Two point charges q_1 and q_2 are placed on the y-axis at positions $y = +a$ and $y = -a$ respectively, as shown in the figure at right. Take the reference potential to be zero at infinity ($V = 0$). With the first two point charges fixed in place, a third point charge q_3 is now brought in from infinity to the position $x = +b$, as shown in the figure at right.

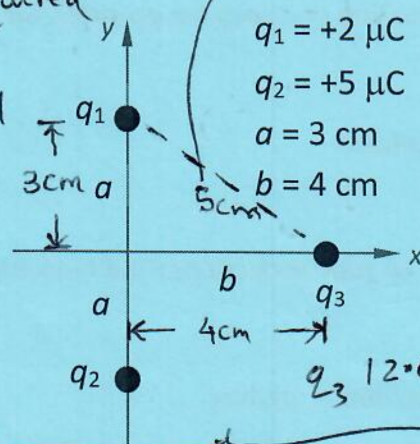
1. It is found that 11.6 J of work are required to bring in this third charge q_3 from infinity.

Find charge q_3. (**6 points**)

$\sqrt{3\text{cm}^2 + 4\text{cm}^2} = 5\text{cm}$

→ The two charges are there already so we are only thinking about Work required to bring q_3

q_1 & q_2 have an Electric potential at q_3 → $\frac{Kq_1}{r_1} + \frac{Kq_2}{r_2}$



$K = 9\times10^9 \frac{Nm^2}{C^2}$

Work required to bring q_3

$(V_1 + V_2)\, q_3 = \text{Work}$

$q_3\ 12.6\ \text{J/C} \times 10^5 = 11.6\,\text{J}$

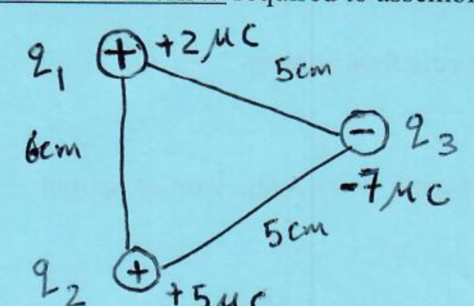
$\left(\frac{Kq_1}{r_1} + \frac{Kq_2}{r_2}\right) q_3 = 11.6\,\text{J}$

$\rightarrow \left(\frac{9\times10^9\,Nm^2/C * 2\times10^{-6}C}{5\times10^{-2}m} + \frac{9\times10^9\,\frac{Nm^2}{C} * 5\times10^{-6}C}{5\times10^{-2}m}\right) q_3$

2. The third point charge is now replaced with a different point charge, q_3 = negative charge [**Your Birth month**] μC, placed at the same location $x = b$ on the x-axis. Calculate the total amount of work W required to assemble all three charges from infinity. (**6 points**)

7

[July]



$W_{total} = U_{12} + U_{23} + U_{13}$

$U_{12} = \frac{Kq_1q_2}{r_{12}}$ $U_{23} = \frac{Kq_2q_3}{r_{23}}$

$U_{13} = \frac{Kq_1q_3}{r_{13}}$

Q1.

$q_3\ 12.6\ \text{J/C} \times 10^5 = 11.6\,\text{J}$

$q_3 = \frac{11.6\,\text{J}}{12.6\,\text{J/C}} \times 10^{-5}$

$q_3 = 9.2\times10^{-6}\,C$

$W_{total} = K\left(\frac{q_1q_2}{r_{12}} + \frac{q_2q_3}{r_{23}} + \frac{q_1q_3}{r_{13}}\right) = 9\times10^9\,\frac{Nm^2}{C^2}\Big(\frac{2\times10^{-6}C * 5\times10^{-6}C}{6\times10^{-2}m}$

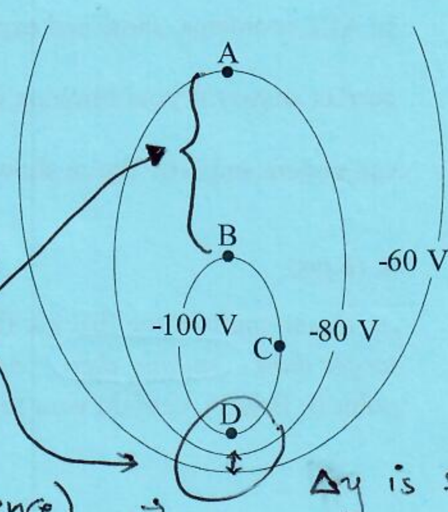
$+ \frac{5\times10^{-6}C * -7\times10^{-6}C}{5\times10^{-2}m} + \frac{2\times10^{-6}C * -7\times10^{-6}C}{5\times10^{-2}m}\Big)$

$= 9\times10^9\,\frac{Nm^{\cancel{2}}}{\cancel{C^2}}\left(\frac{10}{6} * 10^{-10}\frac{\cancel{C^2}}{\cancel{m}} - \frac{35}{5}\times10^{-10}\frac{C^2}{m} - \frac{14}{5}\times10^{-10}\frac{C^2}{m}\right)$

$= 9\times10^9\,Nm\,(1.67\times10^{-10} - 7\times10^{-10} - 2.8\times10^{-10})$

$= 9\times10^9\,(-8.13\times10^{-10})\,Nm \quad = -7.32$ JOULES

Question 3: The next 3-part question refers to the figure on the right, which shows some *equipotential* contours. They are worth **2 points each**. (The points "A" through "D" are simply points in empty space.) Neglect gravity.



A. At which labelled point is the magnitude of the electric field the greatest? (Note: I'm asking about |**E**|, not about voltage)
Why? (2 points)

A&B is much Larger Δy

Δy is small

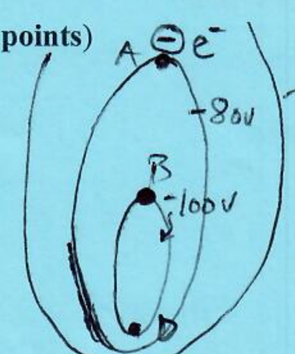
The voltage difference (AKA Potential Difference) is 20V. $\frac{20V}{\text{Small } \Delta y} \Rightarrow$ Greater E

$|\vec{E}| = \left|\frac{\Delta V}{\Delta y}\right|$

Point D has the greatest Magnitude of E

B. An electron (charge -e) is released at point A. Which way will it move at first? **Why?**

(2 points)



~ -60V

If you are an electron would you move down or up?
Going towards B is an increase in Voltage (in a negative sense)
Seems Like going towards MORE Negative potential
- Not very natural.
So going upwards is what the electron (you :)) would do

C. An alpha particle (charge +2e) is moved from point D to point A by an external force.

How much work did the external force do on the particle? (**3 points**)

D → A
initial final

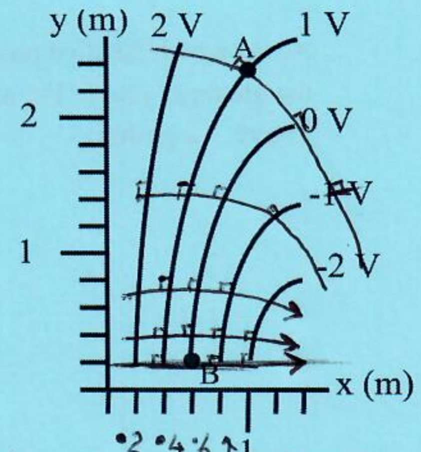
$$\text{Work done} = \Delta U = q * \Delta V \quad V_A - V_D$$
$$= +2e\left(V_f - V_i\right) = +2e\left(-80V - -100V\right)$$
$$(-80V + 100V)$$
$$= +2e\,(+20V)$$

Work done $= +40\,eV$ or If you want it in Joules

$$\frac{40eV \;|\; 1.6\times10^{-19}J}{\;|\; 1eV}$$

Work done $= 6.4\times10^{-18}\,J$

In ALL problems, show and explain your work <u>briefly but clearly</u>. You may get NO credit for a correct answer if your thinking is not easy to follow. Try to be neat and organized, so the grader can understand. The figure shows some equipotential (equal voltage) curves.



4. ***(6 pts)***

A) The strength of the Electric field at point A is **(circle one)** *larger than,* *smaller than,* *equal to* the Electric field strength at point B. Briefly, explain your reasoning: ***(4 pts)***

The Equipotential Lines are closer together at B than at A $|\vec{E}| = \left|\frac{\Delta V}{\Delta x}\right|$ actually $\vec{E} = -\frac{\Delta V}{\Delta r}$

Electric field Lines (vectors too) are perpendicular to Equipotential lines

B) On the diagram or in the space provided. Draw the Electric field lines **(2 pts)**

Also from our Lab 6 (Equipotential & Homework) Electric field Lines point in the direction of decreasing potential: from higher V to lower V

Electric fieldlines are drawn more densely where the $\vec{E}$ field IS <u>STRONGER</u>. MORE LINES TOWARD THE BOTTOM

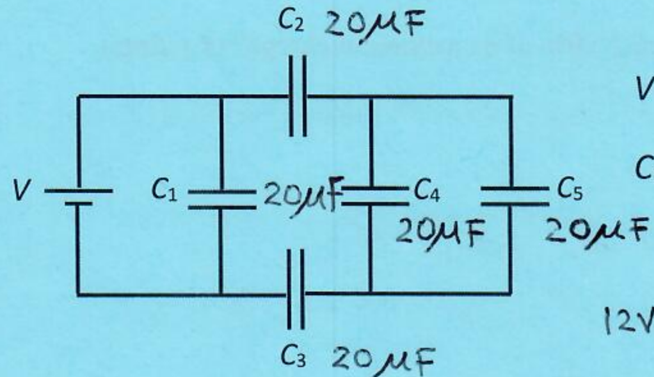
5. ***(4 pts)*** From the information on the figure, estimate the electric field at point B. (That means give us a magnitude with correct units, and also clearly describe the direction)
Briefly, explain how you determined your answer.**(4 pts)**

$\vec{E}$ field from Higher V to Lower V (voltage)

$E = \frac{\Delta V}{\Delta y}$ $\Delta V = 1$ Volt EVERY TICK MARK; EACH TICK MARK IS 0.2m apart

$E = \frac{1V}{0.2m} = 5 V/m$

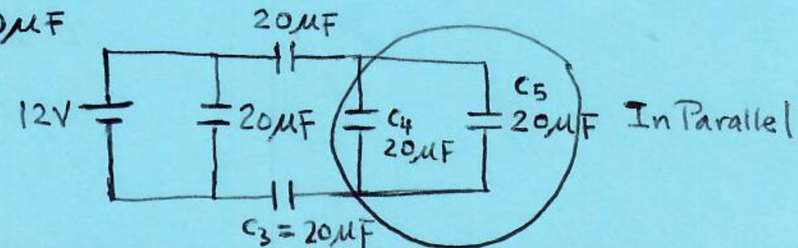
Five identical capacitors are connected to a battery as shown.



$V = 12$ V

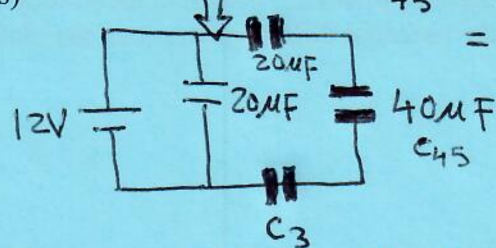
2Ø

$C_1 = C_2 = C_3 = C_4 = C_5 =$[birthday]μF



$C_{45} = C_4 + C_5$
$= 40\mu F$

6. A) Find the charge Q_2 on capacitor C_2: (6 points)



$$\frac{1}{C_{2345}} = \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_{45}}$$

$$C_{2345} = \left(\frac{1}{20} + \frac{1}{20} + \frac{1}{40}\right)^{-1}$$

$$= \left(\frac{5}{40}\right)^{-1} = \frac{40}{5} = 8\mu F$$

C_2, C_{45} & C_3 are in Series

Reducing the circuit to a SIMPLER ONE

B) Find the energy U_1 stored in capacitor C_1: (3 points)

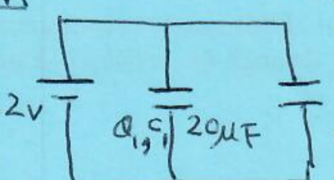
B) $U_1 = \frac{1}{2} C_1 \Delta V_1^2$ or $\frac{1}{2} Q_1 \Delta V_1$

$= \frac{1}{2} 20\mu F (12V)^2$

$= 10\mu F \; 144 V$

$= 1440 \mu J$

$Q_1 = C_1 \Delta V_1$
$= 20\mu F \; 12V$
$= 240 \mu C$

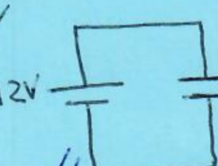


$C_{2345} = 8\mu F$
Parallel capacitors
$C_{12345} = 20 + 8 = 28\mu F$

$Q_{2345} = C_{2345} \Delta V_{2345}$
$= 8\mu F \; 12V$
$= 96 \mu C$

$\boxed{Q_2 = 96\mu C}$

$C_{12345} = 28\mu F$



Series capacitors HAVE Same charge!

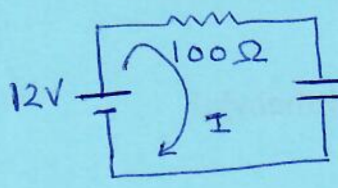
$Q_{total} = 12V * 28\mu F$
$= 336 \mu C$

As a check
Voltage on 20μF (C_2) $= \frac{96\mu C}{20\mu F} = 4.8V$
" on 20μF (C_3) $= 96\mu C / 20\mu F = 4.8V$
Voltage on C_{45} 40μF $= 96/40 = 2.4V$
$\overline{12V}$

7. An RC circuit is designed with a battery supplying 12 V, a resistor with 100 Ω of resistance, and a parallel-plate capacitor with a capacitance of [Birth month] μF. The capacitor is initially uncharged. (**6 pts**)

5

A. How long will it take for the capacitor to reach 90% of its maximum charge? (**2 points**)



capacitor is charging

$Q(t) = Q_{max}(1 - e^{-t/RC})$

$\frac{Q(t)}{Q_{max}} = 1 - e^{-t/RC}$ ← 90%

$0.9 = 1 - e^{-t/RC}$

$-1 \quad -1$

$\cancel{-}0.1 = \cancel{-}e^{-t/RC}$

$\ln 0.1 = \ln(e^{-t/RC})$

$\rightarrow \cancel{-}2.3 = \cancel{-}t/RC$

$t = RC\,(2.3)$

$t = 100\Omega\ 5\mu F\,(2.3)$

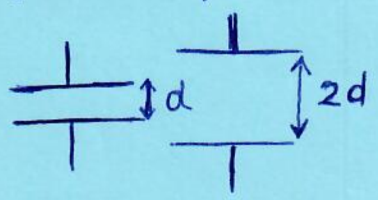
$t = 1150\,\mu\text{seconds}$

B. If the capacitor is then disconnected from the battery when it is at 90% of its maximum charge, then the plates are moved apart so they are twice as far apart as they were originally, what is the potential difference between the plates? (**2 points**)

At 90% $Q_{max} \Rightarrow Q(t) = .9(5\mu F \times 12V) = .9(60\mu C) = 54\mu C$

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

$= \frac{54\mu C}{5\mu F} = 10.8V$

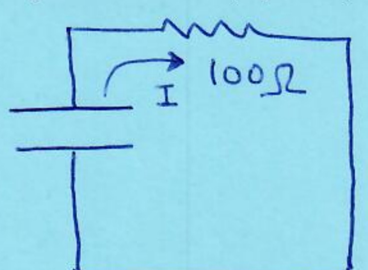


$Q = C\,\Delta V$

stays same ↙ ↗ ΔV Increases

ΔV_{new} will be twice $10.8V * 2 = 21.6V$

C. Now, if this newly reconfigured capacitor is connected only to the resistor, what is the initial current through the resistor? (**2 points**)



$I(t) = I_{max}\, e^{-t/RC}$

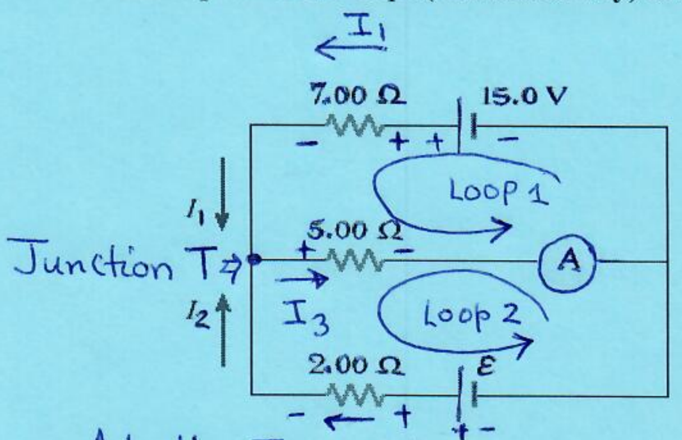
I_{max} is the initial Current

$I_{max} = \frac{\Delta V_{capacitor}}{R} = \frac{21.6V}{100\Omega}$

$I_{max} = 0.216\,A$

8. The ammeter shown in the figure below reads 2.00 A. Find I_1, I_2, and Voltage ε.

Please explain all the steps (**Rules and why**) and reasoning in this problem. (**6 points**).



Kirchhoff's Rules are fundamental to understanding circuits.

⇨ I will use two Voltage Loops. Each Loop: Sum of the voltages add up to Zero. I will be mindful of the VOLTAGE DROPS & RAISES.

At the T-Junction $\Sigma I_{in} = \Sigma I_{out}$ (Current Rule which is a Charge conservation Rule Law)

Starting at T $I_1 + I_2 = I_3 \rightarrow I_3$ Reads 2.00 A

$I_1 + I_2 = 2A$ ——— (1)

Loop 1 starting at T and going Counterclockwise

$-I_3 5\Omega + 15V - I_1 7\Omega = 0$ ——— (2)

$I_3 = 2A$ $\quad -2A(5\Omega) - I_1 7\Omega + 15V = 0$

$-10V + 15V - I_1 7\Omega = 0$

$+I_1 7\Omega \quad + I_1 7\Omega$

$5V = I_1 7\Omega$

$I_1 = 5/7\, A$ $\quad \frac{5V}{7\Omega} = I_1$

or 0.71 A

from Equation 1 $\quad I_2 + I_1 = 2A$

$I_2 + 0.71 = 2A$

Using Loop 2 $\quad I_2 = 2A - 0.71A = 1.29A$

Starting at T ⇨ $I_2 2\Omega - \varepsilon + I_3 5\Omega = 0$

$1.29A\, 2\Omega - \varepsilon + 2A\, 5\Omega = 0$

$-\varepsilon + 12.58V = 0$

$-\varepsilon = -12.58V$

$\varepsilon = 12.58V$