Poor Richard's Book of Physics (50,000 points)

1.) Benjamin Franklin is flying his kite into an electrical storm. A thunderstorm cloud 2000. meters overhead has a net charge of Q = +113 C. Assuming it acts like a point charge, (a) what is the strength of the electric field, *E*, that Ben sees on the ground?

$$E = \frac{kq}{r^2} = \frac{\left(8.988\times10^{9}\ {}^{N\cdot m^2}\!/_{C^2}\right)(113C)}{(2000.m)^2} = 253{,}900\,N/C$$

(b) What is the potential difference, ΔV, between the charged cloud and the neutral ground?

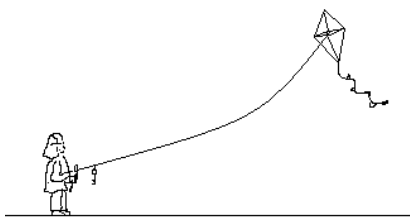
```
The only way to easily do this problem:  assume we can use Δ V = E d .
         (Why might this be a bad assumption otherwise?)
```

$$\Delta V = Ed = (253{,}900\,N/C)(2000.m) = 507{,}800{,}000\,volts$$

(c) If the metal key that is hanging from the wire has a charge $q = +1.04\times10^{-3}\ C$, then find the electric force, F_E, on the key from the overhead thunderstorm cloud.

$$F_E = \frac{kq_1q_2}{r^2} = \frac{\left(8.988\times10^{9}\ {}^{N\cdot m^2}\!/_{C^2}\right)(113C)\left(1.04\times10^{-3}C\right)}{(2000.m)^2} = 264.1N \qquad OR$$

$$F_E = qE = \left(1.04\times10^{-3}C\right)(253{,}900\,N/C) = 264.1N$$



(d) Ben Franklin would have said that his *single electric fluid* would have been added to the metal key to reach $q = +1.04\times10^{-3}\ C$. In truth, how many electrons would have been *added* or *subtracted* to make this *q* ?

$$q = +Ne$$

$$N = \frac{1.04\times10^{-3}C}{1.602\times10^{-19}C} = 6.492\times10^{15}\ electrons\ subtracted$$

(e) Underneath the thunderstorm, a charge of $Q = -113\ C$ is spread out onto the ground, covering an area of 100. meters × 100. meters. Use Gauss's Law to find the magnitude of the electric field, *E*, treating the ground as a sheet of charges.

$$\sigma = \frac{Q}{A} = \frac{-113C}{(100.m)^2} = 0.01130\,C/m^2$$

$$\Phi_E = E(2A) = \frac{q_{inside}}{\varepsilon_0} = \frac{\sigma A}{\varepsilon_0}$$

$$E = \frac{\sigma}{2\varepsilon_0} = \frac{0.01130\,C/m^2}{2\left(8.85\times10^{-12}\ {}^{C^2}\!/_{N\cdot m^2}\right)} = 63{,}840{,}000\,N/C$$

This Problem Should Cap Off The Start of the New Year of the Snake (50,000 points)

2.) A parallel plate capacitor consists of plates with an area $A = 0.100\ m^2$ and a separation of $d = 7.00\ cm$.

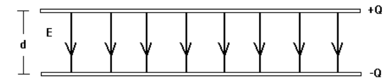
(a) Find the capacitance, *C*. $\varepsilon_0 = 8.85\times10^{-12}\ F/m$

$$C = \varepsilon_0\frac{A}{d} = \left(8.85\times10^{-12}F/m\right)\frac{\left(0.100m^2\right)}{(0.0700m)} = 1.265\times10^{-11}F = 12.65pF$$

(b) If this capacitor is hooked up to a 512 volt battery, find the magnitude of the constant electric field, *E*, between the plates, using the "V = Ed" equation. Sketch some of the E-field lines between the plates in the diagram. *You do not need the answer to (a) for this part.*

$$\Delta V = Ed$$

$$E = \frac{\Delta V}{d} = \frac{512volts}{0.0700m} = 7314V/m$$



(c) Find the magnitude of the electric field between the plates, using the equation $E = \frac{\sigma}{\varepsilon_0}$. The capacitor equation, $C = Q/V$, will get you the charge on one of the plates. *If you did not get an answer to (a), use C = 12.6 pF.*

$$Q = CV = \left(1.265\times10^{-11}F\right)(512volts) = 6.477\times10^{-9}C$$

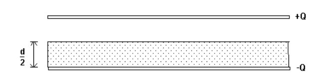
$$\sigma = \frac{Q}{A} = \frac{6.477\times10^{-9}C}{0.100m^2} = 6.477\times10^{-8}C/m^2$$

$$E = \frac{\sigma}{\varepsilon_0} = \frac{6.477\times10^{-8}C/m^2}{8.85\times10^{-12}\ {}^{C^2}\!/_{N\cdot m^2}} = 7319\,N/C$$

(d) How much energy is stored in this capacitor when fully charged?

$$Energy = U = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\left(1.265\times10^{-11}F\right)(512V)^2 = 1.658\times10^{-6}J$$

(e) If half the capacitor is filled with water (κ = 80, Dielectric Strength = ∞), then this becomes two capacitors in *series*. Find the equivalent capacitance of this waterlogged capacitor.



$$C_1 = \varepsilon_0\frac{A}{d} = \left(8.85\times10^{-12}F/m\right)\frac{\left(0.100m^2\right)}{(0.0350m)} = 2.529\times10^{-11}F = 25.29pF$$

$$C_2 = \kappa\varepsilon_0\frac{A}{d} = (80)\left(8.85\times10^{-12}F/m\right)\frac{\left(0.100m^2\right)}{(0.0350m)} = 2.023\times10^{-9}F = 2023pF$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{25.29pF} + \frac{1}{2023pF}$$

$$C_{eq} = 24.98pF$$