

## ELECTRIC FIELDS

Charged objects are surrounded by a distortion in space known as the electric field,  $E$ . The electric field is similar to the gravity field surrounding masses. Like gravity, the electric field is a vector quantity having both magnitude and direction. The electric field of a charged object creates an electric force,  $F_E$ , on other charged objects located in the field, just as the gravity field of a mass creates a force on other objects with mass.

Visual representations and the mathematical equations for electric fields and gravity fields are nearly identical. However, charges and their surrounding electric fields vary from mass and gravity fields in some unique ways. Gravity fields always point toward the mass responsible for the field. However, electric fields can point either toward or away from the charge depending on the sign of the charge. While gravity fields cause objects to only attract each other, electric fields can cause charged objects to attract or to repel one another. These differences make electric fields a little more complicated than gravity fields. The direction of the electric field and its effect on positive and negative charges is extremely important.

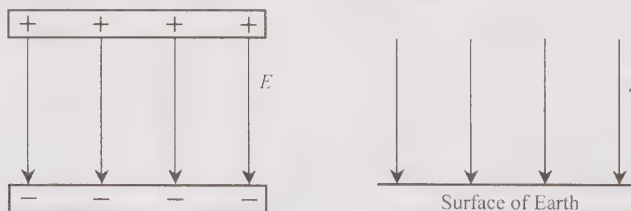
The SAT Subject Test in Physics involves two common electric-field configurations: uniform electric field between charged plates and the electric field surrounding spherical point charges. Each field type has its own set of equations and unique problem sets.

### UNIFORM ELECTRIC FIELDS

**Uniform electric fields** exist between two parallel plates containing equal but opposite charges. These fields are considered to be uniform since both the magnitude and the direction of the field are the same at all points between the plates.

### Visualizing Uniform Fields

Figure 10.1 compares a uniform electric field and a uniform gravity field.



**Figure 10.1** Electric field of charged plates (left) compared to gravity field (right)

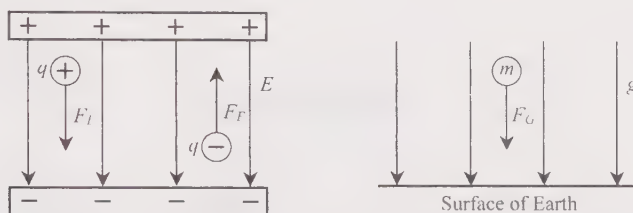
Whereas gravity fields always point toward a mass, such as Earth, electric fields are a bit more complicated due to the existence of two types of charge. An electric field points in the same direction as an electric force points when it is acting on a positive charge. To find the electric field at a point in space due to a charge or to a group of charges, imagine a positive test charge at that location. Determine the direction of force on an imaginary test charge placed in that location. This will be the same as the direction of the electric field. This means that electric fields point away from positive charges and toward negative charges. A uniform field is drawn with parallel and equally spaced arrows. Often diagrams on exams consist of the arrows only, and the plates responsible for the electric field are not shown.

## Magnitude of Uniform Electric Fields

Often the magnitude of the electric field,  $E$ , is given in a problem. Unlike the known value for the gravity field of Earth,  $g = 9.8 \text{ m/s}^2$ , the electric field is unique to the plates used in each problem. Although the electric-field strength,  $E$ , may be given in a problem, you may also be required to calculate it using the equations that appear in the following sections. The units of the electric field are newtons per coulomb (N/C). The units of the gravity field will most likely be reported in meters per second squared ( $\text{m/s}^2$ ). However, when analyzed as a field rather than as acceleration, the units for the gravity field can be reported as newtons per kilogram (N/kg).

## Electric Force in Uniform Electric Fields

If a charge,  $q$ , such as a proton or an electron, is placed into a uniform electric field, it will experience an electric force,  $F_E$ . This is very similar to placing a mass,  $m$ , into the gravity field of Earth. See Figure 10.2.



**Figure 10.2** Force due to uniform fields

The magnitude of force can be determined using the following equations:

Electricity	Gravity
$F_E = qE$	$F_G = mg$

A force is an interaction between an object and an agent. The charged plates are the agent creating an electric field,  $E$ . Charge  $q$  is the object that experiences a force,  $F_E$ . The formula for the magnitude of the electric force is not dependent on whether charge  $q$  is positive or negative.

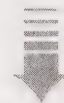
Figure 10.2 clearly shows that the direction of the electric force,  $F_E$ , is dependent on the sign of the charge located in the field. The force acting on a positive charge, such as a proton, will be in the direction of the electric field. However, the electric force acting on a negative charge is opposite the field.

## Kinematics in Uniform Electric Fields

The sum of all forces acting on an object will determine its resulting motion. The electric force is merely another force. Solve problems involving electric force in the same manner as you solve all other problems involving forces.

1. Orient the problem.
2. Determine the type of motion.
3. Sum the force vectors in the relevant direction.
4. Substitute and solve.

**IF YOU SEE  
a charge  
in a uniform  
electric field**



$$F_E = qE$$

The force on a positive charge is in the direction of the electric field, while the force on a negative charge is opposite the field.

One aspect of electric-force problems seems to vary from other force problems. Some problems include the force of gravity, while others ignore it entirely. Why and when is gravity important? Compared with electric force, the force of gravity is incredibly weak. Although the force of gravity is present, its effects are often negligible (too small to affect calculations). Electrons, protons, and ions have insignificant mass, and the force of gravity is usually ignored. In order for gravity to matter, the mass of the charged object must be fairly large. As a general rule of thumb, if the object is large enough to be seen, then the force of gravity is probably important.

Problems on exams frequently test the motion of electrons and protons. The direction of the motion depends on the sign of the charge, with like charges moving in opposite directions and unlike charges moving toward one another. When electrons are compared with protons, keep these facts in mind:

- Electrons and protons have the same magnitude of charge.
- When placed into the same electric field, they will both experience the same magnitude of electric force but in opposite directions.
- The electron has less mass, and the same force will cause it to have a greater acceleration than the proton.

### EXAMPLE 10.2

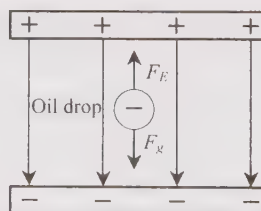
#### Millikan Oil Drop

Robert Millikan determined the charge on an electron by suspending negatively charged oil drops in a uniform electric field created by two charged plates as shown in the diagram below. Determine the charge of an electron in terms of the mass of the oil drop ( $m$ ), the electric field ( $E$ ), and the gravity of Earth ( $g$ ).

#### WHAT'S THE TRICK?

The oil drop has enough mass to include the force of gravity. In addition, there has to be an upward force countering gravity to keep the oil drop stationary.

**Orient the problem:** The electric field points from the positive plate to the negative plate. The electric force on the negative oil drop points upward, opposite the electric field. The force of gravity points downward.



**Determine the type of motion:** This is static equilibrium.

**Sum the force vectors in the relevant direction:** Since the oil drop is stationary, the sum of the forces is zero. Simply set the two opposing forces equal to each other.

$$F_E = F_g$$

**Substitute and solve:**

$$qE = mg$$

Solve  $q$  in terms of the other variables.

$$q = \frac{mg}{E}$$