Name (please print):
Signature:
Student number:

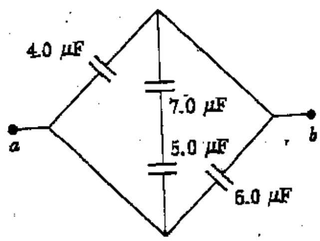
PHYS 1420 06B – Physical Science (F/W11-12)
Test 3B

Answer all questions in the space provided on this test paper. Use pen to write.
Formulae are provided on the last page.

1. (6 marks)

Consider the circuit shown below.

a. What is the equivalent capacitance between points a and b?



7.0µF AND 5.0µF ARE IN SERIES.

$$\frac{1}{C_{eq}} = \frac{1}{7.0\mu F} + \frac{1}{5.0\mu F} = \frac{12}{35\mu F} \Rightarrow C_{eq} = \frac{35\mu F}{12} = 2.9\mu F$$

4.0µF, 6.0µF AND 2.9µF ARE IN PARALLEL.

$$C_{eq} = 4.0\mu F + 6.0\mu F + 2.9\mu F = 12.9\mu F$$

b. A 6.0 V battery is connected between points a and b. What is the charge on the 6.0 µF and 7.0 µF capacitors.

$$C = \frac{Q}{\Delta V}$$

$$Q_{4.0\mu F} = C_4 \, \Delta V = (6.0\times10^{-6} F)(6.0 V) = 36\mu C$$

THE CHARGE ON 7.0µF IS THE SAME AS ON 2.9µF

$$Q_{7.0\mu F} = C_{2.9\mu F} \, \Delta V = (2.9\times10^{-6} F)(6.0 V) = 17.4\mu C$$

2. (8 marks)

Answer the following four questions. Each is worth 2 marks.

a. A potential difference of 80 mV exists between the inner and out surfaces of a cell membrane. The inner surface is negative relative to the outer surface. It is observed that for every three sodium Na^+ ions moving from the interior to the exterior of the cell there are two potassium K^+ ions moving from the exterior to the interior of the cell. What is the net amount of work done to move all five ions?

$$\Delta PE = q_1 \Delta V + q_2 \Delta V = (3)(1.6\times10^{-19}C)(+80\times10^{-3}V) + (2)(1.6\times10^{-19}C)(-80\times10^{-3}V)$$

$$\Delta PE = +1.3\times10^{-20} J.$$

b. What is the electric potential energy of the hydrogen atom? The radius of the hydrogen atom is $r = 5.29\times10^{-11}$ m. Express the answer in electron-volts (eV).

$$PE = k\frac{q_1 q_2}{r} = \left(9.0\times10^{9}\frac{Nm^2}{C^2}\right)\left(\frac{(+1.6\times10^{-19}C)(-1.6\times10^{-19}C)}{5.29\times10^{-11}m}\right)$$

$$PE = -4.36\times10^{-18} J = -27.2 eV.$$

c. How much does it cost to use 1 kWh of electric energy in Toronto between 7 p.m. and 7 a.m.? An electric heater (2.5 kW, 110V) was heating Mark's room in Bethune College residence from 7 p.m. to 7 a.m. How much did it cost to use the heater?

$$E = Pt = (2.5 kWh)(12 h) = 30 kWh$$

$$COST = (30 kWh)\left\{\begin{matrix}\$0.062 \\ \$0.10\end{matrix}\right\} = \begin{matrix}\$1.86 \\ \$3.0\end{matrix}$$ ANSWER IN THIS RANGE WILL BE TAKEN AS CORRECT.

d. After a parallel-plate capacitor is charged by a battery, it is disconnected from the battery and its plate separation is increased. Will the following quantities increase, decrease or remain the same?

-the charge on the plates SAME

- the capacitance DECREASE

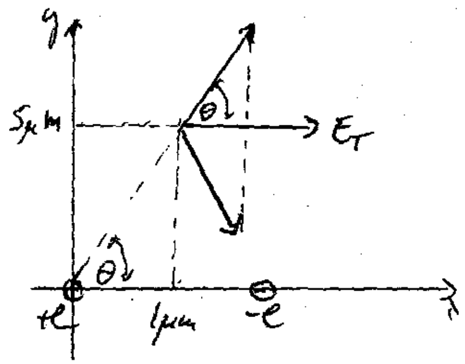
- the energy stored in the capacitor INCREASE

- the potential difference between the plates INCREASE

3. (8 marks)

A molecule of DNA is approximately 2.0 µm long. The ends of the molecule are singly ionized (charge $q = 1.6 \times 10^{-19}$C). The positive end of the molecule is at the origin of the xy plane and the negative end at x = 2.0 µm.

a. Find the magnitude and direction of the electric field produced by the DNA molecule at point P whose coordinates are (1 µm, 5.0 µm).



$$E_1 = E_2 = k\frac{q}{r^2} = \left(9.0\times10^{9}\,\frac{Nm^2}{C^2}\right)\frac{(1.6\times10^{-19}C)}{(1.0\times10^{-6}m)^2+(5.0\times10^{-6}m)^2} = 55.4\,\frac{N}{C}$$

$$E_{1x} = E_{2x} = \left(55.4\,\frac{N}{C}\right)(\cos\theta)$$

$$\cos\theta = \frac{1.0\times10^{-6}m}{\sqrt{(1.0\times10^{-6}m)^2+(5.0\times10^{-6}m)^2}} = 0.442$$

$$E_{1x} = E_{2x} = (55.4\,N/C)(0.442) = 24.5\,N/C$$

$$E_T = 2E_{1x} = 2(24.5\,N/C) = 49\,N/C$$

b. What is the force (magnitude and direction) exerted by the DNA molecule on a Cl^- ion placed at P?

$$F = Eq = |(49\,N/C)(-1.6\times10^{-19}C)| = 7.8\times10^{-18}\,N.$$

DIRECTION: TO THE LEFT (OPPOSITE TO $\vec{E}$ BECAUSE Cl^- IS NEGATIVE)

c. What is the electric potential due to the DNA molecule at P?

$$V = k\frac{(+q)}{r} + k\frac{(-q)}{r} = 0$$

4. (6 marks)

In an electrophoresis experiment a charged DNA molecule (net charge $q = 64.0 \times 10^{-19}$ C) is placed in a gel which fills the space between two large charged parallel metal plates. The plates are separated by 60.0 mm. The electric field between plates is uniform and of magnitude E = 1200.0 N/C.

a. What is the magnitude of the electric force acting on the DNA molecule?

$$F = qE = (64 \times 10^{-19} C)(1200.0 N/C) = 7.7 \times 10^{-15} N$$

b. Determine the change of the electric potential energy of the DNA molecule if it moved 40.0 mm. Does the molecule move towards higher or lower electric potential?

$$\Delta PE = -qE\Delta x \cos\theta = -(64.0 \times 10^{-19} c)(1200.0 N/C)(40 \times 10^{-3} m)\cos 0$$

$$\Delta PE = -3.1 \times 10^{-16} J.$$

DNA MOVES TOWARDS LOWER ELECTRIC POTENTIAL

c. What is the electric force acting on the molecule if the distance between the metal plates is reduced from 60.0 mm to 50.0 mm?

THE SAME AS IN (a)

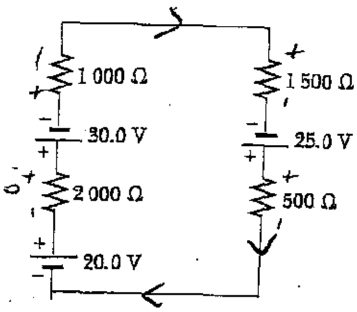
$\vec{E}$ DOES NOT DEPEND ON THE SEPERATION BETWEEN THE METAL PLATES

d. It is observed that despite of the electric force acting on the DNA molecule it moves with constant speed. Explain why. Calculations are not required.

THE DRAG FORCE, WHICH OPPOSES THE ELECTRIC FORCE, INCREASES WITH SPEED OF THE DNA MOLECULE UNTIL BOTH FORCES ARE EQUAL IN MAGNITUDE. WHEN THE NET FORCE ON DNA IS ZERO, ITS SPEED MUST BE CONSTANT IN TIME.

5. (4 marks).

a. Determine the current flowing in the following circuit.



LOOP RULE:

$$20 - 2000I - 30 - 1000I - 1500I + 25 - 500I = 0$$

$$15 = 5000I$$

$$I = 0.003\,A$$

b. How many electrons enter (and leave) each resistor in 1 minute?

$$I = \frac{Q}{t}$$

$$Q = It = (0.003A)(60s) = 0.18C$$

$$N = \frac{Q}{e} = \frac{0.18C}{1.6\times10^{-19}C} = 1.1\times10^{18} \text{ ELECTRONS}$$

$F = k\frac{q_1q_2}{r^2}$, $\vec{E} = \frac{\vec{F}}{q}$, $E = \frac{Q}{\varepsilon_0 A}$, $E = k\frac{q}{r^2}$

$\Delta PE = -W_{el} = -qE\Delta x$, $\Delta V = \frac{\Delta PE}{q}$, $V = k\frac{q}{r}$, $PE = k\frac{q_1q_2}{r}$

$C = \frac{Q}{\Delta V}$, $C = \frac{k\varepsilon_0 A}{d}$, $C_{eq} = \sum_i C_i$, $\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$, $E = \frac{1}{2}Q\Delta V = \frac{Q^2}{2C}$

$I = \frac{\Delta Q}{\Delta t}$, $I = nev_dA$, $\Delta V = IR$, $R_{eq} = \sum_i R_i$, $\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$

$k = 9.0\times10^9\ \frac{Nm^2}{C^2}$, $e = 1.6\times10^{-19}C$, $eV = 1.6\times10^{-19}J$, $\varepsilon_0 = 8.85\times10^{-12}\ \frac{C^2}{Nm^2}$