Physics 9, Fall 2018, Homework #10.

Due at start of class on Friday, November 30, 2018

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Electric force / electric field problems

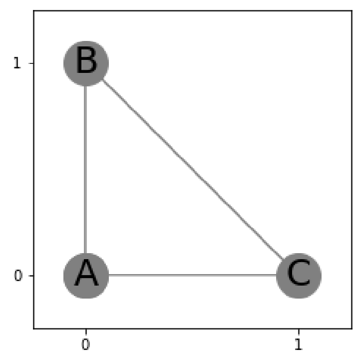
1. Atomic distances (e.g. the size of a single atom) are typically measured in *angstroms:* $1\,\text{Å} = 10^{-10}\,\text{m}$. **(a)** What is the electrostatic force (in Newtons) between two electrons that are separated by a distance of $1.0\,\text{Å}$? Is the force attractive or repulsive? (You should get a number that is larger than a nanonewton but smaller than a micronewton.) **(b)** What is the gravitational force between two electrons that are separated by a distance of $1.0\,\text{Å}$? Is the force attractive or repulsive? (You should get a number for gravity that is about 42 orders of magnitude smaller than your answer for electricity.) **(c)** The radius of an electron's orbit within a hydrogen atom is $0.529\,\text{Å}$. How large would the electrostatic and gravitational forces be for one electron and one proton separated by $0.529\,\text{Å}$? **(d)** If electrical forces are so enormously larger than gravitational forces, why are we so much more aware of gravitational forces in everyday life?

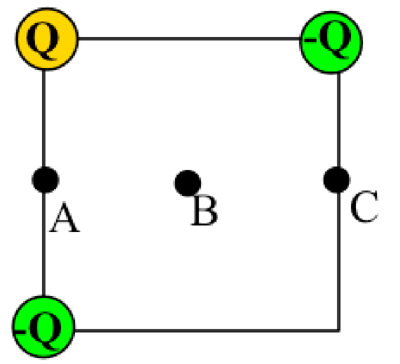
2. **(a)** Calculate the magnitude of the electric field at a distance $0.529 \times 10^{-10}\,\text{m}$ from a single proton. **(b)** Does the electric field point toward the proton or away from it? (The radius of an electron's orbit in a hydrogen atom is $0.529\,\text{Å}$.)

3*. As a result of electric interactions with the atmosphere, Earth exerts an electrostatic force on electrically charged objects near its surface. (Look up "atmospheric electricity" in Wikipedia if you're curious.) The effect can be modeled by assuming there is a negatively charged object at Earth's center with a charge $-6.76 \times 10^5\,\text{C}$. **(a)** What is the electric force exerted by Earth on an electron at Earth's surface? **(b)** How does this force compare with the gravitational force exerted by Earth on this same electron? **(c)** How much charge would you have to put on a penny (mass = 2.5 grams) for the electric repulsion of Earth on the penny to cancel the attractive force of Earth's gravity on the penny? **(d)** How many electrons would you have to add or remove from the penny to achieve this?

4*. A particle at the origin carries charge $-1.00\,\mu\text{C}$. (That's $-1.00 \times 10^{-6}\,\text{C}$.) Located $2.00\,\text{m}$ to the right (along the x-axis) is a second particle that carries charge $+4.00\,\mu\text{C}$. Where on the x-axis could a third particle be placed such that the net force on this third particle would be zero if **(a)** the third particle carries a charge $-2.00\,\mu\text{C}$, or **(b)** the third particle carries a charge $+1.00\,\mu\text{C}$? (There may be a trick to this question, which you can resolve by thinking about the meaning of the electric field.)

5*. A particle of charge $q_A = +1.0\,\mu$C is placed at $(x, y) = (0.0, 0.0)$, a particle of charge $q_B = -1.0\,\mu$C is placed at $(0.0, 1.0)$ m, and a particle of charge $q_C = +2.0\,\mu$C is placed at $(1.0, 0.0)$ m, as shown in the left-hand figure below. **(a)** Calculate the magnitude of the electrostatic force between each pair of particles (pairs AB, AC, BC). **(b)** For each particle (A,B,C) draw arrows showing the electrostatic forces acting on that particle and the vector sum of the forces (a.k.a. "net force") on each particle. **(c)** Write the net force on each particle in vector coordinates (F_x, F_y).



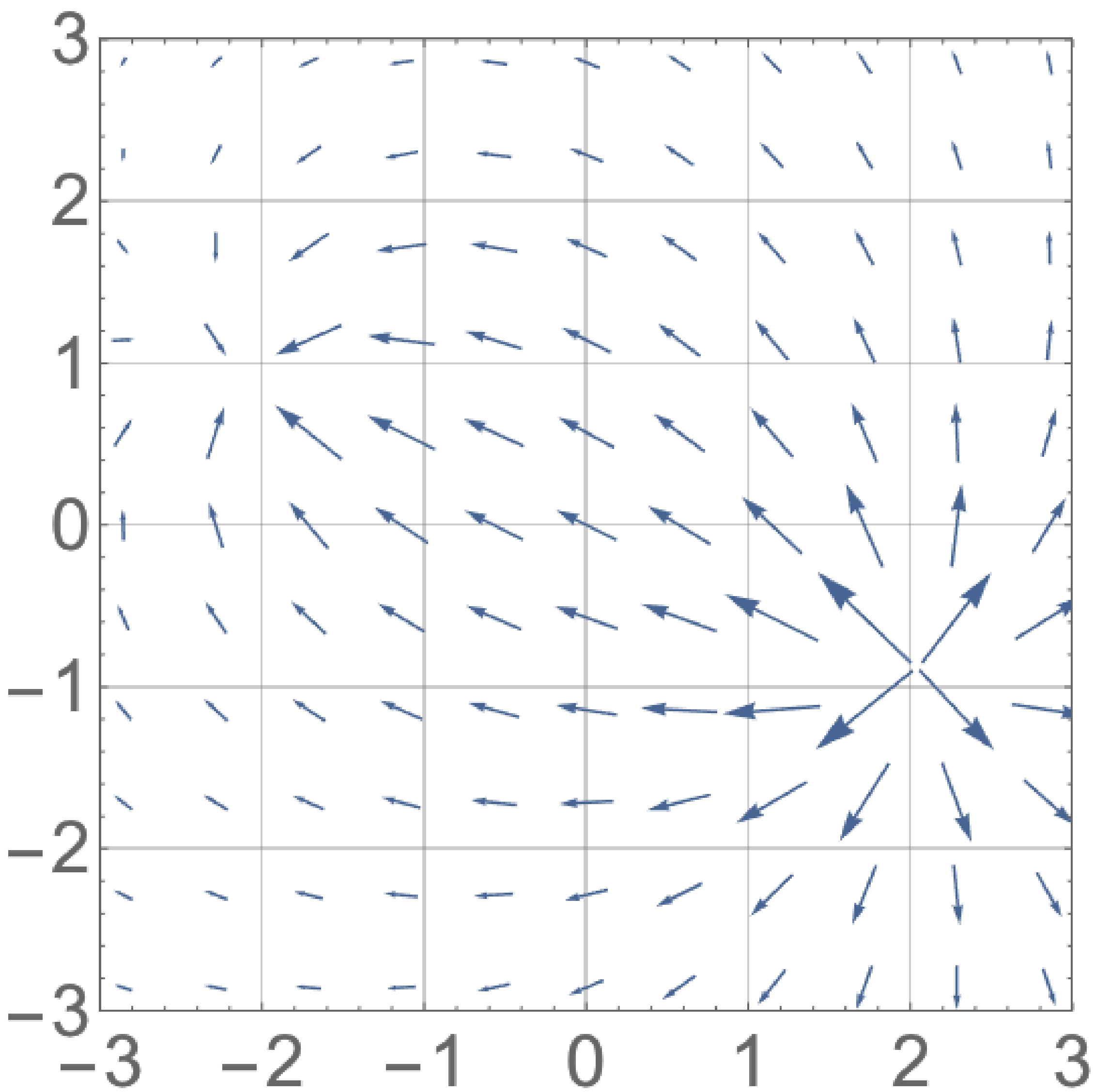


6*. Two negatively charged particles, each of charge $-Q$, are placed at the NE and SW corners of a square, while a positively charged particle with charge $+Q$ is placed at the NW corner, as shown in the right-hand figure above. **(a)** Draw arrows indicating the net force (vector sum of forces) that would be exerted on a fourth particle with charge $+Q$ if it were placed at each of the indicated positions A, B, C. **(b)** Draw electric field lines for the configuration of three particles (without the fourth particle). You may find the online "charges and fields" program helpful for finding the field lines:
`https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html`

7*. Go to `phet.colorado.edu/en/simulation/electric-hockey` and set up your (or a friend's) computer to run Electric Field Hockey. (This is easiest on a computer that already has Java installed. On my Mac, I downloaded the `.jar` file and then in the `Terminal` app I ran E.F.H. using `java -jar electric-hockey_en.jar` after first doing `cd ~/Downloads` but you may find an easier way.) Alternatively, there is an HTML5 (no Java) version of E.F.H. that runs hassle-free within a web browser. It is at
`https://www.physicsclassroom.com/PhysicsClassroom/media/interactive/Electric%20Field%20Hockey/index.html`
Print out a screen shot of your solution for difficulty level 1 (or use level 2 for the HTML5 version). Make sure the "trace" and "field" boxes are checked, so that your printout shows the $\vec{E}$ field vectors and the trajectory of your test charge.

8*. An electron is launched into a region of constant electric field $\vec{E} = 2.0 \times 10^4\,\mathrm{N/C}\,\hat{\jmath}$, with initial velocity $2.1 \times 10^7\,\mathrm{m/s}\,\hat{\imath}$. (Remember that $\hat{\imath} = (1, 0, 0)$ is the unit vector in the x direction, and $\hat{\jmath} = (0, 1, 0)$ is the unit vector in the y direction.) How far has the electron traveled in the y direction by the time it has moved $0.040\,\mathrm{m}$ in the x direction? (Consider only the electric force here, not gravity. Since there is no force in the x direction and there is a constant force in the y direction, this problem is exactly analogous to a projectile-motion problem.)

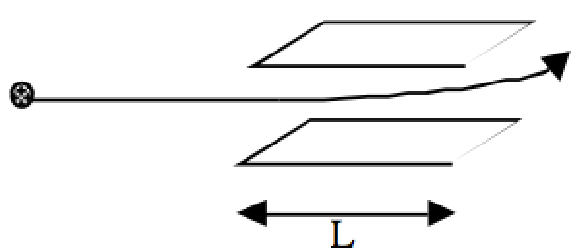
9. The vector field diagram shown in the figure below is produced from an arrangement of two charged particles. **(a)** State the (x, y) locations of the two particles. (Rounding off to the nearest tick is good enough.) **(b)** State the sign of the charge on each of the two particles. **(c)** Determine which of the two charges is larger in magnitude, and explain your reasoning for deciding which one is larger.



10*. Make two vector field diagrams. The first diagram will be for the field due to a single particle of positive charge $+Q$ located at the origin. The second diagram will be for a single particle of negative charge $-2Q$ located at the origin. Describe in words the principal differences between the two diagrams.

Remember **online response** at `positron.hep.upenn.edu/wja/jitt/?date=2018-11-30`

XC1*. Optional/extra-credit. In an inkjet printer, tiny droplets of ink of approximately uniform mass m are given charge q in a charging unit. They are fired toward the paper at speed v. They first pass between charged plates of length L that create a uniform electric field of magnitude E between them, perpendicular to the plates and to the flight path, as shown in the figure below. This deflects the droplets from a straight line and is used to control the formation of characters on the paper. **(a)** Derive an expression for the deflection distance the drop experiences in passing between the plates. **(b)** For ink droplet mass $m = 1.5 \times 10^{-10}\,\mathrm{kg}$, electric field strength $E = 1.2 \times 10^{6}\,\mathrm{N/C}$, plate length $L = 0.010\,\mathrm{m}$, and droplet speed $v = 20\,\mathrm{m/s}$, calculate the droplet charge necessary to result in a deflection of $1.3\,\mathrm{mm}$ ($1.3 \times 10^{-3}\,\mathrm{m}$). **(c)** Is it acceptable to ignore the effects of gravity in this case?



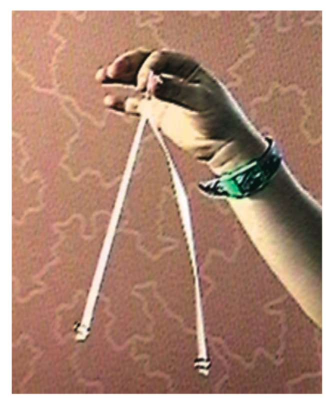


Figure 22.2 Strips of tape just pulled out of a dispenser repel each other. The repulsive force is large enough to keep the strips apart even when they are weighted down by paper clips.

XC2*. Optional/extra-credit. By using information from the packaging of a roll of transparent tape, estimate what fraction of atoms get an electron displaced in order to produce the effect seen in Mazur's Figure 22.2 (reproduced above). You can assume, for this estimate, that the material of the tape is mostly carbon and hydrogen atoms in the ratio of 1:2. You have to make a lot of estimates to work out an answer. If you want something to compare with, my estimate was something like 10^{-12}.

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