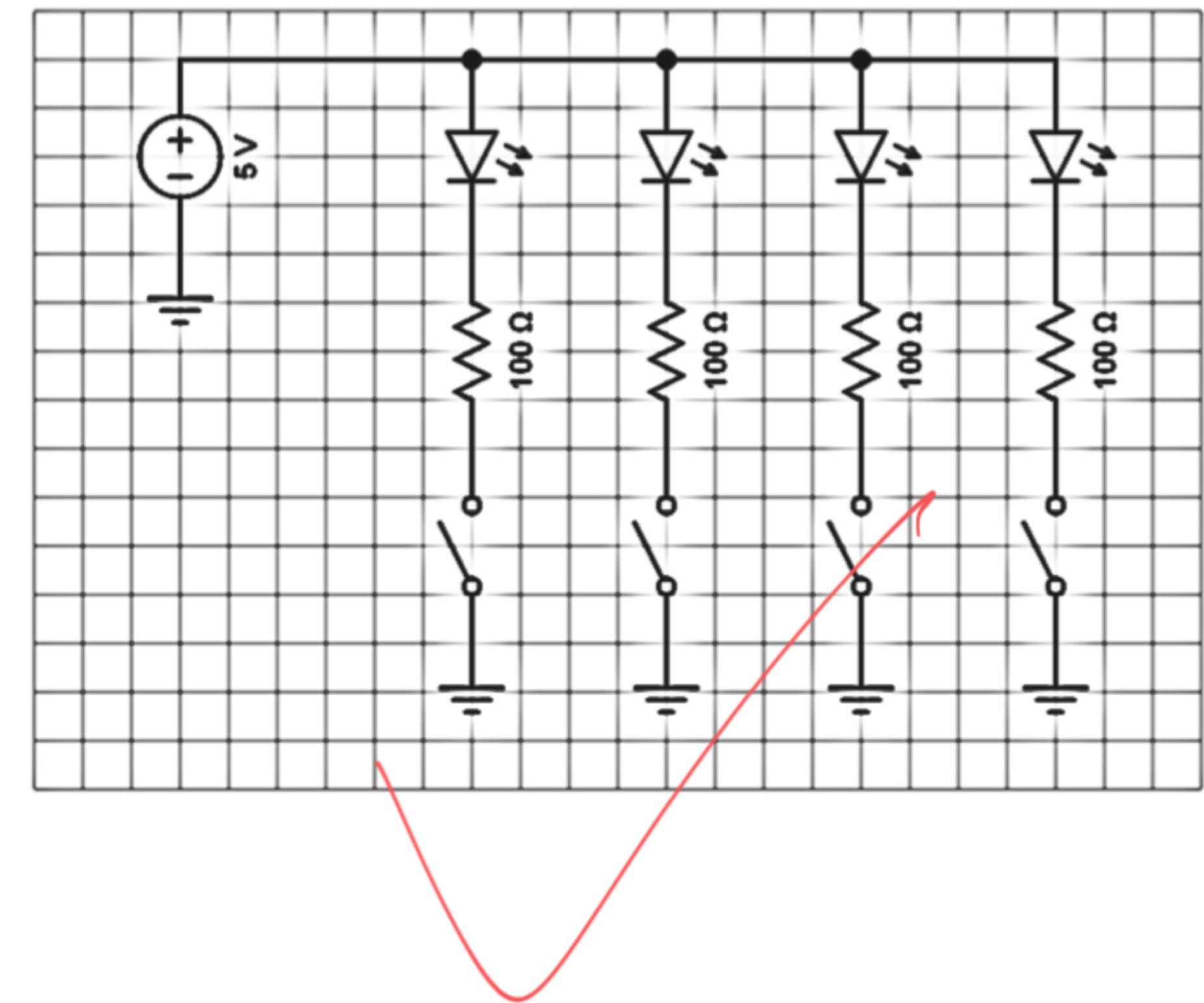
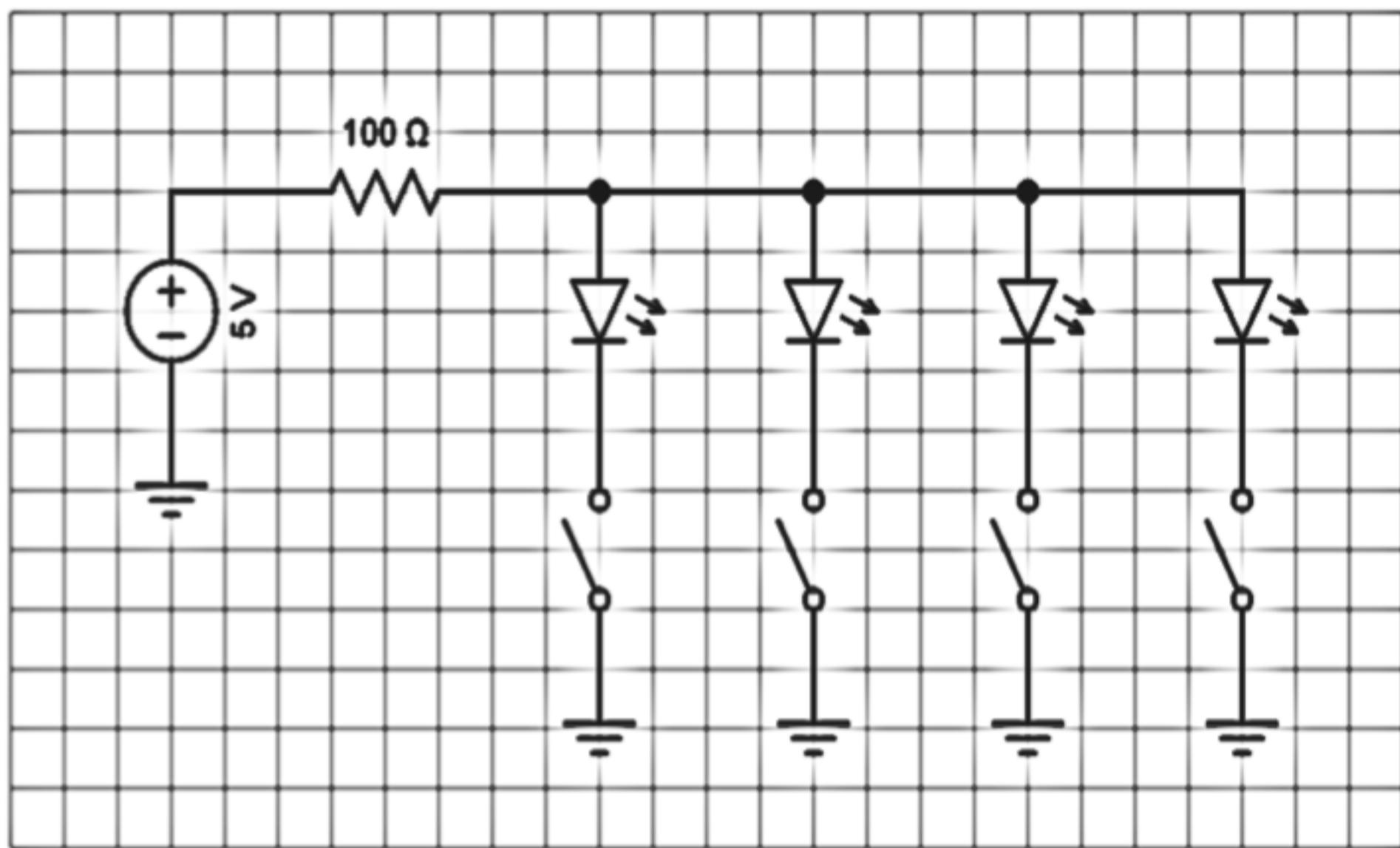
Basic Approach

- If I have many lights, I don't need to turn them all on at once
 - I can create different slots in each time period
 - Say I created 8 slots
 - Then I only need to light $64 / 8$ lights in each slot
- But how do I get the right lights to light up at the right time?
 - Leverage the diode nature of the LED

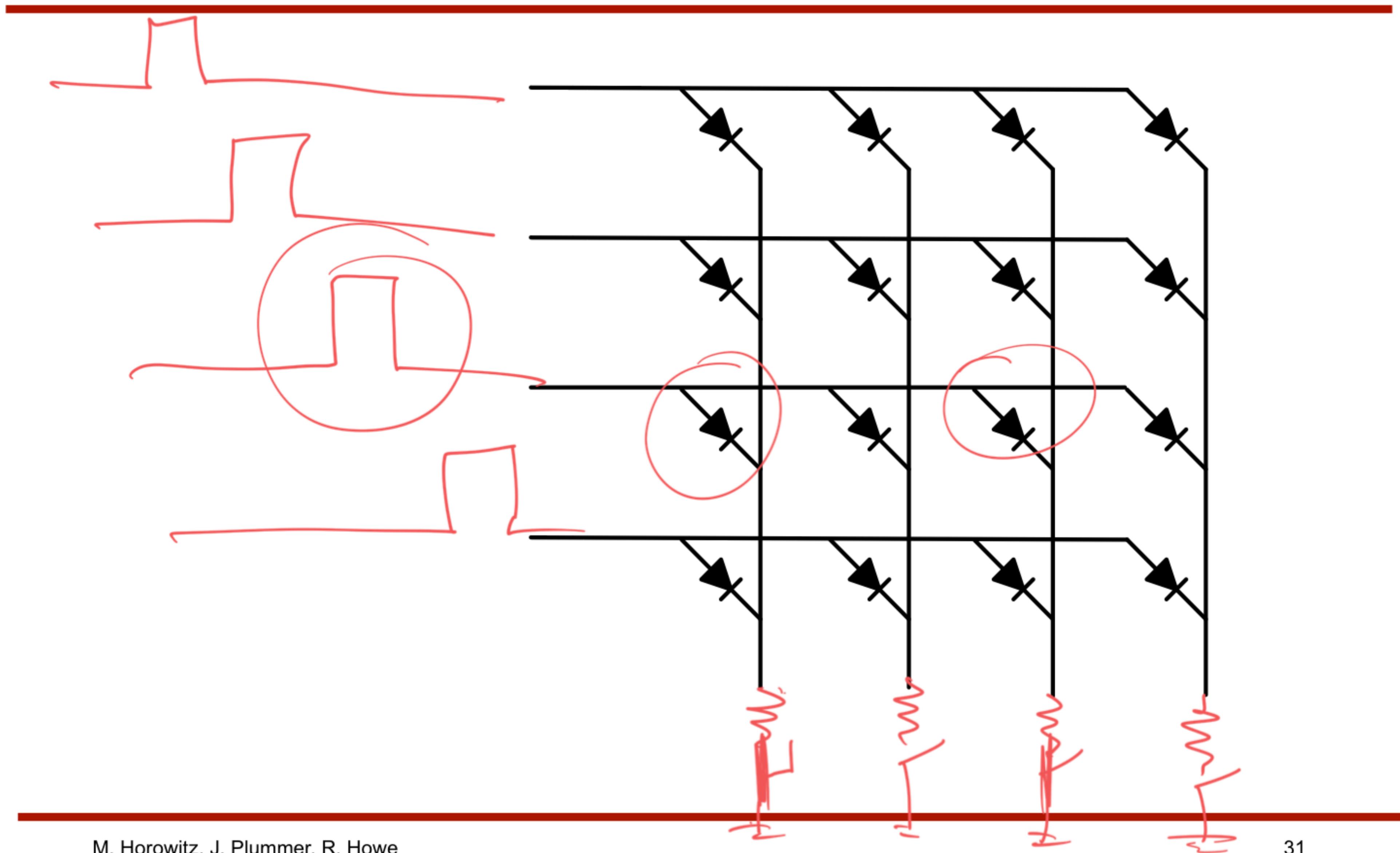
LED Wiring Diagram



LED Wiring Diagram - EveryCircuit

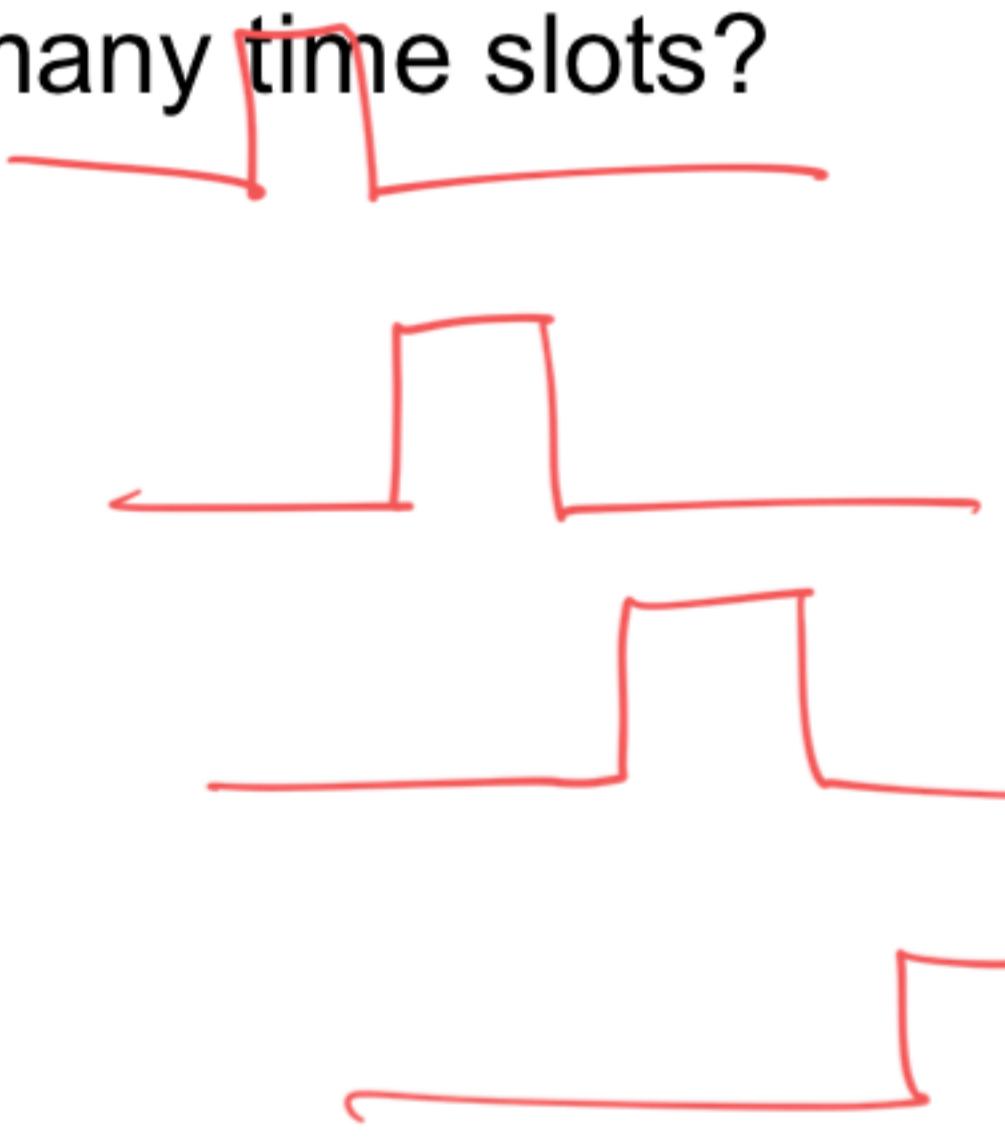


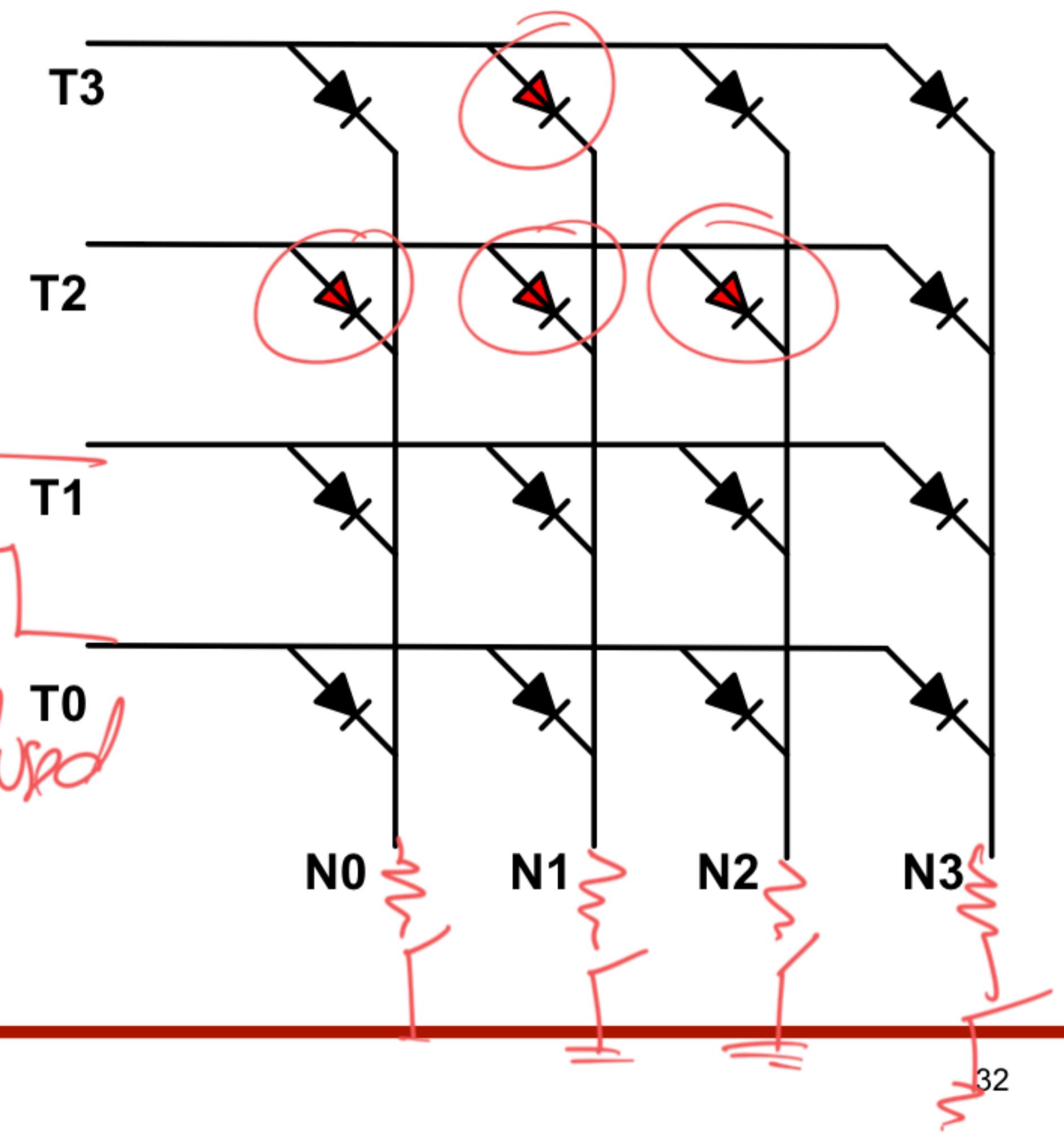
LED Array Wiring Diagram



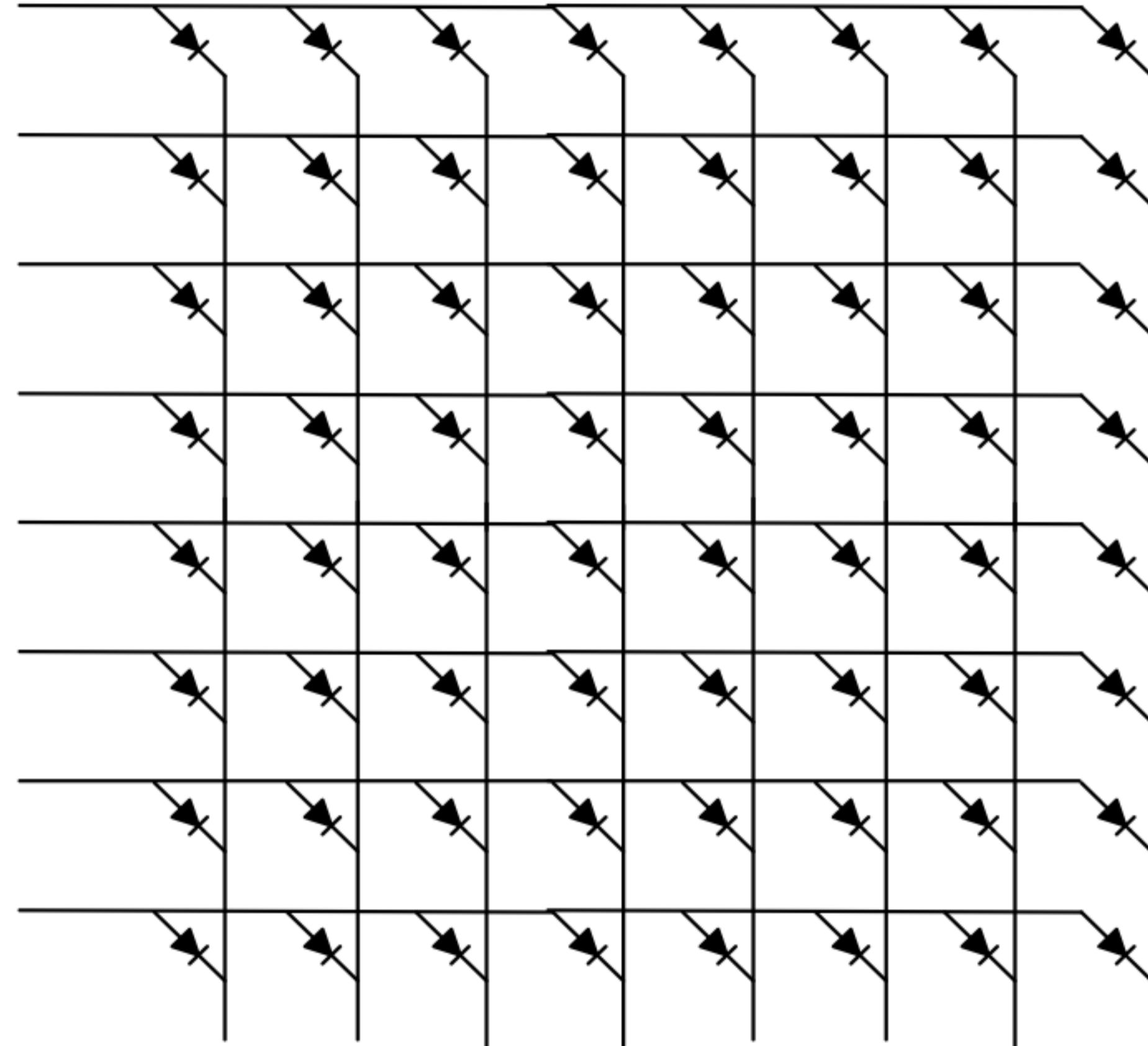
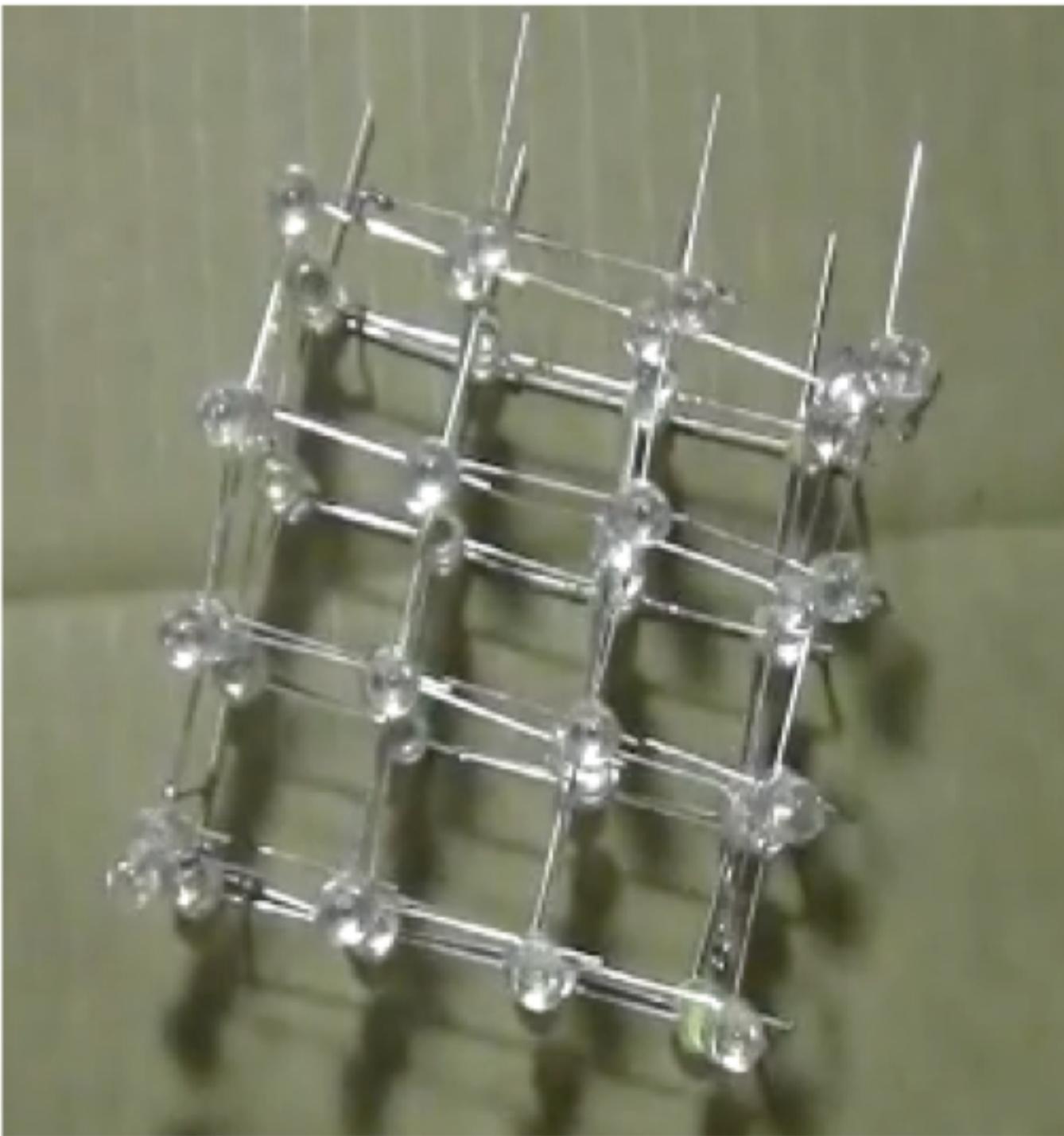
Testing Our Understanding

- If we use time division multiplexing to drive the LED array
 - How do you light up the red LEDs?
 - How many time slots?


T3 high: N1 switch closed
T2 high:



Driving the LED Cube



- Friday's prelab lecture will discuss how to physically construct the cube and how to electrically drive it from your Arduino using the multiplexing methods we discussed today.

Learning Objectives

- Understand that some diodes can produce light from electricity
 - Color is related to the diodes forward voltage
 - 2V (red) to 3V (green and blue)
 - And be able to use LED lights in your design
 - Limit current through diode to 20-40mA
- Understand it is possible to control N^2 lights
 - Using only $2N$ wires
 - Scan/drive a row at a time