Physics 1120 – Homework – 1

1. Estimate the appropriate dosage for an average patient.

$$Assuming\ Cube\ Shape : Volume\ of\ Liver = 10\ cm * 15\ cm * 2\ cm = 300\ cm^3$$

$$300\ cm^3 * \frac{1\ Liter}{1000\ cm^3} * \frac{10\ deci\ liters}{1\ Liter} = 3\ deci\ liters$$

$$Dosage = \frac{3\ \mu g}{1\ deci\ liter} * 3\ deci\ liters = 9\ \mu g$$

2.A Is the formation of the hydrogen bond exothermic (releases energy, reducing the internal energy of the molecules) or endothermic (absorbs energy, increasing the internal energy of the molecule)? Explain briefly

> - $Exothermic$
> - Breaking bonds requires extra energy
> - Creating bonds releases energy

2.B.1 Figure out how many water molecules there are in 1 kg of water

$$1\ kg\ H_2O * \frac{1000\ grams}{1\ kg} * \frac{1\ mol\ H_2O}{18.00988\ grams} * \frac{6.022 * 10^{23}\ molecules}{1\ mol} = 3.3437202246766775 * 10^{25}\ molecules\ of\ H_2O$$

2.B.2 Do you expect that there would be more hydrogen bonds than water molecules or fewer? Explain your reasoning

> - Hydrogen Bonding is weak intermolecular stabilizing force
> - Water molecules are in constant motion, where they are constantly creating and breaking hydrogen bonds
> - On a "freeze frame" image, I would expect:
> $Total\ Number\ of\ Hydrogen\ Bonds = (\ Total\ Number\ of\ Water\ Molecules\ ) - 1$

2.B.3 Figure out in our model of boiling, how many hydrogen bonds are broken in order to boil 1 kg of water.

$$\frac{0.2\ eV}{1\ Hydrogen\ Bond} * \frac{1.6 * 10^{-19} Joules}{1.0\ eV} = \frac{3.2 * 10^{-20}\ Joules}{1\ Hydrogen\ Bond}$$

$$\frac{2.3 * 10^{6}\ Joules}{1\ kg\ H_2O} * \frac{1\ Hydrogen\ Bond}{3.2 * 10^{-20}\ Joules} = 7.18750 * 10^{25} Hydrogen\ Bonds$$

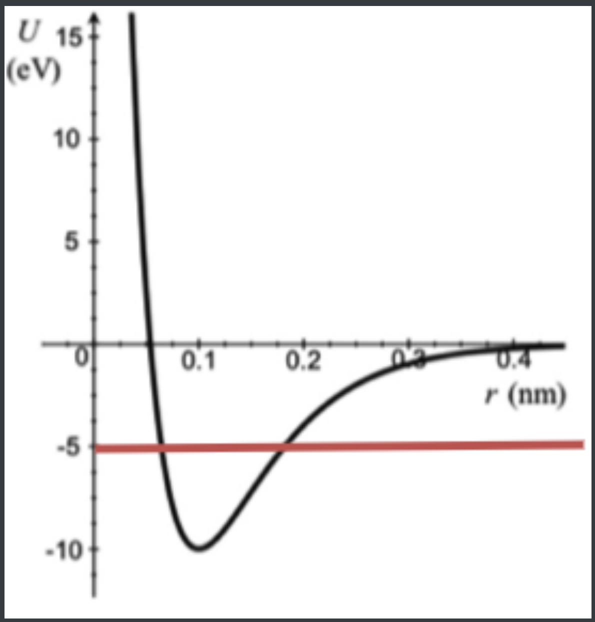
2.B.4 Does your calculation support our simple model or not? Why?

> - It *does* support the simple model
> - The calculation for number of hydrogen bonds broken is close to **double** the amount of the number of molecules in H_2O

3.A If the two atoms approach each other with this energy, how close will they get to each other? Explain why you think so using a description of their motion and how you know this is what they do

> - They can only get to $\approx 0.5\ nm$ because this is where the kinetic energy goes to zero

3.B Draw a line on the graph above that represents the total mechanical energy of the atoms.



3.C After the emission of the photon, are the two atoms bound (into a molecule) or free (they will fly apart)? When they move will there be a minimum or maximum distance they can reach? If so, explain why you think so and find those distances.

> - The line is where kinetic energy is zero
> - After the atoms are $bound$, a photon is released
> - Where the red line intersects the curve is where this happens
> - The minimum distance is $\approx 0.05\ nm$
> - The maximum distance is $\approx 0.18\ nm$

3.D If you answered “free” in part (c), what would have been the energy “lost” necessary to minimally bind them instead? If you answered “bound” in part (c), what would have been the energy “lost” that would have left them minimally free? Please explain as well as offer a numeric answer.

> - "Minimally Free" = Minimum Distance Traveled Before Bound $= 15\ meV$

4.A Consider a gas consisting of a box of N argon atoms. How many degrees of freedom do you expect the gas to have?

> - Unless reality is holographic, there are 3 physical dimensions, so $3 * N$ degrees of freedom

4.B Consider a gas consisting of a box of N carbon-monoxide molecules. Assuming that you can treat the bond as rigid, how many degrees of freedom do you expect the gas to have?

> - 3 Physical Degrees of Freedom
> - (3 Rotational Degrees of Freedom) - 1 Quantum Rule
> - = $5 * N$ degrees of freedom

4.C If you consider a gas consisting of a box of N carbon-monoxide molecules. Assuming that you can treat the bond is a spring that can only vibrate along the axis joining the two atoms (and not sideways), how many degrees of freedom do you expect the gas to have?

> - A normal spring has two degrees of freedom = Kinetic Energy and Physical Energy
> - = $7 * N$ degrees of freedom

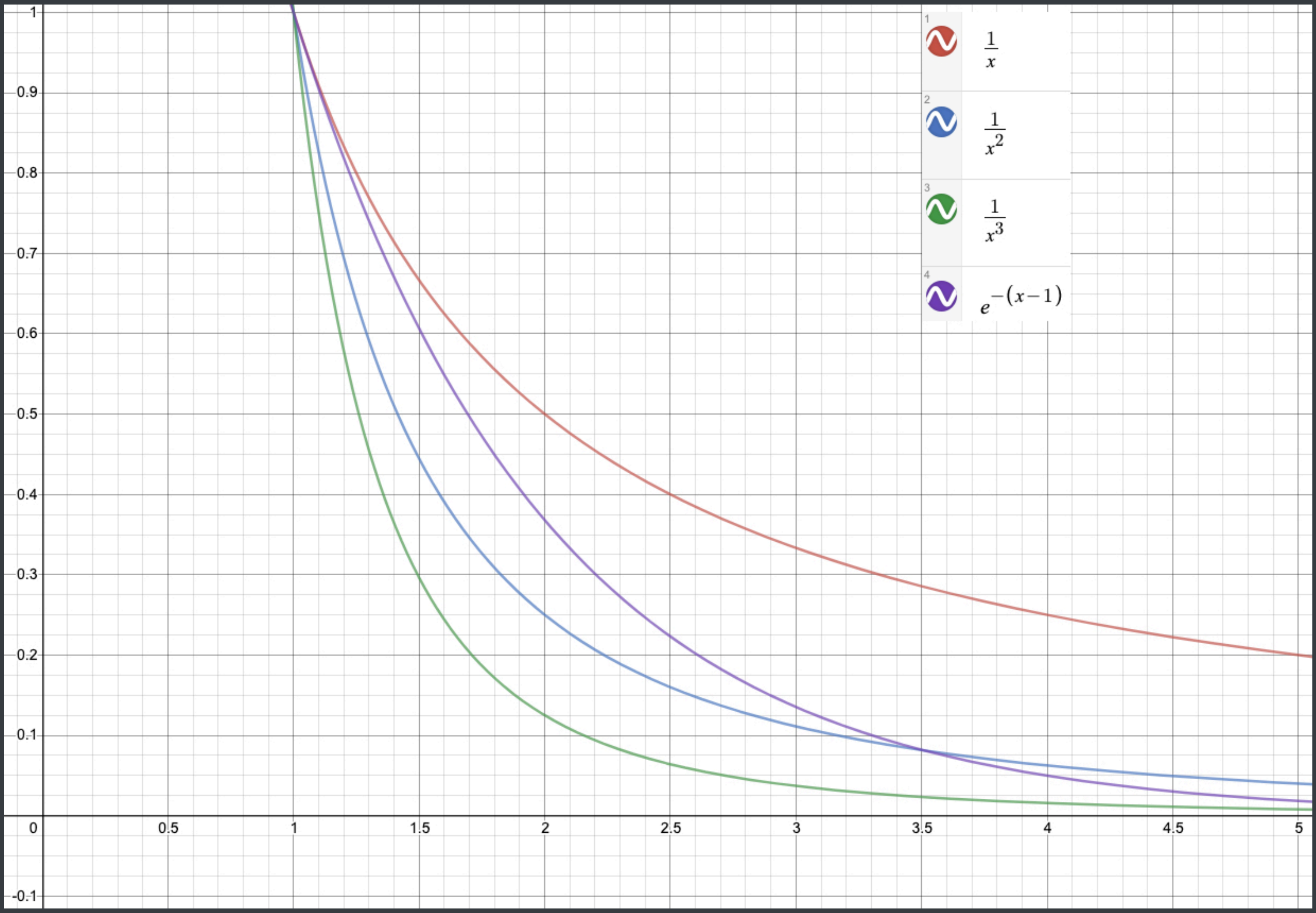
4.D Consider a gas consisting of water vapor with N molecules having three atoms rigidly bonded in an angled shape (not a straight line). How many degrees of freedom do you expect this gas to have?

> - 3 Physical Degrees of Freedom
> - 3 Rotational Degrees of Freedom
> - = $6 * N$ degrees of freedom

4.E On average, when thermal energy is added to a substance, the energy is shared equally among the degrees of freedom. Since the temperature of a substance is proportional to the average energy in a degree of freedom, which of the substances do you expect would have the largest specific heat? (That is, which substance would change temperature the least in response to the addition of a given amount of thermal energy.) Explain.

> - The more degrees of freedom you have, the easier it would be to dissipate heat.
> - The model with the spring has 7 degrees of freedom
> - $\color{red}{Model\ 4.C}$

5.A.1 Which of the power laws fall off faster? Explain why



https://www.desmos.com/calculator/74rd4zxriy

> - $\frac{1}{x^3}$ "falls off" the fastest
> - As the denominator in a fraction increases, the result becomes smaller and smaller

5.A.2 How does the exponential fall off compared to the power laws?

> - These are the inverses of power laws

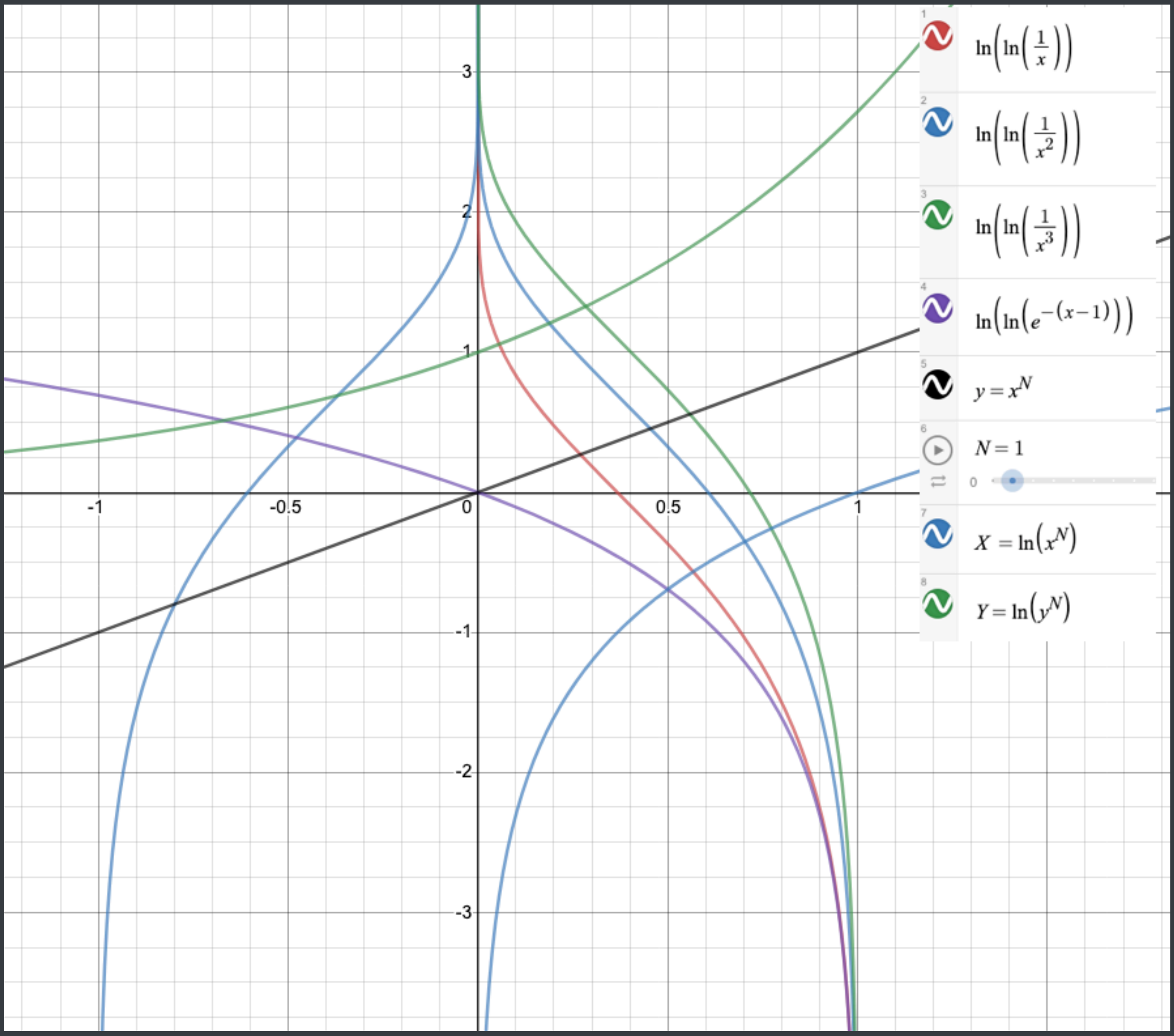
5.A.3 Why did we start at 1 instead of 0?

> - Just for convenience.
> - The these are inverse functions
> - It makes it so the graph is in the 1st quadrant

5.A.4 Why did we choose to plot e^{-x-1} instead of just e^{-x} ?

> - It just aligns it "better" with the other "family" of functions

5.B.1 Show that any power law graph, $y = f(x)$, where $f(x) = x^N$, will look like a straight line
if you plot $X = ln(x)$ vs $Y = ln(y)$ and identify the slope of the straight line that you will find on your log-log plot.



https://www.desmos.com/calculator/t40rbssgiq

> - Slope = 1

5.B.2 Did your power law graphs look like your calculation in part B.1 says they should?

> - Yes

5.B.3 A common statement for these functions is that "the exponential function falls off faster than any power law". Does your graph support this statement? What do you think higher powers would look like?

> - The higher power functions "fall off faster"
> - Exponentials fall off faster than then power laws

Physics 1120 – Homework – 2

1.A Fill in the smallest possible integers that allows the stoichiometry of the reaction equation to be correct

$$2KClO_3 \longrightarrow 2KCl + 3O_2$$

1.B If there are N molecules of potassium chlorate in the initial state, how many product molecules are there?

$$\frac{Products}{Reactants} = \frac{5}{2} = 2.5 * N$$

1.C.1 If the reaction takes place as a constant temperature and volume, the pressure:
$increases$

> $IF\ (Temperature\ and\ Volume = Constant)\ THEN : Pressure \propto N_{molecules}$

1.C.2 If the reaction takes place at a constant temperature and pressure, the volume:
$increases$

> $IF\ (Temperature\ and\ Pressure = Constant)\ THEN : Volume \propto \frac{1}{Pressure}$

1.C.3 If the reaction takes place at a constant volume in a thermally insulated container that allows no heat exchange with the outside world (or the container), the gas temperature:
not enough information given in the problem to decide

> $IF\ (Volume = Constant)\ THEN : Temperature \propto Energy_{released}$
>
> However, we don't know how much energy is released

1.D.1 If the reaction takes place as a constant temperature and volume, the work done by the gas on the outside world is: $zero$

> $$IF\ (Temperature\ and\ Volume = Constant)\ THEN : Work = 0$$

1.D.2 If the reaction takes place at a constant temperature and pressure, the work done by the gas on the outside world is: $positive$

> $$IF\ (Temperature\ and\ Pressure = Constant)\ THEN : Volume \propto Work$$

1.D.3 If the reaction takes place at a constant volume in a thermally insulated container that allows no heat exchange with the outside world (or the container), the work done by the gas on the outside world is: $zero$

> $$IF\ (Volume = Constant)\ THEN : Work = 0$$

2.1 Internal Energy, U_{int}

> - consists of the kinetic energy of the molecules plus the chemical energy of the molecules (negative binding energies) plus the potential energy interactions of the molecules
> - can be considered as the sum of all the kinetic energies of the molecules
> - Used when calculating the total energy of a system: $E = KE + PE + U_{internal}$

2.2 Enthalpy, H

> - used to measure changes in the amount of energy of a system under particular conditions
> - $Enthalpy(H) = U_{internal} + (Pressure * Volume)$
> - positive change in enthalpy means that heat is being input to the system
> - negative change in enthalpy means that heat is being released from the system to its surroundings

2.3 Microstates vs Macrostates

> - The entropy of a particular macrostate is proportional to the logarithm of the number of microstates corresponding to that macrostate
> - $S_{macrostate} \propto ln(Total\ Microstates)$
> - Used for calculating free energy and probability of distribution of free energy

2.4. Gibbs Free Energy, G

> - $G = H - (T * S)$
> - The sign of *G* is defined so that a system will tend to evolve in the direction of **decreasing** *G*.
> - The sign of Δ*G* tells us which direction a reaction (or other process) will proceed

3. Estimate whether we need to consider “stochastic equations” in either compartment.

> $$Volume\ of\ Mitochondria = \pi * (0.5\ \mu m)^2 * 1\ \mu m = 0.7853981633974483\ \mu m^3$$
>
> $$Volume\ of\ Lysosome = \frac{4}{3} * \pi * \left(\frac{1}{3}\ \mu m\right)^3 = 0.15514037795505145\ \mu m^3$$

> $$Density\ of\ H^+ Ions = \frac{1\ mol}{1\ Liter} * \frac{6.022 * 10^{23}\ ions}{1\ mol} * \frac{1\ Liter}{1 * 10^3\ cm^3} * \frac{1 * cm^3}{1 * 10^{12}\ \mu m^3} = \frac{6.022 * 10^8\ ions}{1\ \mu m^3}$$

> $$[H^+] = 10^{-pH}$$
>
> $$Mitochondria\ [H^+] = 10^{-8}$$
>
> $$Lysosome\ [H^+] = 10^{-5}$$

> $$Mitochondria = 0.7853981633974483\ \mu m^3 * (1 * 10^{-8} H^+ ions) * \frac{6.022 * 10^8\ ions}{1\ \mu m^3} = 4.729667739979433\ ions$$
>
> $$Lysosome = 0.15514037795505145\ \mu m^3 * (1 * 10^{-5} H^+ ions) * \frac{6.022 * 10^8\ ions}{1\ \mu m^3} = 934.2553560453199\ ions$$

> - Number of Mitochondria Ions = *stochastic equations*
> - Number of Lysosomes Ions = *normal thermodynamics*

4. Probability and Entropy

http://pi3.sites.sheffield.ac.uk/tutorials/week-9

https://math.stackexchange.com/questions/657977/average-and-variance-of-flipping-a-coin

https://math.stackexchange.com/questions/2262085/pascals-triangle-given-an-n-sided-die

https://www.maplesoft.com/applications/view.aspx?SID=6879&view=html

http://www.math.umbc.edu/~campbell/MEPP/Pascal-Triangle/coin_flip_experiment.html

https://medium.com/i-math/top-10-secrets-of-pascals-triangle-6012ba9c5e23

https://medium.com/i-math/the-drunkards-walk-explained-48a0205d304

https://math.stackexchange.com/questions/1272297/expected-value-for-number-of-ties-in-n-coin-tosses

https://stackoverflow.com/questions/30867312/how-to-calculate-the-entropy-of-a-coin-flip

https://math.stackexchange.com/questions/3993624/entropy-of-a-fair-coin-toss

http://umdberg.pbworks.com/w/page/49691685/Why%20entropy%20is%20logarithmic

$$Logarithmic\ Entropy = k_B * ln(Total\ Microstates\ (W))$$

$$Choose\ M\ out\ of\ N\ Objects = \frac{N!}{(N-M)! * M!}$$

Flipping 1 Coin, N Times:

$$< S >= \sum_{i=1}^{N} (+1 * 0.5) + (-1 * 0.5)$$

Flipping N Coins, N Times:

$$< S >= \sum_{i=1}^{N} \left(+i * \frac{1}{2^{2*i}} \right) + \left(-i * \frac{1}{2^{2*i}} \right)$$

4.1.1 For a single coin flip, list the possible outcomes, i = 1,...?, the value of each outcome, Si, and the probability of each outcome Pi . Use the expectation equation to calculate the average value of a single coin flip.

> $$< S >= \sum_{i=1}^{1} (S_i * P_i) = (S_H * P_H) + (S_T * P_T)$$
>
> $$< S >= \sum_{i=1}^{1} (S_i * P_i) = (+1 * 0.5) + (-1 * 0.5) = 0$$

4.1.2 For flipping two coins, list the possible outcomes, i = 1,...?, the value of each outcome, Si , and the probability of each outcome Pi . Use the expectation equation to calculate the expected average value of the two flips.

> $$< S >= \sum_{i=1}^{2} (S_i * P_i) = (S_2 * P_2) + (S_0 * P_0) + (S_{-2} * P_{-2})$$
>
> $$< S >= \sum_{i=1}^{2} (S_i * P_i) = (+2 * 0.25) + (0 * 0.5) (-2 * 0.25) = 0$$

4.1.3 How about flipping 10 coins? What is the average total expected number of points?

> - Heads and Tails Cancel Out $\therefore$ Points = 0

4.1.4 Consider flipping N coins. If the total number of points obtained from the N flips labels our macrostates, which macrostate is most likely?

> $$< S >= \sum_{i=1}^{N} \left(+i * \frac{1}{2^{2*i}}\right) + \left(-i * \frac{1}{2^{2*i}}\right)$$
>
> - Most likely macrostate is still S = 0

4.2.1 If one flips 2 coins once each, how many different microstates (total distinct outcomes of sets of heads and tails) are there? How many microstates are there if one flips 3 coins once each? What is the total number of microstates associated with flipping N coins once each?

> $$2^N = 2^3 = 8 \; microstates$$

4.2.2 Select the most plausible formula for the entropy S

> $$= A = S = k_B * N * log(2)$$

4.2.4 Can you make sense of this odd result? Discuss! Be clear!

> - Pascal's Triangle and Binomial Distribution
> - The sum of all the probabilities always has to be 1
>   - $\therefore$ area under the curve has to also be 1
> - The probability is growing in relation to the $\frac{1}{\sqrt{distance}}$ from the center of the distribution
>   - As the number of trials increases, you have more of a chance from being af

Physics 1120 - Homework 3

1.A. Which of the expressions below best represents the relative probability of open to closed, $R = \frac{p_{open}}{p_{closed}}$

> $$C = \frac{e^{\frac{-\epsilon_1}{k_B * T}}}{e^{\frac{-\epsilon_2}{k_B * T}}}$$

1.B. Which of the expressions below best represents the absolute probability of finding the channel open?

> $$D = \frac{e^{\frac{-\epsilon_1}{k_B * T}}}{\left(e^{\frac{-\epsilon_1}{k_B * T}}\right) + \left(e^{\frac{-\epsilon_2}{k_B * T}}\right)}$$

1.C. Identify the true statements

> - B = The top of the curve is the probability of finding ion channel closed
> - D = The curves show that the probability of finding the ion channel open is greater at high temperature
> - E = If ($\epsilon_1 - \epsilon_2$) is much less than $k_B * T$, the relative probability R is approximately 1

1.D.1 At approximately what value of $\frac{\epsilon}{k_B * T}$ are the ion channels three times more likely to be closed than open?

> $$@ \frac{\epsilon}{k_B * T} = 1$$

1.D.2. If a membrane could change its value of ϵ , what change would it make to open more ion channels?

> - Make ϵ $\color{red}{lower}$ than normal

2. What was an example that Rey could have come up with? Which student do you agree with (or do you disagree with both), and why? If the 2nd Law of Thermodynamics is true all the time, then how is Rey’s example possible? Or if the 2nd Law isn’t true all the time, what are the circumstances when it is true?

> - Rey could of used a refrigerator as an example
> - Refrigerators reduce entropy by creating more entropy outside than inside
>
> - I agree with Rey
>   - Entropy can only decrease by increasing entropy somewhere else
> - The 2nd Law is always true
>   - Entropy always increases
>   - Entropy inside the fridge decreases, but overall the total entropy of the universe always increases.

3.1. What can you say about the entropy of the two systems?

> - A = The entropy of system 2 is twice as high as that of system 1
> - D = The number of microstates of system 2 is a lot more than twice as high as those of system 1.

3.2.

> - D = S_1 increases and S_2 decreases, but S_1 increases by more.

3.3 What will the total entropy change of the system be as a result?

$$\Delta S_A = \frac{-0.5\ Joules}{350\ K} = \frac{-0.0014285714285714286\ Joules}{1\ Kelvin}$$

$$\Delta S_B = \frac{0.5\ Joules}{250\ K} = \frac{0.002\ Joules}{1\ Kelvin}$$

$$\Delta S = \left(\frac{-0.0014285714285714286\ Joules}{1\ Kelvin}\right) + \left(\frac{0.002\ Joules}{1\ Kelvin}\right) = \frac{0.0005714285714285715\ Joules}{1\ Kelvin}$$

4.1. How do the volume and temperature compare in systems A and B? Be quantitative and explain your reasoning.

> - In StateB the gas has access to twice the volume
>   - $V_B = 2 * V_A$
> - System is isolated from the universe
>   - $T_A = T_B$

4.2.1. Show that W_B , the number of microstates after the expansion, is $2N$ times larger than W_A where N is the number of particles.
Then compare for two particles, and three, and so on, until you've built up the result for N particles.

> $$IF\ Only\ 1\ Particle : W_B = 2 * W_A$$
>
> $$IF\ Only\ 2\ Particles : W_B = 2^2 * W_A$$
>
> $$IF\ N\ Particles : W_B = 2^N * W_A$$

4.2.2. What is the entropy change ΔS_{gas} for the free expansion?

> $$S = k_B * ln(W)$$
>
> $$S_B = k_B * ln\left(2^N * W_A\right) = k_B * ln(W_A) + N * k_B * ln(2) = S_A + N * k_B * ln(2)$$
>
> $$\Delta S_{gas} = S_B - S_A = N * k_B * ln(2)$$

4.2.3. Provide a qualitative argument that explains the sign of ΔS_{gas} by appealing to:

- Energy spreading
- Microstates

> - As $Volume$ increases , the system can disperse energy over larger area
>   - $\therefore entropy$ increases
> - As $Microstates$ increases, there are more "energy bins" for each gas molecule to go into
>   - $\therefore entropy$ increases

4.3.1. What is the change in internal energy ΔU_{gas} from before to after the expansion? How do you know?

> - $\Delta U_{gas} = 0$
> - System is isolated from universe
> - Energy can not leave or enter

4.3.2. How does the change in enthalpy ΔH_{gas} compare to the change in internal energy $\Delta Ugas$ during the expansion? Explain what it represents and how it's different from internal energy.

> - $p * V$ = constant
> - Temperature = constant
> - N = constant
> - Volume = doubled
> - Pressure = halved
> - $\Delta H_{gas} = \Delta U_{gas} = 0$
> - Enthalpy $\neq$ Internal Energy
>   - Includes work done to change volume
> - Expansion = "Free Expansion"
>   - No work is done other than opening valve
>   - ΔH = constant

4.3.3. What's the change in the Gibbs free energy of the gas, ΔG_{gas} , as a result of the free expansion? Explain what it represents and how it's different from internal energy and enthalpy.

> - $\Delta G_{gas} = \Delta H - (T * \Delta S)$
> - $-(T * \Delta S) = -N * k_B * T * ln(2)$
> - Internal Energy = constant
> - Enthalpy = constant
> - $\Delta G_{gas} = negative$ = spontaneous
> - ΔE = constant
> - The gas will spread out to fill the two chambers, but it is VERY unlikely that it would every go backwards into just a single chamber.

Physics 1120 – Homework – 4

1.1 Which of the following statements are true about these charges? Explain your reasoning

> - $a.)$ Charges A and D are positive
>   - The electric field lines point away from positive charges and towards negative charges
> - $c.)$ All the charges are equal magnitude
>   - The red vector arrow lengths are equal length/magnitude

1.2. Which of the following graphs representsthe electric potential along the dotted line (x axis)? (Choose N if none of these graphs are correct.)

> - Graph B

2. Using dimensional analysis, select which of these could give a good representation of the following physical quantities (or select N if none of these could work). Explain your reasonings

> $$[Electric\ Field] = \left[\frac{Force}{Charge}\right] = \left[\frac{Mass * Acceleration}{Charge}\right] = \left[\frac{Mass * Length}{Time^2 * Charge}\right]$$
>
> $$k_c = \frac{8.99 * 10^9\ Newton\ \cdot meters^2}{1\ Coulomb^2}$$
>
> $$[k_c] = \left[\frac{Mass * Length^3}{Time^2 * Charge^2}\right]$$

> $$\left[\frac{Mass * Length}{Time^2 * Charge}\right] = \left[\frac{Mass * Length^3}{Time^2 * Charge^2}\right] * [X]$$
>
> $$\therefore [X] = \left[\frac{Charge}{Length^2}\right]$$

> - 1 = A
> - 2 = G
> - 3 = $None$
> - 4 = F
> - 5 = I

3.1. According tothe potential shown in the graph (using it as shown, whether it correctly corresponds to the diagram or not!), if a test electron were released at the following positions along thex-axis, in what direction would thex-component of the electric force it feels point? (Use L for left, R for right, and 0 for there is no x-component.)

> $$\vec{\nabla} = \left(\hat{i} * \frac{\partial}{\partial x}\right) + \left(\hat{j} * \frac{\partial}{\partial y}\right) + \left(\hat{k} * \frac{\partial}{\partial z}\right)$$
>
> $$E_x = -\frac{\partial V}{\partial x}$$
> $$E_y = -\frac{\partial V}{\partial y}$$
> $$E_z = -\frac{\partial V}{\partial z}$$
>
> - "The electric field is the negative derivative of the electric potential"
> - $Force_{charge} = q * E$
> - Electrons have negative charge
>
> - A.) x = 6 nm = Electric Field Points to the Left , but E_x points to the $Right$
> - B.) x = 1.5 nm = Electric Field Points to the Left , but E_x points to the $Right$
> - C.) x = -6 nm = Electric Field Points to the Left , but E_x points to the $Right$

3.2. Which of the following statements could be true?

> - B = This potential was measured along the horizontal line 1 nm below the charges (y = 0nm)
> - C = This potential was measured along the horizontal line 1 nm above the charges (y = +2nm)

3.3. Suppose a Na+ ion approached this potential from the right along the x-axis and was constrained to move along the x-axis (no y-motion allowed).If it had very little KE but was moving slowly to its left when it was at the point x= 15 nm, and if there it essentially felt V= 0 from the molecule, how far along the axis would it come?

> - E = It would get about to 0.5 nm and bounce back

3.4. For the set of 8 source charges in the figure at the top, is there an equipotential line (really part of a surface in three dimensions) that corresponds to V= 0? If so, where is it? Select your answer(s) and fill in the blank if the answer you select has a blank to fill in:

> - B = Yes. It is a vertical line going through: $x = -0.5$

3.5. It looks from the graph like the position x= 0 is not the local maximum, which is evidently a little to the left. If the diagram matches the graph would this be correct?

> - Yes

4. If you were completely flexible (an octopus rather than a person),how small a cube could you fit yourself into? Do you consider that the trick is probably legitimate or a fake?

> $$Mass = 72.57478\ kilograms$$
>
> $$72.57478\ kilograms * \frac{1000\ cm^3}{1\ kilogram} = 72574.78\ cm^3$$

> $$50\ cm^3 = 50\ cm * 50\ cm * 50\ cm = 125000\ cm^3$$

> $$\frac{125000\ cm^3}{72574.78\ cm^3} = 1.7223614043335715$$

> Yes , assuming fluid shape, you could fit
>
> - Two of them could fit, either they are double jointed, or they can bend in just the right way

5.A. How do the representations of the E-Field using the E-Field sensor and the "Show E-Field" box differ? Which do you prefer and why?

> - "Show E Field" = grid of electric field arrows
> - E Field Sensor = shows electric field only at a point
> - They are both used for different things
>   - The grid lets you see the whole space
>   - The sensor lets you see the magnitude at a particular point

5.B. Can you figure out what grid scale the program uses for the E-field arrow on the E-field sensor? If you can, do it. If you can't, explain why not.

$$Point\ Charge\ Electric\ Field = E = k_c * \frac{q}{r^2}$$

$$1\ meter = 10\ grid\ squares$$

$$2\ large\ grid\ boxes = 1m = 10\ grid\ squares$$

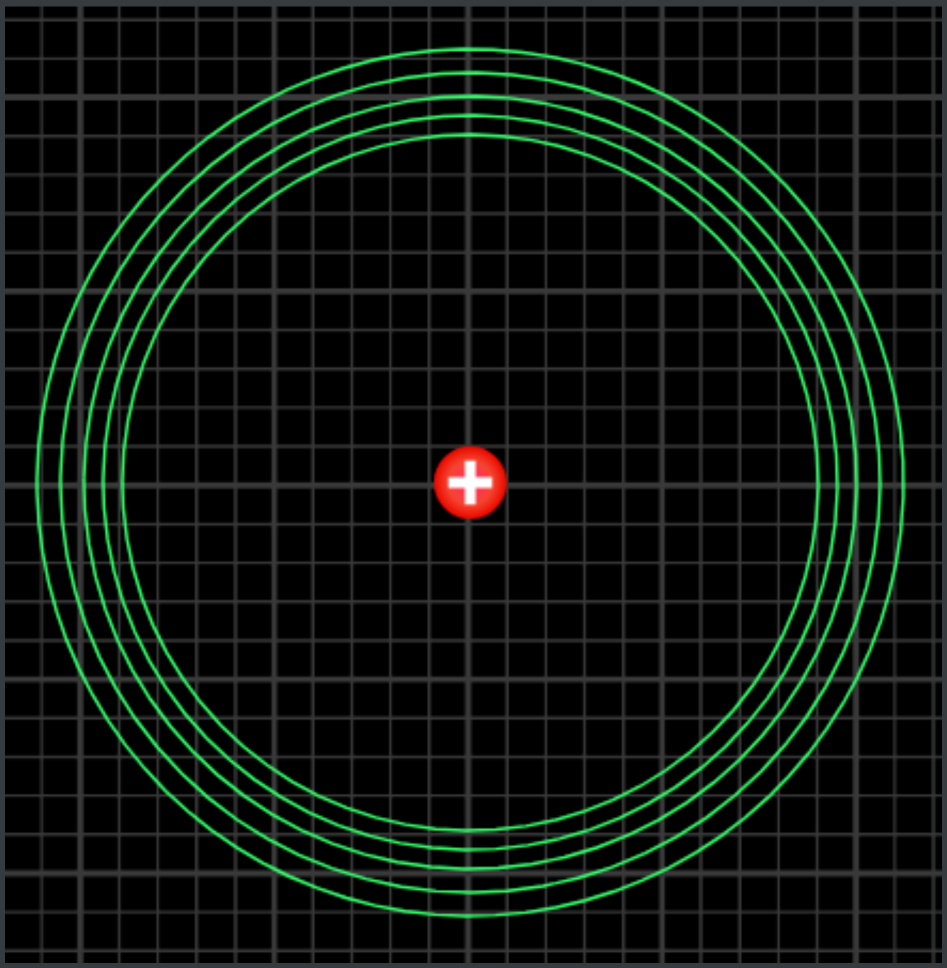
$$1\ nano\ Coulomb's\ Electric\ Field = 4\ grid\ squares * \frac{1\ meter}{10\ grid\ squares} = 0.4\ meters$$

$$E = \frac{8.99 * 10^9\ Newton\ \cdot meters^2}{1\ Coulomb^2} * \frac{1 * 10^{-9}\ Coulombs}{1\ meter^2} = \frac{8.99\ Newtons}{1\ Coulomb}$$

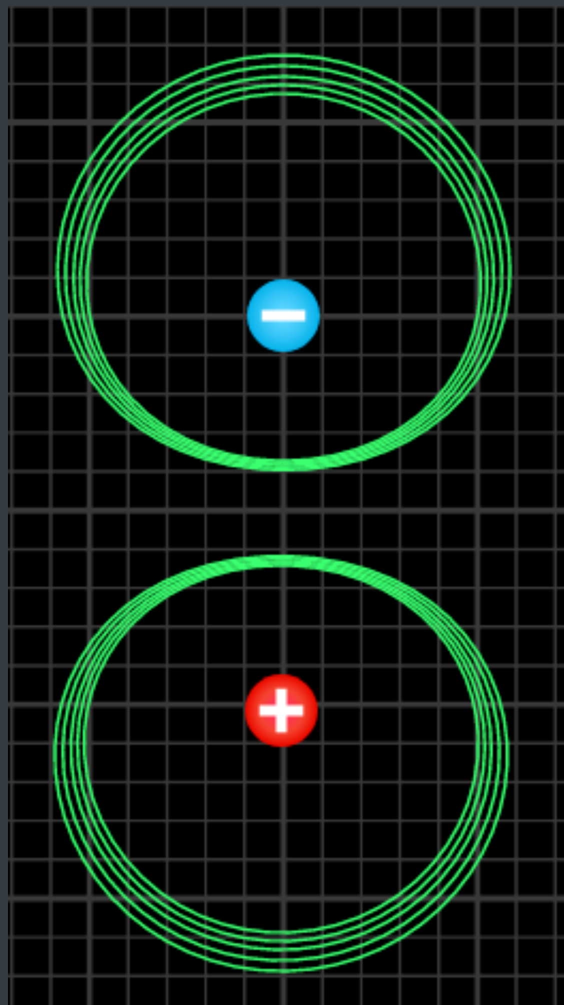
$$Scale = \frac{\frac{8.99\ Newtons}{1\ Coulomb}}{0.4\ meters}$$

5.C. Construct equipotential surfaces for the following 3 configurations: a point charge, a dipole, and a quadrupole (four charges of equal magnitude on the four corners of a square, with the charges on adjacent corners having opposite sign). Draw enough equipotentials to get an idea of the way they behave. Choose values so that the values of the potential on your lines are equally spaced (e.g., draw equipotentials for potential values of 10, 9.5, 9, 8.5, 8, etc.). Sketch a careful graph of the potential along the x-axis. (Take this to run through the center of each configuration but orient your dipole and quadrupole so that the x-axis does not run through a charge. It will, of course, do so for a single charge.)

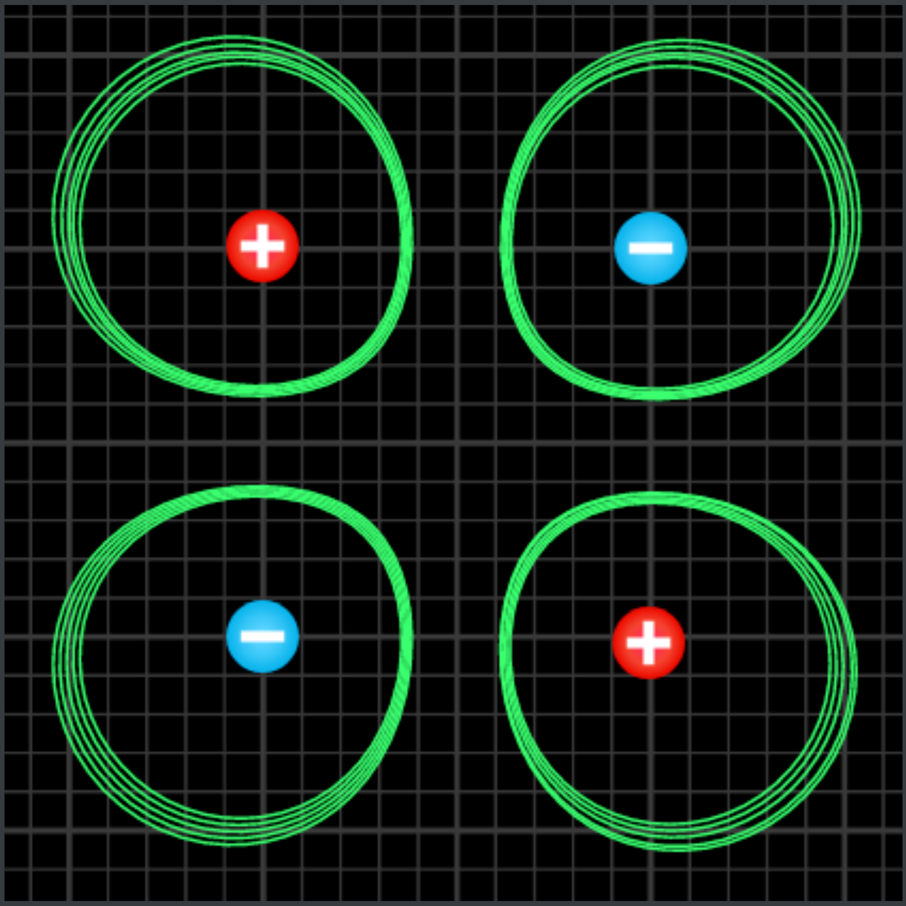
Point Charge



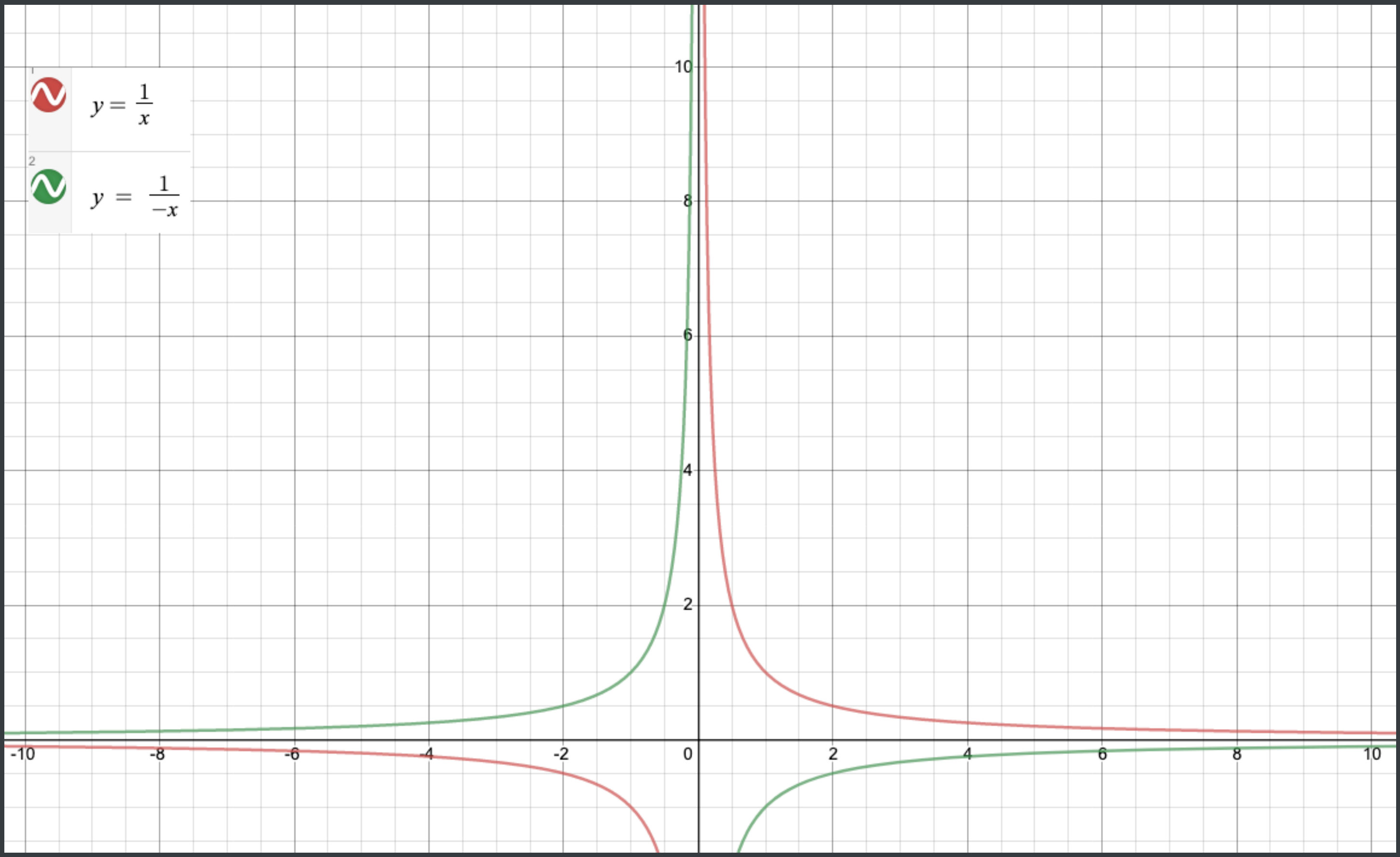
Dipole



Quadrupole



X-Axis Through Center of Dipole and Quadrupole



https://www.desmos.com/calculator/rgil7prmqf

$$Range = [0, \infty]$$

5.D. Which choice did the designer of this program make? Explain your decision with quantitative observations.

> - The programmer made it $3-D$ like
> - The Length of the Vector Lines fall off more similar to $\frac{1}{r^2}$ than to $\frac{1}{r}$

Homework 5

1.A. Express the unit Farad in terms of basic SI units (kilogram, meter, second, Coulomb).

> https://39363.org/NOTES/WSU/2021/Spring/PHY1120/MISC/Constants.html
>
> $$1\ Farad = \frac{1\ Coulomb}{1\ Volt} = \frac{1\ Coulomb}{\frac{1\ Joule}{1\ Coulomb}} = \frac{1\ Coulomb}{\frac{\frac{1\ Kilo\ Gram * 1\ Meter^2}{1\ Second^2}}{1\ Coulomb}} = \frac{1\ Coulomb^2}{\frac{1\ Kilo\ Gram * 1\ Meter^2}{1\ Second^2}} = \frac{1\ Coulomb^2 * 1\ Second^2}{1\ Kilo\ Gram * 1\ Meter^2}$$
>
> $$[Farad] = \frac{[Charge]^2 * [Time]^2}{[Mass] * [Length]^2}$$

1.B. What would be the electric field be between the sheets and what would the charge density on the sheets of the membrane? Explain your reasoning.

> https://physics.ucf.edu/~roldan/classes/Chap24_PHY2049.pdf
>
> $$Electric\ Field\ (E) = \frac{Potential\ Difference\ (\Delta V)}{Length\ (L)}$$
>
> $$Electric\ Field\ (E) = \frac{70\ mV * \frac{1\ Volt}{1000\ mV}}{8\ nm * \frac{1\ Meter}{1{*}10^9\ \ Nano\ Meters}} = \frac{8750000.0\ Volts}{1\ Meter}$$
>
> $$Charge\ Density\ (\sigma) = \frac{Total\ Charge\ (q)}{Surface\ Area\ (A)}$$
>
> $$Charge\ Density\ (\sigma) = \frac{70\ Milli\ Volts * \frac{1\ Volt}{1000\ mV}}{\left(8\ nm * \frac{1\ Meter}{1{*}10^9\ \ Nano\ Meters}\right)^2} = \frac{1093750000000000.0\ Volts}{1\ Meter^2}$$
>
> - Human Cell Radius = $0.5\ \mu\ Meter$
>
> $$Charge\ Density\ (\sigma) = \frac{70\ Milli\ Volts * \frac{1\ Volt}{1000\ mV}}{4 * \pi * \left(0.5\ \mu\ Meters * \frac{1\ Meter}{1{*}10^6\ \ \mu\ Meters}\right)^2} = \frac{22281692032.86535\ Volts}{1\ Meter^2}$$

1.C. How would that change the average E field and the surface charge density that you found in part (B)?

> $$Dielectric\ Constant\ (K) = \frac{Capacitance\ (C)_{dielectric}}{Capacitance\ (C_0)_{vaccum}}$$
>
> $$(Energy\ Density)_{dielectric}\ (u) = \frac{Dielectric\ Constant\ (K) * Permitivity\ In\ Vacuum\ (\epsilon_0) * Electric\ Field^2}{2}$$
>
> $$Surface\ Charge\ Density\ (\sigma) = \frac{Total\ Charge\ (q)}{Surface\ Area\ (A)}$$
>
> - Charge Density = Constant
> - Electric Field = Decreases
> - Potential Difference = $\frac{Potential\ Differecnce}{Dielectric\ Constant}$

1.D. How much work does it take to carry one sodium ion (charge = +e) across the membrane against the field? Express your answer in three ways: eV/ion, Joules/ion, and kilcalories/mole (the last for 1 mole of sodium ions).

> $$\frac{70\ Milli\ Electron\ Volts}{1\ Ion}$$
>
> $$1\ Elementary\ Charge\ (e) = 1.602176634 * 10^{-19} Coulomb$$
>
> $$Total\ Charge\ (q) *\ Potential\ Difference\ (\Delta V) = 1\ Elementary\ Charge *\ Potential\ Differnce\ (\Delta V)$$
>
> $$= 1.602176634 * 10^{-19} Coulomb * \frac{0.07\ Joule}{1\ Coulomb} = \frac{1.121523643800000 * 10^{-20}\ Joules}{1\ Ion}$$
>
> $$\frac{1.121523643800000 * 10^{-20}\ Joules}{1\ Ion} * \frac{6.022 * 10^{23}\ Ions}{1\ Mole} = \frac{6753.815382963601\ Joules}{1\ Mole}$$
>
> $$1\ Kilo\ Calorie = \frac{4.184\ Kilo\ Joules}{1\ Mole}$$
>
> $$\frac{6753.815382963601\ Joules}{1\ Mole} * \frac{1\ Mole}{4184\ Joules} = \frac{1.6080512816580004\ Kilo\ Calories}{1\ Mole}$$

2.A. Rank the capacitors according to the magnitude of the electric field between their plates.

> $$(a = b) < (c = d)$$

2.B. Rank the capacitors according to the amount of charge on their top plates.

> $$d > (b = c) > a$$

2.C. Rank the capacitors according to the net (total) amount of charge they contain.

> $$a = b = c = d$$

3.A. Explain why in this situation a potential difference (Nernst potential for Na+) would develop across the membrane and specify which side of the membrane would have the higher potential.

> $$Na^+ = \frac{\frac{8.314\ Joules}{1\ Kelvin \cdot mol} * (37 + 273.15\ ^\circ K)}{+1.0 * \frac{96485}{Volt \cdot mol} * \frac{1\ Volt}{1000\ mV}} * ln\left(\frac{[150]\ milli\ molar}{[5]\ milli\ molar}\right) = 90.89789804537297\ milli\ volts$$
>
> - To balance concentration levels across the membrane, sodium ions will flow from outside to inside the cell
> - The overall Nersnt potential will change as sodium diffuses across the membrane.
>
> $$Concentration_{outside} > Concentration_{inside} : ln\left(\frac{[outside]}{[inside]}\right) = Positive$$
>
> $$Concentration_{outside} = Concentration_{inside} : ln\left(\frac{[outside]}{[inside]}\right) = 0$$
>
> $$Concentration_{outside} < Concentration_{inside} : ln\left(\frac{[outside]}{[inside]}\right) = Negative$$
>
> - The side of the membrane with the majority of positive charge will have the "highest" potential at any given time.

3.B. If the Nernst potential for the sodium ions in our toy model is 60 mV, what would the concentration of NaCl be on the inside of the cell? Show your work.

$$\frac{\frac{8.314\ Joules}{1\ Kelvin\cdot mol} * (37 + 273.15\ ^\circ K)}{+1.0 * \frac{96485}{Volt\cdot mol} * \frac{1\ Volt}{1000\ mV}} * ln\left(\frac{[150]\ milli\ molar}{[X]_{inside}\ milli\ molar}\right) = 60\ milli\ volts$$

$$\frac{[150]\ milli\ molar}{[X]_{inside}\ milli\ molar} = e^{\left(60\ milli\ volts * \frac{+1.0*\frac{1\ Volt}{1000\ mV}}{\frac{8.314\ Joules}{1\ Kelvin\cdot mol}*(37+273.15\ ^\circ K)}\right)}$$

$$[X]_{inside}\ milli\ molar = \frac{[150]\ milli\ molar}{e^{\left(\frac{60\ milli\ volts\ *\ +1.0\ *\ \frac{96485}{Volt\cdot mol}*\frac{1\ Volt}{1000\ mV}}{\frac{8.314\ Joules}{1\ Kelvin\cdot mol}*(37+273.15\ ^\circ K)}\right)}} = 15.888071478941217\ milli\ molar$$

$$\cancel{\Delta V = \frac{k_B * T}{q} * ln\left(\frac{c_2}{c_1}\right)}$$

$$\cancel{\Delta V = \frac{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin} * (37 + 273.15\ ^\circ Kelvin)}{q} * ln\left(\frac{c_2}{c_1}\right)}$$

$$\cancel{ln\left(\frac{[150]_{outside}\ milli\ molar}{[X]_{inside}\ milli\ molar}\right) = \frac{60\ milli\ volts * q}{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin} * (37 + 273.15\ ^\circ Kelvin)}}$$

$$\cancel{\frac{[150]_{outside}\ milli\ molar}{[X]_{inside}\ milli\ molar} = e^{\left(\frac{60\ milli\ volts*q}{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin}*(37+273.15\ ^\circ Kelvin)}\right)}}$$

$$\cancel{[X]_{inside}\ milli\ molar = \frac{[150]_{outside}\ milli\ molar}{e^{\left(\frac{60\ milli\ volts*q}{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin}*(37+273.15\ ^\circ Kelvin)}\right)}}}$$

$$\Delta V = \frac{k_B * T}{q} * ln\left(\frac{c_2}{c_1}\right)$$

$$\frac{k_B * T}{q} * \frac{1\ Electron\ Volt}{1.602176634 * 10^{-19}\ Coulombs}$$

$$\frac{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin} * (37 + 273.15\ ^\circ Kelvin)}{+1} * \frac{1\ Electron\ Volt}{1.602176634 * 10^{-19}\ Coulombs} = 0.026726659112543266\ Volt * \frac{1000\ mV}{1\ Volt} = 26.726659112543267\ mV$$

$$\Delta V = ln\left(\frac{60\ mV}{26.726659112543267\ mV}\right)$$

$$\Delta V = e^{\left(\frac{-1*60\ mV}{26.726659112543267\ mV}\right)} = 0.10593288989449076$$

$$[X]_{inside}\ milli\ molar = 0.10593288989449076 * [150]_{outside}\ milli\ molar = 15.889933484173614\ milli\ molar$$

3.C. Will the presence of these ions increase the Na+ Nernst potential across the membrane, decrease it, or leave it the same? Explain your reasoning.

> $$Na^{+} = \frac{\frac{8.314\ Joules}{1\ Kelvin\cdot mol} * (37 + 273.15\ ^{\circ}K)}{+1.0 * \frac{96485}{Volt\cdot mol} * \frac{1\ Volt}{1000\ mV}} * ln\left(\frac{[150 + 0.04]_{outside}\ milli\ molar}{[15.888071478941217 + 4]_{inside}\ milli\ molar}\right) = 54.00592705658827\ Milli\ Volts$$
>
> $$54.00592705658827\ Milli\ Volts < 60\ Mili\ Volts = \color{red}{Decreased}$$

> $$Na^{+} = \frac{\frac{1.380649*10^{-23}\ Joules}{1\ Kelvin} * (37 + 273.15\ ^{\circ}Kelvin)}{+1} * \frac{1\ Electron\ Volt}{1.602176634 * 10^{-19}\ Coulombs} * \frac{1000\ mV}{1\ Volt} = 26.726659112543267\ mV$$
>
> $$= 26.726659112543267\ mV * ln\left(\frac{[150 + 0.04]_{outside}\ Milli\ Molar}{[15.889933484173614 + 4]_{inside}\ Milli\ Molar}\right) = 54.00624406707057\ Milli\ Volts$$
>
> $$54.00624406707057\ Milli\ Volts < 60\ Milli\ Volts = \color{red}{Decreased}$$

3.D. In the refined toy model can you calculate the Nernst potential for Cl- ions? If yes, calculate it. If not, explain why not.

> - You $\textit{can not}$ calculate the Nernst potential for chloride
> - They said there are ONLY ion channels for sodium
>   - $\therefore$ chloride ions cannot cross the membrane
>   - $\therefore$ no chloride gradient
>   - $ln\left(\frac{150}{0}\right)$ = divide by zero error

4.1. Which of the following are true statements?

> B = The lower curve represents a solution at higher temperature

4.2. In an ionic solution with a smaller Debye length, which of these effects will happen?

> D = Oppositely charged objects have a smaller tendency to attract

Homework 6

$$|Charge\ on\ Each\ Capacitor\ Plate| = Capacitance\ (C) * Voltage\ Difference\ Across\ Capacitor\ Plate\ (\Delta V)$$

$$V_1 - V_2 = \frac{Q}{C}$$

$$Total\ Resistance\ in\ Parallel = R_T = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{R_i}\right)}$$

$$Voltage\ Difference\ (\Delta V) = Current\ (I) * Resistance\ (R)$$

$$I_{in} = I_{out}$$

$$1\ Ohm\ (\Omega) = \frac{1\ Joule \cdot\ Second}{1\ Coulomb^2}$$

$$1\ Volt = \frac{1\ Joule}{1\ Coulomb}$$

$$1\ Watt = \frac{1\ Joule}{1\ Second} = \frac{kg \cdot m^2}{s^3} = Power$$

$$I = \frac{\Delta V}{R} = \frac{\frac{1\ Joule}{1\ Coulomb}}{\frac{1\ Joule \cdot\ Second}{1\ Coulomb^2}} = \frac{\cancel{1\ Joule}}{\cancel{1\ Coulomb}} * \frac{1\ Coulomb^{\cancel{2}}}{\cancel{1\ Joule}\ \cdot\ Second} = \frac{1\ Coulomb}{1\ Second}$$

$$Total\ Resistance\ in\ Series = \sum_{i=1}^{n}(R_i)$$

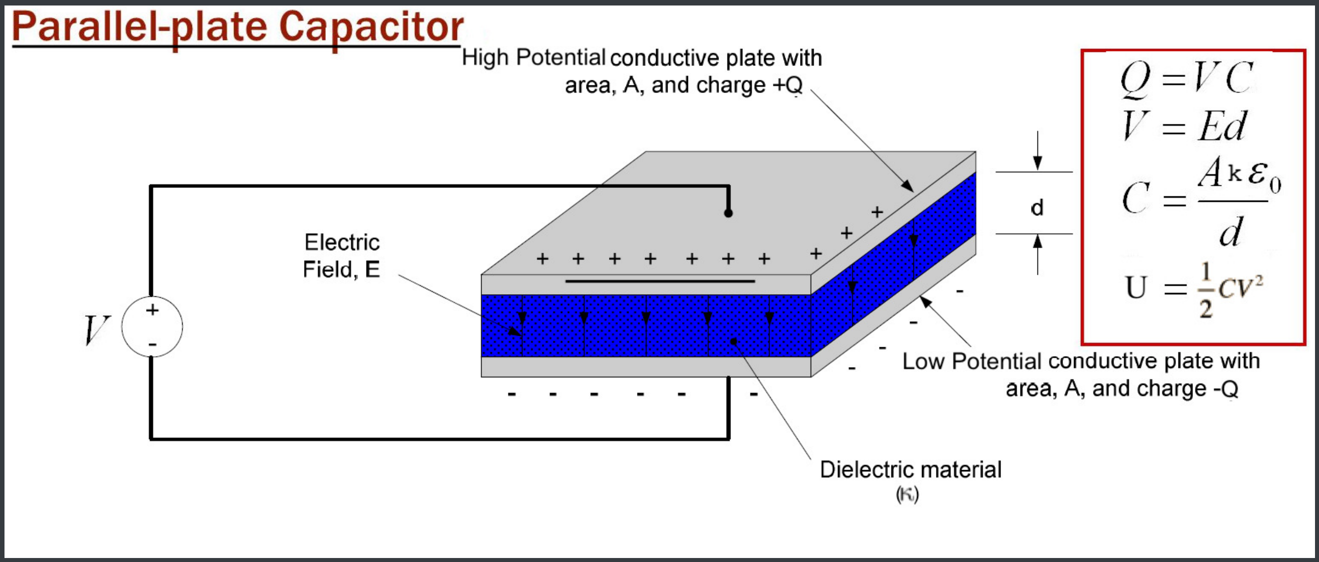
$$Capacitance\ in\ Series = C_{eq} = \frac{1}{\sum_{i=1}^{n}\left(\frac{1}{C_i}\right)}$$

$$Capacitance\ in\ Parallel = \sum_{i=1}^{n}(C_i)$$

$$Voltage\ Drop\ on\ Individual\ Resistor = \frac{Resistance_{individual}\ \Omega}{Resistance_{total}\ \Omega} * (Voltage_{total})$$

$$\Delta V_{across\ R_1} = Current\ (I) * R_1 = \frac{V * R_1}{Resistance_{total/eq}} = \frac{V * R_1}{R_1 + R_2}$$

1.A.1 What is the charge on the negative plate of capacitor C1 ? On the positive plate of capacitor C2 ? On the negative plate of capacitor C2 ? Explain how you know.



- Charge on C_1 Negative Plate = Negative Charge
- Equal and opposite to positive C_1 on top plate
- Charge on C_2 Positive Plate = Positive Charge
  - Equal and opposite to negative charge on bottom of C_1 plate
- Charge on C_2 Negative Plate = Negative Charge
- Equal and opposite to positive charge on C_1 top plate

1.A.2 If the voltage rise in the battery is ΔV, what is the voltage drop across each of the individual capacitors? Explain how you know.

> $$Voltage\ Drop\ C_1 = C_1 * \Delta V_1$$
>
> $$Voltage\ Drop\ C_2 = C_2 * \Delta V_2$$

1.A.3 Using your result above, find the effective capacitance of the combined pair of capacitors. (That is, what you would measure their capacitance as if they were contained in a box and you didn't know they were two separate capacitors.)

> $$Capacitance_{Effective} = \frac{Total\ Charge\ (Q)}{Total\ Voltage\ Drop\ (V_0)}$$
>
> $$V_0 = \Delta V_{C_1} + \Delta V_{C_2} = \frac{Q}{C_1} + \frac{Q}{C_2}$$
>
> $$V_0 = Q * \left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$
>
> $$Capacitance_{Effective} = \frac{Q}{V_0}$$
>
> $$Capacitance_{Effective} = \frac{\cancel{Q}}{\cancel{Q} * \left(\frac{1}{C_1} + \frac{1}{C_2}\right)} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2}} = \frac{1}{\frac{C_2}{C_1 * C_2} + \frac{C_1}{C_1 * C_2}} = \frac{1}{\frac{C_1 + C_2}{C_1 * C_2}} = \frac{C_1 * C_2}{C_1 + C_2}$$

1.B.1. If the charge on the positive plate of capacitor C1 is Q1 (a positive charge) and the charge on the positive plate of capacitor C2 is Q2 (a positive charge), what is the charge on the negative plate of capacitor C1 ? On the negative plate of capacitor C2 ? Explain how you know.

> - All the charges must balance , and capacitors must remain neutral
> - Negative Plate of C_1 = $-Q_1$
> - Negative Plate of C_2 = $-Q_2$

1.B.2 If the voltage rise in the battery is ΔV, what is the voltage drop across each of the individual capacitors? Explain how you know.

> - There are no resistors in the circuit, therefore there should be no voltage drop

1.B.3 Find Q1and Q2 in terms of C1, C2, and V0

> $$Q = C * \Delta V$$
>
> $$\Delta V_0 = \Delta V_1 = \Delta V_2$$
>
> $$Q_1 = C_1 * V_0$$
>
> $$Q_2 = C_2 * V_0$$

1.B.4 Using your results above, find the effective capacitance of the combined pair of capacitors. (That is, what you would measure their capacitance as if they were contained in a box and you didn't know they were two separate capacitors.

> $$Total\ Charge\ (Q) = Q_1 + Q_2$$
>
> $$Capacitance_{effective} = \frac{Q}{V_0} = \frac{(C_1 * \cancel{V_0}) + (C_2 * \cancel{V_0})}{\cancel{V_0}} = C_1 + C_2$$

1.C Can you relate the relationships you found above to how the capacitance depends on the shape (area and plate separation) of the capacitor? If you can, explain how. If you can't, explain why not.

> $$Capacitance\ (C) = \frac{Permittivity\ of\ Dielectric\ (\epsilon) * Area\ of\ Plates\ (A)}{Distance\ Between\ Plates\ (d)}$$

2.A When the network reaches a steady state is there any current through the batteries and resistors? Explain briefly why you think so.

https://archive.is/20130902130618/http://biology.unm.edu/toolson/b435/equivcirc.html

> - Current will flow everywhere in the single loop with the batteries
> - It will not flow through the left loop with the capacitor once its charged and reached a steady state

2.B. If you think that there is no current in the batteries and resistors in the steady state, find the voltage drop across each resistor. If you think that there is current, find the current through and voltage drop across each resistor.

> $$Current\ (I) = \frac{Voltage\ (\Delta V)}{Resistance\ (R)} = \frac{3 * V_0}{2 * R}$$

2.C. Is there a voltage difference across the plates of the capacitor? If so, find it. If not, explain why there is none.

> $$V_1 - V_2 = \frac{Total\ Charge\ (Q)}{Capacitance\ (C)}$$
>
> $$1\ Ohm\ (\Omega) = \frac{1\ Joule \cdot\ Second}{1\ Coulomb^2}$$
>
> $$1\ Volt = \frac{1\ Joule}{1\ Coulomb}$$
>
> $$\Delta V = \frac{Charge\ (Q) * Distance\ (d)}{Permittivity\ of\ Dielectric\ (\epsilon) * Area\ (A)}$$
>
> $$Voltage\ Difference\ (\Delta V) = V_0 - \left(\frac{3 *\ V_0}{2 * R}\right)$$

3.A. Which of the following statements are likely to be at least partially responsible for the validity of Ohm's law for this resistor?

> - $i.$ The resistor is made from a material that is a conductor
> - $iv.$ Moving charges in the resistor feel a resisting drag force that is linearly proportional to their velocity.

3.B. Suppose that the original resistor is replaced by a resistor of the same length and identical material but twice the cross sectional area. Further suppose that the potential drop across the resistor is the same as for the original. The current through the new resistor will be

> - $ii.$ Twice as big as for the original resistor

3.C. Suppose that the original resistor is replaced by a resistor of the same cross sectional area and identical material but twice the length. Further suppose that the potential drop across the resistor is the same as for the original. The current through the new resistor will be

> $iii.$ Half as big as for the original resistor

3.D. Suppose that the original resistor is replaced by a resistor of the same physical dimensions but made of a material that has half the density of charges to carry current, but each carrier has double the charge of those in the original resistor. Further suppose that the potential drop across the resistor is the same as for the original The current through the new resistor will be

> $ii.$ Twice as big as for the original resistor

4.1 Which of the following must be true of the currents in the circuit?

> - *d.* $i_A = i_B + i_C$

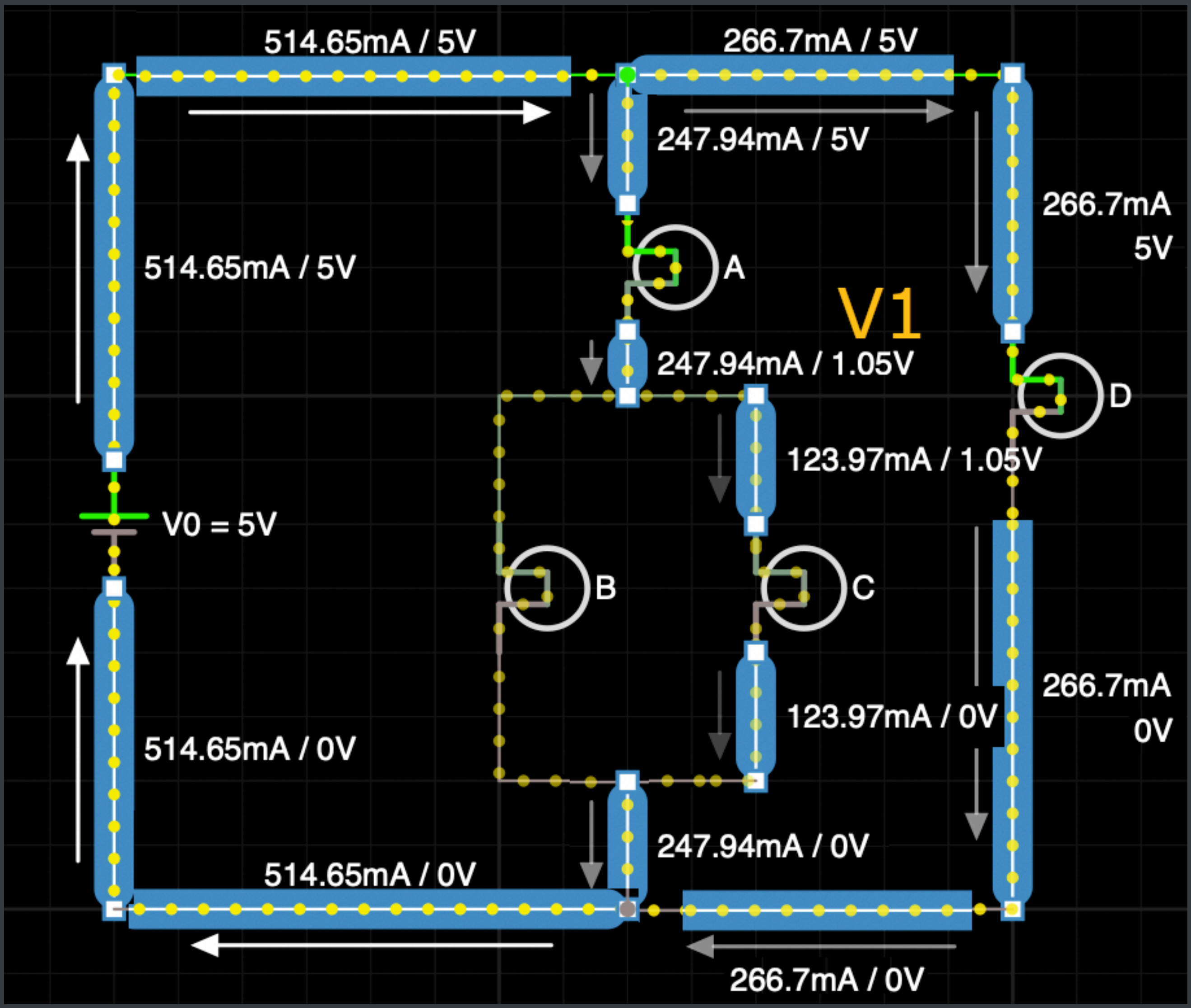
4.2. What is the relationship between i_B and i_C?

> - *d.* $i_B = 2 * i_C$

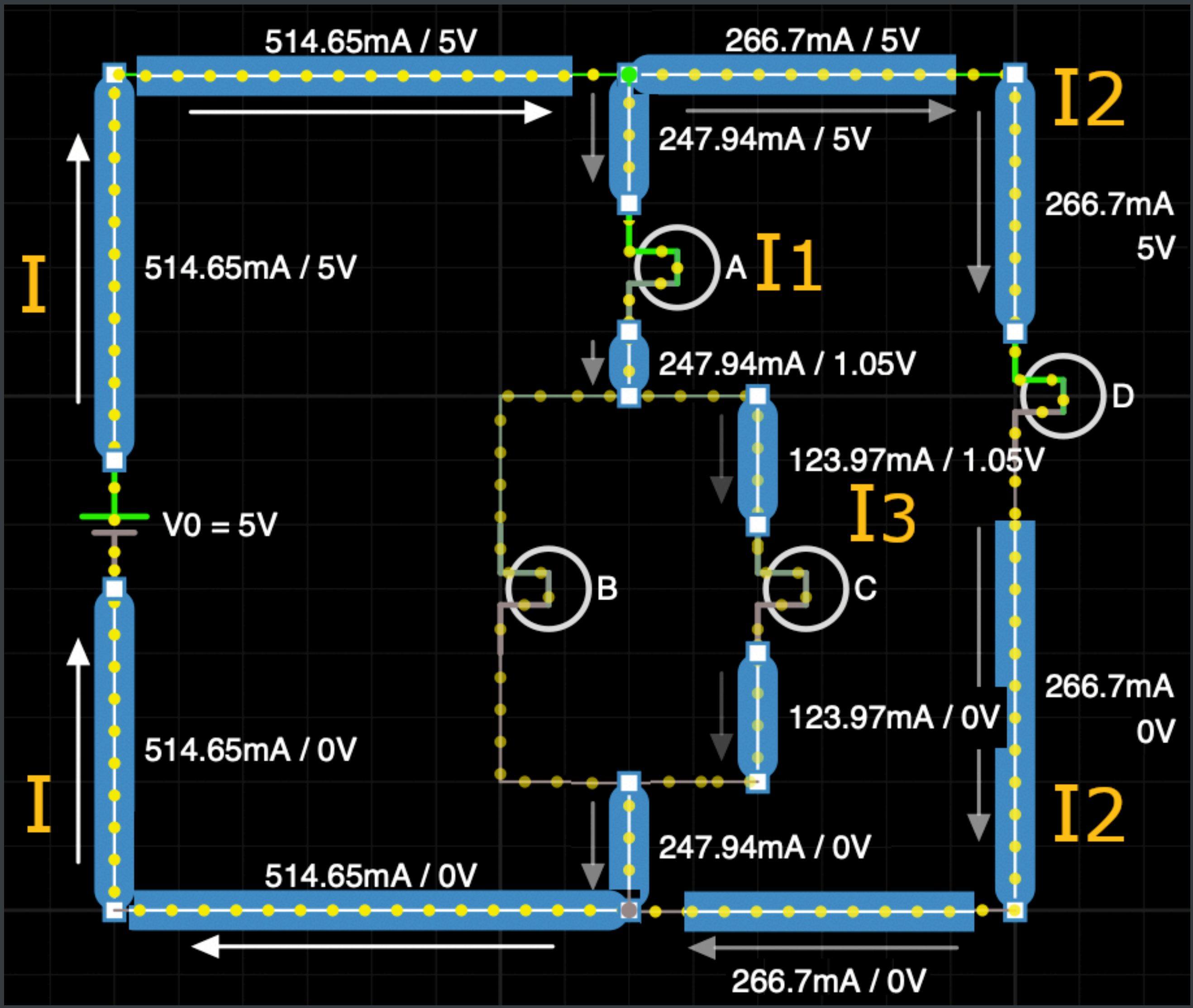
4.3. Which of the following must be true about the potential drops in the circuit?

> - *e.* $\Delta V_0 = \Delta V_A + \Delta V_B$
> - *f.* $\Delta V_0 = \Delta V_A + \Delta V_C$

5.1.A Draw a copy of this circuit and make a "voltage map", showing the voltage at each point in the circuit. If you have some points at which there is a voltage you do not know, give it a name (e.g., "V1 ").



5.1.B. Assume that the current through the battery is equal to I (the letter "eye", not the number "one"). Draw a copy of this circuit and make a "current map", showing the current at each point in the circuit. If you have some points at which there is a current you do not know, give it a name (e.g., "I1 ").



514.65mA / 5V
266.7mA / 5V
I2
247.94mA / 5V
266.7mA
5V
I
514.65mA / 5V
A
I1
247.94mA / 1.05V
D
123.97mA / 1.05V
V0 = 5V
I3
B
C
266.7mA
0V
123.97mA / 0V
514.65mA / 0V
I
I2
247.94mA / 0V
514.65mA / 0V
266.7mA / 0V

5.1.C. Use Kirchhoff's three principles to generate as many independent equations relating the voltages, currents, and resistances in your maps as you can. Solve for the voltage drops across each of the bulbs and the currents through each of the bulbs and the battery in terms of the given parameters, V0 and R.

> $$R_{eq} = \left[\frac{1}{R_A + \left(\frac{1}{R_B} + \frac{1}{R_C} \right)^{-1}} + \frac{1}{R_D} \right]^{-1}$$
>
> $$Total\ Current = \frac{V_0}{\left[\frac{1}{R_A + \left(\frac{1}{R_B} + \frac{1}{R_C} \right)^{-1}} + \frac{1}{R_D} \right]^{-1}}$$

> $$I_{in} = I_{out}$$
>
> $$I_A = I - I_D$$
>
> $$I_D = \frac{V_0}{R_D}$$
>
> $$I_B = I_C = \frac{I_A}{2}$$

Left Loop

$$V_0 - (I_A * R_{eq}) - (I_C * R_{eq}) = 0$$

Outer Loop

$$(I_A * R_{eq}) + (I_C * R_{eq}) = (I_D - I_A) * R_{eq}$$

$$I_D = (2 * I_A) + I_C$$

Inner Loop

$$(I_A - I_C) * R_{eq} = I_C * R_{eq}$$

$$I_A = 2 * I_C$$

System of Equations Solver

$$I_A = \frac{2 * I_D}{5}$$

$$V_0 = \frac{3 * I_D * R_{eq}}{5}$$

$$I_D = \frac{5 * V_0}{3 * R_{eq}}$$

$$I_A = \frac{2 * \left(\frac{5 * V_0}{3 * R_{eq}}\right)}{5} = \frac{2 * V_0}{3 * R_{eq}}$$

$$I_B = I_C = \frac{I_D}{5} = \frac{\frac{5 * V_0}{3 * R_{eq}}}{5} = \frac{V_0}{3 * R_{eq}}$$

5.2.A What do you expect will happen to the current through bulb A, bulb D, and the battery? Make this decision before you do any calculations. Explain why you made the choice you did.

> - Lamps B and C are in Parallel to each other and then in series with Lamp A
>   - Voltage Drop = $\frac{2*V_0}{3}$
> - When Lamp B is removed:
>   - A and C are now in series
>   - Resistance Increases
>   - There voltage drop becomes $\frac{V_0}{2}$
>   - Bulb C becomes brighter
>   - Bulb A becomes Dimmer
>   - Current from Battery = Sum of Current in Parallel Loops
>   - = Decreases

5.2.B Now repeat the tasks you carried out in part 1 to solve for the voltage drops across each of the bulbs and the currents through each of the bulbs and the battery in terms of the given parameters, V0 and R.

> $$I_A = I_C = \frac{V_0}{R_A + R_C}$$
>
> $$I_D = \frac{V_0}{R_D}$$
>
> $$V_0 - V_D = 0$$

$$I_0 = I_A + I_B$$

$$I_A = \frac{V_0 - V_{1_{unknown}}}{R}$$

$$I_B = I_C = \frac{V_{1_{unknown}}}{R}$$

$$I_D = \frac{V_0}{R}$$

$$I_x = I_0 - I_D$$

$$V_0 - (I_A * R_A)$$

$$I_A = \frac{V_0}{2 * R}$$

$$V_1 = \frac{V_0}{2}$$

$$I_D = \frac{V_0}{R}$$

$$I_C = \frac{3 * V_0}{2 * R}$$

5.2.C Did your results agree with your predictions? If you made a correct prediction, do you see how the equations lead to this result? If they do not, do you see what went wrong with your reasoning? Discuss!

> - Yes they agree
> - The total resistance in parallel of Lamp B and C is less than resistance of Lamp A and C in series
>   - Total resistance increased when Lamp B was removed
> - Voltage drop on Lamp A Before Lamp B is Removed = $\frac{2*V_0}{3}$
> - Voltage drop on Lamp A After Lamp B is Removed = $\frac{V_0}{2}$
> - Voltage drop after removed is larger
>   - This agrees with Lamp A becoming dimmer

Physics 1120 – Homework 7

1. Fill out the table by matching the graphs below with each of these quantities in these cases A and B. If none work, put 9.

Gravitational P.E.

$$Case\ A = 0.1\ kg * \frac{10\ N}{1\ kg} * 0.2\ meters = 0.2\ N \cdot meters = 0.2\ Joules$$

$$Case\ B = 0.1\ kg * \frac{10\ N}{1\ kg} * 0.6\ meters = 0.6\ N \cdot meters = 0.6\ Joules$$

Elastic P.E.

$$Case\ A = \frac{5\ N}{1\ meter} * 0.3\ meters^2 = 0.225\ Joules$$

$$Case\ B = \frac{5\ N}{1\ meter} * 0.5\ meters^2 = 0.625\ Joules$$

Kinetic Energy

$$Case\ A = \left(0.1\ kg * \frac{9.8\ N}{1\ kg} * -0.1\ meter\right) + \left(\frac{\frac{5\ N}{1\ meter} * \left((0.3\ meters)^2 - (0.2\ meters)^2\right)}{2}\right) = 0.026999\ Joules$$

$$Case\ B = \left(0.1\ kg * \frac{9.8\ N}{1\ kg} * -0.3\ meter\right) + \left(\frac{\frac{5\ N}{1\ meter} * \left((0.5\ meters)^2 - (0.2\ meters)^2\right)}{2}\right) = 0.230999\ Joules$$

	Case A	Case B
Gravitational P.E.	5	6
Elastic P.E.	1	8
Kinetic Energy	3	4
Total Energy	7	2

2. Estimate the electric energy stored in the polarized membrane of a motor neuron. Be sure to clearly state your assumptions and how you came to the numbers you estimated, since grading on this problem will be mostly based on your reasoning, not on your answer.

> - Assume axon = parallel plate capacitor
>
> $$Area\ of\ Capacitor\ Plate = Circumference * Length$$
>
> $$Area\ of\ Capacitor\ Plate = \left(2 * \pi * 10\ \mu m * \frac{1\ Meter}{1 * 10^{6} \mu m}\right) * Length\ (L) = 6.283185307179587 * 10^{-5}\ meters * Length_{meters}$$
>
> $$Capacitance = \frac{Area\ of\ Capacitor\ Plate\ (A)}{4 * \pi * Coulomb's\ Constant\ (k_c) * Plate\ Separation\ Distance\ (d)}$$
>
> $$Capacitance = \frac{6.283185307179587 * 10^{-5}\ meters * Length_{meters}}{4 * \pi * \frac{8.9875517923 * 10^{9}\ Newton \cdot meters^{2}}{1\ Coulomb^{2}} * Plate\ Separation\ Distance\ (d)}$$
>
> $$= \frac{6.283185307179587 * 10^{-5}\ meters * Length_{meters}}{4 * \pi * \frac{8.9875517923 * 10^{9}\ Newton \cdot meters^{2}}{1\ Coulomb^{2}} * 8\ nm * \frac{1\ Meter}{1 * 10^{9}\ nm}} = \frac{6.283185307179587 * 10^{-5}\ meters * Length_{meters}}{\frac{903.5272539023186\ Newton \cdot meters^{3}}{1\ Coulomb^{2}}} = \frac{6.283185307179587 * 10^{-5}\ meters * Length_{meters} * 1\ Coulomb^{2}}{903.5272539023186\ Newton \cdot meters^{3}}$$
>
> $$= \frac{6.283185307179587 * 10^{-5} Coulombs^{2}}{903.5272539023186\ Newton \cdot meters} = 6.954062846519148 * 10^{-8}\ Farads$$
>
> $$Energy = \frac{Capacitance\ (C) * \Delta V^{2}}{2}$$
>
> $$Energy = \frac{6.954062846519148 * 10^{-8}\ Farads * \left(70\ mV * \frac{1\ Volt}{1000\ mV}\right)^{2}}{2} = 1.7037453973971913 * 10^{-10}\ Joules$$

3.A. Find the period (T) , frequency (f) , and angular frequency (ω_0) of the oscillation.

$$Period\ (T) = 2\ seconds$$

$$Frequency\ (f) = \frac{1}{T} = \frac{1}{2\ seconds} = 0.5\ Hertz$$

$$Angular\ Frequency = 2 * \pi * frequency = 2 * \pi * 0.5\ Hertz = \frac{\pi\ Radians}{1\ second}$$

3.B. If the spring constant is k = 2.5 N/m, can you find the mass of the cart? If you can, do it and explain your reasoning. If you can't, explain why not.

$$Angular\ Frequency\ (\omega) = \sqrt{\frac{Spring\ Constant\ (k)}{Mass\ (m)}}$$

$$Mass = \frac{Spring\ Constant\ (k)}{(Angular\ Frequency\ (\omega))^2} = \frac{\frac{2.5\ Newtons}{1\ meter}}{\left(\frac{\pi\ Radians}{1\ second}\right)^2} = \frac{2.5\ Newtons}{1\ meter} * \frac{1\ Second^2}{\pi\ Radians^2}$$

$$= \frac{\frac{2.5\ kg \cdot\ meters}{1\ second^2}}{1\ meter} * \frac{1\ Second^2}{\pi\ Radians^2} = 0.25330295910584444\ kg$$

3.C. Find the effective spring constant between the two atoms.

$$Spring\ Constant\ (k) = Mass\ (m) * Angular\ Frequency\ (\omega)^2$$

$$Spring\ Constant\ (k) = (2.3 * 10^{-26}\ kg)_{nitrogen} * \left(\frac{4.5 * 10^{18}\ radians}{1\ second}\right)^2 = \frac{4.65750 * 10^{11}\ Newton}{1\ Meter} * \frac{1\ Meter}{1 * 10^9\ nm} = \frac{465.75\ Newtons}{1\ nano\ meter}$$

4.1.A. Resistor (R)

> $$Resistance\ (R) = \frac{Potential\ Difference\ (\Delta V)}{Current\ (I)}$$
>
> $$[Resistance\ (R)] = \frac{\frac{M*L^2}{T^2*Q}}{\frac{Q}{T}} = \frac{M*L^2}{Q^2*T}$$

4.1.B. Capacitor (C)

> $$Capacitance\ (C) = \frac{Charge\ (Q)}{Potential\ Difference\ (\Delta V)}$$
>
> $$[Capacitance\ (C)] = \frac{Q}{\frac{M*L^2}{T^2*Q}} = \frac{Q^2*T^2}{M*L^2}$$

4.1.C. Inductor (L)

> $$Inductor\ (L) = \frac{Potential\ Difference\ (\Delta V)}{\frac{dI}{dt}}$$
>
> $$[Inductor\ (L)] = \frac{\frac{M*L^2}{T^2*Q}}{\frac{Q}{T}} = \frac{M*L^2}{Q^2}$$

4.2.A. Use dimensional analysis to construct two constants with the dimension T (time), one using R and C, the other using L and C.

> $$[R*C] = \frac{M*L^2}{Q^2*T} * \frac{Q^2*T^2}{M*L^2} \cdot = T$$
>
> $$[L*C] = \frac{M*L^2}{Q^2} * \frac{Q^2*T^2}{M*L^2} = T^2$$

4.2.B. Explain how you got your answers

> - For [R*C] , the units all just cancel , and you are left with Time
> - For [L*C] , the units all just cancel , and you are left with $Time^2$

4.2.C. Which do you think is which? Why?

> - Period of Oscillation = [L*C]
>   - Inductor = momentum through the stored energy in capacitor
> - Decay Time = [R*C]
>   - Time constants are usually linear time

5.A. When the pendulum is at -30° , what form(s) of energy does it have?

> Potential Energy

5.B. At what angle is the pendulum swinging the fastest?

> @ 0°

5.C. At which locations is the acceleration equal to zero?

> Nowhere , in the simulation the pendulum is always swinging

5.D. How does the tension of the rope compare to the force of gravity when the angle is 0 degrees?

> $Tension > Gravity$

5.E. With the pendulum swinging back and forth, where is the tension equal to zero?

> $Tension = 0$ @ $\pm 90^\circ$

5.F. What is the period of oscillation?

> 2 seconds

5.G. How does the period of oscillation depend on the initial angle of the pendulum when released?

> $Period \propto Angle_{initial}$

5.H. How does the period of the pendulum depend on mass?

> $Let\ Independent = \perp\!\!\!\perp$
>
> $Period\ \perp\!\!\!\perp\ Pendulum's\ Mass$

5.I. How does the period of the pendulum depend on the length?

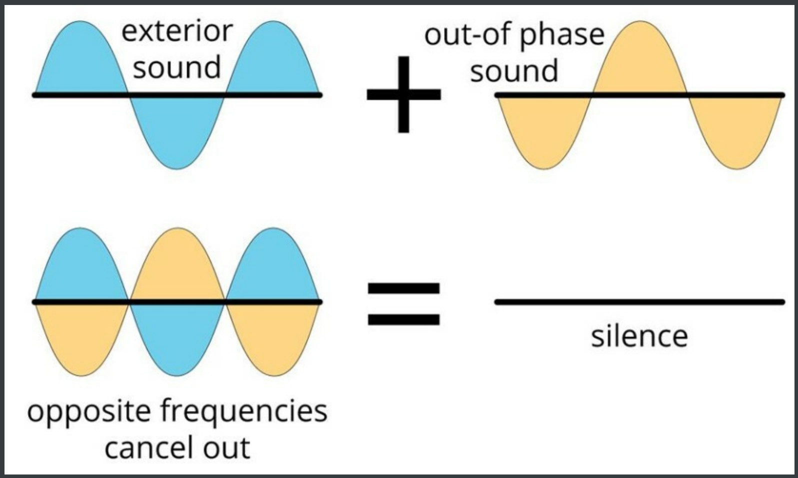
> $Period \propto Length$

5.J. How does the period of oscillation depend on the value of g?

> $Period \propto \frac{1}{g}$

Physics 1120 – Homework 8

1. Can there be such a thing as noise canceling headphones? If so, how would they work? (What would the basic principles be, and how would they be implemented?) If not, what is the best physics based argument or evidence that they are no more than an invention of the marketing department?

> 
>
>
> https://dsp.stackexchange.com/questions/23173/how-do-can-we-cancel-out-noises-while-listening-voice-on-headphones
>
> - They are not a gimmick
>   - I have used the bose noise-cancelling headphones for around 2 years
>   - They work wonders
> - They work by using a microphone to detect the frequencies of the surrounding environment, and then they play an opposite, out-of phase wave that "destructs" the environmental frequencies.

2.A. The graph of the y displacement of the spot of paint as a function of time.

> Graph "A"

2.B. The graph of the y velocity of the spot of paint as a function of time.

> Graph "F"

2.C. The graph of the x velocity of the spot of paint as a function of time.

> Graph "B"

2.D. The graph of the y component of the force on the piece of string marked by the paint as a function of time.

> Graph "D"

3.A.1 What is the function, $y(x,t)$, that describes the shape of the spring at a time t if this pulse is moving to the right with the speed V_0 ?

> $$y(x,t) = f(x - (V_0 * T))$$

3.A.2. Is it possible to predict the width of the pulse that moves along the spring? If so, find it. If not, explain why not

> - Yes

$$Width\ of\ the\ Pulse = V_0 * \Delta T = \frac{250\ cm}{1\ Second} * (0.5\ Seconds - 0\ Seconds) = 125\ cm$$

3.B.1. Is the wave shape described by this function moving to the left (in the direction of the negative x axis) or to the right (in the direction of the positive x axis)?

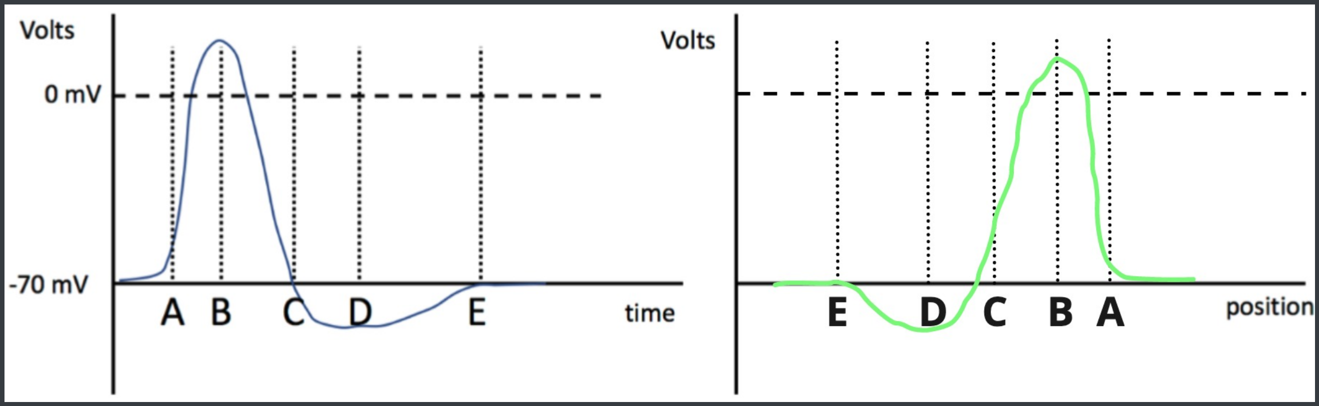
> - To the right

3.B.2. How fast is the shape traveling down the spring?

> https://en.wikipedia.org/wiki/Phase_velocity
>
> $$Speed\ of\ a\ Wave\ (V) = Frequency\ (f) * Wavelength\ (\lambda)$$
>
> https://en.wikipedia.org/wiki/Dispersion_(water_waves)
>
> $$Phase\ Velocity = \frac{Angular\ Frequency\ (\omega)}{Wave\ Number\ (k)}$$
>
> $$Phase\ Velocity = \frac{25\ Hertz\ \left(\frac{cycles}{1\ second}\right)}{\frac{0.125\ Wave\ Lengths}{1\ cm}} = \frac{200\ cm \cdot Cycles}{1\ Wave\ Length \cdot Second}$$

4.1.1. Sketch the shape of the action potential as a function of position at some arbitrary moment in time.

4.1.2. Label the features of your sketch (A, B, C, D, E)

> 

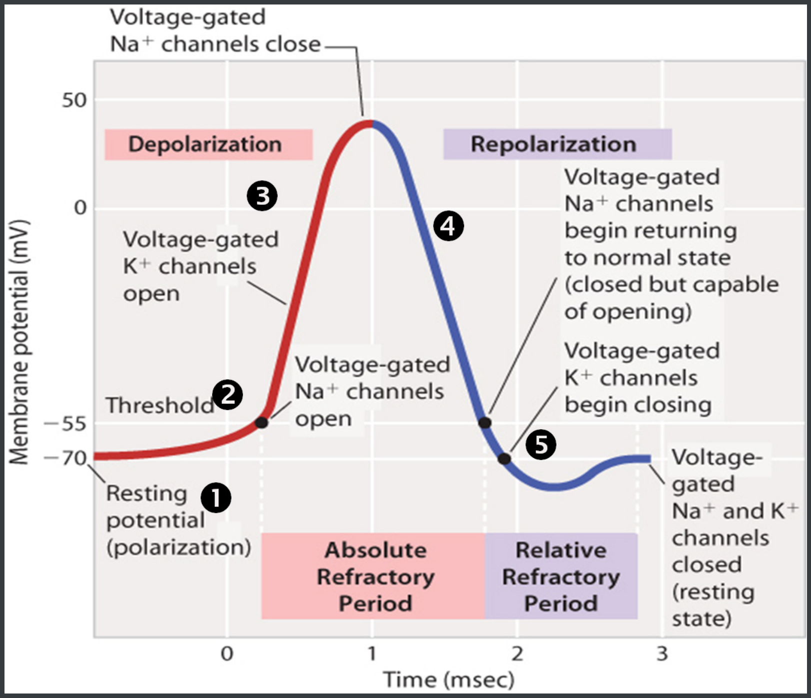
4.1.3. What is the approximate distance between points A and E on your sketch?

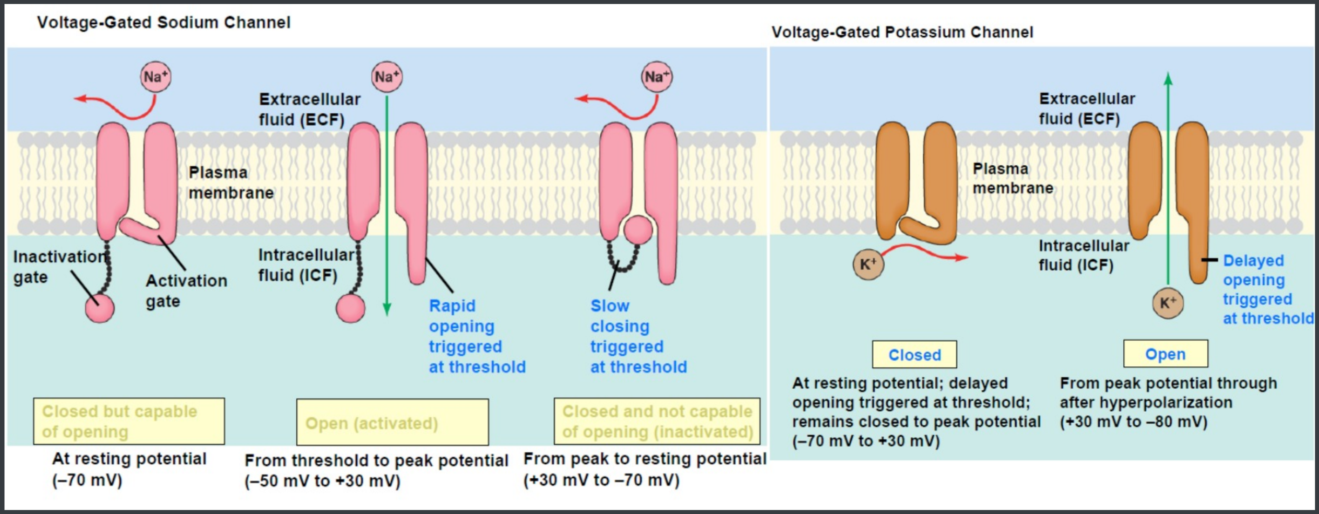
> $$Distance = Pulse\ Velocity * \Delta T$$
>
> $$Distance = \frac{20\ meters}{1\ second} * 4\ ms * \frac{1\ second}{1000\ ms} = 0.08\ meters$$

4.1.4. Given these constraints, how might action potentials be used to convey more than one piece of information?

> https://en.wikipedia.org/wiki/Synaptic_plasticity
>
> $$External\ Stimulus\ Amplitude \propto Frequency\ of\ Action\ Potentials$$
>
> - The frequency of action potentials can be used in synaptic plasticity
> - Long term potentiation or long term depression (synaptic plasticity) is based on the frequency and time duration of action potentials

4.1.5. How might the cell membrane actually control the electric potential that exists between the inside and outside of the cell and what quantities could be measured to test your proposed mechanism?

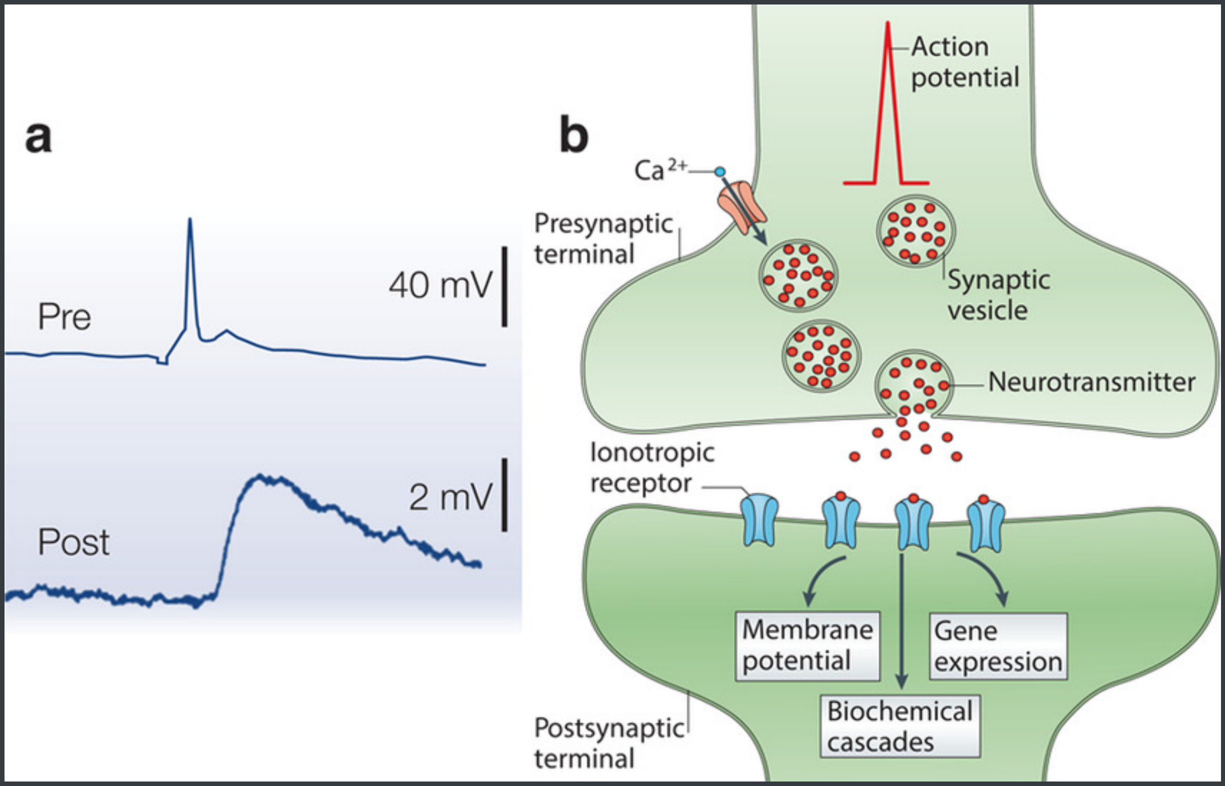




- https://en.wikipedia.org/wiki/Voltage-gated_ion_channel
- Neuron cells control the electric potential inside and outside through voltage-gated ion channels
- The Nernst equation includes a $ln\left(\frac{[C_{outside}]}{[C_{inside}]}\right)$ operator

- Voltage-gated Ion channels open and close in response to different voltages they experience
    - In this way, the cell can control the concentrations of a particular ion inside and outside the cell

4.1.6. How much of a change in potential can these neurotransmitters induce, and for how long?



- The change in membrane potential during the relative refractory period , point "C" to point "E" , is around $15\ mV$
- The time duration between point "C" and point "E" is around $0.8\ ms$

Physics 1120 – Homework 9

Ignore the effects of gravity in this problem. Briefly explain each of your answers

1.A. How do the tensions in the two parts of the string compare?

> - A , The tensions in the two parts of the string are the same
> - Both tensions cancel
>   - $\therefore$ Both magnitudes are the same

1.B. How do the speeds of wave propagation in the two parts of the string compare?

> - B , The speed of propagation is greater in the light part of the string
>
> $$Wave\ Propagation\ Speed = \sqrt{\frac{Tension}{Linear\ Mass\ Density\ of\ String}}$$
>
> - Tension is constant
>
> $$Wave\ Propagation\ Speed \propto \sqrt{\frac{1}{Linear\ Mass\ Density\ of\ String}}$$

1.C. After the last bit of the pulse has reached the joining point, the heavy side of the string will display

> - C , a pulse of smaller width
> - After the joining point, the wave propagation speed is slower
>   - Pulse can't travel as far per unit time
>   - $\therefore$ width is smaller

1.D. How does the time it takes bits of matter on the heavy side of the string to go up and down compared to what it took the bits of matter on the light side of the string?

> - C , They will move up and down in the same amount of time on both sides of the string
> - Period is the same

1.E. How will the frequency of the oscillation of the bits of matter on the heavy side of the string compare to what is was on the light side of the string?

> - C , The frequency will be the same on both sides of the string
> - Period is the same
>   - $\therefore$ frequency is the same

1.F. How will the wavelength on the heavy side of the string compare to what it was on the light side of the string?

> - B , The wavelength will be greater on the light side of the string
> - $$Wavelength\ (\lambda) = \frac{Velocity}{Frequency}$$
> - Doesn't travel as far on the heavy side per period
>   - $\therefore$ wavelength on heaver side is smaller

2. For each of the changes described below give the factor by which the period changes.

$$Wave\ Period\ (T) = \frac{1}{Frequency\ (f)} = \frac{Wavelength\ (\lambda)}{Velocity\ (v)}$$

$$Wave\ Propagation\ Velocity = Frequency\ (f) * Wavelength\ (\lambda)$$

$$Wave\ Propagation\ Velocity = \sqrt{\frac{Tension\ (T)}{Linear\ Mass\ Density\ of\ String\ (\mu)}}$$

$$Angular\ Velocity\ (\omega) = 2 * \pi * Frequency\ (f)$$

$$Frequency\ (f) = \frac{Angular\ Velocity\ (\omega)}{2 * \pi}$$

$$Power\ Transmitted\ By\ String\ Wave = \frac{Linear\ Mass\ Density\ (\mu) * Angular\ Velocity\ (\omega)^2 * Wave\ Amplitude\ (A)^2 * Wave\ Propagation\ Velocity\ (v)}{2}$$

2.A. The string is replaced by one of twice the mass but of the same length

> - If wavelength = Constant
>   - $Frequency \propto Velocity$
>   - $V = \sqrt{\frac{T}{2*\mu}}$
>   - $Period = \sqrt{\frac{2*\mu}{T}}$
>   - $= \sqrt{2}$

2.B. The wave length of the starting shape is divided by three

> - $= \frac{1}{3}$

2.C. The amplitude of the oscillation is doubled

> - $= 1$

2.D. The tension of the string is halved

> - $= \sqrt{2}$

3.1. Graph A is a graph of the string's shape and graph B is a graph of the string's transverse velocity

> - A , a right going traveling wave

3.2. Graph A is a graph of both the string's shape and the string's transverse velocity

> - C , a part of a standing wave growing in amplitude at time t_1

3.3. Graph B is a graph of the string's shape and graph A is a graph of the string's transverse velocity

> - B , a left going traveling wave

4.1. Using dimensional analysis, propose an equation for the speed of sound in air using only these two parameters. Calculate what speed of sound your formula predicts and compare it to the real speed of sound. How well does the formula created by dimensional analysis do?

> $$Pressure = \frac{Force}{Area} = \frac{Newtons}{meters^2} = \frac{kilo\ gram \cdot meters}{meters^2 \cdot seconds^2} = \frac{1\ kilo\ gram}{1\ meter \cdot seconds^2}$$
>
> $$Density = \frac{Mass}{Volume} = \frac{kilo\ grams}{meters^3}$$
>
> $$Air\ Velocity = \sqrt{\frac{Air\ Pressure}{Air\ Density}} = \sqrt{\frac{\frac{1\ kilo\ gram}{1\ meter \cdot seconds^2}}{\frac{kilo\ grams}{meters^3}}} = \sqrt{\frac{1\ kilo\ gram}{1\ meter \cdot seconds^2} * \frac{meters^3}{1\ kilo\ gram}} = \sqrt{\frac{1\ meter^2}{1\ second^2}} = \frac{[Length]}{[Time]}$$
>
> $$Air\ Velocity = \sqrt{\frac{100,000\ Pascals}{\frac{1\ kilo\ gram}{1\ meter^3}}} = \sqrt{\frac{\frac{100,000\ kilo\ grams}{1\ meter \cdot seconds^2}}{\frac{1\ kilo\ gram}{1\ meter^3}}} = \sqrt{\frac{100,000\ kilo\ grams}{1\ meter \cdot seconds^2} * \frac{1\ meter^3}{1\ kilo\ gram}} = \sqrt{\frac{100,000\ meters^2}{1\ second^2}} = \frac{316.22776601683796\ meters}{1\ second}$$
>
> $$Actual\ Speed\ of\ Sound\ Through\ Air\ on\ Wikipedia = \frac{343\ meters}{1\ second}$$
>
> $$Percent\ Error = \left|\frac{343 - 316.22776601683796}{343}\right| * 100\% = 7.805316030076397\ \%$$

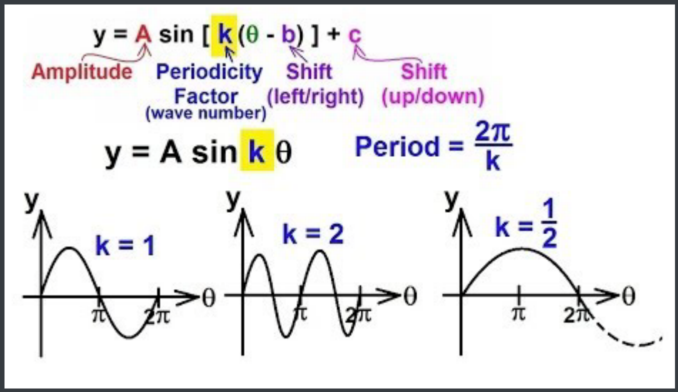
4.2. Write the equation for the frequency of the n-th standing wave for the closed-open string, expressing your answer in terms of n (the number of which standing wave it is counting 1 as the first one allowed), L, (the length of the string), and V_0 (the speed of waves on the string.

> $$Frequency\ (f) = \frac{((2 * n) + 1) * V_0}{4 * Length}$$

4.3. Using your results from parts 1 and 2 and an estimate of the size of your vocal cavity, estimate the frequency of the lowest normal mode in your vocal cavity.

> https://en.wikipedia.org/wiki/Vocal_tract
>
> $$Let\ Length\ (L) = 16.9\ cm = 0.169\ meters$$
>
> $$Length = \frac{Lowest\ Frequency\ (\lambda)}{4}$$
>
> $$Frequency = \frac{Air\ Velocity}{Wave\ Length\ (\lambda)}$$
>
> $$Frequency = \frac{\frac{343\ meters}{1\ second}}{4 * 0.169\ meters} = 507.39644970414196\ Hz$$

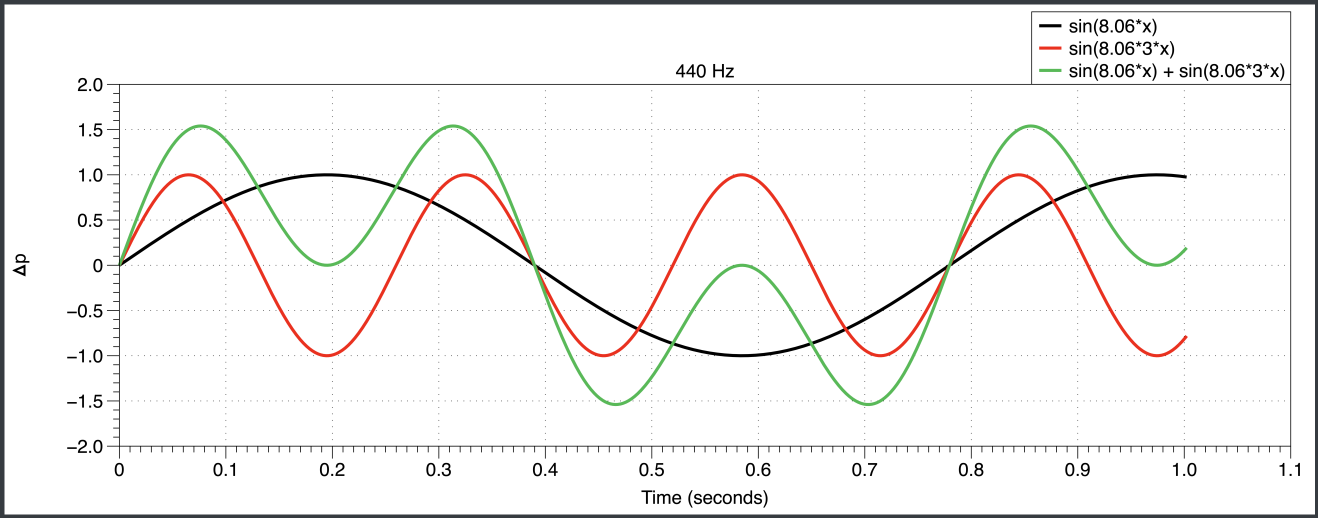
5.1. Use Excel (or comparable) to produce a graph of one period of a sine wave. Add to this a second sine wave of equal amplitude and three times the frequency. Finally, produce the curve that is the sum of these two waves. Label the vertical-axis as "delta p" and the horizontal-axis as "time". If the frequency of the first wave were 440 Hz and the time axis were in seconds, what would be the value of t (time, in seconds) at the end of the sketch of one period?



$$Wave\ Period\ (T) = \frac{1}{Frequency\ (f)} = \frac{Wavelength\ (\lambda)}{Velocity\ (v)} = \frac{1}{440\ Hz} = \frac{1}{\frac{440\ Cycles}{1\ Second}} = 0.0022727272727272726\ seconds$$

$$Wave\ Length = \frac{Wave\ Velocity\ (v)}{Wave\ Frequency\ (f)} = \frac{\frac{343\ meters}{1\ second}}{\frac{440\ Cycles}{1\ second}} = 0.7795454545454545\ meters$$

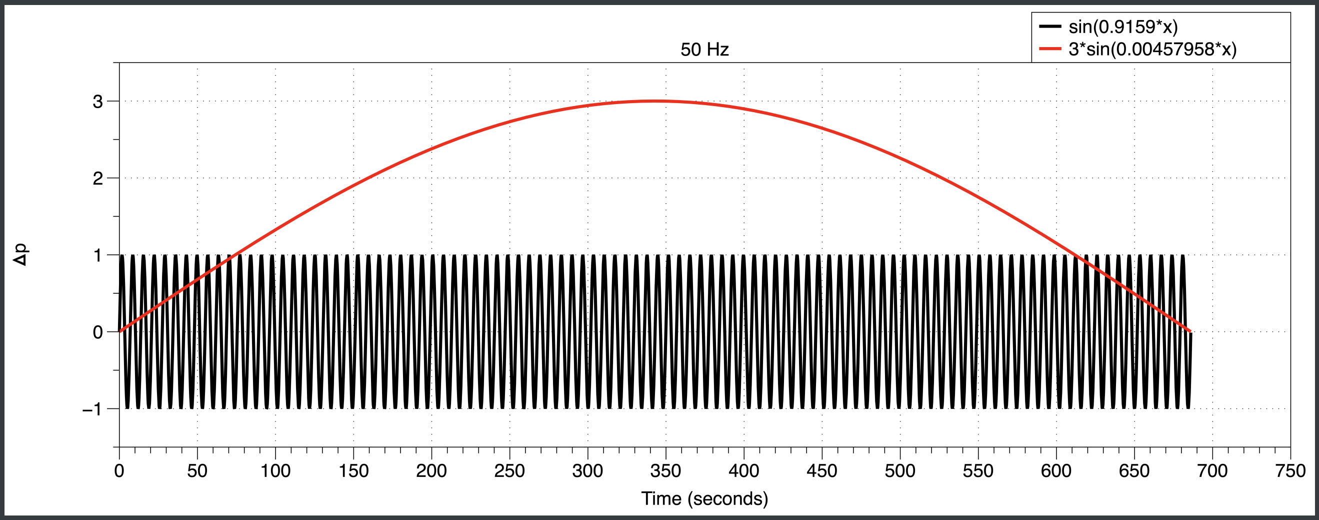
$$Angular\ Wave\ Number\ (k) = \frac{2 * \pi}{Wave\ Length\ (\lambda)} = \frac{2 * \pi}{0.7795454545454545\ meters} = 8.060062784720168$$

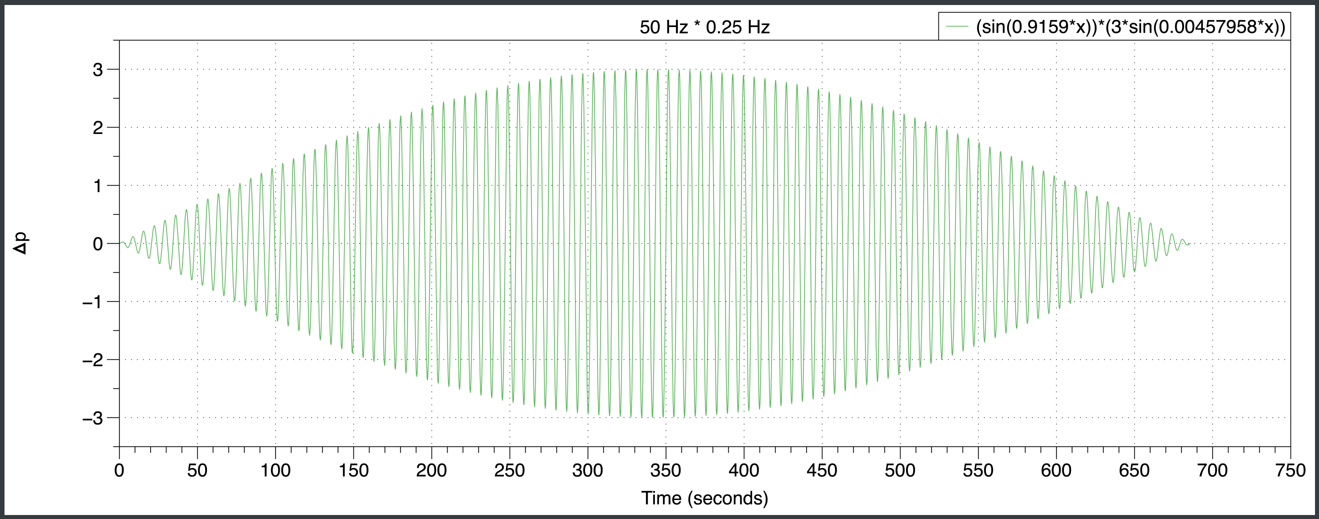


5.2. Produce a new graph showing one hundred periods of a sine wave. Add a second wave to this graph, with three times the amplitude but with a frequency two hundred times lower. Instead of the superposition of the two waves, produce a graph of the product of these two waves. How might a person describe what she heard?

> **1st Wave**
>
> $$Wave\ Period\ (T) = \frac{1}{Frequency\ (f)} = \frac{Wavelength\ (\lambda)}{Velocity\ (v)} = \frac{1}{50\ Hz} = \frac{1}{\frac{50\ Cycles}{1\ Second}} = 0.02\ seconds$$
>
> $$Wave\ Length = \frac{Wave\ Velocity\ (v)}{Wave\ Frequency\ (f)} = \frac{\frac{343\ meters}{1\ second}}{\frac{50\ Cycles}{1\ second}} = 6.86\ meters$$
>
> $$Angular\ Wave\ Number\ (k) = \frac{2 * \pi}{Wave\ Length\ (\lambda)} = \frac{2 * \pi}{6.86\ meters\ meters} = 0.9159162255363827$$
>
> $$Total\ Time\ for\ 100\ Periods = 0.02\ Seconds * 100 = 2\ seconds$$
>
> $$Total\ Time\ for\ 100\ Periods = 6.86\ Seconds * 100 = 686\ seconds\ ?$$

> **2nd Wave**
>
> $$Wave\ Period\ (T) = \frac{1}{Frequency\ (f)} = \frac{Wavelength\ (\lambda)}{Velocity\ (v)} = \frac{1}{\frac{50}{200}\ Hz} = \frac{1}{\frac{0.25\ Cycles}{1\ Second}} = 4\ seconds$$
>
> $$Wave\ Length = \frac{Wave\ Velocity\ (v)}{Wave\ Frequency\ (f)} = \frac{\frac{343\ meters}{1\ second}}{\frac{0.25\ Cycles}{1\ second}} = 1372.0\ meters$$
>
> $$Angular\ Wave\ Number\ (k) = \frac{2 * \pi}{Wave\ Length\ (\lambda)} = \frac{2 * \pi}{1372.0\ meters} = 0.004579581127681914$$





- What does it sound like?
  - Link to Google Colab Python Generated Auido Code = https://colab.research.google.com/drive/1nRu8ECq6mqCuT2GPA51TMvUXciENa2_r
    - For some reason I could never get the audio to play on google colab notebook , so I recorded a video of it playing locally
- Python Generated Audio Demo = https://www.youtube.com/watch?v=bUPfauMDfR0

5.3. What are the $x-$ and $y-$ axes? What do the colors represent? Which sound sample have you selected? Describe the relationship between what you see in the spectrogram and what you hear.

> - X-Axis = Time (seconds)
> - Y-Axis = Frequency (kilo Hertz)
> - Colors:
>   - Darker = Low Intensity
>   - Orange and Yellow = High Intensity
> - Sound Sample = Bird Song (Song Thrush)
>
> $$Intensity \propto \sqrt{Amplitude} \propto \sqrt{Frequency}$$
>
> - Louder sounds = Higher Intensity

Physics 1120 – Homework 10

1.A. What is the energy of the emitted photon (in electron volts)?

> $$Energy = \frac{h * c}{\lambda} = \frac{1239.84193\ eV \cdot nm}{590\ nm} = 2.101427\ eV$$

1.B. At room temperature (T ~ 300 K), what is the probability that a sodium atom has its electron excited up to the 3p state?

> $$\frac{P(3p)}{P(3s)} = e^{-\left(\frac{\Delta E}{k*T}\right)} = e^{-\left(\frac{2.1\ eV}{\frac{8.61733262145*10^{-5}\ eV}{1\ K}*300\ K}\right)} = 5.266839447935011 * 10^{-36}$$

1.C. At the temperature of the flame (T ~ 1500 K), what is the probability that a sodium atom has its electron excited up to the 3p state?

> $$\frac{P(3p)}{P(3s)} = e^{-\left(\frac{\Delta E}{k*T}\right)} = e^{-\left(\frac{2.1\ eV}{\frac{8.61733262145*10^{-5}\ eV}{1\ K}*1500\ K}\right)} = 8.796502205965437 * 10^{-8}$$

1.D. If we have 1 gram of sodium in our spoon, about how many atoms in the burner flame have their electron excited up to the 3p state at any one time? (Possibly useful fact: the atomic weight of sodium is 23 Da = 23 AMU.)

> $$N = \left(23\ grams\ Na * \frac{1\ mol}{22.9898\ grams\ Na} * \frac{6.02214076 * 10^{23}\ atoms}{1\ mol}\right) * 8.796502205965437 * 10^{-8} = 5.299727762048432 * 10^{16}$$

2.1. If you were wearing the shoe shown in the picture on the right, which letter best represents where the red buckle on the shoe would appear to be when seen in the mirror?

> - E

2.2. From which of the indicated locations, I, II, III, and IV is the image of B visible?

> - A , From 1 and 3 Only

2.3. Is Maxwell smart? Or does he need to go back and redo Physics 2? Explain.

> - He is not "smart"
> - The mirror would need to be at least half his height

2.4.1. Which will Charlie see himself as? Check all that apply.

> - Right Side Up
> - Taller

2.4.2. Now which will he see himself as? (compare to himself, not to the situation in 4.1) Check all that apply

> - Right Side Up
> - Taller
> - Bigger than in 2.4.1

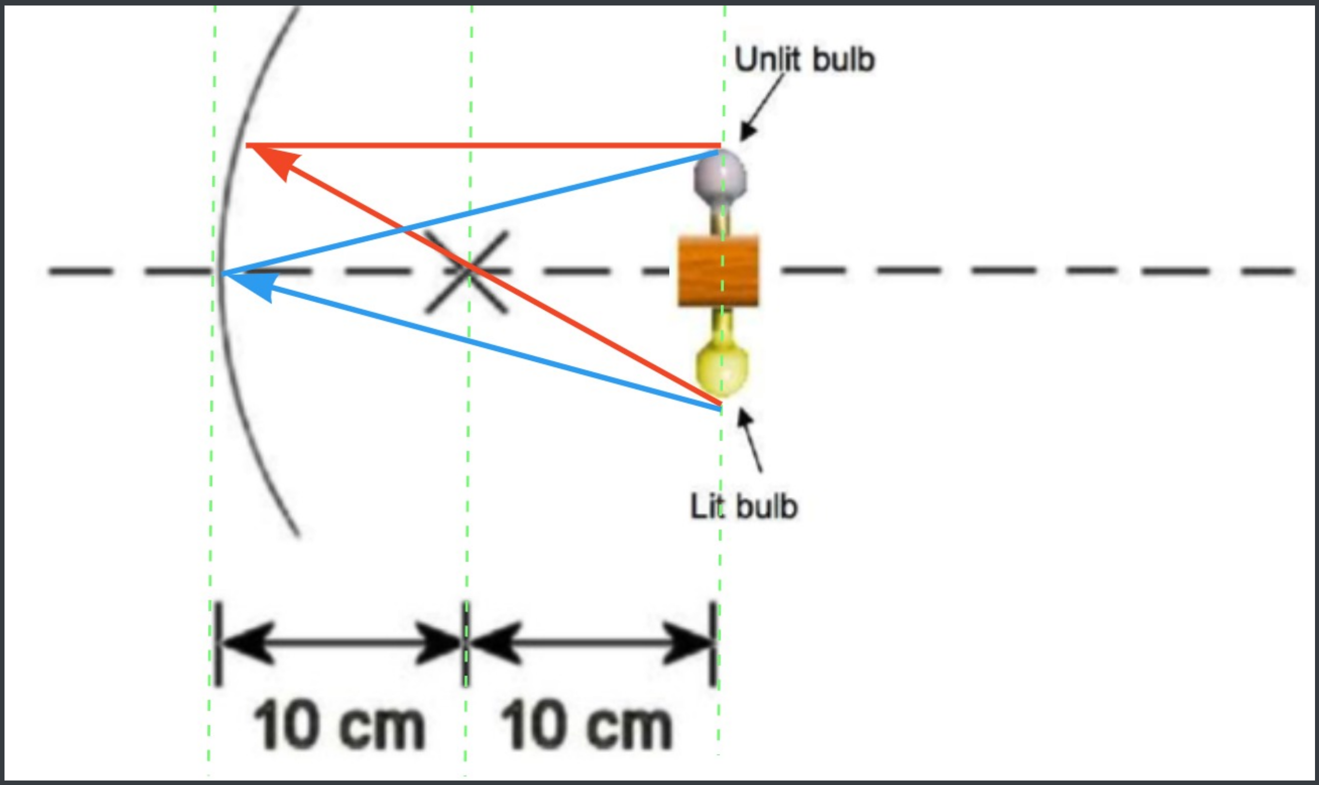
3.A. Where do you have to place the box in order to have the image appear right on top of the unlit bulb?

> $$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$
>
> $$\frac{1}{f} = \frac{1}{d} + \frac{1}{d} = \frac{2}{d}$$
>
> $$d = 2 * f = R$$
>
> - Place the bulb at the center of the sphere where the mirror was cut and at a distance of twice the focal distance from the mirror

3.B. How big will the image of the lit bulb be compared to the size of the lit bulb?

> $$\frac{h'}{h} = \frac{i}{o} = \frac{d}{d} = 1$$
>
> - Same size

3.C. On the figure below, sketch the correct position of the lit bulb and draw a ray diagram to confirm your calculation.



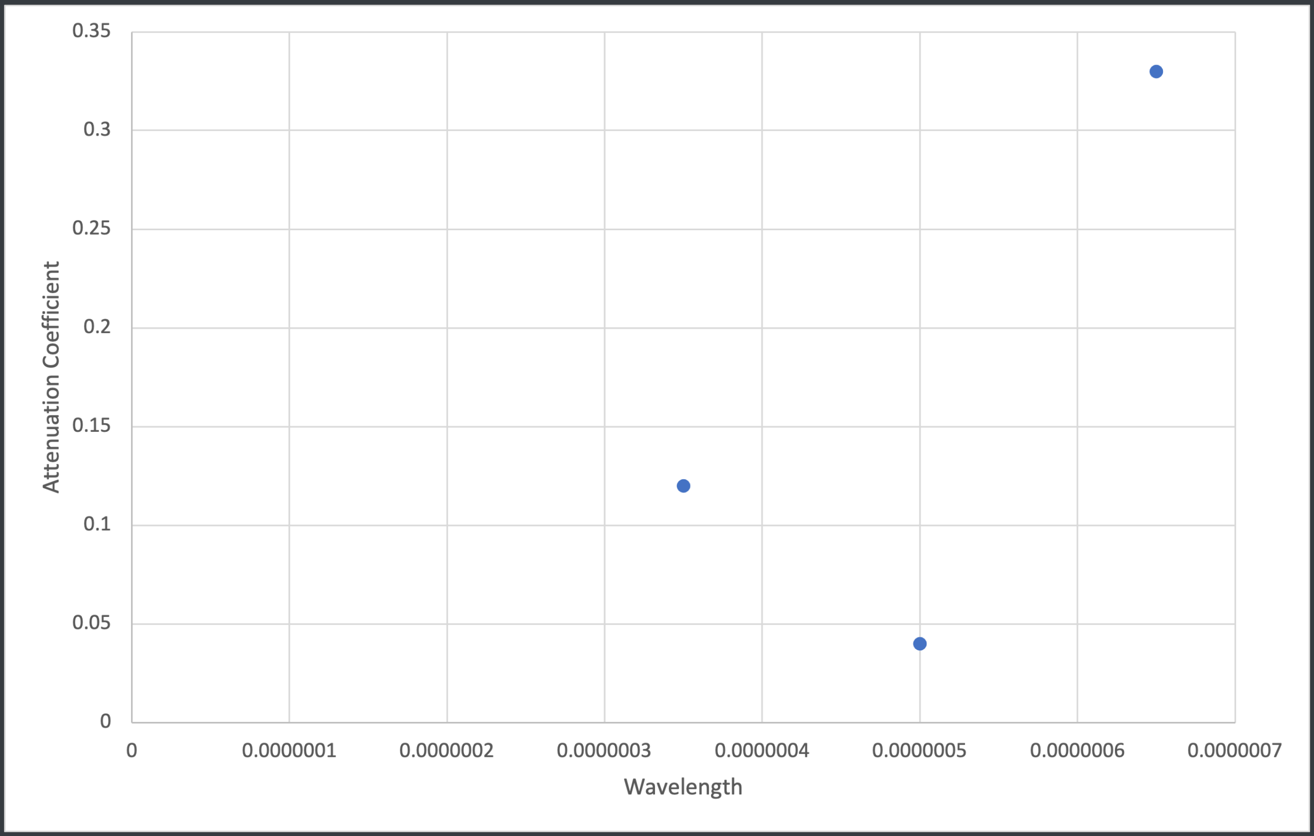
4.A. What are the dimensions of α (in terms of M[mass], L[length], and T[time])?

> $$\alpha = \frac{1}{meter} = \frac{1}{[Length]}$$

4.B. Write an equation for the ratio of the two intensities after a distance, d. Handle your symbols and functional dependences carefully! Then simplify your expression.

> $$\frac{d(e^{-\alpha * x})}{dx}$$
>
> $$let\ \theta = -\alpha * x$$
> $$\therefore \frac{d(e^{\theta})}{d\theta} = e^{\theta}$$
>
> $$\frac{d(e^{-\alpha * x})}{dx} = \frac{d(e^{\theta})}{d\theta} * \frac{d(-\alpha * x)}{dx}$$
>
> $$= -\alpha * e^{-\alpha * x}$$

4.C. Use a spreadsheet to plot the intensity of light at these three frequencies as it penetrates into clear water at these three wavelengths assuming that the intensity of each at the top of the water is 1 W/m2 .



4.D. Give a physical interpretation of the two parameters in this equation, I_0 and α.

> - I_0 = initial light intensity
> - α = the rate of attenuation of the light intensity due to reflection and absorption

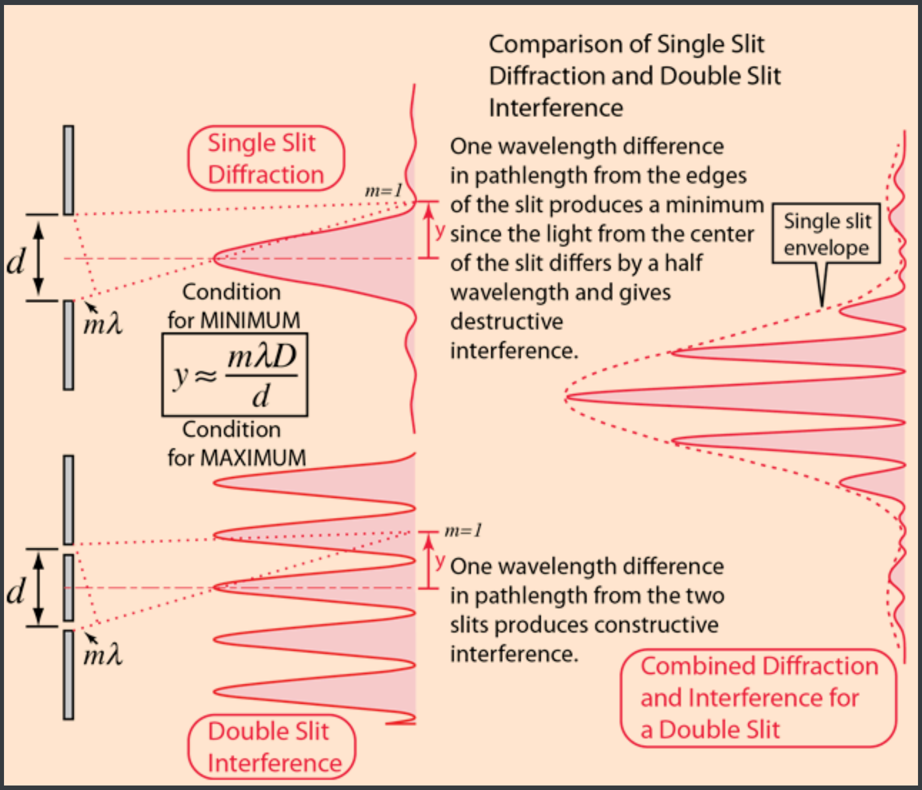
Homework 11

- http://www.physics.smu.edu/~yejb/teaching/1304_2018s/notes/Lecture_Notes/chapter36_diffraction.pdf
- http://www.jirkacech.com/public/Thesis/node8.html
- https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_University_Physics_(OpenStax)/Book%3A_University_Physics_III_-_Optics_and_Modern_Physics_(OpenStax)/03%3A_Interference/3.03%3A_Mathematics_of_Interference
- https://byjus.com/physics/waves/
- http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/sinint.html
- https://cronodon.com/Atomic/Photon.html
- https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_University_Physics_(OpenStax)/Book%3A_University_Physics_III_-_Optics_and_Modern_Physics_(OpenStax)/04%3A_Diffraction/4.02%3A_Single-Slit_Diffraction
- http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/slits.html#c1

$$Width\ of\ Central\ Fringe = \frac{Order\ of\ Interference\ (m) * Wave\ Length\ (\lambda) * Distance\ to\ Screen\ (D)}{Width\ of\ Single\ Slit\ (a)}$$

$$Wave\ Length\ (\lambda) = \frac{Width\ of\ Central\ Fringe * Width\ of\ Single\ Slit\ (a)}{Distance\ to\ Screen\ (D)}$$

$$\therefore Wave\ Length \propto Width\ of\ Single\ Slit\ (a)$$



http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/sindoub.html

$$let\ m = order\ of\ the\ interference = \frac{Separation\ of\ Slits\ (a)}{Width\ of\ Slit\ (d)}$$

$$let\ \theta = \frac{\pi * Width\ of\ Slit\ (a)}{Wavelength\ (\lambda) * Distance\ to\ Screen\ (D)}$$

$$let\ Ratio = \frac{Separation\ Distance\ of\ Slits\ (a)}{Width\ of\ Slit\ (d)}$$

$$Width\ of\ Slit\ (a) * sin(\theta) = Order\ of\ Interference\ (m) * Wavelength\ (\lambda)$$

$$\theta = sin^{-1}\left(\frac{Wavelength\ (\lambda)}{Width\ of\ Slit\ (a)}\right)$$

3.A. From which energy state should the electron be excited if we want to excite the lowest energy state above the ground state?

> - Excite the electron in the highest occupied state $N = 11$ into the first open state $N = 12$

3.B. What is the energy of this photon in eV?

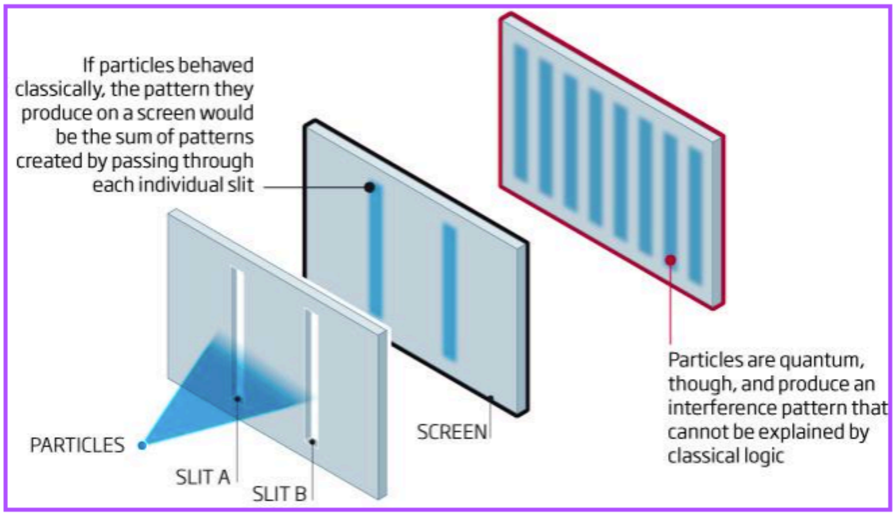
> $$Energy = Planck's\ Constant\ (h) * Frequency\ (f) = \frac{Planck's\ Constant\ (h) * Speed\ of\ Light\ (c)}{Wavelength\ (\lambda)}$$
>
> $$Energy = \frac{1239.84193\ eV \cdot nm}{450\ nm} = 2.755204288888889\ eV$$

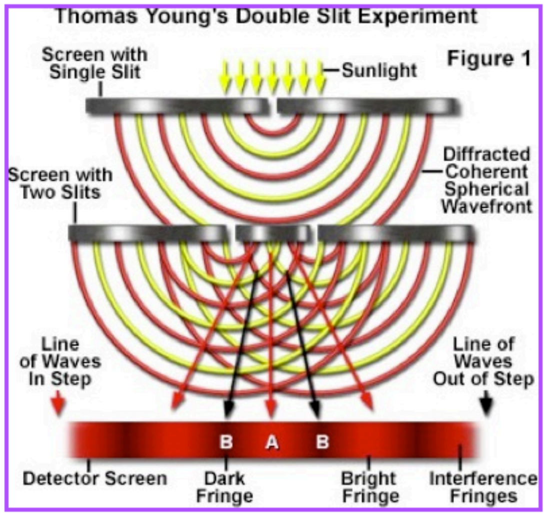
3.C. Use the vibrating string model of the electrons in the chromophore to estimate the size of the chromophore, L. The actual length is about 3 nm. Is the model giving you a reasonable result?

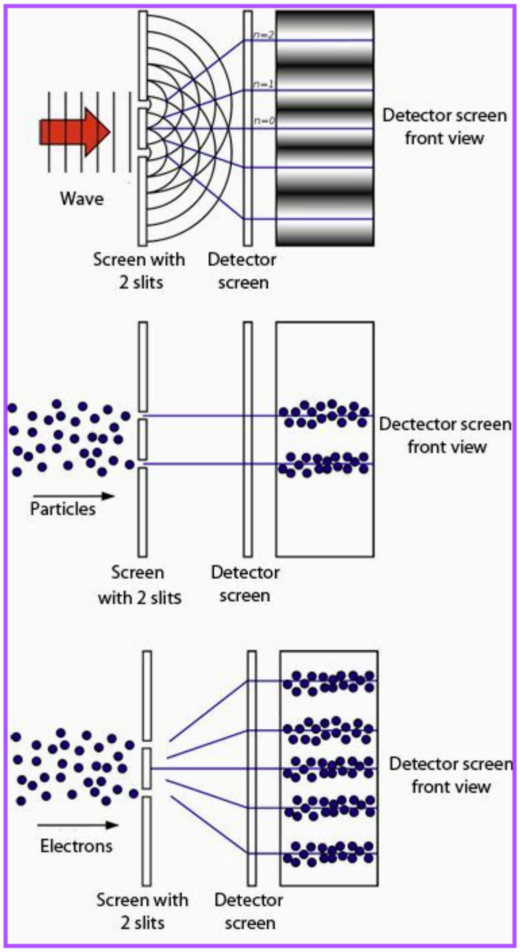
> $$\Delta E = \frac{0.75\ eV \cdot nm^2 * \left((12)^2 - (11)^2\right)}{L^2}$$
>
> $$L^2 = \frac{0.75\ eV \cdot nm^2 * \left((12)^2 - (11)^2\right)}{\Delta E}$$
>
> $$L = \left(\frac{0.75\ eV \cdot nm^2 * \left((12)^2 - (11)^2\right)}{\Delta E}\right)^{\frac{1}{2}}$$
>
> $$L = \left(\frac{0.75\ eV \cdot nm^2 * \left((12)^2 - (11)^2\right)}{2.755204288888889\ eV}\right)^{\frac{1}{2}} = 2.509742897451731\ nm$$
>
> $$Percent\ Error = \left|\frac{3.0 - 2.509742897451731}{3.0}\right| * 100\% = 16.34190341827564\ \%$$

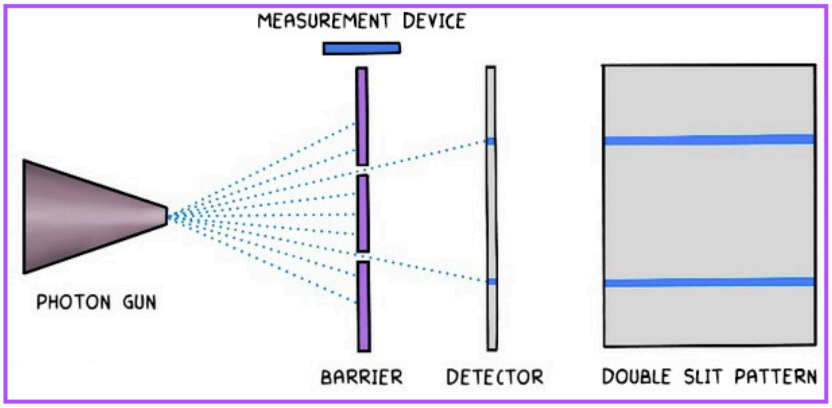
4. When light is passed through two narrow slits, the result produced on a distant screen is not the result predicted by the ray model of light. Discuss the prediction that the ray model makes and how an alternative model can explain these results. When different models predict different outcomes, how do we know which model is right?

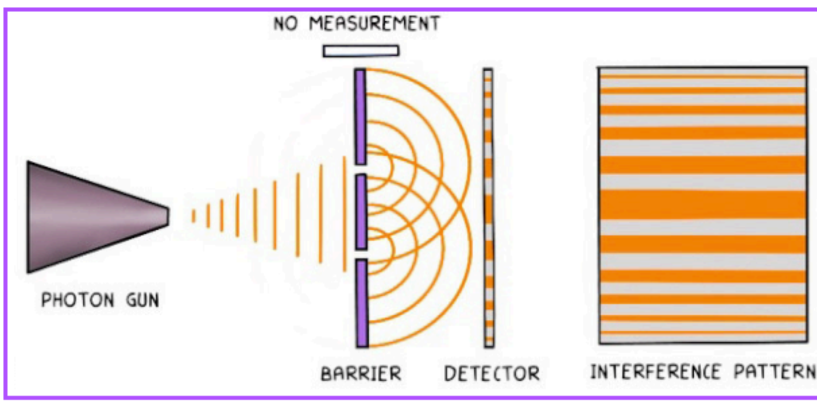
- https://en.wikipedia.org/wiki/Double-slit_experiment
- https://www.scienceme.com/what-is-schrodingers-cat-and-can-i-pet-him

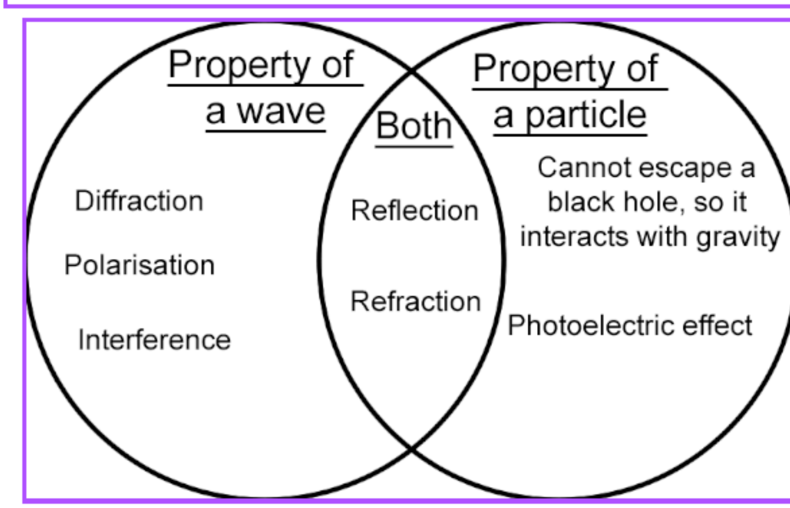

If particles behaved classically, the pattern they produce on a screen would be the sum of patterns created by passing through each individual slit
PARTICLES
SLIT A
SLIT B
SCREEN
Particles are quantum, though, and produce an interference pattern that cannot be explained by classical logic


Thomas Young's Double Slit Experiment
Figure 1
Screen with Single Slit
Sunlight
Diffracted Coherent Spherical Wavefront
Screen with Two Slits
Line of Waves In Step
Line of Waves Out of Step
B
A
B
Detector Screen
Dark Fringe
Bright Fringe
Interference Fringes


Wave
Detector screen front view
Screen with 2 slits
Detector screen
Particles
Dectector screen front view
Screen with 2 slits
Detector screen
Electrons
Detector screen front view
Screen with 2 slits
Detector screen


MEASUREMENT DEVICE
PHOTON GUN
BARRIER
DETECTOR
DOUBLE SLIT PATTERN


NO MEASUREMENT
PHOTON GUN
BARRIER
DETECTOR
INTERFERENCE PATTERN


Property of a wave
Both
Property of a particle
Diffraction
Polarisation
Interference
Reflection
Refraction
Cannot escape a black hole, so it interacts with gravity
Photoelectric effect

> - In the double slit experiment, if photons acted only as a particle (the ray model), you would expect them to follow the normal distribution around points directly parallel on the screen with the two slits.
> - However, what is observed in experiments are multiple normal distributions, matching the "fringes"
> - The electron's "observed" position on the screen is determined strictly by its probability function.
> - This makes the resulting pattern on the screen the same as if each individual electron had passed through both slits
> - I think it is still up for debate which one is correct. All Schrödinger's equation provides is a probability, not an exact location. However, in experimental practice, the wave model is the best we can observe and rationalize today.