HW #3 Solutions

Ch 17 Questions

Q6) Yes. A particle with a *negative* charge moving from lower potential to higher potential will have its potential energy decrease. For example suppose the a charge of -3 C moves from a potential of +10V to a potential of +15V. Then its potential energy = qV goes from -30 J to -45 J, a decrease in PE of 15 J. This only works for a negative charge. The potential energy of a positive charge always increases if its potential increases.

Q11) If the potential in a region is the same everywhere, then no matter which direction one moves in the region, the potential never changes. By $\Delta V = Ed$, if $\Delta V = 0$ then $E = 0$.

Q13) Deciding to call the potential of the earth -10 V would not change anything *physical*. Only *differences* in potential matter physically. a) The potential over every point would be decreased by 10V. b) The electric field would not change because $E = \Delta V/d$, and ΔV between the points is still the same.

Ch 17 Problems

P6) $\Delta V = Ed = 640\ \text{V/m} \cdot 0.011\text{m} = 7.04\ \text{V}$ or 7.0 V to two sig. fig. Notice I am ignoring the - sign. It would not make sense to say that the voltage is -7.0 V because no specification of which plate is positive or which plate is negative has been made. However, you should realize that the + plate is at a higher potential than the negative plate by 7.0V.

P10) If the change in potential energy in moving the charge from a to b were zero, then the work done by the external force would equal the increase in KE. Since the work done is *greater* than the increase in kinetic energy, the work done must also be increasing the potential energy of the charge.

Work done = increase in PE + increase in KE

$$15.0\times10^{-4}\,J = \Delta PE + 4.82\times10^{-4}\,J \quad \text{and therefore } \Delta PE = 10.18\times10^{-4}\,J$$

Since ΔV = ΔPE/q, $\Delta V = \dfrac{10.18 \times 10^{-4} J}{8.5 \times 10^{-6} C} = 119.8V$ or 120 V to correct sig. fig. Notice I am not worrying about the minus sign of the charge, but one should think about whether the potential increases or decreases in moving from a to b. The potential energy increases, but since the charge is negative, we know that the potential must decrease.

P16) Calculate the potential at the point midway between the charges and at the potential at the point 12 cm closer to one of the charges. Then use W = ΔPE, and ΔPE = qΔV. To find the potential at each point, use the formula for the potential of a point charge and the principle of superposition. Call the point midway between the charges A and other point B.

$$V_A = \frac{kQ_1}{r_1} + \frac{kQ_2}{r_2} = \frac{9 \times 10^9 \cdot 35 \times 10^{-6}}{0.16} + \frac{9 \times 10^9 \cdot 35 \times 10^{-6}}{0.16} = 3{,}940{,}000V$$

$$V_B = \frac{kQ_1}{r_1} + \frac{kQ_2}{r_2} = \frac{9 \times 10^9 \cdot 35 \times 10^{-6}}{0.28} + \frac{9 \times 10^9 \cdot 35 \times 10^{-6}}{0.04} = 9{,}000{,}000V$$

Thus $W = \Delta PE = q\Delta V = 0.5 \times 10^{-6} \cdot (9{,}000{,}000 \, {}^{J}\!/_{C} - 3{,}940{,}000 \, {}^{J}\!/_{C}) = 2.5J$

Notice that the potential at B is greater than the potential at A. The charge is being moved away from one of the + charges, which should decrease the potential, but it is moving toward the other + charge, which increases the potential. Apparently the effects do not balance. If you think about the electric field this makes sense. The field at the midpoint between the two charges is zero because the fields from each charge cancel, but the field closer to one of the charges is not zero because now the fields do not cancel. As a matter of fact, the field is away from the nearer charge, so as the charge is moved from the midpoint, it is being moved against the field and the potential increases. (See additional problem 5 for the field of 2 positive charges).

P21) Use conservation of energy: $E_i = E_f$. Initially, the kinetic energy is 0 so all of the energy is potential energy. At the end the potential energy is zero because $r \Rightarrow \infty$ and $V = \dfrac{kQ}{r} \Rightarrow 0$. The final kinetic energy is the sum of the kinetic energies of the two particles.

$$E_i = KE_i + PE_i = 0 + q_1\left(\frac{kq_2}{r}\right) = 9.5\times10^{-6}\left(\frac{9.0\times10^9\cdot 9.5\times10^{-6}}{.035}\right) = 23.2J$$

$$E_f = \frac{1}{2}mv^2 + \frac{1}{2}mv^2 + 0 = mv^2$$

Using m = 0.000001 kg and solving for v gives v = 4820 m/s.

It is interesting to think about the fact that each particle has a kinetic energy, but there is only one potential energy. We say that the PE is in the system, not owned by either particle. A particle by itself cannot have PE, it is only when two particles interact that we get PE. The potential energy we calculated is the work done to bring the two charges together to a separation of 3.5 cm from an infinite distance apart. This could be done by moving both charges, or by keeping one charge fixed and moving the other, but in either case the work done is the same so is the ΔPE. Since we assume the PE is zero at infinity we have $PE = q_1\left(\frac{kq_2}{r}\right) = \left(\frac{kq_1q_2}{r}\right)$.

We tend to forget about this subtlety because for gravity we often say that a mass has some potential energy. It would be more correct to say that the earth/mass system has potential energy.

P65) Using conservation of energy we can determine the speed of the electron before it enters the plates.

$$E_i = KE_i + PE_i = 0 + q_eV_i; \quad E_f = KE_f + PE_f = \frac{1}{2}mv^2 + q_eV_f$$

Solving for *v* gives $v = \sqrt{\frac{2q_e(V_i - V_f)}{m}}$.

The problem says the pot. diff. is 5500V. To accelerate the electron it must move in the opposite direction of the field so the potential increases. In other words V_i-V_f is a *negative* number. But the charge is negative so we get a positive number (whew!). Plugging in we get $v = 4.4\times10^7$m/s. This is the speed of the electron as it enters the field.

Now the problem is like a projectile motion problem. The speed in the horizontal direction remains constant at 4.4×10^7m/s. The electron gains a velocity in the vertical direction. If we can figure that out we can find the angle.

The field is uniform, so the electron feels a constant force and therefore has a constant acceleration in the +y direction, where up in the figure is +.

For constant accleration we know $v_{fy} = v_{0y} + a_y t$.

t is the time the electron is in the field. Using $x=v_x t$ and x = 6.5 cm we find $t= 1.47\times10^{-9}$ s .

To find a_y use Newton: $a_y = F_y/m$ and $F_y = qE_y$ and $E=\Delta V/d$.

Plugging in we get

$E = 250V/0.013m=19200$ V/m = 19200 N/C
$F = 1.6\times10^{-19}$ C $\times19200$ N/C = 3.1×10^{-15} N
$a = 3.1\times10^{-15}$ N/9.11×10^{-31} kg = 3.4×10^{15} m/s^2
$v_y = 3.4\times10^{15}$ m/s^2 $\times$ 1.47×10^{-9} s = 5.0×10^{6} m/s

Now use $\tan\theta = v_y/v_x$ so $\theta = 6.5^o$

Nice problem. Perhaps with a slightly different twist it would be a nice problem to put on Exam 1.

AP1

a) $E = \Delta V/d$ = 5600V/.08m = 70,000 V/m = 70,000 N/C
b) Force on + end = qE = 3.7×10^{-9}C · 70,000 N/C = 0.00026 N toward the negative plate. Force on the - end is the same magnitude but toward the + plate.
c) Net force is zero. This might be slightly surprising, since the grass seed is closer to the - plate, but the field is uniform so it doesn't matter. If the dipole were in a non-uniform field then the forces might not cancel. We saw this in the grass seed demo with one point charge. The grass seeds moved toward the charge.
d) The net torque will turn the grass seed clockwise.
e) When the grass seed is aligned with the field the torque will be zero. Thus the grass seeds give us a picture of the field.

AP2

a) $\Delta V = E\cdot d$ = 3,000,000 V/m · 0.20m = 600,000 volts. Wow! That's a lot of potential difference. Stand clear!

b) $\Delta V = E \cdot d = 3{,}000{,}000\ V/m \cdot 0.001m = 3{,}000$ volts. Hmmm I thought 120 V is enough to kill a person. Oh but the amount of charge is very small, like microcoulombs. Our bodies can tolerate a little charge racing through us. But it still doesn't feel good.

c) $E = \Delta V/d = 75{,}000{,}000\ V/1500m = 50{,}000$ volts. Not enough to cause breakdown in dry air, but the air is very moist during a thunderstorm, and humid air is a much poorer insulator than dry air.

AP3 Use Conservation of energy

a) Assume the potential energy is zero initially. Then

$$E_i = E_f; \quad KE_i + PE_i = KE_f + PE_f; \quad \frac{1}{2}(1.67\times10^{-27}kg)(3.9\times10^5 m/s)^2 + 0 = 0 + qEd$$

Solve for d: $d = 3.9\times10^5 J/qE = \dfrac{1.27\times10^{-16}J}{1.6\times10^{-19}C\cdot 6900N/C} = .115m$

b) Redefine the zero for potential energy at the negative plate of the apparatus. $PE_i = qEd$ with $d = 0.43$ m. $KE_i = 0$. $PE_f = 0$. $KE_f = ½ mv^2$.

Solve for v. $v = 7.5\times10^5$ m/s.

AP5

Look online for a picture of equipotential lines for two like point charges. Here is a pretty cool place to go.

www.its.caltech.edu/~phys1/java/phys1/EField/EField.html

After the window opens up set the charge to +2 using the slider on the upper right side of the simulation. Then somewhere over on the left side of the black field to produce a single point charge. Click a bit to the right to produce a second charge. You get the field lines and the lines of equipotential. Have fun!

The equipotential line that goes through A is pretty straightforward. It is just an oval. The one that goes through B is harder. You can't tell if it is supposed to be sort of a peanut (in the shell) shape enclosing both charges, or a single oval about the left hand charge. I will accept both answers, but only one is actually correct. To figure out which is correct you have to make some measurements on the picture. The potential at B is $V = \frac{kQ}{r_1} + \frac{kQ}{r_2}$, where r is the distance from B to each of the charges. I measure the distances as 2.45 cm and 4.00 cm. The amount of charge doesn't actually matter, so for simplicity assume that each charge is $1.11 \times 10^{-10} C$. Then $kQ = 1$, so the potential is $\frac{1}{0.0245} + \frac{1}{.0400} = 65.8$.

Now calculate the potential at the center of the diagram. The charges are 5.85 cm apart so the distance from the charge to the center is 2.925 cm. Use $V = \frac{kQ}{r_1} + \frac{kQ}{r_2}$ to calculate the potential with $r_1 = r_2 = 2.925$ cm. The answer is 68.3. The potential at the midpoint between the charges is higher than the midpoint at B. But we know from Problem 16 earlier that the potential at the midpoint is lower than the potential anywhere else along the line joining the two charges. So the equipotential line going through B cannot cross the line joining the two charges because the potential along that line is always ≥ 68.3. Hence the peanut shape is actually the correct shape.