# A Low-Cost and High-Performance Conductivity Meter[1]

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Several apparatuses for conductivity experiments have been described in this *Journal*. Qualitative or semi-quantitative conductivity demonstrations are suitable for beginning-level chemistry courses (*1–5*). On the other hand, an accurate conductivity meter is needed in physical chemistry and instrumental analysis experiments. Low-cost solutions for assembling and putting into use a large number of instruments in a classroom have been proposed by other authors (*6–9*). The equipment described bellow is stable and accurate enough for quantitative experiments, still keeping the low cost and simplicity of construction and use.

## Principles and Implementation

Figure 1 shows the block diagram of the conductivity meter. The oscillator generates a triangular wave, instead of the classical sinusoidal wave, that is applied to one of the electrodes. The other electrode is coupled to the input of a current-to-voltage converter, remaining at ground potential. After rectification and filtering, the output dc voltage becomes proportional to the conductance. This voltage is read out with a low-cost 3 1/2-digit multimeter.

Figure 2 shows the circuit, which is based on an integrated circuit TL084. The operational amplifiers A1 and A2 comprise the oscillator. The advantages of this implementation are its simplicity, stability, and ease of controlling frequency and amplitude. The frequency is given by

$$f = \frac{1}{4R_3C_1}\left(\frac{R_2}{R_1 + P_1}\right) \quad (1)$$

and the amplitude of the triangular wave is given by

$$V_T = V_Q\frac{R_1 + P_1}{R_2} \quad (2)$$

where $V_Q$ is close to the power supply voltage—12 V, in this case. The components were selected to give amplitude and frequency of ca. 80 mV and 2 kHz, respectively. The switch S1 allows one to select the sensitivity between two ranges with a 1:100 ratio. The operational amplifier A4 and peripheral components rectify, while R8, R9, and C2 filter, the triangular wave. The resulting signal is a dc voltage that is proportional to the conductance. A low-cost and high-impedance digital multimeter is used to measure this voltage. The complete list of components is showed in Table 1.

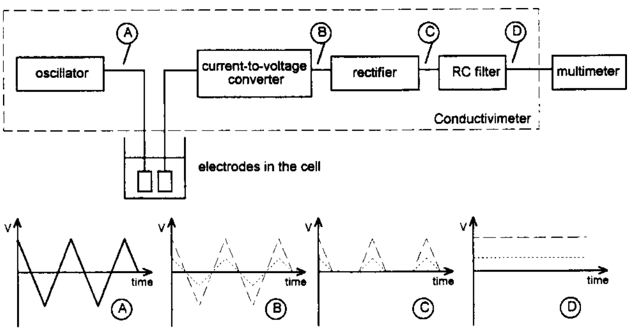


Figure 1. Block diagram of the conductivity meter. The graphics show two situations: low-conductance solution (dotted line) and high-conductance solution (dashed line) measurements.

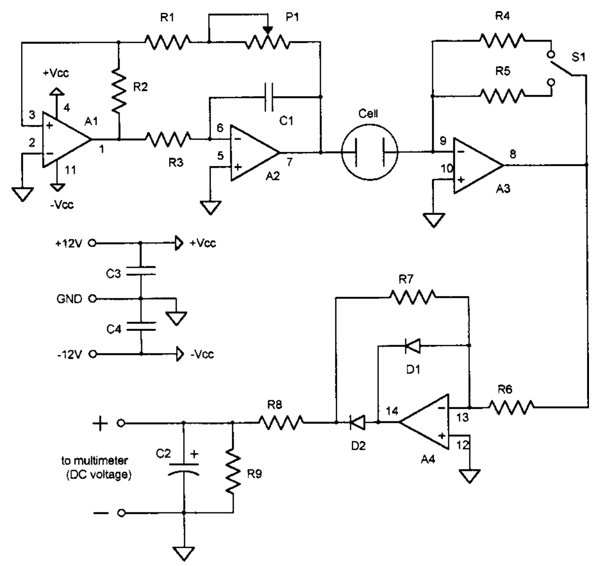


Figure 2. Diagram of the conductivity meter. See Table 1.

**Table 1. Components for the Conductivity Meter[a]**

| Part | Item | Value | Remarks |
|---|---|---|---|
| R1 | resistor | 1.00 kΩ | metal film 1% |
| R2 | resistor | 220 kΩ | metal film 1% |
| R3 | resistor | 200 kΩ | metal film 1% |
| R4 | resistor | 4.99 kΩ | metal film 1% |
| R5 | resistor | 499 kΩ | metal film 1% |
| R6 | resistor | 10.0 kΩ | metal film 1% |
| R7 | resistor | 10.0 kΩ | metal film 1% |
| R8 | resistor | 2.00 kΩ | metal film 1% |
| R9 | resistor | 8.06 kΩ | metal film 1% |
| C1, C3, C4 | capacitor | 100 nF | ceramic |
| C2 | capacitor | 47 µF | electrolytic 25 V |
| P1 | trimpot | 1 kΩ | 15 turns |
| S1 | switch | — | 1 pole × 2 positions |
| D1, D2 | diode | 1N914 | — |
| A1–A4 | operational amplifier | TL084 | 4 op. amp. on a chip |

[a]See Figure 2.

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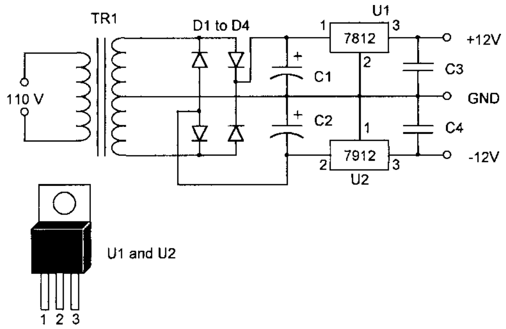


Figure 3. Optional ± 12-V power supply. See Table 2.

**Table 2. Components for the Power Supply[a]**

| Part | Item | Value | Remarks |
|---|---|---|---|
| TR1 | transformer | 110 V to 12+12 V | — |
| D1–D4 | diode | 1N4007 | or other for 1A and 50 V at least |
| C1, C2 | capacitor | 1000 µF | electrolytic 25 V |
| C3, C4 | capacitor | 100 nF | ceramic |
| U1 | voltage regulator | 7812 | — |
| U2 | voltage regulator | 7912 | — |

[a]See Figure 3.

After calibration (through P1), the output signals are of 10 mS/V and 100 µS/V for the two available ranges (through S1). In combination with the 200-mV and 2-V scales of the multimeter, it is possible to select one of the following full scales (F.S.): 19.99 µS, 199.9 µS, 1.999 mS, and 19.99 mS.

If no experiments in high-resistance medium will be carried out, then the resistor R5 and the switch S1 may be suppressed. The same applies to P1 if the calibration is not essential, which is the case for conductometric titrations. This procedure reduces the cost even more.

The circuit is powered by a regulated symmetrical ±12-V supply. It is possible to use two 12-V batteries or the circuit shown in Figure 3. The power consumption of the conductivity meter is so low that, in principle, even 50 of them could be supplied with this circuit. Table 2 shows the list of components for this circuit.

### *The Conductometric Cell*

Since platinum electrodes are very expensive, we preferred to build the cell with a low-cost material: stainless steel. Another option is graphite (*6–9*), but it is fragile. Figure 4 shows a cell made with two 10×20-mm stainless steel plates attached to a Plexiglas body. The copper wire tips are stripped and soldered to the plates with silver solder. The rear faces of the electrodes are protected with epoxy resin.

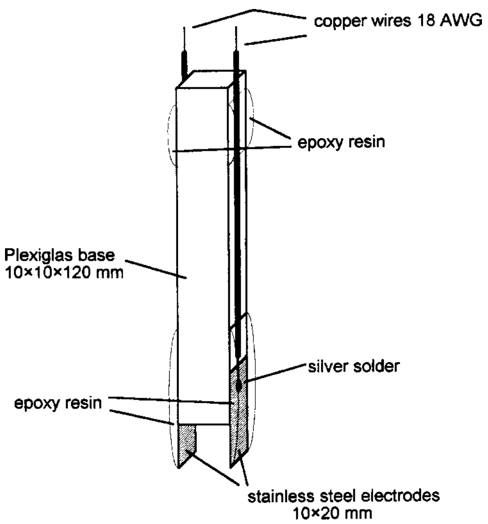


Figure 4. Conductance cell with stainless steel electrodes.

## Results and Discussion

Table 3 summarizes the performance of the 25 assembled apparatuses. The results are impressive even when compared with commercial instruments. Owing to the large number of circuits to be made, we developed a layout for the printed circuit board. A positive or negative image of the circuit may be obtained from the authors upon request. The approximate cost of the components for the instrument in our country is U.S. $20, including plastic case, plugs, and cables. The multimeter is also used in combination with two other instruments: a potentiometer and an apparatus for photometric titration. Thus, its cost (U.S. $30) can be shared.

The parts of the power supply (Fig. 3), assembled in a case with connectors for three conductivity meters, had a cost of about U.S. $20. The cell may be made from scraps and its cost is very low.

Figure 5 shows the results of four sets of measurements with the following apparatuses: the proposed conductivity meter with stainless steel cell (S), the proposed conductivity meter with commercial platinum cell (P), a Metron conductivity meter model E 382 (Switzerland) with commercial platinum cell (M), and a Hanna conductivity meter model HI 8820N (Canada) with a 4-ring probe (H). Six solutions of KCl (0.001, 0.005, 0.01, 0.02, 0.05, and 0.1 M) were

**Table 3. Performance of Apparatus in the Less Sensible Scale of S1[a]**

| Parameter | Min. Value | Typical Value | Max. Value | Unit |
|---|---|---|---|---|
| Work frequency | 1.5 | 2.0 | 2.7 | kHz |
| Peak-to-peak voltage between electrodes | 60 | 80 | 100 | mV |
| Precision[b,c] | | | | |
| F.S. 200 mV | | ± (0.5% + 1 digit) | | — |
| F.S. 2 V | | ± (0.8% + 1 digit) | | — |
| Residual conductance[d] | | | | |
| F.S. 200 mV | −20 | −5 | +41 | µS |
| F.S. 2 V | −0.02 | 0 | +0.04 | mS |
| Linearity[e] | | | | |
| Correlation coefficient | | .999999 | | — |
| Rel. SD | | 0.02 | | % |

[a]See Figure 2.
[b]When used with MIC-2200A multimeter at 25 °C.
[c]Only in titration, because the calibration deviation was not included.
[d]Measurement with cell out of liquid. (This value can be subtracted.)
[e]For a set of 29 points obtained from measurements over precision resistors (no cell was used).

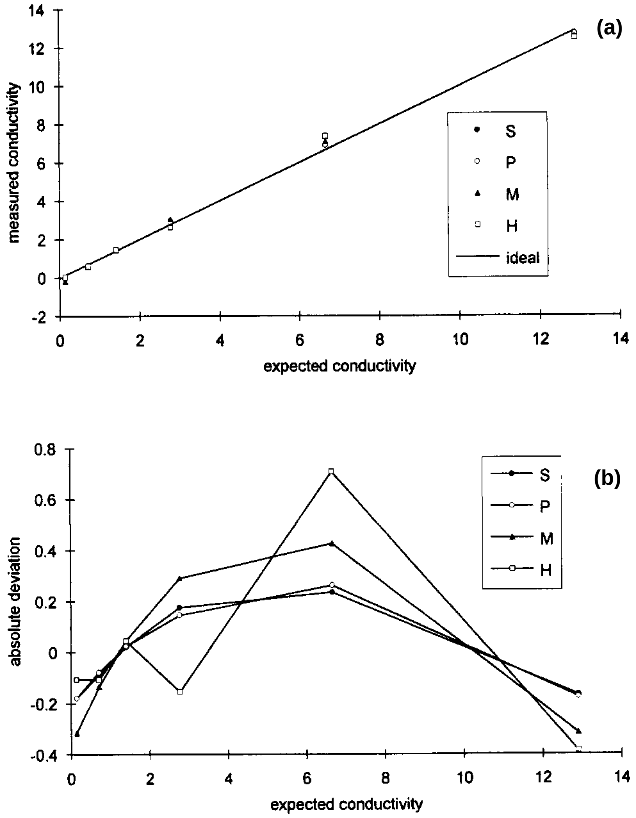


Figure 5. Results for the proposed conductivity meter with stainless steel cell (S), proposed conductivity meter with commercial platinum cell (P), Metron conductivity meter model E 382 (Switzerland) with commercial platinum cell (M), and Hanna conductivity meter model HI 8820N (Canada) with a 4-ring probe (H). (a) Measured values; (b) residuals. All measurements are given in mS cm$^{-1}$.

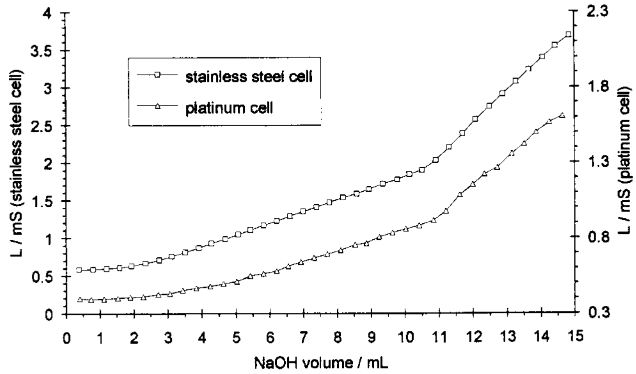


Figure 6. Conductometric titration of 10-mL aliquot of acetic acid ca. 0.1 M plus 80 mL of water vs. NaOH ca. 0.1 M. Results with the stainless steel cell and commercial platinum cell are shown.

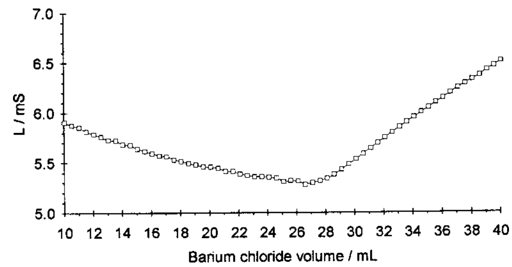


Figure 7. Conductometric titration of 25-mL aliquot of $Na_2SO_4$ ca. 0.05 M plus 50 mL of water vs. $BaCl_2$ ca. 0.05 M.

used. The conductivities of these solutions were obtained from reference *10* and used to calibrate the conductivity meters. Figure 5a shows the measured values versus expected conductivities, given in mS cm$^{-1}$. The linear correlation coefficients are .999, .999, .998, and .997 for the S, P, M, and H apparatuses, respectively. The residuals are shown in Figure 5b. The conductivity meter M is an old piece of equipment used in the undergraduate laboratory, in which the new conductivity meters were substituted. The Hanna is a modern digital device but its performance is comparable to that of the proposed conductivity meter.

We have attained good results in the experiments carried out in our laboratory as showed in Figures 6 and 7. The low voltage applied to the cell is advantageous because bright electrodes may be used (their platinization is unnecessary). However, the stainless steel electrodes are not suitable for very oxidant and strong acid media. To avoid hydrolysis of the epoxy resin, the electrode must be kept dry when not in use. In spite of these limitations, the cell is robust enough to endure handling even by careless students.

## Note

1. Presented in part at the XVII Annual Meeting of the Brazilian Chemical Society, 1994, Caxambu-MG.

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