

INEXPENSIVE CHEMICAL INSTRUMENTATION: A STUDENT POTENTIOMETER

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ABSTRACT. — Instructions for construction of an inexpensive student potentiometer, accurate to ± 1 millivolt, are presented. This simple, compact, and sturdy instrument is well-suited to student use for all types of potentiometric measurements in high school or university chemistry or physics laboratories. It can be constructed readily from commercially available components by a high school student having only a rudimentary background in fundamental electrical theory.

Modern instruction in chemistry, even at the elementary level, requires the application of instrumental measurement techniques in order to illustrate theoretical discussions of such topics as electrochemistry, electrodeposition, coulometry, potentiometry and potentiometric titrations, polarography, etc. Unfortunately, most commercially available instruments for elementary use are relatively expensive—often prohibitively so for high schools and small colleges, as well as too sophisticated for the relative beginner to understand. It is the purpose of this and subsequent articles to present component price lists and sources, constructional details, and performance data for instruments designed to meet three requirements: (1) low unit cost, in order that high schools and colleges might possess such instruments in relatively large numbers, if desired; (2) high-level performance characteristics, consistent with cost of readily available commercial components; and (3) relative ease and simplicity of construction, so that high school or college students of limited theoretical and practical electrical background might construct the instruments as a part of their profes-

sional training. Each of the instruments described in this and subsequent articles has been constructed by a high school junior as a part of his work in connection with participation in a National Science Foundation sponsored Summer Institute at the senior author's institution.

One of the most important instruments required for electrical measurements in chemistry or physics is the student potentiometer. Because of the fundamental nature and wide variety of its applications, this instrument was selected as the first for development within the requirements previously specified.

MATERIALS

A list of the electrical and other components required for construction of the potentiometer is given in TABLE I. The prices shown are those for single-item purchase at price levels current at the time of writing; quantity purchase of some items may result in substantial reduction of total construction costs. Although all components listed were obtained from Allied Electronics Corporation, 100 North Western Avenue, Chicago, Illinois, equivalent components are available from a variety of other commercial electrical and electronic supply houses.

Commercial equipment employed in testing the potentiometers included a Sargent Wide-Range four-volt potentiometer, Serial No. 905003, Cat. No. S-30260, a Leeds and Northrup Portable Potentiometer, Serial No. 776379, Cat. No. 7655, an Eppley unsaturated cadmium standard cell, Sargent Cat. No. S-30385, and a voltage divider assembled from a pair of 1.35-volt mercury batteries and a 100-ohm linear taper radiopotentiometer.

TABLE 1. — Potentiometer Components

Quantity Required	Description	Allied Electronics Stock Number	Price
1.....	MICROAMMETER, 50-0-50 microamperes DC, zero-center, 3½-inch, Knight Clearview.....	67 Z 306	\$ 9.86
1.....	MICROPOT, 1000-ohm, Amphenol-Borg Model 2151B, 10-turn, $\pm 0.25\%$ linearity.....	29 Z 512	6.90
1.....	MICRODIAL, Amphenol-Borg Series 1320, 10-turn, for Micropot.....	29 Z 696	5.82
1.....	CABINET, sloping-panel, 7-inch aluminum, Universal Type AC-1613.....	88 Z 649	2.10
2.....	BATTERIES, Mercury, 1.35-volt, Mallory Type RM 12R.....	55 Z 929	2.10
1.....	SWITCH, toggle, DPDT, Cutler-Hammer Type 8363K7.....	34 Z 503	1.09
1.....	CONTROL, Mallory Type U-2 Midgetrol, 500 ohms, linear taper.....	29 Z 709	1.02
1.....	CONTROL, Mallory Type U-41 Midgetrol, 100K ohms, linear taper.....	29 Z 767	1.02
1.....	SWITCH, push-button, SPST-N.O., Grayhill Type 4001.....	34 Z 870	0.90
6.....	JACKS, banana, H. H. Smith Type 1509, 3 red, 3 black.....	43 Z 941	0.72
1.....	SWITCH, toggle, SPST, Cutler-Hammer Type 8280K16.....	43 Z 942	0.52
1.....	HOLDER, battery, Keystone Type 140.....	34 Z 500	0.38
2.....	KNOBS, Harry Davies Type 1600.....	55 Z 902	0.28
	MISCELLANEOUS (hook-up wire, screws, etc.), est.....	44 Z 127	0.20
	Total.....		\$32.91

Construction tools required include screwdriver, needle-nose and side-cutter pliers, 4-inch crescent wrench, 100-watt soldering iron and rosin-core solder, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{3}{8}$ -inch drills and either a hole cutter or a nibbling tool.

CONSTRUCTION DETAILS

The potentiometer employs the null-balance principle, in which the potential to be measured is balanced by another equal and opposite potential; as a result, no current is drawn from the circuit whose potential is being measured. This "compensation" technique is the basis for numerous electrical and electronic measuring circuits, as well as for many automatic recording devices. The schematic wiring diagram of the circuit used in the potentiometer constructed by the authors is shown in FIGURE 1; front and rear views of completed instruments are shown in FIGURE 2. The circuit used is similar to conventional compensation circuits (Willard, Merritt, and Dean, 1965, pp. 4-6). Mercury batteries power the circuit, thus making a Battery

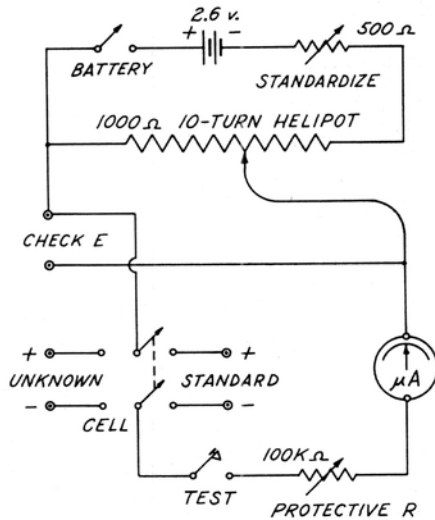


FIGURE 1. — Schematic wiring diagram for student potentiometer.

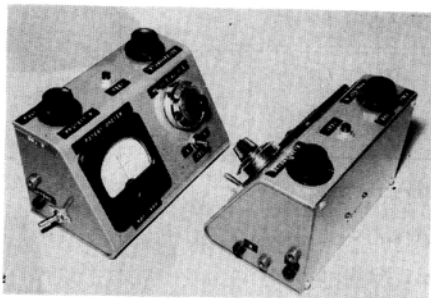


FIGURE 2. — Completed student potentiometers.

switch desirable; external connections for checking the condition of the batteries with a voltmeter have been added. A zero-center microammeter, along with a suitable protective resistor, serves in lieu of a galvanometer (Tabbutt, 1962).

For instructional purposes, the two halves of the cabinet should be wired so that, after removal of the four self-tapping retaining screws furnished with the aluminum cabinet, the halves of the cabinet may be separated from each other by several inches. The use of various colors of hook-up wire, appropriately laced into a connecting bundle between the two halves of the case, permits convenient tracing and study of the circuits.

Operational procedure is conventional for balance-type potentiometric circuits (Willard, Merritt, and Dean, 1965, p. 5). The relative values of the standardizing resistor and the helipot permit standardization of the potentiometer at a dial setting of 509, i.e., one-half the output, in millivolts, of the standard cell (1.018 volts); thus, the instrument is essentially direct-reading, requiring only multiplication by two of the dial setting representing an unknown voltage. Other appropriate dial settings for standardization may be used if it is desired to vary the operational voltage range of the instrument.

A number of details have been incorporated into the potentiometer for convenience in operation and storage which may be omitted without impairing the performance of the instrument, resulting in still smaller construction costs. In this category are the banana jack terminals, the double-pole double-throw Cell switch, the Battery switch, and the aluminum cabinet itself. The specific location of the various components in the case is

a matter for the individual builder to determine, depending on the specific application desired; for the authors' purposes, the orientation of components shown in FIGURE 2 has been found to be quite efficient, while leaving the internal spacing such that ample room is available inside the cabinet for wiring.

PERFORMANCE AND APPLICATIONS

Performance data for three of the potentiometers described, compared with those for two commercial potentiometers, are given in TABLE 2. These data were obtained by picking off various voltages from a potential divider, assembled from a pair of mercury batteries and a 100-ohm radiopotentiometer, and measuring the divider output with each of the five potentiometers in random turn, each instrument having been appropriately standardized initially against either a self-contained Weston-type standard cell or the Epply Student Cell (an easily constructed inexpensive standard cell suitable for the latter purpose has been described by Tabbutt, 1962). It is noteworthy that no significant difference appears in the results obtained with the five potentiometers; the two commercial instruments are priced in the \$150-300 range (including internal standard cells, in each instance, but exclusive of working batteries).

Potentiometer No. 7 (TABLE 2) cost approximately \$10 more to build than Nos. 1 and 4; the performance of the less expensive models is equally good. Potentiometer No. 1 was constructed in July, 1965 and has been extensively used throughout the ensuing year by several high school students, as well as by about thirty college students. Potentiometer No. 4 was constructed in July, 1966 and had been completed for less than a week at the time the performance data were taken. These facts and the comparison data shown indicate the rugged, yet accurate and reproducible characteristics of the instrument.

Several of the potentiometers described have been used extensively for all types of potentiometric measurements and have been found to be accurate, convenient, and reproducible in every instance. They are particularly well-suited for use in potentiometric titrations employing metallic indicator electrodes prepared by the method described by Waser (1964, p. 408) and either saturated calomel or silver-silver chloride reference electrodes. Other ap-

TABLE 2. — Potentiometer Performance
Compared with That of Two Commercial Instruments.

Sargent Wide Range	Leeds and Northrup Portable	No. 1 1965	No. 4 1966	No. 7 ¹ 1966
0.051 v.	0.053 v.	0.052 v.	0.051 v.	0.052 v.
0.285	0.287	0.285	0.286	0.287
0.553	0.555	0.553	0.555	0.554
0.763	0.762	0.762	0.762	0.763
0.940	0.941	0.940	0.941	0.940
1.048	1.049	1.047	1.049	1.048
1.602		1.602	1.604	1.604
1.906		1.904	1.906	1.906

¹ This instrument was constructed from better quality components, including 25-0-25 microammeter, $\pm 0.1\%$ linearity helipot, and snap-action push-button switch.

plications include their use as potential sources and/or current measuring devices for polarography, voltage standardization for constant potential sources, and direct current voltage measurements of all types up to 2.5 volts.

ACKNOWLEDGEMENTS

The senior author is grateful to the Illinois State Academy of Science for a grant which financed the initial purchase of components employed in construction of the prototype of the instrument described in this paper. The authors acknowledge the support of the National Science Foundation, whose grants GE-7706 (1965) and GW-595 (1966) made possible the participation of the junior authors. At the time initial construction of the instruments was

completed, Mr. Linnenbom and Mr. Coleman were juniors at Gonzaga College High School, Washington, D.C. and Denfeld High School, Duluth, Minnesota, respectively.

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Manuscript received July 28, 1966.