SEMI FOUNDATION

Learning About Semiconductor Technology

SEMICONDUCTOR FRONT-END MANUFACTURING

HIGH SCHOOL ENGINEERING
HIGH SCHOOL PHYSICS
HIGH SCHOOL MATHEMATICS

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Semiconductor Front-End Manufacturing

Lesson Overview	Career Highlight
Students will learn about the manufacturing methods used to transform raw Silicon (and other metalloids) into positively- and negatively-charged components. They will also learn about diodes and transistors–along with their functions–and will be taught how those components function within a computing system.	Electrical Engineer

STEM Course Connections	21st Century Skills	CTE Alignment
High School Engineering High School Physics High School Mathematics	Critical Thinking Problem Solving	Energy, Environment, and Utilities Pathway

Engineering Activity	
Science and Engineering Practice #3	Students will understand what diodes and transistors are and how it functions within a computer. Students will build a simple transistor pair.

Materials

- AA batteries
- Breadboard
- Copper wire
- CR-2032 Battery
- Darlington Pair Lab Handout
- Light-Emitting Diodes
- NPN-type transistors
- Paper Clips
- Resistors (47 Ohm)
- Resistors (10,000 Ohm)
- Student Handout

Essential Questions

1. How are diodes and transistors critical to the development of advanced computing devices?
2. How do raw Metalloid elements get processed into useful electronic components that can be used in complex devices?
3. How can including a transistor in a circuit change the flow of electricity through that circuit?

Prerequisite Knowledge

Students should have a basic knowledge of what a microchip is, and the uses for microchips within the semiconductor industry. Recommended HTU lessons include: Introduction to Semiconductors; What are Semiconductors?; Education and Career Pathways; Semiconductor Industry Introduction + Pathways

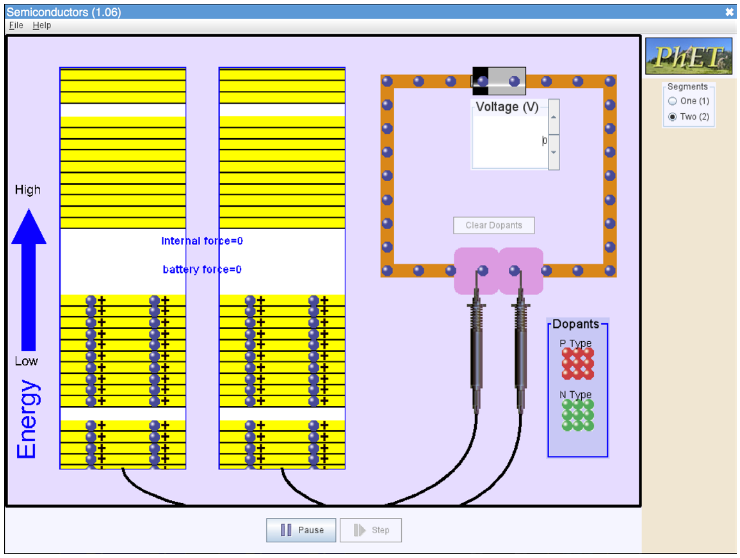
Engage

Understanding the Fundamentals of Diodes - (10 mins)

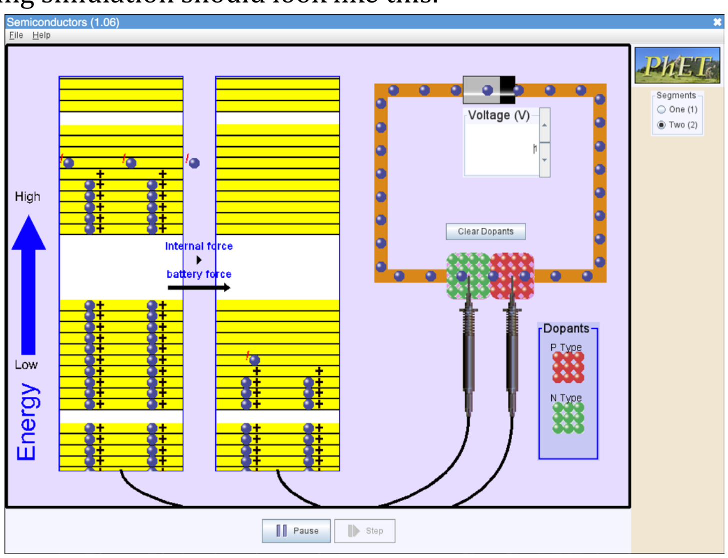
- *Teacher Note: All you will need for this demonstration is a CR2032 battery and a Light-Emitting Diode, both available on Amazon for less than three dollars.*
- Teacher will explain that a Diode is a two-terminal electronic component that only allows current to flow in one direction. To demonstrate this, show the class a Light-Emitting Diode (LED), which they have likely heard of before. Explain that the LED, like all diodes, will only allow current to flow in one direction, and therefore will not illuminate if the power source is connected with the poles in the incorrect orientation.
- **Predict -** In Section A of the Student Handout, students will make a prediction of what will happen when the positive pole of a Light-Emitting Diode is connected to the positive terminal of a battery, and also what happens when the positive pole of the LED connects to the negative terminal of a battery. *Students should predict that the LED will only illuminate in one configuration; when the cathodes for both are touching each other.*
- Hold up the CR2032 battery so that the class can see, then allow one terminal of the Light-Emitting Diode to contact the positive side of the battery (the side with the writing, or flat side) and touch the other side to the negative side of the battery (the raised side). Then, alternate the poles that each of the terminals contact. Students will notice that the LED only lights up in one configuration (when the LED's cathode, or long wire, contacts the battery's cathode), and does not illuminate when the terminals are reversed.
- **Observe -** Students will record the results of the demonstration in their own words in Section A of the Student Handout.
- **Explain -** Students will describe why the LED was only illuminated in one of the two configurations in Section A of the Student Handout. *Students should understand that because the diode only illuminates when the positive terminals contact each other, electricity is only able to flow in one direction.*
- Students will answer the following question in Section A of the Student Handout:
    - Given what you have witnessed here, what is a conclusion you can draw about Diodes? *A diode only allows for flow of electricity in a single direction.*

Diode Simulation - (20 mins)

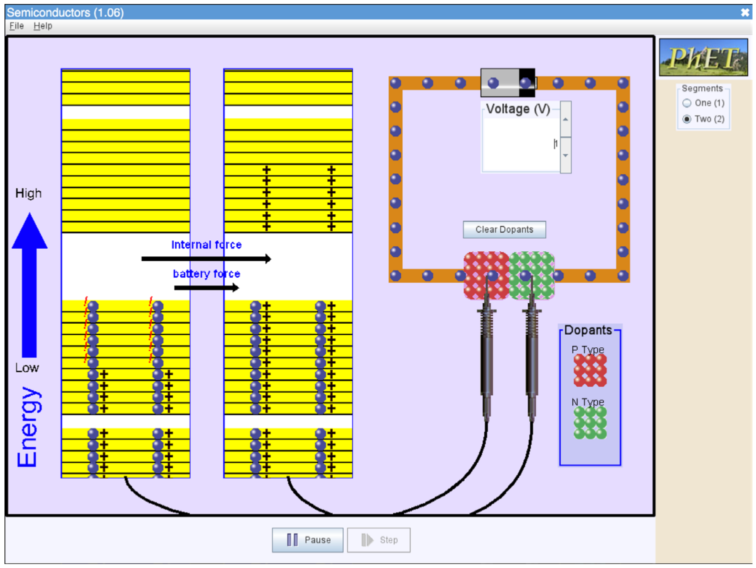
- Students will use their laptops and open a [PhET simulation]() explaining doped semiconductors in diodes.
- Open the PhET Simulation. Students should see this on their screen.



- **Predict -** Students will increase the battery voltage from 0 to 1.0v. They will then be asked to make a prediction in Section B of their [Student Handout]() of what will happen if they put a P-type dopant on the right and an N-type dopant on the left, and vice versa.
- Students will then click and drag an N-type dopant to the left opening, and a P-type dopant to the right opening. The resulting simulation should look like this.



- **Observe -** Students will record the results in Section B of their [Student Handout](). *Teacher Note: Students should observe electrons freely moving through the system thanks to the N-type junction being connected to the negative terminal of the battery, and the P-type junction being connected to the positive terminal of the battery.*
- Students will then select "Clear Dopants," and drag the dopants to the opposite positions, as pictured here.



- Students will record these results in Section B of their [Student Handout]() as well. *Teacher Note: Students should observe that instead of flowing through the system as it did before, the electrical flow will stop and the electrons will balance out within the system.*
- **Explain -** In Section B of the Student Handout, students will explain why they believe the semiconductor dopants behaved the way they did. *The junction between the N-type and P-type dopants resists the flow of electricity in one direction, and only allows it to flow unidirectionally.*

Explore

Transistors Explained - (10 mins)

- Students will watch a [Video]() explaining the primary functions of transistors, as well as the basics of how they work. They will answer the following questions on Section C of the [Student Handout]().
  - Name two primary functions of a transistor. *They can act as a switch, or as an amplifier.*
  - What does doping do to a semiconductor? *It either positively- or negatively-charges the semiconductor.*
  - What is the major difference between a diode and a transistor? *A diode consists only of one positively- and one negatively-doped semiconductor, while a transistor contains two positive and one negative layers, or two negative and one positive layers.*
- Students will share their responses as a class.

Why are Transistors Used in Computing - (10 mins)

- Students will watch a [Video]() that describes how transistors are utilized in computing systems, and how they replaced vacuum tubes. In Section D of the [Student Handout](), they will answer the following questions.
  - What is the type of logic that most binary computers utilize? *Boolean Logic*
  - How does a computer make interpretations of “true” or “false?” *By using 1s and 0s.*
  - What did the first computers use to make calculations before transistors? *Vacuum tubes, or Diodes and Triodes.*
  - What are the three components of a Transistor? *Emitter, Base, Collector.*

- What are some reasons that transistors replaced vacuum tubes? *They're smaller, they use less power, and they are more reliable.*

Logic Gates - (10 mins)

- Students will read the following article about logic gates and answer the following questions in Section E of the Student Handout.
  - What is a Logic Gate? *A series of transistors combined into a series of complimentary arrangements,*
  - How many types of Logic Gates are there, and what are they? *Seven. They are: AND, OR, NOT, NAND (not AND), NOR (not OR), XOR, XNOR (not XOR)*
  - Where does the term "Boolean Logic," used to describe binary logic systems, come from? *From the creator of logic gates, George Boole.*

Transistors as Building Blocks of Microchips - (5 mins)

- Students should think about connections to other life science classes and make comparisons to other building blocks.
- In Section F of the Student Handout, students will fill in the blank for each of the following:
  - **Amino acids** are the building blocks of: *proteins*
  - **Atoms** are the building blocks of: *molecules*
  - **Transistors** are the building blocks of: *microchips*

Explain

Transistor Size - (10 Mins)

- Video - Students will watch the video and answer the following questions in Section G of the Student Handout.
  - What is surprising to you about the layout of the transistors at the microscopic level? *Answers may vary. The layout is very precise despite being much smaller than the eye can see.*
  - At the time this video was created, how small were we able to create transistors? *20 Nanometers*
  - Why are shrinking transistor sizes so important in advancing technology? *The more transistors we can squeeze into a smaller space, the more compact and powerful our computing devices can become.*
- Students will share answers as a class.

Moore's Law - (10 Mins)

- Video - Students will watch a video about Moore's Law and the development of increasingly smaller and more complex transistor arrays, and answer the following questions in Section H of the Student Handout.
  - In your own words, what is Moore's Law? *Every two years, the number of transistors we will be able to fit onto a single integrated circuit doubles.*
  - Why do you think that reduction in transistor size is slowing down in recent years? *Transistors are now being made that are as small as the wavelengths of light that are used to design them.*
  - Do you think that integrated circuits will continue to double in size and complexity indefinitely? *Answers may vary, but due to the finite size of molecular structures, eventually we will be unable to shrink the size of an integrated circuit any further.*
- Students will share answers with the class.

Academic Vocabulary Development (20 mins)

- Students will develop their academic vocabulary in Section I of the Student Handout.

Elaborate

Webquest - (50 mins)

- *Teacher Note: Students can participate in the entire lesson for each of the sections below to extend the lesson plan, or just read each section and answer the questions below.*
- Read Lesson 1
- Answer the following questions in Section J of Student Handout:
  - Invite students to think of examples of devices that have become smaller and more compact over the years. (almost any portable electronic device such as radios, tape players, CD players, computers, and medical devices such as pacemakers and hearing aids) Ask students to speculate about what kinds of breakthroughs made the smaller devices possible. *Answers will vary.*
- Read the Background section in Lesson 2
- Answer the following question in Section J of Student Handout:
  - What do you think Sir Isaac Newton meant by the quote "If I have seen farther than others, it is because I have stood on the shoulders of giants?" *By relying on the successes of great scholars who came before, I have been given the tools I need to make further great discoveries.*
  - What examples can you give where others "stood on the shoulders of giants?" *Nearly any example here works. Scientific progress rarely occurs in a vacuum.*
  - What types of electronics interest you? *Answers will vary.*
  - What do you know about these inventions and their creators? *Answers will vary.*
  - What skills did these inventors need to have? *Patience, creativity, good communication, etc.*
- Students will share their answers, and discuss how Newton's quote pertains to the scientific process.
- Read Lesson 3
- Answer the following question in Section J of Student Handout:
  - Approximately how large were the original transistors? *About the size of a pencil eraser.*
  - Why would ENIAC, the vacuum tube equivalent to a computer, require a vast amount of air conditioning to cool it? *Modern computers generate heat, but ENIAC's vacuum tubes had to be heated up in order to function at all, meaning they were constantly getting hotter and hotter.*
- Read Lesson 4
- Answer the following question in Section J of Student Handout:
  - When was the first transistor created, and who built it? *1947 by William Shockley.*
  - What function does a P-N Junction provide? *It is the primary reason that electricity is not able to flow through a transistor unless power is applied to the base.*

Evaluate

Darlington Pair Lab - (45 mins)

- Students will construct a Darlington Pair utilizing the following components:
  - 1 Breadboard
  - 2 NPN-type transistors
  - Copper wire
  - 2 AA batteries

  - 1 Paper Clip
  - 1 47 Ohm Resistor
  - 1 10,000 Ohm Resistor
  - 1 Light-Emitting Diode
- Students will follow the instructions provided within the Darlington Pair Lab file. *Teacher Note: If the requisite materials cannot be sourced or in-person learning is impossible, this lab can also be completed digitally via TinkerCAD, which will require users to create an account. The completed version of the digital model used can be found via this link.*
- Once students have completed the experiment, explain how the two transistors functioning together are able to amplify the overall output of the power system.
- Students will answer the following questions in Section K of the Student Handout.
  - How does a Darlington Pair work? *Two similar types of transistors can be used to increase the overall output of a power source.*
  - What do you think one potential use for a darlington transistor is? *High-powered switches, audio amplification, sensor signal amplification.*
  - How do you think arrangements of different transistors might pertain to logic gates? *Different logic gates are created by different combinations of transistors and diodes.*

Extend

Students can extend their learning by participating in the following HTU lessons: What is Electricity?; What are Circuits?; Types of Circuits; Electrical Loads; The Silicon in Silicon Valley

CA NGSS Standards

HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

CTE Alignment

B7.0 Understand the interrelationships among components of systems.

Resources

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Name		Date	

Semiconductor Front-End Manufacturing Student Handout

Directions: Students read the prompts and answer in complete sentences in the box to the right.

Engage

Section A: Understanding the Fundamentals of Diodes	
Predict - What do you think will happen when the **positive** terminal of the LED touches the **positive** terminal of the battery?	
What do you think will happen when the **positive** terminal of the LED touches the **negative** terminal of the battery?	
Observe - In your own words, describe what occurred in the demonstration.	
Explain - What do you think caused the LED to behave the way that it did in both demonstrations?	
Given what you have witnessed here, what is a conclusion you can draw about Diodes?	
Section C: Diode Simulation	
Follow the instructions for the PhET diode simulation	
Predict - What do you think will happen if you connect a P-type semiconductor to the **negative** battery terminal and an N-type semiconductor to a **positive** battery terminal?	

What do you think will happen if you connect a P-type semiconductor to the **positive** battery terminal and an N-type semiconductor to a **negative** battery terminal?	
Observe - Record the results of connecting the N-type dopant to the negative battery terminal and the P-type dopant to the positive battery terminal.	
Record the results of connecting the N-type dopant to the positive battery terminal and the P-type dopant to the negative battery terminal.	
Explain - What did you notice about the systems when the dopants were switched? Why do you believe the circuits behaved differently?	

Explore:

Section C: Transistors Explained	
Watch the video about transistors, and answer the following questions.	
Name two primary functions of a transistor.	
What does doping do to a semiconductor?	
What is the major difference between a diode and a transistor?	

Section D: Why Transistors are Used in Computing	
Watch the video, and answer the following questions.	
What is the type of logic that most binary computers utilize?	
How does a computer make interpretations of “true” or “false?”	
What did the first computers use to make calculations before transistors?	
What are the three components of a Transistor?	
What are some reasons that transistors replaced vacuum tubes?	
Section E: Logic Gates	
Read the article about Logic Gates and answer the questions below.	
What is a Logic Gate?	
How many types of Logic Gates are there, and what are they?	

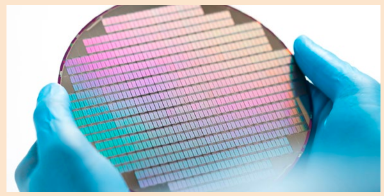
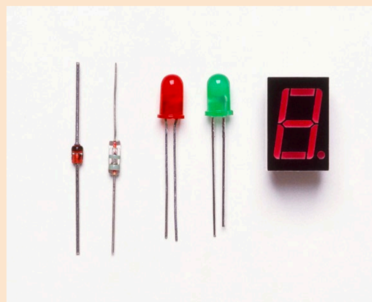
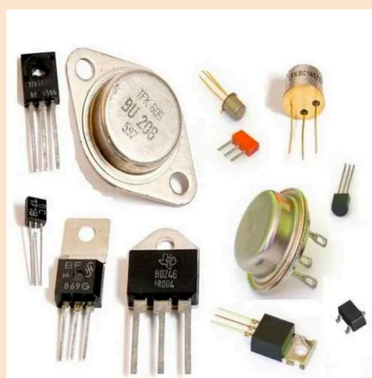
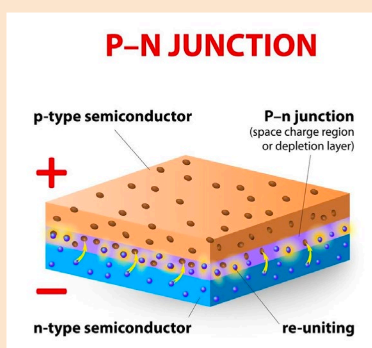
Where does the term "Boolean Logic," used to describe binary logic systems, come from?	
Section F: Transistors as Building Blocks	
Answer the following questions.	
Amino Acids are the building blocks of:	
Atoms are the building blocks of:	
Transistors are the building blocks of:	

Explain:

Section G: Transistor Size	
Watch the video about transistor size and answer the following questions.	
What is surprising to you about the layout of the transistors at the microscopic level?	
At the time this video was created, how small were we able to create transistors?	
Why are shrinking transistor sizes so important in advancing technology?	
Section H: Moore's Law	
Watch the video about Moore's Law, and answer the questions below.	
In your own words, what is Moore's Law?	
Why do you think that reduction in transistor size is slowing down in recent years?	

Do you think that integrated circuits will continue to double in size and complexity indefinitely?	

Section I: Academic Vocabulary

<table>
<tr><th>Word</th><th>Definition</th><th>Image</th><th>Description in Own Words</th></tr>
<tr><td>Semicon-
ductor</td><td>A material that can conduct electricity under certain conditions but not others.</td><td></td><td></td></tr>
<tr><td>Diode</td><td>A two-terminal electronic device that allows electric current to flow in only one direction.</td><td></td><td></td></tr>
<tr><td>Transistor</td><td>A semiconductor device used to amplify or switch electronic signals.</td><td></td><td></td></tr>
<tr><td>Junction</td><td>The boundary between two different types of semiconductors in a transistor.</td><td>
</td><td></td></tr>
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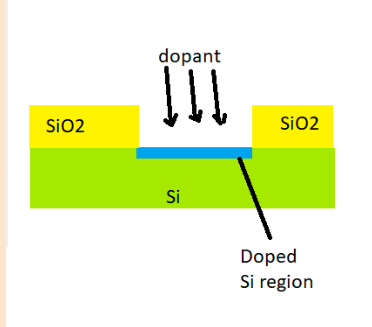
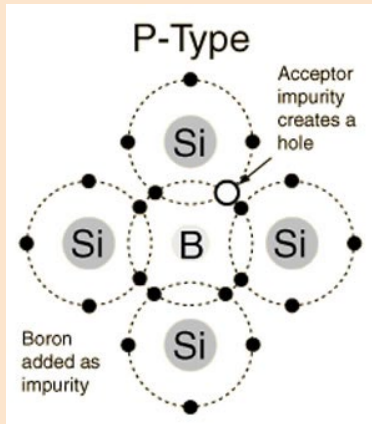
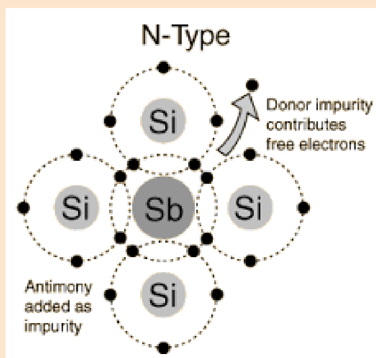
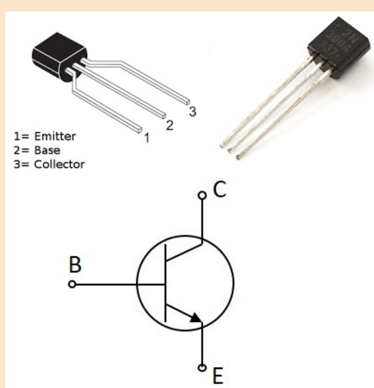
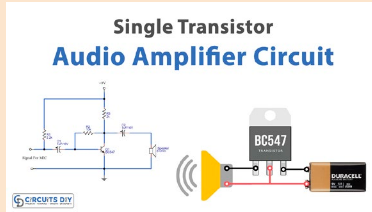
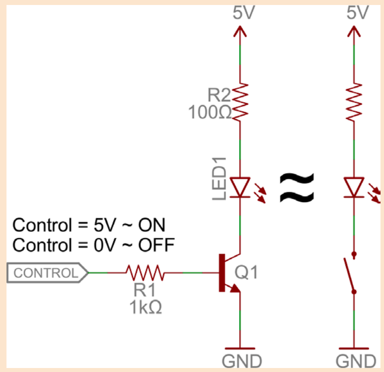
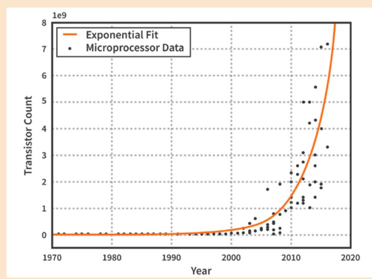
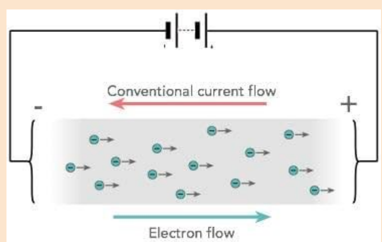
<table>
<tr><td>Doping</td><td>The process of intentionally adding impurities to a semiconductor material to alter its electrical properties.</td><td>
</td><td></td></tr>
<tr><td>P-Type</td><td>A type of material doped with impurities that accept electrons, resulting in excess positive charge carriers.</td><td>
</td><td></td></tr>
<tr><td>N-Type</td><td>A type of material doped with impurities that donate electrons, resulting in excess negative charge carriers.</td><td>
</td><td></td></tr>
<tr><td>Base</td><td>The region of a transistor that controls the flow of current between the emitter and collector.</td><td rowspan="3">
</td><td></td></tr>
<tr><td>Collector</td><td>The region of a transistor that collects electrons or holes from the base.</td><td></td></tr>
<tr><td>Emitter</td><td>The region of a transistor that emits electrons or holes into the base.</td><td></td></tr>
</table>

Amplifier	A device that increases the amplitude of an electrical signal.		
Switch	A device that can open or close a circuit to allow or prevent the flow of electrical current.		
Moore's Law	The observation that the number of transistors on a microchip doubles approximately every two years, resulting in exponential growth in computing power.		
Current	The flow of electric charge through a conductor.		

Elaborate:

Section J: WebQuest	
Read Lesson 1 and answer the following questions.	
What are some examples of devices that have become smaller and more compact over the years?	
What are some technological breakthroughs that you think might have led to improvements in these smaller devices?	

Read the Background section of Lesson 2 and answer the following questions.	
What do you think Sir Isaac Newton meant by the quote "If I have seen farther than others, it is because I have stood on the shoulders of giants?"	
What examples can you give where others "stood on the shoulders of giants?"	
What types of electronics interest you?	
What do you know about these inventions and their creators?	
What skills did these inventors need to have?	
Read Lesson 3 and answer the following questions.	
Approximately how large were the original transistors?	
Why would ENIAC, the vacuum tube equivalent to a computer, require a vast amount of air conditioning to cool it?	
Read Lesson 4 and answer the following questions.	
When was the first transistor created, and who built it?	

What function does a P-N Junction provide?	

Evaluate:

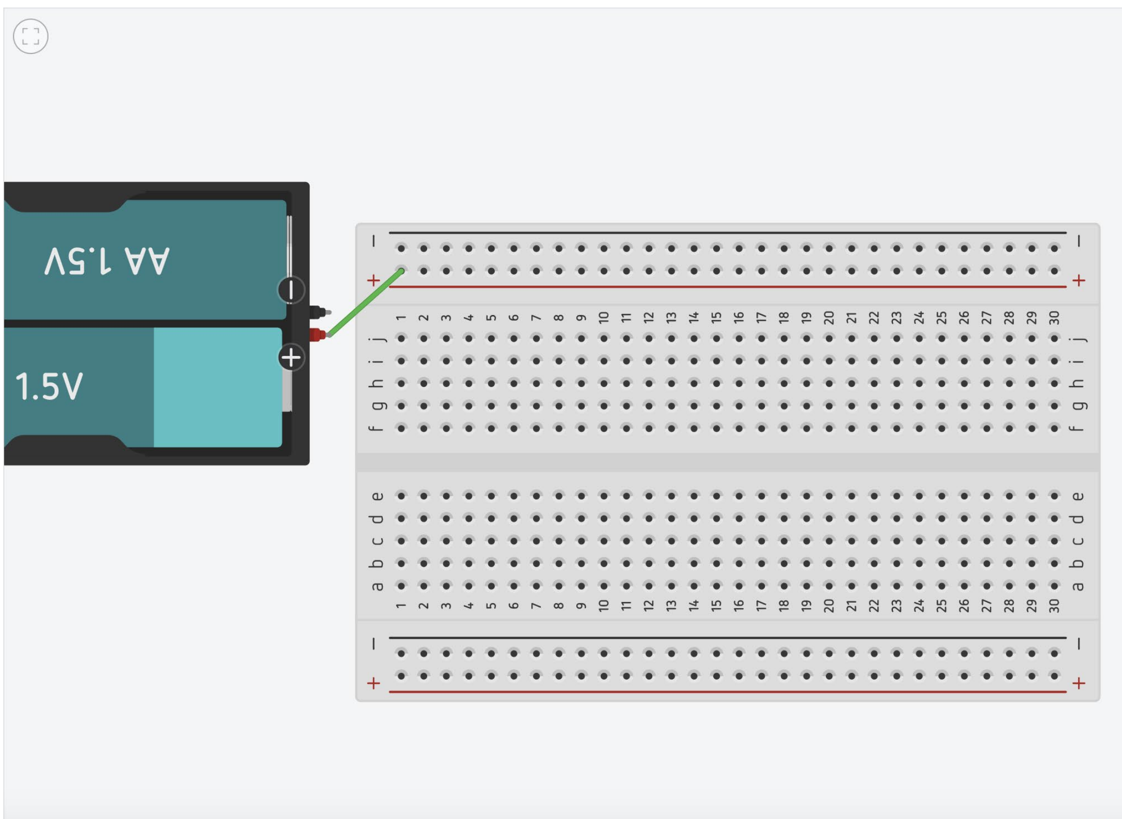
Section K: Darlington Pairs	
Follow the instructions for the Darlington Pair lab. Once that is completed, answer the following questions.	
How does a Darlington Pair work?	
What do you think one potential use for a darlington transistor is?	
How do you think arrangements of different transistors might pertain to logic gates?	

Darlington Pair Lab

For this lab, you will need:

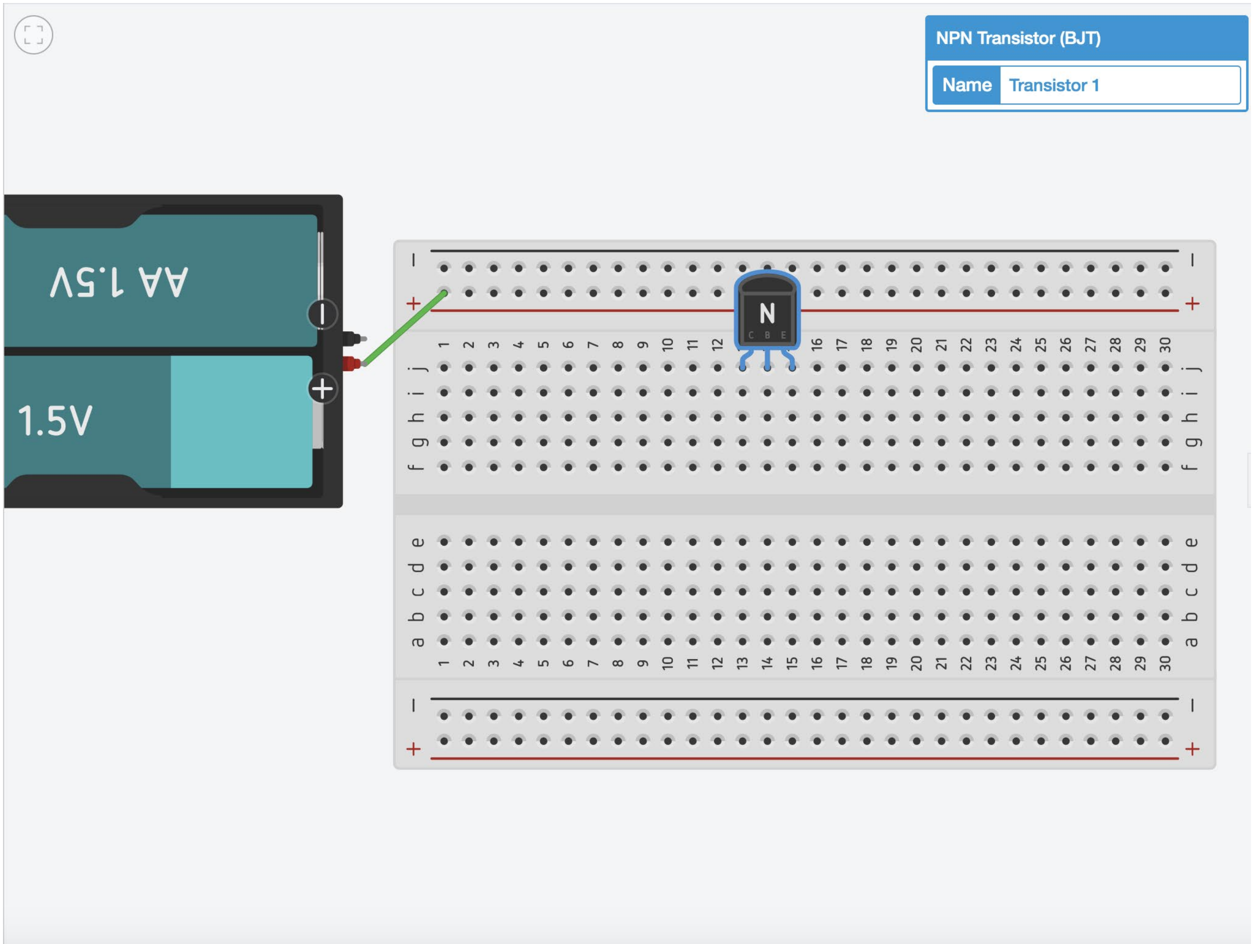
- 1 Breadboard
- 2 NPN-type transistors
- Copper wire
- 2 AA batteries
- 1 Paper Clip
- 1 47-Ohm Resistor
- 1 10,000 Ohm Resistor
- 1 Light-Emitting Diode

Step 1: Connect the breadboard to the power supply's **POSITIVE** (+) terminal. **DO NOT CONNECT THE NEGATIVE TERMINAL YET.**

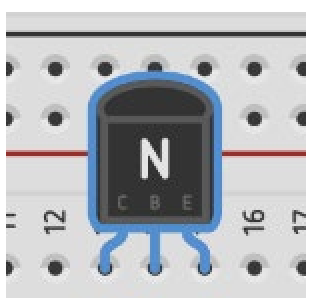


*Note: On each breadboard, you will see **numbered rows** and **lettered columns**. Breadboards transfer power across the numbered rows. Anything that is in the same numbered row as another component will be connected to the same circuit.*

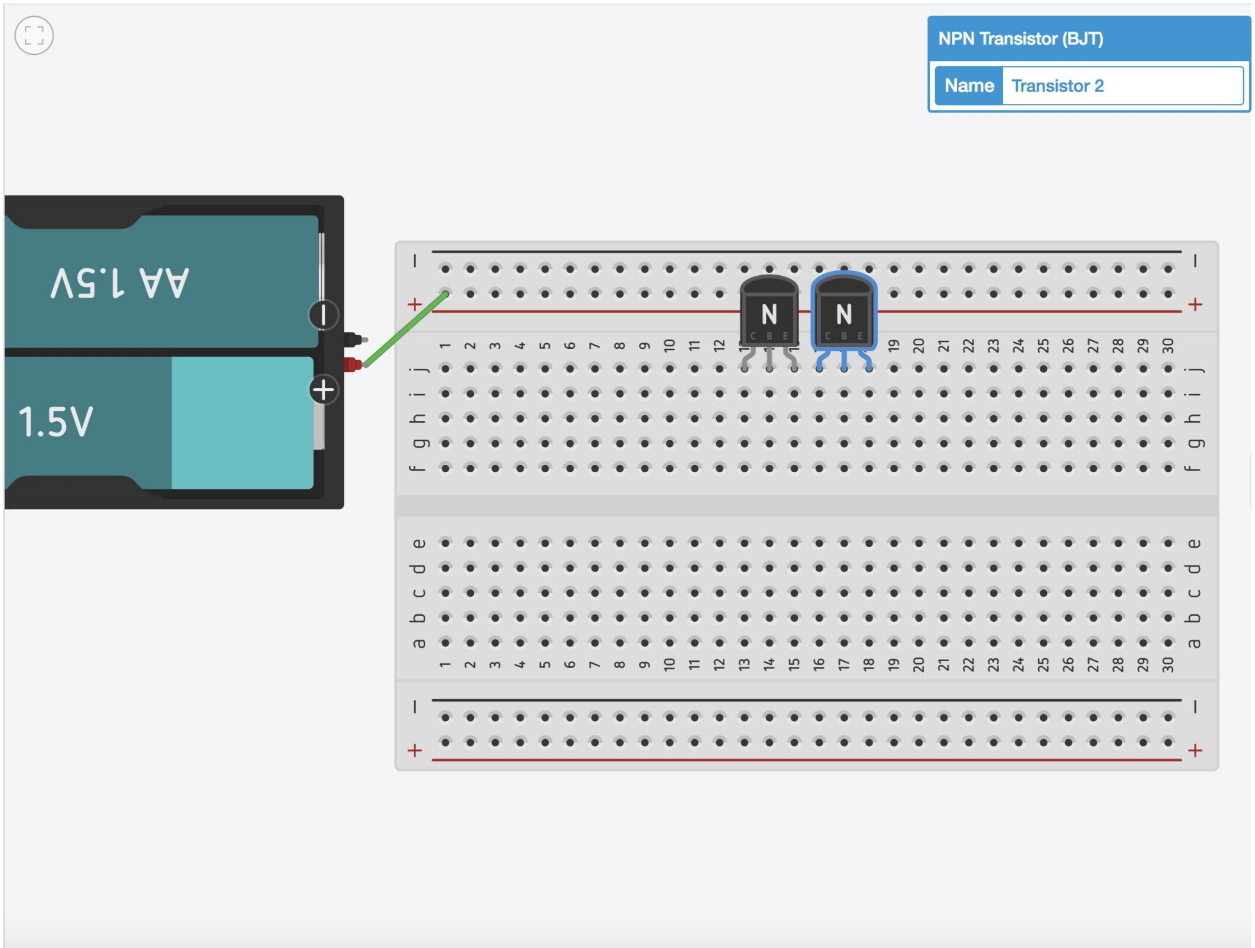
Step 2: Connect a transistor (Transistor 1) to the breadboard with the pins running along the long axis. Ensure the **Emitter** is closest to the **right**, and the **Collector** is closest to the **left**.

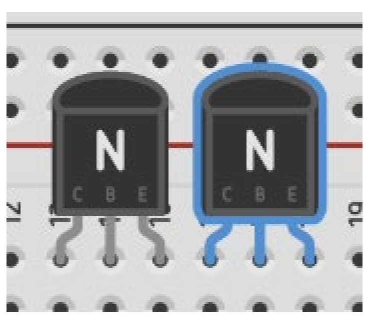


Note: On most NPN transistors, if the flat side of the transistor is facing you, the collector will be on the left and the emitter will be on the right.

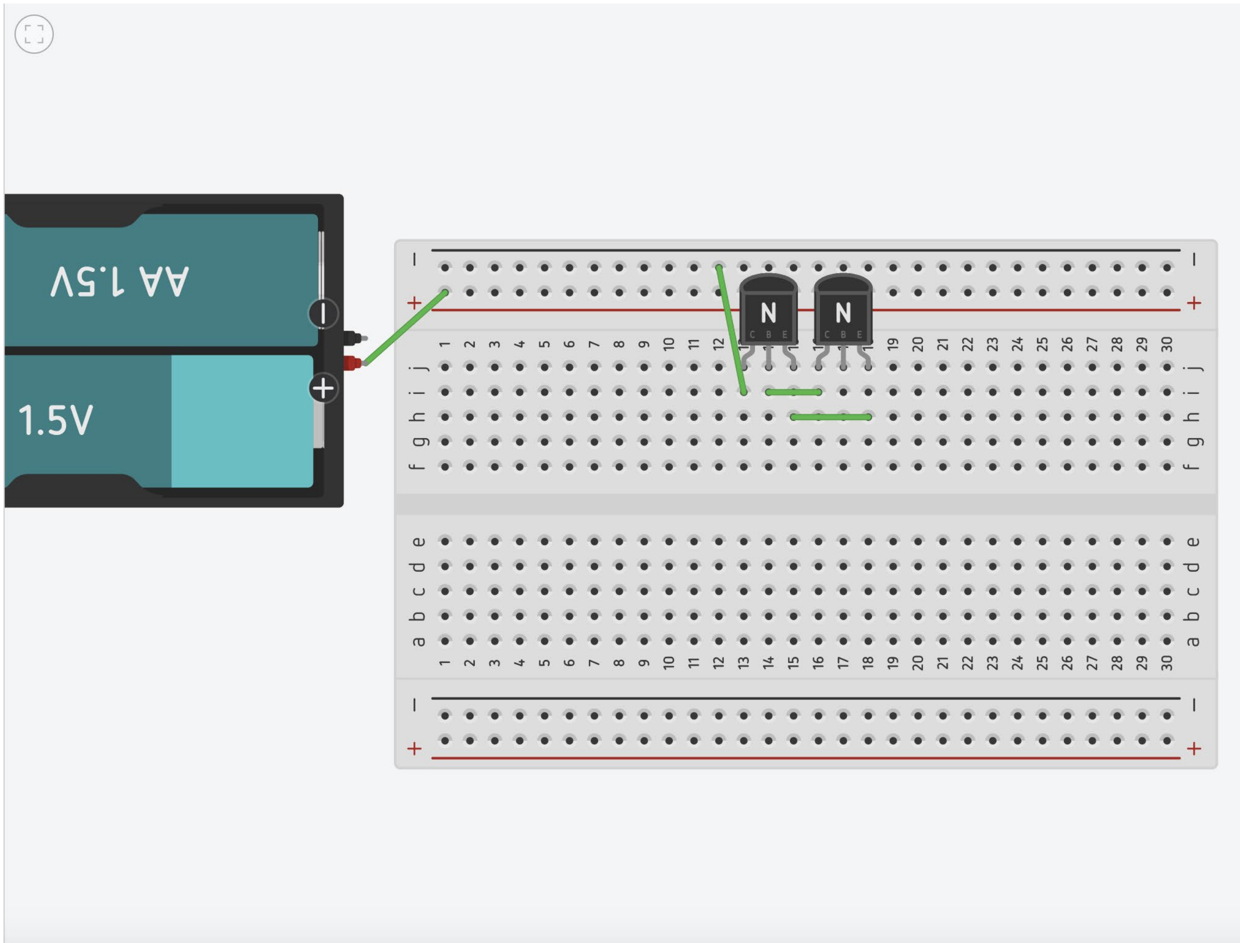


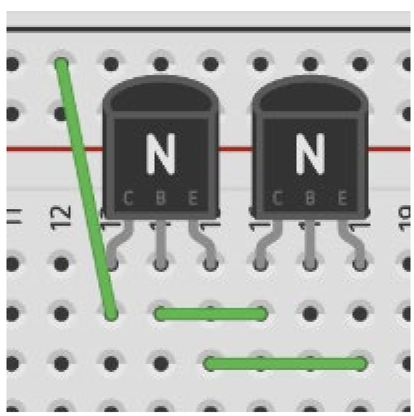
Step 3: Connect another transistor (Transistor 2) to the breadboard, next to Transistor 1. **Ensure the terminals are in separate numbered rows.** If they are in the same lettered column, as pictured, that will not be a problem.



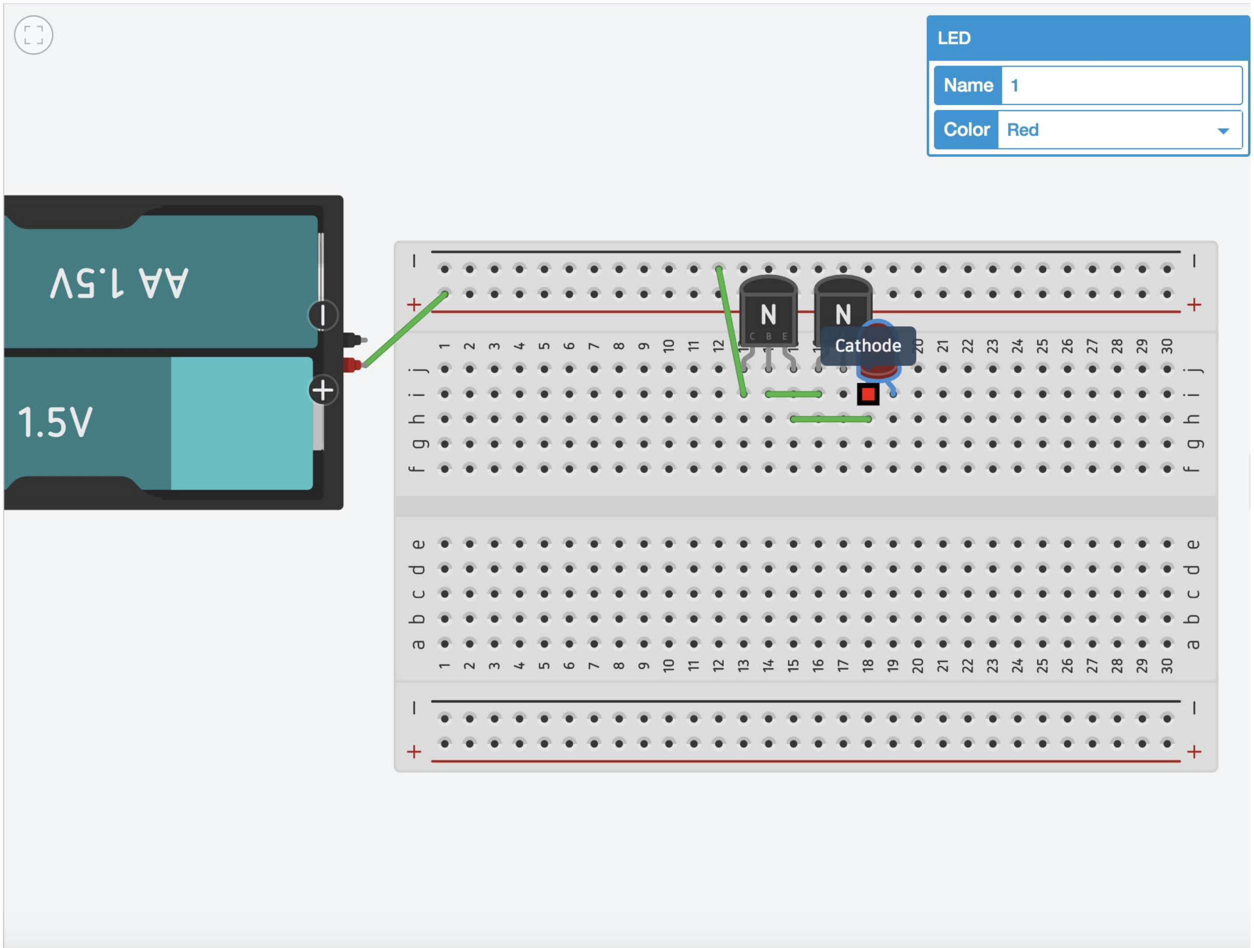


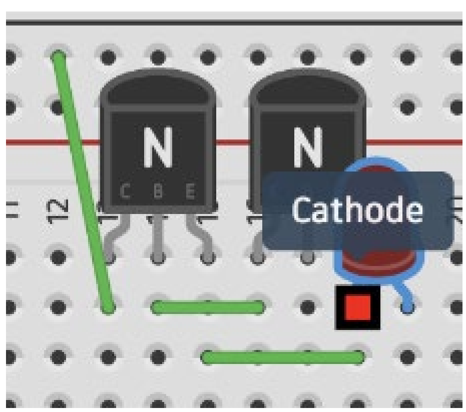
Step 4: Use copper wire to connect the Collector from Transistor 1 to the Negative section of the breadboard's power strip, then use another piece of wire to connect the Base of Transistor 1 to the Collector of Transistor 2. Finally, use a piece of copper wire to connect the Emitter of Transistor 1 to the Emitter of Transistor 2.





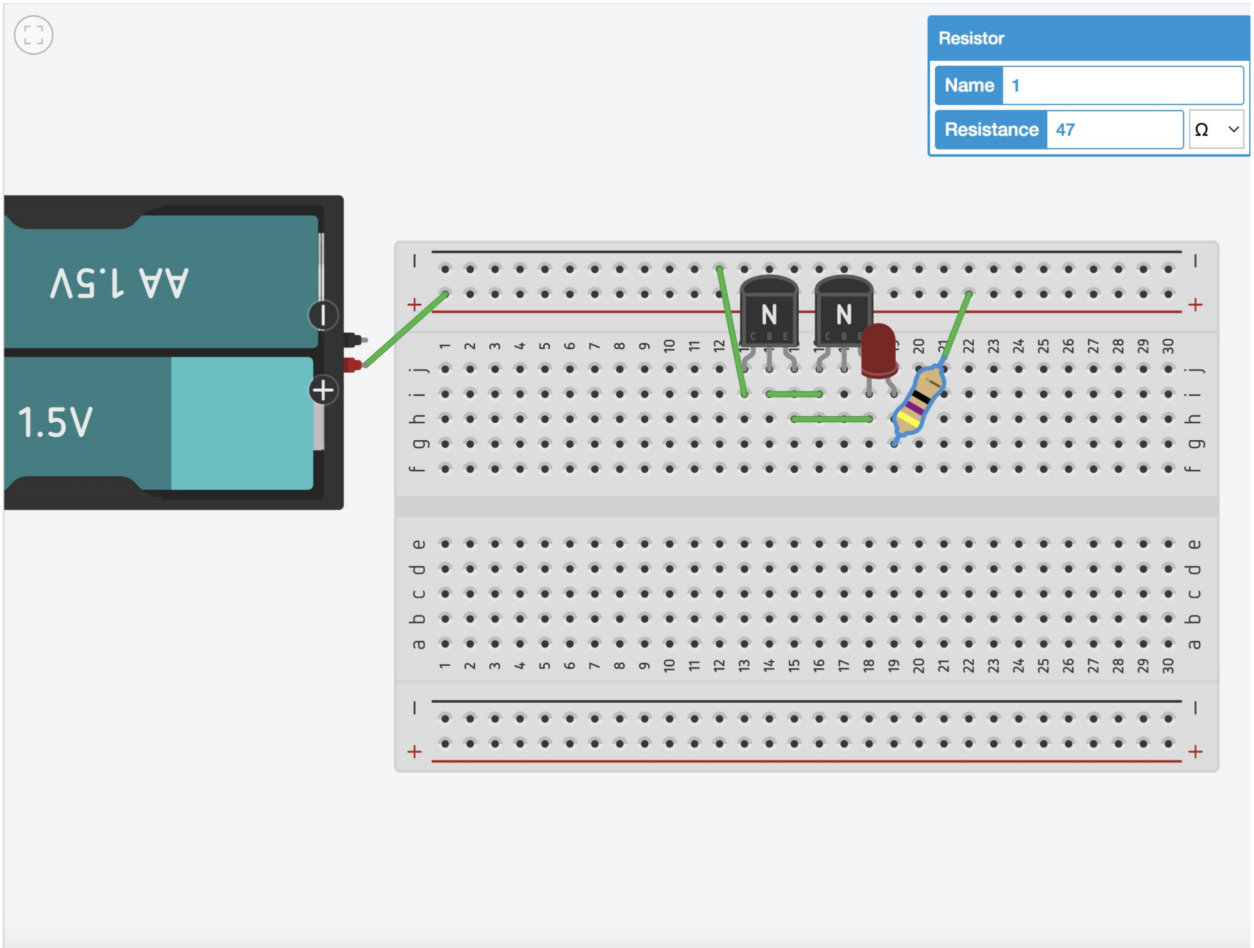
Step 5: Connect a Light-Emitting Diode to the same numbered row as the Emitter for Transistor 2. Connect the anode to a new row on the breadboard that has not been utilized yet.

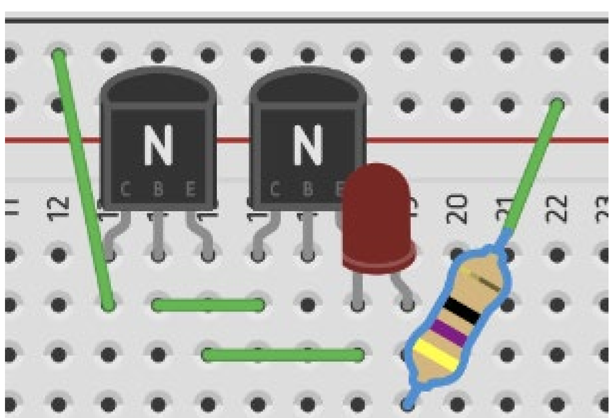




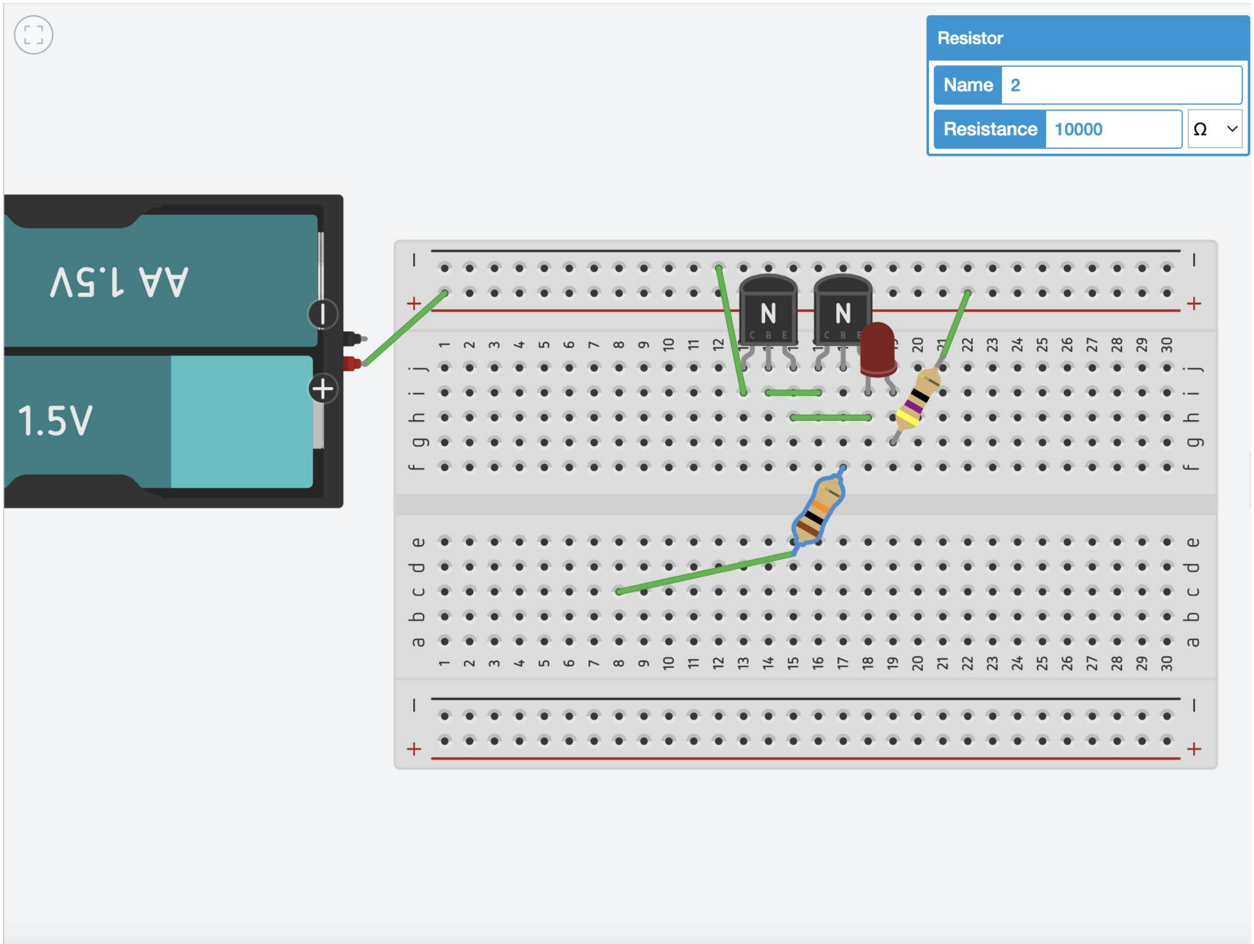
Note: The Cathode on an LED is the longer wire.

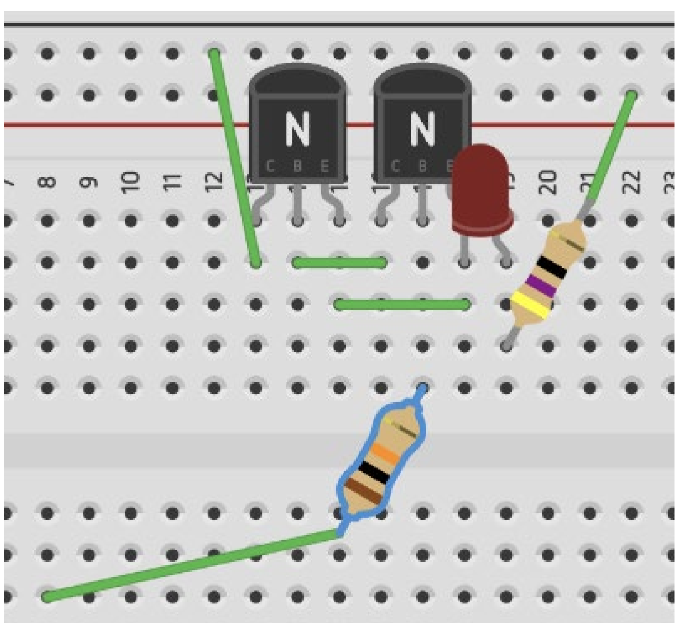
Step 6: Connect a 47-Ohm resistor to the same numerical row as the anode of the LED, then attach the other end to the positive side of the breadboard's power strip.



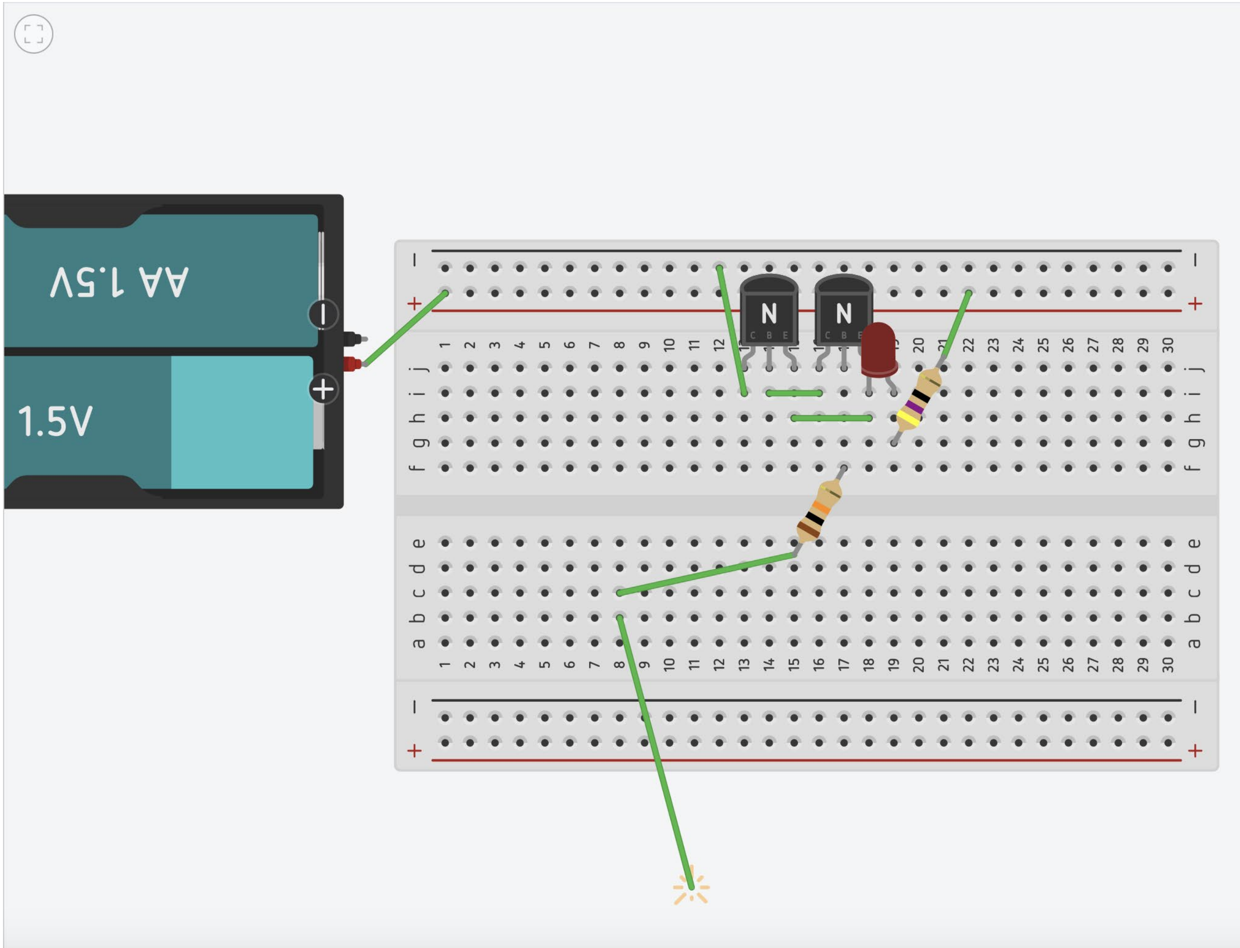


Step 7: Connect a 10,000-Ohm resistor to the Base of Transistor 2. Connect the other end to a previously unused numerical row on the breadboard.



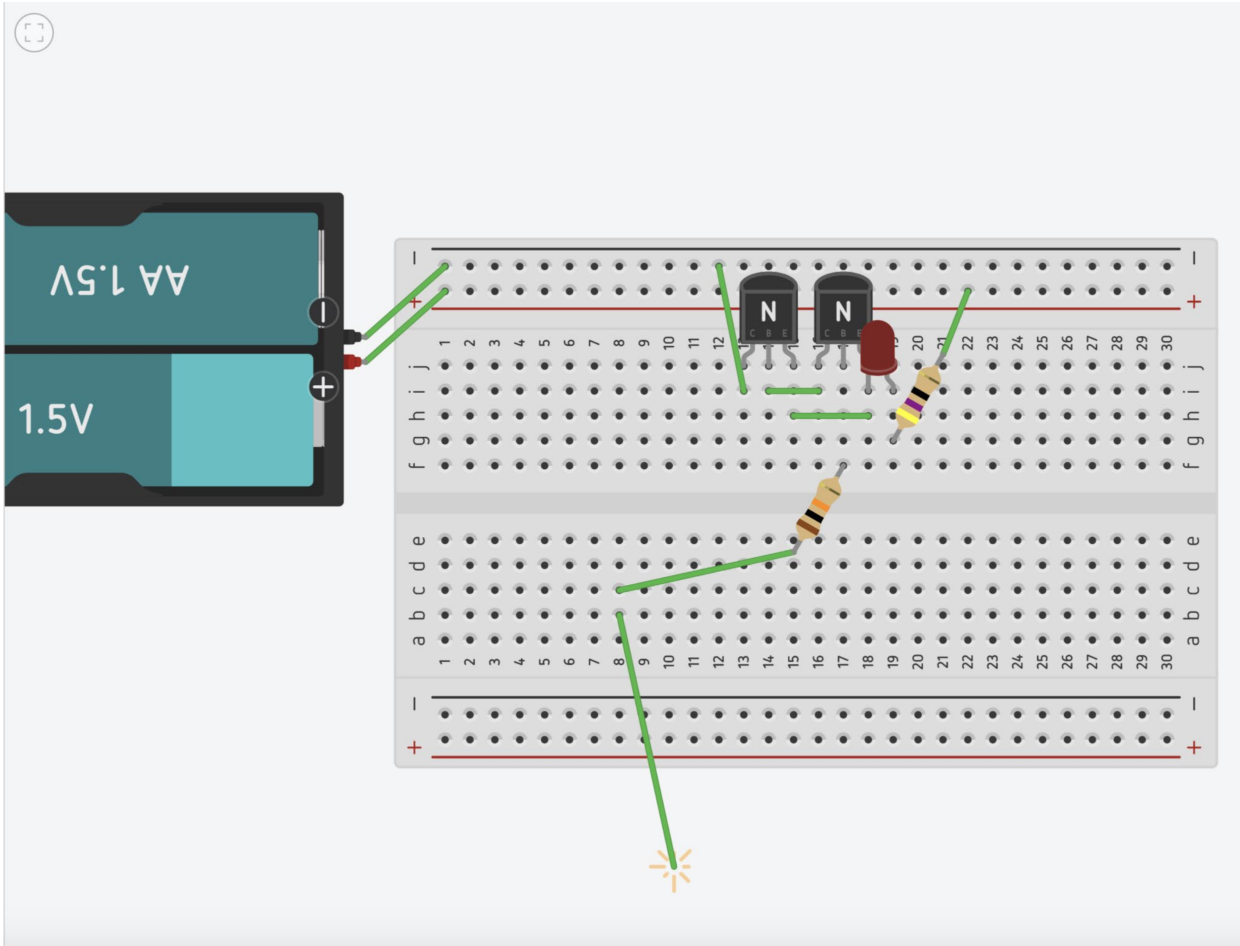


Step 8: Connect the paperclip to the same numerical row as the other side of the 10,000-Ohm Resistor.



Note: If utilizing TinkerCAD instead of building a physical model, instead of using a paperclip, connect the other end of the wire shown to the positive terminal of the breadboard's power strip. This will serve to ground the system.

Step 9: Connect the negative terminal of the battery to the negative power strip on the breadboard.



Step 10: Touch the paperclip with your finger. The Light-Emitting Diode should light up. *Note: If using TinkerCAD, simply select "Start Simulation" in the top right corner of the screen.*

What's Happening? A Darlington pair is a configuration of two bipolar transistors (NPN or PNP), typically of the same type, connected together to amplify a weak input signal.

The first transistor acts as a voltage amplifier, and its output is connected to the base of the second transistor, which acts as a current amplifier.

This arrangement provides a high current gain, as the two transistors effectively work together to amplify the input signal.

The output of the Darlington pair is taken from the collector of the second transistor, resulting in a significantly larger overall current amplification when compared to a single transistor configuration.