E40M
LEDs, Time Multiplexing

Reading

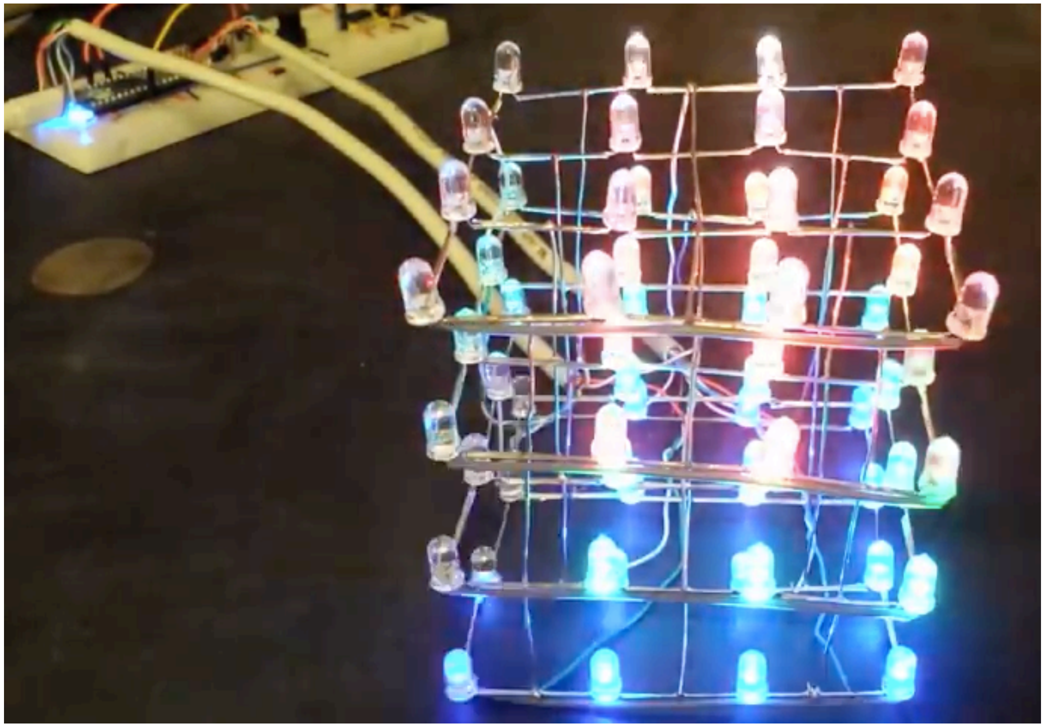
- Course Reader 2.6 – LEDs
- Course Reader 5.8 - Multiplexing
- LEDs
  - https://learn.adafruit.com/all-about-leds
  - http://dangerousprototypes.com/docs/Basic_Light_Emitting_Diode_guide
- LED Multiplexing
  - http://www.instructables.com/id/Multiplexing-with-Arduino-and-the-74HC595/step1/What-Is-Multiplexing/

LED Cube – Project #3

- In the next several lectures, we'll study

- Concepts
  - Coding
  - Light
  - Sound
  - Transforms/equalizers

- Devices
  - LEDs
  - Analog to digital converters

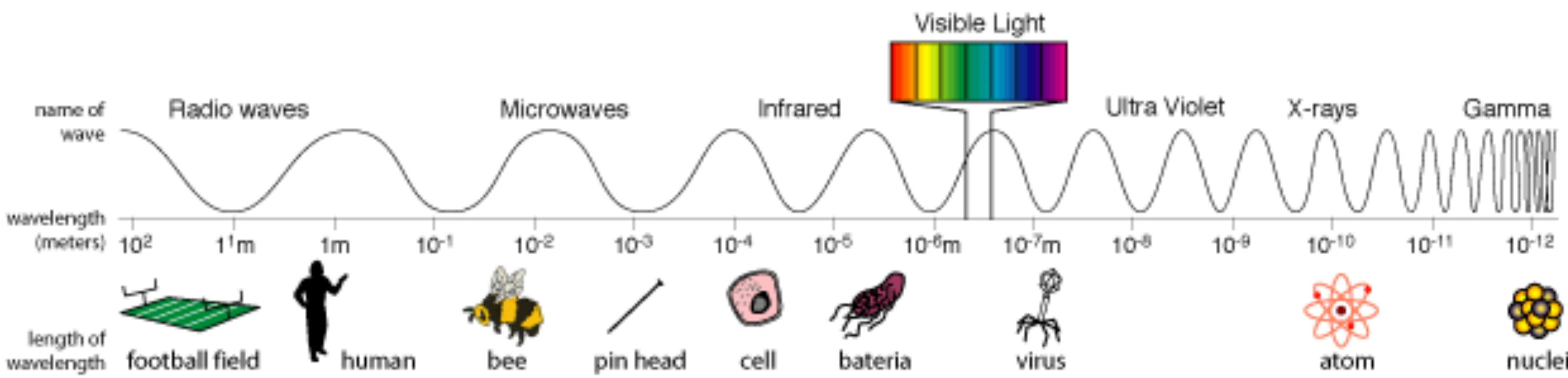


Music responsive LED Cube

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/λ
- Part of electromagnetic spectrum:
- All waves transport power



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

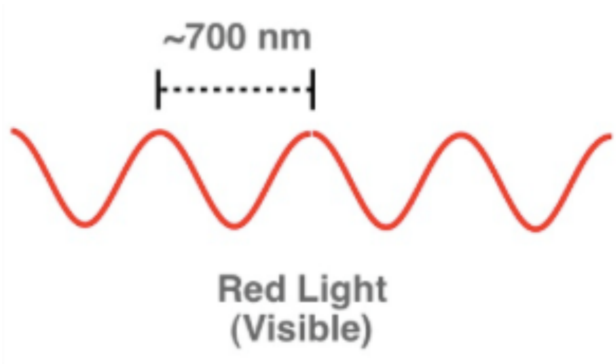
Quantum Mechanics - Photons

- 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 = 6.6E-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 = 1.6E-19 J
  - hc = 1.24ev-μm

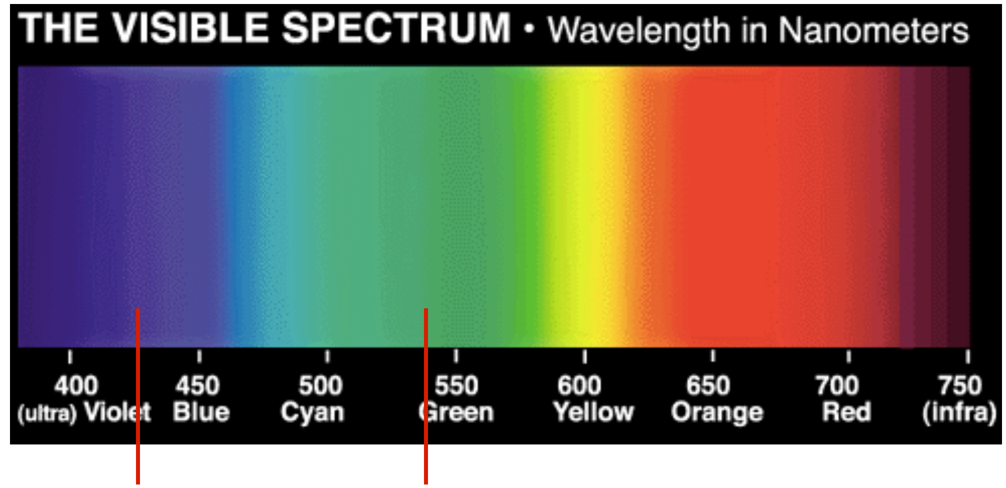
Energy of Photons

- Visible light = 0.63μm (red), 0.55μm (green), 0.47μm (blue)
  - Infrared lights, used in remotes are around 1μm
- 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

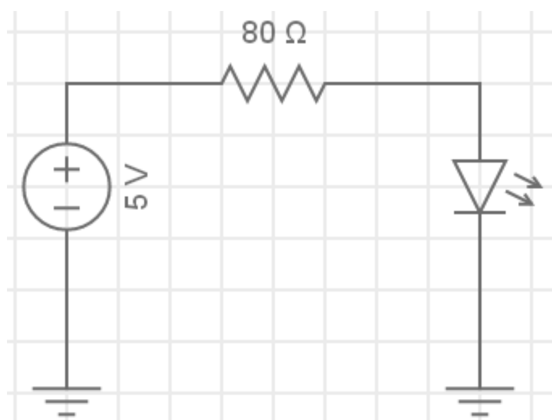
Energy of Photons



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



3 eV 2.3 eV



- 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/m^2
  - 300 lux - Office lighting
  - 10k lux - Full sunlight (not direct)
  - 32k – 100k lux - Direct sunlight

- At green (550nm), 680 lux = 1W/m^2
  - Other freq require less lux for 1W/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

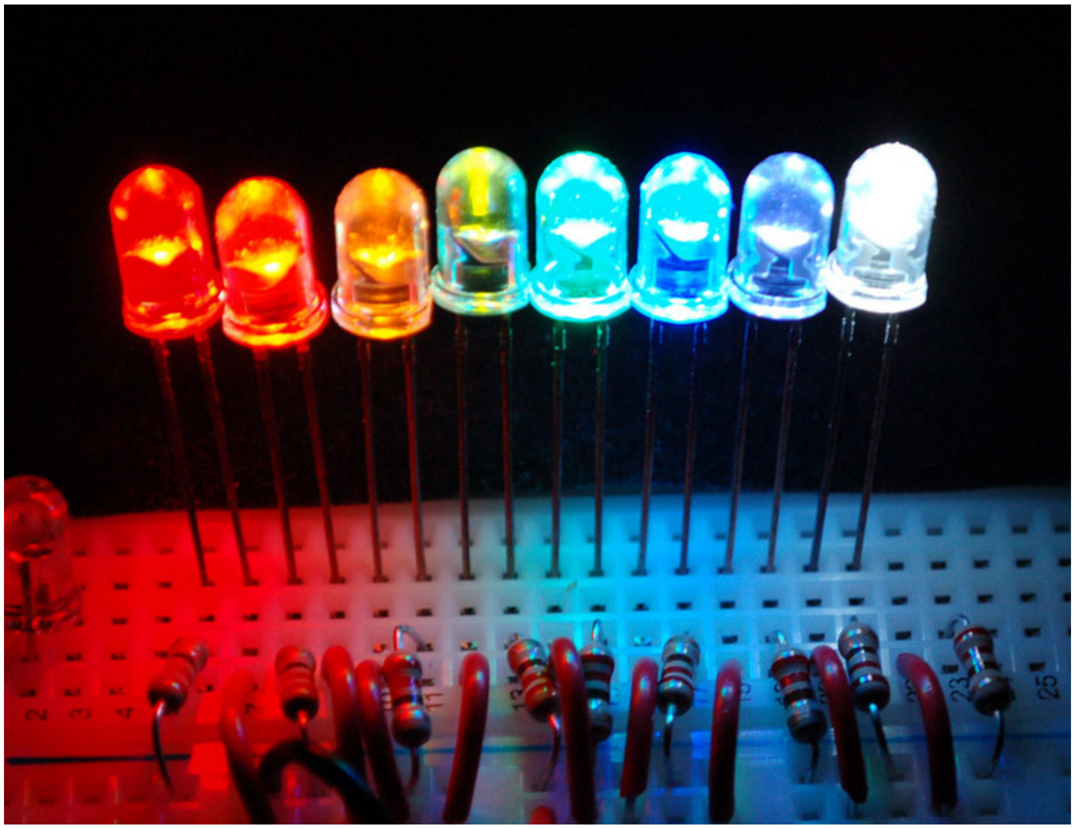
LEDs

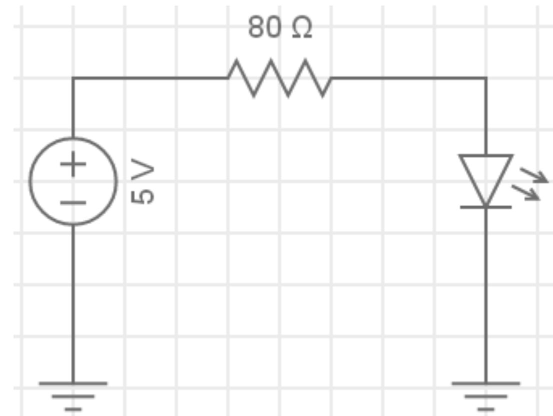
Generating Light from Electricity

- Use heat

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

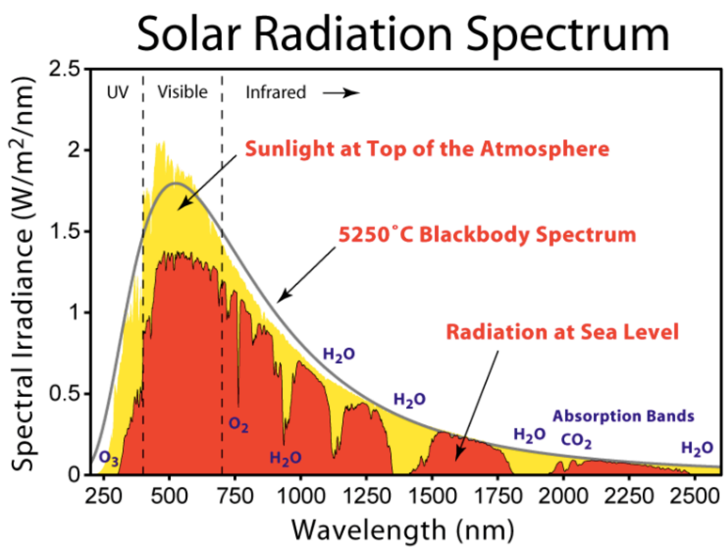
- For some materials
  - "Direct band-gap" materials
  - This energy can emit a photon

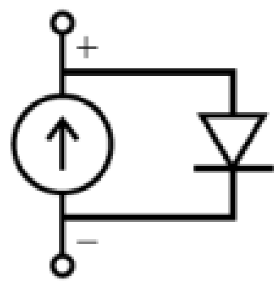
LED Voltage Drop and Color

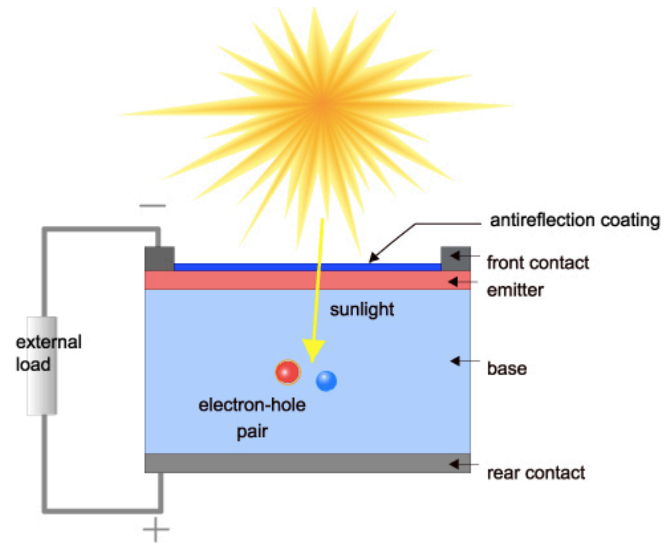
- The color of the photon depends on energy
- The energy available depends on the voltage
  - Each electron that flows can create one photon
    - If it takes two, the two have to happen at the same time (unlikely)
  - V_f for a blue LED is larger than for a Red LED

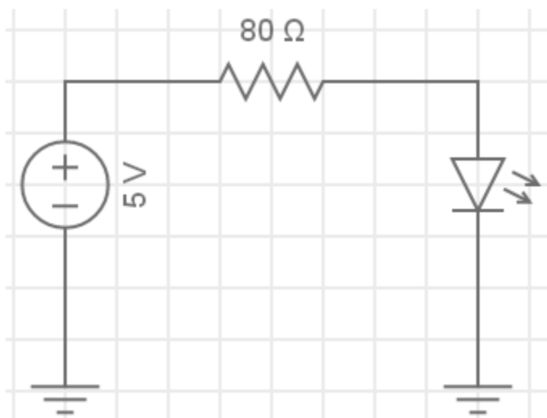
DIALIGHT P/N	EMITTED COLOR	MATERIAL	LENS COLOR	LUMINOUS INTENSITY (mcd) If = 20 ma			DOMINANT WAVELENGTH (nm) If = 20 ma			FORWARD VOLTAGE (V) If = 20 ma			VIEWING ANGLE ° DEGREES
				MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
598-8010-107F	RED	AlInGaP	Water Clear	30	40	80	630	635	642	1.7	2.2	2.4	140
598-8020-107F	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

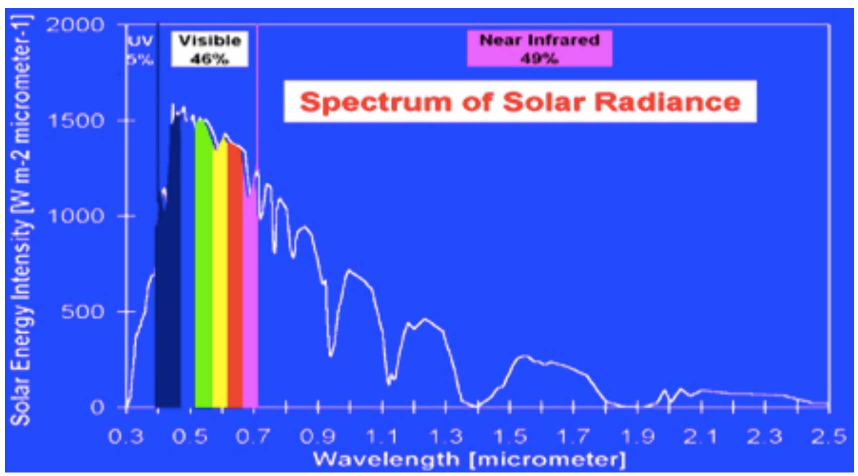
FYI – How Do Light Emitting Diodes and Solar Cells Actually Work?





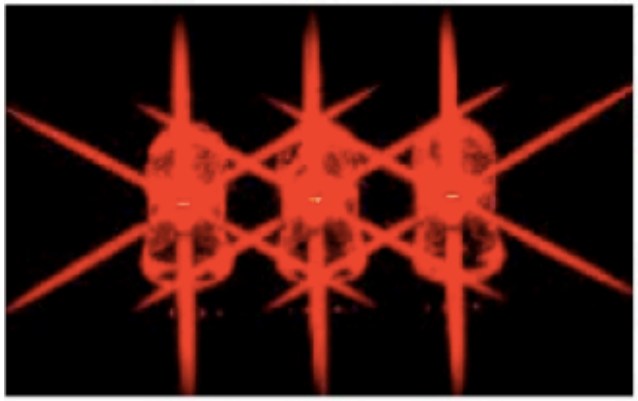


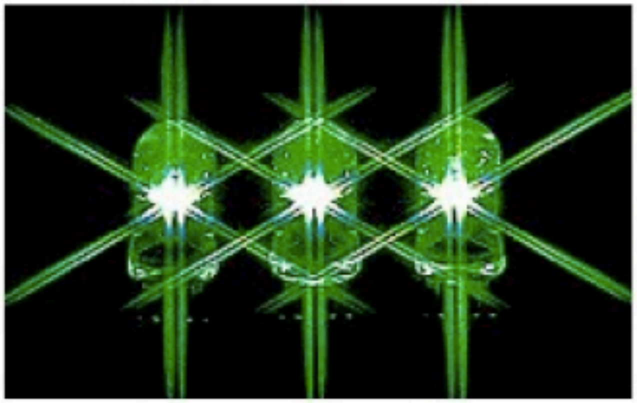


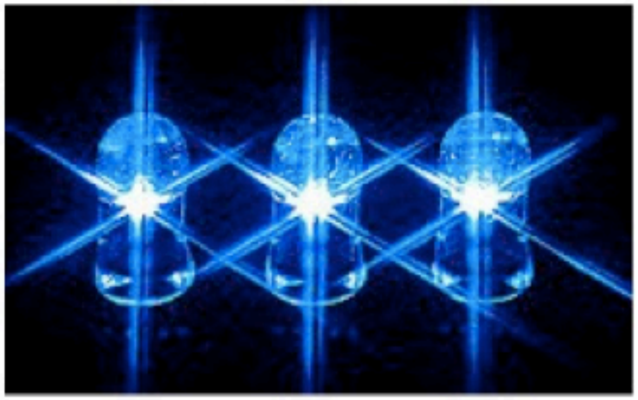


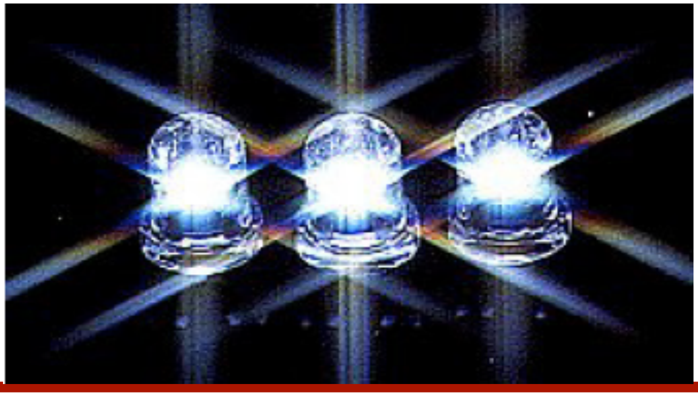
FYI – Full Color LED Displays and Solid State Lighting (https://en.wikipedia.org/wiki/Light-emitting_diode)

- 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.









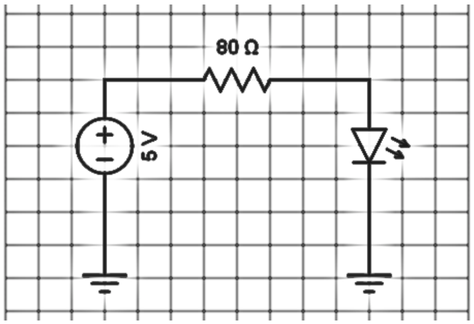
White LEDs utilize blue emission of GaN or InGaN to excite fluorescence in a phosphor which emits yellow light. Blue + yellow appears white to the eye. Alternatively, phosphors are used that emit green and red. Blue + green + red = white

Using LEDs

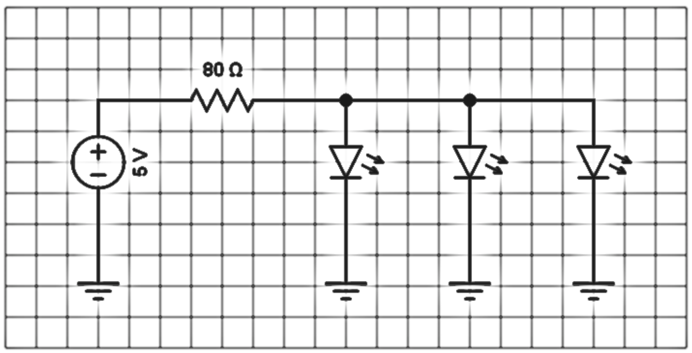
- They are diodes
  - Current only flows in one direction
  - Voltage not very sensitive to current
    - Often have an internal resistance

- 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 = 150Ω; 2V/20mA = 100Ω
    - And the Arduino pin has a resistance of 30Ω

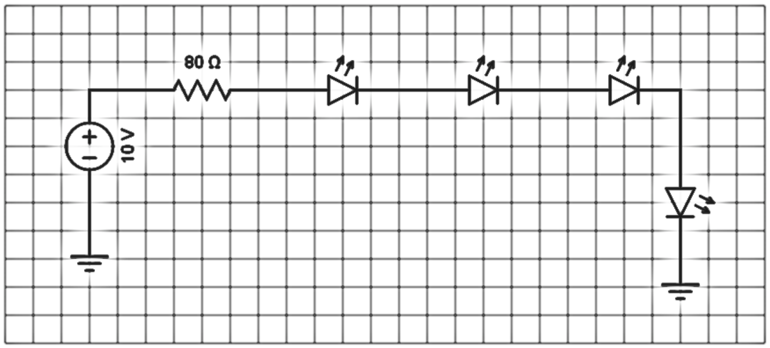
Using LEDs in Simple Circuits



- Always use a series R with an LED



- Do not wire LEDs in parallel

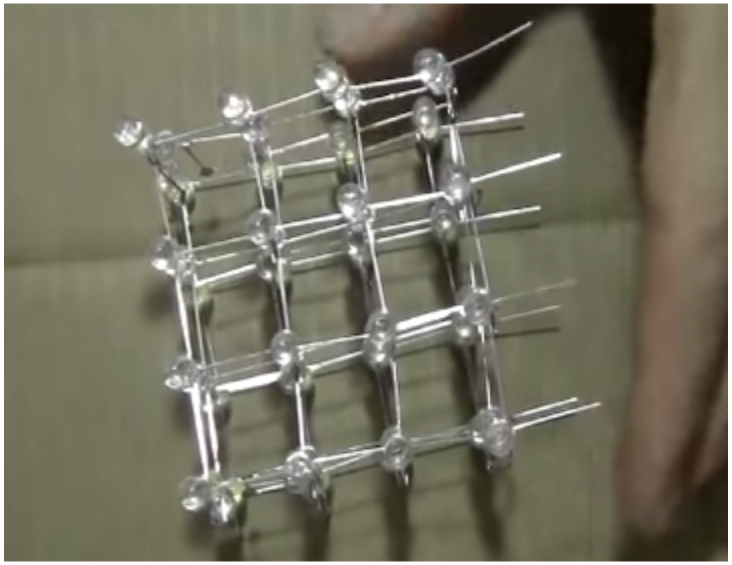


- Series connection is fine with a higher V

LED CUBE

LED Cube

- You are building a 4 x 4 x 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.

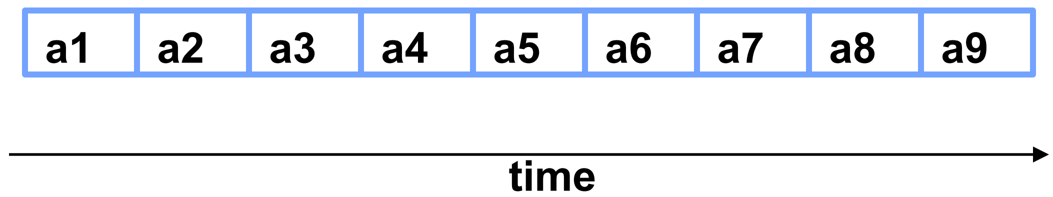
- How are we going to do this?

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

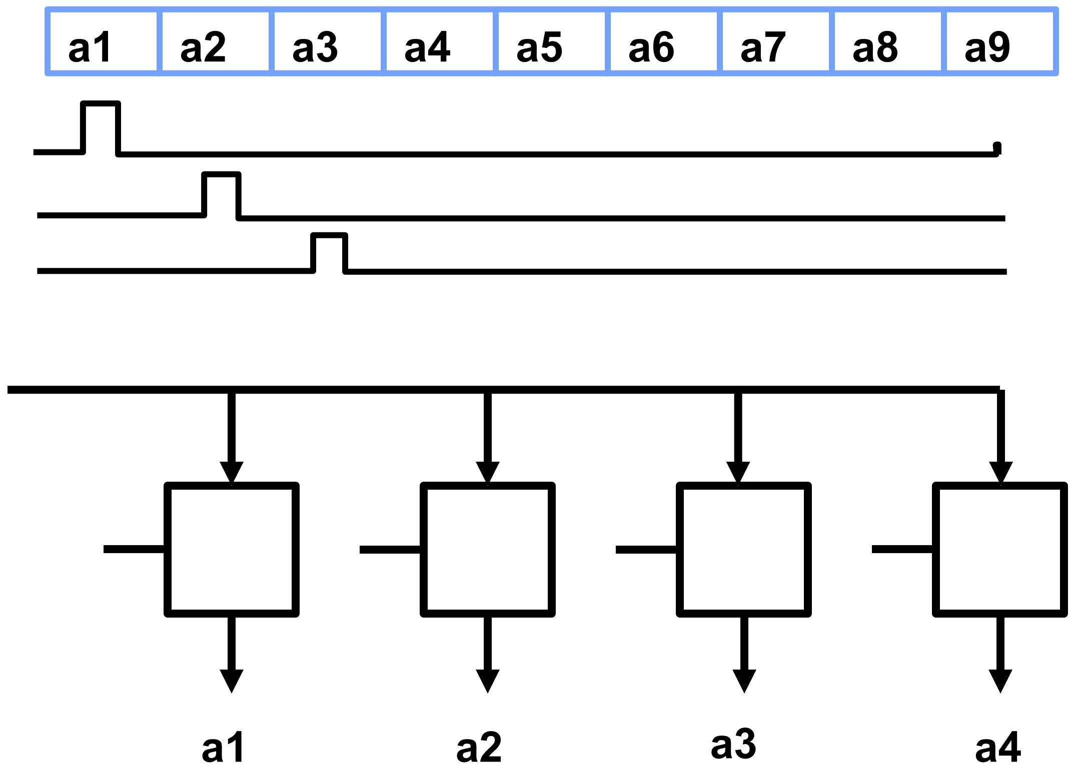


- Also called
  - Time division multiplexing
  - Or just multiplexing

- Heavily used
  - Ethernet
  - Serial ports
  - USB (universal serial bus)
  - I^2C, 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

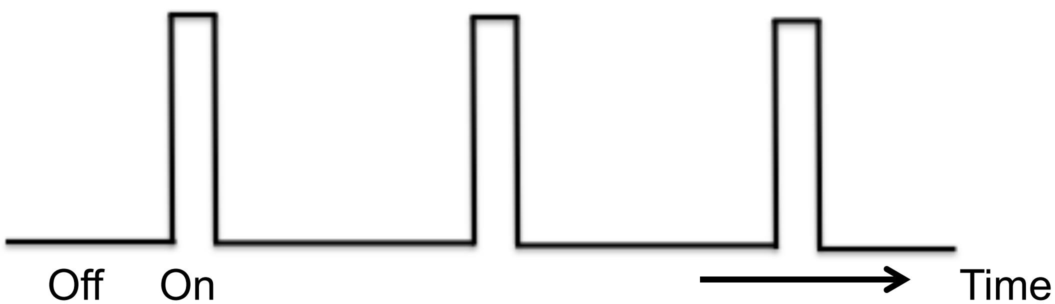
- Serial communication works well between two chips
  - And there are some LEDs that have a chip packaged w/ them
    - But not most

- 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



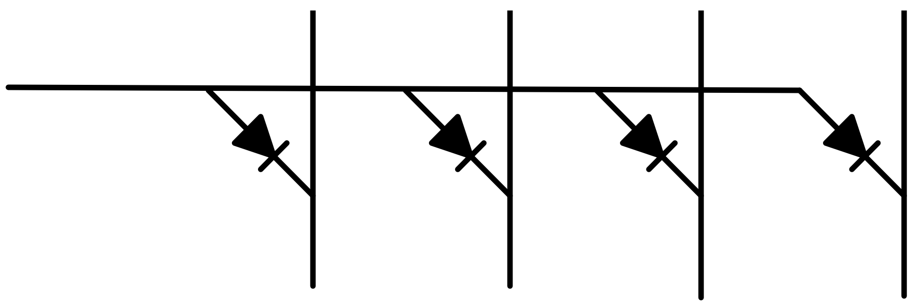
- Electronics takes advantage of the fact that your eyes are slow
  - Creates more outputs than wires
  - Creates analog light output values on digital pins

Basic Approach

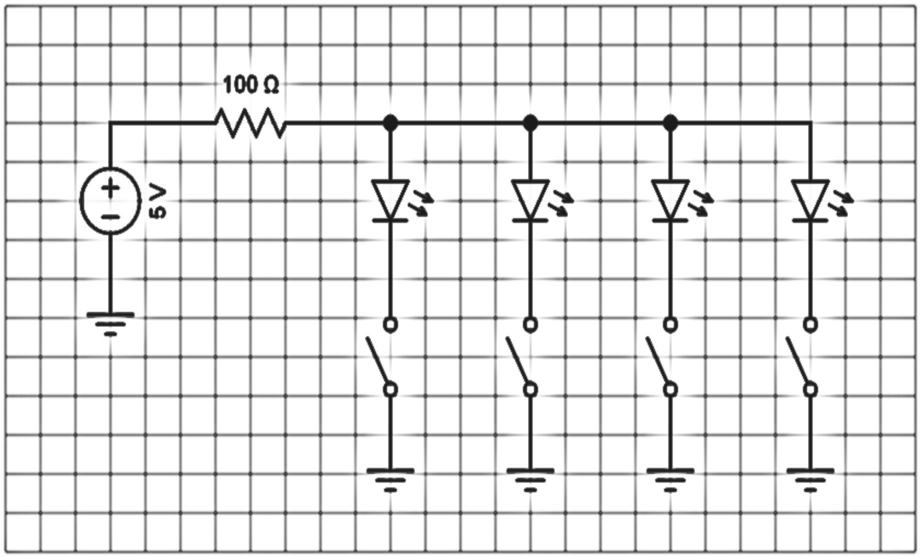
- If I have many lights, I don’t need to turn them all on at once
  - I can create different slots in each time period
    - Say I created 8 slots
  - Then I only need to light 64 / 8 lights in each slot

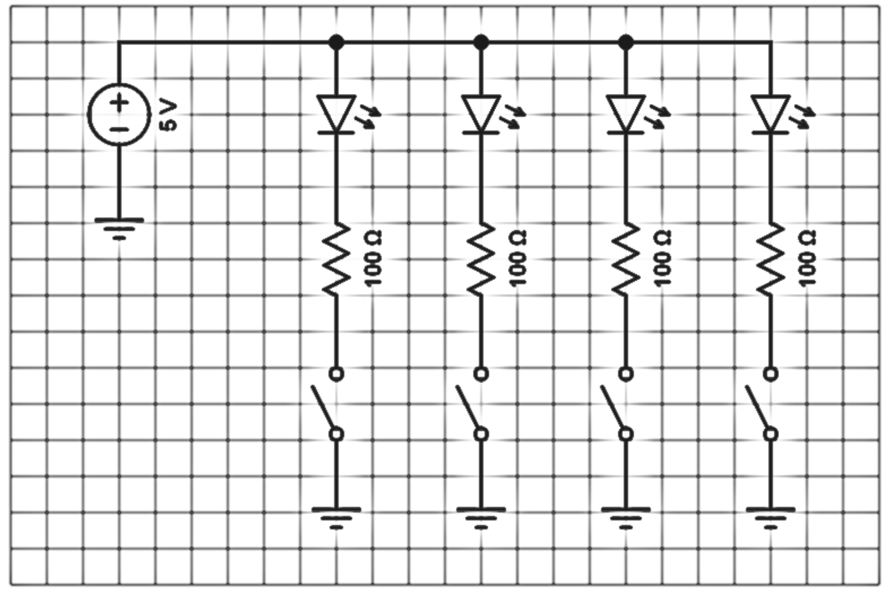
- But how do I get the right lights to light up at the right time?
  - Leverage the diode nature of the LED

LED Wiring Diagram

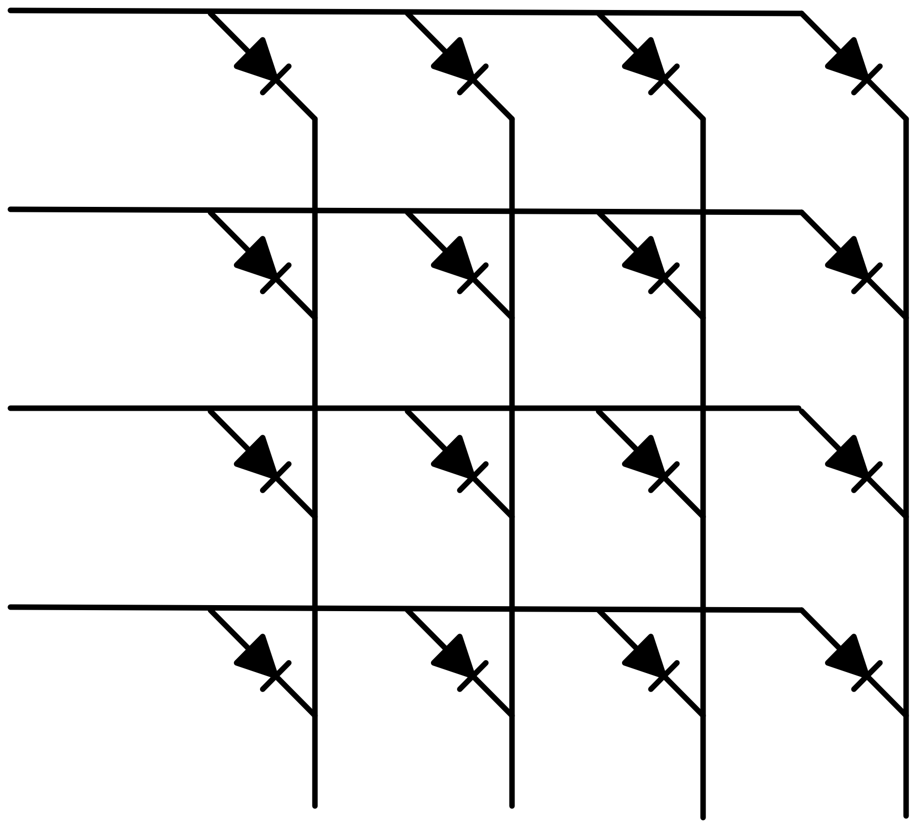


LED Wiring Diagram - EveryCircuit



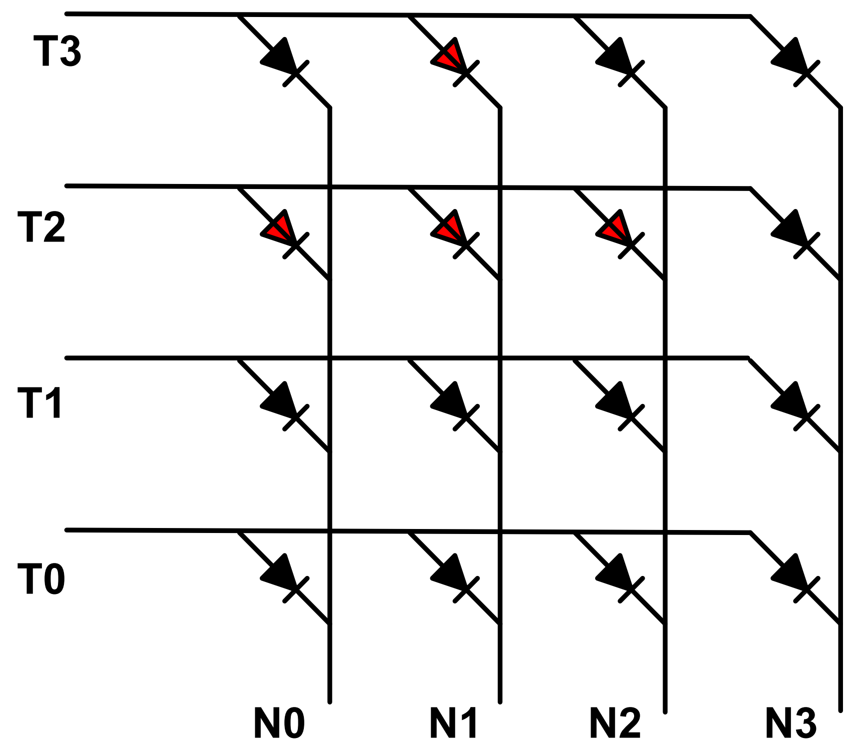


LED Array Wiring Diagram

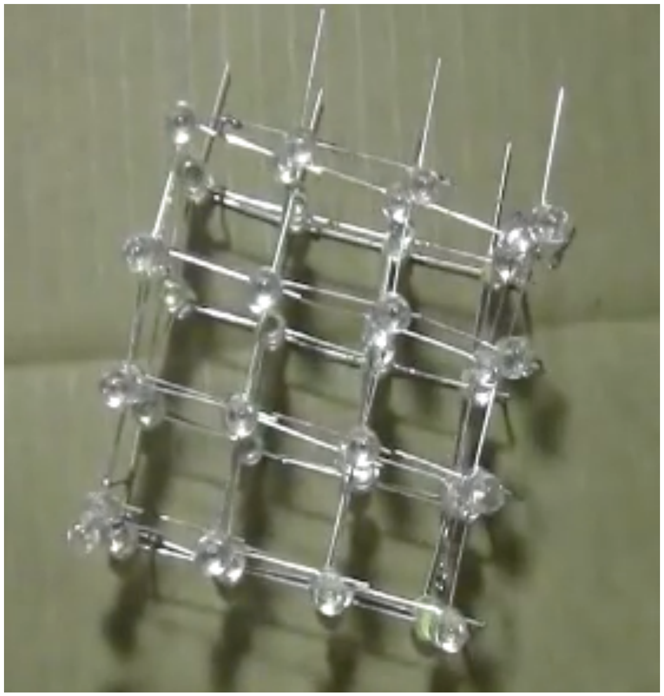


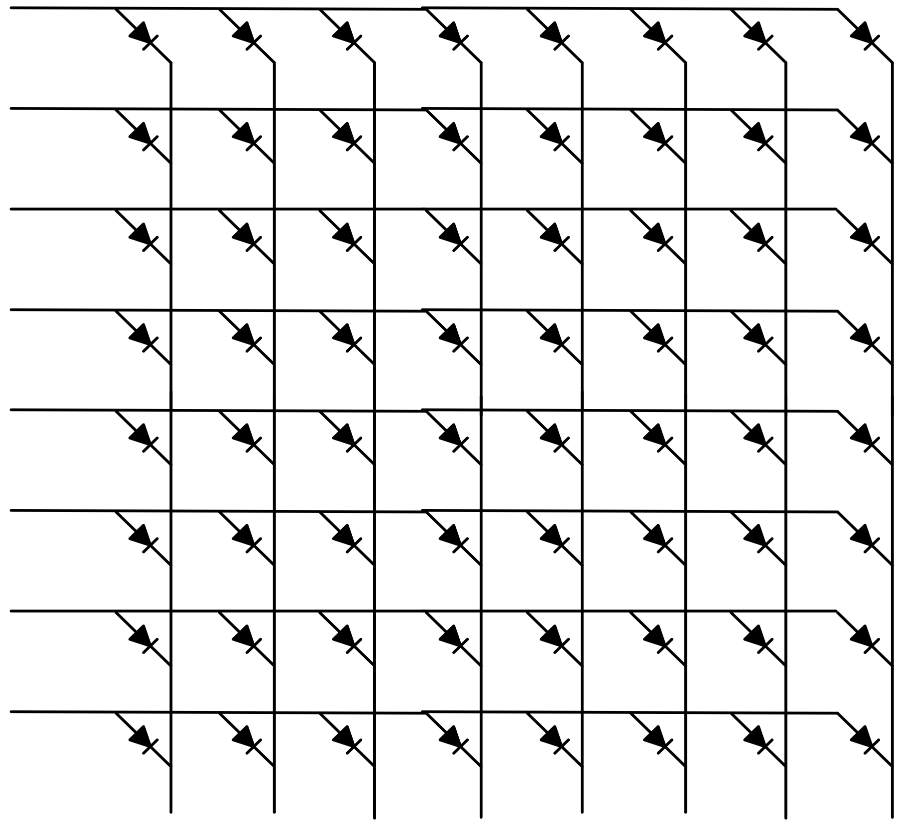
Testing Our Understanding

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



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