

EQUIPMENT BUILD PLAN

ELECTRICITY & MAGNETISM

Circuit Demonstration Boards

This is a family of simple wooden boards, each built around one idea: bulbs in series and parallel, batteries in series, batteries in parallel, a two-switch 'three-way' light, a one-or-the-other switch puzzle, a diode that only lets current through one way, and a continuity tester for checking what conducts. They share the same construction methods (bolt terminals, clip leads, trimmed battery holders), so once you have built one, the rest go quickly.

Written from Bruce's original workshop handout. Bruce's final review of this plan is in progress.

What it shows

Seven small wooden boards turn abstract circuit diagrams into bulbs that students can light, dim and puzzle over with their own hands.

Key ideas: series circuits, parallel circuits, voltage, switches, diodes, complete circuits, conductivity, ions in solution

Safety (Adult build / supervision). An adult should handle sawing, the heated utility knife and soldering. The boards run on 1.5-4.5 V from household cells



<div>DIFFICULTY</div> <div>Intermediate</div>	<div>BUILD TIME</div> <div>1-2 hours per board</div>
<div>COST</div> <div>About \$8-15 per board</div>	<div>SAFETY</div> <div>Adult build / supervision</div>
<div>GOOD FOR</div> <div>Teachers, Makers</div>	

and are safe for students to use. On the batteries-in-parallel board, make sure every cell faces the same way: a cell inserted backward is short-circuited by the others and can get hot. When testing liquids with the continuity tester, use only household ammonia and vinegar, work in a ventilated room, and never mix ammonia with bleach.

CONSTRUCTION

Build it

Materials

- ☐ **1/4 in plywood or other thin board** · one piece per board, about 6 × 8 in
Size is flexible; cut, sand and varnish
- ☐ **Miniature bulb bases (screw type) and bulbs** · 1-3 per board
Match bulb voltage to the board; see each section
- ☐ **Single-cell battery holders (C or D)** · 1-3 per board
- ☐ **Small machine bolts, about 1 in, with nuts** · several per board
Act as screw terminals for clip leads
- ☐ **Insulated hookup wire** · a few feet
- ☐ **Solid copper house wire, 12 or 14 gauge** · about 2 ft
For the bus wires on the series-parallel board
- ☐ **Alligator clip leads** · several
Ring (eyelet) crimp terminals on one end make them easy to bolt down
- ☐ **Ring crimp terminals and butt-splice connectors** · a few
- ☐ **Double-throw knife switches** · 2
For the three-way switch board
- ☐ **Single-pole double-throw switch** · 1
For the one-or-the-other board
- ☐ **Rectifier diode, such as a 1N4001** · 1
For the diode board
- ☐ **Small screw eye** · 1
Strain relief for battery leads
- ☐ **Small wood screws** · as needed
- ☐ **Printed paper labels** · as needed
Sealed under varnish
- ☐ **6-9 V miniature bulb (or a small 9 V buzzer), 9 V battery clip and 9 V battery** · 1 each
For the continuity tester. A 1.5 V cell and bulb is too weak to show salt water conducting.

- ☐ **Solid copper wire, 14 gauge** · two pieces about 1 ft long
Probes for the continuity tester; any sturdy wire works

Tools

Saw for cutting plywood

Drill with bits for small bolts and pilot holes

Screwdriver

Wire strippers

Pliers or crimping tool

Soldering iron and solder

Utility knife or small saw (for trimming battery holders)

Sandpaper and varnish

1

Make the boards

Cut a board for each circuit from 1/4 in plywood, sand the edges and varnish it. Lay out the parts before drilling anything so the wiring paths are short and easy for students to trace.

2

Add bolt terminals

Drill holes for small bolts wherever a student will need to clip on a lead. Wrap a bare wire end around the bolt under the board or under a nut on top, and tighten the nut down against the wood to clamp it. Bolts make far more reliable connection points than bare wire.

3

Trim the battery holders

Store-bought holders have tall side walls that make it hard for small hands to remove cells. Cut part of each side wall away with a small saw, or with a utility knife blade warmed so it slices the plastic. Leave enough of the holder to grip the cell.

4

Make clip leads and strain relief

Crimp a ring terminal onto one end of a lead so it can be bolted down, and solder or crimp an alligator clip onto the other. Where battery leads leave the board, loop them through a small screw eye so a tug does not pull on the solder joints.

5

Board 1: bulbs in series and parallel

Mount a battery holder and three bulb bases. Run two bus wires of bare 12 gauge house wire from bolt to bolt along the board and connect the battery to the nearest bolts on each bus. Bolt a clip lead to each terminal of every bulb base so students can clip each bulb across the buses (parallel), chain bulbs end to end (series), or mix the two.

6

Board 2: batteries in series

Mount a bulb base at one end and three battery holders end to end along the board. Wire them in a chain: the far end of the first holder runs on a long wire to the bulb, its other end joins the next holder, and so on, with the last holder returning to the bulb's other terminal. At each junction add a bolt with a short jumper clip lead so students can bridge across an empty holder and run the board with one, two or three cells.

7

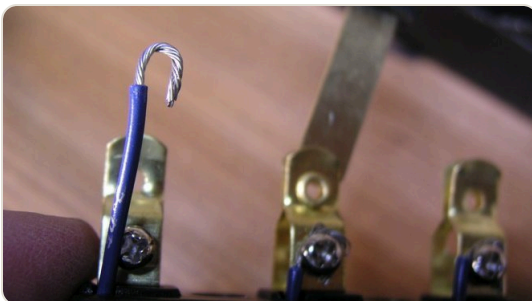
Board 3: batteries in parallel

Mount a bulb base and three battery holders. Join all the red (positive) leads together and all the black (negative) leads together, scraping a little insulation off each and soldering the joints. Run the positive bundle to one side of the bulb base and the negative bundle to the other.

8

Board 4: three-way switch

Mount a one- or two-cell battery holder, a bulb base and two double-throw knife switches. Attach the wires to the switches from the underside before screwing them down. One battery lead goes to the center (common) terminal of the first switch; its two outer terminals connect by two wires to the two outer terminals of the second switch; the second switch's common goes to the bulb, and the bulb returns to the battery.



9

Board 5: one-or-the-other puzzle

Run three wires from a double-throw switch under its base to three bolt terminals, then screw the switch down. Mount two bulb bases, join one terminal of each bulb to a shared bolt with a single wire, and give each bulb's other terminal its own bolt. Put alligator clips on a battery holder's leads and supply two loose clip leads. Leave it unwired: the students' job is to make the switch light one bulb or the other.



10

Board 6: diode tester

Mount a battery holder, a bulb base and three bolts labeled A, B and C. Wire the bulb base between bolts B and C, then wrap the diode's leads around bolts A and B and tighten the nuts on them. Extend the battery leads (solder or crimp), run them through a screw eye for strain relief, and finish them with alligator clips.

11

Board 7: continuity tester

On a small board, about 3 × 4 in, screw down a bulb base and a 9 V battery clip, and screw in two 1 in bolts as probe terminals. Wire one battery lead to the first bolt, the other battery lead to the bulb base, and the bulb base to the second bolt. Strip both ends of two 1 ft pieces of 14 gauge wire, wrap (and if needed solder) one end of each around a bolt, and tighten the nuts down; the free ends are the probes.

12

Label and test each board

Print labels on a computer printer, lay them into wet varnish and add a few more coats so they will not peel. Test every board with fresh cells before handing it to students.

THE PHYSICS

How it works

In a series circuit there is only one path, so the same current passes through every part. Add a second bulb in series and the battery's voltage is shared between them, so the current drops and both glow dimmer. In parallel, each bulb

Using it

- Series and parallel: compare one, two and three bulbs in series, then

gets its own path straight across the battery, so each gets the full voltage and glows as brightly as a single bulb would.

Batteries in series add their voltages: 1.5 V, then 3 V, then 4.5 V, and the bulb gets brighter with each cell. Batteries in parallel keep the voltage at 1.5 V, so the bulb's brightness does not change; what changes is how long the set can keep it lit, because the cells share the load.

A three-way light uses two double-throw switches connected by two 'traveler' wires. The light is on whenever both switches point to the same traveler, so flipping either switch changes the state. This is the same idea that lets you control a stairway light from the top or the bottom.

A diode is a one-way valve for current. Connected one way (forward biased) it conducts with only a small voltage drop, about 0.7 V for a silicon diode; reversed, it blocks current and the bulb stays dark. Electrons in the wires actually flow from the negative terminal toward the positive one, which is opposite to the 'conventional current' arrow printed on the diode.

The continuity tester is a circuit with a gap in it. Whatever you bridge the probes with becomes part of the circuit: a good conductor lights the bulb fully, a poor one dimly, an insulator not at all. Dry salt does not conduct because its ions are locked in a crystal, and pure water has very few ions, but dissolve the salt and its sodium and chloride ions are free to move, carrying current through the water. Tiny bubbles on the probes are hydrogen and oxygen from the electrolysis of water.

in parallel. Then wire two bulbs in series alongside a single bulb in parallel and ask why the single bulb is much brighter.

- Batteries: show the series board with one, two and three cells and ask what changed. Then do the same on the parallel board and ask why nothing visible changed.
- Three-way switch: ask students to draw the layout and trace the path of the current for each combination of switch positions, then explain how either switch can turn the light on or off.
- One-or-the-other: give students the board, the battery clips and two test leads and challenge them to make the switch light the left bulb in one position and the right bulb in the other. Then have them draw their solution and trace both paths.
- Diode: clip the battery to B and C and the bulb lights either way round. Move one clip to A so the diode is in the circuit, and the bulb lights only when the battery faces one way. Ask students to figure out which end of the diode must face the positive terminal.
- Continuity tester: have students sort classroom objects into conductors and insulators, check whether bulbs and fuses are good, and test liquids. Try dry salt, tap water and salt water. Then test household ammonia and vinegar separately (both are poor

conductors because they form few ions), mix a little of each and test again: the mixture conducts well because the reaction makes many more ions. Look for bubbles on the probes.

GO FURTHER

Variations

- Add a fourth bulb to the series-parallel board for longer chains.
- Use a buzzer or small motor in place of a bulb on any of the boards.
- For the diode board, try a light-emitting diode (with a suitable resistor) to show a diode that lights up itself.
- Continuity tester with a buzzer: wire a small 9 V buzzer in place of the bulb. Bruce found it more sensitive, since the pitch changes as resistance changes, but warns that a room full of buzzers gets annoying quickly.

IF IT DOESN'T WORK

Troubleshooting

IF THIS HAPPENS

A bulb will not light

TRY THIS

Check that the bulb is screwed fully into its base, that the cells are fresh and facing the right way, and that every bolt nut is tight on its wire.

IF THIS HAPPENS

Series bulbs are too dim to see

TRY THIS

Use lower-voltage bulbs or add a cell; three bulbs in series on a small battery may barely glow.

IF THIS HAPPENS

Bulb burns out on the batteries-in-series board

TRY THIS

The bulb must be rated for at least the full 4.5 V of three cells.

IF THIS HAPPENS

Diode board never lights through A

TRY THIS

Reverse the battery clips; if it still does not light, check the diode with the bulb alone, since it may be damaged or wired to the wrong bolts.

IF THIS HAPPENS

Continuity tester will not show salt water conducting

TRY THIS

Use a 9 V battery with a 6-9 V bulb, keep the probes close together in the liquid, and add more salt.

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