

Experiment #6: Electrolysis—The Charge of the Electron

Purpose: To determine by electrolysis the value of the charge of the electron.

Equipment:

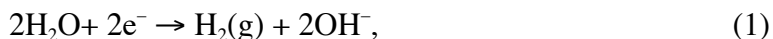
Electrolysis Apparatus
Variable Power Supply (PASCO Interface)
Digital Multimeter
Sodium Hydroxide (NaOH) 400 mL/gal Solution in Water
Stop-watch

Discussion:

This experiment combines what you learned in Physics I about gases with the idea of the quantization of charge—that is, the fact that free charge exists only in multiples of a fundamental unit, which is the charge of an electron or a proton. In this lab, you will measure the magnitude of this basic unit, and compare your result to the accepted value of 1.602×10^{-19} C.

You may have performed an electrolysis procedure previously, in chemistry for example. In that case, you may recall that an electrolytic solution is one in which positive and negative solute ions are moving about freely in a solvent. If a potential difference is applied between two electrodes dipped into the solution, the negative ions in the solution will move toward the positive electrode while the positive ions migrate toward the negative electrode. This is also the principle behind electroplating.

The electrolysis cell you will use is a plastic rectangular tray with two vertical electrodes sealed into its bottom face. Two inverted, graduated test tubes are used to collect the gases that form during electrolysis. In this experiment, you will perform electrolysis of water. Pure water is not a good conductor, so an electrolyte—in our case, sodium hydroxide (NaOH)—is added to make the solution conducting. If a current is passed through a solution of NaOH, gas bubbles form at each electrode. Oxygen gas is formed at the positive electrode and hydrogen gas at the negative electrode. The reactions are as follows. At the cathode (negative electrode), reduction occurs to produce anions (negatively charged ions),



while the oxidation reaction at the anode (positive electrode) produces cations (positively charged ions),



The anions move toward the anode and the cations to the cathode, as their names suggest. Doubling (1) and adding it to (2) to balance electron number and letting OH^- recombine with H^+ to produce H_2O , the net reaction is



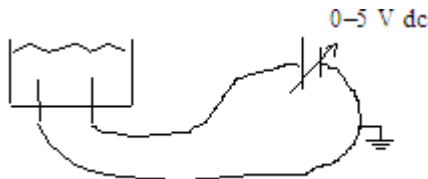
It is thus easy to distinguish the cathode from the anode because twice as much hydrogen as oxygen gas is produced. Also notice from Eq. (1) that for each hydrogen molecule formed at the cathode, two electrons have been taken from the electrode. So if one measures how many hydrogen molecules have been produced, the number of electrons, which have contributed to the current, can be determined.

In the experiment, you will pass a known current I for a measured period of time t through

the cell; the product of these two values gives the total charge that flowed through the circuit. During that time, you will collect a measured volume V of hydrogen gas. This is the volume of hydrogen at the current conditions of absolute temperature T and pressure P . The temperature is that of the apparatus and hence of the room. The pressure is that of the hydrogen gas in the tube. To determine this, first note that if the water level inside the tube is equal to that in the surrounding tray outside the tube, then the total gas pressure inside the tube equals atmospheric pressure P_{atm} just like in a barometer. However, the gas in the tube is not pure hydrogen, but includes some water vapor that evaporated from the solution. The partial pressure of hydrogen thus equals P_{atm} minus the vapor pressure P_v of water, whose value you can look up in the CRC Handbook of Physics and Chemistry. Given the volume, temperature, and pressure, the Ideal Gas law can be used to find the number of moles of hydrogen gas collected. Since one mole of a gas contains Avogadro's number (6.022×10^{23}) of molecules, you can then determine the number of hydrogen molecules produced in the experiment, and doubling that gives the total number of electrons which contributed to the current. Finally, the charge of one electron equals the total charge that passed through the circuit divided by the total number of electrons.

Procedure:

1. Add dilute NaOH solution to the plastic tray to cover the tops of the electrodes by about 1 cm.



2. Wire together the components as shown in the figure below. Have your circuit checked by the lab instructor before proceeding.
3. Using plastic tongs, immerse a test tube in the NaOH solution and fill it completely with liquid. Gripping the test tube with the tongs, carefully invert it over an electrode so that the mouth of the test tube rests vertically on the support around the base of the electrode. The mouth of the tube should remain underwater throughout this operation so that no air can enter the tube. Repeat this step for the other tube.
4. Double-click on the “Expt06” icon in the phylabii folder on your computer’s desktop. You will see a setup in which there are two analog output windows that represent the voltage and current output from the power supply.
5. First we will perform an adjustment run. Adjust the dc voltage output on the signal generator to read 4.5 V. Click the “Mon” button ON in the DATA WINDOW and then click the SIGNAL GENERATOR ON. Check the value of the OUTPUT CURRENT and adjust the dc voltage of the signal generator until you get approximately 50 mA of current. Check that gas bubbles are beginning to form on the electrodes. Click the SINGAL GENERATOR OFF. In this way, we have adjusted the current so that it will be ready to go immediately in the next run.
6. Empty out the two test tubes and repeat step 3 so that we can start over fresh. Now click the SINGAL GENERATOR ON anew, and **SIMULTANEOUSLY start your stop-watch** to begin the first real run. About 10-15 minutes later, when the gas level in the

hydrogen tube reaches the water level in the tank, simultaneously CLICK the SIGNAL GENERATOR OFF and stop your stop-watch. Record the displayed total elapsed time and output current (an average if it has changed) in your notebook.

7. Once the bubbles have settled out, read and record the gas volume V in mL from the bottom of the meniscus on the hydrogen tube.
8. Repeat steps 2 through 10 to get a second reading of time, current, and volume of gas.
9. When you are done, please CLICK the SIGNAL GENERATOR OFF if necessary, empty the test tubes, and clean up your work bench.
10. Measure room temperature T in $^{\circ}\text{C}$ and atmospheric pressure P_{atm} in torr, using the thermometer and barometer in the lab room. Then look up the vapor pressure P_v of water in torr at the measured room temperature in the CRC Handbook.
11. Type the following spreadsheet into Excel with a header such as “**Electrolysis Experiment: First Run**”. A sample (with made-up values) is shown on the bottom of the following page. Then highlight and duplicate all of these cells and paste it below the first set in the spreadsheet, changing its header to “**Second Run**”. Change only the variable data for the second run; Excel should automatically recompute the results for this run.

Spreadsheet:

First row—call it **Variable Data**

Enter the measured volume of hydrogen gas V_{mL} in mL.

Enter the average current I in mA.

Enter the run time t in s.

Second row—call it **Fixed Data**

Enter room temperature T_{C} in °C.

Convert to K by typing in the formula $T_{\text{K}} = T_{\text{C}} + 273.15$.

Convert V to m^3 by typing in the formula $V_{\text{m}^3} = 1\text{e} - 6 * V_{\text{mL}}$.

Enter P_{atm} in torr.

Enter P_{v} in torr.

Third row—call it **Calculations** (format all values in scientific notation)

Compute hydrogen gas pressure P in Pa as $P = (P_{\text{atm}} - P_{\text{v}}) * 101325 / 760$.

Compute the number of moles n of H_2 in mol as $n = P * V_{\text{m}^3} / (8.314 * T_{\text{K}})$.

Compute the number of molecules N of H_2 as $N = n * 6.022\text{e}23$.

Compute the number of electrons N_e which flowed through the circuit as $N_e = 2 * N$.

Compute the total charge Q in C which flowed through the circuit as $Q = I * t / 1000$.

Fourth row—call it **Results**

Compute the experimental value of e in C as $e_{\text{exp}} = Q / N_e$. Format in scientific notation.

Enter the accepted value of e in C as .

Compute the percent error as $\%error = \text{abs}(e_{\text{theor}} - e_{\text{exp}}) / e_{\text{theor}}$ and format as 2 digit %.

Variable Data

V	I	t
(mL)	(mA)	(s)
6.1	100.8	490

Fixed Data

T	T	V	P_atm	P_vapor
(°C)	(K)	(m^3)	(torr)	(torr)
22.1	295.1	0.0000061	760.3	22.3

Calculations

P_H2	n_H2	N_H2	N_e	Q
(Pa)	(mol)			(C)
9.84E+04	2.45E-04	1.47E+20	2.95E+20	4.94E+01

Results

e_exp	e_theor	%error
(C)	(C)	
1.68E-19	1.602E-19	4.6%

Supplemental Questions:

1. If a current of 50 mA flows in a wire for 10 minutes, how many electrons passed through any cross section of the wire? Give your answer to 2 significant figures.
2. Suppose that the volume of hydrogen gas at STP (i.e., the temperature is 0 °C and the partial pressure of H₂ is 1 atm) collected at the cathode in an electrolysis experiment is 8 mL. How many moles of hydrogen does this correspond to? How many molecules of hydrogen gas have been collected? How many electrons contributed to the electrolytic current?
3. Use the Ideal Gas law to calculate the volume in L of 1.00 mol of an ideal gas at STP.
4. University Physics students only: Suppose you accidentally stop your reaction too early or late so that the level of the liquid inside the hydrogen tube is 1.0 cm higher or lower than the water level in the tank. By what percentage will the gas pressure inside the tube be different from atmospheric pressure? (Hint: The pressure at depth h in a liquid of density ρ equals atmospheric pressure plus ρgh . Recall that the density of water is $1.0 \text{ g/cm}^3 = 1000 \text{ kg/m}^3$.) This is very nearly equal to the percent error that this will contribute to the experimental value of e . You should find a small answer, indicating that it doesn't matter if you undershoot or overshoot the liquid level slightly when doing the experiment, so don't count that as an error source in the Results section of your lab write-up! In contrast, how big would the error be if we did not include the correction for the vapor pressure of water in our analysis: in other words, what percent is P_v of P_{atm} ?