Teacher's Preparatory Guide

Lesson 5: Transistors as Switches & Amplifiers

Purpose: The purpose of this activity is to become familiar with transistors and their uses as switches and amplifiers. Transistors have N-P-N or P-N-P junctions. LEDs, previously used in Lessons 2, 3, and 4, only had an N-P junction.

Time required: one class period **(**45 – 55 minutes)

Level: High School Physics

Teacher Background:

Transistors:

Transistors act as switches and amplifiers. Current can enter a transistor through the base and collector leads. When the current leaves through the emitter lead, the current is the sum of the collector and base current. The amplification of current is determined by Equation 1.

$$h_{FE} = \frac{I_C}{I_B} \qquad \text{Eq 1.}$$

A transistor is based on the properties of a diode. Diodes are polar and only allow the flow of current in one direction. Diodes are based on the N-P model. Transistors are either N-P-N or P-N-P. In this lab an N-P-N transistor will be used. Further information on transistors can be found the resource section including applications in nanoelectronics.

Breadboards:

Be familiar with how breadboards work so that students may construct the circuit on a breadboard. A breadboard is nothing more than a rectangular plastic board with numerous small holes. The purpose of the holes is to allow insertion of electronic components to assist in building and testing an electronic circuit. Further information on breadbords can be found the resource section

Materials (For each lab set-up)

- 1 k Ω resistor (2)
- 680 Ω resistor (or something close)
- 2N3904 Transistor
- LED
- 9 V battery
- Battery connector

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- Jumper wires
- Breadboard

Advance Preparation: Purchase LEDs, breadboards, batteries, and transistors. All may be purchased at local electronics stores or online.

Safety Information:

Make sure the power supplies or batteries are disconnected when changing circuit components.

Pre Lab Activity:

1. Discuss the three leads of the transistor.
2. Discuss how transistors are the building blocks of integrated circuits.
3. Discuss how transistors can be made to be so small that they are micro and nano-sized.

Procedure is in Student Guide below:

Student Worksheet (with answers in red)

Lesson 5: Transistors as Switches & Amplifiers

Objective: The objective of this lab is to become familiar with transistors and their use as switches and amplifiers. You will learn that transistors are the building blocks of integrated circuits and that transistors are manufactured on the micro and nanoscales. When this lesson was written in 2008 the transistor size averaged between 55 and 65nm. At the time this lesson was re-edited in 2019, the size was down to 8nm. At the 10nm size and integrated circuit can have 5,300,000,000 transistors accounting for the enhanced capabilities and speed of electronic devices. Read about this progression at https://en.wikipedia.org/wiki/Transistor_count.

Materials: (for each group)

- 1 kΩ resistor (2)
- 680 Ω resistor (or something close)
- 2N3904 Transistor
- LED
- 9 V battery
- Battery connector
- Jumper wires
- Breadboard

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Introduction:

In this lab an NPN transistor will be used to show its characteristics as a switch. NPN transistors are also used for its amplification properties. Figure 1 illustrates an example of the type of transistor you will be using. Place the transistor in front of you and look at the bottom. Face the leads toward you. With the curved part facing upward the legs are labeled emitter, base, and collector from left to right, as shown in Figure 1. It is very important to know the identity of each leg. If they are connected incorrectly the circuit will not work and the transistor may break. The circuit schematic symbol is shown in Figure 2. The arrow indicates the direction of the current. Current enters the collector and base leads. If no current flows through the base lead, no current may enter the collector. If no current flows through the base or collector, no current leaves through the emitter.

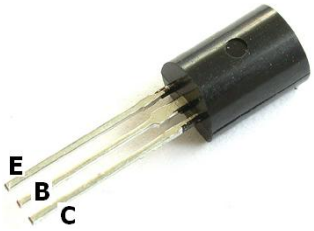

Figure 1. An NPN transistor with leads labeled as emitter, base, and collector . (www.reuk.co.uk/What-is-a-Transistor.htm)

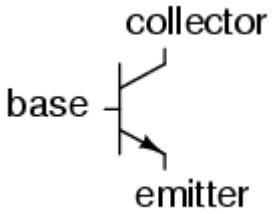

Figure 2. Transistor circuit schematic symbol. *(www.allaboutcircuits.com/vol_3/chpt_4/1.html)*

Experimental Setup:

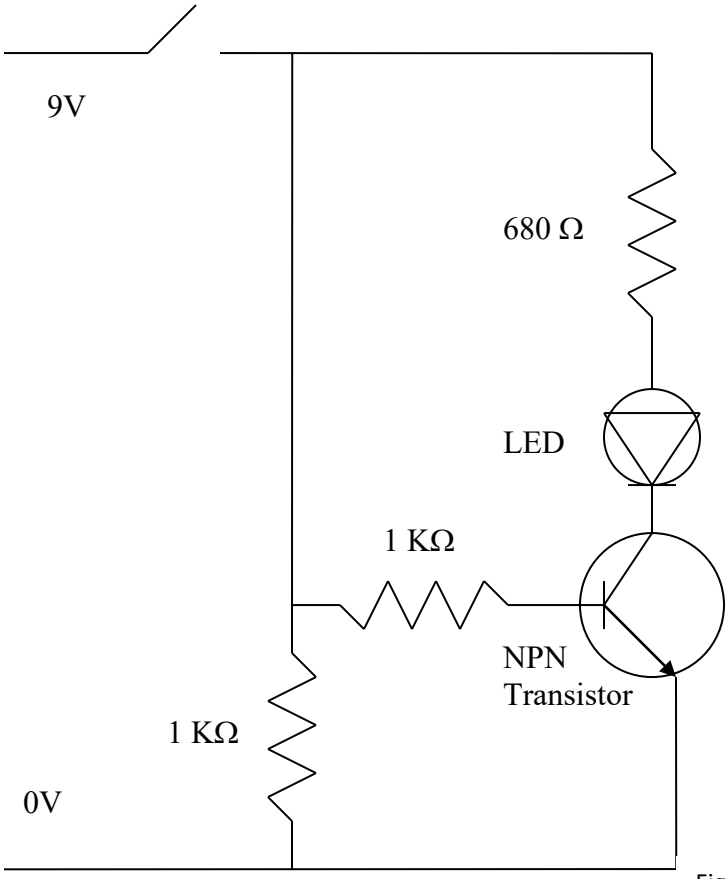

Figure 3. Circuit schematic

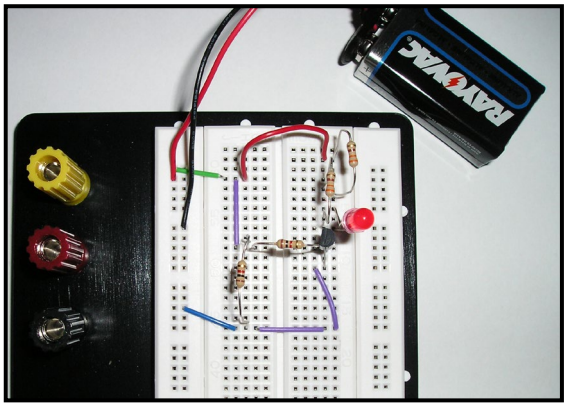

Figure 4. Breadboard Circuit

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Procedure:

1. Connect the circuit as shown above in the experimental setup section. Leave the switch open or battery unattached so that you don't electrocute yourself.
2. Double check to see that the transistor leads are properly placed.
3. Make sure that the red lead of the battery is attached to switch. If the polarity is switched the LED will not light up.
4. Turn the switch to the ON position or attach the battery.
5. What happens to the LED? *The LED lights up.*
6. Measure the current entering the collector lead of the transistor.
7. Record the data in Table 1.
8. Measure the current entering the base lead of the transistor.
9. Record the data in Table 1.
10. Measure the current leaving the emitter lead of the transistor.
11. Remove the battery or turn off the switch.
12. Detach the 1 k□ resistor connected to the base lead of the transistor as shown in Figure 5.

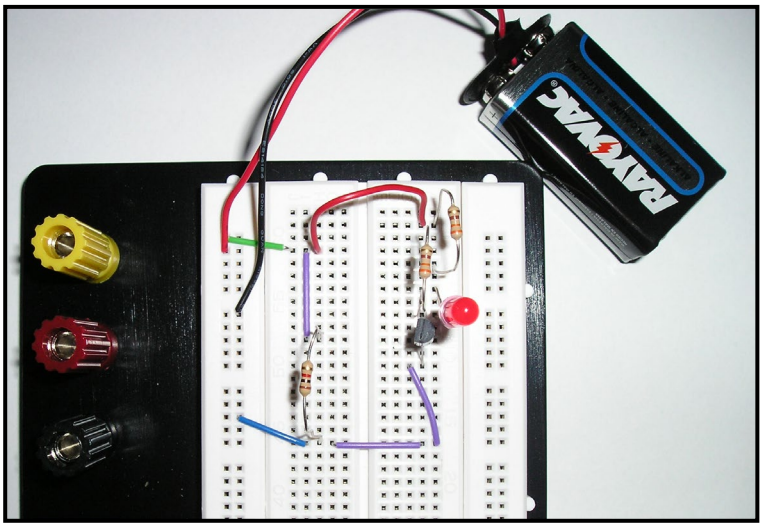

Figure 5. Circuit with the base resistor removed.

13. Reattach the battery.
14. Repeat steps 4 through 12. *This time the LED will not light up because there is no current entering the base lead.*

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Record Data:

Table 1. Current data for the transistor.

Circuit	Collector Current (A)	Base Current (A)	Emitter Current (A)
1			
2			

Analysis and Conclusion:

1. Why doesn't the second circuit's LED light up?
   The "switch" is turned off. No current is supplied to the base lead.
2. What is the base's role in a transistor?
   The base current switches the transistor on or partially on. If the base provides no current then the transistor is turned off.
3. What was the current gain for the first circuit?
   Gain = I_C/I_B. The gain is the collector current divided by the base current.
4. What is the current gain for the second circuit?
   Gain = I_C/I_B. The gain is the collector current divided by the base current.

Cleanup: Turn off the power supply and dismantle the circuit. Put the jumper wires back in the case and components in their proper place.

Extension Activity: Have students explore Moore's Law and the impact nanotechnology has had and is having on electronics. They should propose their solution for electronics in a post-Moore's Law world. Tell them to be imaginative and explore means that may not be possible today.

Assessment: Answer the analysis and conclusion section questions. You may want to examine their lab work for further assessment.

Resources:

To learn more about nanotechnology, electronics and transistors, below are some web sites with resources:

Breadboards:

The Basics: http://www.technologystudent.com/elec1/bread1.htm

How to use a Breadboard: https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard/all

What is a Breadboard: http://wiring.org.co/learning/tutorials/breadboard/

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What is a Breadbord YouTube video: https://www.makeuseof.com/tag/what-is-breadboard/ (among many others)

Transistors

How Transistors Work https://electronics.howstuffworks.com/transistor4.htm
What is a Transistor: http://www.reuk.co.uk/What-is-a-Transistor.htm
Bipolar Junction Transistors: http://www.allaboutcircuits.com/vol_3/chpt_4/1.html
The Transistor Switch: https://www.wisc-online.com/learn/career-clusters/stem/sse3703/the-transistor-switch

Transistors and Nanotechnology

https://www.dummies.com/education/science/nanotechnology/shrinking-transistors-with-nanotechnology/
https://www.understandingnano.com/nanotechnology-electronics.html
https://www.nanowerk.com/nanotechnology-news2/newsid=50895.php
https://qz.com/852770/theres-a-limit-to-how-small-we-can-make-transistors-but-the-solution-is-photonic-chips/

National Science Education Standards

Physical Science Standards

- Structures and properties of matter
- Interactions of energy and matter
- Conservation of energy

Science and Technology

- Understandings about science and technology

Next Generation Science Standards

PS1.A: Structure and Properties of Matter

HS-PS1-1: Each atom has a charged substructure consisting of a nucleus, which is made HS-PS1-3: The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.

HS-PS3: Energy

HS-PS3-2. Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects).

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