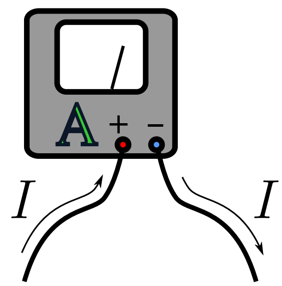
302L S20 Homework 7

Due Friday (3/13) at 3pm. Submit your answers via Quest on assignment "homework 7"

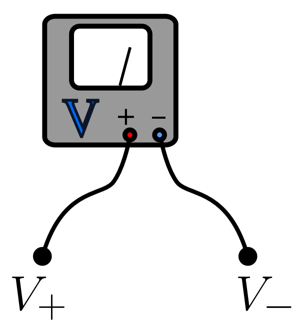
Note: the order of the question choices on Quest are automatically randomized and so may be different from the order on this document.

Refer to the lecture 14 notes as you attempt to answer these questions. It will also be helpful to know how resistors combine in series and parallel.

An *ammeter* is a device with an extremely *small* resistance that measures the current I entering its positive (+) terminal and exiting its negative terminal[1]:



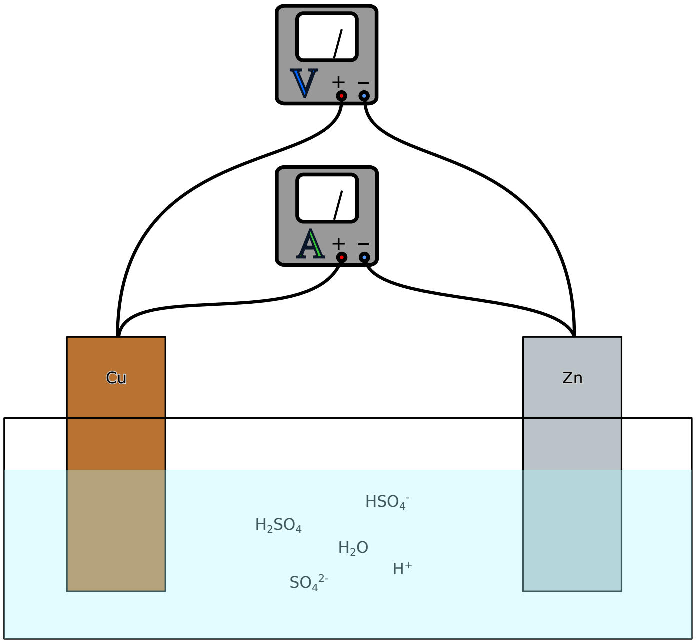
A *voltmeter*, on the other hand, is a device with an extremely *large* resistance that measures the potential difference $V \equiv V_+ - V_-$ between its positive and negative terminals[2]:



Now suppose we take a Zn/Cu battery like the one we discussed in class and connect across its plates both an ammeter and a voltmeter:

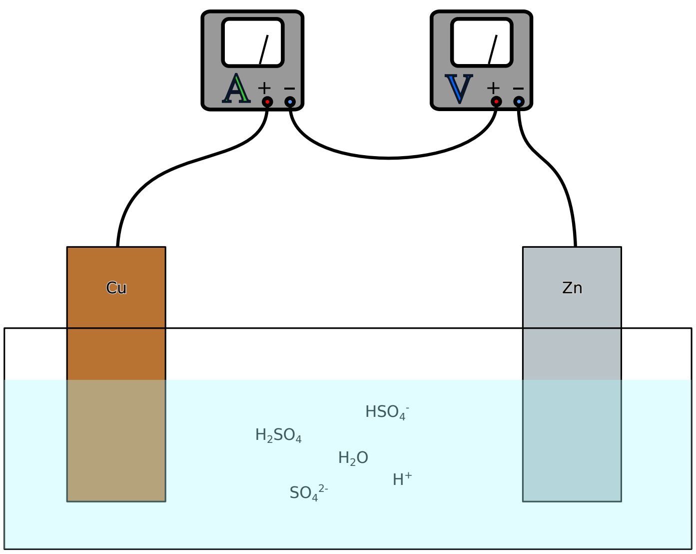
[1]The ammeter is designed to display a positive (i.e. > 0) result when there is a net flow of positive charge into its positive terminal, or, equivalently, when there is a net flow of negative charge out of its negative terminal.

[2]The voltmeter is designed to display a positive result when the electric potential at its positive terminal (V_+) is greater than the electric potential at its negative terminal (V_-).



so that the two meters are connected *in parallel*. Having done this, we wait until both meters read a steady value, at which point we find that the ammeter measures a current I_p and the voltmeter reads a voltage V_p.

Now suppose we connect our meters *in series* like so:



Like last time, we wait for the meters to settle to a steady value, and then record the current I_s on our ammeter and the voltage V_s on our voltmeter.

Question 1 (part 1 of 8):

Which of the following is true about the rate of reaction (5), the "**battery reaction**"?

(a) The rate is faster when the meters are connected in parallel.

(b) The rate is faster when the meter are connected in series.

(c) The rate for the series and parallel arrangements are the same.

Hint #1: The further a reaction is from equilibrium, the faster the reaction rate. Does the ammeter's very low resistance make it more like an open switch or a closed switch? Ask yourself the same question about the voltmeter's very large resistance.

Hint #2: In which arrangement do we have reaction (5), the "**battery reaction**", as the rate limiting reaction? In which arrangement is reaction (6), the "**conduction reaction**", the rate limiting reaction?

Question 2 (part 2 of 8):

Which of the following is true:

(a) $I_p \ll I_s$

(b) $I_p \approx I_s$

(c) $I_p \gg I_s$

Hint: What can we say about the rate of the **battery reaction** and the rate of the **conduction reaction** when the voltage across the plates is steady? How does the rate of the **conduction reaction** relate to the current conducting between the plates?

Question 3 (part 3 of 8):

Which of the following is true:

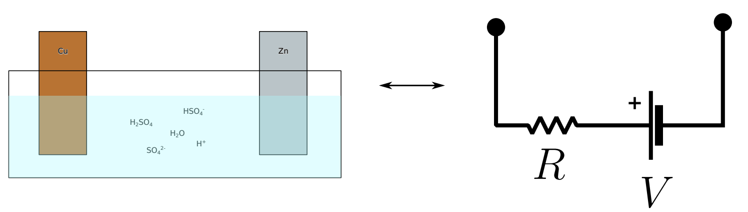
(a) $V_p \ll V_s$

(b) $V_p \approx V_s$

(c) $V_p \gg V_s$

Question 4 (part 4 of 8):

Suppose we want to model[3] our battery as a series combination of an "ideal" voltage source[4] of voltage V and a resistor of resistance R, known as the "internal resistance" of the battery:



[3]It is difficult to give a precise definition of the verb "to model", but typically we understand it to mean "to replace a complicated system by a simpler system".

[4]An ideal voltage source of voltage V is a device that supplies whatever current is necessary in order to maintain a voltage V across its terminals. No real world device can accomplish this since it is impossible to supply infinite current, but many devices for many purposes are very well described as ideal voltage sources.

What value should we select for V and R so that our model of the battery best reproduces the measurements made on the actual battery with our voltmeter and ammeter? Specifically, what should we select for V and R so that we measure a current I_p with the meters in parallel and a voltage V_s when the meters are in series? (Question 8 may provide a hint.)

(a) $V = V_s,\ R = V_s/I_s$

(b) $V = V_s,\ R = V_s/I_p$

(c) $V = V_s,\ R = V_p/I_s$

(d) $V = V_s,\ R = V_p/I_p$

(e) $V = V_p,\ R = V_s/I_s$

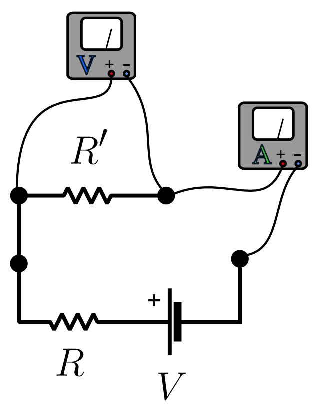
(f) $V = V_p,\ R = V_s/I_p$

(g) $V = V_p,\ R = V_p/I_s$

(h) $V = V_p,\ R = V_p/I_p$

Question 5 (part 5 of 8):

Suppose we connect a resistor of resistance R' to our model of a battery and simultaneously measure the voltage across the battery and the current through it:



We then make two sets of measurements:

- We record the voltage V_A on the voltmeter and the current I_A on the ammeter when the resistance R' is equal to a very large resistance $R_A \gg R$.
- We repeat the measurement using another very large resistance R' equal to $R_B = 2R_A$, obtaining a voltage V_B and current I_B.

From these measurements we can conclude that when $R' \gg R$:

(a) a battery acts approximately as a source of constant voltage.

(b) a battery acts approximately as a source of constant current.

(c) a battery acts as a source of both constant current and constant voltage.

(d) a battery acts as a neither source of constant current nor a source of constant voltage.

Question 6 (part 6 of 8):

Consider another pair of measurements where:

- we record the voltage V_A on the voltmeter and the current I_A on the ammeter when the resistance R' is equal to a very small resistance $R_A \ll R$, and then
- we repeat the measurement using another very small resistance R' equal to $R_B = R_A/2$, obtaining a voltage V_B and current I_B.

From these measurements we can conclude that when $R' \ll R$:

(a) a battery acts approximately as a source of constant voltage.

(b) a battery acts approximately as a source of constant current.

(c) a battery acts as a source of both constant current and constant voltage.

(d) a battery acts as a neither source of constant current nor a source of constant voltage.

Question 7 (part 7 of 8):

Finally, consider a pair of measurements where:

- we record the voltage V_A on the voltmeter and the current I_A on the ammeter when the resistance R' is equal to $R_A = R/2$, and then
- we repeat the measurement using a resistance R' equal to $R_B = 2R$, obtaining a voltage V_B and current I_B.

From these measurements we can conclude that when R' is of the same order of magnitude as R:

(a) a battery acts approximately as a source of constant voltage.

(b) a battery acts approximately as a source of constant current.

(c) a battery acts as a source of both constant current and constant voltage.

(d) a battery acts as a neither source of constant current nor a source of constant voltage.

Question 8 (part 8 of 8):

A typical AA battery has an emf of 1.5 V and a short circuit current of 9.5 A. The short circuit current of a battery is the current conducted across its two terminals when they are connected together by a good conductor (i.e. a resistor with a very small resistance). Estimate the internal resistance of a AA battery:

(a) $0.16\,\text{m}\Omega$

(b) $0.16\,\Omega$

(c) $0.16\,\text{k}\Omega$

(d) $0.16\,\text{M}\Omega$

Question 9:

A Zn/Cu voltaic cell like the one described in the lecture has contains .01 moles of sulphuric acid. Estimate the battery's *capacity*, or the total amount of charge that can be drawn from the battery before it "dies", i.e. before all the sulphuric acid is consumed by the **battery reaction**.

(a) 0.05 mA h

(b) 5 mA h

(c) 500 mA h

Where 1 mA h is the amount of charge conducted by 1 mA of current over one hour.

Hint: How much charge is transferred from the copper plate to the zinc plate for every molecule of sulphuric acid that dissociates?

Question 10 (part 1 of 2):

Suppose a K^+ ion and a Na^+ ion in liquid water have the same average time τ between collisions with the surrounding water molecules. If an electric field E is applied to both ions, which ion possesses the higher drift velocity?

(a) the potassium ion

(b) the sodium ion

(c) both experience the same drift velocity

Hint: See equation (7) from the lecture 14 notes.

Question 11 (part 2 of 2):

Suppose a K^+ and a Ca^{2+} ion in liquid water have the same average time τ between collisions with the surrounding water molecules. If an electric field E is applied to both ions, which ion possesses the higher drift velocity?

(a) the potassium ion

(b) the calcium ion

(c) both experience the same drift velocity

Question 12 (part 1 of 2):

Suppose we have a solid block with side lengths a, b, and c that is composed of a material with resistivity ρ. Taking its two ends to be the rectangles with side lengths a and b, what is the resistance of this block?

(a) $\rho ab/c$

(b) $\rho c/ab$

(c) ρabc

Hint: See equation (12) from the lecture 14 notes.

Question 13 (part 2 of 2):

What is the resistance of this same block, now taking its two ends to be the rectangles with side lengths b and c?

(a) $\rho c/ab$

(b) ρabc

(c) $\rho a/bc$

Question 14 (extra credit)

What is the approximate drift speed of electrons in a piece of 1 mm diameter copper wire carrying 1 A of current? If we assume that one electron per copper atom acts as a charge carrier, then the density of charge carrying electrons in copper is $n \approx 1 \times 10^{23}\,\mathrm{cm}^{-3}$. Pick the answer that most closely matches your calculated result:

(a) $0.0001\,\mathrm{cm\,s^{-1}}$

(b) $0.01\,\mathrm{cm\,s^{-1}}$

(c) $1\,\mathrm{cm\,s^{-1}}$

(d) $100\,\mathrm{cm\,s^{-1}}$

(e) $10\,000\,\mathrm{cm\,s^{-1}}$

(Assuming your answer is correct, how long does it take an electron to travel from the switch to reach a light bulb 10 m away after you flick on the lights?)