E40M
LEDs, Time Multiplexing

Reading

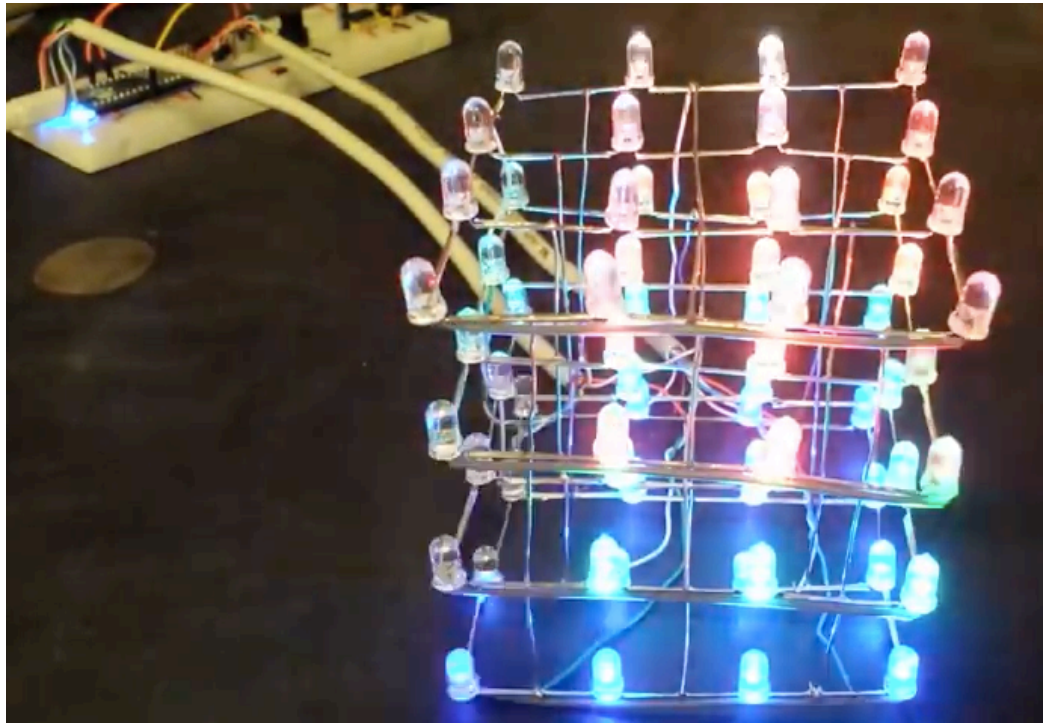
- Course Reader 2.6 – LEDs
- Course Reader 5.8 - Multiplexing
- LEDs
  - https://learn.adafruit.com/all-about-leds
  - http://dangerousprototypes.com/docs/Basic_Light_Emitting_Diode_guide
- LED Multiplexing
  - http://www.instructables.com/id/Multiplexing-with-Arduino-and-the-74HC595/step1/What-Is-Multiplexing/

LED Cube – Project #3

- In the next several lectures, we'll study

- Concepts
  - Light
  - Sound
  - Transforms/equalizers
  - Multiplexing

- Devices
  - LEDs
  - Analog to digital converters

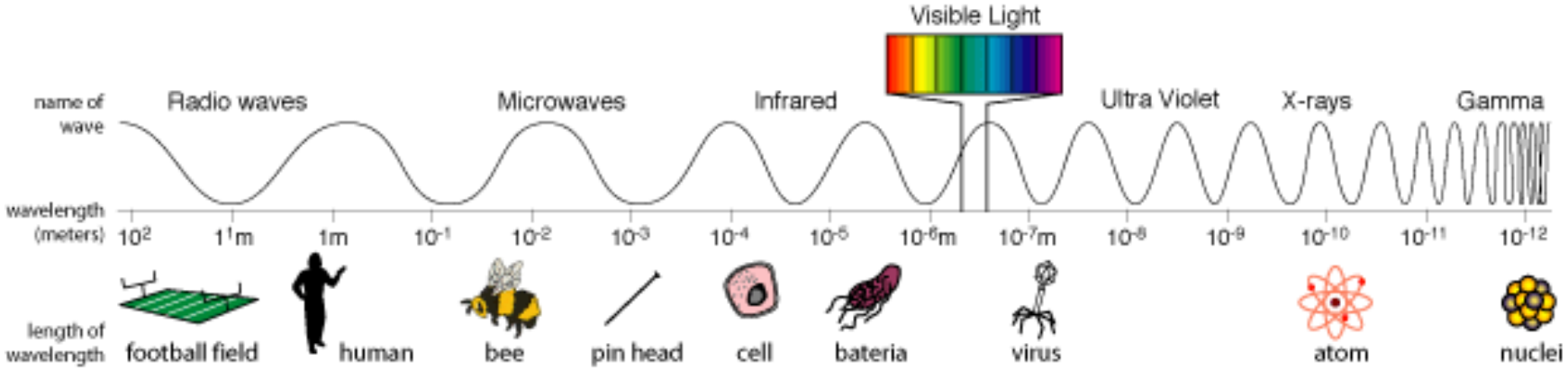


Music responsive LED Cube

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

What is Light?
(A Little Physics Review)

- 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)

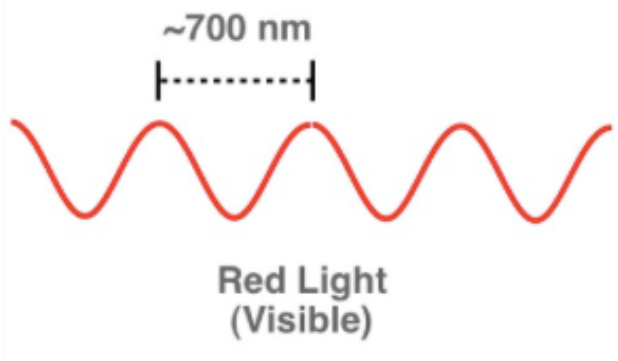
Quantum Mechanics – Photons (A Little Physics Review)

- 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

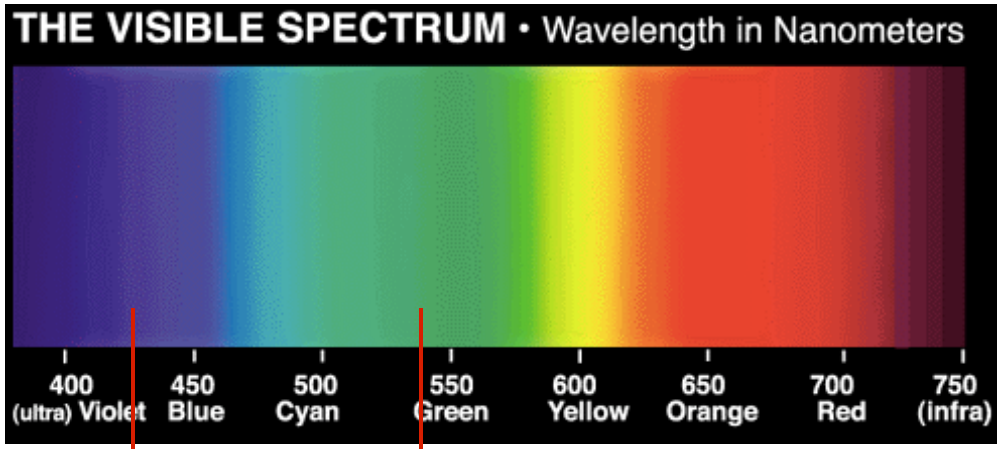
- Each photon has a precise energy
  - Set by the wavelength
  - $E = hc/\lambda$; where h is Planck's constant = 6.6E-34 Jsec

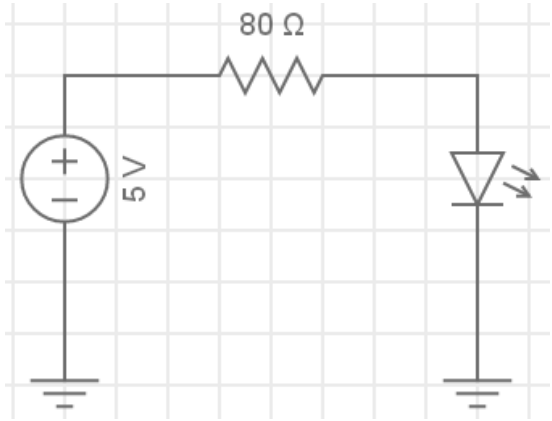
- It will be useful to calculate energy in eV (electron volts)
  - This is the energy needed to move one electron, one volt
  - q * 1V = 1.6E-19 J
  - hc = 1.24ev-μm

Energy of Photons
(A Little Physics Review)



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





- 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

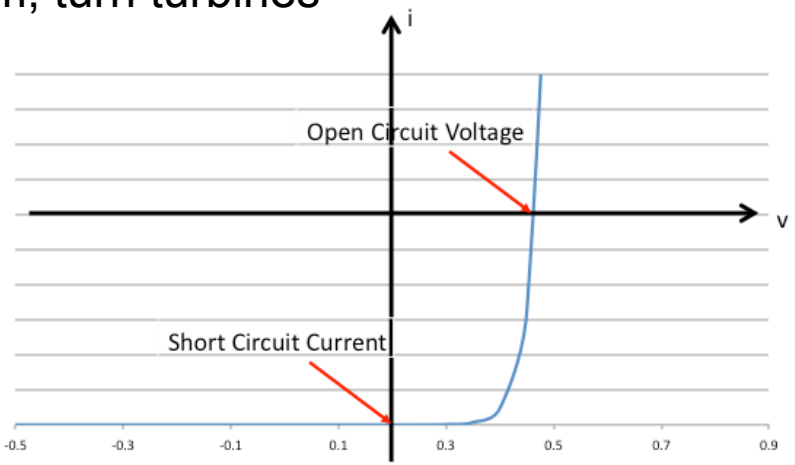
- Total light emitted is measured in lumens
  - Comparing light bulbs compares lumen output
  - 60Watt bulb is about 800 lumens

- Illumination on a surface is in lux
  - Lumens/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 (e.g. photodiodes)
  - Can directly generate electricity with some of the energy

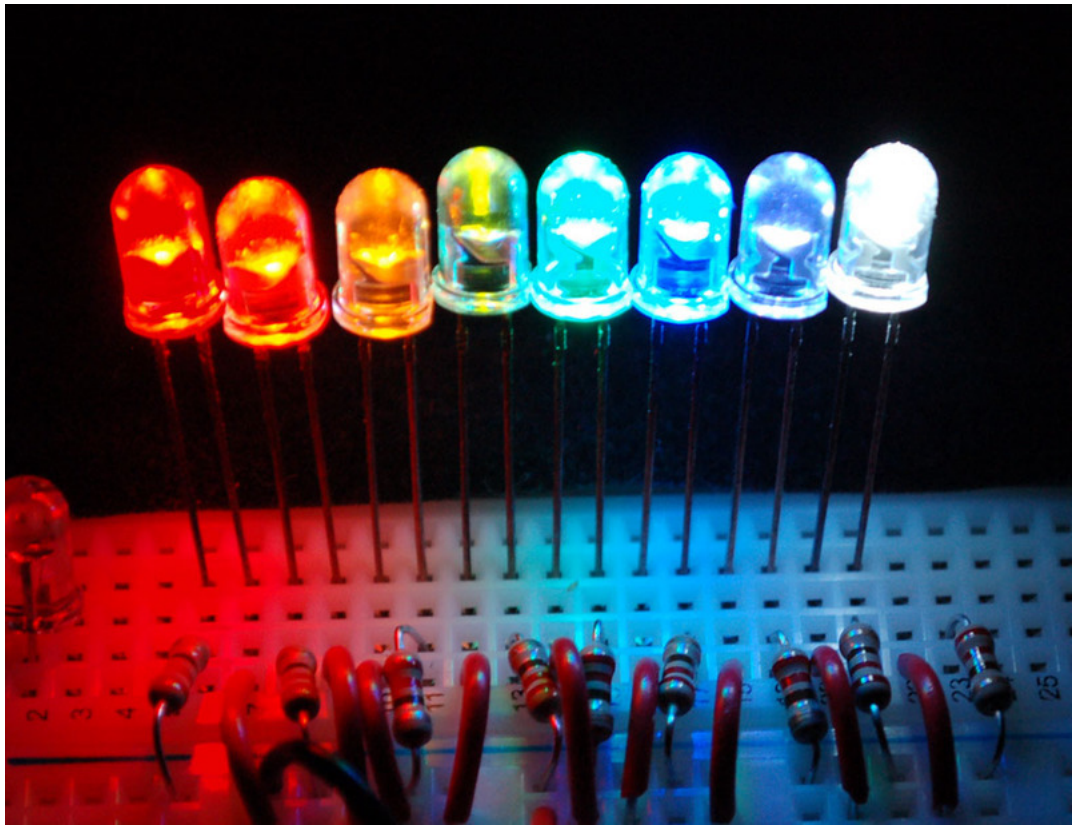


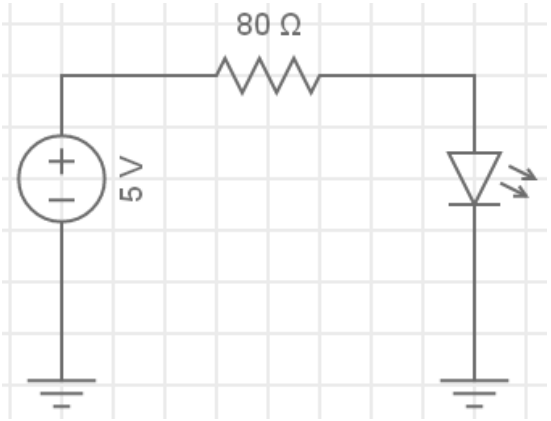
Generating Light from Electricity

- Use heat

Use plasma

Light Emitting Diodes - LEDs

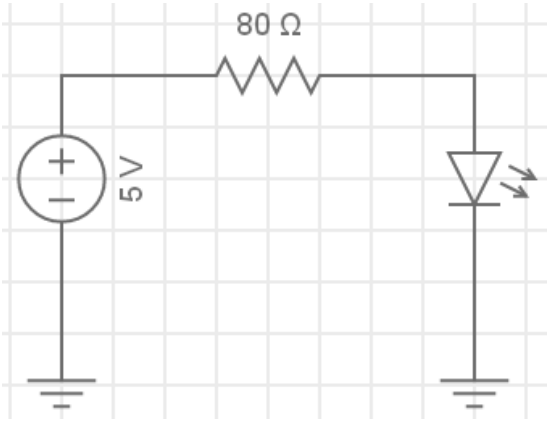




- How do we get different colors?
- How does this relate to a solar cell which operates in reverse?

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

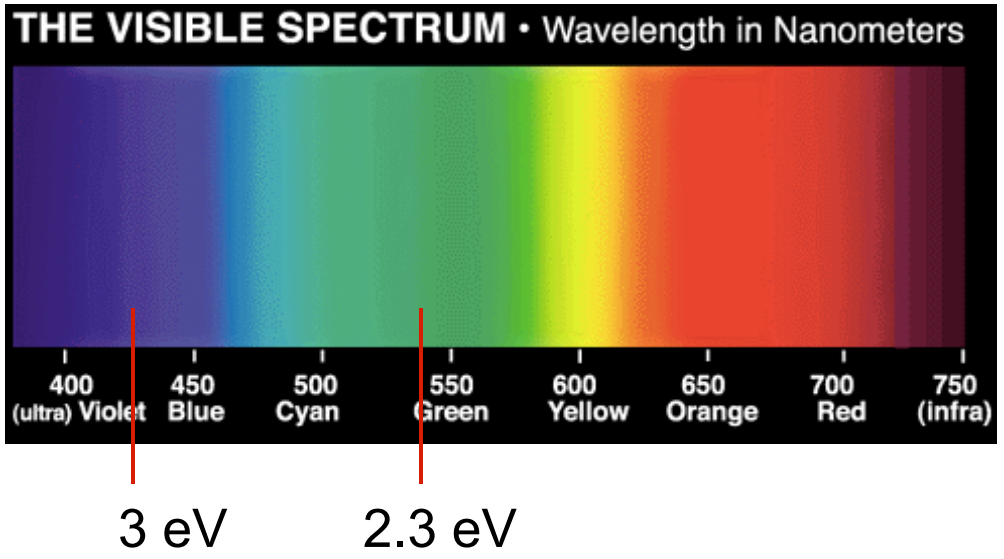
- For some materials
  - “Direct band-gap” materials
  - This energy can emit a photon

LED Voltage Drop and Color

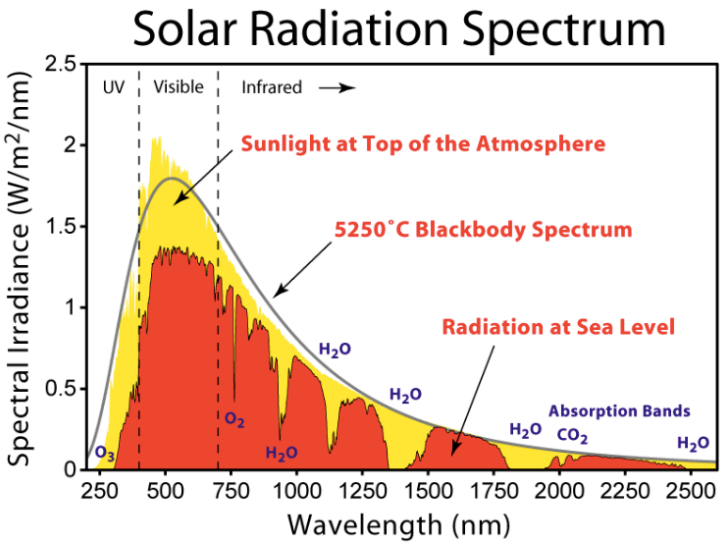
- The color of the photon depends on energy

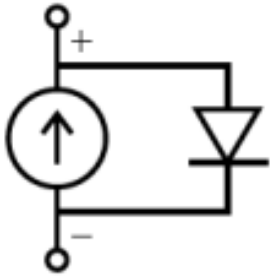
- The energy available depends on the voltage
  - Each electron that flows can create one photon
    - If it takes two, the two have to happen at the same time (unlikely)
  - V_f for a blue LED is larger than for a Red LED

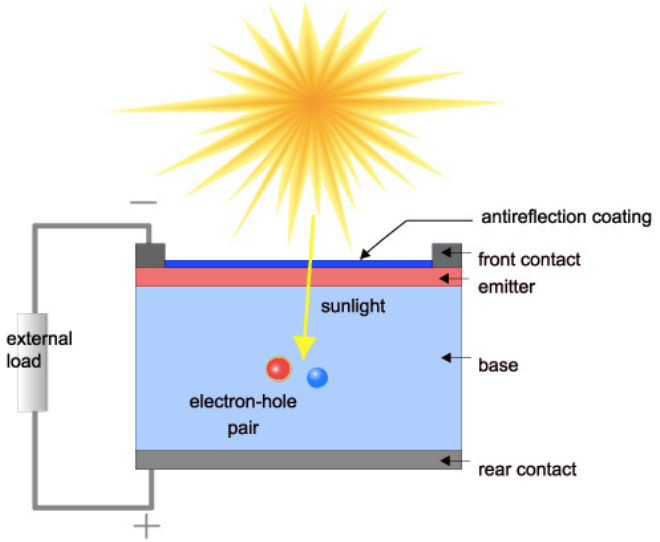
$$E = \frac{hc}{\lambda} = \frac{1.24\text{eV}}{\lambda(\mu\text{m})}$$

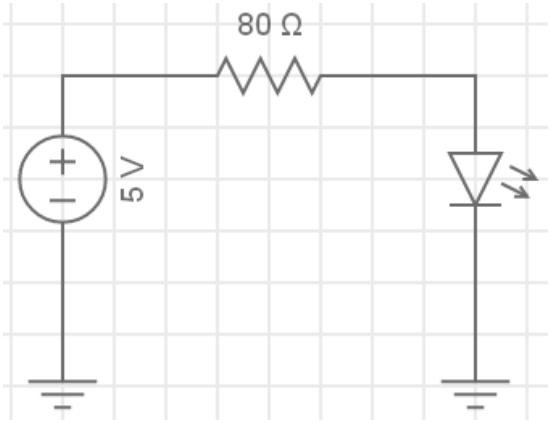


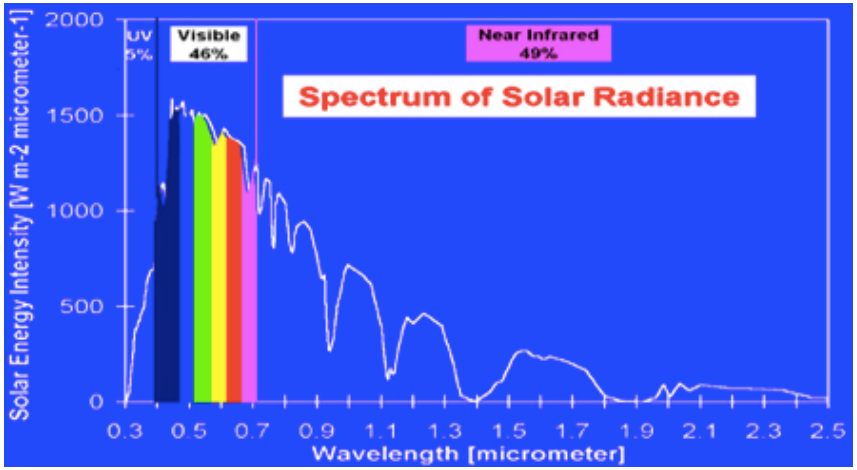
FYI – How Do Light Emitting Diodes and Solar Cells Actually Work?





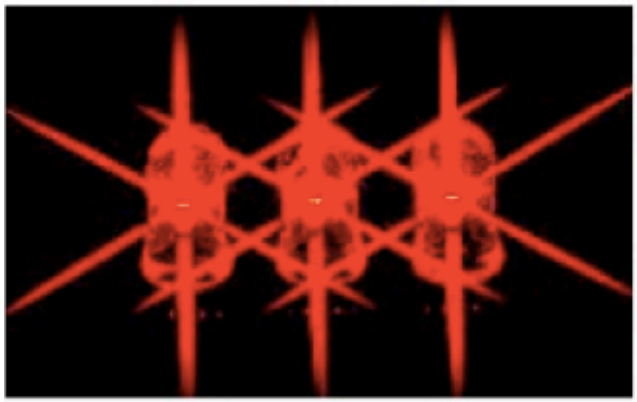
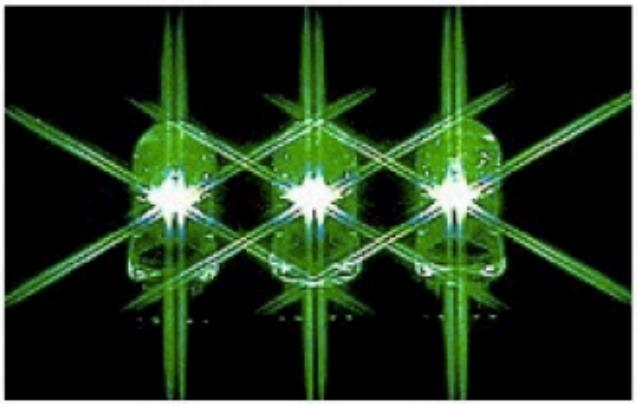
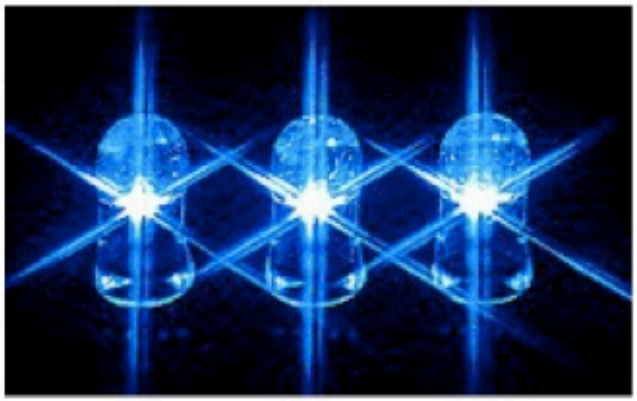
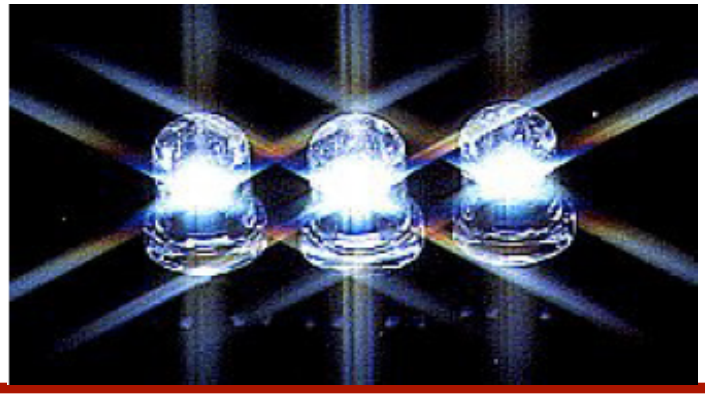






FYI – Full Color LED Displays and Solid State Lighting (https://en.wikipedia.org/wiki/Light-emitting_diode)

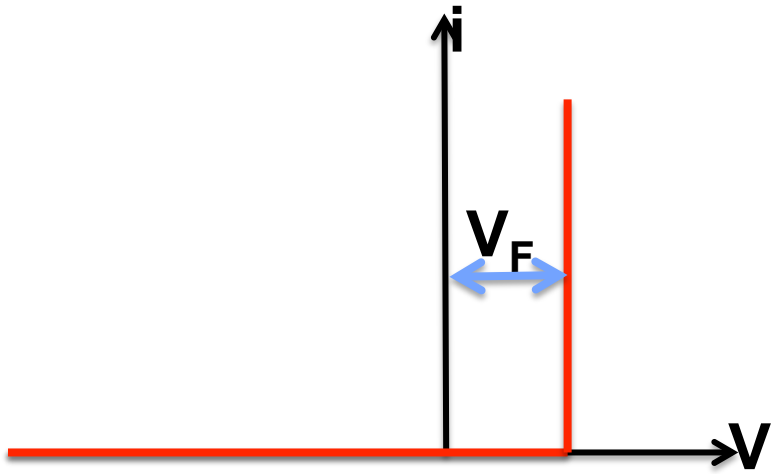
- Red/orange/green LEDs have been used in small displays for 30 years. Nakamura's invention of InGaN LEDs has dramatically changed the lighting world – not only creating blue LEDs for full color displays, but creating the possibility of solid state lighting.

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

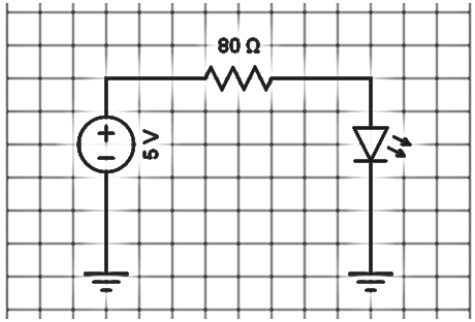
Using LEDs

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

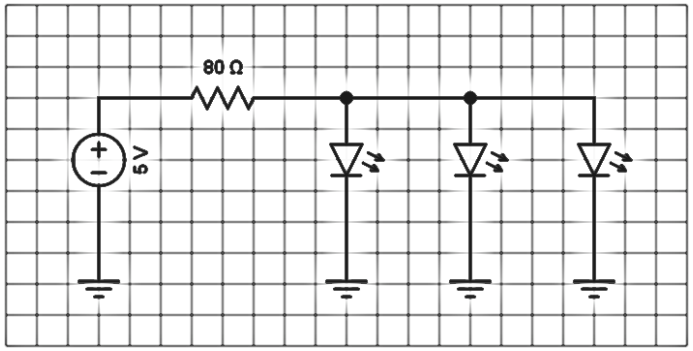


- You should use external resistance to limit current
  - Set current at around 20mA (30mA max)
  - Voltage drop across diode is 2-3V (V_F)
  - Voltage drop across resistor is 3-2V if driven from 5V supply
  - R = V/I = 3V/20mA = 150Ω; 2V/20mA = 100Ω
    - And the Arduino pin has a resistance of 30Ω

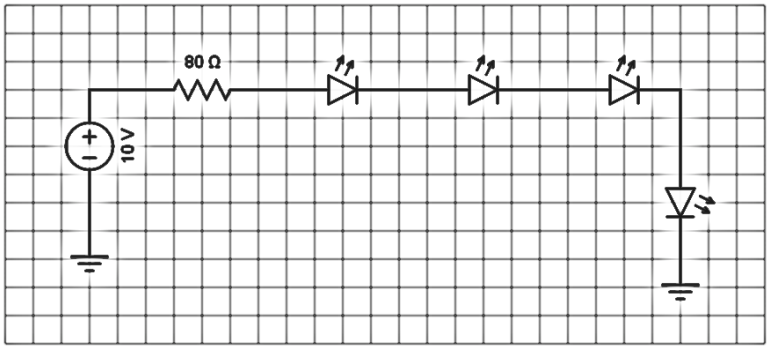
Using LEDs in Simple Circuits



- Always use a series R with an LED



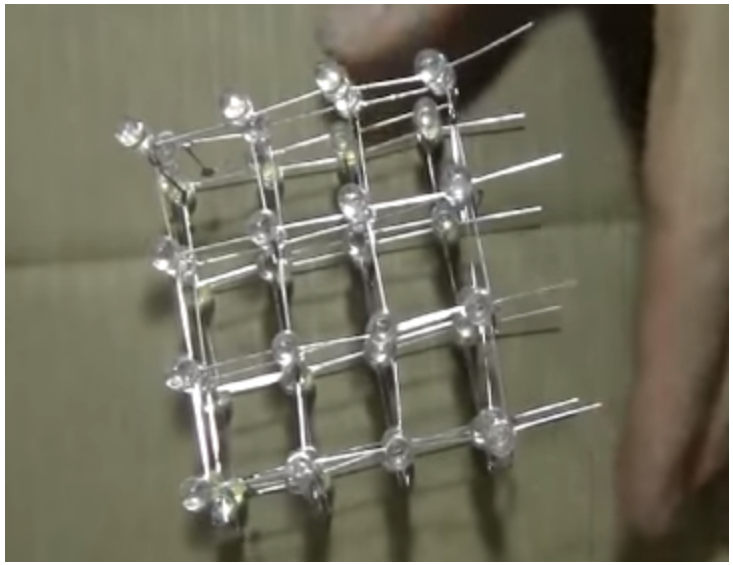
- Do not wire LEDs in parallel



- Series connection is fine with a higher V

LED Cube

- 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.

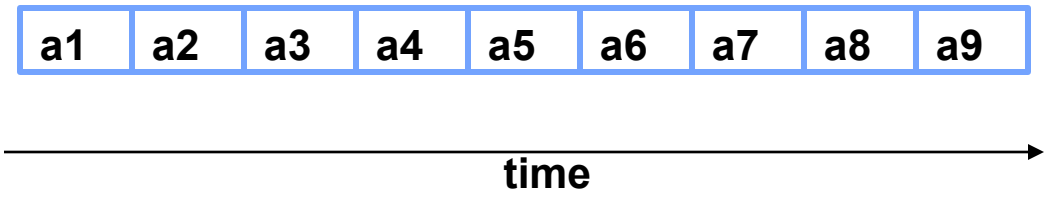
The Control Problem

- 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?

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

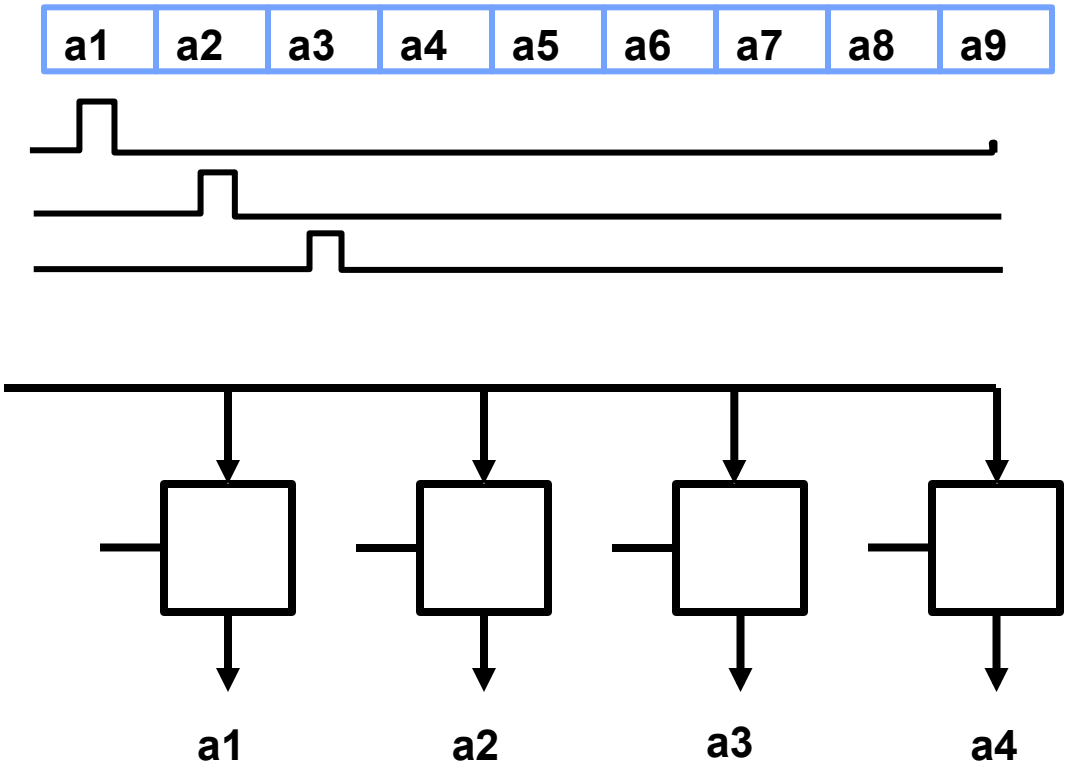
- Clearly need to get more than 1 bit/wire
  - The way computers do it is serial communication
  - Transmit different bits at different times



- Also called time division multiplexing or just multiplexing
- Heavily used in Ethernet, Serial ports, USB (universal serial bus)

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

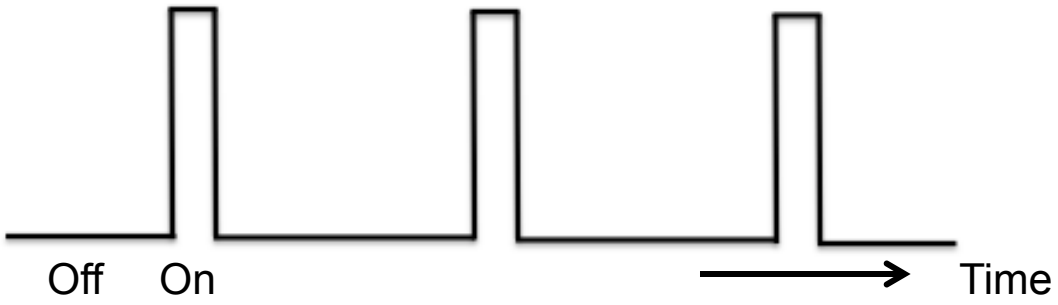


Dealing With Lights and Switches

- 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



- Or you can create displays using a rotating line of LEDs e.g.
  - **https://www.youtube.com/watch?v=2hASOre63Nk**

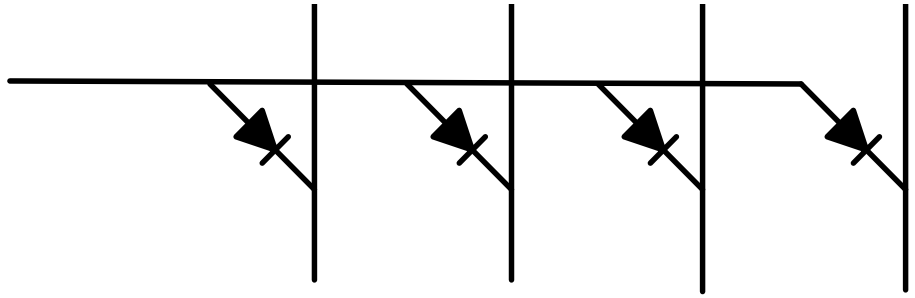
Basic Approach

- In our LED cube, we'll take advantage of the fact that your eyes are slow
  - Create more outputs than wires
  - Create analog light output values on digital pins

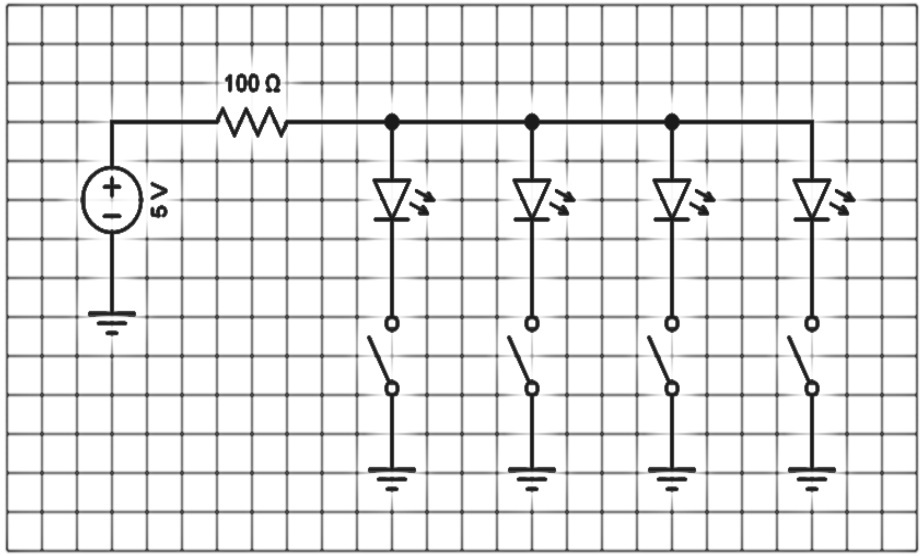
- If I have many lights, I don't need to turn them all on at once
  - I can create different slots in each time period
    - Say I created 8 slots
  - Then I only need to light 64 / 8 lights in each slot

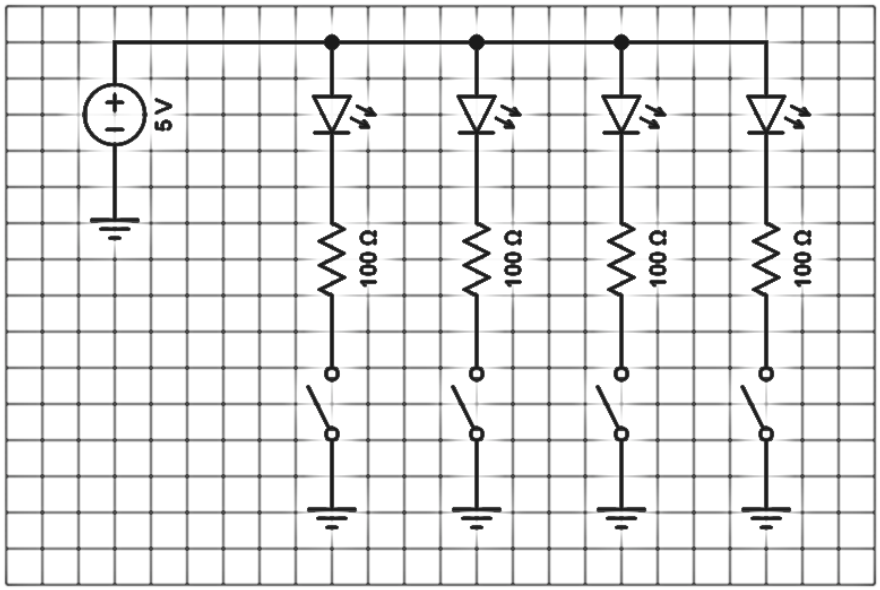
- But how do I get the right lights to light up at the right time?
  - Leverage the diode nature of the LED

LED Wiring Diagram

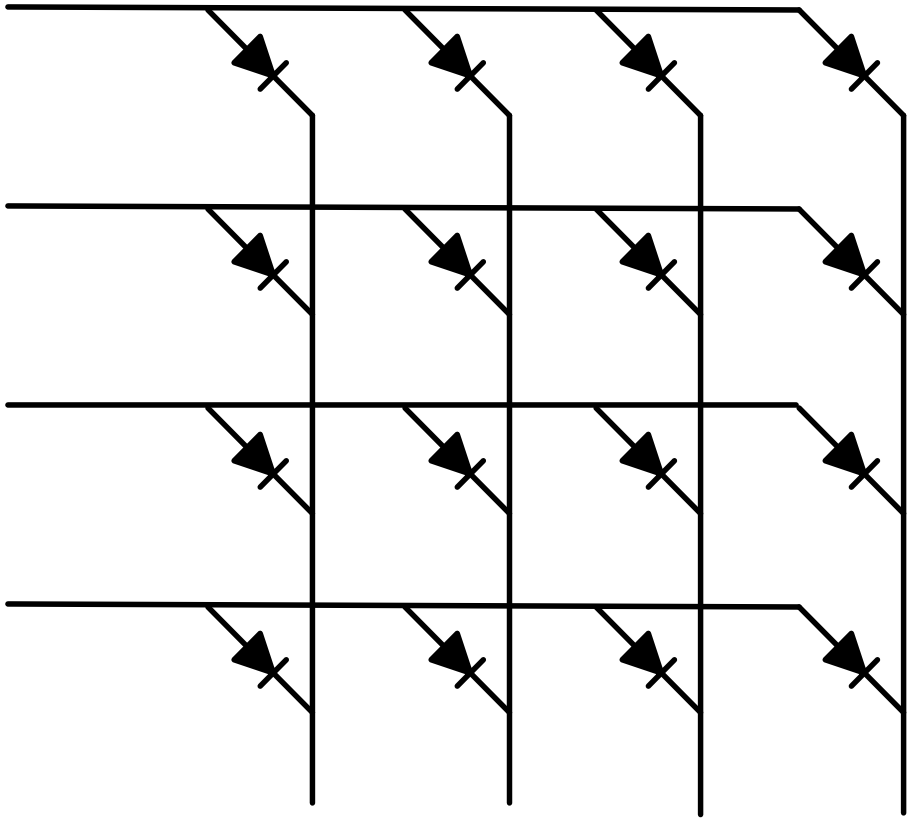


LED Wiring Diagram - EveryCircuit



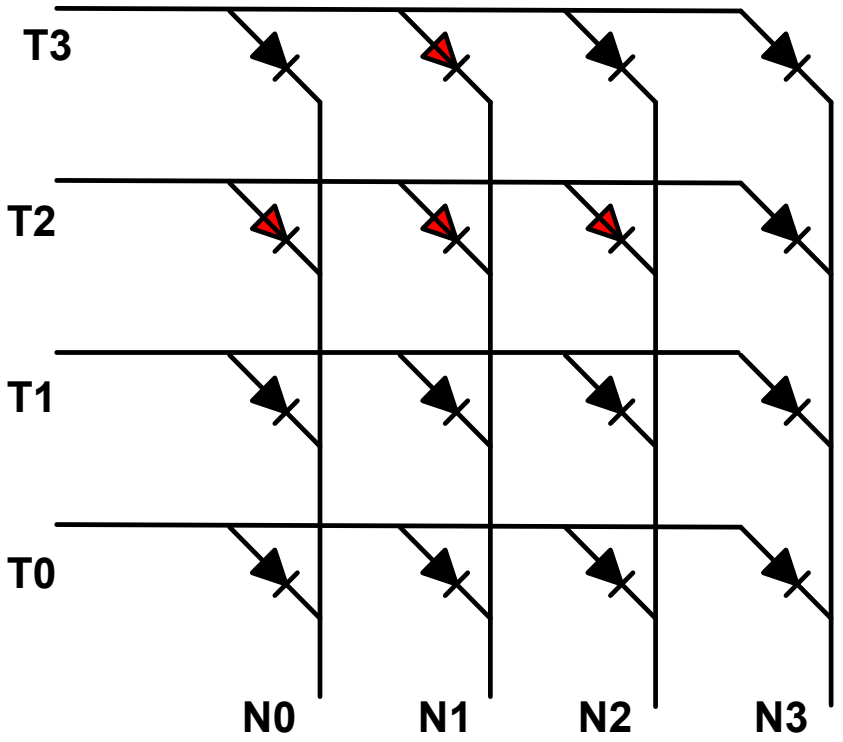


LED Array Wiring Diagram

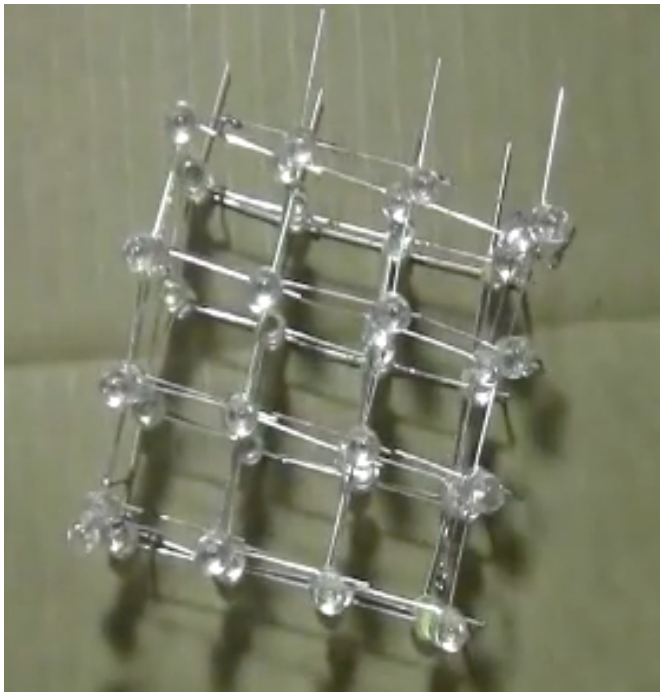


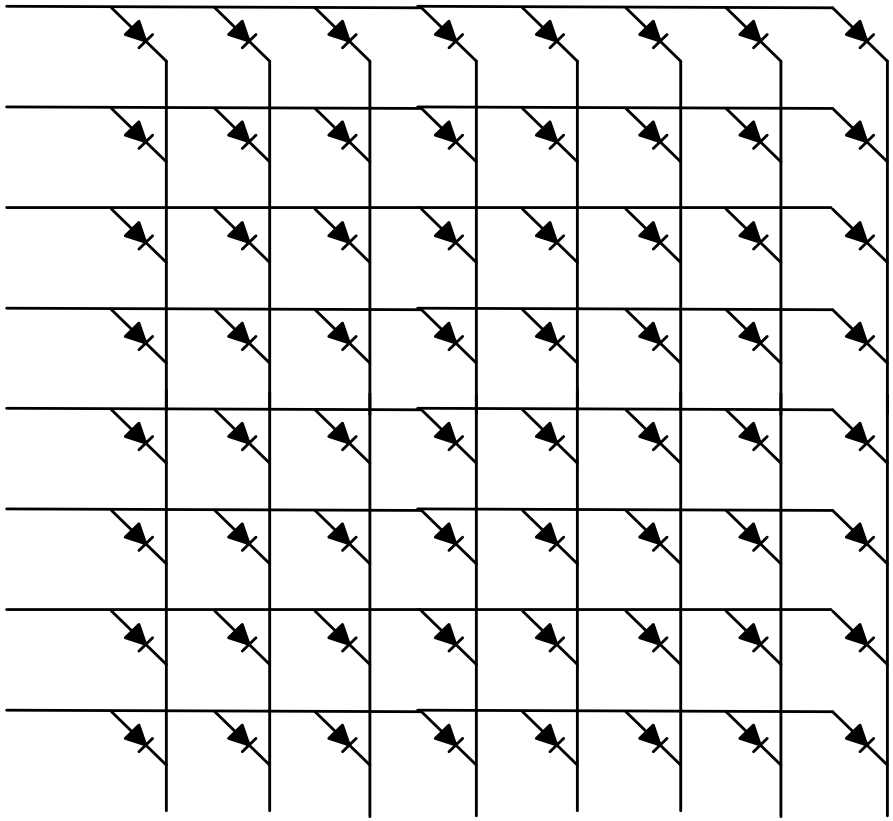
Testing Our Understanding

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



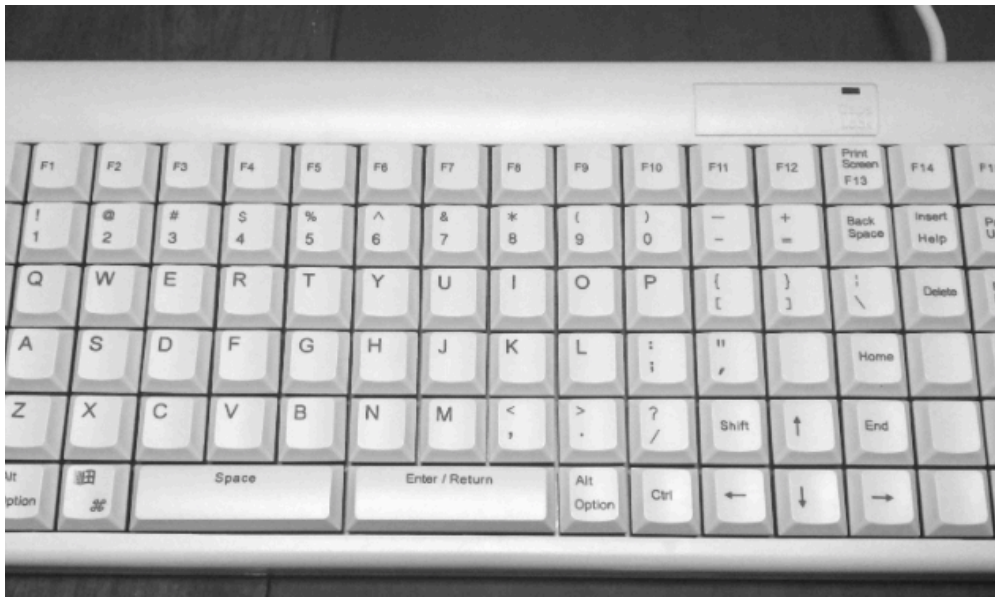
Driving the LED Cube

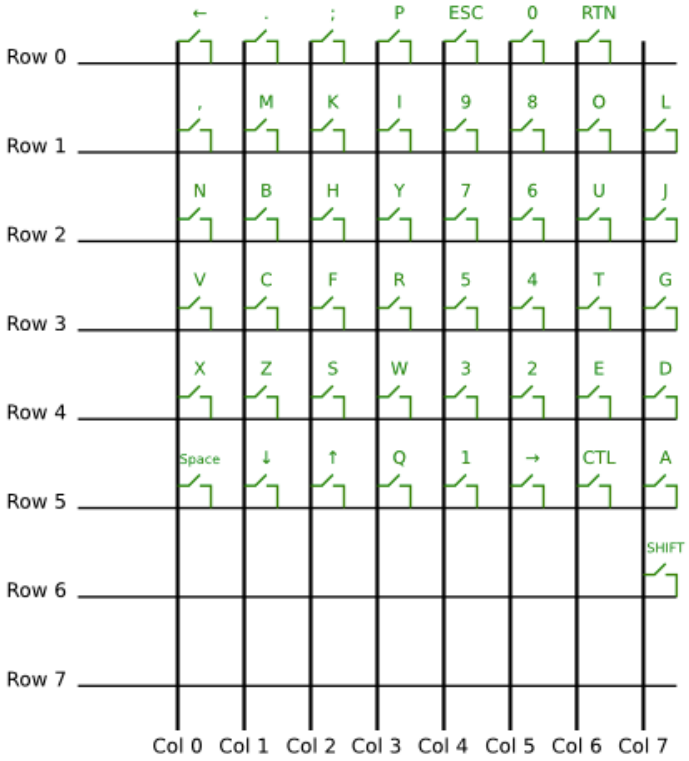




- Friday's prelab lecture will discuss how to physically construct the cube and how to electrically drive it from your Arduino using the multiplexing methods we discussed today.

Other Examples of Systems Using Multiplexing





- Keyboards generally use row and column accessing to determine which key has been pressed. The rows and columns can be scanned much faster than anyone can type!

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