A Simple Audio Conductivity Device

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Testing the conductivity of a substance has become a standard method of analysis in many high school and college physical science laboratory courses. The conductivity of a substance can furnish important insights into its chemical nature. Electrical properties of metals and nonmetals, ionic or covalent bonding type, electrolyte concentration, and water purity can rapidly be determined using this method of analysis. Traditional conductivity devices used 15-W light bulbs connected to 110-V wall socket power sources. Safer and more portable devices have been designed that using alkaline batteries and blinking light emitting diodes (LED) (*1–3*).[1] We have elementary students build a crude conductivity device using a 9-V battery, a battery snap connector, and small Christmas tree light. Other devices using digital multimeters (*4*) or spinning of propeller blades (*5*) have also been used to identify conducting materials. However, all these instruments either lack the sensitivity needed to measure small differences in conductivity or require expensive meters.

To solve these problems, we have built a simple audio conductivity device that is very sensitive to current flow (Fig. 1) (*6*). It uses a 9-V battery as a power supply and allows the relative resistance differences between substances to be detected by the frequency of its audible tones. The device is based on the inverse relationship between resistance and frequency of tone. Substances of high resistance produce a low-frequency tone and substances of low resistance produce a high-frequency tone. The device, which can distinguish between small concentration differences in electrolytic concentration, has proved to be a real "attention getter" in classroom demonstrations.

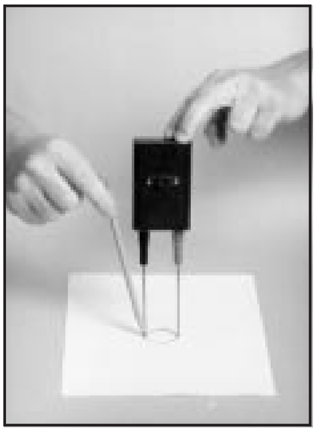

Figure 1. Photograph of conductivity device.

Apparatus Description

Figure 2 shows the audible resistance measuring circuit that can be constructed in a few hours. The circuit is built around a CMOS 74C04 hex inverter. U1a and U1b form the audio oscillator circuit while U1c and U1d are used to buffer and invert the signal, respectively. The output of U1c is fed to P1, a piezoelectric transducer. This signal is also inverted by U1d and fed 180 degrees out of phase to the other terminal of the P1. This arrangement doubles the voltage applied to P1, providing additional driving voltage for the transducer without any additional components. Perf-board or wire-wrap (*7*) construction is recommended, as is the use of a socket for U1. The apparatus can be housed in a small plastic enclosure using stiff cut-off nails or copper wire for the probes. An integrated circuit (IC) socket is highly recommended. If any component is going to fail, it will be the IC. While many piezo transducers work, there will be differences in the amplitude of the sound produced. After some experimentation with different piezo elements, the one listed in Table 1 was found to work quite well. Overall construction cost is less than \$20, which includes case and battery.

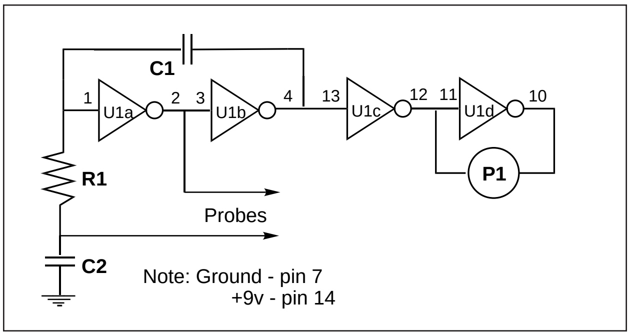

Figure 2. Circuit diagram of conductivity device.

Construction

This section describes the general construction and wire schemes for the conductivity device.[2] Figure 3 can be used as a guide for the placement of electronic components inside the conductivity device. The Radio Shack enclosure listed in Table 1 can be used if the circuit board is cut to 2 3/16 × 3/4 inches (Fig. 4). Make sure components are mounted with 1/8 inch of clear space on both ends of the board and that the components do not extend beyond the edges of the board. Then drill a 3/16-inch hole near the top of the enclosure for the piezo element. Scratch the inside of the enclosure with sandpaper, align the hole in the piezo element with the hole in the enclosure, and cement together. Drill mounting holes and secure the on/off switch with the nuts provided. Banana jacks are mounted to the removable front panel of the enclosure by drilling two holes in the panel and securing with the hardware provided with the jacks. Copper wire electrodes (#12) can be soldered to the banana plugs and inserted into the banana jacks. The wires from the circuit board should be soldered to the lug provided with each jack.

The circuit board can be constructed on perf-board as shown in Figure 4. Insert the IC socket and two capacitors into the perf-board. Build the circuit board using an IC socket with the IC removed from the socket. This will prevent static electricity from destroying the device during construction. Note that pins 5 and 9 are connected to pin 7 of the IC. It is standard procedure to connect all unused inputs of a CMOS device to ground, as it reduces current drain and increases battery life. One wire from the on/off switch should be connected to the red wire from the battery clip, and the other wire to pin 14 of the IC. Then con-

Table 1. Parts List for Conductivity Device

Part	Item	Description	Vender[a] Number
1	Case enclosure	Transmitter case	R.S. 270-293
2	Battery	9 volt	Duracell
3	On/off switch	Push on/push off	R.S. 275-1565
4	R1	3.3k ohm resistor	R.S. 271-1328
5	Piezo transducer		R.S. 273-073
6	Banana plugs	Solderless type	R.S. 274-721c
7	Electrodes	Copper wire, 12 gauge	
8	Banana jacks		R.S. 274-661
9	Perfboard		R.S. 276-1395
10	U1	LM74C04 hex inverter	M.E. 526-NTE74C04
11	14 pin IC socket	Solder or wire wrap	R.S. 276-1999
12	C1, C2	0.1 MFD capacitor	R.S. 272-135
13	Battery clip	9 volt	R.S. 270-325

[a]Venders: R.S. is Radio Shack, 400 One Tandy Center, Fort Worth, TX 76102 (Tel. 1-800/843-7425); M.E. is Mouser Electronics, 11433 Woodside Ave., Santee, CA 92701-4795 (Tel. 1-800/346-6873).

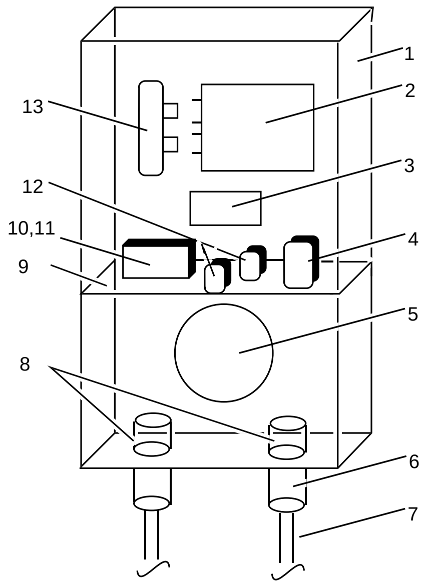

Figure 3. Diagram indicating placement of parts (see Parts List).

nect the black wire from the battery clip to pin 7 of the IC. Connect the battery clip, the on/off switch, the wires going to the probes, and finally, the wires to the piezo element to the IC unit as shown. After all connections have been made, plug the IC into its socket. Double check your wiring to be sure there are no unwanted solder bridges and that all connections are properly made. Slide and mount the perf-board and probe holder into the enclosure between the piezo element and the on/off switch as shown in Figure 3. It should stay in place securely, but you can use a drop or two of glue to hold it in place. Secure the case with the two screws provided, insert a fresh 9-V alkaline battery, replace the battery cover, and you are now ready to perform conductivity experiments.

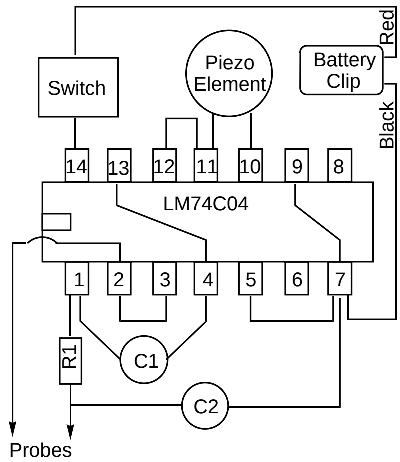

Figure 4. Wiring diagram of conductivity device.

Experiments

We have discovered a novel experiment in which the relative resistance of various widths of pencil lines drawn on paper can be determined (see Fig. 1). Have students draw two filled-in circles with a pencil on a sheet of paper such that each probe can be pressed onto the center of each circle. Each circle should be approximately 1/8 inch in diameter. Next have students draw a line connecting the two circles. At this time, a very slow (motorboating) sound may be heard. Now have students gradually increase the thickness of the line connecting the two circles. While thickening the line, an obvious increase in the frequency of the tone will be heard. Students may also want to draw several separate lines connecting the two circles following different paths. These too should have the same effect as making one line and then making it thicker. As the width of the line is increased, the resistance between the two circles decreases. This is because the effective resistance of a parallel electrical circuit decreases as more resistance is connected in parallel. Making the lines wider adds more paths for electrons to flow between the two points. Various fluids can also be tested using this device. Try, for example, distilled water, tap water, vinegar, dilute hydrochloric acid, and salt water. Different resistances indicate different concentrations of electric current–carrying ions in the liquid. A particularly interesting experiment that is well demonstrated using the audioconductivity apparatus is to test distilled water and note the pitch of the tone heard. Upon adding ordinary table salt to the water (adding sodium and chloride ion, Na^+ and Cl^-, respectively), an increase in pitch of tone is readily noticeable. A similar experiment involves the dilution of a salt water solution with distilled water. A decrease in the pitch of the tone should be noticed.

Other Ideas

Test an orange. First test the peal, then pierce the orange with the probes. Any difference in tone? How does the conductivity of an orange compare with that of a lemon, apple, and potato? Remember, for accurate results, it is essential that the probes be cleaned with distilled water between tests to avoid contamination.

Conclusion

Other classical experiments reported in the literature can be performed using this audio conductivity device. The apparatus is inexpensive and easy to build and provides one of the few audio demonstrations available (besides an explosion) for the science classroom. Because it is audible, we have found it to be a fun activity that focuses students' attention and provides a strong foundation for understanding the concepts of conductivity.

Acknowledgment

We would like to acknowledge the Research Corporation Cottrell Grant Program for financial support of this project.

Notes

1. An affordable version of a LED conductivity tester is available from Science Kit and Boreal Laboratories, 777 East Park Drive, Tonawanda, NY 14150.

2. Step-by-step directions for the construction of this conductivity meter are available by writing to the authors at Department of Chemistry, California State University, San Bernardino, CA 92407, or on JCE Online (*http://jchemed.chem.wisc.edu/*).

Literature Cited

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