JOURNAL OF CHEMICAL EDUCATION
Article
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Designing, Constructing, and Using an Inexpensive Electronic Buret

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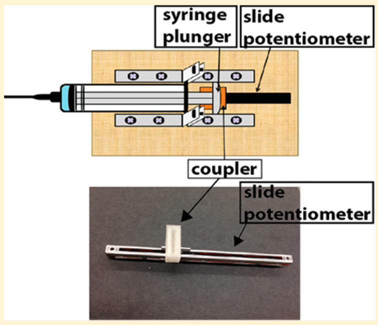
Supporting Information

ABSTRACT: A syringe-based, electronic fluid dispenser is described. The device mechanically connects a syringe plunger to a linear slide potentiometer. As the syringe plunger moves, the electrical resistance between terminals of the potentiometer varies. Application and subsequent measurement of a DC voltage between the potentiometer pins is used to track the syringe plunger position and meter the volume dispensed. The syringe's plunger is actuated manually by the device's user. The dispensing device offers volumetric accuracy of better than 1% when the dispensed volumes were >10 mL. The device has been used for a traditional acid–base titration experiment and produced quantitative results indistinguishable from the conventional approach using a buret. The device is inexpensive, easy for students to understand, and simple to construct.



KEYWORDS: *High School/Introductory Chemistry, Upper-Division Undergraduate, Analytical Chemistry, Titration/Volumetric Analysis, Laboratory Equipment/Apparatus, Computer-Based Learning, Laboratory Instruction, First-Year Undergraduate/General*

INTRODUCTION

In recent years, there has been an explosion of interest in developing creative and inexpensive solutions for teaching chemistry at the secondary and undergraduate level. Many accounts in this journal have outlined a variety of ingenious approaches for teaching molecular spectroscopy,[1−9] separation science,[10,11] and electrochemistry.[12−14] However, one area that seems to have received far less attention is the development of an inexpensive device for dispensing volumes of fluid. Such an electronic buret would be valuable for titration experiments in the lab. Commercially available electronic burets have existed for many years, but these devices have not gained widespread popularity in the teaching laboratory owing to their high cost.[15] Our literature search has uncovered a few attempts at automated volume dispensing (e.g., titrations), but these methods often rely on the use of traditional burets.[16,17]

It is the purpose of this work to build a low-cost electronic dispenser based on a linear slide potentiometer coupled to a disposable syringe. The potentiometer is used as a voltage divider, and the voltage at the center terminal is monitored with a voltmeter or an inexpensive digitizer such as an Arduino. The Arduino microcotroller board has been attracting more and more interest as a potential technical aid in chemical education.[18,19] It is an inexpensive electronic platform (approximately $25 USD) that can receive information from various sensors. One example of its use is the photometer recently demonstrated by McClain.[20] In this report, we present data on the accuracy and precision of measurements achieved by dispensing different volumes of water using the syringe dispenser. The new electronic buret is also compared with a traditional glass buret for acid–base titration experiments. The device has great potential for lab use and for introductory electronics experiments.

METHODS

Electronic Buret Design

Figure 1 illustrates the device achieved by combining a syringe and a 10kΩ linear slide potentiometer (Mouser P/N 688-RSA0N11S9A0K). The two components are stabilized by affixing them to a wood board. The syringe is held in place by four L-shaped stainless steel brackets securing the finger flange of the syringe. The end of the syringe plunger is embedded into a groove cut within a piece of wood (coupler) using a Dremel tool and disk-shaped cutting tool. The bottom of the coupler is glued to the slide of the potentiometer. When the syringe plunger is pulled or pushed by the user, the position of the slide of the potentiometer will be changed. The volume of the liquid or gas contained within the syringe is directly proportional to the resistance between two terminals of the potentiometer. By applying a constant DC voltage (here 5 V from an Arduino or external power supply) across the potentiometer, the voltage at the center pin will scale with syringe position. This voltage can easily be measured by the Arduino's analogue input channel or a voltmeter. We found the Arduino and voltmeter methods produce identical results. The voltmeter has the advantage of being lower cost. The voltage change (initial vs final) can be measured as an indicator of the volume dispensed. The circuit connections are also shown in Figure 1. The first terminal of the potentiometer is connected to the ground of the Arduino board or black voltmeter lead. The second terminal is connected to AI0 of the Arduino or red voltmeter lead, and the third is connected to 5VDC provided by the Arduino board or alternative power supply.

dx.doi.org/10.1021/ed500509p | J. Chem. Educ. XXXX, XXX, XXX−XXX

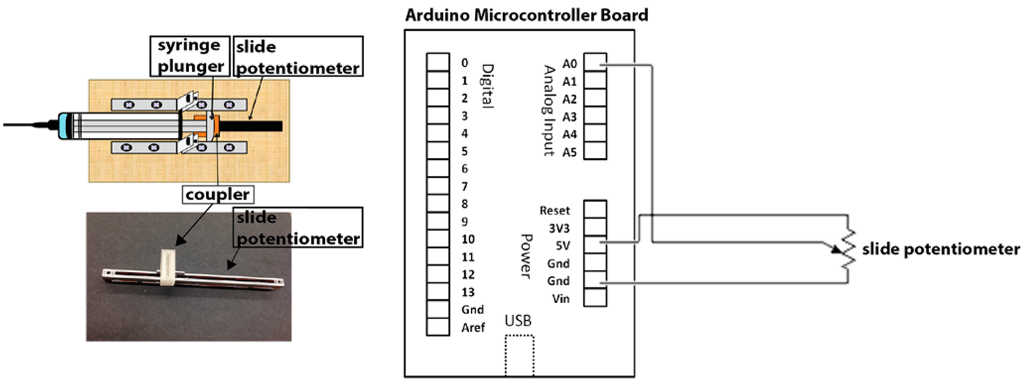


Figure 1. Device schematic and circuit diagram. The syringe plunger is affixed to a coupler within which a groove was cut to accept the plunger. The coupler was glued to the slide of a 10 kΩ linear potentiometer. The syringe was mounted to a large wooden block to fix its position. As the syringe plunger moves, the slide moves along with it changing the position of the potentiometer. If a voltmeter is used, the red lead will contact the A0 line and the black lead contacts the Gnd terminal.

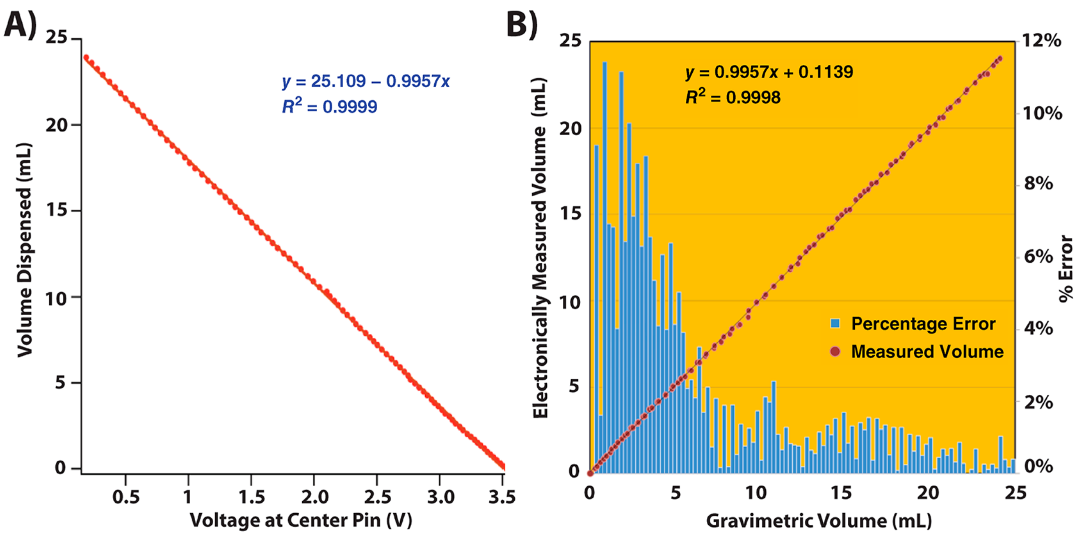


Figure 2. Calibration plot and accuracy of volume measurement for the syringe dispenser. (A) Plot of gravimetrically determined volume dispensed vs voltage observed at potentiometer center pin. (B) Plot of the electronically indicated volume (after calibration) vs gravimetric volume. The second *y*-axis in (B) reports the absolute value of % error between electronic and gravimetric volume measurements.

■ RESULTS AND DISCUSSION

Filling the Syringe

In our experiments, a 30 mL disposable plastic syringe was used. Experimentation revealed that when the fluid level within the syringe was greater than approximately 25 mL the voltage/volume measurement returned by the electronic buret was often inaccurate. This could be a result of the plunger not sealing properly or not being perfectly parallel with the syringe body. To combat this effect, we developed a syringe-filling procedure that must be followed to obtain accurate results. After washing the syringe with solvent, the syringe should be filled with the solution to be dispensed to the point where the plunger is very near the end of the barrel. Next, the syringe should be checked for air bubbles, and they should be removed if necessary. Then, 5−10 mL of fluid should be dispensed to a waste container. This step will allow the syringe plunger to move to the region in which more accurate measurements are obtained. Quantitative dispensing of fluid can then begin. In spirit, the process is very similar to steps students use for filling a glass buret and assuring the tip is full prior to use in a titration.

Calibration

The approach measures the voltage at the potentiometer center terminal that must be converted to a volume. To achieve this, we carried out a procedure in which the voltage was measured along with the mass of water dispensed from the syringe. The mass was measured with an analytical balance and converted to volume using water's density at the specified temperature. For each measurement, approximately 0.2 g of water was dispensed out of the syringe into a glass container with a cap on (to minimize effect of water evaporation during experiment). The mass of water could be measured with an analytical balance to 0.0001 g. Volume was calculated by dividing the observed mass by the density of water. In this experiment, the water temperature was 23 °C so a density of 0.99754 g/mL was used for volume calibration. For each data point, the total water mass and the observed voltage were recorded. Figure 2A reports the calibration curve we obtained from the procedure. The best-fit line has an R^2 of 0.9999, indicating excellent linearity between the variables. The calibration data can then be used for additional experiments with the syringe dispenser.

dx.doi.org/10.1021/ed500509p | J. Chem. Educ. XXXX, XXX, XXX−XXX

Accuracy

After calibration, the accuracy of the syringe dispenser was tested in separate experiments by comparing the electronically indicated dispensed volume with the gravimetrically determined volume. Figure 2B reports a plot of the electronically measured vs gravimetric volume dispensed and the apparent % error observed for each trial on the second *y*-axis. As observed, the two volumes scale linearly as expected. The slope of the resultant best-fit line was 0.9957 ± 0.002, indicating a very slight bias in which the electronically indicated volume is underestimated on average. It is also worth examining the relative accuracy of the device as a function of volume dispensed (blue data in Figure 2B). As observed, the relative error was greater when small fluid volumes were dispensed. Percent errors were examined among data binned by the total volume dispensed. Average values for each bin are reported in Table 1.

Table 1. Accuracy Comparison for the Electronic Buret and Glass Burets

range of volumes dispensed (mL)	electronic buret, avg % error obsd	glass buret, typical % error expected[a]
0−5	5.72	>2
5−10	1.32	1−2
10−15	0.96	0.67−1
15−20	0.82	0.5−0.67
20−25	0.36	0.4−0.5

[a]Glass buret values were not measured but rather are assumed based on a tolerance of 0.1 mL. This is similar performance to class B burets.

For 0−5 mL water dispensed, the average percent error was 5.72%. For 5−10 mL dispensed, the average percent error dropped to 1.32%. For 10−15 mL, 15−20 mL, and 20−25 mL water dispensed, the average percent errors were 0.96%, 0.82%, and 0.36%, respectively. Typical tolerance for glass burets (50 mL) is on the order of 0.05−0.1 mL depending on buret class. For dispensed volumes >10 mL, the electronic syringe appears to offer similar performance to class B burets.

■ TITRATIONS WITH THE ELECTRONIC BURET

An obvious laboratory use of the syringe dispenser developed is for titrations. This has encouraged our project team to conduct a strong acid−base titration of NaOH−HCl with the setup. In this experiment, 25 mL of approximately 0.1 M NaOH solution was prepared and placed into the syringe following the recommended procedure. Then, 15 mL of 0.1 M HCl was added into a 150 mL flask along with 2−3 drops of phenolphthalein. By slowly pushing the plunger of the syringe, NaOH solution was added to the titration flask drop by drop. When the color of the solution turned faint pink and did not disappear, the titration was stopped and the dispensed volume was noted. Three replicate trials were conducted to examine reproducibility. For comparison, a parallel titration experiment was performed with a glass buret. The results of the titration analysis are reported in Table 2.

The volume of NaOH (aq) solution consumed for the acid−base titration was indicated to be 16.49 ± 0.12 mL (mean ±95% conf int) as measured by the syringe dispenser. For the glass buret, 16.50 ± 0.12 mL (mean ±95% conf int) of base solution was used to get to the end point. The absolute difference between the two methods was only 0.01 mL, which is considerably less than the confidence interval. As such, the experimental results are indistinguishable. The molarity of NaOH (aq) calculated based on the molarity of HCl (aq) and volume of NaOH used were also very similar. Molarity was 0.0909 (95% conf int = 0.007) and 0.0907 mol/L (95% conf int = 0.007) from the electronic buret and glass buret, respectively. The absolute difference was only 0.0002 mol/L.

Table 2. Comparison of Electronic and Glass Buret for Titration Conducted by Graduate Students

description	electronic buret (mean + 95% CI)	glass buret (mean + 95% CI)
vol of titrant required to reach end point (mL)	16.49 ± 0.12 mL	16.50 ± 0.12 mL
indicated molarity of titrant	0.0909 ± 0.007 M	0.0907 ± 0.007 M

The success of our project team's trial with the device has led us to employ the electronic buret in an authentic analytical laboratory course at our institution. Students from two sections of the lab class were given the option of using the electronic buret for one trial during an experiment in which an aqueous sodium hydroxide solution was standardized with primary standard potassium biphthalate (KHP). For additional trials, the students used a glass buret to standardize the same sodium hydroxide solution. After completing the experiment, the students were then asked to compute the molarity of the sodium hydroxide solution and complete a short survey about the experience (see the Supporting Information for the survey). The project team then compiled the quantitative titration results and survey data.

Fourteen student groups used the electronic buret over the period of 2 days. The sodium hydroxide concentration determined via the glass and electronic buret was computed, and the mean percent difference between glass and electronic buret ((electronic − glass)/glass) was found to be 1.90% for the student trials. The standard deviation of percent difference results was 3.43 for this data set. A summary of undergraduate student results are presented in Table 3.

We note that 1.90% difference lies well within 1 standard deviation of the mean, indicating the electronic buret offers similar results to the glass buret. The results indicate the electronic buret can be applied for acid−base titration in analytical chemistry courses without substantial losses in performance relative to the glass buret case.

Table 3. Percentage Difference in Molarity of Titrant for Undergraduate Student Groups

student group, N = 14	difference in concentration (%)
1	−4.49
2	−2.43
3	−1.00
4	0.57
5	0.78
6	0.85
7	1.54
8	1.72
9	2.64
10	3.19
11	3.34
12	4.18
13	7.21
14	8.50
mean ± std dev	1.90 ± 3.43

dx.doi.org/10.1021/ed500509p | J. Chem. Educ. XXXX, XXX, XXX−XXX

For the opinion survey, students were asked to rate their experience with the electronic buret on a 5-point scale (5 being most positive). Several questions were posed to consider their "general impression of the device," ease of use, electronic syringe design, comparison with a glass buret, and the devices utility in analytical lab. Table 4 lists the mean student responses for each query.

Table 4. Student Opinions of Electronic Buret

query	mean score on 1−5 scale (N = 29 responses)
What is your general impression of the electronic syringe?	4.10
How easy is the electronic syringe to use?	4.34
Do you think it is a good design for an electronic syringe?	4.00
How do you rate the electronic syringe when compared to a glass buret?	3.89
Do you think it is a useful device in analytical lab?	4.41

The students' "overall impression" of the electronic buret scored a 4.1 on the five-point scale. The highest student rating was 4.41 for the devices usefulness in the analytical lab. Apparently, the students felt the device was simple to use as "ease of use" also scored well at 4.34. The lowest score of 3.89 was for comparing the electronic syringe to a glass buret. The student "free-response" comments were generally positive (student comments are also published in the Supporting Information). Many students commented that reading a voltage from the voltmeter was preferred compared to estimating a buret reading. The students felt this may lead to more accurate results provided the calibration was correct. Several students commented that the device was easy to use and had better control of drop-by-drop addition of the titrant. Other students were less positive and felt the design layout of the device made it awkward for them to use. We believe these students may prefer to swirl the titration flask with their right-hand and dispense titrant with their left. Additional concerns included the limited volume of titrant available for use (about 25 mL) and the difficulty of removing of air bubbles from the syringe. Several students suggested we automate the device and incorporate end-point detection.

SUMMARY

An electronic buret has been developed that offers similar performance to class B burets. The device is easy to construct within a few hours and quite inexpensive (<\$20 if using voltmeter or <\$50 including the Arduino board). Building the device in class could provide students with a valuable introduction to electronics or alternatively spice up routine titration experiments.

ASSOCIATED CONTENT

Supporting Information

The student survey instrument and responses to the survey are available in Supporting Information. This material is available via the Internet at http://pubs.acs.org.

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Author Contributions

Graduate students T.C. and Q.Z. performed experiments, reported data, generated figures, and contributed to editing the manuscript. J.T. conceived the design for the device and contributed to authoring the manuscript.

Notes

The authors declare no competing financial interest.

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