Unit 1

Circuit Basics

KVL, KCL, Ohm's Law

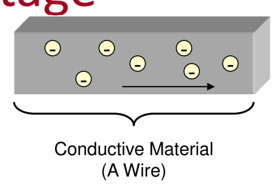
LED Outputs

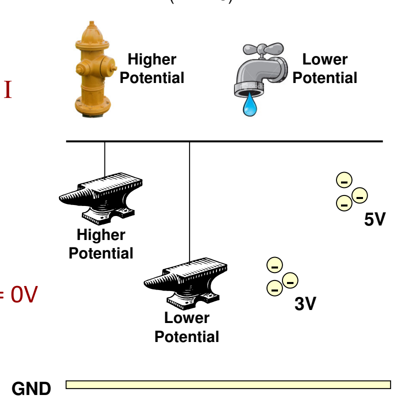
Buttons/Switch Inputs

VOLTAGE AND CURRENT

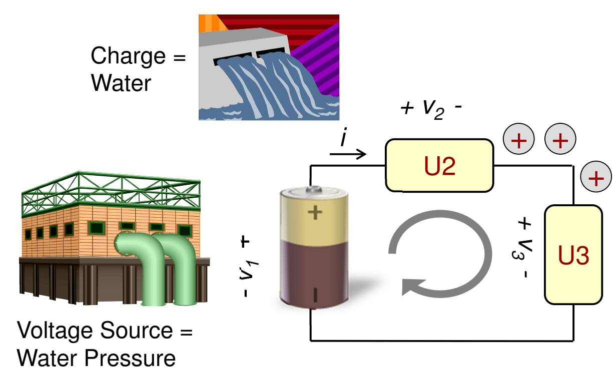
Current and Voltage

- Charge is measured in units of Coulombs
- Current – Amount of charge flowing through a ___________in a certain _____________
  – Measured in _________ = Coulombs per second
  – Current is usually denoted by the variable, I
- Voltage – Electric _________ energy
  – Analogous to mechanical potential energy (i.e. ___________)
  – Must measure ___________ points
  – Measured in Volts (V)
  – Common reference point: Ground (GND) = 0V
    • Often really connected to the ground



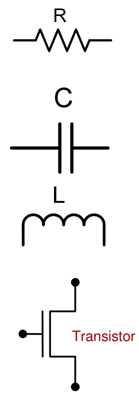


Current / Voltage Analogy



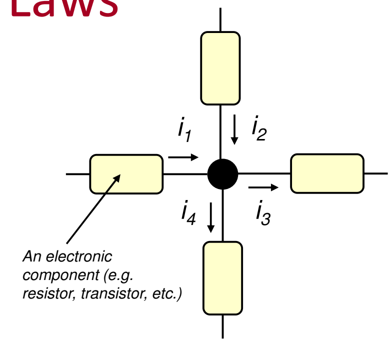
Meet The Components

- Most electronic circuits are modeled with the following components
- Resistor
  - Measures how well a material conducts electrons
- Capacitor & Inductor
  - Measures material's ability to store charge and energy
- Transistor
  - Basic amplification or switching technology



Kirchhoff's Laws

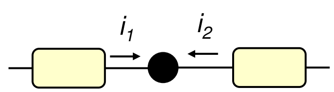
- Common sense rules that govern current and voltage
  - Kirchhoff's Current Law (KCL)
  - Kirchhoff's Voltage Law (KVL)
- Kirchhoff's Current Law (KCL)
  - The current flowing _____ a location (a.k.a. node) must equal the current flowing _____ of the location
  - …or put another way…
  - The sum of current at any location must _________



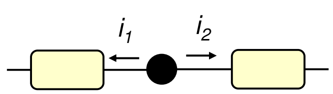
KCL says _____________

Kirchhoff's Current Law

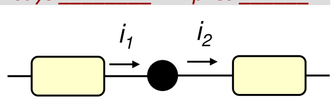
- Reminder: KCL says ____________________
- Start by defining a _________ for each current
  - It does not matter what direction we choose
  - When we solve for one of the currents we may get a ____________current
  - "Negative" sign simply means the direction is ___________ of our original indication
- In the examples to the right the top two examples the directions chosen are fine but physically in violation of KCL…
- …but KCL helps us arrive at a consistent result since solving for one of the current values indicates…
  - The __________ of i1 and i2 are the same
  - They always flow in the ________ direction of each other (if one flows in the other flows out or vice versa)



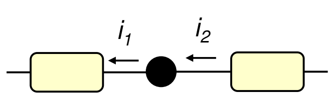
KCL says _________…implies ______



KCL says _________…implies ______



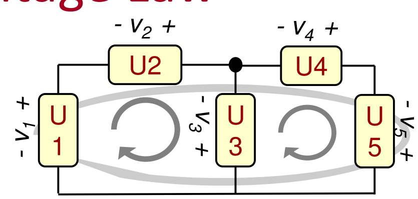
KCL says ______



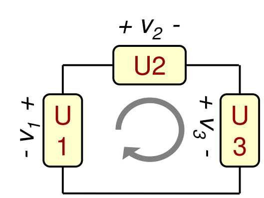
KCL says ______

Kirchhoff's Voltage Law

- Kirchhoff's Voltage Law (KVL)
  - The sum of voltages around a _____ (i.e. walking around and returning to the ___________) must 0
  - Define "polarity" of voltage and then be consistent as you go around the loop…obviously when you solve you may find a voltage to be negative which means you need to flip/reverse the polarity



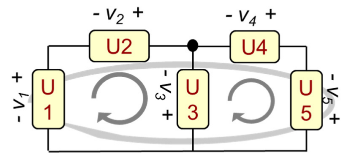
KVL says:
____
____
____



KVL says:
____
____

A Brief Summary

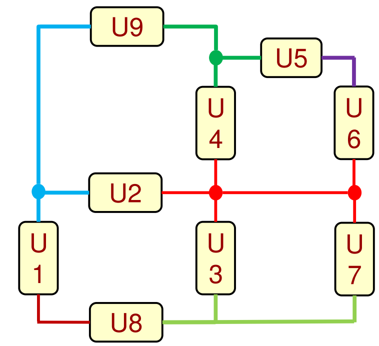
- KCL and KVL are ___________ and ________ no matter what kind of devices are used
  - The yellow boxes could be ANY electronic device: resistors, batteries, switches, transistors, etc…KVL and KCL will still apply
  - In a few minutes, we'll learn a law that only applies to resistors (or any device that can be modeled as a resistor)
- Some KVL or KCL equations may be ____________
  - Writing the equation for loop {v1,v2,v3} and {v3,v4,v5} may be sufficient and writing {v1,v2,v4,v5} may not be necessary
  - But as a novice, feel free to ____________
- Kirchoff's Laws apply to non time-varying circuits or circuits in the steady-state



KVL says:
$v_1+v_2+v_3=0$
$v_1+v_2+v_4+v_5=0$
$-v_3+v_4+v_5=0$

Nodes

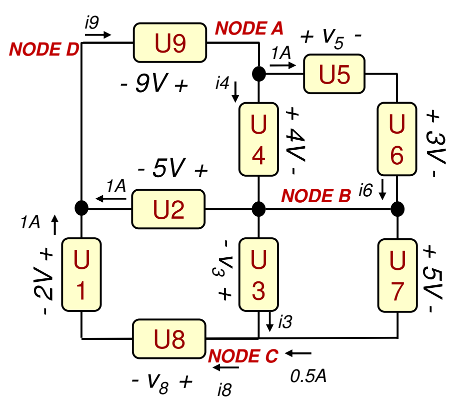
- ***(Def.)*** An **electric node** is the junction of _____________ devices connected by wires
- ________ voltage at any point of the node
- How many nodes exist in the diagram to the right?



Practice KCL and KVL

- Use KCL to solve for i3, i4, and i6
- Use KVL to solve for v3, v8, v5

Hint: Find a node or loop where there is only one unknown and that should cause a domino effect

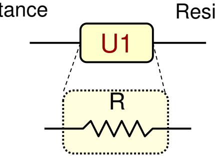


Resistance and Ohms Law

- Measure of how hard it is for current to flow through the substance
- Resistance = ____________________
  - How much _________ do you have to put to get a certain __________ to flow
- Measured in Ohms (Ω)
- Ohm's Law
  - **I = _____ or V = _____**
  - R __ => I __

Large Resistance

Small Resistance



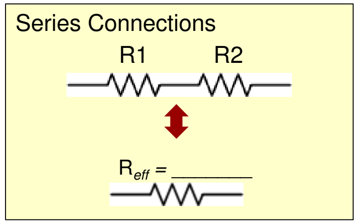
Schematic Symbol for a Resistor

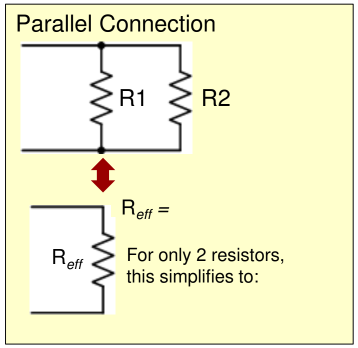
Ohm's Law ONLY applies to resistors (or devices that can be modeled as a resistor such as switches and transistors)

http://usc.scout.com/2/926916.html
http://www.zimbio.com/photos/Marquise+Lee/Oregon+v+USC/9qQqBuy838Z

Series & Parallel Resistance

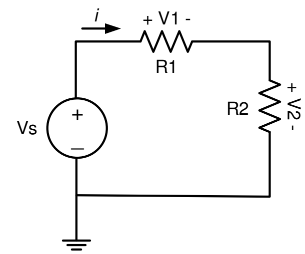
- Series resistors = same current must pass through both
- Parallel resistors = each connects to the same two nodes (same voltage different applied to both)
- Series and parallel resistors can be combined to an equivalent resistor with value given as shown…

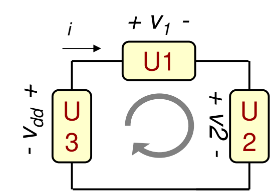




Solving Voltage & Current

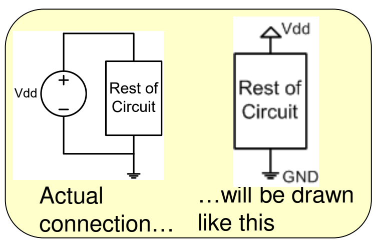
- Given the circuit to the right, let…
  - Vdd = +5V, R1 = 400 ohms, R2 = 600 ohms
- Solve for the current through the circuit and voltages across each resistors (i.e. V1 and V2)
  - Since everything is in _______, KCL teaches us that the current through each component must be the _______, let's call it *i*
    - *i* = ________________________
  - This alone lets us compute V1 and V2 since Ohm's law says
    - V1 = _____ and V2 = ______
    - V1 = ___ and V2 = ____
  - Though unneeded, KVL teaches us that
    - Vdd-V1-V2=0 or that Vdd = V1 + V2



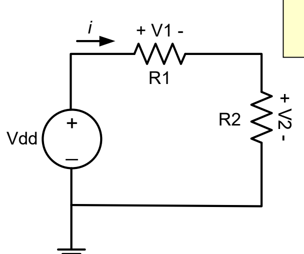


Voltage Supply Drawings

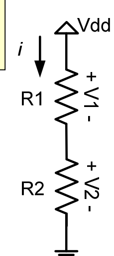
- The voltage source (Vdd) in the left diagram (i.e. the circle connected to the "Rest of Circuit") is shown in an alternate representation in the right diagram (i.e. the triangle labeled "Vdd")
- In the left diagram we can easily see a KVL loop available
- There is still a KVL loop available in the right diagram



Tip: **Vdd** is the name of the source voltage used for digital '1' signals. GND (0V) is often used for digital '0' signals.



Both are drawings of the same circuit (i.e. they are equivalent)

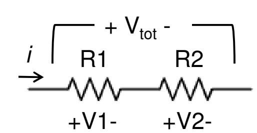


Shortcut: Voltage Dividers

- A shortcut application of KVL, KCL, and Ohm's law when two resistors are in series (**must be in series**)
- When two resistors **are in series** we can deduce an expression for the voltage across one of them
  - (1) i = ____ / ________; (2) V1 = i*R1; (3) V2 = i*R2
  - Substituting our expression for i into (2) and (3)

$$V1 = V_{tot}\left[\frac{R1}{R1+R2}\right] \text{ and } V2 = V_{tot}\left[\frac{R2}{R1+R2}\right]$$

- The voltage across one of the resistors is proportional to the value of that resistor and the total series resistance
  - If you need 10 gallons of gas to drive 500 miles, how much gas you have you used up after driving 200 miles?
    - Gas = ______________, Mileage = _________________



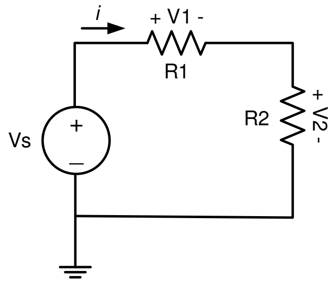
Voltage Divider Eqn: If two resistors R1 and R2 are in series then voltage across R1 is:

V1 = ________________

Memorize this. We will use it often!

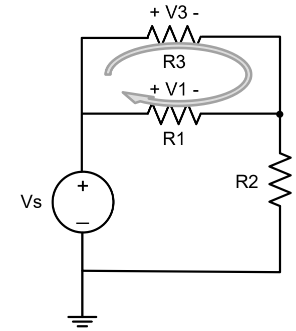
Solving Voltage & Current

- Reconsidering the circuit to the right with…
  - Vdd = +5V, R1 = 400 ohms, R2 = 600 ohms
- Solve for the current through the circuit and voltages across each resistors (i.e. V1 and V2)
  - We can use the voltage divider concept to immediately arrive at the value of V2
  - $V2 =$



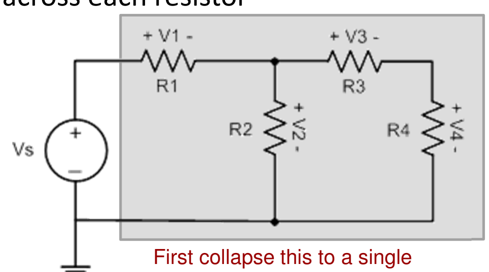
Solving Voltage & Current

- Consider the circuit on the right…
- What is the relationship between V1 and V3?
- Can you solve for the voltage V1 (in terms of Vs, R1, R2, R3)?
- Can you solve for the voltage V2 (in terms of Vs, R1, R2, R3)?



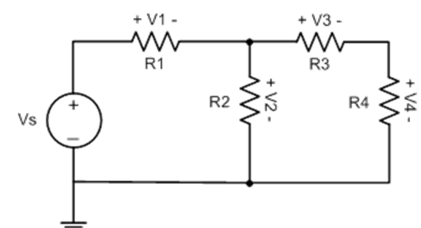
A Problem…

- Given the following parameters…
  - Vs=5V, R1=4, R2 = 12, R3 = 2 and R4 = 10 ohms.
- Can we use the voltage divider concept to immediately solve the voltage across R2 or do we need to first do some manipulation? What about R4?
- First, find the total equivalent resistance (R_{eq}) seen by Vs and then solve for the voltage across each resistor



First collapse this to a single equivalent resistance, R_{eq}

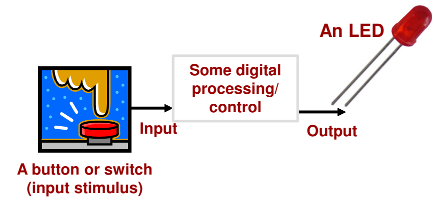
…Continued (Blank Workspace)

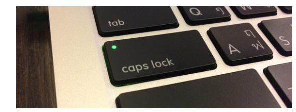


LEDS AS OUTPUTS AND SWITCHES/BUTTONS AS INPUTS

Generating Inputs & Measuring Outputs

- Where do inputs to a digital circuit originate?
  - Usually as ________ from another digital circuit (i.e. USB connecting to your laptop's main processing system)
  - For our class right now: A ____________ controlled by a human (can be on or off)
- How will we know what voltage is coming out of a digital circuit?
  - Could use a voltmeter or oscilloscope (don't be afraid to use the equipment in our lab!)
  - ________ are commonly used to show the status of a digital output to a human



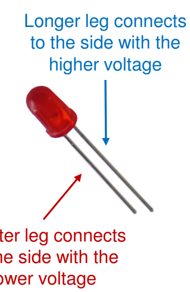


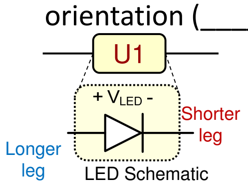
Each key on your keyboard is essentially a digital input generated by a push button (pressed or not pressed)

The status indicator on the Caps Lock button is simply an LED controlled by a digital output.

(Light-Emitting) Diodes

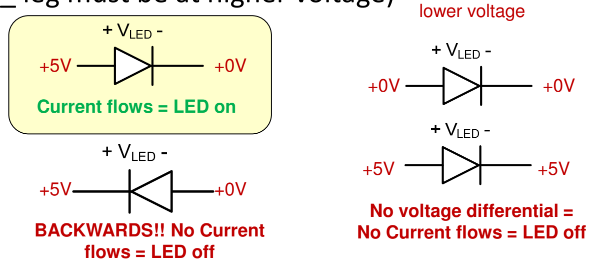
- The simplest output we can control is an LED (Light-emitting diode) which is like a tiny light bulb
- An LED glows ('on') when current ________ through it (i.e. when there is a voltage ___________ across it)
- LEDs are polarized meaning they only work in one orientation (________ leg must be at higher voltage)





LED Schematic Symbol

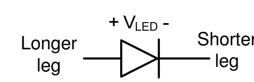
http://www.custobots.com/sites/default/files/imagecache/product_full/products/Solarbotics-redLED.gif



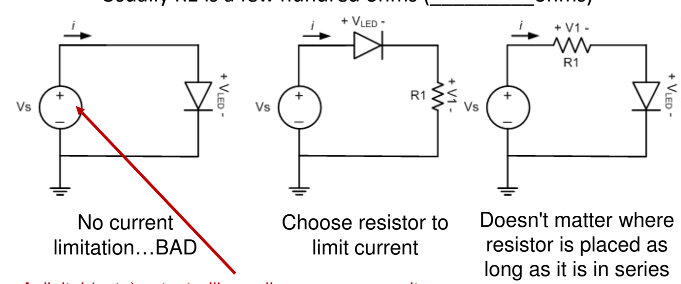
Main Point: To be 'on', there must be a voltage difference across the LED making current flow.

Need for Series Resistor with LEDs

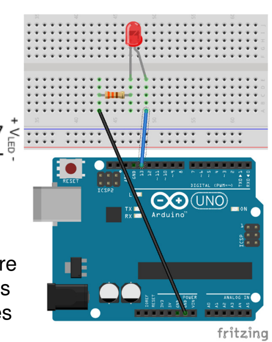
- **Problem**: LEDs may allow too much current to flow which may blow out the LED
- **Solution**: Use a series resistor to limit current
  - Amount of current will determine _____________ of LED
  - R↑ then i __ and thus LED brightness ___
  - $i = V1/R1 = (Vs-V_{LED}) / R1$
  - Usually R1 is a few hundred ohms (_________ohms)



LED Schematic Symbol



A digital (gate) output will usually serve as our voltage source that can be either '0' (0V) or '1' (5V)



Breadboard view

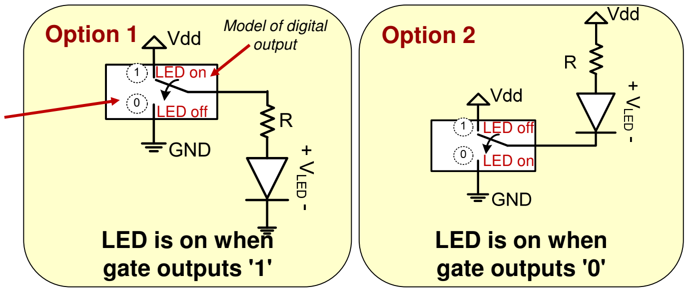
Main Point: LED's should always be connected ________with a current-limiting resistor

LED Connection Approaches

- When letting a digital output control an LED, the value (i.e. '0' = low or '1' = high voltage) that causes the LED to light up depends on how the circuit is wired
  - Note: Gates can often _____ (take in) more current than they can _________ (push out), so option 2 may be preferred…but let's not worry about this now…let's use option 1

This box represents a digital output (e.g. your Arduino) that can generate a high (1) or low (0) voltage.

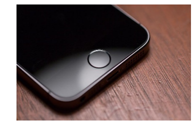
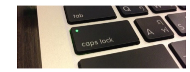
What digital output value must be present for the LED to be on?



Main Point: LED's can light for either a logic '1' or '0' output…it depends on how they are wired.

Switch and PushButton Inputs

- Switches and pushbuttons can be in one of two configurations: ______ or ________
  - Switches can be opened or closed and then ________ in that position until changed
  - Pushbuttons are open by _________ and require you to push them to close the circuit (they then open when you release)
- Can be used as an input to digital device

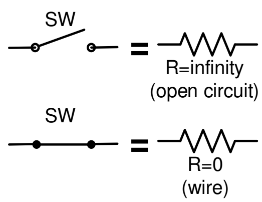



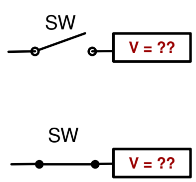
Example pushbuttons

Example switch

Switches and Pushbuttons

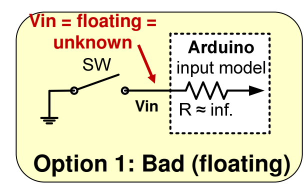
- Important Note 1: We can model a button or switch as a resistor of either 0 ohms or inf. (very large) ohms
  - When open a SW/PB looks like an _________ resistance (no current can flow)
  - When closed a SW/PB looks like a _______ (R=0) and no voltage drops across it
- **Question**: What voltage does an open or closed switch (pushbutton) generate?
- **Answer**: ________________.
- Important Note 2:
  - SW or PBs don't produce digital 0's or 1's ________________, they control what voltage (PWR/GND) is connected to your device



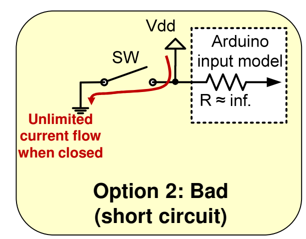


Connecting a Switch

- Switches only ___________ the voltage going into a device, **they do not produce a voltage** (0V or 5V) by themselves
- Option 1: Attach one side to GND and the other side to the device
  - When the switch=open, nothing is connected to the device (a.k.a. "__________")
  - A floating input may sometimes appears as zero, and other times as a one.
  - We need the inputs to logic gates to be in either the 0 or 1 state…not floating
- Option 2:
  - When switch closed => ____ resistance connection from power to ground = __________ current flow…BAD!!! (This is known as a "**short circuit**").



Switch Closed = 0V (Logic 0) to input
Switch Open = ??? (does not work)

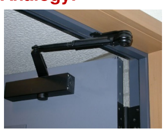


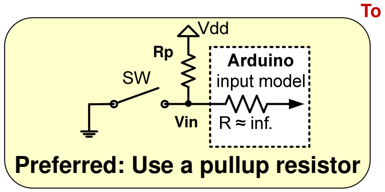
Switch Open = Vdd=5V (Logic 1) to input
Switch Closed = Short Circuit (does not work)

Preferred Wiring of Switches

- Solution: Put GND on the far side and a "pull-up" resistor at the input side
  - "Pull-up resistor" used to hold the input high unless something is forcing it to a zero
  - SW open => Arduino input looks like inf. Resistance in series with Rp. Thus _______ through Rp and thus no voltage drop across Rp…Vin = _______
  - SW closed => Direct wire from GND to input…input = _______…Also current flowing from Vdd to GND is limited by Rp preventing a short circuit.
  - Usually Rp is large (10k ohms) to limit current

Analogy:





To calculate Vin when switch is open:

$Vin = Vdd - V_{RP}$

Vin = Vdd – ______

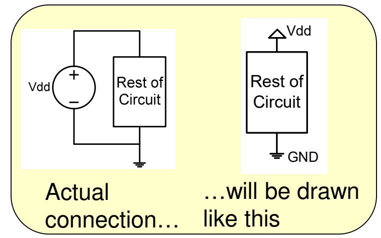
i_{RP}=__ since in _______ with _______ resistance of Arduino input

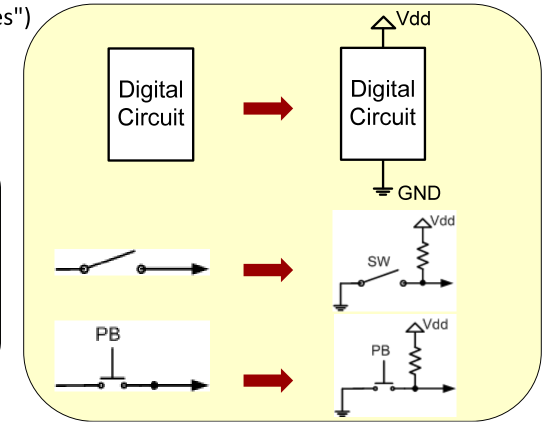
Thus, Vin = ______

Main Point: Buttons & switches should have GND connected to one side & a pull-up resistor on the other

Power & Ground Connections

- Easy mistake when you're just learning to wire up circuits:
  - Wire the inputs & outputs but forget to connect power and ground
- All circuits and chips require a connection to a power source and ground
  - Digital circuits (aka "gates")
  - Switches
  - Buttons





Summary

- KCL and KVL apply to **ALL** electronic devices
- Ohm's law applies **ONLY** to resistors and governs the relationship between the current through and the voltage across a resistor
- A resistor network can be collapsed to **a single equivalent resistance** by applying series and parallel transformations
- If two or more resistors are in series, the voltage across any of those resistors can be quickly found by applying the **voltage divider equation**
- LEDs are used as digital outputs and must be wired in the correct direction
- Switches can be modeled as a small (0) resistance when closed or large (inf.) resistance when open