Chapter 2 Notes: Electric Fields

What is an electric field, and where does it come from?

The influence of electrical forces is seen when various objects (such as plastic or rubber rods, or tapes) are observed to attract and repel each other. We have described these objects as being "charged." It has been found that the charge on these objects ultimately is due to very small subatomic particles, called protons and electrons. Protons have positive charge, while electrons have negative charge. (The other important subatomic particle, the neutron, is uncharged, or "neutral," and does not experience electrical forces.) When we charge tapes or other objects, the sources of the charge are the protons and electrons in the atoms and molecules composing the objects.

CHARGED PARTICLES "ALTER" SPACE: Charged particles exert strong forces on each other, either attractive or repulsive; these are what we call "electrical" forces. The magnitude of the force depends on the amount of the charge. Although the forces are exerted even when the particles are far apart from each other, the effect does ***not*** happen instantaneously. Careful measurements show that it takes a certain (small) amount of time for the charges to influence each other. Apparently, each charged particle produces some change in the space surrounding it, and this "alteration" in space eventually results in a force being experienced by any other charged particle that is present in the neighborhood. The alteration "permeates" space, in that it is apparently present ***everywhere***. No matter where you place a charged particle in the space surrounding another charged particle, it will experience a force as a result. But the force is stronger when one is closer to the charged particle that is the "source" of the alteration in space.

THIS ALTERATION IS CALLED THE "ELECTRIC FIELD": This "alteration" in space that is produced by a charged particle is not a material object (it doesn't have mass) and is ordinarily invisible. However, it is a real physical entity; it has properties such as energy and momentum, and may be detected in many different ways. This entity has been given the name "***electric field***" (symbol: ***E***), and it is a vector quantity: it has both magnitude and direction. We can detect its presence by observing that a charged particle placed in an electric field will always experience a force which will tend to "push" (or pull) that charged particle in some particular direction.

Electric fields are produced by particles with electric charge; a charged particle is always involved at some stage in the production of an electric field. The charged particles responsible for the production of the field are called "source" charges. When we place a charged particle in an electric field to detect the presence of the field, or to measure the strength (magnitude) of the field, the particle we use is called a "***test***" charge. We always assume that the test charge is so small that it has no influence on the source charges, and that therefore the test charge ***does not alter the existing electric field in any way.*** (If the test charges were too large they might alter the location of the source charges, and in so doing they would change the electric field.) Of course, the test charges produce their *own* electric field, but we assume that this field is much smaller than the field produced by the source charges, and so we can ignore it.

FUNDAMENTAL RELATIONSHIPS OF THE ELECTRIC FIELD: There are four relationships that are critical to understanding the nature of electric fields. (Two of these relationships are actually different versions of each other.)

I.   ***Force on a charged particle:*** If any particle with charge q is located at a point in space where an electric field is present [an electric field that has been created by "source" charges that are considered to be far away] then ***the particle experiences a force.***
     a. The ***magnitude*** of the force is given by this equation:

$$F = |q| E$$

        The magnitude of the force equals the product of the magnitude of the electric field, and the absolute value of the charge. (So a charge q and a charge $-q$ will experience a force of the same magnitude, at a given point in space.)
     b. The ***direction*** of the force is:
        i. in the ***same*** direction as the electric field direction, in the case of a ***positive*** charge;
        ii. in the direction ***opposite*** that that of the electric field, in the case of a ***negative*** charge.

II. **Magnitude and direction of the electric field:** The magnitude and direction of the electric field at a particular point in space can be found by placing a "test" charge at this point. A "test" charge is a charge so small [small amount of *charge*, not necessarily small in size] that it has no influence on the electric field itself. The amount of charge on the test charge is symbolized by q_{test}.

    a.   The **magnitude** of the electric field at a point P is given by this equation:

$$E = \frac{F_{q_{test}}}{|q_{test}|}$$

        Here, F_{qtest} is the magnitude of the force experienced by the test charge (q_{test}) at the point P.

    b. The **direction** of the electric field at a point P is defined to be the same as *the direction of the force experienced by a **positive** test charge placed at that point.*

III. **Electric Field produced by a "point" charge:** A point charge Q (i.e., an extremely small particle containing a charge of Q) will produce an electric field at every point P in space;

    a.   the **magnitude** of the field it produces at point P is given by this relationship:

$$E = \frac{k|Q|}{r^2}$$

Q $\bullet$ $\cdots\cdots\cdots\cdots\cdots\cdots\cdots\longrightarrow$ r P $\vec{E}$
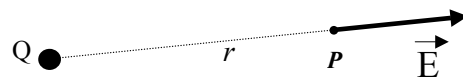
        Here, r is the distance from the charge Q to the point P.

    b.   The **direction** of the field it produces at P is **away** from Q if Q is a positive charge, and it is **toward** Q if Q is a negative charge. In either case, it is directed along the straight line connecting Q to the point P.

IV. **Net electric field due to <u>many</u> point charges:** The **net** electric field at a point in space is equal to the **vector sum** of all of the individual electric fields at that point, produced by all source charges present. Mathematically, this is expressed by this equation:

$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + ... + \vec{E}_n$$

    Here, E_1 is the electric field at point P produced by charge Q_1; E_2 is the electric field at point P produced by charge Q_2, and so on. (We are assuming that there are n source charges, labeled Q_1 on up to Q_n.)

Source charges "present" or "absent" (out of the picture)?

A very confusing aspect of problems involving the electric field is that sometimes we have to explicitly consider the detailed properties of the source charges – the magnitude of their charge, their location, etc. – and at other times we completely ignore the source charges.

Source charges absent: Sometimes the source charges are "out of the picture," and we have no information about them except that there is an electric field present, and we know that the source charges that produced it must be *somewhere.* In this type of problem, we are given information about the **electric field** that is present, but **not** about the source charges which produced it. Instead, our attention will be focused on the **test** charges, and on how they are affected by the electric field. (When the source charges are "out of the picture," we sometimes say that there is an "external" electric field present. This means that the electric field is produced by charges that are "external" to the region that is being shown.)

Source charges present: In other types of problems involving the electric field, we are given information about the source charges and we have to take this information into consideration. For instance, we may have to determine the magnitude and direction of the electric field at a certain point in the neighborhood of one or more source charges. In order to solve a problem of this type, we need to remember the formula for the magnitude of the electric field at a point in space near a single charged particle. The magnitude E of the electric field at a point a distance r from a particle with charge Q is given by $E = kQ/r^2$. ($k = 9 \times 10^9$ N m^2/C^2.)

How do you know whether source charges are present or absent? The wording of each problem should allow you to decide if it is a "source charges present" problem, or if instead the source charges are absent, and "out of the picture."

1)   If the problem gives ***explicit information about the electric field*** — for instance, that it is uniform, or "strong," or points in some particular direction — it is very likely that you do not have to worry about the source charges. You only have to figure out what would happen to different test charges when placed somewhere in the field. (E.g.: What forces are acting on the charges? Where will they move?)

2)   If the problem gives information about the magnitude and location of one or more charged particles, and asks you to ***figure out something about the electric field at a particular location,*** then "source charges are present." You will probably have to find the electric field vector due to each source charge, and find the vector sum to get the "net" field at a particular point. The magnitude of the field at a point due to a source charge Q is given by $E = kQ/r^2$ where r is the distance from the point to the source charge. The direction of the field is along the line connecting the point and the charge, either away from the source charge if it is positive, or toward it if it is negative. (Why?) Note that if the source charges are not present in the problem you can ***not*** make use of the equation $E = kQ/r^2$, because you have no way of knowing the value of r!

Example #1: *A proton is located at (−1 m, 0 m) and two protons are located at (+1 m, 0 m). What is the magnitude of the **net electric field** at the origin?*

A. 0 N/C
B. 0.36×10^{-9} N/C
C. 0.72×10^{-9} N/C
D. 1.08×10^{-9} N/C
E. 1.44×10^{-9} N/C
F. 2.88×10^{-9} N/C
G. 4.32×10^{-9} N/C
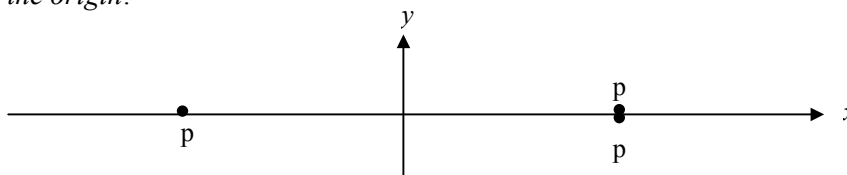
Example #2: *A uniform electric field is present in a certain region of space. In order to measure the strength of this field, you place a particle with charge q at some point and measure the force on that particle. If you remove the charge q, and instead you place a charge 2q at that same point, the electric **field** magnitude (**not** the force) you now measure at that point will be:*
    A. *the same.*
    B. *twice as large.*
    C. *four times as large.*
    D. *half as large.*
    E. *one quarter as large.*

Example #3: *A particle with charge +q and mass m is held at a certain point in apparently empty space, and then released to move freely. It is observed to move with initial acceleration a toward the north. If a particle with charge −q and mass 2m is now placed at the same point, it will:*
    A. *move with acceleration a towards the north.*
    B. *move with acceleration 0.5a towards the north.*
    C. *move with acceleration 2a towards the north.*
    D. *move with acceleration a towards the south.*
    E. *move with acceleration 0.5a towards the south.*
    F. *move with acceleration 2a towards the south.*

Example #4: *At a particular point in otherwise empty space, a 4.6-C charge is placed and it experiences an electrical force of 14.8 N. If this charge is removed, and instead a 6-C charge is placed at that point, what will be the magnitude of the force that it will experience?*

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Answers and explanations:

#1. In this problem you are asked to find the net electric field at the origin, with three charged particles present (all protons). There will be three separate field contributions, one for each "source" charge; you have to find the vector sum of all three. The *magnitude* of each of the three fields is the same; it is:

$$F = (9 \times 10^9 \text{ N m}^2/\text{C}^2)\,(1.60 \times 10^{-19} \text{ C}) / (1 \text{ m})^2 = 1.44 \times 10^{-9} \text{ N/C}.$$

One field is directed toward the *positive x* axis, two are directed toward the *negative x* axis. We could write the result this way: $E_{net\,x} = E_{1\,x} + E_{2\,x} + E_{3\,x} = (1.44 \times 10^{-9} \text{ N/C}) + (-1.44 \times 10^{-9} \text{ N/C}) + (-1.44 \times 10^{-9} \text{ N/C}) = -1.44 \times 10^{-9}$ N/C. The *y* component of the net field is zero, and so the magnitude of the net electric field is equal to the magnitude of the *x* component of the net field, which is 1.44×10^{-9} N/C. (So the answer is "E.")

#2. In this problem, you are told that "a uniform electric field is present in a certain region of space." From this you should conclude that the field will *always* be uniform, and will not be influenced by any charges you place in the field. You are not given any information about the source charges, and so you must assume that the field is a fixed "external" field. The source charges will not be influenced by any other charges that might be brought in, and the field has a given magnitude and direction at every point in space which will ***not*** be affected in any way by a test charge. If you now bring in a test charge *q* to determine the magnitude and direction of the field at some point, the test charge will experience a force whose magnitude is given by $F_q = qE$. The magnitude and direction of **E** are determined by the source charges; they have a specific value at each point in space, and they will not be changing. If, however, you put a test charge *2q* at the point where you had originally placed the *q* charge, the ***force*** on this new test charge will have twice the magnitude as that on the original test charge: $F_{2q} = 2qE$. The ***field*** at that point did not change, just the magnitude of the force on the (different) test charge. So, the answer is "A. the same."

#3. In this problem, you are told that a charged particle is held at a certain point in "apparently empty space," and when it is released it begins to accelerate. This tells you that there must be an electric field present at the point where it is released. Once again you are not given any information about the source charges, and so you can only determine the properties of the electric field by "probing" it with various test charges. As discussed above, if a *positive* charge located at some point in space experiences a force in some direction, then a *negative* charge at that same point will experience a force in the **opposite** direction. (Just consider, for instance, a point in the neighborhood of a positive source charge fixed at the origin. Put a positive test charge at that point, and it will move *away* from the origin; put a negative test charge there, and it will move *toward* the origin.)

The magnitude of the force on a test charge in an electric field is given by $F = |q|E$. The *magnitude* of the force on a charge *+q* is the same as that on a charge *–q*; only the *directions* are different (opposite). So here, the magnitude of the force on the two charged particles is the same; if the positive charge is forced to move north, then the negative charge will accelerate toward the south. However, the magnitude of the acceleration is proportional to the ratio of *[force] ÷ [mass]*. This means that the acceleration of the more massive particle (mass = 2*m*) will be ***half*** that of the less massive particle (since the force is the same for both). Therefore, the particle with charge *–q* has acceleration *a*/2, and moves toward the south. (Answer is "E.")

#4. Once again, a charged particle is placed at a point in "otherwise empty space," and it experiences a force. There must be an electric field present, and we can find the magnitude of this field. It is given by $E = F/q = $ *14.8 N/4.6 C* = 3.22 N/C. If we now place a 6-C charge at the same point in space, it will be influenced by the ***same*** electric field, and so the force on this particle will be given by $F = qE = $ (6 C) (3.22 N/C) = 19.3 N.

Note that ***nowhere*** in problems #2, #3, or #4 could you use the equation $E = kQ/r^2$, because at no time did you have any information about any source charge *Q*. (In fact, there may have been many source charges present, but you had no information about any of them.) The source charges *were* present in #1, but you could also use your result to determine the force that would act on a ***test*** charge (e.g., *q* = –*e*) placed at the origin in that situation.

→→ **_Try it!_**