

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Contents

| | |
|---|----|
| Introduction..... | 3 |
| Lesson 1. Electricity, Conductors and Non-Conductors..... | 4 |
| Lesson 2. Batteries, Cells, Chemistries, Voltage, Capacity..... | 10 |
| Lesson 3. Voltage, Current and Resistance: Ohm's law..... | 17 |
| Lesson 4. Power and Energy: Watt's law and Joule's Law..... | 25 |
| Lesson 5. Semiconductors: Diodes, Light-Emitting Diodes, Solar Cells..... | 28 |
| Lesson 6. Transistors..... | 35 |
| Lesson 7. Capacitors..... | 43 |
| Lesson 8. Inductors and Transformers..... | 51 |
| Lesson 9. Electronic Components..... | 58 |
| Lesson 10. Electronics Prototyping: Build your own circuits..... | 58 |
| Lesson 11. Electronics Deconstruction: See how things work..... | 58 |

Table of Figures

| | |
|--|----|
| Figure 1: Simple Electrical Continuity Tester..... | 5 |
| Figure 2: Electronics Prototyping Kit..... | 6 |
| Figure 3: Electronics Prototyping Board..... | 6 |
| Figure 4: Electronic Components and Electronic Component Symbols..... | 7 |
| Figure 5: Testing for Electrical Continuity..... | 8 |
| Figure 6: Testing a Potato..... | 8 |
| Figure 7: Testing a 2B Pencil..... | 8 |
| Figure 8: Digital Multi-Meter..... | 11 |
| Figure 9: Internal Structure of a Carbon-Zinc Battery..... | 12 |
| Figure 10: Battery Shapes and Sizes..... | 12 |
| Figure 11: Battery Holders..... | 13 |
| Figure 12: Battery Chemistries..... | 15 |
| Figure 13: DC Regulated Power Supply..... | 18 |
| Figure 14: Banana Plug Clip Leads..... | 18 |
| Figure 15: Electronic Resistor Series, Tolerance and Preferred Values..... | 21 |
| Figure 16: Resistor Coloured Bands..... | 21 |
| Figure 17: Resistor Colour Codes..... | 22 |
| Figure 18: Resistor Colour Code Examples..... | 23 |
| Figure 19: 9V LED Circuit..... | 23 |
| Figure 20: Using a Component Tester to test diodes..... | 29 |
| Figure 21: PN Junction Internal Structure and Circuit Symbol..... | 30 |
| Figure 22: Diode Physical Package and Connections..... | 31 |
| Figure 23: Schottky Diode..... | 32 |
| Figure 24: Zener Diode..... | 32 |
| Figure 25: Light Emitting Diode (LED)..... | 33 |
| Figure 26: Internal View of an LED..... | 33 |
| Figure 27: Internal Structure of an LED..... | 33 |
| Figure 28: Physical appearance of a typical transistor..... | 37 |
| Figure 29: NPN transistor internal structure, physical connections and circuit symbol..... | 38 |
| Figure 30: PNP transistor internal structure, physical connections and circuit symbol..... | 38 |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



| | |
|--|----|
| Figure 31: NPN Transistor Current Gain..... | 39 |
| Figure 32: PNP Transistor Current Gain..... | 39 |
| Figure 33: Using a Component Tester to test transistors..... | 40 |
| Figure 34: NPN Transistor Electrical Continuity Tester..... | 41 |
| Figure 35: PNP Transistor Electrical Continuity Tester..... | 41 |
| Figure 36: Capacitor Types..... | 44 |
| Figure 37: Electrolytic Capacitor..... | 45 |
| Figure 38: Electrolytic Capacitor Structure..... | 46 |
| Figure 39: Capacitor Circuit Symbols..... | 46 |
| Figure 40: Charging a capacitor..... | 46 |
| Figure 41: Discharging a capacitor..... | 47 |
| Figure 42: Capacitor Charging and Discharging..... | 48 |
| Figure 43: Capacitor Timing Circuit 1..... | 49 |
| Figure 44: Capacitor Timing Circuit 2..... | 49 |
| Figure 45: Magnetic Field..... | 52 |
| Figure 46: Electromagnetic induction..... | 52 |
| Figure 47: Electromagnetism..... | 53 |
| Figure 48: Inductors: Air Core, Ferrite Core and Circuit Symbol..... | 53 |
| Figure 49: Inductor test circuit..... | 54 |
| Figure 50: Transformer and Circuit Symbol..... | 56 |
| Figure 51: Transformer test circuit..... | 57 |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Introduction

The School Amateur Radio Club Network® is pleased to present a series of introductory electronics workshops on our [SARCNET](http://www.sarcnet.org) website. These workshops include: Electronics, Electronic Components, Electronics Prototyping and Electronics Deconstruction. In conjunction with these workshops, we also provide teacher lesson plans. Please note that we are not teachers and that this information is provided for reference only.

In this series students will learn:

1. Electrical scientists: Volta, Ampère, Ohm, Watt and Joule
2. Electrical quantities and symbols: Voltage, current, resistance, power and energy (V, I, R, P, E)
3. Electrical units and symbols: Volt, Amp, Ohm, Watt and Joule (V, A, Ω , W, J)
4. Electrical unit multipliers and symbols: Mega, kilo and milli (M, k, m)
5. Electrical formulas: Ohm's law, Watt's law and Joule's Law
6. Electrical material: Conductors, non-conductors, poor-conductors and insulators
7. Electronic components:
 1. Batteries, polarity, positive, negative, terminals, holders, electrodes, electrolytes, chemistries
 2. Switches and wires, open-circuit, short-circuit
 3. Resistors, colour codes
 4. Diodes, semiconductor junction, anode, cathode, Silicon-, Schottky-, Zener-, Light-Emitting Diode
 5. Transistors, bipolar junction, NPN and PNP, emitter, base, collector, current gain
 6. Capacitors, electric field, electric charge
 7. Inductors, electromagnetism, electromagnetic induction, magnetic field
 8. Transformers, primary and secondary windings, polarity, magnetic cores
8. Electronic component symbols and electronic circuit diagrams
9. Electronic instruments: Regulated DC power supply, digital multi-meter, component tester
10. Electronics prototyping, kit construction, soldering
11. Electronics deconstruction, desoldering

Each lesson is divided into the following sections:

1. Purpose: The aim of the lesson
2. Introduction: A statement, which can be read out at the start of the lesson, to introduce the topic
3. Safety: Important safety warnings covering risk areas and precautions to be taken
4. Key Learning Areas: High level, curriculum-based, topics covered in the lesson
5. Learning Outcomes: Details of what the student should learn in the lesson and details of what new skills the student should acquire
6. Year Level: The lesson is suitable for the year level shown
7. Lesson Time: The approximate time to deliver the lesson
8. Resources: Equipment and parts required to complete the lesson
9. Teacher Tasks: Actions the teacher should take in delivering the lesson
10. Student Tasks: Expectations for the students taking the lesson
11. Discussion: Further questions and answers for discussion if time permits
12. Evaluation: Approach to assessment

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 1. Electricity, Conductors and Non-Conductors

| |
|---|
| Purpose Introduction to SARCNET Electronics Workshops series, starting with basic conductors and non-conductors. |
| Introduction “In this lesson we will learn about electricity and the materials that conduct and don’t conduct electricity” |
| Safety WARNING: DO NOT ALLOW THE BATTERY WIRES TO TOUCH EACH OTHER WHEN THE SWITCH IS ON. THIS IS CALLED A SHORT CIRCUIT AND CAN RESULT IN THE BATTERY AND WIRES GETTING HOT, MELTING THE PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! |
| Key Learning Areas <ol style="list-style-type: none">1. Electricity, conductors and non-conductors2. Batteries, switches and wires3. Electronic component symbols4. Circuit schematic diagrams5. Electronics prototyping |
| Learning Outcomes <p>This lesson plan will give students an opportunity to learn that:</p> <ol style="list-style-type: none">1. Electricity is created in a battery2. Electricity can flow through wires3. The flow of electricity can be switched on and off by a switch4. Electronic components can be represented by using component symbols5. Electronic circuits can be drawn using circuit schematic diagrams6. An electronics prototyping-board can be used to connect electronic components together7. The flow of electricity can be indicated by the illumination of a Light Emitting Diode8. A resistor is necessary to protect the LED from too much flow of electricity9. Electricity flows through conductors and not through non-conductors10. Conductors are usually metals11. Non-Conductors are usually non-metals12. The terms: Circuit, Resistors, Current and Electrons are introduced |
| Year Level Year 5 or 6 |
| Lesson Time 45 Minutes for one (1) teacher-built tester 90 Minutes for multiple student-built testers |
| Resources <p>For each tester you will need parts from our SARCNET STEM Kit #1 - Electronics Prototyping Kit (see Figure 2), or you can purchase the following parts separately.</p> <ol style="list-style-type: none">1. Switched Battery Holder (3V)2. AA Cells (x2)3. 510Ω 1/4W 5% resistor: Green, Brown, Black, Gold; or4. 510Ω 1/4W 1% resistor: Green, Brown, Black, Black, Brown5. Light Emitting Diode6. 170 Contact Electronics Prototyping Board <p>Plus the following parts not included in the kit:</p> <ol style="list-style-type: none">1. 150mm Pin Leads (x2), or hook-up wire cut, stripped 10mm and tinned at each end |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

In addition, the class will need one (1) set of the following items:

1. A selection of different conductors and non-conductors to test: E.g. A spoon, paper clip, aluminium foil, plastic pen, teacup, glass, paper etc.
2. A selection of different poor conductors: E.g. A small potato see Figure 6, an egg cup of tap water with some salt; and
3. A 2B pencil, split down the middle to reveal the lead. Carefully groove opposite sides of the pencil with a box-cutter blade. Repeat to gently deepen the cut to close to the lead. When deep enough, use your fingernails to split and remove the wood down one whole side of the pencil. The lead should remain attached to the wood on the other side of the pencil, which will prevent the lead from breaking. See Figure 7.

Teacher Tasks

1. Provide students with the lesson introduction and safety briefing above
2. Pre-build one (1) simple electrical continuity tester. The wiring of the tester is shown in Figure 1; or
3. Provide sufficient parts and additional directions for all students to build their own. The parts come from our [SARCNET STEM Kit #1](#) - Electronics Prototyping Kit (see Figure 2), or you can purchase the parts separately. Note: Building their own tester will take students an additional 45 minutes. Do not provide batteries until the student's circuit is checked and the whole class has been briefed. The completed tester should look like the photograph in Figure 19.

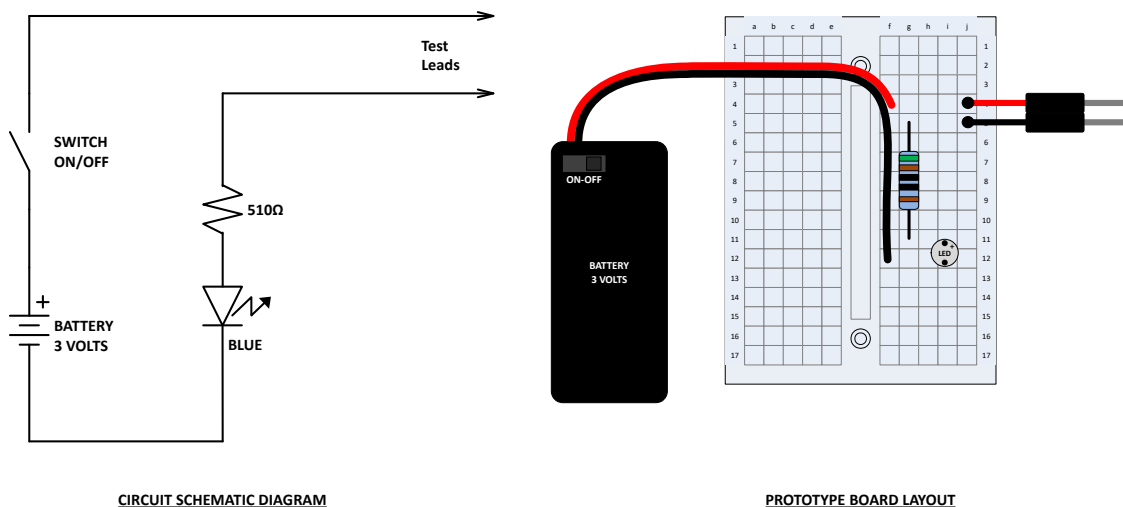


Figure 1: Simple Electrical Continuity Tester

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

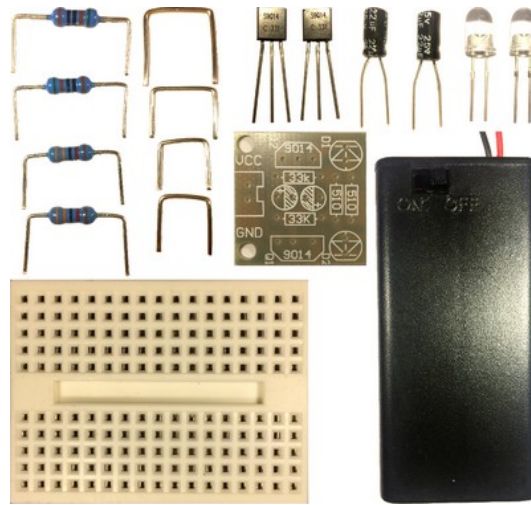


Figure 2: Electronics Prototyping Kit

4. Examine the Electronics Prototyping Board. See Figure 3.
 - a. **Caution: On the back of the Electronics Prototyping Board is a double-sided adhesive pad. Never peel off the yellow backing paper as it will permanently stick to any surface. Subsequently trying to remove it from the surface will ruin the board.**
 - b. The Electronics Prototyping Board is used to easily create temporary, experimental, electronic circuits without the need for soldering or a printed circuit board.
 - c. The board has 10 columns by 17 rows of holes. Each hole is an electrical socket, with a metal spring contact, connecting it to the four adjacent holes, on the same side of the same row of the board as shown by the blue lines in Figure 3.
 - d. The wires and leads of electronic components can pushed into the holes. The holes are spaced 0.1 inches apart so that the board even accepts standard, dual in-line, integrated circuit packages when placed across the central canyon. The wires and electronic components can later be removed and reused.
 - e. Electronic component leads are thin and delicate. **Do not bend them or they will break.** Carefully line up leads with the centre of the holes, press them lightly on both sides and wiggle the component from side to side until the leads slide more easily into the socket.

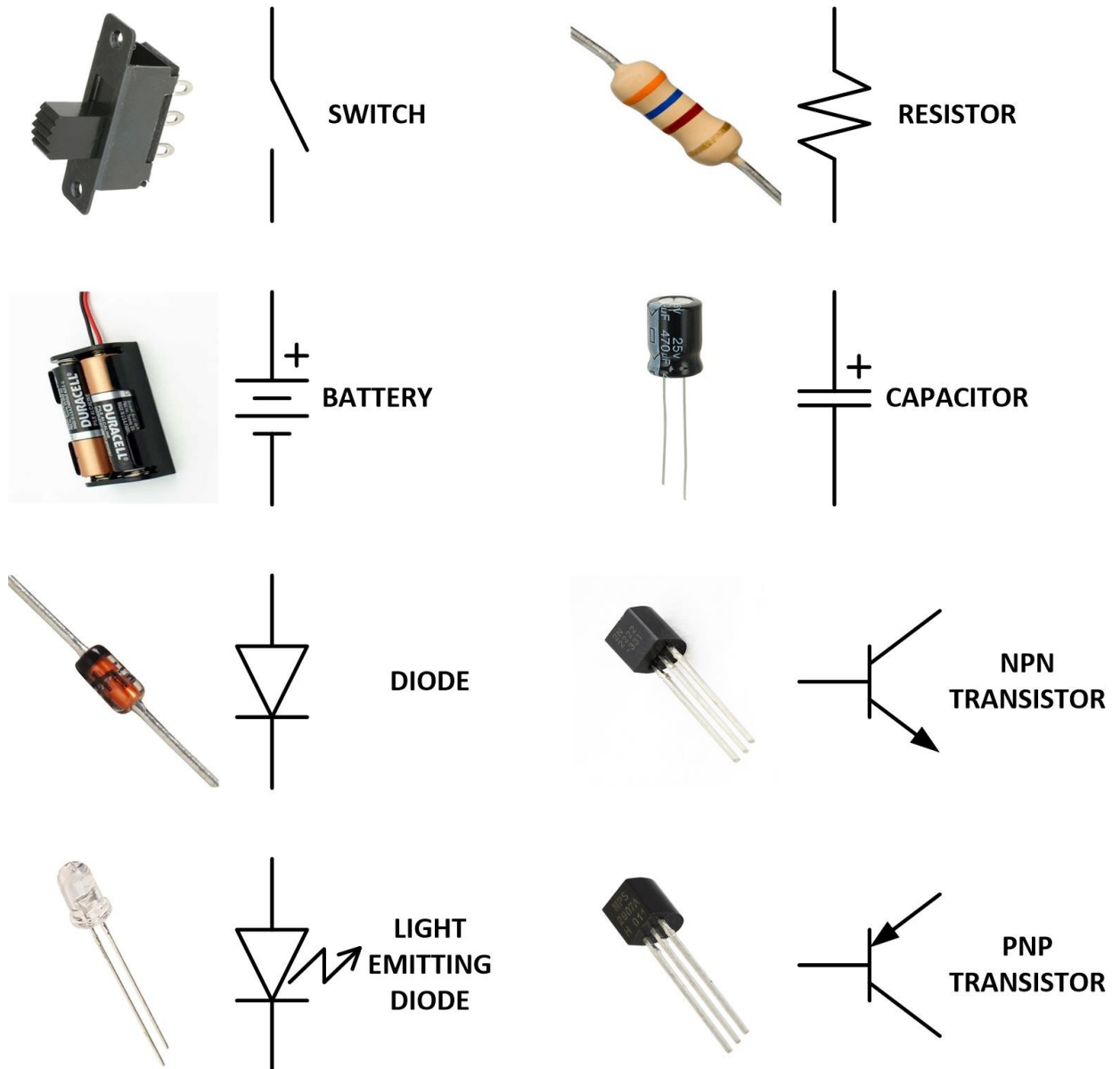


Figure 3: Electronics Prototyping Board

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

5. Introduce electronic components and their circuit symbols. See Figure 4. Each electronic component has a shorthand symbol that is easy to draw. (Note: This will be covered in more detail in a later lesson plan)



ELECTRONIC COMPONENT SYMBOLS

Figure 4: Electronic Components and Electronic Component Symbols

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

6. Briefly describe the name and function of each of the components in the simple electronic continuity tester (Note: This will be covered in more detail in a later lesson plan)
 - a. With reference to the circuit diagram and physical layout in Figure 1, identify each of the electronic components: The battery, switch, wires, resistor, LED and test leads.
 - b. Explain that each electronic component has a symbol and that the symbol is shown in the schematic diagram connected to other components by lines, which represent the wires.
 - c. Explain: "Electricity flows from the battery, through the switch and the test leads, through the item under test. It then flows back through the resistor and the LED to the battery. The electronics prototyping board is just used to connect all the electronic components and wires. If sufficient electricity flows, the LED will illuminate. Only good conductors will let sufficient electricity to flow. Note: The resistor is used just to protect the LED from too much flow of electricity, which may damage it."
7. Demonstrate the operation:
 - a. When you touch the ends of the test leads to a conductor the LED will illuminate. Try a spoon, a paper clip, aluminium foil, etc. See Figure 5.
 - b. When you touch the ends of the test leads to a non-conductor the LED will not illuminate. Try a plastic pen, a teacup, a glass, paper, etc. See Figure 6.
 - c. When you touch the end of the test leads to a poor conductor the LED may illuminate dimly. Try a potato, egg-cup of salty water and the lead of a split 2B lead pencil. See Figure 7.



Figure 5: Testing for Electrical Continuity

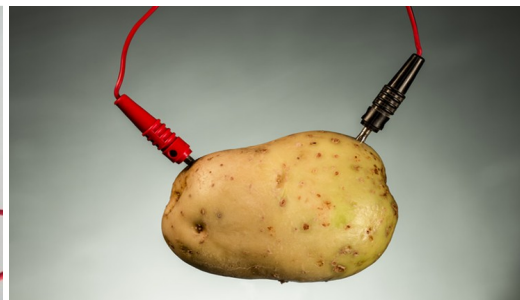


Figure 6: Testing a Potato



Figure 7: Testing a 2B Pencil

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Student Tasks

1. Students use the tester to discover which materials are conductors and non-conductors
2. Students sort the collection of materials provided into conductors (which illuminate the LED) and non-conductors (which do not illuminate the LED)

Discussion

1. Discuss the similarities and differences between the materials which are conductors and non-conductors. Can we make any assumptions about metals and plastics?
2. Electricity always flows in a loop, from the source and back again. We call this an electric **circuit**. If you break the circuit, anywhere, the electricity stops flowing. Try it.
3. Some conductors are not very good. They resist the flow of electricity. We call them **resistors**. Try various lengths of pencil lead, a small potato or an egg-cup of water (into which you may need to dissolve one or two grains of salt), even your wet finger. The LED will only glow dimly for resistors.
4. Some materials hardly conduct electricity at all. They are called non-conductors or insulators. The difference is that a non-conductor may not conduct electricity under most circumstances, but insulators are specifically designed not to conduct electricity under any circumstances. For example: Pure water is a non-conductor, but it would not be used as an insulator, like a glazed ceramic material. That is because even a small amount of impurities, like salt, in the water can cause it to conduct.
5. The flow of electricity is what makes all electric circuits work. We call this electric **current**. But what is "flowing" in the wires? It is not water or air. It is **electrons** moving from one atom to the next. They are so small that you can't see them.

Evaluation

Ask the class questions. Encourage each student to answer.

1. What makes the LED illuminate? (Electricity flowing through the conductor)
2. Where does the electricity come from? (The battery)
3. What is inside a battery that makes electricity? (Chemicals)
4. Can batteries be dangerous? (Yes, if there is a short circuit they can create heat or fire)
5. Can you turn the electricity on and off with the switch? (Yes)
6. What types of materials allow electricity to flow and make the LED illuminate? (Metals) What do we call them? (Conductors)
7. What types of materials do not allow electricity to flow? (Non-metals) What do we call them? (Non-conductors)
8. What do we call poor conductors? (Resistors)
9. What do we call the loop along which electric current flows? (Circuit)
10. Can you trace the circuit through which the electricity flows? (Battery, switch, wire, board, wire, conductor, wire, board, resistor, board, LED, board, wire, battery)
11. What is another name for the flow of electricity? (Current)
12. All materials are made of atoms. What part of the atom flows inside metals? (Electrons)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 2. Batteries, Cells, Chemistries, Voltage, Capacity

| |
|--|
| Purpose To understand batteries in depth. |
| Introduction “In this lesson we will learn about the different types of batteries, how they work and how to use them” |
| Safety WARNING: DO NOT SHORT-CIRCUIT BATTERIES BY CONNECTING THEIR TERMINALS TOGETHER. THE BATTERY AND CONNECTING WIRES CAN GET HOT, MELTING PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! SHORT-CIRCUITED BATTERIES CAN GET HOT AND EXPLODE! WARNING: DO NOT ALLOW CHARGING BATTERIES TO GET HOT. THEY CAN CATCH FIRE AND EXPLODE. ALWAYS MONITOR BATTERY CHARGING AND TURN OFF THE CHARGER WHEN FINISHED. |
| Key Learning Areas <ol style="list-style-type: none">1. Battery chemistry and sizes2. Battery terminals, polarity and connections3. Battery voltage and cells4. Battery capacity and state of charge5. Battery types: Non-rechargeable and rechargeable6. Battery safety |
| Learning Outcomes <p>This lesson plan will give students an opportunity to learn that:</p> <ol style="list-style-type: none">1. Batteries store electrical energy using internal (dangerous/corrosive) chemicals and electrode structures2. Batteries come in different shapes and sizes for different applications3. Battery terminals are polarised, provide connection to external electrical circuits4. Battery holders, clips and clamps provide for external wired connections5. Battery rated voltage is determined by the number of cells and the chemistry in the cells6. Battery rated capacity is related to battery size7. Battery actual voltage and capacity is determined by the state of charge (charged/discharged)8. Battery types: Carbon and alkaline non-rechargeable types9. Battery types Nickel Cadmium, Nickel Metal Hydride, Lead-Acid and Lithium-Ion rechargeable types |
| Year Level Year 5 or 6 |
| Lesson Time 45 Minutes |
| Resources <ol style="list-style-type: none">1. As many different battery types as you can find. Charged or discharged, it does not matter.2. As many different battery holders, or devices with battery holders, as you can find3. Sufficient charged batteries to fit in some of the battery holders4. At least one rechargeable battery type (discharged) and a suitable device and charger for it5. A Digital Multi-Meter (Figure 8) to measure voltage. Preferably auto-ranging. |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Figure 8: Digital Multi-Meter

Teacher Tasks

1. Introduce the lesson as shown above
2. Batteries store electrical energy using internal (dangerous/corrosive) chemicals and electrode structures
 - a. Show a carbon-zinc D-Cell. Ask: What does a battery do? Ask: What is inside?
 - b. Show and discuss Figure 9. Chemicals, called electrolytes, inside the battery react with the electrode material to produce electricity. Electrodes conduct the electricity to the battery terminals.
 - c. Ask: What happens when a battery leaks? (Chemicals are poisonous and corrosive!).

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

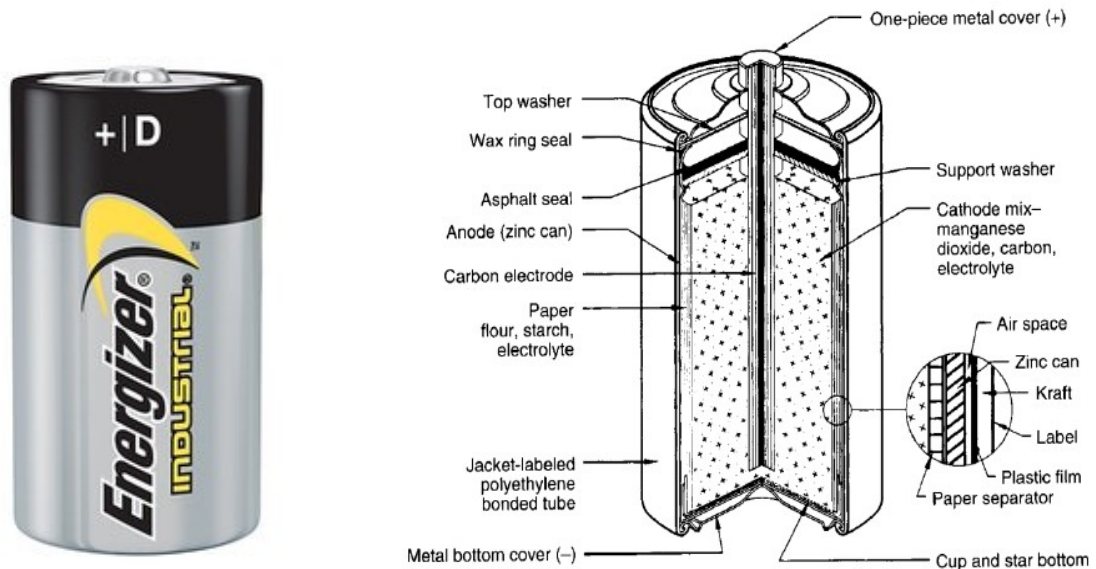


Figure 9: Internal Structure of a Carbon-Zinc Battery

3. Batteries come in different shapes and sizes for different applications
 - a. Ask: What would each of the batteries in Figure 10 be used for?



Figure 10: Battery Shapes and Sizes

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

4. Battery terminals are polarised, provide connection to external electrical circuits
 - a. Batteries have two conductive metal terminals, identified as Positive (+) and Negative (-), to indicate the direction in which the electric current will flow in an external circuit connected to those terminals. Outside of the battery, electric current always flows from the positive terminal to the negative terminal.
 - b. Since the terminals have opposite polarities (like the North and South poles). We say batteries are “polarised”. It is very important to match the battery polarity with the external circuit. By convention, red wires are always connected to the positive terminal and black wires to the negative terminal.
5. Battery holders, clips and clamps provide for external wired connections.
 - a. These are used to make good electrical connections to the battery, while also making it easy to replace the battery when it is flat. See Figure 11.
 - b. Since a battery is polarised, the battery holder always indicates the correct way to insert the battery?
 - c. A battery holder or clip will have red and black wires indicating the polarity.
 - d. Ask: What happens if a battery is inserted the wrong way into a battery holder? (The device may not work or could be damaged).
 - e. Ask: What happens if the red and black battery wires are connected the wrong way to a device? (The device may not work or could be damaged).

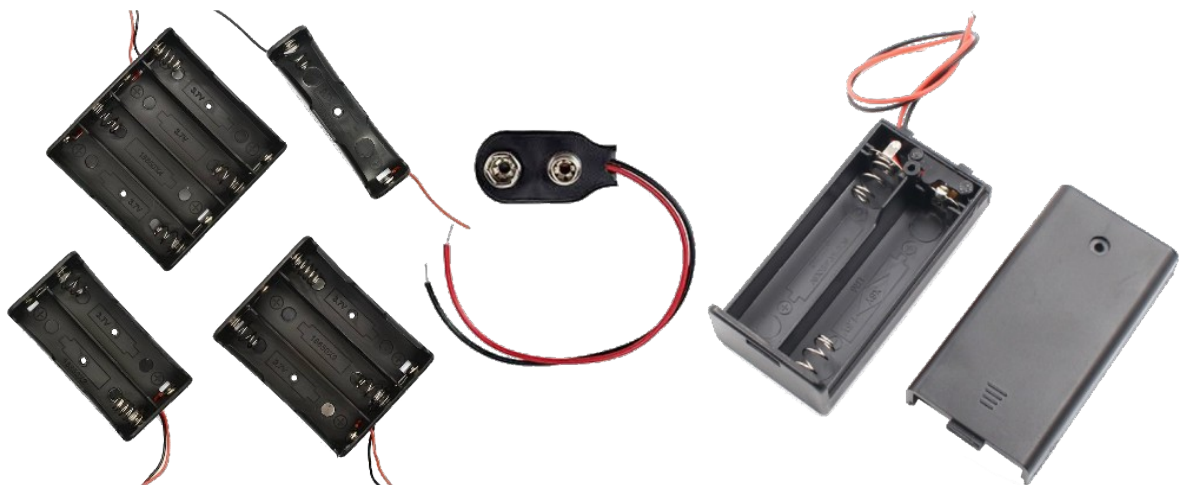


Figure 11: Battery Holders

6. Battery rated voltage is determined by the number of cells and the chemistry of the cells
 - a. Inspect a D-cell. Ask: Why is it called a cell and not a battery? (It only has one internal chamber)
 - b. Inspect that it has a rated voltage of 1.5Volt.
 - c. The voltage indicates how strong (or forceful) the cell is.
 - d. The quantity of electrical voltage (symbol V) is measured in the units of Volt (symbol V), which is named after the Italian physicist Alessandro Volta (1745-1827).
 - e. All carbon-zinc cells have the same voltage. Cells with different chemistry can have different voltages.
 - f. Cells can be connected in series, like in the barrel of a torch, to increase the voltage. The cells are

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



- then formed into a battery. Ask: How many volt would batteries made of 2, 3 or 4 cells have? (3V, 4.5V, 6V)
- The more volts the brighter the torch!
 - Ask: Which of the items in Figure 10 are cells and which are batteries (The 9V is a battery)
 - Ask: How many 1.5V cells would be inside a 9V battery? (6)
 - Demonstrate how to use the multi-meter to measure the battery voltage. (Set to volts. Set to the appropriate range if not auto ranging. Connect red probe to the positive terminal, black probe to the negative terminal. Turn multi-meter off afterwards to save its batteries)
 - Measure the voltage of fully charged cells: One cell by itself (1.5V). Two and three cells in series (3V and 4.5V). Three cells in series, with one cell reversed (1.5V)
 - Ask: Why is it only 1.5V not 3V? (The cell voltages are added $1.5V + 1.5V - 1.5V = 1.5V$. One reversed cell effectively cancels out the voltage of another cell!)
7. Battery rated capacity is related to battery size
- Ask: Which cell in Figure 10 will power a torch for the longest time? (The D-cell, because it is bigger)
 - Ask: If the 1.5V cells in Figure 10 all have the same strength? Why are some bigger than others? (So that they last longer, when new)
 - Ask: Why do bigger cells last longer? (Because they have more chemicals and greater rated capacity)
 - The rated battery voltage indicates how strong the cell is (how bright the light) the rated battery capacity indicates how much energy it has (how long the light shines).
8. Battery actual voltage and capacity is determined by the state of charge (charged/discharge)
- Ask: What is the difference been a new battery and a used battery? (The new battery is charged, the used battery is flat, or discharged).
 - Ask: If a new, fully charged, cell has a voltage of 1.5V, what is the voltage of a flat, or fully discharged cell? (Zero Volt).
 - The actual battery voltage and actual battery capacity depend on the battery's state of charge, ranging from fully charged to fully discharged.
 - Ask: Which battery has a greater actual capacity and voltage: A 50% charged battery or a 25% discharged battery? (25% discharged battery = 75% charged battery).
 - Demonstrate how to compare the battery rated voltage with the battery actual voltage using a Digital Multi-Meter, set to the DC Voltage range, (see Figure 8) to determine the battery state of charge: Charged or discharged. Note: The red probe goes to the positive battery terminal.
 - Supervise the activity.
9. Battery types: Carbon and alkaline non-rechargeable types
- Ask: What different battery chemistries can you see in Figure 12? (Lead-Acid, Nickel-Metal Hydride, Silver-Oxide, Mercury-Oxide, Nickel-Cadmium, Lithium-Ion, Carbon-Zinc, Lithium, Alkaline)
 - Discuss: Figure 12 and Table 1. Different battery chemistries are suited to different applications.
 - Ask: Which batteries last longer, carbon batteries or alkaline batteries (Alkaline)
 - Ask: Why? (Alkaline batteries use more advanced chemicals, hence they cost more).
 - Ask: Can you recharge carbon-zinc batteries? (No)
 - Ask: Why? (The internal chemical reaction is not reversible, so they are not rechargeable and can even explode if connected to a charger!)
 - Ask: What do we do with dead batteries? (Take them to a re-cycling centre)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Figure 12: Battery Chemistries

Table 1: Battery Characteristics

| Battery Type | Cell Voltage | Rechargeable | Application |
|----------------------|--------------|--------------|-------------|
| Lead-Acid | 2.0 V | Yes | Cars |
| Nickel Metal Hydride | 1.2 V | Yes | Torches |
| Silver-Oxide | 1.55 V | No | Watches |
| Mercury-Oxide | 1.35 V | No | Cameras |
| Nickel Cadmium | 1.2 V | Yes | RC Models |
| Lithium Ion | 3.7 V | Yes | Laptops |
| Carbon-Zinc | 1.5 V | No | Toys |
| Lithium | 1.5 V | Yes/No | Remotes |
| Alkaline | 1.5 V | No | Remotes |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



10. Battery types: Nickel-Cadmium, Nickel-Metal Hydride, Lead-Acid and Lithium-Ion rechargeable types
 - a. Ask: What types of batteries can be recharged? (Nickel-Cadmium, Nickel-Metal Hydride, Lead-Acid and Lithium-Ion)
 - b. Ask: How do we recharge them? (Connect them to an appropriate charger designed specifically for the battery chemistry)
11. Battery safety. **Important.**
 - a. Ask: What could happen if we short-circuit a charged battery with a piece of wire? (The wire could get hot and burn, the batteries could overheat, explode and start a fire).
 - b. What could happen if we put recharging batteries, or a device being recharged, under a blanket or pillow? (The batteries could overheat, explode and start a fire).
 - c. Ask: What could happen if we use the wrong type of battery charger? (The batteries could overheat, explode and start a fire)
 - d. Ask: What could happen if we forget to turn off the charger when it is finished charging? (The batteries could overheat, explode and start a fire)

Student Tasks

1. Students answer questions and join in the discussions.
2. Students use a multi-meter to discover the cell and battery voltages.
3. Students use a multi-meter to discover which batteries are charged by comparing the actual measured voltage with the rated voltage printed on the battery.

Discussion

1. Why do we often call a D-Cell a battery? (The distinction is a technical matter. Now you know better.)
2. Why are batteries important for renewable energy production (They store intermittent solar and wind power)
3. Who invented the battery (Alessandro Volta, Italian Physicist in 1791. The scientific quantity of Voltage and its unit of measurement, the Volt, is named after him). Imagine if we had no batteries?
4. Why does it take so long to recharge batteries? (The chemical reaction would generate too much heat if we charged batteries faster).
5. Why don't rechargeable batteries last forever? (Each charge/discharge cycle corrodes the batteries electrodes. They eventually disintegrate.)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity. E.G. Make a 6V battery (4 x 1.5V battery in series). Make a 1.5V battery that will last longer (4 x 1.5V in parallel). Charge a flat rechargeable battery for 1, 2, 5 minutes to see how long it lasts in a torch.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 3. Voltage, Current and Resistance: Ohm's law

| |
|---|
| Purpose |
| To explore how voltage, current and resistance in a simple circuit are related by Ohm's law. |
| Introduction |
| "In this lesson we will learn how the voltage, current and resistance in a simple circuit are related. We will use Ohm's law to calculate the resistance of a circuit" |
| Safety |
| WARNING: DC REGULATED POWER SUPPLIES CAN GENERATE SUFFICIENT CURRENT IN A CIRCUIT TO MAKE WIRES AND RESISTORS HOT, MELTING PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! ALWAYS USE A DC REGULATED POWER SUPPLY UNDER ADULT SUPERVISION. |
| Key Learning Areas |
| <ol style="list-style-type: none">1. Use of a DC Regulated Power Supply instead of a battery2. The quantity of electrical voltage (symbol V) is measured in units of Volt (also symbol V), which is named after the Italian physicist Alessandro Volta (1745-1827).3. The quantity of electrical current (symbol I) is measured in units of Amp (symbol A), which is named after the French physicist Andre-Marie Ampère (1775-1836).4. The quantity of electrical resistance (symbol R) is measured in units of Ohm (symbol Ω), which is named after the German physicist Georg Ohm (1789-1854).5. Common SI multipliers used in this lesson are milli (symbol m) and kilo (symbol k)6. Ohm's law: $V = I \times R$ or $I = V \div R$ or $R = V \div I$7. Calculating electronic resistor values8. Resistor series, tolerance, preferred values and colour codes |
| Learning Outcomes |
| This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none">1. How to use a DC Regulated Power Supply2. Why current flows in a circuit3. Why more voltage causes more current to flow in a circuit4. Why some materials resist the flow of current5. How to find out how much resistance is in a circuit6. How to calculate the resistance in a circuit7. How to safely connect an LED to a 9V battery |
| Year Level |
| Year 5 or 6 |
| Lesson Time |
| Two lessons, 45 Minutes each |
| Resources |
| <ol style="list-style-type: none">1. A DC Regulated Power Supply with digital displays for voltage and current with a resolution of 10mV and 1mA as shown in Figure 132. Red and black banana plug leads with alligator clips as shown in Figure 143. Two LEDs4. A Component Tester see Figure 245. Split 2B Pencil see Figure 7.6. 1.2kΩ 1/4W resistors7. 9V Batteries8. 9V Battery clips |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Figure 13: DC Regulated Power Supply Figure 14: Banana Plug Clip Leads

Teacher Tasks

1. Introduce the lesson, as above.
2. Introduce the DC Regulated Power Supply
 - a. Explain: that the DC Regulated Power Supply can be used like a battery, where the maximum voltage and current can be precisely set and the actual voltage, current and power can be measured.
 - b. Show connecting the power supply input plug to the AC mains
 - c. Show the red and black output terminals
 - d. Explain: that the green terminal is connected to the metal case
 - e. Ask: Which is positive (red) and which is negative (black)
 - f. Ask: Is the power supply polarised or unpolarised? (Polarised: Meaning it matters which way you connect it to a circuit)
 - g. Show how red and black banana plug leads with alligator clips, make it easy to connect it to a circuit
 - h. Ask: How can I use the power supply to illuminate an LED? (Connect the LED to the alligator clips)
 - i. Explain: The quantity of electrical voltage (symbol V) is measured in units of Volt (also symbol V), which is named after the Italian physicist Alessandro Volta (1745-1827).
 - j. Ask: What voltage should I use? (2V or as displayed on your component tester)
 - k. Ask: What happens if I supply too little voltage? (The LED will not illuminate)
 - l. Ask: What happens if I supply too much voltage? (The LED gets hot and burns out)
 - m. Explain: The quantity of electrical current (symbol I) is measured in units of Amp (symbol A), which is named after the French physicist Andre-Marie Ampere (1775-1836).
 - n. Ask: What happens if I supply too little current? (The LED will not illuminate)
 - o. Ask: What happens if I supply too much current (The LED gets hot, burns out, and the wires get hot)
 - p. Show how to turn on the power supply and connect the leads
 - q. Show how to adjust the power supply voltage to 2V
 - r. Show how to adjust the power supply current to 0A (the voltage will also drop to zero)
 - s. Show how to connect the alligator leads together and adjust the maximum current to 1A
 - t. Show how to connect the LED to the alligator leads: Red to long lead, black to short lead.
 - u. Show that the LED illuminates. Record the electrical current drawn by the LED (0.006A).
 - v. Ask: What is the direction of current flow? (From the positive terminal to the negative terminal)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



www.sarcnet.org

- w. Ask: What is the path of electrical current flow called? (A circuit)
- x. Show how to reduce the voltage – The LED does not illuminate
- y. Show how to increase the voltage, slowly, above 2V – The LED grows dim, hot and burns out
- z. Show that the LED is now permanently damaged: Back at 2V it is dim or burnt out.
- aa. Throw the LED in the bin. QED.
3. Electrical current flows in a circuit whenever a voltage is applied to it
 - a. Set the power supply to 1V
 - b. Show that connecting the leads causes current to flow in the circuit
 - c. Ask: Why is the power supply voltage now zero. (There is a short circuit)
 - d. Adjust the maximum current to 1A
 - e. Show that disconnecting the leads returns the current to zero
 - f. Connect the leads to the ends of the pencil lead 15cm apart
 - g. Show that some current is flowing, but not the full 1A as before
4. The power supply can be used to measure the amount of electrical current flowing into the circuit.
 - a. Show the A symbol on the power supply current meter
 - b. Show the decimal point on the power supply meter
5. It is common to use milli as a standard multiplier: One thousandths of an Amp is called one milliamp “mA”.
 - a. Measure and record the current in pencil lead in mA
 - b. Explain: that the measured current was 0.200A = 200mA
 - c. Explain: 0.001A = 1mA, 0.01A = 10mA, 0.1A = 100mA, and 1.0A = 1000mA
 - d. Ask: What is 2.5A in milliamps? (2500mA). What is 0.87A in milliamps? (870mA).
6. The more voltage applied to a circuit, the more current flows in the circuit
 - a. Show how increasing and decreasing the voltage, a little, increases and decreases the current
7. Resistors are poor conductors of electric current
 - a. Show that connecting the good conducting leads together permits 1A of current to flow
 - b. Explain: that the pencil lead lets less current flow in the circuit because it is a poor conductor
 - c. Explain: that poor conductors resist the flow of electric current
 - d. Explain: that this is because the atoms in the poor conductor are not uniformly spaced, like in a metal which is a good conductor, and the electrons are not as free to flow between the atoms
 - e. Explain: that the pencil lead is made from graphite, a form of carbon
 - f. Explain: that poor conductors can be useful in electric circuits to reduce current flow to safe levels
 - g. Explain: that poor conductors used for this purpose are called resistors
8. The more electrical resistance in the circuit, the less current flows in a circuit
 - a. Show that moving the alligator clips closer together on the pencil lead increases the current
 - b. Show that moving the alligator clips further apart on the pencil lead reduces the current
9. The quantity of electrical resistance (symbol R) is measured in units of Ohm (symbol Ω), which is named after the German physicist Georg Ohm (1789-1854).
10. It is common to use kilo and Mega as a standard multipliers: One thousand Ohm is called one kilo-ohm “k Ω ”. One million Ohm is called one mega-Ohm “M Ω ”.
11. When writing or printing the decimal values of Ohm the Ω symbol can sometimes be hard to print. It can be replaced: For example 1.23 Ω , 4.56k Ω and 7.89M Ω can be written 1R23, 4k56 and 7M89.
12. The resistance in a circuit is equal to the voltage across to the resistor, divided by the current flowing in the circuit:
 - a. If the voltage is V, the current is I and the resistance is R, then $R = V \div I$ (Ohm’s law)
 - b. Connect the alligator clips to either end of the pencil lead (15cm apart)
 - c. Measure and record the voltage, in Volt, across the pencil lead (1.000V)
 - d. Measure and record the current, in Amp, flowing through the pencil lead (0.200A)
 - e. Calculate the resistance of the pencil lead, in Ohm, using Ohm’s law:

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



$$R = V \div I = 1 \text{ Volt} \div 0.2 \text{ Amp} = 5 \text{ Ohm, written as } 5\Omega$$

13. A resistor can be used to reduce the current flowing through a circuit to a safe level. Use Ohm's law to calculate the resistance required to permit a 2V LED to operate safely on a 9V battery:
 - a. Note that there are now three components in the circuit: The power supply, the resistor and the LED. If the power supply maintains a voltage of 9V then the voltage across the resistor and the voltage across the LED must add up to 9V. If the voltage across the LED is 2V, then the voltage across the resistor must be:
$$V = 9V - 2V = 7V$$
 - b. If the safe current flowing through the LED is $I = 6\text{mA} = 0.006\text{A}$, this must also be the same as the current flowing through the resistor.
 - c. We can now use Ohm's law to calculate the resistance of the required resistor:
$$R = V \div I = 7 \div 0.006 = 1166 \text{ Ohm, which be written as } 1.166\text{k}\Omega.$$
 - d. However, resistors only come in "preferred values": Looking in our parts drawers, we have to select either are A 1k Ω or 1.2k Ω resistor. A 1.2k Ω should be close enough. See the next section for details on preferred values.
 - e. Adjust the power supply voltage to 9V
 - f. Connect a 1.2k Ω resistor to the red alligator clip
 - g. Connect the short wire of the LED to the black alligator clip
 - h. Connect the free end of the resistor to the long wire of the LED using another alligator clip lead, or your fingers. The LED illuminates normally, using a higher voltage that would otherwise destroy it!
14. Intermission – Have a break or start here in the next lesson
15. Introduce the lesson, as above.
16. Resistor series, tolerance, preferred values and colour codes.
 - a. Just like motor cars, resistors are manufactured in different series. Called E6, E12, E24, E48, E96 and so on. Each series specifies a different range of preferred values.
 - b. Unlike motor cars, resistors are manufactured in a more or less random fashion and then sorted afterwards into separate bins of different preferred values.
 - c. To understand this, suppose the only preferred resistor values on sale are are 1.0 Ω , 1.5 Ω and 2.2 Ω etc, you cannot buy a value of 1.65 Ω , instead you will have to select the closest preferred value of 1.5 Ω . Now, you might be lucky and actually get a 1.65 Ω value, but that is not guaranteed. Remember, the printed value on the resistor is the preferred value, not the actual value. Resistor values are in specified in Ohm with multipliers kilo (k) and mega (M).
 - d. Depending on the manufacturing and sorting processes, different resistor series also have different tolerances and temperature coefficients.
 - e. Each electronic resistor series specifies the resistor tolerance. The resistor tolerance indicates how much the actual value of the resistor could vary from the specified preferred value. The tolerance is expressed as a percentage e.g. $\pm 20\%$, $\pm 10\%$, $\pm 5\%$, $\pm 2\%$ and $\pm 1\%$ etc. The plus and minus symbol (\pm) indicates that the actual value could be higher or lower by as much as the specified amount. A tolerance of $\pm 5\%$, for example, means that a resistor with a preferred value of 100 Ω could be as low as 95 Ω or as high as 105 Ω . A lower resistor tolerance means that the actual resistor value will be closer to the preferred resistor value.
 - f. The resistor temperature coefficient indicates how much the actual value of the resistor could vary due to internal power dissipation or ambient temperature changes. Expressed as parts per million (ppm), per degree Celsius, a 1ppm temperature coefficient would indicate that a 1M Ω resistor could increase by as much as 1 Ω if its temperature was increased by 1°C. Resistors normally have a positive temperature coefficient, increasing their value with increasing temperature, just like this.
 - g. Each resistor series shown in Figure 15 specifies the tolerance and the number of preferred values available in each decade. The E number itself specifies the number of preferred values in each decade.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

The actual preferred values in the x1 decade are also shown.

- h. A decade identifies the multiplier (x1, x10, x100, x1000 and so on) for the preferred values. If there is a preferred value of 1.5 in the x1 decade, there will also be values of 15, 150, 1500, 15000 and so on in the x10, x100, x1000, x10000 decades.

| Series | Tolerance | Preferred Values |
|--------|-----------|--|
| E6 | ±20% | 1.0, 1.5, 2.2, 3.3, 4.7, 6.8 |
| E12 | ±10% | 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2 |
| E24 | ±5% | 1.0, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2.0, 2.2, 2.4, 2.7, 3.0, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1 |
| E48 | ±2% | 1.00, 1.05, 1.10, 1.15, 1.21, 1.27, 1.33, 1.40, 1.47, 1.54, 1.62, 1.69, 1.78, 1.87, 1.96, 2.05, 2.15, 2.26, 2.37, 2.49, 2.61, 2.74, 2.87, 3.01, 3.16, 3.32, 3.48, 3.65, 3.83, 4.02, 4.22, 4.42, 4.64, 4.87, 5.11, 5.36, 5.62, 5.90, 6.19, 6.49, 6.81, 7.15, 7.50, 7.87, 8.25, 8.66, 9.09, 9.53 |
| E96 | ±1% | 1.00, 1.02, 1.05, 1.07, 1.10, 1.13, 1.15, 1.18, 1.21, 1.24, 1.27, 1.30, 1.33, 1.37, 1.40, 1.43, 1.47, 1.50, 1.54, 1.58, 1.62, 1.65, 1.69, 1.74, 1.78, 1.82, 1.87, 1.91, 1.96, 2.00, 2.05, 2.10, 2.15, 2.21, 2.26, 2.32, 2.37, 2.43, 2.49, 2.55, 2.61, 2.67, 2.74, 2.80, 2.87, 2.94, 3.01, 3.09, 3.16, 3.24, 3.32, 3.40, 3.48, 3.57, 3.65, 3.74, 3.83, 3.92, 4.02, 4.12, 4.22, 4.32, 4.42, 4.53, 4.64, 4.75, 4.87, 4.99, 5.11, 5.23, 5.36, 5.49, 5.62, 5.76, 5.90, 6.04, 6.19, 6.34, 6.49, 6.65, 6.81, 6.98, 7.15, 7.32, 7.50, 7.68, 7.87, 8.06, 8.25, 8.45, 8.66, 8.87, 9.09, 9.31, 9.53, 9.76 |

Figure 15: Electronic Resistor Series, Tolerance and Preferred Values

- i. Ask: Suppose you need a 150Ω resistor. Which series should you select it from? (E6, E12 and E24 all have $1.5 \times 100 = 150\Omega$ values. However, E24 will give you the lowest tolerance, if that is important)
- j. Ask: Suppose you need a 360kΩ resistor. Which series should you select it from? (E24, because $3.6 \times 100000 = 360k\Omega$. Note: If you selected a 330kΩ from the E12 series, it could have an actual value from 270kΩ to 390kΩ, which might be good enough for your application, but you will need to check)
- k. Resistors are small and printing numbers on their cylindrical bodies is difficult. Resistor manufacturers came up with a solution of printing different coloured bands instead of numbers. See: Figure 16.

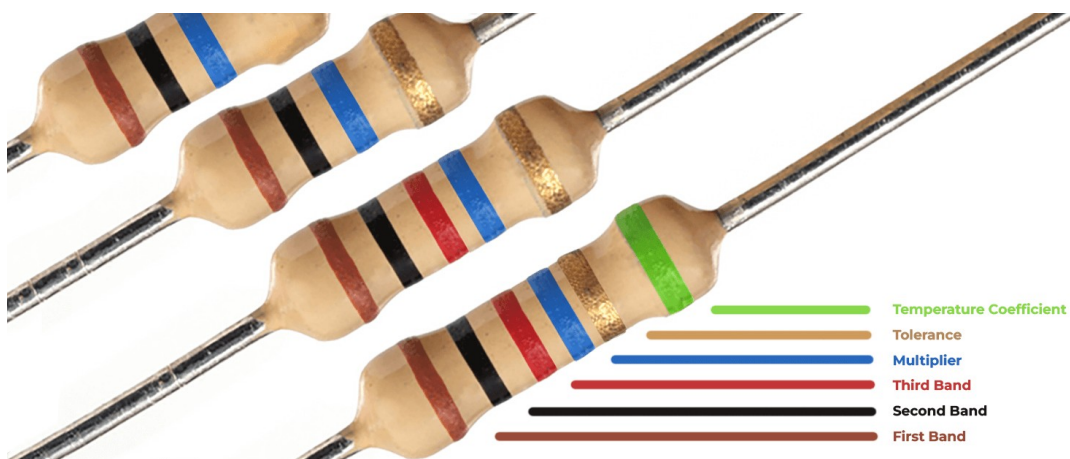


Figure 16: Resistor Coloured Bands

- l. After sorting, manufacturers print coloured bands on the outside of the resistor to identify the preferred value, tolerance and temperature coefficient.
- m. The resistor colour codes are shown in Figure 17.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



www.sarcnet.org

- n. The colours black, brown, red, orange, yellow, green, blue, purple, grey, and white are used to represent the numbers 0 to 9.
- o. The colours silver and gold have special significance.
- p. Exercise: Write down your home telephone number in the resistor colour code using coloured pencils.
- q. Resistors can have 3, 4, 5 or 6 coloured bands. All resistors have at least 3 bands. The E48 and E96 series can have 4, 5 or 6 bands.
- r. The significance and interpretation of each band in the series is shown in Figure 17.
- s. The first 2 or 3 bands represent digits
- t. The band after the digits represents a multiplier
- u. Explain: To evaluate the preferred value, multiply the digits by the multiplier:
 1. Evaluate brown, red, orange = $12 \times 1000 = 12000$ or $10k\Omega$
 2. Evaluate yellow, grey, purple, red = $487 \times 100 = 48700 = 48.7k\Omega$
 3. Evaluate green, blue, red, silver = $562 \times 0.01 = 5.62\Omega$
- v. The band after the multiplier (if there is one) indicates the tolerance in percentage (%) of actual resistance value.
- w. The band after the tolerance indicates the temperature coefficient
- x. Exercise: Work through the examples in Figure 18 to test student comprehension. Provide the 3 to 6 colours and have the students work out the preferred value, tolerance and ppm as appropriate. Extra points for using the correct symbols: k, M, \pm , %, ppm and Ω .

| RESISTOR COLOUR CODES | | | | | | |
|-----------------------|-----------------|--------|---------|------------------|--------------|------------|
| SERIES | ALL | | E48 E96 | ALL | E48 E96 | |
| 3 BANDS | BAND 1 | BAND 2 | | BAND 3 | | |
| 4 BANDS | BAND 1 | BAND 2 | | BAND 3 | BAND 4 | |
| 5 BANDS | BAND 1 | BAND 2 | BAND 3 | BAND 4 | BAND 5 | |
| 6 BANDS | BAND 1 | BAND 2 | BAND 3 | BAND 4 | BAND 5 | BAND 6 |
| COLOUR | PREFERRED VALUE | | | MULTIPLIER | TOLERANCE | TEMP COEFF |
| None | | | | | $\pm 20\%$ | |
| Silver | | | | $\times 0.01$ | $\pm 10\%$ | |
| Gold | | | | $\times 0.1$ | $\pm 5\%$ | |
| Black | 0 | 0 | 0 | $\times 1$ | | 250ppm |
| Brown | 1 | 1 | 1 | $\times 10$ | $\pm 1\%$ | 100ppm |
| Red | 2 | 2 | 2 | $\times 100$ | $\pm 2\%$ | 50ppm |
| Orange | 3 | 3 | 3 | $\times 1000$ | $\pm 3\%$ | 15ppm |
| Yellow | 4 | 4 | 4 | $\times 10000$ | $\pm 4\%$ | 25ppm |
| Green | 5 | 5 | 5 | $\times 100000$ | $\pm 0.5\%$ | 20ppm |
| Blue | 6 | 6 | 6 | $\times 1000000$ | $\pm 0.25\%$ | 10ppm |
| Purple | 7 | 7 | 7 | | $\pm 0.1\%$ | 5ppm |
| Grey | 8 | 8 | 8 | | $\pm 0.05\%$ | 1ppm |
| White | 9 | 9 | 9 | | | |

Figure 17: Resistor Colour Codes

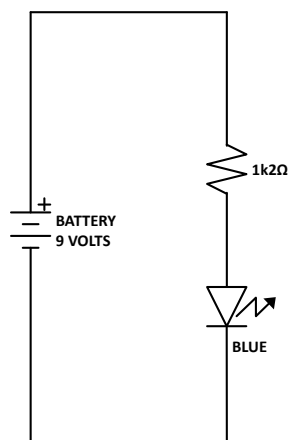
The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

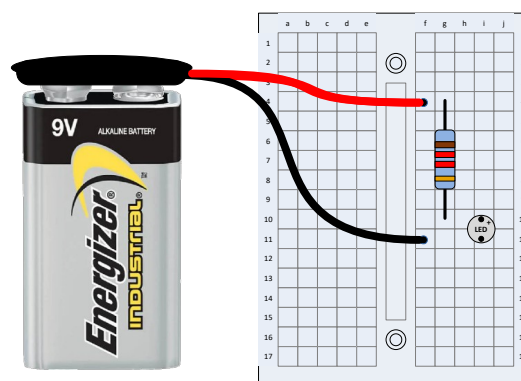
| SERIES | BANDS | EXAMPLE | | | | | | ANSWER |
|--------|-------|---------|---|---------|----------|-------|-------|-------------------|
| E6 | 3 | 1 | 5 | x0.01 | ±20% | | | 0.15Ω ±20% |
| E12 | 4 | 2 | 7 | x0.1 | ±10% | | | 2.7Ω ±10% |
| E24 | 4 | 3 | 9 | x1 | ±5% | | | 39Ω ±5% |
| E48 | 5 | 4 | 8 | 7 | x1 | ±2% | | 487Ω ±2% |
| E96 | 6 | 6 | 4 | 9 | x10 | ±1% | 20ppm | 6.49kΩ ±1% 20ppm |
| E6 | 3 | 1 | 0 | x1000 | ±20% | | | 10kΩ ±20% |
| E12 | 4 | 2 | 7 | x10000 | ±10% | | | 270kΩ ±10% |
| E24 | 4 | 3 | 6 | x100000 | ±5% | | | 3.6MΩ ±5% |
| E48 | 5 | 4 | 6 | 4 | x100000 | ±0.5% | | 46.4MΩ ±0.5% |
| E96 | 6 | 1 | 0 | 2 | x1000000 | ±0.1% | 10ppm | 102MΩ ±0.1% 10ppm |

Figure 18: Resistor Colour Code Examples

17. Build your own circuit to connect a 2V LED safely to a 9V battery
 - a. Connect a 9V battery clip to a Prototyping Board
 - b. Connect a 1.2kΩ resistor to the Prototyping Board
 - c. Connect a LED to the Prototyping Board
 - d. Check the circuit
 - e. Connect a 9V battery to the 9V battery clip
 - f. Check the LED illuminates



CIRCUIT SCHEMATIC DIAGRAM



PROTOTYPE BOARD LAYOUT

Figure 19: 9V LED Circuit

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Student Tasks

1. Students answer questions and join in the discussions.
2. Students help adjust the voltage and current of a DC regulated power supply under adult supervision
3. Students build a circuit using a 9V battery, 1.2k Ω resistor and an LED

Discussion

1. What would happen if you connected the LED to the 9V battery without the resistor? (It will get hot, dim and likely fail)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity. E.G. Calculate the resistor value for powering a LED from 12V, using the power supply.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 4. Power and Energy: Watt's law and Joule's Law.

| |
|---|
| Purpose To explore how power is used to transfer energy in a circuit. |
| Introduction "In this lesson we will learn how energy can be transferred from an energy source to a circuit using electrical power. We will use Watt's law to calculate the power needed and Joule's law to calculate the amount of energy transferred." |
| Safety WARNING: DC REGULATED POWER SUPPLIES CAN GENERATE SUFFICIENT CURRENT IN A CIRCUIT TO MAKE WIRES AND RESISTORS HOT, MELTING PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! ALWAYS USE A DC REGULATED POWER SUPPLY UNDER ADULT SUPERVISION. |
| Key Learning Areas <ol style="list-style-type: none"> 1. A battery, or power supply, can supply energy to a circuit 2. A battery is a primary source of energy – it contains chemicals which react to generate electrical energy. 3. A power supply is a secondary source of energy – it uses electrical energy generated at a power station. 4. In an electrical circuit containing just an energy source and a resistor: <ol style="list-style-type: none"> a. The voltage at the source is the Electro-Motive Force pushing electrical current through the resistor b. The flow of electrical current through the resistor causes it to get hot c. A resistor converts the electrical energy from the source into heat energy d. The voltage and current combined provide the power needed to transfer the energy e. The energy transferred is equivalent to the amount of power needed over a given time 5. The quantity of power (symbol P) is measured in units of Watt (symbol W), which is named after Scottish inventor James Watt (1736–1819). 6. The quantity of energy (symbol E) is measured in units of Joule (symbol J), which is named after English physicist James Joule (1818–1889). 7. The quantity of time (symbol T) is measured in units of seconds (symbol s) 8. The power required is the voltage (V) multiplied by the current (I). $P = V \times I$. Watt's law. 9. The energy transferred is the power (P) multiplied by the time (T). $E = P \times T$. Joule's law. 10. Calculating power and energy |
| Learning Outcomes This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none"> 1. How to transfer energy from a power supply to a resistor 2. How to convert electrical energy into heat energy 3. How to measure the voltage across the resistor and the current in the resistor 4. How to calculate the power needed to transfer energy to the resistor 5. How to calculate the energy transferred to the resistor 6. That energy cannot be destroyed only converted into other forms of energy |
| Year Level Year 5 or 6 |
| Lesson Time 45 Minutes |
| Resources <ol style="list-style-type: none"> 1. A DC Regulated Power Supply with digital displays for voltage, current and power, with a resolution of 10mV, 1mA and 100mW. See Figure 13. 2. Red and black banana plug leads with alligator clips as shown in Figure 14. |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



www.sarcnet.org

3. Split 2B Pencil. Carefully groove opposite sides of the pencil with a box-cutter blade. Repeat to gently deepen the cut to close to the lead. When deep enough, use your fingernails to split and remove the wood down one whole side of the pencil. The lead should remain attached to the wood on the other side of the pencil, which will prevent the lead from breaking. See Figure 7.

Teacher Tasks

1. A battery, or power supply, can supply energy to a circuit
 - a. Show a 1.5V cell, it only has one chamber
 - b. Show a 9V battery, which is made of 6 cells connected in series
 - c. Show a DC regulated power supply, which can be set to 1.5V or 9V easily
2. A battery is a primary source of energy – it contains chemicals which react to generate electrical energy.
 - a. Show a diagram of the internal structure of a battery. It contains chemicals.
3. A power supply is a secondary source of energy – it uses electrical energy generated at a power station.
 - a. Show that the power supply has an input cable and output terminals
 - b. Explain: "That it cannot generate electricity by itself"
 - c. Ask: "Where does its energy come from?" (A power station)
4. In an electrical circuit containing just an energy source and a resistor:
 - a. The voltage at the source is the electromotive force pushing electrical current through the resistor
 - i. Show the voltmeter on the power supply
 - ii. Set it to 2.2V. Teacher note: The set voltage is dependent on the pencil's resistance. The pencil shown had a resistance of 5Ω. With 2.2V applied to the pencil the current drawn was 0.440A and the power used was 0.968W. The voltage you set should indicate a power of about 1W on the power supply. Any more than 1W will get the pencil too hot. 5W could burn the pencil and start a fire! Do not leave the power supply unattended.
 - iii. Show the voltage is indicated on the power supply voltmeter
 - iv. Show that the current flowing in the circuit is zero because it is not connected
 - b. The flow of electrical current through the resistor causes it to get hot
 - i. Connect the alligator leads to the either side of the pencil lead
 - ii. Show that current is now flowing as indicated on the power supply ammeter
 - iii. After a minute or so allow the students to touch the pencil lead – It will be quite warm.
 - c. A resistor converts the electrical energy from the source into heat energy
 - i. Ask: "Where is the energy coming from?" (The power station, via the power supply)
 - ii. Ask: "What type of energy is it?" (Electrical energy)
 - iii. Ask: "Where is the energy going to?" (The pencil lead, which is a resistor)
 - iv. Ask: "What type of energy is it?" (Heat)
 - v. Ask: "What has converted the electrical energy into heat?" (The resistor)
 - d. The voltage and current combined provide the power needed to transfer the energy
 - i. Explain: "Just like the voltage provides the Electro-Motive Force needed to push current through the resistor, the combination of voltage and current provides the power needed to push electrical energy into the resistor."
 - ii. Ask: "What is the voltage applied to the resistor?" (2.2V as shown on the voltmeter)
 - iii. Ask: "What is the current flowing through the resistor?" (0.440A as shown on the ammeter)
 - e. The energy transferred is equivalent to the amount of power needed over a given time
 - i. Ask: "Is the power supply transferring energy to the resistor?" (Yes, because it is getting hot)
 - ii. Ask: "What is causing the energy transfer?" (The electrical power from the power supply – Not just the voltage or the current, but a combination of both)
 - iii. Ask: "Is the amount of energy being transferred changing?" (Yes, it is increasing with time)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



5. The quantity of power (symbol P) is measured in units of Watt (symbol W), which is named after Scottish inventor James Watt (1736–1819).
 - a. Explain: “The power needed to transfer energy to the resistor is provide by the both the voltage, which forces the current through the resistor, and the current which flows through the resistor.”
 - b. Ask: “What is the power needed to heat the resistor?” (0.9W as shown on the wattmeter)
6. The quantity of energy (symbol E) is measured in units of Joule (symbol J), which is named after English physicist James Joule (1818–1889).
 - a. Ask: “Suppose 60 Joule of energy is transferred to the resistor in 1 minute, how much would be transferred in two minutes?” (120J)
 - b. Ask: “Will the resistor keep getting energy from the power supply when it reaches its maximum temperature” (Yes, although the power input [voltage and current] is constant, the energy transferred to the resistor is increasing all the time)
 - c. Ask: “Will the resistor keep getting hotter and hotter?” (No, it will reach a maximum temperature and stay there, in equilibrium, because surrounding air currents are taking the heat energy away)
 - d. Ask: “Where is the energy from the power station going? (The electrical energy from the power station is transferred to the resistor via the power supply. The resistor converts the electrical energy into heat energy. The surrounding air transfers the heat energy to the Earth’s atmosphere. The Earth’s atmosphere transfers the heat energy to space as infrared radiation).
 - e. Explain: “Energy cannot be destroyed only converted into other forms of energy – This is called the Law of Conservation of Energy.”
 - f. Ask: “What are the other forms of energy?” (Mechanical, chemical, electrical, thermal, radiant and nuclear energy)
7. The quantity of time (symbol T) is measured in units of seconds (symbol s)
8. The power (P) needed is the voltage (V) multiplied by the current (I). $P = V \times I$. Watt’s law.
9. The energy (E) transferred is the power (P) multiplied by the time (T). $E = P \times T$. Joule’s law.
10. Calculating power and energy:
 - a. Ask: “If the voltage across the resistor is 2.2V and the current flowing through the resistor is 0.44A what is the power in the resistor?” ($2.2 \times 0.44 = 0.9W$)
 - b. Ask: “If the power in the resistor is 0.9W, how much energy is transferred to the resistor over 120 seconds. ($0.9 \times 120 = 108J$)
 - c. Explain: “One Joule is actually a very small amount of energy. It is equivalent to the energy of one watt of power over one second of time”. Much larger quantities of energy, measured over a period of one hour are more commonly used. For example, one kilowatt hour (1 kWh) equals 3,600,000 Joule or 3.6 Mega Joule (3.6 MJ).”

Student Tasks

1. Students answer questions and join in the discussions
2. Students adjust the power supply voltage and sense the heat coming from the pencil lead
3. Students write down equations and use a calculator to find the correct answer

Discussion

1. Ask: “What would happen if you increased the voltage so that the power in the resistor was 5W?” (It would get too hot and burn the wood, possibly starting a fire)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity. E.G. Try different voltages and pencil lead resistance by sliding the alligator clips along the lead. Calculate the power and energy for different values of voltage and current.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 5. Semiconductors: Diodes, Light-Emitting Diodes, Solar Cells.

| |
|---|
| Purpose To explore devices with a single, semiconductor junction including diodes, light-emitting diodes, Zener diodes, Schottky diodes and photo-voltaic cells. |
| Introduction "In this lesson we will learn about simple semiconductors called diodes." |
| Safety WARNING: DC REGULATED POWER SUPPLIES CAN GENERATE SUFFICIENT CURRENT IN A CIRCUIT TO MAKE WIRES AND RESISTORS HOT, MELTING PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! ALWAYS USE A DC REGULATED POWER SUPPLY UNDER ADULT SUPERVISION. |
| Key Learning Areas <ol style="list-style-type: none"> Conductors pass current the same way in both directions; semi-conductors pass current differently in each. <ol style="list-style-type: none"> Semiconductors are formed at the junction of two slightly different types of the same material. Semiconductors are typically made from silicon or germanium. Silicon doped with a small amount of Boron creates a conductive, P-type material. Silicon doped with a small amount of Arsenic creates a conductive, N-type material. Fusing the P-type and N-type materials together creates a semiconducting junction. A diode is the simplest semiconductor device. <ol style="list-style-type: none"> It has only one semiconducting junction. The P-side and the N-side of the junction have external electrical connections. The connections are called the Anode (on the P-side) and the Cathode (on the N-side). Current normally flows from Anode to Cathode, but can flow the other way given enough voltage. A minimum threshold voltage is required to make current flow across a semiconducting junction. The threshold voltage of a PN junction is usually quite low. This is called the forward voltage. The threshold voltage of an NP junction can be very high. This is called the reverse voltage. Different types of diodes have different forward and reverse voltages, supporting useful applications. <ol style="list-style-type: none"> The forward voltage of a normal silicon diode is about 0.7 Volt The forward voltage of a Schottky diode is typically 0.1 – 0.3 Volt The reverse voltage of normal diodes is typically from 50 to 1000 Volt The reverse voltage of a Zener diode is typically from 3 – 30 Volt Using a power supply to measure diode forward and reverse voltages Using a component tester to identify the diode type and forward voltage Current flowing across a semiconductor junction can produce light Conversely, light hitting a semiconductor junction can produce an electrical voltage The structure of a Light Emitting Diode |
| Learning Outcomes This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none"> The differences between conductors and semiconductors How semiconductors are made and how they work The semiconductor diodes: The anode, cathode, forward and reverse voltage How to use an LED to create and detect light |
| Year Level Year 5 or 6 |
| Lesson Time 45 Minutes |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

Resources

1. A DC Regulated Power Supply with digital displays for voltage and current with a resolution of 10mV and 1mA as shown in Figure 13
2. Red and black banana plug leads with alligator clips as shown in Figure 14
3. A Simple Electrical Continuity Tester see Figure 1
4. A Component Tester see Figure 20
5. A Multi-Meter
6. A 1N4001 Diode
7. A 1N5819 Schottky Diode
8. A 1N4736 (6.8V) Zener diode
9. A 2.8V blue Light Emitting Diode (LED) with a clear plastic enclosure
10. A magnifying glass or projecting microscope

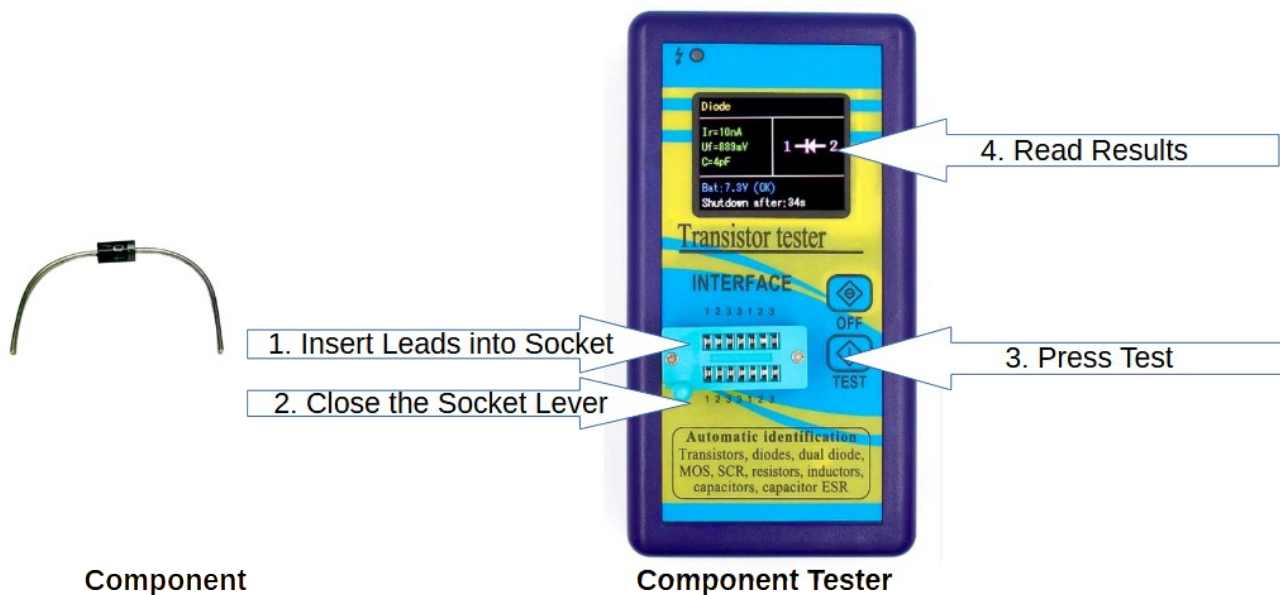


Figure 20: Using a Component Tester to test diodes

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

Teacher Tasks

1. Conductors pass current the same way in both directions; semi-conductors pass current differently in each.
 - a. Make a simple electrical continuity tester
 - b. Test a conductor (pin-lead) in both directions
 - c. Show the current flows in both directions as indicated by the illumination of the LED
 - d. Test a 1N4001 diode in both directions
 - e. Show the current only flows in one direction
2. Semiconductors are formed at the junction of two slightly different types of material.
 - a. Semiconductors are typically made from silicon or germanium.
 - i. Show Silicon and Germanium on the Periodic Table of the Elements.
 - ii. Explain: Silicon is a chemical element with the symbol Si and atomic number 14. It is a hard, brittle crystalline solid with a blue-grey metallic lustre.
 - iii. Explain: Germanium is a chemical element with the symbol Ge and atomic number 32. It is a hard, brittle crystalline solid with a greyish-white metallic lustre.
 - iv. Explain: Pure silicon and germanium are poor conductors of electricity.
 - b. Explain: A semiconductor, doped with a little Boron, creates a conductive, P-type material.
 - c. Explain: A semiconductor, doped with a little Arsenic, creates a conductive, N-type material.
 - d. Explain: A semiconductor is doped by heating it in a furnace with these other chemicals.
 - e. Explain: Fusing the P-type and N-type materials together creates a semiconducting junction.
3. A diode is the simplest semiconductor device.
 - a. It has only one semiconducting junction
 - b. The P-side and the N-side of the junction have external electrical connections
 - c. The connections are called the Anode (on the P-side) and the Cathode (on the N-side)
 - d. Current normally flows from Anode to Cathode, but can flow the other way given enough voltage
 - e. Show the structure and symbol of a diode in Figure 21
 - f. Show the physical appearance and connections of a diode in Figure 22

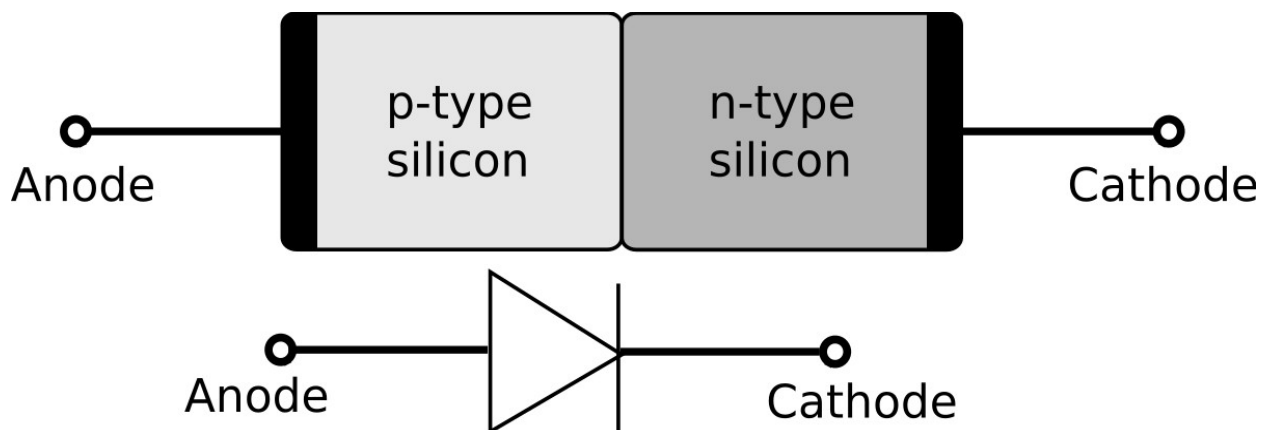


Figure 21: PN Junction Internal Structure and Circuit Symbol

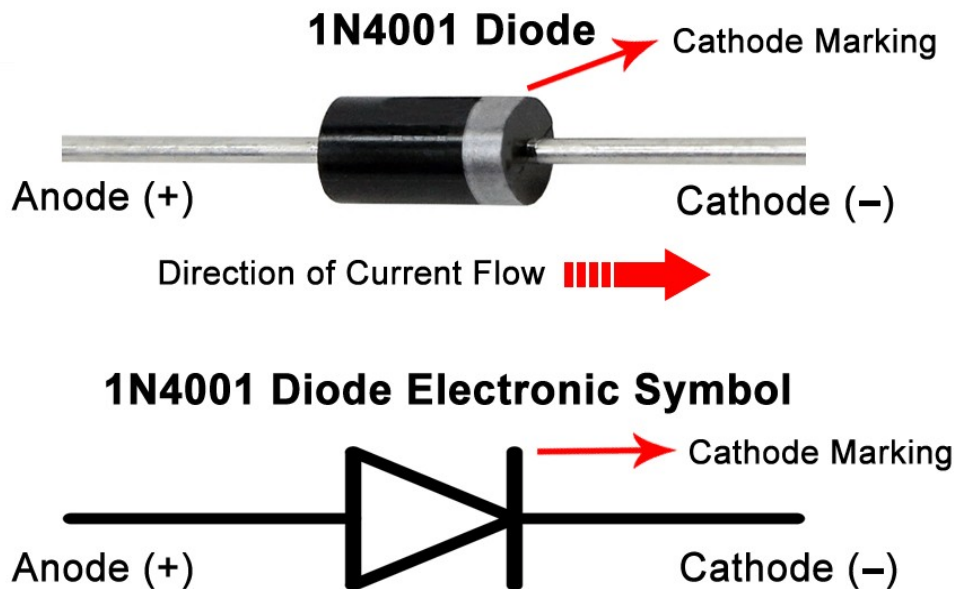


Figure 22: Diode Physical Package and Connections

4. A minimum threshold voltage is required to make current flow across a semiconducting junction.
 - a. The threshold voltage of a PN junction is usually quite low. This is called the forward voltage.
 - i. Adjust the DC Regulated Power Supply to 1 VDC.
 - ii. Connect the DC Regulated Power Supply Leads together and set the maximum current to 0.01A (10mA).
 - iii. Connect the positive (red) lead to the anode of a 1N4001 diode and the negative (black) lead to the cathode of the diode.
 - iv. Measure the forward voltage displayed on the power supply. It should be around 0.66V.
 - b. The threshold voltage of an NP junction can be very high. This is called the reverse voltage.
 - i. Reverse the power supply connections to the 1N4001 diode.
 - ii. Adjust the DC Regulated Power Supply to 30 VDC.
 - iii. Observe that there is no current flowing and that the voltage is 30V
 - iv. Explain this is because the Reverse Voltage of a 1N4001 diode is at least 50V.
 - v. **IMPORTANT:** Adjust the DC Regulated Power Supply to 1 VDC for safety.
5. Different types of diodes have different forward and reverse voltages, supporting useful applications.
 - a. The forward voltage of a normal silicon diode is about 0.7 Volt
 - b. The forward voltage of a Schottky diode is typically 0.1 – 0.3 Volt
 - i. Explain the Schottky diode is like a normal diode except that the Anode of the junction is made from a metal such as molybdenum, platinum, chromium or tungsten.
 - ii. Show the symbol of a Schottky diode in Figure 23.

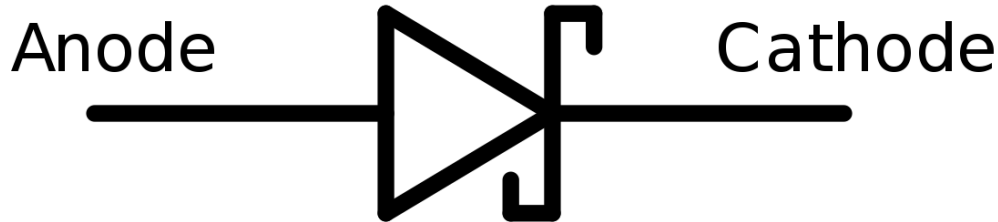


Figure 23: Schottky Diode

- iii. Repeat the forward voltage test for an 1N5819 Schottky diode. It should be around 0.22V.
- c. The reverse voltage of normal diodes is typically from 50 to 1000 Volt
 - i. Explain: We can't measure those voltages in class because they are dangerous.
- d. The reverse voltage of a Zener diode is typically from 3 – 30 Volt
 - i. Repeat the reverse voltage test for a 1N4736 (6.8V) Zener diode. It should be around 6.8V.
 - ii. Show the symbol of the Zener diode in Figure 24.

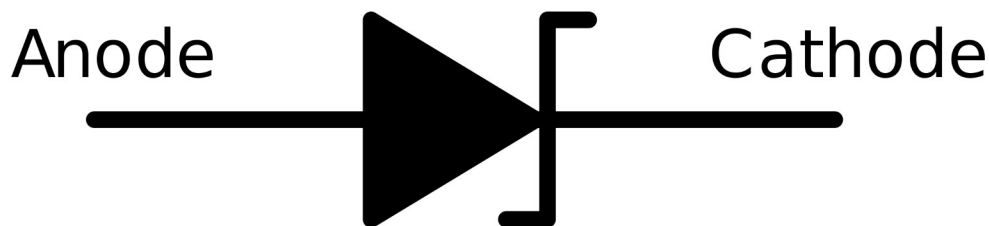


Figure 24: Zener Diode

- e. Using a power supply to measure diode forward and reverse voltages.
 - i. As shown above. This time allow students to make the measurements themselves.
- 6. Using a component tester to identify the diode type and forward voltage.
 - a. See Figure 33 for how to use a component tester.
 - b. Connect each type of diode to the component tester.
 - c. Observe the component test identifies the type of diode and its forward voltage.
 - d. Note: The component test may not correctly identify some types of diodes
- 7. Current flowing across a semiconductor junction can produce light
 - a. Adjust the DC Regulated Power Supply to 2.8 VDC.
 - b. Connect the DC Regulated Power Supply Leads together and set the maximum current to 0.01A (10mA).
 - c. Connect a blue 2.8V LED to the DC Regulated Power Supply.
 - i. Connect the positive (red) lead to the Anode.
 - ii. Connect the negative (black) lead to the Cathode.
 - d. Show that the LED illuminates.
- 8. Conversely, light hitting a semiconductor junction can produce an electrical voltage
 - a. Select the DC voltage range of a multi-meter.
 - b. Connect the test leads of the multi-meter to a LED.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

- c. Shine a bright light (e.g. from the lamp on your mobile device) into the LED.
- d. Observe that the LED produces a voltage (typically, around 1V)
- e. Explain: The LED is working like a tiny Solar Cell (aka Photovoltaic Cell)
9. The structure of a Light Emitting Diode
 - a. Show the symbol of the LED in Figure 25
 - b. Look at an LED using a magnifying glass or microscope. Note: An LED with a clear plastic enclosure is required.
 - c. Observe the internal structure of the LED as shown in Figure 26
 - d. Describe the internal structure of the LED as shown in Figure 27
 - e. Students may wish to draw and annotate their own diagrams of the internal structure
 - f. Connect the LED to the DC Regulated power supply as above
 - g. Observe light is emitted from the LED chip itself
 - h. Adjust the voltage to dim the light so that the bond wire(s) can be seen

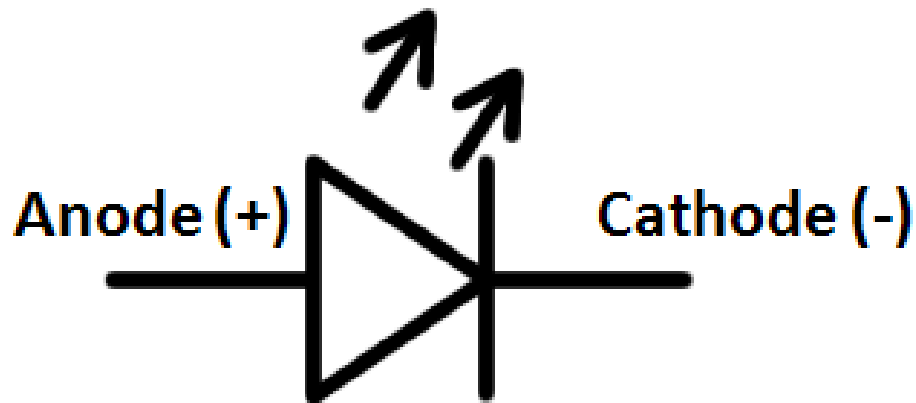


Figure 25: Light Emitting Diode (LED)

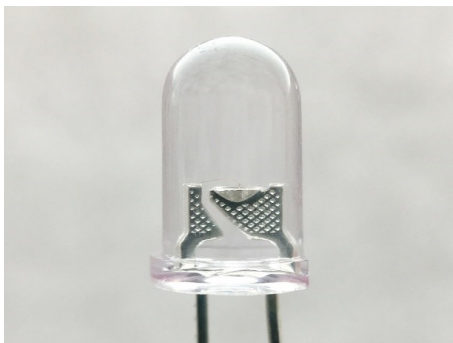


Figure 26: Internal View of an LED

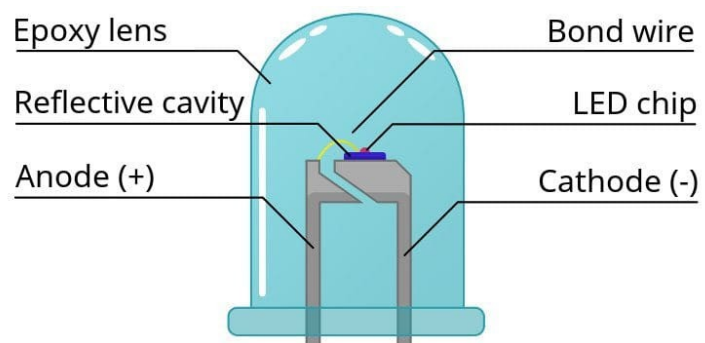


Figure 27: Internal Structure of an LED

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Student Tasks

1. Students answer questions and join in the discussions.
2. Students help adjust the voltage and current of a DC regulated power supply under adult supervision
3. Students use a component tester and multimeter to test diodes.

Discussion

1. Diodes can be used to drop the voltage in a circuit by a fixed amount. If the forward voltage of one diode is 0.66V, how much voltage drop would there be across two diodes connected in series? (1.32 V)
2. The reverse voltage of a Zener diode is 6.8V. What voltage would be required to power a 2.8V LED using this Zener diode? ($6.8 + 2.8 = 9.6$ V) Try it, using the power supply set to 9.6V . Remember to connect the positive power supply lead to the Cathode (black band) of the Zener diode. Draw the circuit using the proper symbols.
3. How could you use a diode to protect a battery-operated device from reverse (potentially destructive) battery connection? (Connect a diode in series with the battery lead) Which side of the diode would you connect to the positive terminal of the battery (The anode) What type of diode would you use for this application? (A Schottky diode because it has the lowest forward voltage drop)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 6. Transistors.

| |
|---|
| Purpose |
| To explore devices, with two semiconductor junctions, also called bipolar junction transistors. |
| Introduction |
| "In this lesson we will learn about bipolar junction transistors." |
| Safety |
| WARNING: DO NOT ALLOW THE BATTERY WIRES TO TOUCH EACH OTHER WHEN THE SWITCH IS ON. THIS IS CALLED A SHORT CIRCUIT AND CAN RESULT IN THE BATTERY AND WIRES GETTING HOT, MELTING THE PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! |
| Key Learning Areas |
| <ol style="list-style-type: none">1. A Bipolar Junction Transistor (BJT) has two semiconductor junctions between alternating p-type and n-type semiconductor material. There are two types of BJT: They are PNP and NPN transistors. Note: There are other types of transistors including: FETs (JFETs & MOSFETs) and IGBTs, but not covered here.<ol style="list-style-type: none">a. Inspect the physical appearance of a transistor.b. Explore an NPN transistor internal structure, physical connections and circuit symbolc. Explore a PNP transistor internal structure, physical connections and circuit symbol2. Transistors are used to switch or amplify electrical current.<ol style="list-style-type: none">a. A very small current flowing between the Base and Emitter will cause a large current to flow between the Collector and the Emitter.b. Current flows in the direction of the arrow on the transistor circuit symbol.<ul style="list-style-type: none">• In an NPN transistor, current flows into the Base and Collector and out of the Emitter.• In a PNP transistor, current flows into the Emitter and out of the Base and Collector.c. The ratio of the large Collector current to the small Base current is called the current gain.d. Typical BJT current gain can be several hundred times.3. Using a component tester to identify the type of transistor, its symbol, pin-outs, forward voltage and current gain.4. A minimum forward voltage between the Base and the Emitter is required to make current flow between the Collector and the Emitter. The forward voltage is about 0.7 Volt.5. In a practical circuit, external resistors are used to limit the current flowing through the Base and the Collector to safe levels.<ol style="list-style-type: none">a. A small resistor is used in the Collector circuitb. A large resistor is used in the Base circuit6. Turning on an LED using a BJT:<ol style="list-style-type: none">a. NPN transistor circuitb. PNP transistor circuit |
| Learning Outcomes |
| This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none">1. The different types, internal structure, physical connections, circuit symbols and operation of Bipolar Junction Transistors.2. How a transistor may be used to switch or amplify currents3. How to identify a transistor and measure its characteristics with a component tester.4. How to build a simple continuity tester with a transistor. |
| Year Level |
| Year 5 or 6 |
| Lesson Time |
| 45 Minutes |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Resources

1. You need to build two simple circuits (see Figure 34 and Figure 35) with parts from our [SARCNET STEM Kit #1](https://www.sarcnet.org/SARCNET-STEM-Kit-1) - Electronics Prototyping Kit (see Figure 2), or you can purchase the following parts separately. Note: This is for one (1) circuit:
 - a. Switched Battery Holder (3V)
 - b. AA Cells (x2)
 - c. 170 Contact Electronics Prototyping Board (Breadboard)
 - d. 510Ω ¼W 5% resistor: Green, Brown, Black, Gold
 - e. 33kΩ ¼W 5% resistor: Orange, Orange, Orange, Gold.
 - f. Light Emitting Diode
 - g. 150mm Pin Leads (x2), or hook-up wire cut, stripped 10mm and tinned at each end
 - h. A 3-hole Wire Link
 - i. An NPN transistor for one tester
 - j. A PNP transistor for the other tester (not included in the kit)
2. A Component Tester as shown in Figure 33

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



www.sarcnet.org

Teacher Tasks

1. Show the students how to inspect the physical appearance of a typical transistor
 - a. Transistors come in all shapes and sizes: Some as big as your hand and some you can only see under a microscope!
 - b. Transistors are usually packaged in a plastic case, sometimes with a metal tab to assist mounting it and cooling it, sometimes in a fully metal case
 - c. Small transistors either have metal pads or wire leads to connect them, by soldering them, to a printed circuit board
 - d. All transistors have three connections: They are called the Collector, the Base and the Emitter.
 - e. The transistor you will be using today looks like the one shown in Figure 28
 - f. Note that it has a cylindrical body with a flat face
 - g. The flat face is used to orient the transistor so that the three leads can be identified
 - h. The flat face is usually printed with the part number of the transistor so that it can be identified
 - i. The part number can be used to look up the transistor data sheet on-line
 - j. The transistor data sheet will identify the type of the transistor and its specific characteristics
 - k. To insert the transistor into an electronics prototyping board you will have to splay the leads a bit so that they line up with the holes.

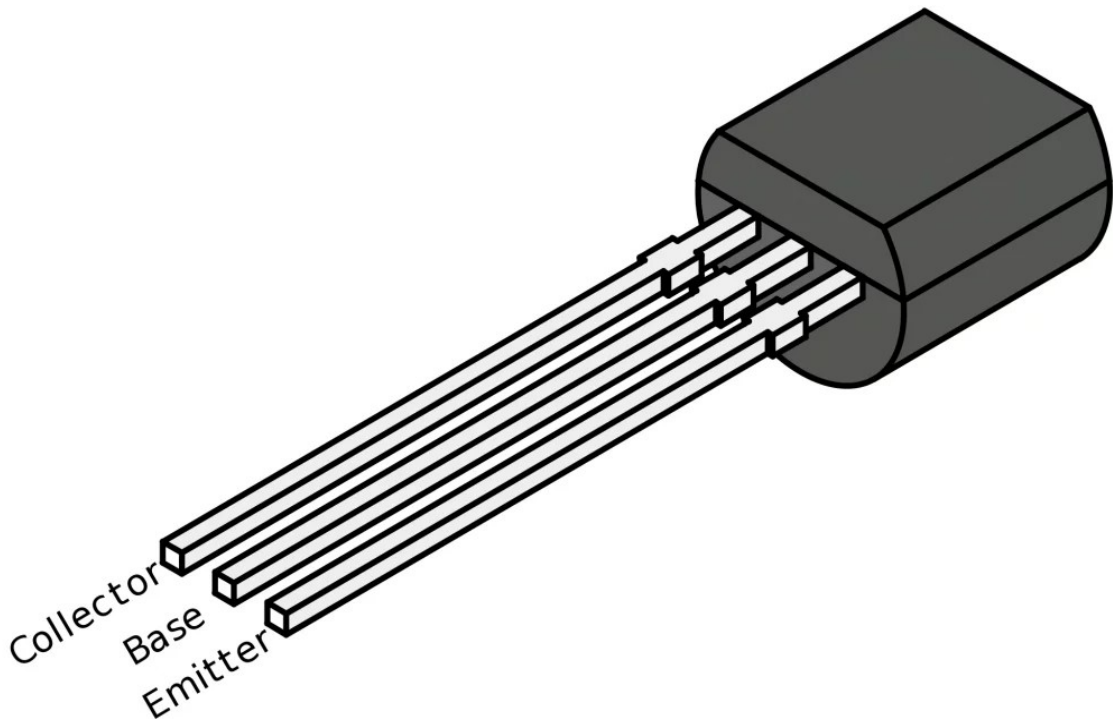


Figure 28: Physical appearance of a typical transistor

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

2. Explain that a Bipolar Junction Transistor (BJT) has two semiconductor junctions between alternating p-type and n-type semiconductor material. There are two types of BJT: PNP and NPN.
- a. The internal structure, physical connections and circuit symbol of an NPN transistor is shown in Figure 29

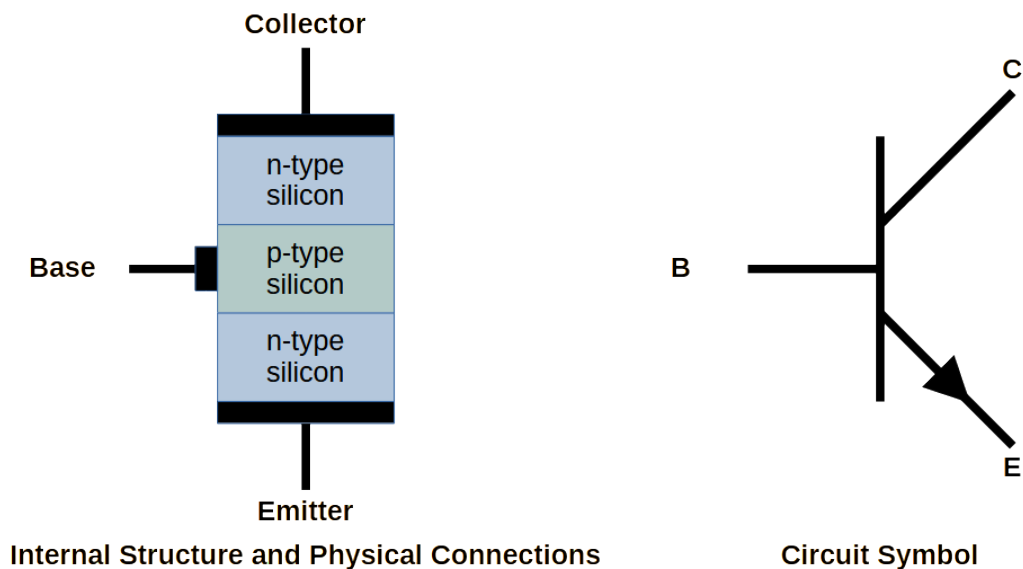


Figure 29: NPN transistor internal structure, physical connections and circuit symbol

- b. The internal structure, physical connections and circuit symbol of an PNP transistor is shown in Figure 30

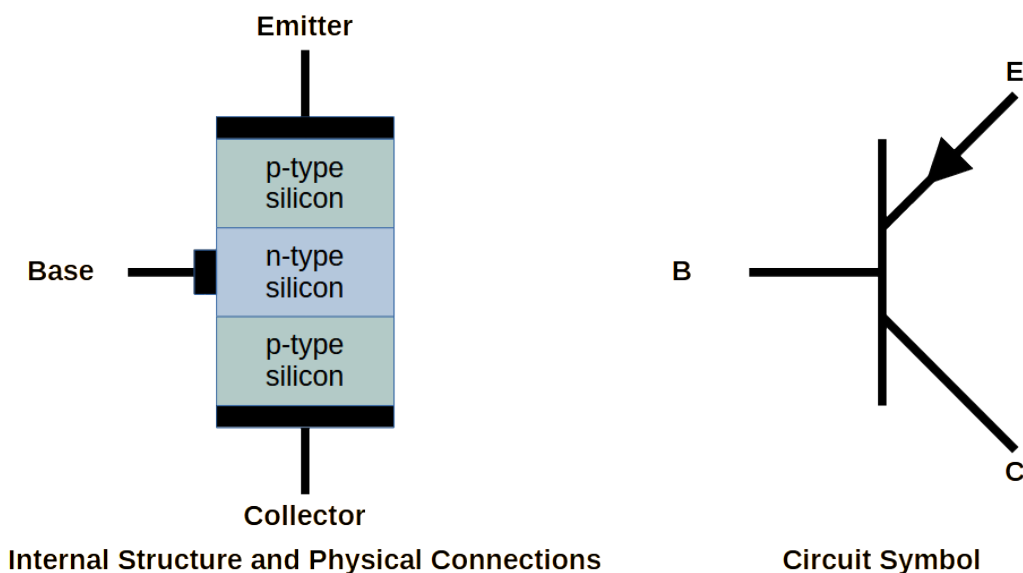


Figure 30: PNP transistor internal structure, physical connections and circuit symbol

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

3. Explain that BJTs are used to switch or amplify electrical current
 - a. A very small current flowing between the Base and Emitter will cause a large current to flow between the Collector and the Emitter
 - b. Current flows in the direction of the arrow on the Emitter
 - i. In an NPN transistor, current flows into the Base and Collector and out of the Emitter as shown in Figure 31

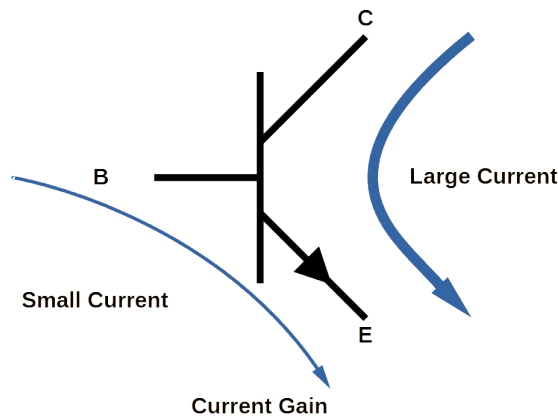


Figure 31: NPN Transistor Current Gain

- ii. In a PNP transistor, current flows into the Emitter and out of the Base and Collector as shown in Figure 32

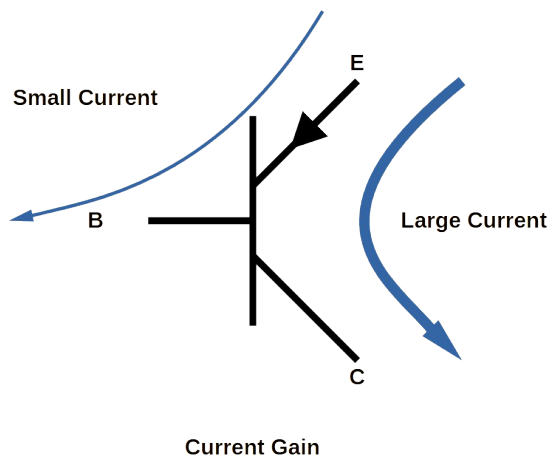


Figure 32: PNP Transistor Current Gain

- c. The ratio of the large Collector current to the small Base current is called the current gain
 - d. Typical BJT current gain can be several hundred times
 4. Explain that a minimum forward voltage between the Base and the Emitter is required to make current flow between the Collector and the Emitter. The forward voltage is typically about 0.7 Volt.
 5. Show that in a practical circuit, external resistors are used to limit the current flowing through the Base and the Collector to safe levels
 - a. A small resistor is used in the Collector circuit because the current is usually large
 - b. A large resistor is used in the Base circuit because the current is usually small

The School Amateur Radio Club Network[®]

Electronics Workshop – Lesson Plans

6. Show how to use a component tester to identify the type of transistor, its symbol, pin-outs, forward voltage and current gain.
- Insert a transistor into the socket on the component tester. Use pins numbered 1, 2 and 3.
 - Close the socket lever to hold the transistor securely in place.
 - Press the TEST button
 - Read the results. In this case, which may not be the same for your transistors, the display shows:
 - The device is an NPN Bipolar Junction Transistor (BJT)
 - The circuit symbol of the device
 - The Emitter is connected to Pin 1 of the socket
 - The Collector is connected to Pin 2 of the socket
 - The Base is connected to Pin 3 of the socket
 - The current gain (h_{FE}) is 217 (Meaning that for every milliamp of current flowing in the Base circuit, there can be up to 217 milliamps flowing in the collector circuit)
 - The base forward voltage is 672mV (Meaning that the minimum voltage required in the base circuit, to get current flowing in the collector circuit is 0.672V)
 - Use the component tester to identify the transistors you will be using as shown in Figure 33. Make a note of the different markings on the transistor and then list the information above. You will need to draw the package outline of the transistor, so that you can identify the position of its Collector, Base and Emitter leads later.

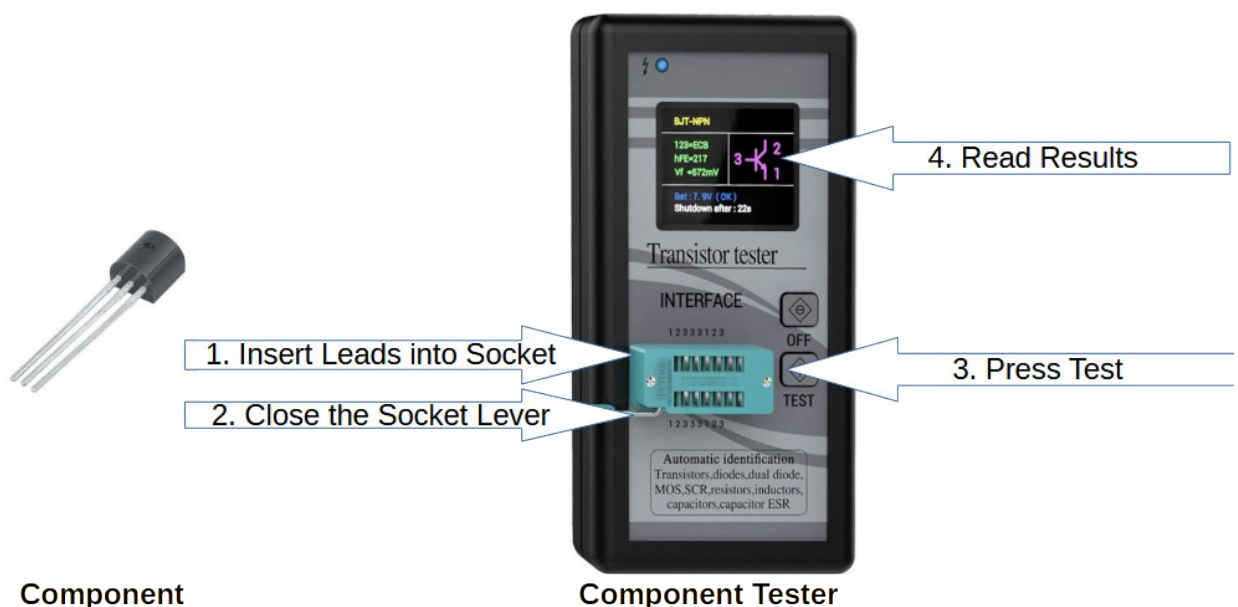


Figure 33: Using a Component Tester to test transistors

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

7. Get the students to build and test the following circuits which demonstrate turning on an LED using a BJT
- NPN transistor circuit (Figure 34). When the battery switch is turned on and a small current flows into the base of the transistor, a larger current will flow through the LED, illuminating it. The small base current may be created by touching the test leads together or even just holding them between your fingers. The 510Ω resistor limits the LED current. The $33k\Omega$ resistor limits the Base current. If either resistor was replaced with a conductor, the LED or the transistor could be damaged. Be sure to get the students to draw their own circuit schematic diagrams.

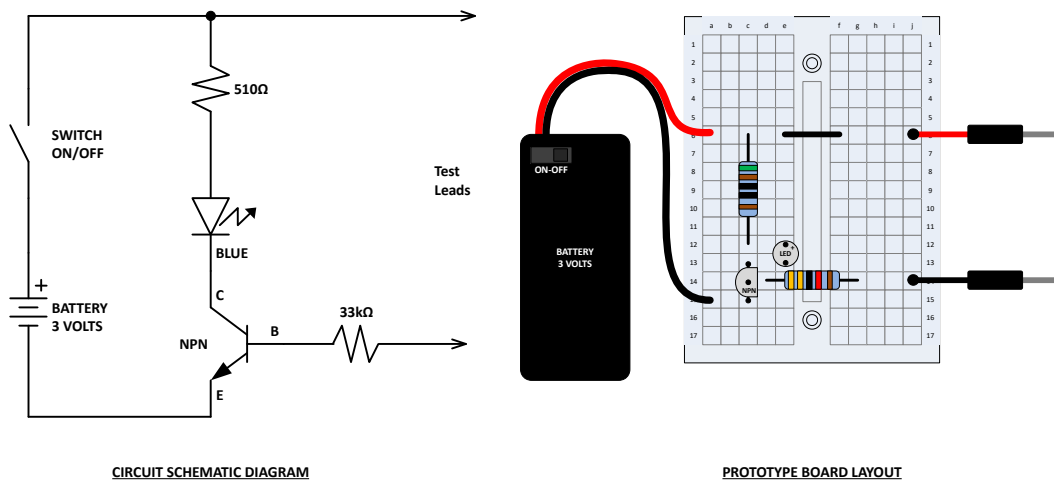


Figure 34: NPN Transistor Electrical Continuity Tester

- PNP transistor circuit (Figure 35). When the battery switch is turned on and a small current flows out of the base of the transistor, a larger current will flow through the LED, illuminating it. The small base current may be created by touching the test leads together or even just holding them between your fingers. The 510Ω resistor limits the LED current. The $33k\Omega$ resistor limits the Base current. If either resistor was replaced with a conductor, the LED or the transistor could be damaged. Be sure to get the students to draw their own circuit schematic diagrams.

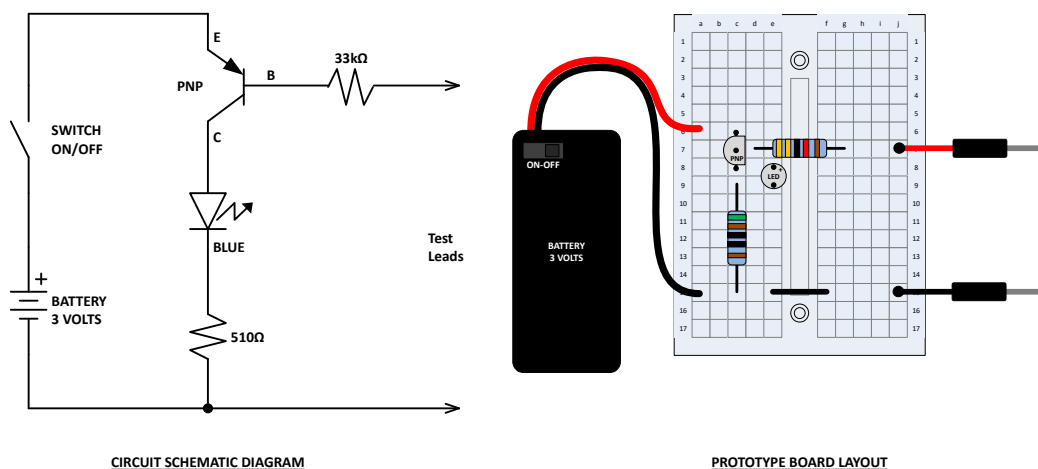


Figure 35: PNP Transistor Electrical Continuity Tester

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Student Tasks

1. Students answer questions and join in the discussions.
2. Students use a component tester to test transistors
3. Students record the results of the test and draw a diagram of the transistor package.
4. Students build and test a circuit using an electronics prototyping board.
5. Students draw the circuit schematic diagram of the circuit they have built.

Discussion

1. Transistor can be used to switch large currents on and off using small currents. We can demonstrate this by touching the test leads together and watching the LED go on and off. Can we use the same circuit to demonstrate that transistors can amplify small currents? (Yes, by holding the test leads against our skin, or a poor conductor, we can see that the LED glows dimly, but the current flowing through the LED is still much more than the current flowing through our skin or the poor conductor)
2. Design a circuit, using a transistor, that will sound an alarm if the water level in a tank rises too high. (Use the same circuit as before. Mount the test leads apart, but at the high-water mark, so when the water touches them it will cause a small current to flow. Test it with the LED first, then replace the LED with a 3V beeper, or use a power supply instead of the battery to provide a higher voltage for some other device like a motor)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 7. Capacitors

| |
|--|
| Purpose To discover the properties and applications of capacitors. |
| Introduction “In this lesson we will learn about capacitors. Capacitors are electronic components which store electrical energy.” |
| Safety WARNING: DO NOT ALLOW THE BATTERY WIRES TO TOUCH EACH OTHER WHEN THE SWITCH IS ON. THIS IS CALLED A SHORT CIRCUIT AND CAN RESULT IN THE BATTERY AND WIRES GETTING HOT, MELTING THE PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! WARNING: CONNECTING A POLARISED CAPACITOR TO A BATTERY, AROUND THE WRONG WAY, WILL RESULT IN THE CAPACITOR GETTING HOT AND POSSIBLY EXPLODING, BURNING YOU OR EVEN STARTING A FIRE! THE CAPACITOR WILL BE PERMANENTLY DAMAGED. ALWAYS CONNECT THE POSITIVE (+) LEAD OF THE CAPACITOR TO TO THE POSITIVE (+) TERMINAL OF THE BATTERY. WARNING: CONNECTING A CAPACITOR TO A POWER SUPPLY VOLTAGE GREATER THAN THE CAPACITOR’S SPECIFIED WORKING VOLTAGE WILL RESULT IN THE CAPACITOR GETTING HOT AND POSSIBLY EXPLODING, BURNING YOU OR EVEN STARTING A FIRE! THE CAPACITOR WILL BE PERMANENTLY DAMAGED. ALWAYS CONNECT THE CAPACITOR TO A VOLTAGE BELOW THE SPECIFIED WORKING VOLTAGE. |
| Key Learning Areas <ol style="list-style-type: none">1. Capacitor types and structure, including polarised and non-polarised capacitors2. Capacitor theory of operation, capacity units and working voltage3. Capacitor circuit symbol4. Electrical energy storage in a capacitor, charging and discharging5. Capacitor circuit application: Simple timing circuit |
| Learning Outcomes This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none">1. How to identify a capacitor2. The structure of a capacitor and the unit of capacitance (Farad)3. The importance of capacitor polarity and working voltage4. How to charge and discharge a capacitor5. How to use a capacitor in a timing circuit |
| Year Level Year 5 or 6 |
| Lesson Time Two 45 Minute Lessons |
| Resources For each student you will need: <ol style="list-style-type: none">1. Electronics Prototyping board2. 2 x 1.5V AA batteries3. 3V switched battery holder4. 33kΩ and 510Ω 1/4W resistors5. 22μF 25V electrolytic capacitor |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

6. 2V blue LED
7. NPN transistor
8. Two pin-leads

Teacher Tasks

1. Introduce the lesson
2. Explain: Capacitors are electronic components used to store electrical energy. They are like tiny rechargeable batteries, but they can be charged and discharged much faster than a battery.
3. Explain: There are many different types of capacitors as shown in Figure 36
 - a. Paper capacitors were popular in old valve (vacuum tube) equipment
 - b. Ceramic, polystyrene, polycarbonate, mylar, silver mica, feed-thru, trimmer and variable capacitors are mainly used in radio circuits (covered in a later lesson)
 - c. Bipolar and polyester capacitors are used in higher voltage, mains powered circuits
 - d. Electrolytic and tantalum capacitors are used in safe battery circuits
4. Explain: We will only be using electrolytic capacitors, as shown in Figure 37, in safe battery circuits

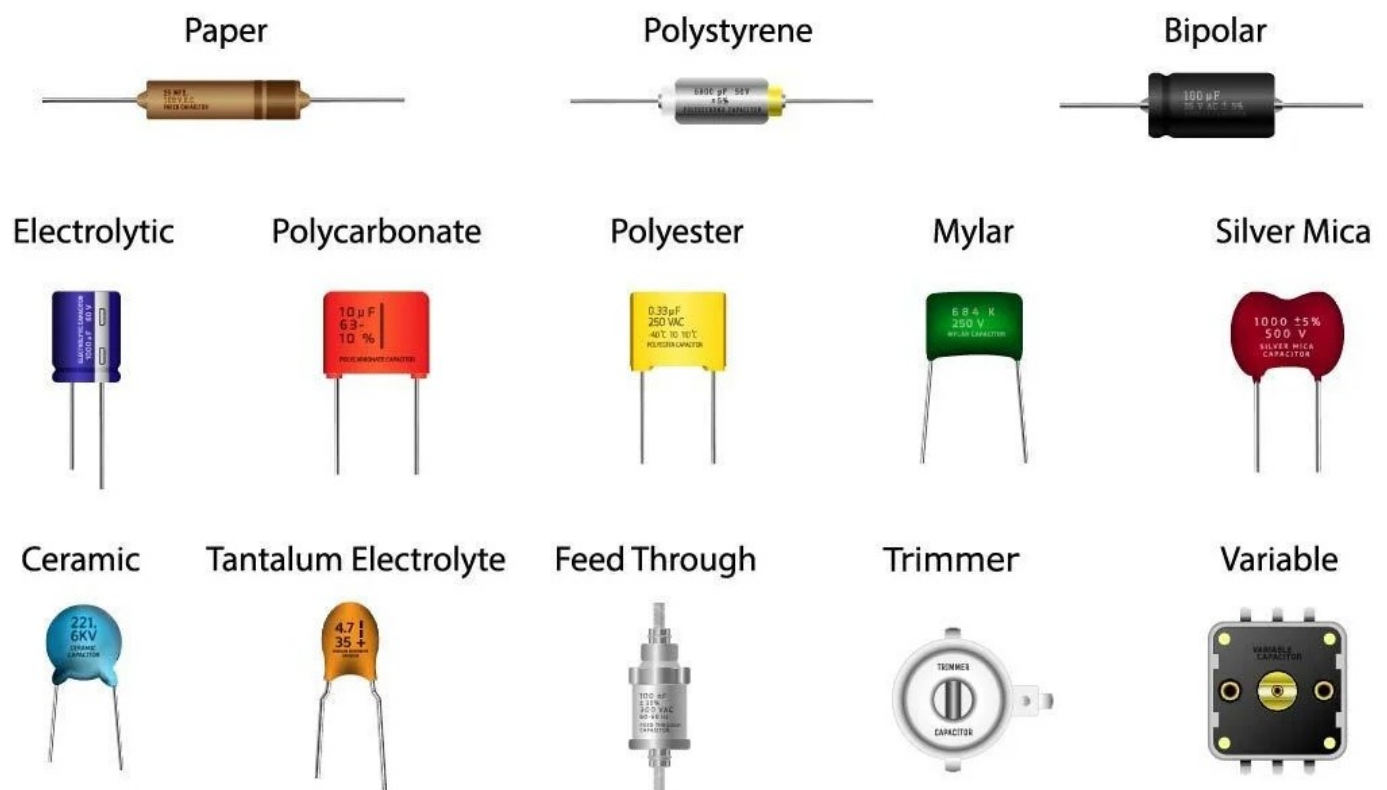


Figure 36: Capacitor Types

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

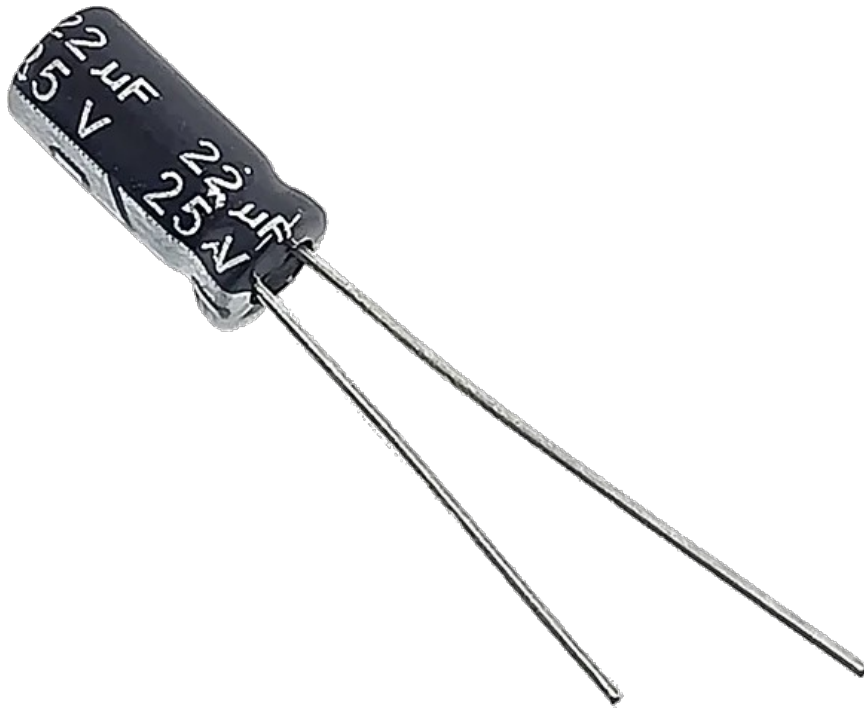




Figure 37: Electrolytic Capacitor

5. Explain: Most capacitors are non-polarised, but like a battery, electrolytic and tantalum capacitors are polarised: They have positive (+) and negative (-) leads: Remember to always connect the the positive (+) lead of the capacitor to the positive (+) terminal of the battery.
 - a. The positive (+) lead on a capacitor is the longest lead
 - b. The negative (-) lead on a capacitor has this symbol: 
6. Explain: All capacitors are essentially made from two conductive surfaces, or plates, held in close proximity to one another, but never touching. Indeed the two surfaces are often separated by an air-gap or a special insulating material called a dielectric. The larger the capacitor the larger the surface areas of the two plates. Electrolytic capacitors are made using an ingenious method of winding two layers of aluminium foil, tightly together in a spiral fashion, forming a cylindrical structure. The two foil tapes are separated by a very thin layer of paper soaked in an electrolyte solution. The capacitor's connecting leads are attached to each foil. See Figure 38 for details.
7. The circuit symbols for non-polarised and polarised capacitors is shown in Figure 39. It reflects the fact they are essentially made of two separate plates.
8. The unit of capacitance is the Farad, which is named after English scientist Michael Faraday (1791–1896). Since 1 Farad is a very large capacitance, it is more common to use micro-Farads, symbol (μF).
9. Ask: Examine the electrolytic capacitor
10. Ask: Draw a picture of it, its leads and its markings
11. Ask: What is the value of the capacitor? ($22\mu\text{F}$)
12. Ask: Which is the positive lead? (The lead without the  symbol)
13. Ask: What is the working voltage of the capacitor? (25V)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

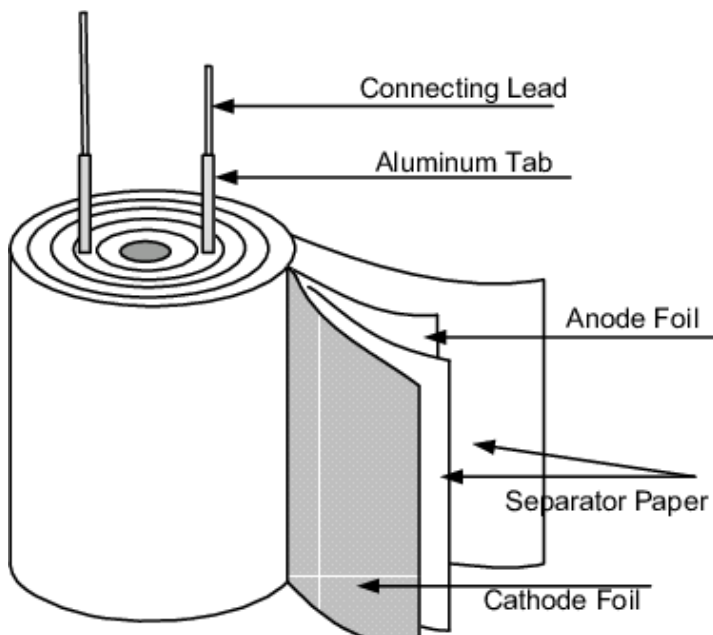


Figure 38: Electrolytic Capacitor Structure

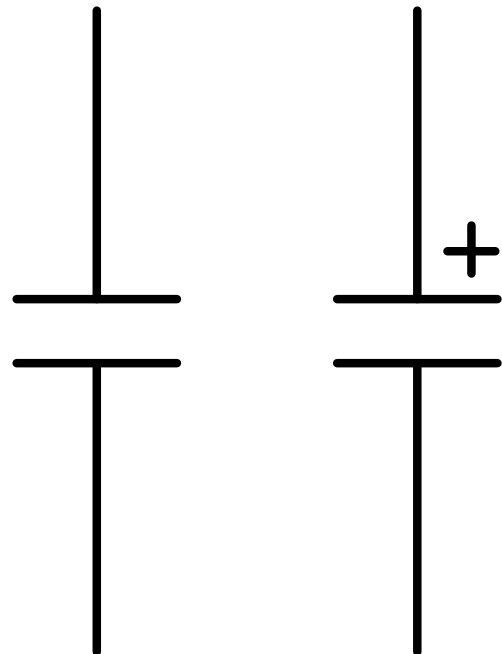


Figure 39: Capacitor Circuit Symbols

14. Explain: A capacitor can be charged by momentarily connecting it to a battery as shown in Figure 40. When a capacitor is discharged, there is an even distribution of positive and negative charges on both plates of the capacitor. When a battery is connected, an electric current flows for a short time. It moves the positive charges to one plate and the negative charges to the other plate and then stops flowing. When the battery is disconnected the capacitor will remain charged (for a long time).
15. Ask: Why will the capacitor eventually discharge? (Internal current leakage in the dielectric or external static electricity in the air will cause the capacitor to discharge over time)

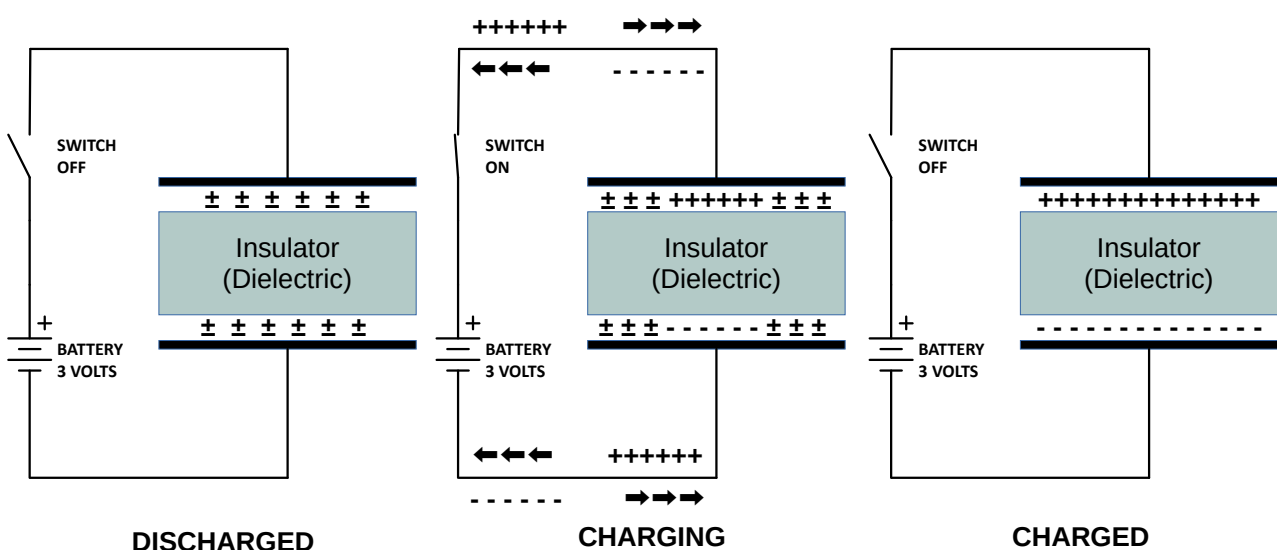


Figure 40: Charging a capacitor

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

16. Explain: A charged capacitor can be discharged by connecting it to a load, for example an LED, as shown in Figure 41. When the switch is closed and the load is connected, an electric current flows for a short time. It moves the positive and negative charges, in opposite directions, back to their original positions in the discharged state. Then the electric current stops flowing. The LED will flash on when the capacitor is discharging.

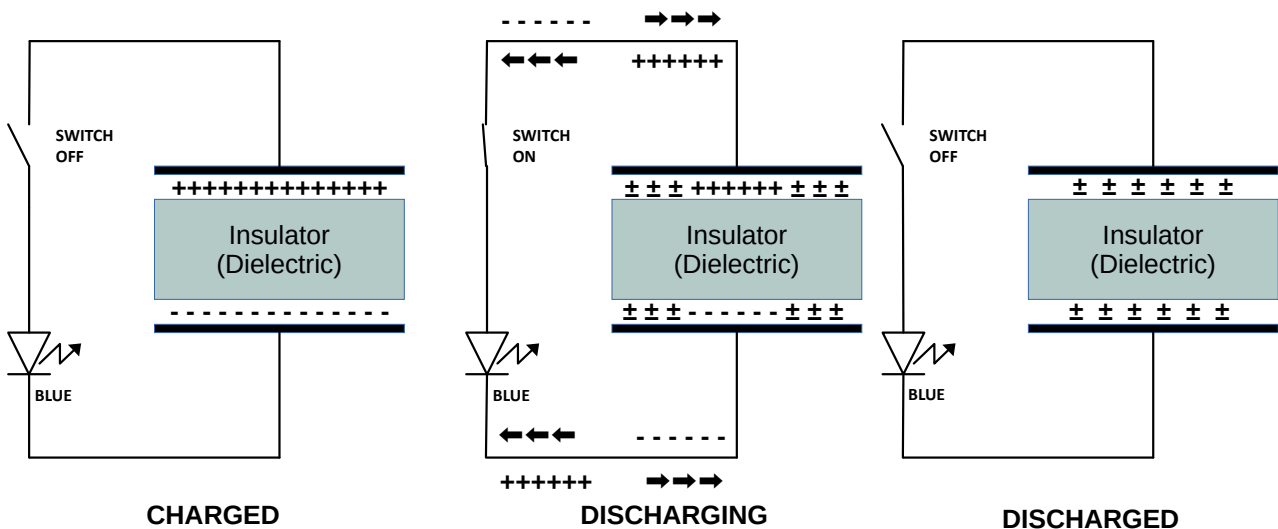


Figure 41: Discharging a capacitor

17. Discover: A capacitor can be charged and discharged.
- Provide safety warnings about shorting out the battery leads and reversing the capacitor.
 - Each student builds the circuit in Figure 42 using a prototyping board, 2x1.5V AA batteries, 3V switched battery holder, 22 μ F 25V electrolytic capacitor and 2V blue LED.
 - Turn the battery switch on.
 - Insert the capacitor into the prototyping board, connecting it to the battery: The capacitor is charged almost instantly.
 - Move the capacitor to connect it to the LED: The capacitor is discharged almost instantly, flashing the LED on.
 - Experiment to see what else discharges a charged capacitor before connecting it to the LED:
 - Waiting 5 minutes. Why? (Internal leakage or external static electricity discharges the capacitor)
 - Holding the leads in your fingers for 30 seconds. Why? (Moist fingers conduct electricity)
 - Putting the leads in water. Why? (Impurities in water make it conduct)
 - Touching the leads to a metal object. Why? (Metal is a good conductor)

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

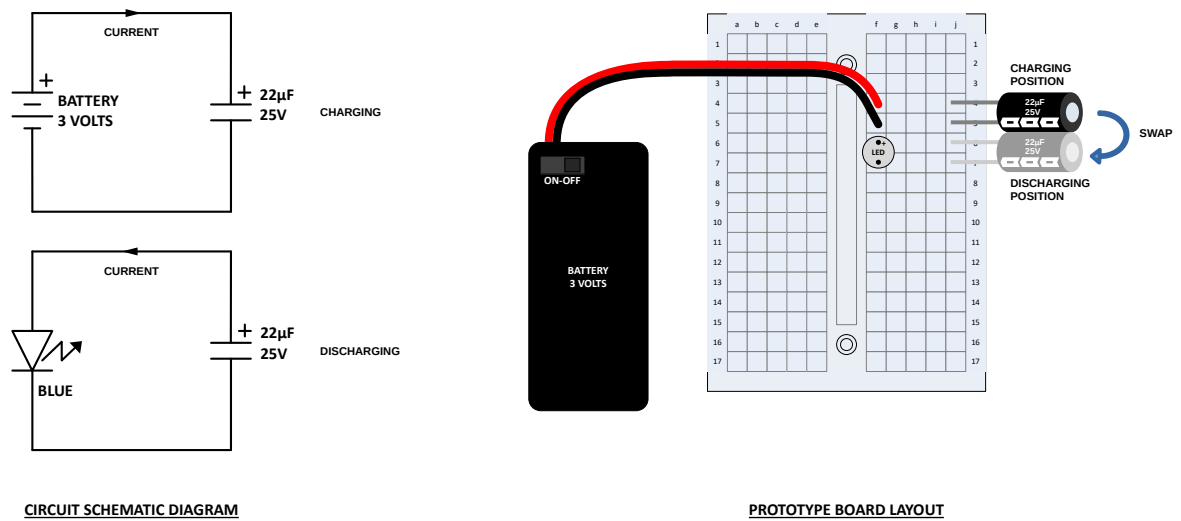


Figure 42: Capacitor Charging and Discharging

18. Explain: The maximum amount of electrical energy that can be stored in a capacitor is given by the formula: $E = \frac{1}{2} \times C \times V^2$ Where:
 - a. E is the electrical energy in Joule
 - b. C is its specified capacitance in Farad
 - c. V is its specified working voltage in Volt
19. Ask: What is the maximum amount of electrical energy that can be stored in a 22µF, 25V capacitor at 25V? ($\frac{1}{2} \times 0.000022 \times 25 = 0.006825$ J)
20. Explain: 0.006825 J is equivalent to the energy of 6.825 mA of constant current flowing for 1 second
21. Intermission
22. Discover: Build your own electronic timer. We discovered that a capacitor can discharge slowly provided that only a small amount of current is taken from it. This timer circuit uses that idea to turn a light on for about 30 seconds.
 - a. Provide safety warnings about shorting out the battery leads and reversing the capacitor.
 - b. Each student builds the circuit in Figure 43 using a prototyping board, 2 x 1.5V AA batteries, 3V switched battery holder, 33kΩ and 510Ω 1/4W resistors, 22µF 25V electrolytic capacitor, 2V blue LED, an NPN transistor and two pin leads. Provide the batteries after the circuit has been checked.
 - c. Turn the battery switch on.
 - d. Touch the pin-leads together for a short time. The LED illuminates and stays illuminated for more than 30 seconds.
 - e. Explain: When the battery is switched on, and the pin-leads are connected together: The capacitor is charged up via the 33kΩ resistor; a very small current flows into the base of the NPN transistor causing it to turn on; this causes a much larger current to flow through the 510Ω resistor and the LED which turns the LED on. When the pin leads are disconnected: The capacitor discharges via a very small amount of current into the the base of the NPN transistor, keeping it turned on for a time until the capacitor is finally discharged. Note: The 510Ω resistor is required to limit the current through the 2V LED. The 33kΩ is required to limit the current into the base of the NPN transistor.
 - f. Explain: You will notice that although the LED stays on, its light slowly dims until it turns off. This is because the transistor base current, from the discharging capacitor, is also slowly diminishing. A better timing circuit would use additional transistors to cut off the light more abruptly after the time-out period.

The School Amateur Radio Club Network[®]

Electronics Workshop – Lesson Plans

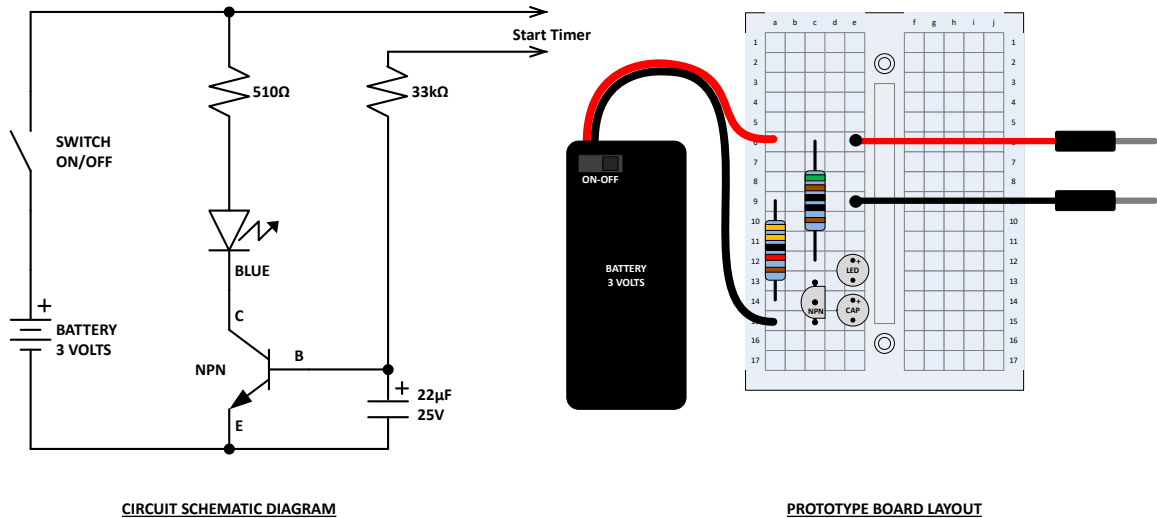


Figure 43: Capacitor Timing Circuit 1

- Each student modifies the circuit in Figure 43 to match the circuit in Figure 44. Simply remove the capacitor, spread the leads apart a little bit and re-insert it across the pin-leads.
- Touch the leads together for a short time. The LED illuminates and stays illuminated for more than 30 seconds.
- Explain: When the battery is switched on, the capacitor is charged by current flowing from the battery, through the switch, through the capacitor, through the 33kΩ resistor and back to the battery via the base and emitter of the NPN transistor. The small current flowing into the base of the NPN transistor causes a much larger current to flow through the 510Ω resistor and the LED, which turns the LED on. As the capacitor is charging, the current slowly diminishes until the LED turns off. When the pin-leads are connected together, the capacitor is discharged almost instantly. Then, when the pin-leads are disconnected, the charging process above starts again and the LED turns on for a about 30 seconds.

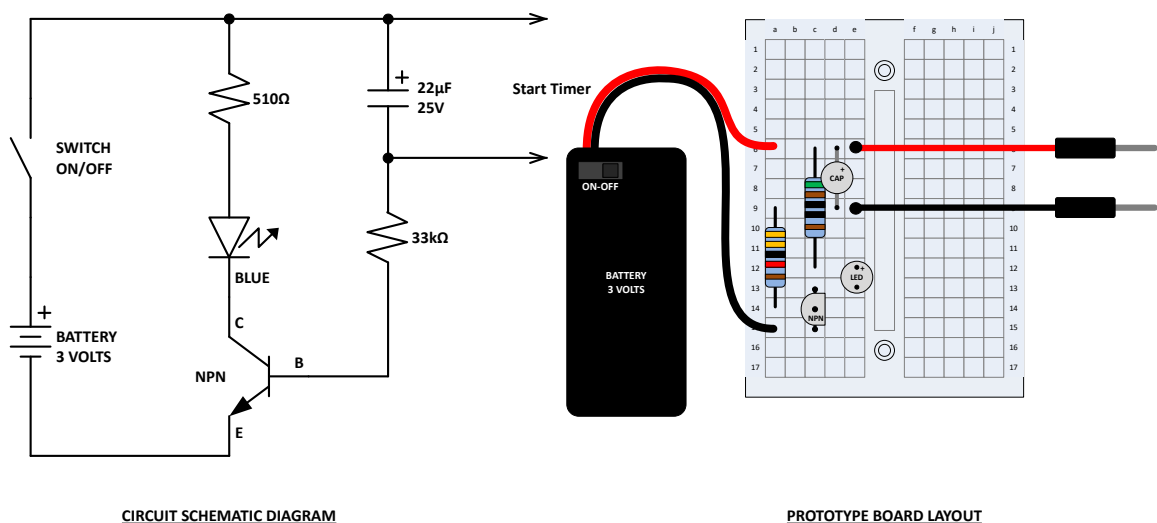


Figure 44: Capacitor Timing Circuit 2

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Student Tasks

1. Students answer questions and join in the discussions
2. Students draw a picture of a capacitor, its leads and its markings
3. Students build a circuit to demonstrate charging and discharging of a capacitor
4. Students calculate the amount of energy stored in a capacitor
5. Students build a circuit to demonstrate how a capacitor is used in an electronic timer

Discussion

1. How could you increase the time delay in the timer circuit? (Increase the capacitance by adding more capacitors)
2. What would happen if you remove the $33k\Omega$ resistor (the NPN transistor would be destroyed when the pin-leads are connected together, this is because the base-emitter current will be sufficient to overheat the semiconductor junction)
3. In circuit 1 the delay time is caused by the capacitor discharging via the $33k\Omega$ resistor. In circuit 2 the delay time is caused by the capacitor charging via the $33k\Omega$ resistor. Are the time delays exactly the same? (No. In circuit 1 the capacitor is charged only to 0.7V. In circuit 2 the capacitor is charged to $3 - 0.7 = 2.3V$. Note: 0.7 Volt is the forward voltage of the base-emitter, P-N junction.)
4. What other differences are there in the two circuits?
 1. Circuit 1: The timer is not triggered and the LED is off when the battery is first turned on
 2. Circuit 2: The timer is triggered and the LED is on when the battery is first turned on
5. What applications can you think of for a capacitor timing circuit? (A hall-way light timer)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 8. Inductors and Transformers

| |
|---|
| Purpose |
| To discover the properties and applications of inductors and transformers. |
| Introduction |
| "In this lesson we will learn about inductors and transformers. Inductors are electronic components which store magnetic energy. Transformers are electronic components which use electromagnetic induction to transfer electrical energy." |
| Safety |
| WARNING: DO NOT ALLOW THE BATTERY WIRES TO TOUCH EACH OTHER WHEN THE SWITCH IS ON. THIS IS CALLED A SHORT CIRCUIT AND CAN RESULT IN THE BATTERY AND WIRES GETTING HOT, MELTING THE PLASTIC, BURNING YOU OR EVEN STARTING A FIRE! |
| Key Learning Areas |
| <ol style="list-style-type: none">1. Electromagnetism2. Electromagnetic induction3. Magnetic cores and magnetic coupling4. Transformers |
| Learning Outcomes |
| This lesson plan will give students an opportunity to learn: <ol style="list-style-type: none">1. The relationship between electric currents and magnetic fields in a wire2. The structure of an inductor and the unit of inductance (Henry)3. How to charge and discharge an inductor4. How inductors can be coupled together to form a transformer5. The structure of a transformer and the polarity of transformer windings6. How to use a transformer to transfer electric current |
| Year Level |
| Year 5 or 6 |
| Lesson Time |
| Two 45 Minute Lessons |
| Resources |
| For each student you will need: <ol style="list-style-type: none">1. Electronics Prototyping board2. 2 x 1.5V AA batteries3. 3V switched battery holder4. Two 2V blue LEDs5. Miniature audio transformer 8Ω to 1000Ω C.T. (About 2 Henry inductance) |

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

Teacher Tasks

1. Introduce the topic.
2. Explain: An invisible magnetic field is created by a permanent bar magnet. The magnet has North and South magnetic poles. A compass can be used to visualise the direction of the magnetic field as shown in Figure 45.

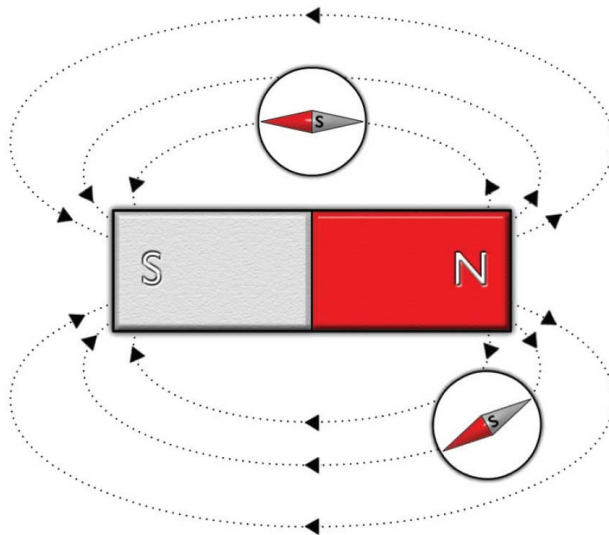


Figure 45: Magnetic Field

3. Explain: When an electric current flows through a wire, it induces a magnetic field in the form of a circle around the wire as shown in Figure 46.

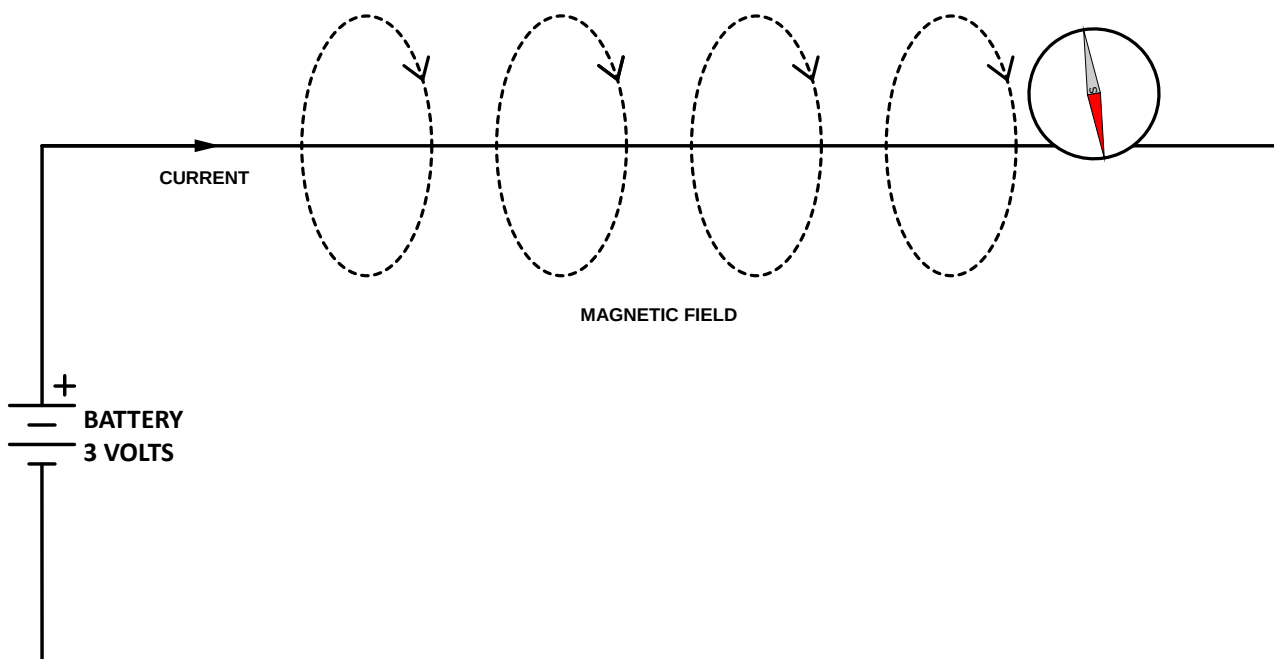


Figure 46: Electromagnetic induction

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

4. If the wire is then wound into a coil, as shown in Figure 47, the induced magnetic field forms into the same shape as that for a permanent bar magnet. The field becomes stronger and more useful. For example: If we wind the coil of wire over a soft iron rod, we will have created a simple electromagnet (try it). We can use the electromagnet to pick up small pieces of iron. This effect is called electromagnetism.

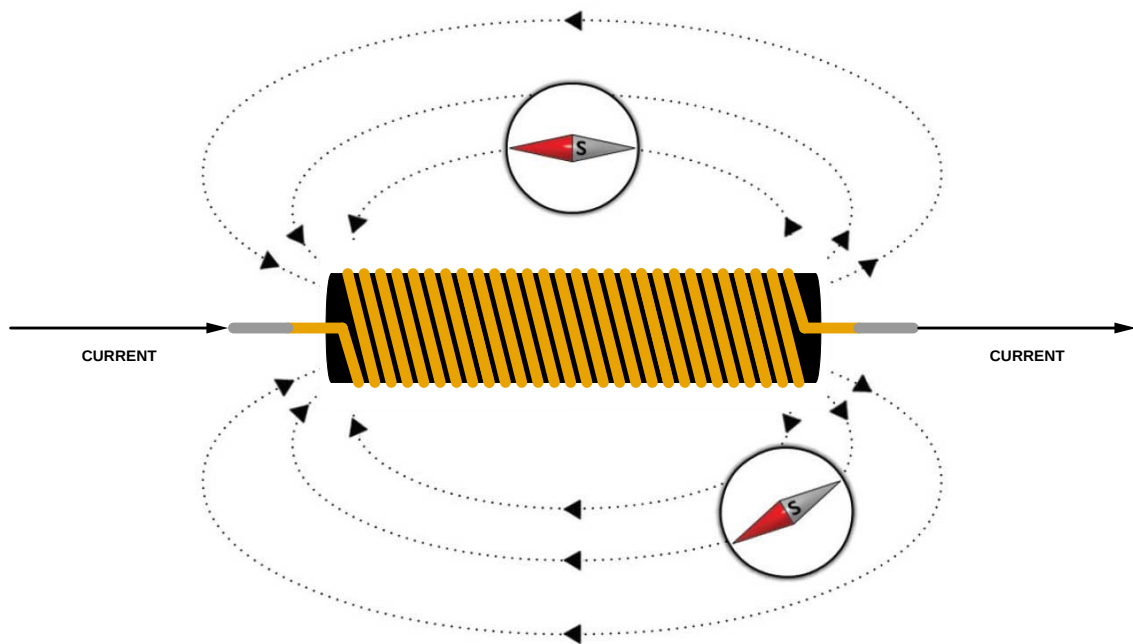


Figure 47: Electromagnetism

5. Explain: We have seen that an electrical current in a wire creates a magnetic field. The converse is also true: A changing magnetic field near a wire creates an electric current in the wire. This effect is called electromagnetic induction.
6. Explain: An inductor is an electronic component that maximises the electromagnetic induction effect by forming the wire into a coil and sometimes using a magnetic core. See Figure 48 showing different types of inductors and the circuit symbol of a ferrite-cored inductor. The symbol has a stylised coil and, optionally, two parallel lines representing the magnetic core.
1. An inductor converts electrical energy into magnetic energy when it is charged
 2. An inductor converts stored magnetic energy into electric energy when it is discharged
 3. The magnetic core of an inductor can be air, or better still, soft iron or other materials like ferrite
 4. Activity: Inspect a real inductor and draw a picture of it and its circuit symbol.

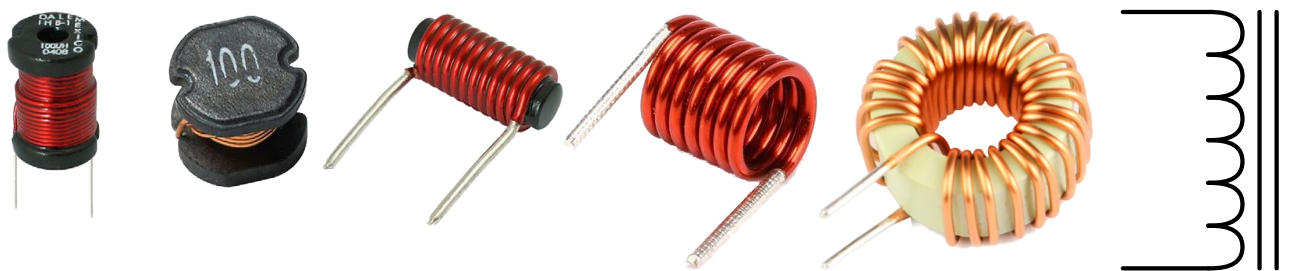
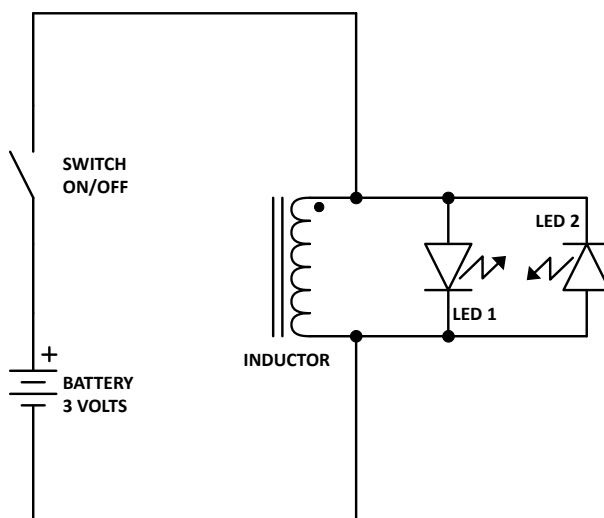


Figure 48: Inductors: Air Core, Ferrite Core and Circuit Symbol

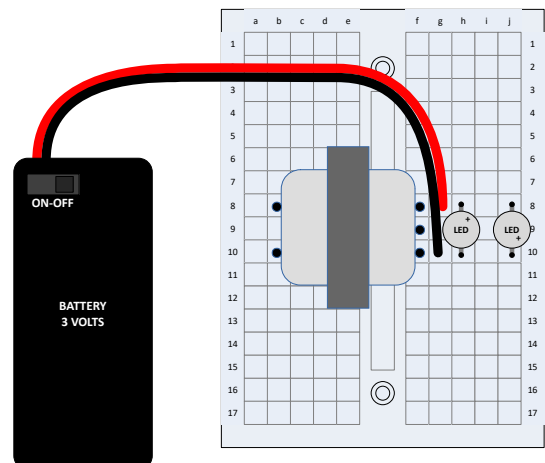
The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans

7. Explain: To investigate the properties of an inductor, students will build the circuit shown in Figure 49.
 1. Explain: The inductors shown in Figure 48 are too small to demonstrate charging and discharging of inductors using batteries and LEDs. These type of inductors are used in radio circuits. In this experiment we will be using one of the two inductors enclosed in a miniature transformer.
 2. Discover: Turn the switch on and off several times and observe the behaviour of the LEDs
 3. Explain: Inductors can be charged and discharged.
 1. When we turn the switch on, electric current from the battery flows through the inductor and the LED 1. No current flows through LED 2 because it is reversed. LED 1 comes on and stays on. The current flowing through the inductor creates a magnetic field in the inductor core.
 2. When we turn the switch off, electric current from the battery stops flowing through the inductor and LED 1. LED 1 goes off immediately. However, when the current going through the inductor stops, the magnetic field in the inductor core starts to collapse, as there is no electric current to sustain it. This rapidly-changing magnetic field in the inductor core has a surprising effect: It induces a large negative voltage (called back-EMF) on the inductor terminals, and for a short period of time. That voltage is sufficient to illuminate LED 2.
 3. The fact that LED 2 flashes on for a short period after we disconnect the battery proves that energy has been stored in the inductor. The inductor was charged with energy when the current was flowing through it and it discharged its energy when the current stopped.



CIRCUIT SCHEMATIC DIAGRAM



PROTOTYPE BOARD LAYOUT

Figure 49: Inductor test circuit

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



www.sarcnet.org

8. Explain: The unit of inductance is the Henry, symbol H, named after Joseph Henry (1797–1878), the American scientist who discovered electromagnetic induction independently of, and at about the same time as, Michael Faraday (1791–1867) in England.
9. Explain: The maximum amount of electrical energy that can be stored in an inductor is given by the formula: $E = \frac{1}{2} \times L \times I^2$ Where:
 1. E is the electrical energy in Joule
 2. L is its specified inductance in Henry
 3. I is the magnetising current in Amp
10. Ask: What is the maximum amount of electrical energy that can be stored in a 2H inductor with a magnetising current of 1 Amp? ($\frac{1}{2} \times 2 \times 1 = 1$ J)
11. Explain: 1 J is equivalent to the energy of 1 Amp of constant current flowing for 1 second
12. Intermission
13. Explain: Placing two inductors together, in close proximity, effectively creates a transformer
 1. A transformer is an electronic component containing two or more inductors that are magnetically coupled.
 1. A transformer is used to transfer energy from one electrical circuit to another
 2. A transformer has at least two separate coils, or windings, usually wound around the same magnetic core
 3. The appearance and circuit symbol of a transformer is shown in Figure 50
 1. The two windings are shown as stylised coils with connection points at each end
 2. The magnetic core material is shown as two parallel lines
 3. Each winding has at least two connections
 4. Some windings may have a third connection to the centre of the coil: Called a centre-tap, it is usually designated C.T. Multi-taped transformers may have even more connections and identify each tap with a different letter or number.
 5. The windings are usually designated primary windings and secondary windings. There may be more than one of each. A primary winding is usually connected to the input circuit. A secondary winding is usually connected to the output circuit, but that is somewhat arbitrary.
 6. Dots on the circuit symbol, near one end of each winding, indicate the polarity of the windings with respect to each other. A positive voltage on the lead with a dot on one winding will produce a positive voltage on the lead with a dot on another winding.
 7. Activity: Inspect a real transformer and draw a picture of it and its circuit symbol.

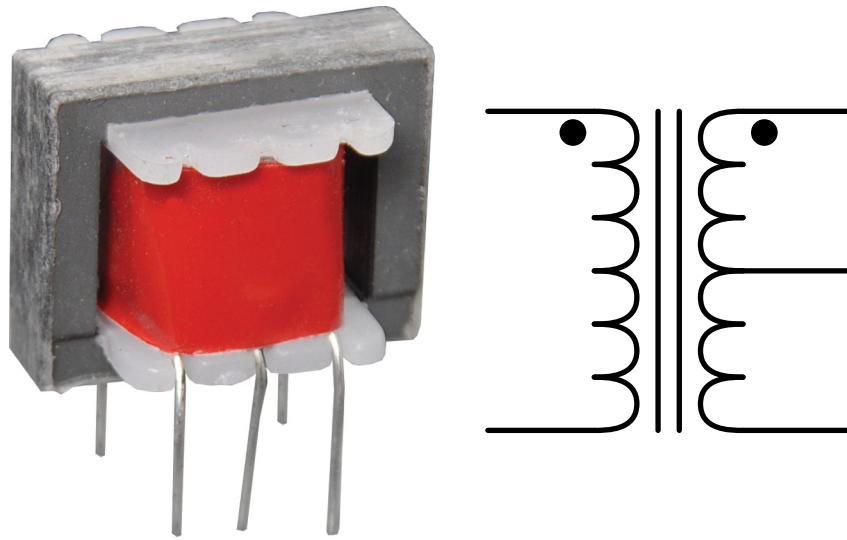
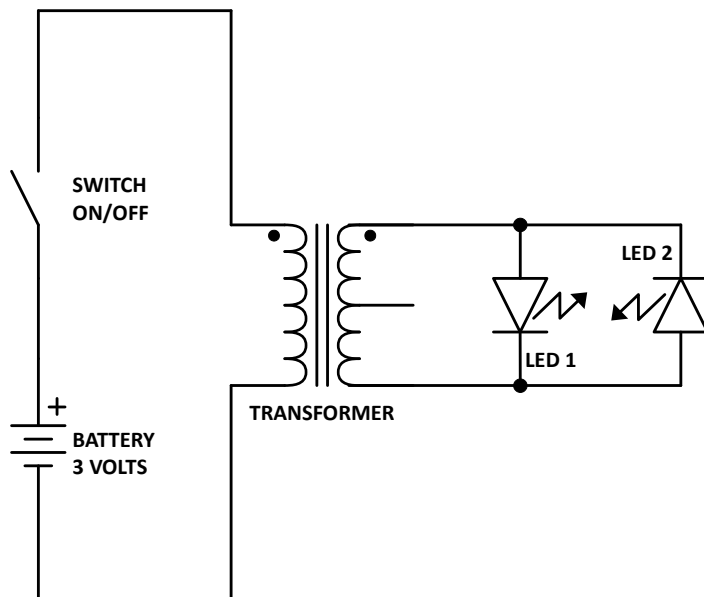


Figure 50: Transformer and Circuit Symbol

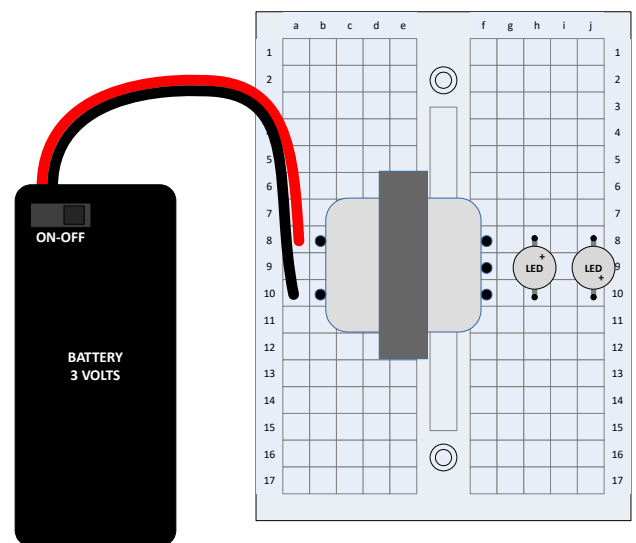
14. Explain: To investigate the properties of a transformer, students will build the circuit shown in Figure 51. If you have previously built the inductor test circuit, in Figure 49, this is a simple matter of re-connecting the battery leads to the two connection points on the other side of the transformer. We will call this the primary winding, with the secondary winding connected to the LEDs.
1. Discover: Turn the switch on and off several times and observe the behaviour of the LEDs
 2. Explain: Transformers can transfer energy from one circuit to another.
 1. When we turn the switch on, electric current from the battery flows through the primary winding of the transformer. The electric current initially creates and then sustains a magnetic field in the transformer core. The initially changing magnetic field in the transformer's core induces a positive electric current in the secondary winding of the transformer, which flashes LED 1 on for a short period. Note LED 1 does not stay illuminated, because the electric current in the secondary winding is only induced when the magnetic field initially changes from off to on.
 2. When we turn the switch off, electric current from the battery stops flowing through the primary winding of the transformer. The magnetic field in the transformer core quickly collapses. The changing magnetic field in the transformer's core induces a negative electric current in the secondary winding of the transformer, which flashes LED 2 on for a short period. Note LED 2 does not stay illuminated, because the electric current in the secondary winding is only induced when the magnetic field changes from on to off.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



CIRCUIT SCHEMATIC DIAGRAM



PROTOTYPE BOARD LAYOUT

Figure 51: Transformer test circuit

Student Tasks

1. Students answer questions and join in the discussions
2. Students draw a picture of an inductor, its leads and its circuit symbol
3. Students build a circuit to demonstrate charging and discharging of an inductor
4. Students calculate the amount of energy stored in the inductor
5. Students draw a picture of a transformer, its leads and its circuit symbol
6. Students build a circuit to demonstrate how a transformer is used to transfer energy between two circuits

Discussion

1. Can a transformer be used to turn a LED on continuously? (No. A transformer cannot be used to transfer a steady current between the primary winding and the secondary winding. It only transfers a current when the primary winding current is changing).
2. What can transformers be used for? (Transformers have limited application for steady currents. However, they are very useful for transferring pulses of current and alternating currents – which we have not covered yet.)

Evaluation

Participation in answering questions and class discussion is a good sign that students are enthusiastically learning the presented material. If not satisfied, try increasing the amount of practical hands-on investigation, measurement, discovery and creativity.

The School Amateur Radio Club Network®

Electronics Workshop – Lesson Plans



Lesson 9. Electronic Components

Lesson 10. Electronics Prototyping: Build your own circuits.

Lesson 11. Electronics Deconstruction: See how things work.