

## Wire-by-Number project kit introduction

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By Tony R. Kuphaldt

When I was young, my parents purchased a "Science Fair 150-in-one" project kit from Radio Shack. This kit was a wooden box with a stiff cardboard "backplane" inserted in it, into which dozens of electronic components were mounted. A small coil spring was attached to each component terminal, these springs serving as solderless connection points for the components. By pulling upward on a spring and opening spaces between the coils, one could insert a piece of stranded wire. When the spring was released, its tension clamped the wire in place, providing a mechanical and electrical connection. It was a primitive form of solderless breadboarding, except that the components were stationary and only the wires could be moved.

The kit came with a detailed instruction book, describing (in this case) 150 different electronic projects that could be built by connecting components together. Each project was complete with a schematic diagram, a pictorial diagram of the wires connecting the components together, and a description of the circuit and what it should do. Most of the projects were noise-making oscillators: morse code practice sounders, sirens, bird calls, whistles, etc. The kit came complete with a ferrite coil and variable capacitor, so simple radio circuits could also be built. A small solar cell and cadmium sulphide cell were provided for light-sensitive projects, and it even had a meter movement, relay, and a primitive integrated circuit.

However, the best part of this kit was the "wiring sequence" given for each project. Each spring coil had a number written next to it, and all you had to do to build any circuit in the book was connect the spring clips together in the order stated by the wiring sequence. No knowledge of electronics was necessary at all!

As primitive as this kit may sound (and it was!), it possessed tremendous educational value. First, being able to build functioning circuits by simply following wiring sequences allowed a novice like myself to immediately experience the thrill of hobby electronics. Once a circuit was built, I could experiment with disconnecting different wires, bridging components with my fingers (to create a high-value shunt resistance), and making other slight modifications, and immediately experience the results. The very short time required to go from a wiring sequence to a working circuit helped my young, relatively inattentive mind engage in the subject with a greater level of enthusiasm than if I would have had to follow complex instructions, and this naturally led to greater learning. The wiring sequence also made the construction process "fool-proof," eliminating so many of the connection problems normally faced in breadboarding.

Also, a very important skill I learned from this kit was how to spatially abstract from schematic diagrams to real circuitry where the components aren't laid out the same. This is a learning competency often neglected in modern breadboarding, where students have the freedom of locating components almost anywhere on the board they wish. Having all the components in fixed locations forced me to think differently than I would have otherwise. This spatial-relations skill has benefited me tremendously in my professional electronics career, and it is something I see numerous students struggle to master.

Now that I teach electronics, I wonder how beneficial my old "Science Fair" kit would be to my students, and how it might compare to modern, solderless breadboards as a teaching tool. Certainly, the spring-clip method of wire connections does not reflect industry wiring practice, and as such might be frowned upon because it lacks authenticity, but the same may be said about solderless breadboards. *Nobody* builds anything remotely permanent on a solderless breadboard (or at least they shouldn't!). In industry, circuits are either soldered, wire-wrapped or built with terminal blocks if re-configurability is crucial.

So, I thought, why not create a modernized version of the old "Science Fair" project kits using screw-type terminals to serve as semi-permanent connection points between components? Like the spring-coil kits,

each terminal could be marked by a label, the labels being used as reference points in wiring sequence lists. Students could build circuits in a "fool-proof" way in a very short time, learn to spatially abstract between schematic diagrams and the real thing, and have a relatively durable form of construction to work with (suitable for transport between home and school in less-than-ideal conditions). Best of all, students could *build* their own kit from a collection of components, a set of terminal strips, and a piece of plywood or some other suitable base material upon which to mount it all. This last benefit can be a great boost for "tactile" learners, who learn best when using their hands.

Having circuits specified by wiring sequence would allow "painless" construction for beginning students, but not all projects would have to be this easy. For added challenge, later circuits could be specified by schematic diagram only, with students having to figure out the wiring sequences on their own. This would actually be more challenging to students than building circuits on a solderless breadboard, because they would have to spatially abstract to a greater degree (not having the freedom to place components in such a way as to mimic the schematic's layout). The "Science Fair kit" format of wiring thus enables a wider range of learning for students than breadboards.

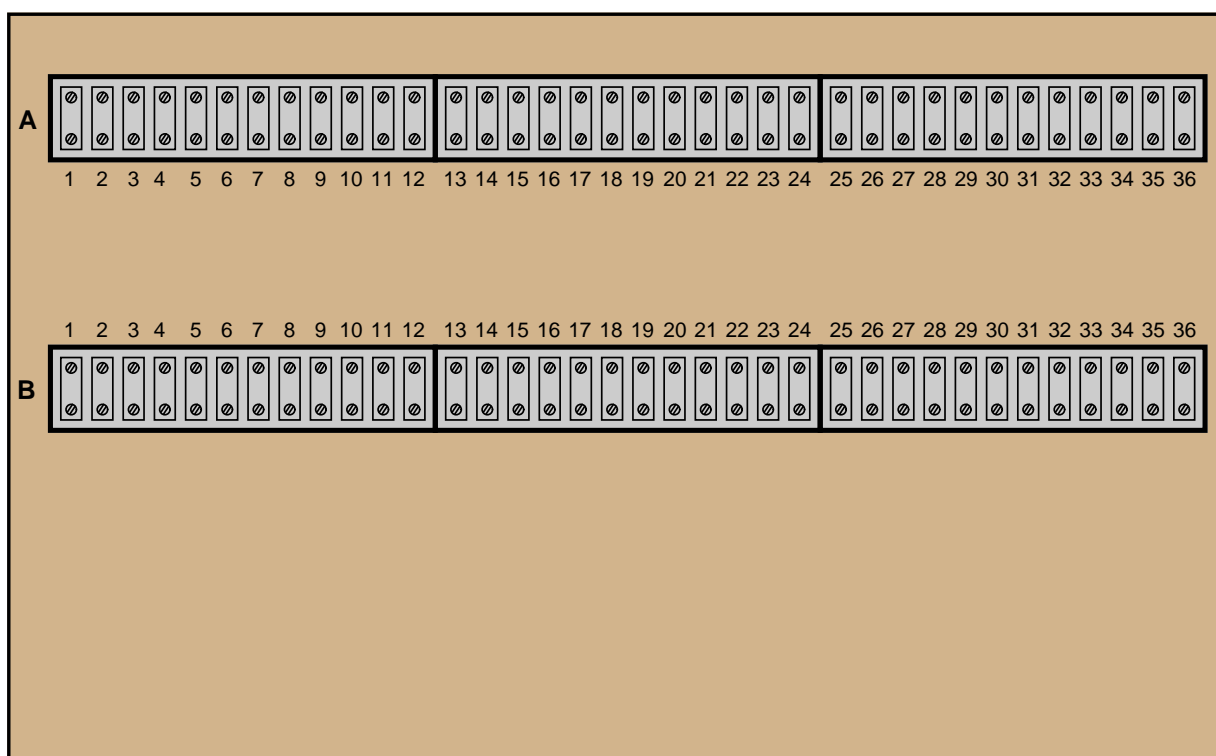
The main disadvantage I see to the "Science Fair kit" method of circuit construction is limited component count compared to breadboards. Many complex circuits simply could not be built in this fashion, because the necessary terminal count would be so high. Also, the long wiring lengths necessary to span distances between terminals creates relatively large parasitic inductances and capacitances, limiting circuit speeds and potentially decreasing signal-to-noise ratios. However, despite these disadvantages, a great many educational circuits could be built in this format, with what I believe to be superior educational benefits over breadboarding.

The purpose of this document is to outline the plans for such a kit – which I will refer to as the "Wire-by-Number" kit – and to suggest how one may be used in a teaching environment.

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## Proposed board layout

The basic layout of the Wire-by-Number board is two parallel rows of 36 terminals, comprised of three 12-position terminal blocks laid end-to-end. The terminal strips are anchored to a wooden board (I suggest a half-inch by 6 inch by 18 inch "hobby" or "craft" board) by means of #4 screws.



Small components connect to the top points of the "A" strip, while large components connect to the bottom points of the "B" strip. This is why the two strips are offset from center on the wooden board: to give room to support larger components along the lower row. Connecting wires between terminals go in the space between the two rows of terminal strips. I strongly recommend that students follow the general rule of no more than two conductors inserted into each terminal hole, and to keep one side of each terminal strip exclusively devoted to components. This latter rule allows replacement of components without disturbing the interconnecting wires.

Other layouts are, of course, possible. If necessary, additional lengths of terminal blocks may be added, but this would likely be unwieldy. As it is, this layout provides 72 terminals in a space less than 4 inches by 1 foot.

I recommend using 12-position "Euro" style direct-mount terminal strips with wire protectors. These are far less costly than modular terminal blocks of the type commonly used in industrial wiring. If purchased in quantity, their price should be less than \$1.00 apiece (2004 prices, United States dollars).

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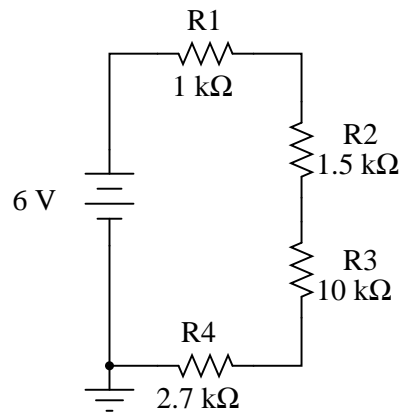
## Question 1

### Wire-by-Number project: simple voltage divider

#### Description:

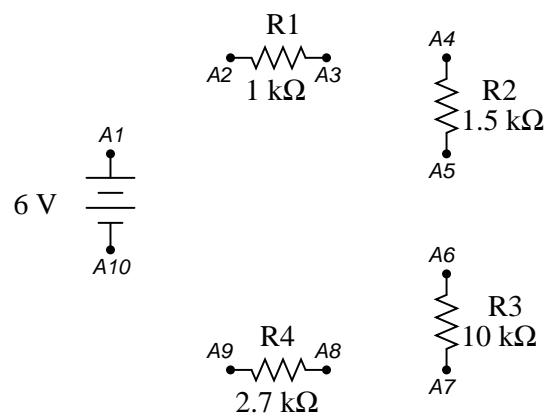
Build a voltage divider using four resistors, powered by a 6 volt battery or power supply.

#### Schematic diagram:

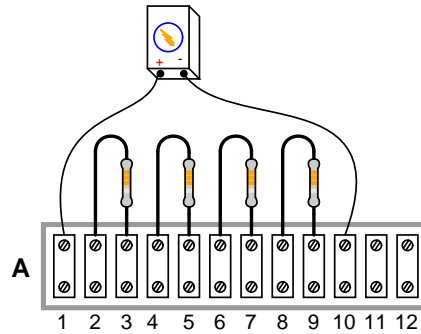


#### Components:

- Battery (6 V): A1=+ , A10=- (ground)
- Resistor R1, 1 kΩ: A2, A3
- Resistor R2, 1.5 kΩ: A4, A5
- Resistor R3, 10 kΩ: A6, A7
- Resistor R4, 2.7 kΩ: A8, A9



#### Pictorial diagram:



Wiring sequence:

- A1-A2
- A3-A4
- A5-A6
- A7-A8
- A9-A10

Tasks:

Calculate the total resistance of this series circuit using the formula provided. Then, with the voltage source *disconnected* (detach the "+" wire from terminal A1), measure the total series resistance of the four resistors, between terminals A2 and A9. Note both the predicted and the measured values in the following table, and don't forget to include the proper unit symbol ( $\Omega$ ) with your data! Calculate the percentage error between the calculated ("predicted") and measured values using the following formula:  
 Error =  $\frac{\text{Measured} - \text{Predicted}}{\text{Predicted}} \times 100\%$ .

| Variable    | Formula                 | Predicted | Measured | Error |
|-------------|-------------------------|-----------|----------|-------|
| $R_{total}$ | $R_1 + R_2 + R_3 + R_4$ |           |          |       |

Connect the voltage source back to the circuit (attach "+" to A1 and "-" to A10). Verify that 6 volts DC is present between terminals A1 and A10 using your voltmeter. Predict the correct values for the following voltage drops, then verify these voltage drop predictions by measuring with your voltmeter. Don't forget to include the proper unit symbol (V) with your data!

| Variable | Formula   | Predicted | Measured | Error |
|----------|---|-----------|----------|-------|
| $V_{R1}$ | $V_{source} \left( \frac{R_1}{R_{total}} \right)$ |           |          |       |
| $V_{R2}$ | $V_{source} \left( \frac{R_2}{R_{total}} \right)$ |           |          |       |
| $V_{R3}$ | $V_{source} \left( \frac{R_3}{R_{total}} \right)$ |           |          |       |
| $V_{R4}$ | $V_{source} \left( \frac{R_4}{R_{total}} \right)$ |           |          |       |

Predict and measure current in this voltage divider circuit by breaking it open at any point and connecting a DC ammeter in series with the break. *Be very careful that you do not connect your ammeter test probes directly across a source of substantial voltage, such as the battery or power supply! Remember to check your multimeter's setting (voltage versus current) before connecting the test probes to the circuit.*

| Variable    | Formula                        | Predicted | Measured | Error |
|-------------|--------------------------------|-----------|----------|-------|
| $I_{total}$ | $\frac{V_{source}}{R_{total}}$ |           |          |       |

Simulate an "open" fault in the circuit by removing resistor R3 from its terminal strip. Predict what effects this will have on the same variables (*increase, decrease, or no change*), then verify using your multimeter. To measure the voltage drop across R3, which is no longer in the circuit, simply measure voltage across the terminals it used to be connected to (A6 and A7):

**Fault condition: resistor R3 open**

| Variable    | Predicted effect | Measured effect |
|-------------|------------------|-----------------|
| $V_{R1}$    |                  |                 |
| $V_{R2}$    |                  |                 |
| $V_{R3}$    |                  |                 |
| $V_{R4}$    |                  |                 |
| $I_{total}$ |                  |                 |

Explain why the variables changed as they did, and whether or not this agreed with your original expectations:

|             |  |
|-------------|--|
| Explanation |  |
|-------------|--|

Now, simulate a "short" fault by connecting a piece of wire between the terminals where resistor R3 used to connect (A6 and A7), and repeat the same predictions/measurements:

**Fault condition: resistor R3 shorted**

| Variable    | Predicted effect | Measured effect |
|-------------|------------------|-----------------|
| $V_{R1}$    |                  |                 |
| $V_{R2}$    |                  |                 |
| $V_{R3}$    |                  |                 |
| $V_{R4}$    |                  |                 |
| $I_{total}$ |                  |                 |

Explain why the voltages changed as they did, and whether or not this agreed with your original expectations:

|             |  |
|-------------|--|
| Explanation |  |
|-------------|--|

Questions remaining:

*Here is where you write any questions or comments you have about this experiment.*

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Answer 1

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Notes 1

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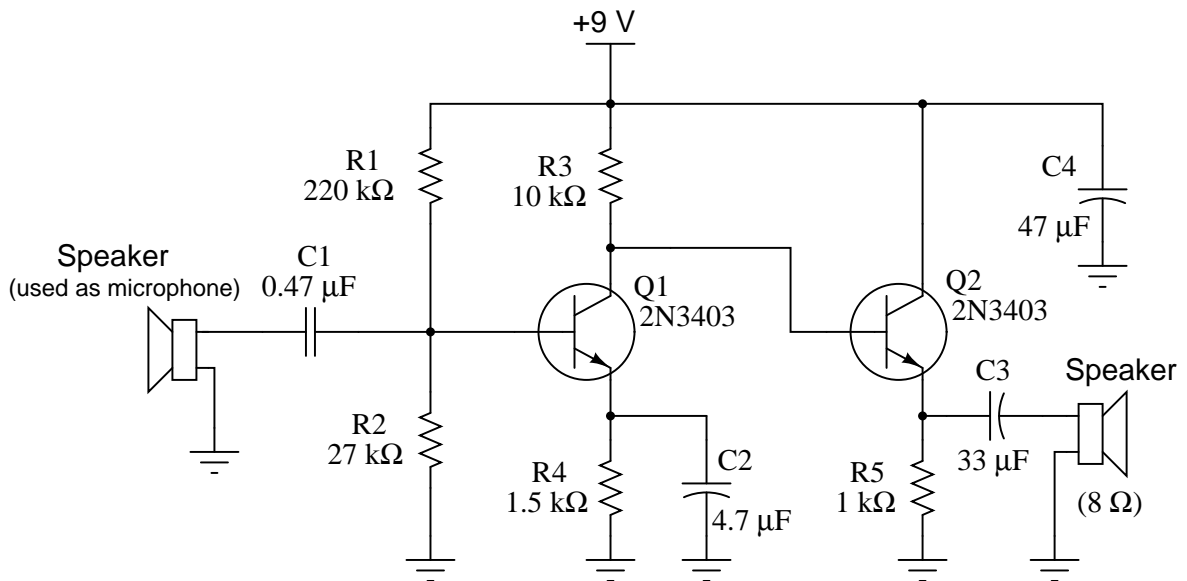
## Question 2

### Wire-by-Number project: Two-stage, class A, audio transistor amplifier

#### Description:

This circuit amplifies sounds detected by the microphone (actually, a small speaker used as a microphone), and amplifies them to be heard on a speaker.

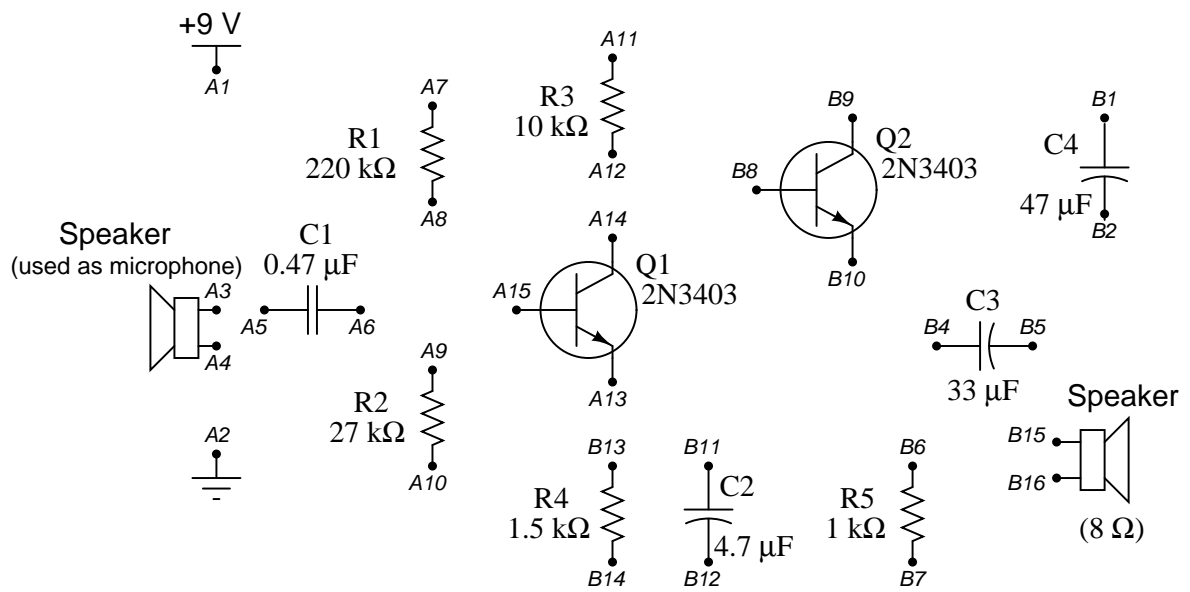
#### Schematic diagram:



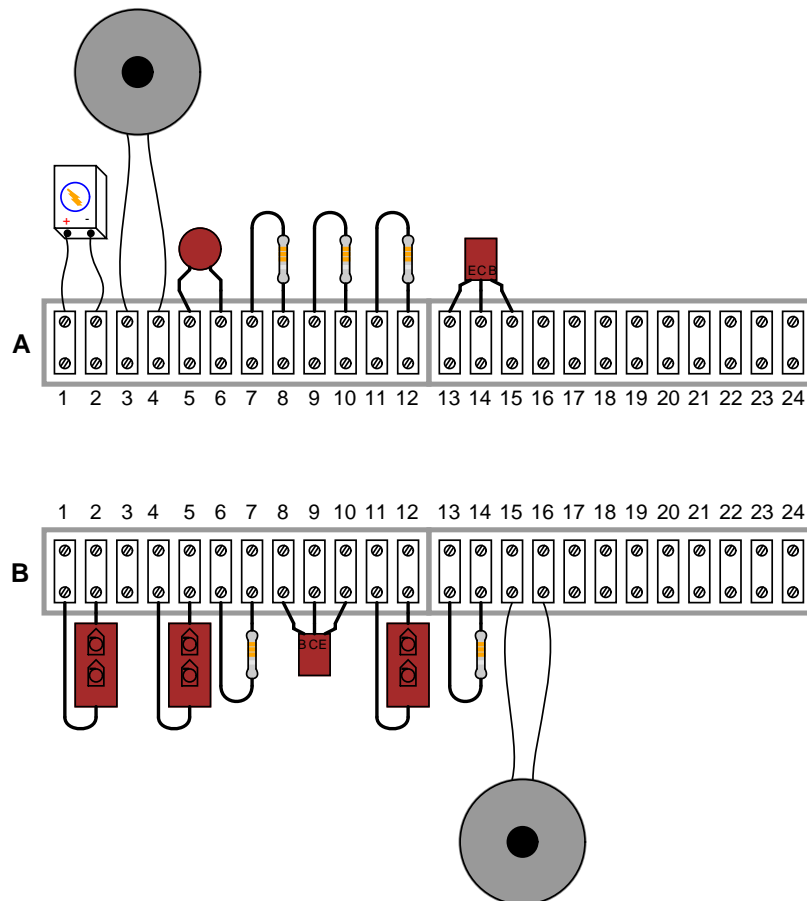
#### Components:

- Battery (9 V): A1=+ , A2=- (ground)
- Small speaker (used as microphone): A3, A4
- Capacitor C1, 0.47  $\mu$ F: A5, A6
- Resistor R1, 220 k $\Omega$ : A7, A8
- Resistor R2, 27 k $\Omega$ : A9, A10
- Resistor R3, 10 k $\Omega$ : A11, A12
- Transistor Q1, 2N3403 (NPN): A13=e, A14=c, A15=b
- Capacitor C4, 47  $\mu$ F: B1=+, B2=-
- Capacitor C3, 33  $\mu$ F: B4=+, B5=-
- Resistor R5, 1 k $\Omega$ : B6, B7
- Transistor Q2, 2N3403 (NPN): B8=b, B9=c, B10=e
- Capacitor C2, 4.7  $\mu$ F: B11=+, B12=-
- Resistor R4, 1.5 k $\Omega$ : B13, B14
- Small speaker: B15, B16





Pictorial diagram:



Wiring sequence:

- B1-A1-A7-A11-B9
- B2-A2-A4-A10-B7-B12-B14-B16
- A3-A5
- A6-A8-A9-A15
- A12-A14-B8
- A13-B13-B11
- B4-B6-B10
- B5-B15

Tasks:

When you have the circuit built, you should be able to lightly touch the cone of the microphone with your fingertip and hear "scratching" sounds coming from the output speaker. If you hear no sound from the output speaker at all, even when tapping the microphone cone with your finger, then your circuit has a problem.

Predict the correct values for the following DC (quiescent) voltages, then verify by measuring with your voltmeter. Don't forget to include the proper unit symbol (V) with your data! Calculate the percentage error of the measured values using the following formula:  $\text{Error} = \frac{\text{Measured} - \text{Predicted}}{\text{Predicted}} \times 100\%$

| Variable    | Formula   | Predicted | Measured | Error |
|-------------|---|-----------|----------|-------|
| $V_{R2}$    | $\approx V_{\text{battery}} \left( \frac{R_2}{R_1 + R_2} \right)$ |           |          |       |
| $V_{R4}$    | $\approx V_{R2} - 0.7$  |           |          |       |
| $V_{b(Q2)}$ | $V_{\text{battery}} - R_3 \left( \frac{V_{R4}}{R_4} \right)$      |           |          |       |
| $V_{R5}$    | $\approx V_{b(Q2)} - 0.7$   |           |          |       |

Remove the bypass capacitor C2 (terminals B11 and B12), and test the circuit again by lightly touching the microphone cone with your fingertip. What do you notice about the volume level of the output, compared to when the capacitor was in place? Explain why there is a change in volume when this capacitor is removed:

|             |  |
|-------------|--|
| Explanation |  |
|-------------|--|

Re-measure the DC voltages using your voltmeter. Have they changed substantially since removing the capacitor? Explain why or why not:

|             |  |
|-------------|--|
| Explanation |  |
|-------------|--|

Questions remaining:

*Here is where you write any questions or comments you have about this experiment.*

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Answer 2

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Notes 2

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### Question 3

#### Wire-by-Number project: (PROJECT NAME HERE)

Description:

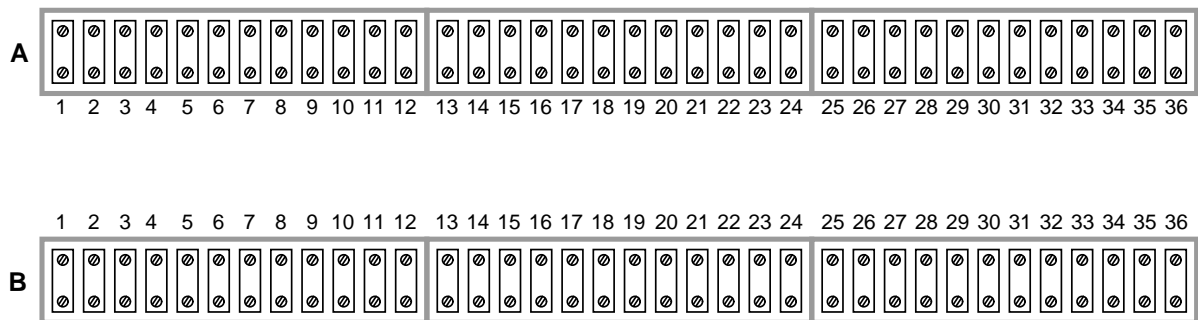
(DESCRIPTION HERE)

Schematic diagram:

Components:

- Battery (6 V): A1=+ , A2=- (ground)
- Resistor R1, ??? k $\Omega$ : A3, A4
- 
- 

Pictorial diagram:



Wiring sequence:

- A1-A6-B5
- 
- 
- 

Tasks:

(DESCRIPTIVE TEXT GOES HERE)

(DESCRIPTIVE TEXT GOES HERE)

Predict the correct values for the following variables, then verify by measuring with your test equipment. Don't forget to include the proper unit symbols (V, mA,  $\Omega$ ) with your data! Calculate the percentage error of the measured values using the following formula:  $\text{Error} = \frac{\text{Measured} - \text{Predicted}}{\text{Predicted}} \times 100\%$

| Variable | Formula   | Predicted | Measured | Error |
|----------|---|-----------|----------|-------|
| $V_{R1}$ | $V_{supply} \left( \frac{R_1}{R_1 + R_2} \right)$ |           |          |       |

(DESCRIPTIVE TEXT GOES HERE)

(DESCRIPTIVE TEXT GOES HERE)

Explain why these effects were observed:

|             |  |
|-------------|--|
| Explanation |  |
|-------------|--|

Questions remaining:

*Here is where you write any questions or comments you have about this experiment.*

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Answer 3

(PROVIDE ONE OR TWO APPROXIMATE FIGURES, OR QUALITATIVE RESULTS, THAT STUDENTS CAN USE TO VERIFY PROPER CIRCUIT OPERATION.)

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Notes 3

(NOTES FOR INSTRUCTOR)