Physics 260, Exam 3, May 4, 2005, Dr. Baden

Please do all problems, and show your work clearly. Credit will not be given for answers with no work shown. Partial credit will be given. Note: in some or all of these problems, you will need the electromagnetic constant $k=9x10^9 Nm^2/C^2=1/(4\pi\varepsilon_0)$. Please read the problems first, you don't have to do them in any particular order.

Problem 1 (25 points). A charge of 4nC ("n"$\equiv 10^{-9}$) is moved from infinity to a point 15cm away from a charge of 8nC.

a) Calculate the potential energy needed to do this. (figure 1a)

b) Next, calculate the electric potential V (aka voltage) at a point **P** that forms an equilateral triangle with the 2 charges as in figure 1b. Assume that the potential at infinity is zero: $V(\infty)=0$.

c) How much potential energy is needed to move a 7nC charge from infinity to point P as in figure 1c?

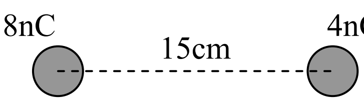


Figure 1a

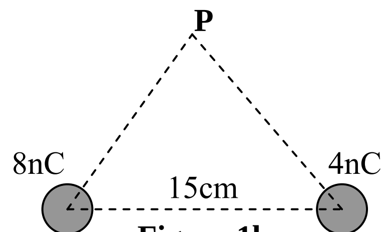


Figure 1b

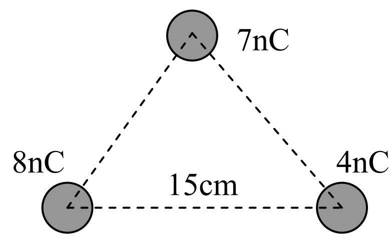


Figure 1c

a) The voltage at a point 15cm away from the 8nC charge is given by: $V=\frac{kQ}{r}=\frac{9x10^9 \bullet 8x10^{-9}}{0.15}=480 Volts$ **where we take the reference voltage to be V(∞)=0 The potential energy needed to move a 4nC charge to that position from infinity is given by the product of the charge and the voltage:** $U=qV=4x10^{-9}\bullet 480=1.92x10^{-6}J$

b) The point at the top of the equilateral triangle is also 15cm away from both the 8nC and the 4nC charge. The voltage at that point is just the sum of the voltage due to each charge, which is given by $V_1=\frac{kQ}{r}=\frac{9x10^9 \bullet 8x10^{-9}}{0.15}=480 Volts$ **from the 8nC charge and** $V_2=\frac{kQ}{r}=\frac{9x10^9 \bullet 4x10^{-9}}{0.15}=240 Volts$ **from the 4nC charge, or** $V_{total}=V_1+V_2=720 Volts$

c) The potential energy needed to move a 7nC charge to that point is again the product $U=qV=7x10^{-9}\bullet 720=5.04x10^{-6}J$

Problem 2 (25 points). On a clear sunny day, it's a fact that close to the surface of the earth, a constant vertical electric field (perpendicular to the earth's surface) of about **130 N/C** points down into the flat ground. This field is actually due to the charging of the earth from lightening and other natural phenomenon. Calculate

a) The surface charge density **σ** (charge per area) on the ground for these conditions,

The constant electric field is generated by the surface charge density on the ground. Since the field is constant, it looks just like the field due to an infinite plane with constant charge density σ. The field due to a constant charge density is given by $E=\sigma/\varepsilon_0=130N/C$. Solve for $\sigma=\varepsilon_0 E=8.85x10^{-12}C^2/Nm^2 \bullet 130N/C=1.2x10^{-9}C/m^2$

b) The potential difference between the ground and a point **1m** above the ground.

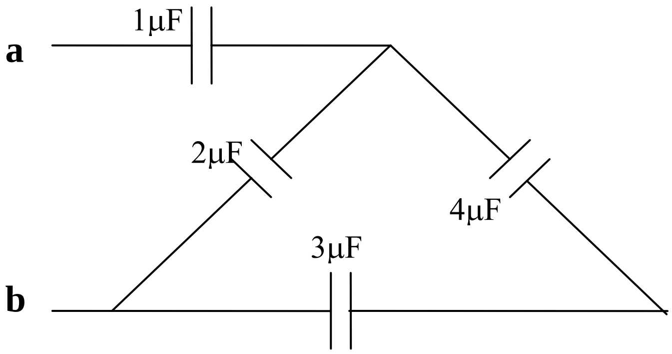
the relationship between a constant electric field and the potential difference across a distance Δx is given by $\Delta V=E\Delta x$. This gives $\Delta V=130V/m \bullet 1m=130V$. Note that voltage decreases in the direction of the electric field (remember the positive point charge has an electric field which points away from the charge, and a potential that decreases from infinity at r=0 to zero at r = ∞). Since the field points down, then the voltage decreases from 130V at 1m to 0 volts at the ground.

Problem 3 (25 points). How many electrons should be removed from an initially uncharged spherical conductor of radius **0.3m** to produce a potential of **7.5kV** at the surface?

The potential at the surface of a conductor is given by $V=kQ/R$. For V=7.5kV and r=0.3m, we can solve for $Q=VR/k=7500V \bullet 0.3m/9x10^9Nm^2/C^2=2.5x10^{-7}$Coulombs. This total charge has N_e electrons of $1.6x10^{-19}$ C each, so the number of electrons in $2.5x10^{-7}$ Coulombs is given by

$N_e=Q/e=2.5x10^{-7}C/1.6x10^{-19}=1.56x10^{12}$ electrons.

Problem 4 (25 points). Find the equivalent capacitance between points **a** and **b** in the circuit in the figure.



The 4μF capacitor on the right is in series with the 3μF capacitor on the bottom, and they form an equivalent capacitance given by $1/C'_{eq} = 1/3 + 1/4 = 7/12$ **which gives** $C'_{eq} = 12/7\ \mu F$ **. The new configuration is shown in Figure 5a. This capacitor is now in parallel with the 2μF capacitor, which gives an equivalent capacitance** $C''_{eq} = 12/7 + 2 = 26/7\,\mu F$ **as shown in Figure 5b. This equivalent capacitor is in series with the 1μF capacitor, which gives an overall equivalent capacitance of** $1/C_{eq} = 1/1 + 7/26 = 33/26$ **or** $C_{eq} = 26/33\,\mu F = 0.79\,\mu F$

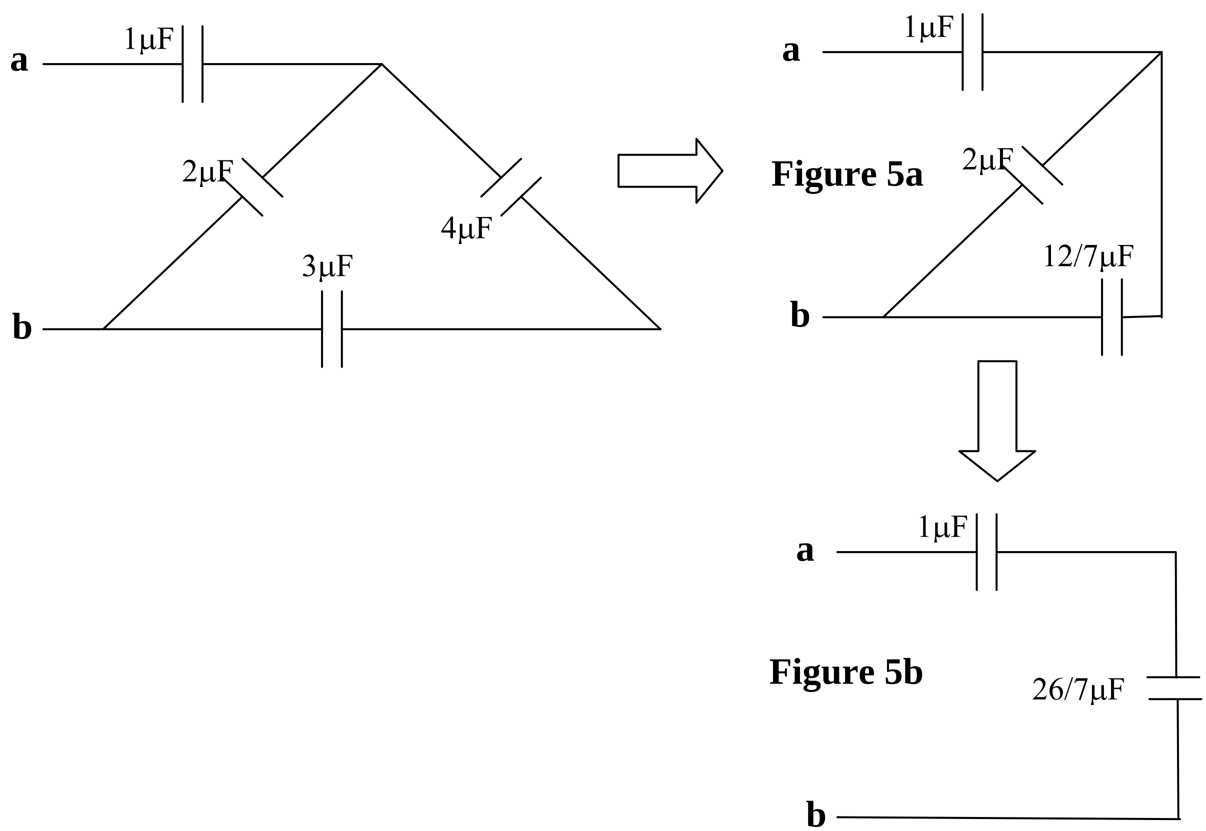


Figure 5a

Figure 5b