

# Study Guide for PHYS135B Module 2, Spring 2021

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**Instructions:** Work each problem *before* checking your answer with the key (to follow on Moodle).

## 1 Memory Bank

1.  $V = (4/3)\pi r^3$  ... The volume of a sphere.
2.  $m = \rho V$  ... The relationship between mass  $m$ , density  $\rho$ , and volume  $V$ .
3.  $\vec{F} = k \frac{q_1 q_2}{r^2} \hat{r}$  ... Coulomb Force
4.  $k = 9 \times 10^9 \text{ N C}^{-2} \text{ m}^2$  ... Remember  $k = 1/(4\pi\epsilon_0)$ .
5.  $q_e = 1.6 \times 10^{-19} \text{ C}$  ... Charge of an electron/proton
6. Atomic mass: the number of grams per mole of a substance
7.  $N_A = 6.03 \times 10^{23}$  ... Avagadro's number
8.  $\vec{F} = q\vec{E}$  ... Electric field and charge
9.  $\vec{E}(z) = \frac{\sigma}{\epsilon_0} \hat{z}$  ... Electric field of two oppositely charge planes each with charge density  $\sigma$
10.  $\epsilon_0 \approx 8.85 \times 10^{-12} \text{ F/m}$
11.  $U = q\Delta V$  ... Potential energy and voltage
12. 1 eV: an electron-Volt is the amount of energy one electron gains through 1 V.
13.  $V(r) = k \frac{q}{r}$  ... Voltage of a point charge
14.  $\vec{E} = -\frac{\Delta V}{\Delta x}$  ... E-field is the slope or change in voltage with respect to distance
15.  $V(x) = -Ex + V_0$  ... Voltage is linear between two charge planes
16.  $Q = C\Delta V$  ... Definition of capacitance
17.  $C = \frac{\epsilon_0 A}{d}$  ... Capacitance of a parallel plate capacitor
18.  $C_{tot}^{-1} = C_1^{-1} + C_2^{-1}$  ... Adding two capacitors *in series*.
19.  $C_{tot} = C_1 + C_2$  ... Adding two capacitors *in parallel*.
20.  $i(t) = \Delta Q / \Delta t$  ... Definition of current.
21.  $v_d = i / (nqA)$  ... Charge drift velocity in a current  $i$  in a conductor with number density  $n$  and area  $A$ .
22.  $R_{tot}^{-1} = R_1^{-1} + R_2^{-1}$  ... Adding two capacitors *in parallel*.
23.  $R_{tot} = R_1 + R_2$  ... Adding two capacitors *in series*.
24.  $\Delta V = IR_{tot}$  ... Ohm's Law
25.  $P = IV$  ... Relationship between power, current, and voltage.
26.  $V_C(t) = \epsilon_1 (1 - \exp(-t/\tau))$  ... voltage across the capacitor in an RC series circuit. The time constant is  $\tau = RC$ .
27.  $i(t) = \frac{\epsilon_1}{R} \exp(-t/\tau)$  ... Current in an RC series circuit.
28.  $i_{in} = i_{out}$  ... Kirchhoff's junction rule.
29.  $\epsilon_1 + \epsilon_2 + \epsilon_3 + \dots = 0$  ... Kirchhoff's loop rule.

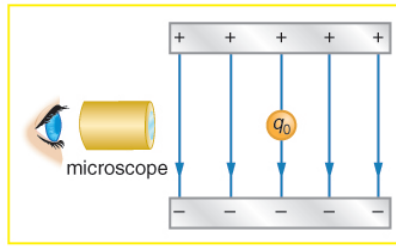


Figure 1: The classic Millikan oil drop experiment was a measurement of the charge of an electron.

## 2 Electric Charge and Electric Fields

- Two charges exert  $F_C = 5.00$  N of force on each other. What will  $F_C$  be if the distance between them triples?
  - If one charge is 1 nC, and the other is 2 nC, what is the distance between them if  $F_C = 5.00$  N?
- The classic Millikan oil drop experiment was the first to measure accurately the electron charge. Oil drops were suspended against the gravitational force by a vertical electric field. (See Fig. 1.) The drops have radius  $1.0\mu\text{m}$ , and a density of  $920\text{ kg/m}^3$ . (a) Find the weight of the drop. (b) If the drop has a single excess electron, find the electric field strength needed to balance its weight.
- Suppose two positive, identical charges are located a distance  $d$  apart. (a) Sketch the electric field below. (b) Sketch the electric field if instead one of the charges is negative.

## 3 Potential Energy and Voltage

- What is the electric field across an  $10.00\text{ nm}$  thick human nerve cell membrane if (a) the voltage across it is  $50\text{ mV}$ ? You may assume a uniform electric field. (b) Suppose this cell membrane is part of a nerve cell. How much energy would an electron gain if dropped through the  $50\text{ mV}$  voltage and accelerated across the cell freely? Express your answer in electron-Volts (eV).
- Think back to the PhET simulations of parallel lines of charge.** Suppose a parallel plate capacitor is formed from a positive plate and a negative plate of charge. The plates' areas  $A$  are the same, and the plates' charges ( $\pm Q$ ), and charge densities ( $\pm Q/A = \pm\sigma$ ) are the same as well. (a) Write the expression for the electric field between the plates. (b) Suppose  $Q = 1\text{ nC}$ , and  $A = 10\text{ mm}^2$ . What is the value of the electric field between the plates? (c) Suppose 0 volts corresponds to the location of the negative plate. Draw the voltage as a function of distance between the plates. (d) What is the voltage near the positive plate, if the plates are separated by a distance  $d = 1\text{ mm}$ ?

## 4 Capacitors

1. What is the capacitance of the capacitor in the previous problem?
2. (a) Consider the same capacitor again, and suppose a second identical capacitor is connected *in parallel* with it. What is the total capacitance? (b) How much charge would the pair of capacitors store if the voltage across them was 5 volts?
3. How much energy in Joules would this charge have if it was all put to work?

## 5 Current, Resistance, and DC Circuits

1. Three identical resistors  $R$  are connected *in parallel*, and powered by an adjustable voltage source. The voltage and *total current* measurements are shown below. Determine the value of  $R$ .

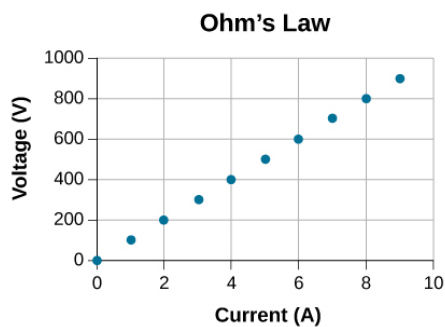


Figure 2: A graph of voltage versus current.

2. (a) Using the PHeT tool for DC circuit construction, design a circuit in which a battery with *fixed voltage* lights a bulb, but the bulb brightness can be dimmed or brightened. *Hint: use other components in series with the bulb.* Draw your design below. (b) Now make a parallel circuit in which two bulbs can be brightened or dimmed independently, and use switches to turn them on or off independently. Draw your design below.

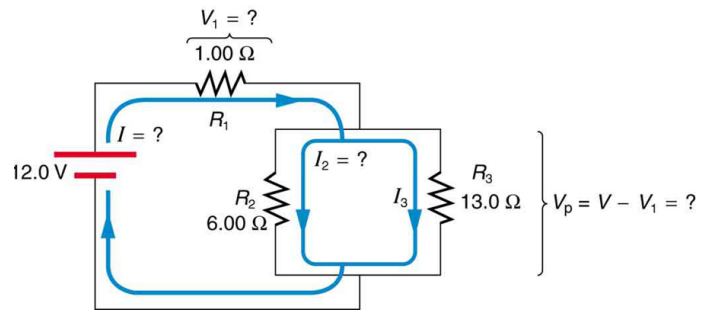


Figure 3: A DC circuit with three resistors.

3. Figure 3 shows a combination of series and parallel resistors and a battery. (a) Find the total resistance. (b) What is the IR voltage decrease in  $R_1$ ? (c) Find the current  $I_2$  through  $R_2$ . (d) What power is dissipated by  $R_2$ ?