1B-1 Winter 2021: FINAL

Show all your work and use proper units throughout. This final is open-book but not open-Chegg and must be completed without help. Please write your answers into the boxes. If you submit your work with your own formatting please try to submit the same number of pages as the template. You have 24 hours to submit your answers.

1. Please complete part A of this final on KUDU!

Problem 2 (18 points)

A sunken sailboat lies at the bottom of the ocean (1.025 g/cm^3) at a depth of 75 m. The boat has a mass of $1.3 \cdot 10^3$ kg and an effective (apparent) weight of $4.0 \cdot 10^3$ N.

(a) Sketch a free-body diagram of the boat showing all relevant forces and the net force. [4 points]

(b) What is the (average) density of the boat? [8 points]

(c) You want to raise the boat using an air-filled balloon. What is the minimum balloon volume required to raise the boat? [4 points]

(see next page)

(d) You use a full 20 liter compressed air tank with a gauge pressure of 220 atm (at the surface) to fill the balloon from zero volume at depth. Given that the product of pressure and volume stays constant in a gas (as long as the temperature stays constant) and that the pressure inside the balloon equals the ambient pressure, what will be the gauge pressure in the tank once the balloon has been filled to the volume required to lift the boat? [2 points]

Problem 3

(14 points)

Gel electrophoresis is a laboratory method used to separate mixtures of negatively charged DNA according to molecular size. The molecules are pushed by an electric field at constant and very small velocity v through a gel that produces a drag force $\mathrm{F}_d = -b \cdot v$. The field is produced by two parallel-plate electrodes connected to a 60 V battery.

(a) Sketch the apparatus and show the sign of the charges on the two plates, the electric field lines, and the equipotential lines for 20 V and 40 V. Draw a free-body-diagram of all relevant forces acting on a DNA molecule showing qualitatively correct length and direction. Indicate also the direction of the migration of the negatively charged molecules (velocity). *(6 points)*

(b) If the two plates are 15 cm apart and the drag coefficient for a particular size DNA molecule is $b = 7.7 \cdot 10^{-13}$ Ns/m, what is the (constant) velocity of the DNA? Assume that each DNA molecule has a charge of -e. *(5 points)*

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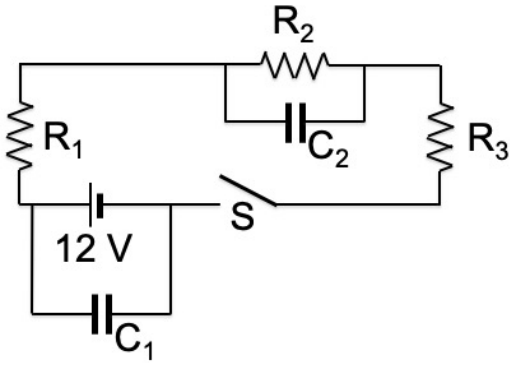
(c) Does the electric potential energy of a DNA molecule increase, decrease, or stay the same as it migrates through the apparatus?
If it changes, explain where the difference in energy goes or comes from. *(3 points)*

Problem 4

(18 points)

Consider the circuit shown below with three resistors $R_1 = R_2 = 1.5\ k\Omega$ and R_3=500 Ω, and two capacitors C_1=C_2=500 pF.



a. The switch is initially open. What are the charges on C_1 and C_2? *[2 points]*

b. You now close the switch. Calculate the power dissipated in each of the three resistors right after the switch is closed but the charges on the capacitors have not yet changed significantly (t=0). *[4 points]*

c. What are the charges on the capacitors after the switch has been closed a very long time? *[4 points]*

d. Qualitatively correct sketch the current flowing through R_3, the voltage drop across R_1, and the charge on C_2 as a function of time from t=0 and for several RC time constants. *[5 points]*

3. The switch has been closed for a very long time. If you open the switch, what will happen to the charge on C_2 and what will be the time constant of this change? *[3 points]*