Applied Physics

BS Software Engineering/Information Technology

1st Semester

Lecture # 4

THE ELECTRIC FIELD

Presented By

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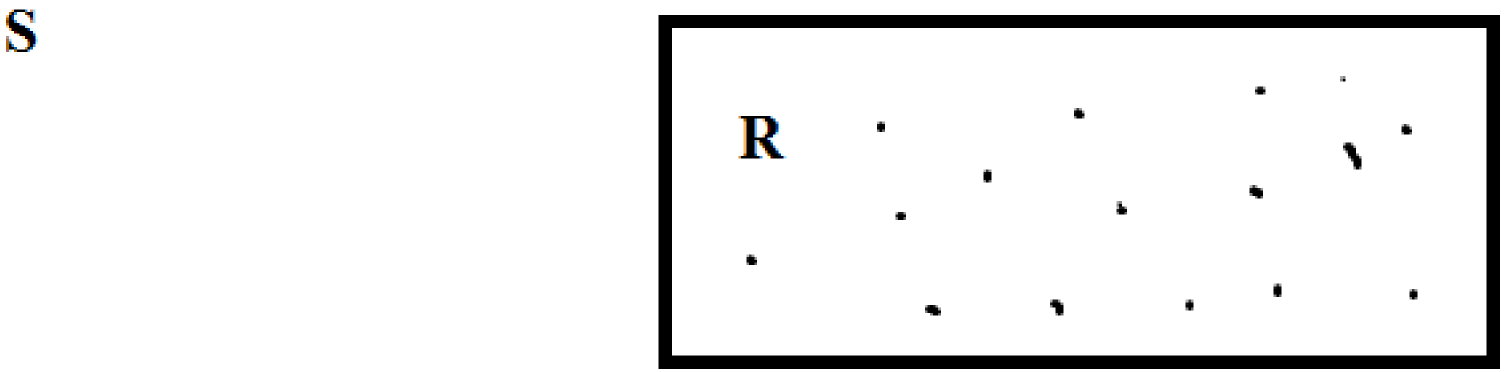
Lecture # 4

- The Field
- The Electric Field
- The Electric Field of Point Charges
- Electric Field Lines
- Assignment # 2

FIELDS



If we can associate a physical quantity at each point in a region R of space S, then we can say that a FIELD exists in that region.

FIELDS

scalar fields

static fields

$T(x,y,z)$

time-varying fields

$T(x,y,z,t)$.

The temperature has a definite value at every point in the room in which you may be sitting. You can measure the temperature at each point by putting a thermometer at that point, and you could then represent the temperature distribution throughout the room either with a mathematical function, say, $T(x,y,z)$, or else with a graph plotting the variation of T. Such a distribution of temperatures is called a *temperature field*. In a similar fashion we could measure the pressure at points throughout a fluid and so obtain a representation for the *pressure field*, describing the spatial variation of pressure. Such fields are called *scalar fields*, because the temperature T and pressure p are scalar quantities. If the temperature and pressure do not vary with time, they are also *static fields*; otherwise they are *time-varying fields* and might be represented mathematically by a function such as $T(x,y,z,t)$.

FIELDS

vector field

static fields

$\vec{V}(x, y, z)$

time-varying fields

$\vec{V}(x, y, z, t)$

FIELDS

$\boxed{\textit{scalar fields} + \textbf{vector field}}$

static fields

time-varying fields

$T(x,y,z)$

$T(x,y,z,t)$.

$\vec{V}(x, y, z)$

$\vec{V}(x, y, z, t)$

Before the concept of fields became widely accepted, the force between gravitating bodies was thought of as a direct and instantaneous interaction. This view, called *action at a distance*, was also used for electromagnetic forces. In the case of gravitation, it can be represented schematically as

$$\text{mass} \rightleftarrows \text{mass},$$

indicating that the two masses interact directly with one another. According to this view, the effect of a movement of one body is instantaneously transmitted to the other

$$\text{mass} \rightleftarrows \text{field} \rightleftarrows \text{mass},$$

in which each mass interacts not directly with the other but instead with the gravitational field established by the other. That is, the first mass sets up a field that has a certain value at every point in space; the second mass then interacts with the field at its particular location. The field plays the role of an intermediary between the two bodies.

THE ELECTRIC FIELD $\vec{E}$

The previous description of the gravitational field can be carried directly over to electrostatics. Coulomb's law for the force between charges encourages us to think in terms of action at a distance, represented as

$$\text{charge} \rightleftarrows \text{charge.}$$

Again introducing the field as an intermediary between the charges, we can represent the interaction as

$$\text{charge} \rightleftarrows \text{field} \rightleftarrows \text{charge.}$$

$$F = k\frac{q_1 q_2}{r^2}\,.$$

$$F = k\frac{q\,q_0}{r^2}\,.$$

$$\frac{F}{q_0} = k\frac{q}{r^2}$$

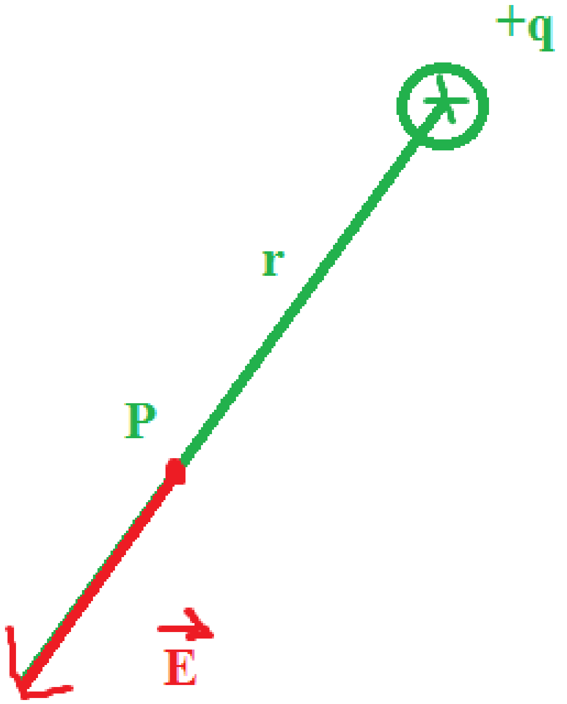
$$\mathbf{E} = \frac{\mathbf{F}}{q_0}\,.$$

$$\mathbf{E} = \frac{\mathbf{F}}{q_0} \qquad \text{——— (1)}$$

$$\boxed{\mathbf{E} = k\frac{q}{r^2} \qquad \text{——— (2)}}$$

$E \propto q$

$E \propto \frac{1}{r^2}$

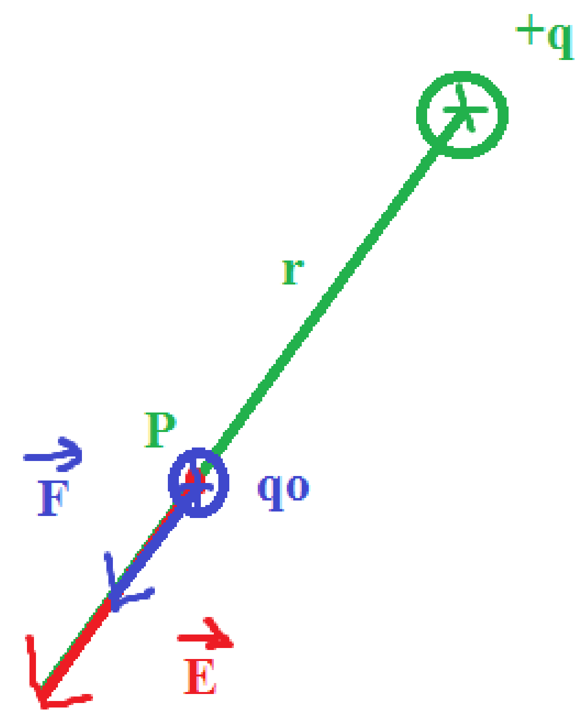


$$\mathbf{E} = \frac{\mathbf{F}}{q_0} \quad \text{———} \quad (1)$$

$$\mathbf{E} = k\frac{q}{r^2} \quad \text{———} \quad (2)$$

$E \propto q$

$E \propto \frac{1}{r^2}$



$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q_0} \qquad (1)$$

$$\vec{\mathbf{E}} = k\frac{q}{r^2}\hat{\mathbf{r}} \qquad (2)$$

THE ELECTRIC FIELD OF POINT CHARGES

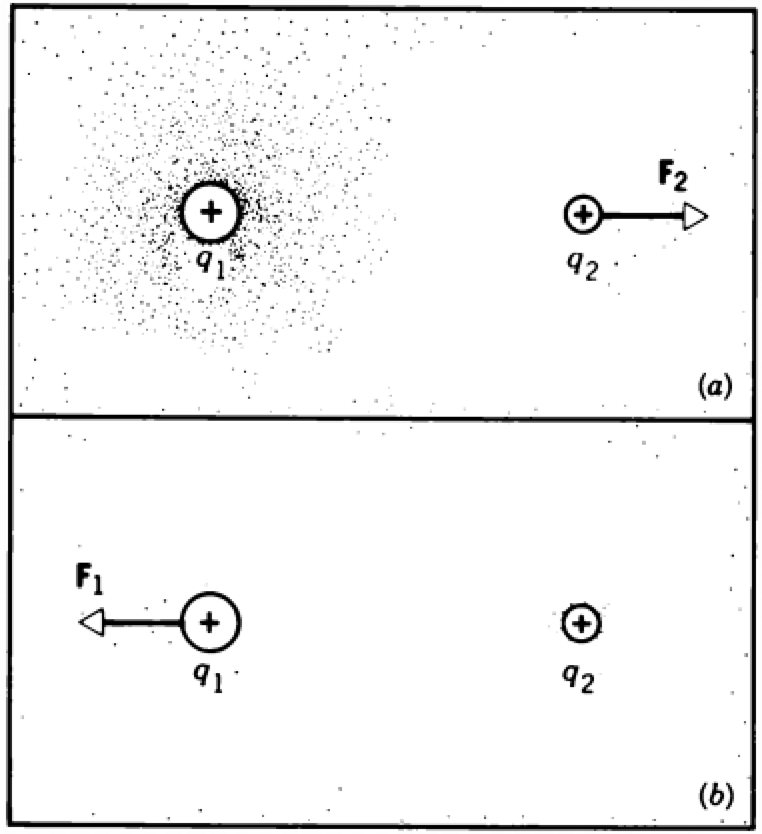
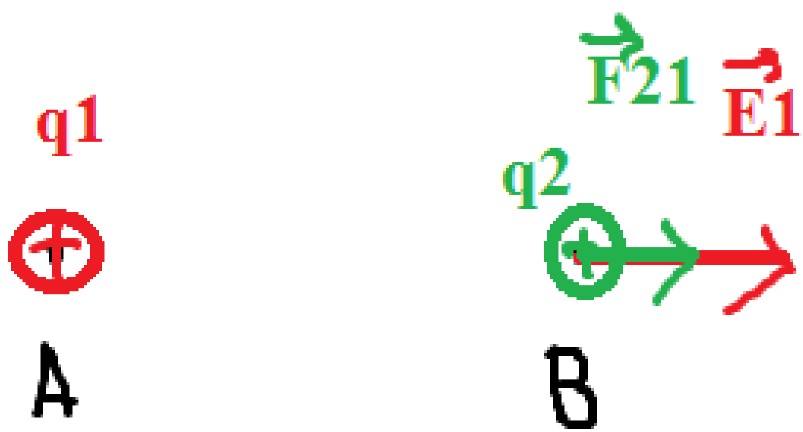
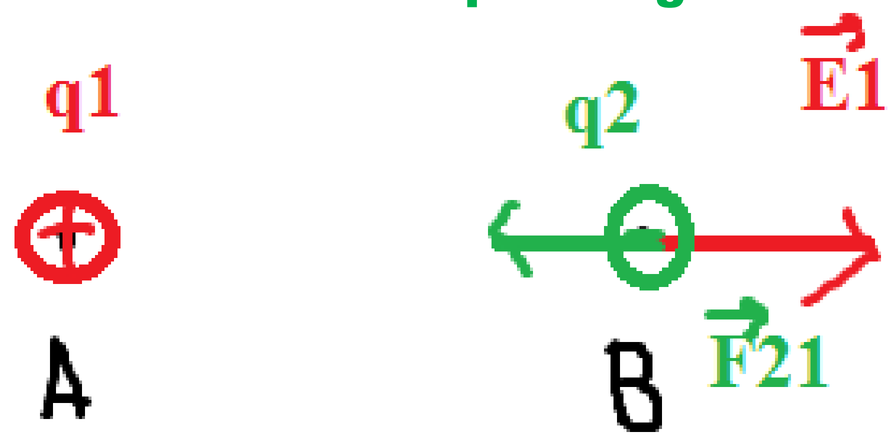


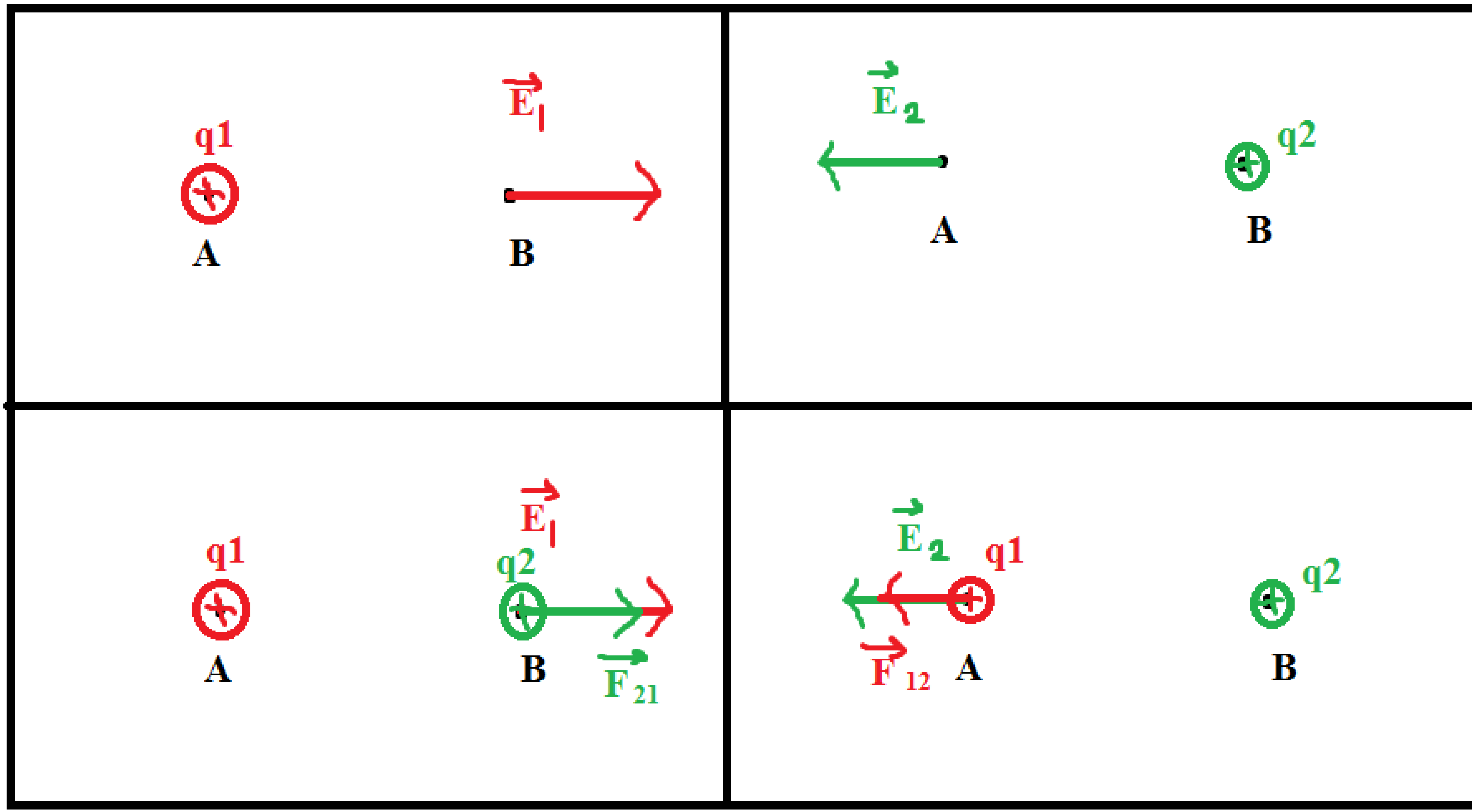
Figure 1 (*a*) Charge q_1 sets up an electric field that exerts a force $\mathbf{F}_2$ on charge q_2. (*b*) Charge q_2 sets up an electric field that exerts a force $\mathbf{F}_1$ on charge q_1. If the charges have different magnitudes, the resulting fields will be different. The forces, however, are always equal in magnitude and opposite in direction; that is, $\mathbf{F}_1 = -\mathbf{F}_2$.

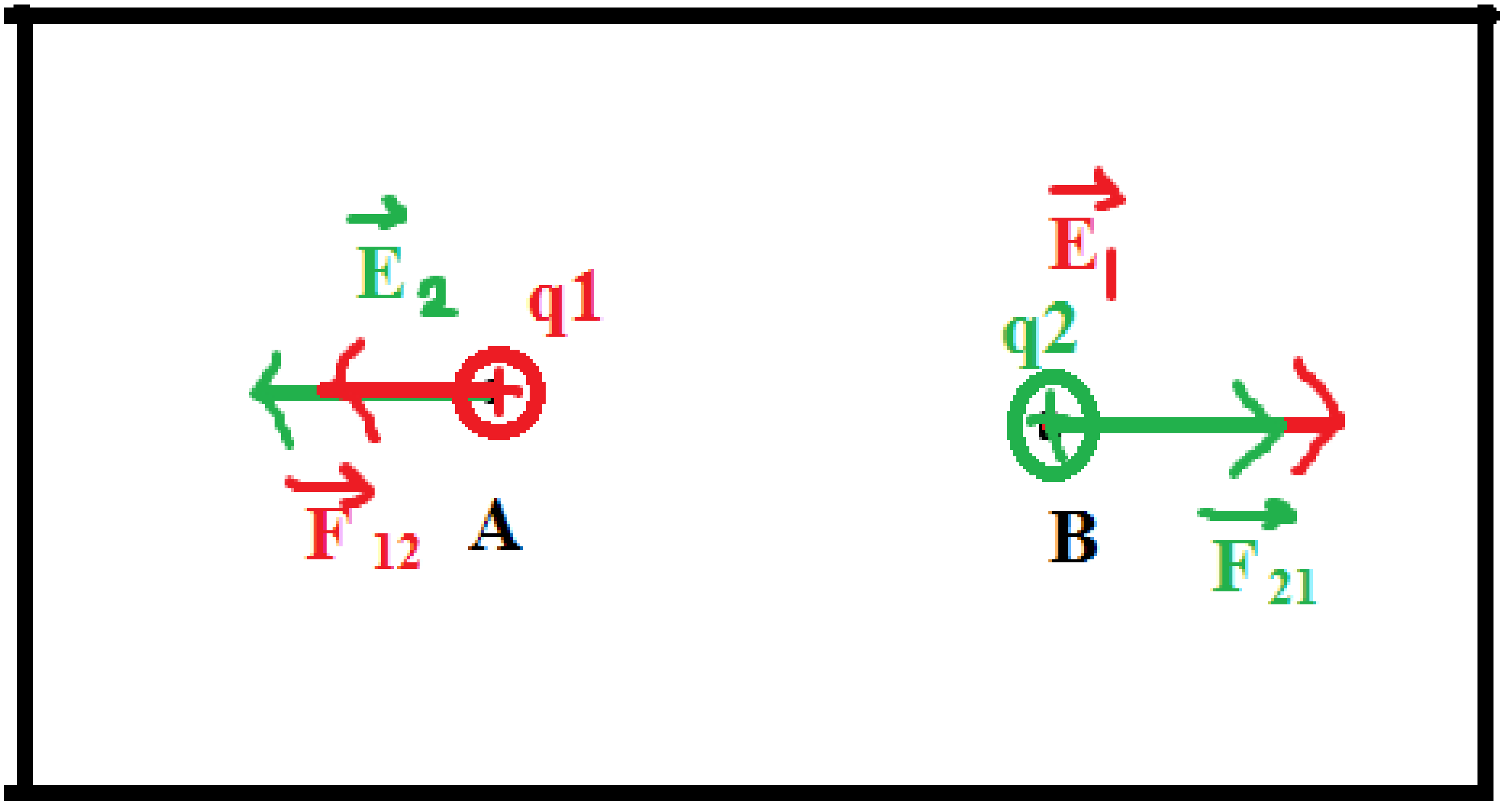

q1
$\vec{E1}$
A
B


$\vec{F21}$
$\vec{E1}$
q1
q2
A
B

If q2 is negative charge




q1
E1
A
B
E2
q2
A
B
q1
E1
q2
A
B
F21
E2
q1
q2
F12
A
B



Electrostatic forces obey Newton's third law of motion.

THE ELECTRIC FIELD OF POINT CHARGES

Let a positive test charge q_0 be placed a distance r from a point charge q. The magnitude of the force acting on q_0 is given by Coulomb's law,

$$F = \frac{1}{4\pi\epsilon_0} \frac{qq_0}{r^2} .$$

The magnitude of the electric field at the site of the test charge is, from Eq. 2,

$$E = \frac{F}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} . \qquad (4)$$

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}}{q_0}\,.$$

$$\vec{\mathbf{E}} = \lim_{q_0 \to 0} \frac{\vec{\mathbf{F}}}{q_0}$$

Principle of superposition applied to electric field

To find $\mathbf{E}$ for a group of N point charges, the procedure is as follows: (1) Calculate $\mathbf{E}_i$ due to each charge i at the given point *as if it were the only charge present*. (2) Add these separately calculated fields vectorially to find the resultant field $\mathbf{E}$ at the point. In equation form,

$$\begin{aligned} \vec{\mathbf{E}} &= \vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2 + \vec{\mathbf{E}}_3 + \cdots \\ &= \sum \vec{\mathbf{E}}_i \quad (i = 1, 2, 3, \ldots, N). \end{aligned} \tag{5}$$

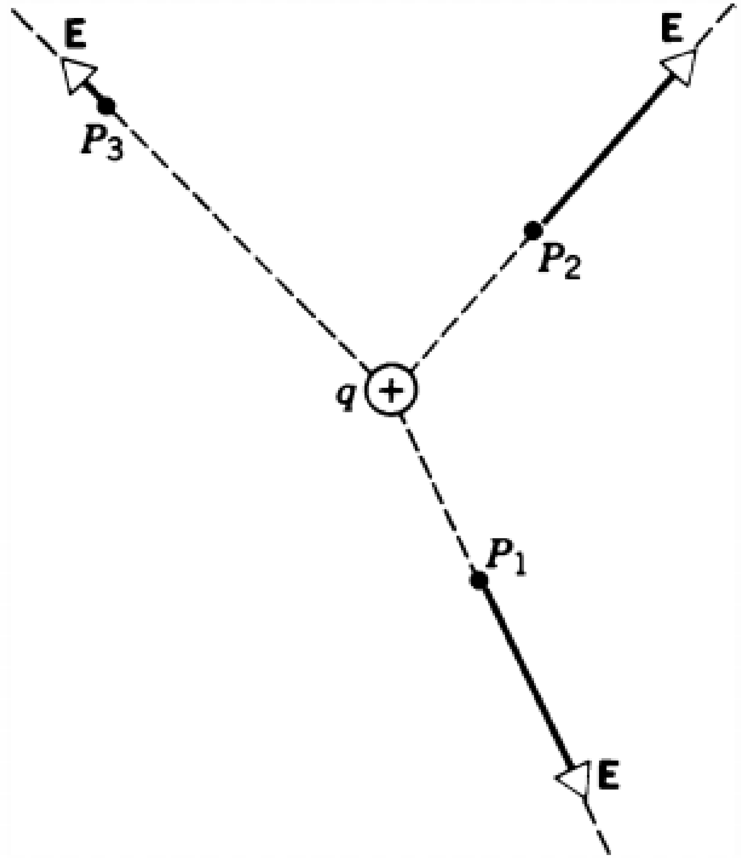
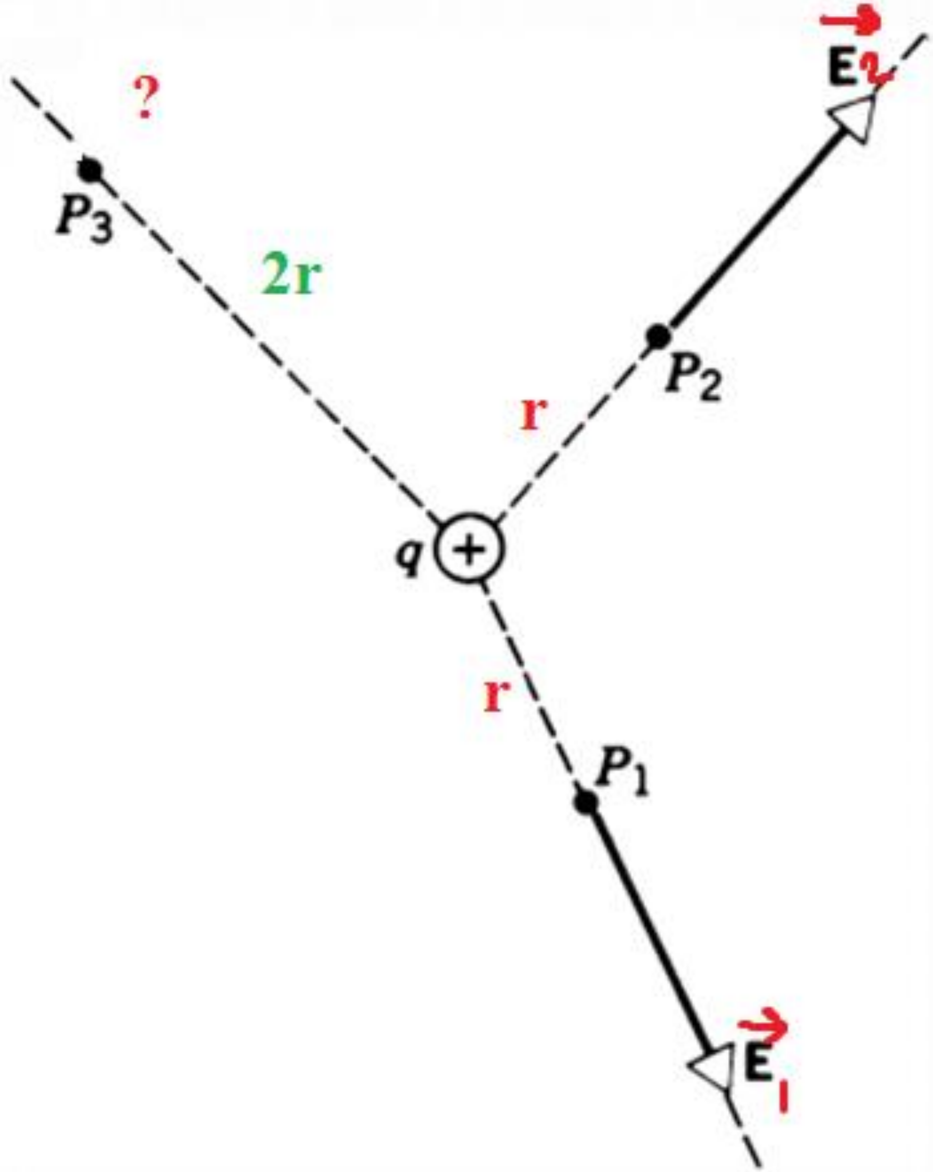


Figure 2 The electric field **E** at various points near a positive point charge q. Note that the direction of **E** is everywhere radially outward from q. The fields at P_1 and P_2, which are the same distance from q, are equal in magnitude. The field at P_3, which is twice as far from q as P_1 or P_2, has one-quarter the magnitude of the field at P_1 or P_2.

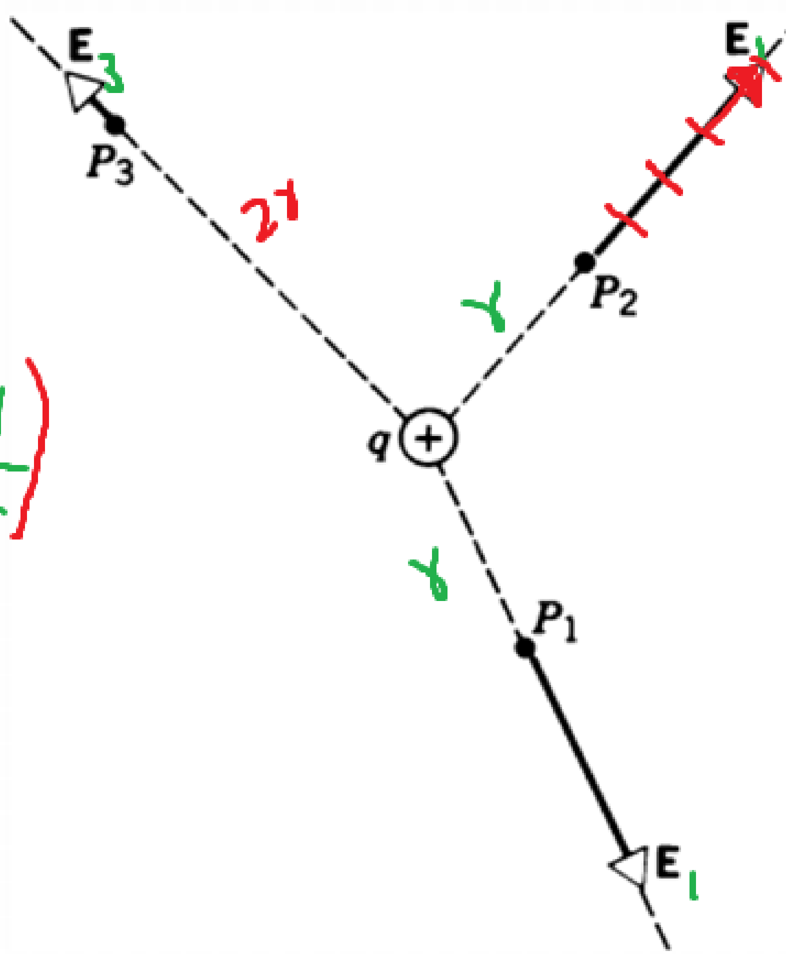


?
P_3
2r
$\vec{E}_2$
P_2
r
q
+
r
P_1
$\vec{E}_1$

$$E_1 = \frac{kq}{r^2} = E_2$$

$$E_3 = \frac{kq}{(2r)^2} = \frac{1}{4}\left(\frac{kq}{r^2}\right)$$

$$E_3 = \frac{1}{4} E_1$$

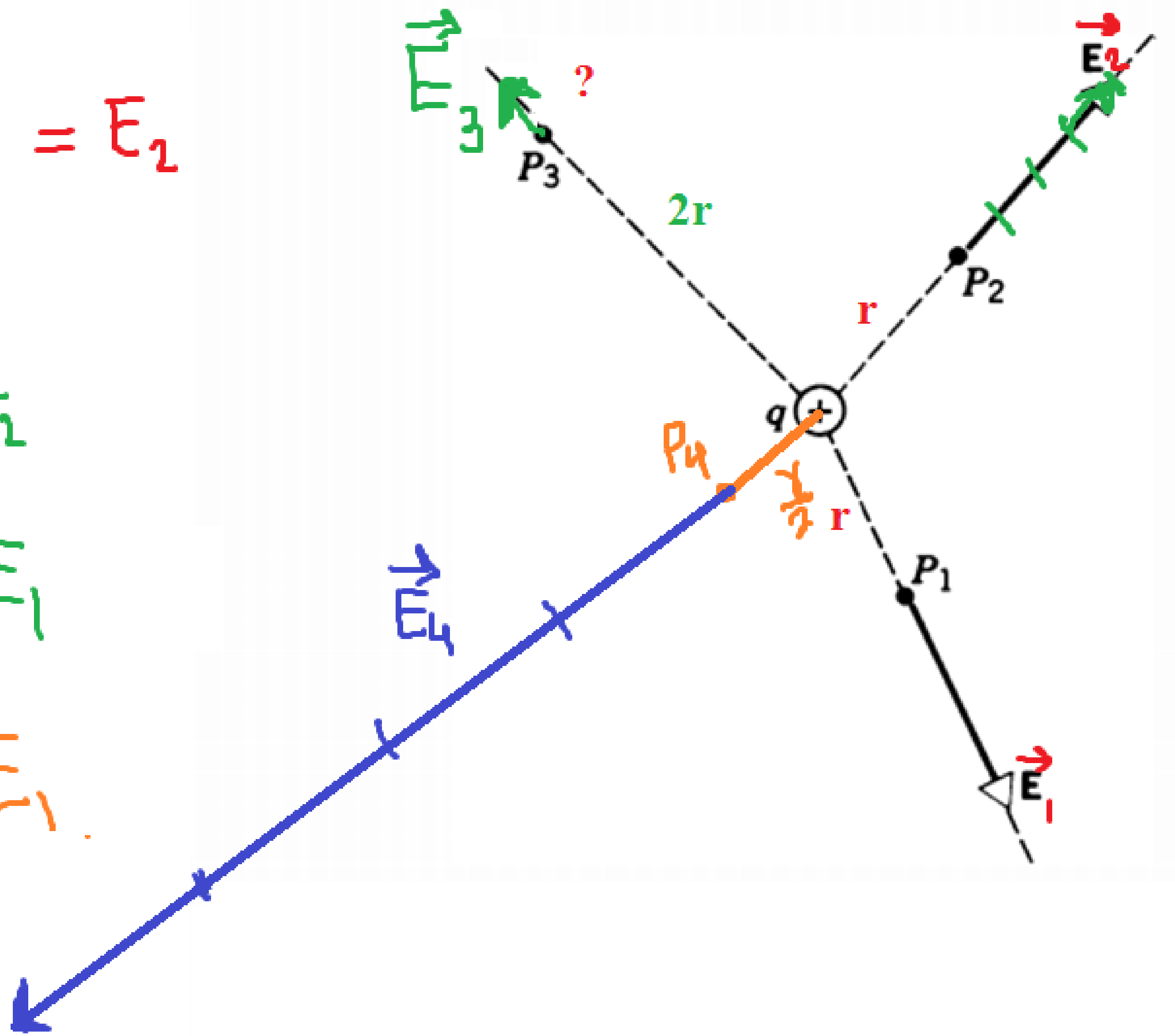


$$E_1 = \frac{Kq}{r^2} = E_2$$

$$E_3 = \frac{Kq}{(2r)^2}$$

$$E_3 = \frac{1}{4} E_1$$

$$E_4 = 4 E_1$$



Sample Problem 1 A proton is placed in a uniform electric field $\mathbf{E}$. What must be the magnitude and direction of this field if the electrostatic force acting on the proton is just to balance its weight?

Solution From Eq. 2, replacing q_0 by e and F by mg, we have

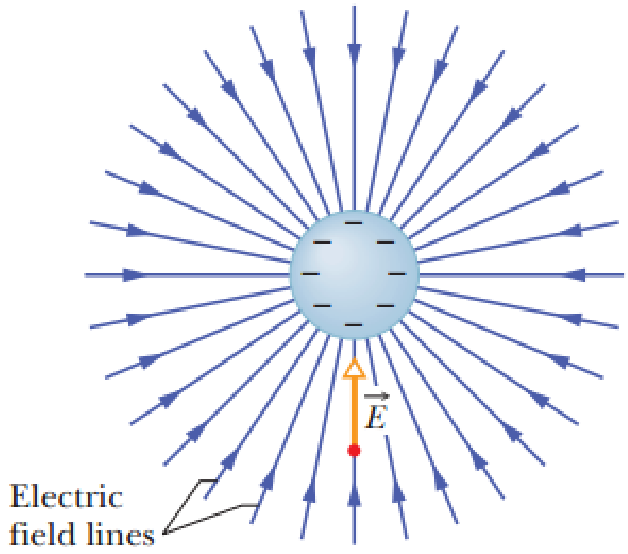
$$E = \frac{F}{q_0} = \frac{mg}{e} = \frac{(1.67 \times 10^{-27}\ \mathrm{kg})(9.8\ \mathrm{m/s^2})}{1.60 \times 10^{-19}\ \mathrm{C}}$$

$$= 1.0 \times 10^{-7}\ \mathrm{N/C},\ \text{directed up.}$$

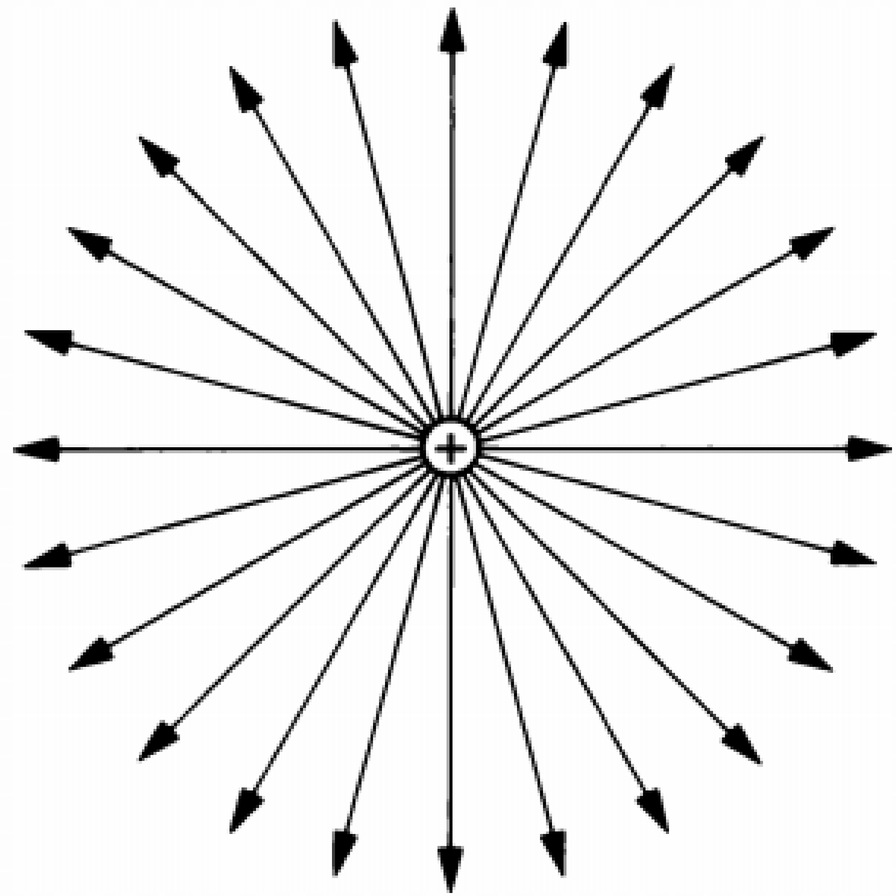
This is a very weak field indeed. $\mathbf{E}$ must point vertically upward to float the (positively charged) proton, because $\mathbf{F} = q_0\mathbf{E}$ and $q_0 > 0$.

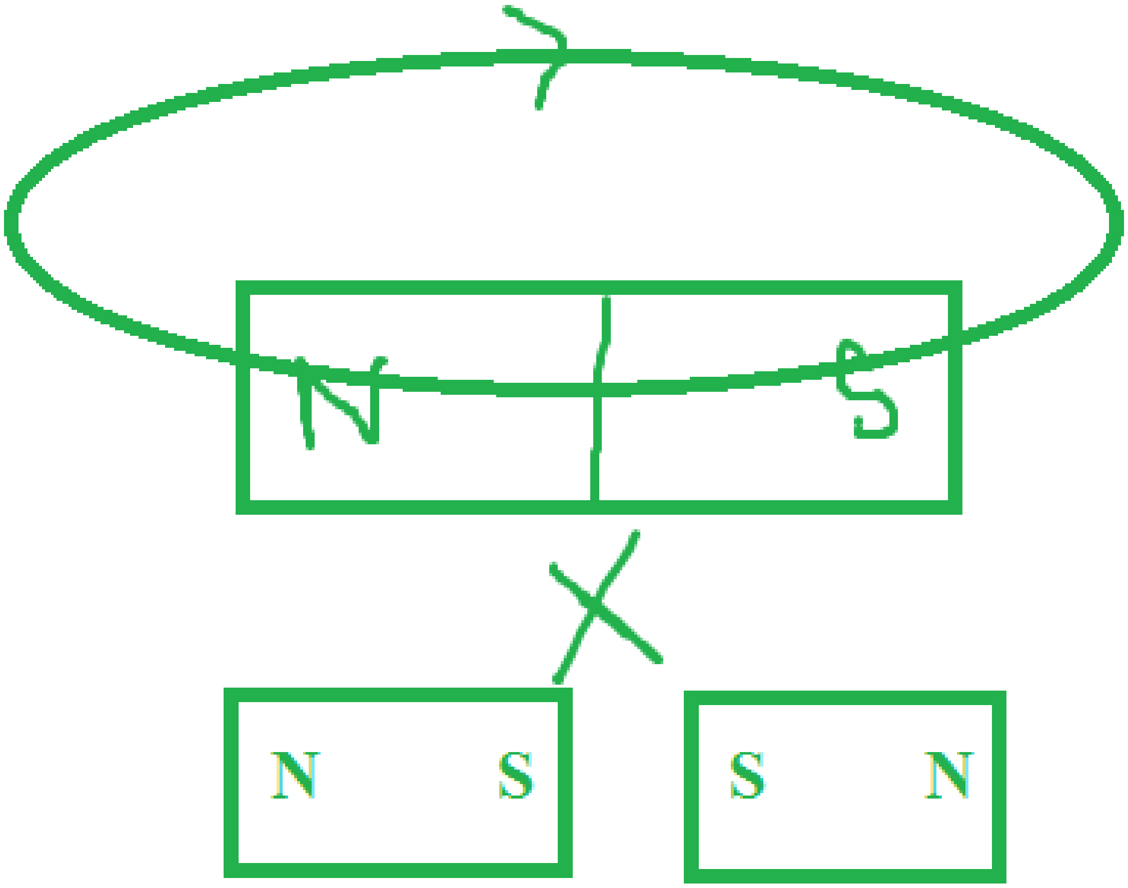
Properties of Electric Field Lines

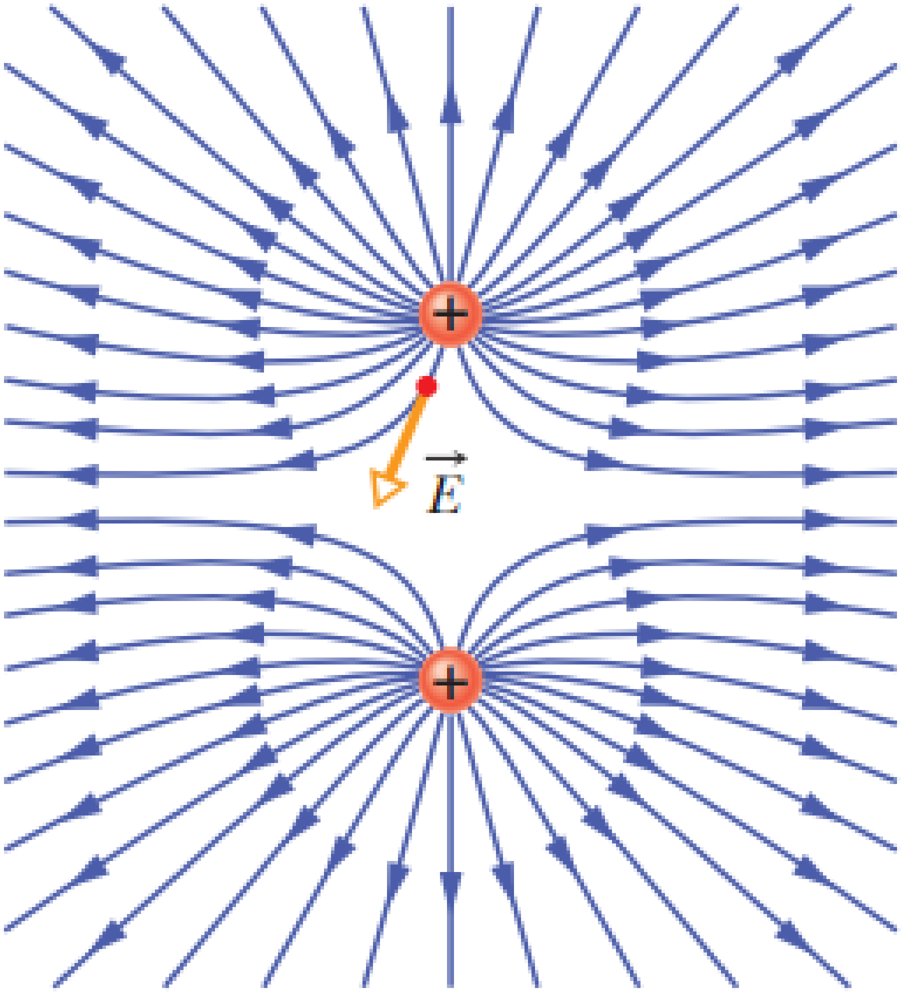
Electric Field Lines

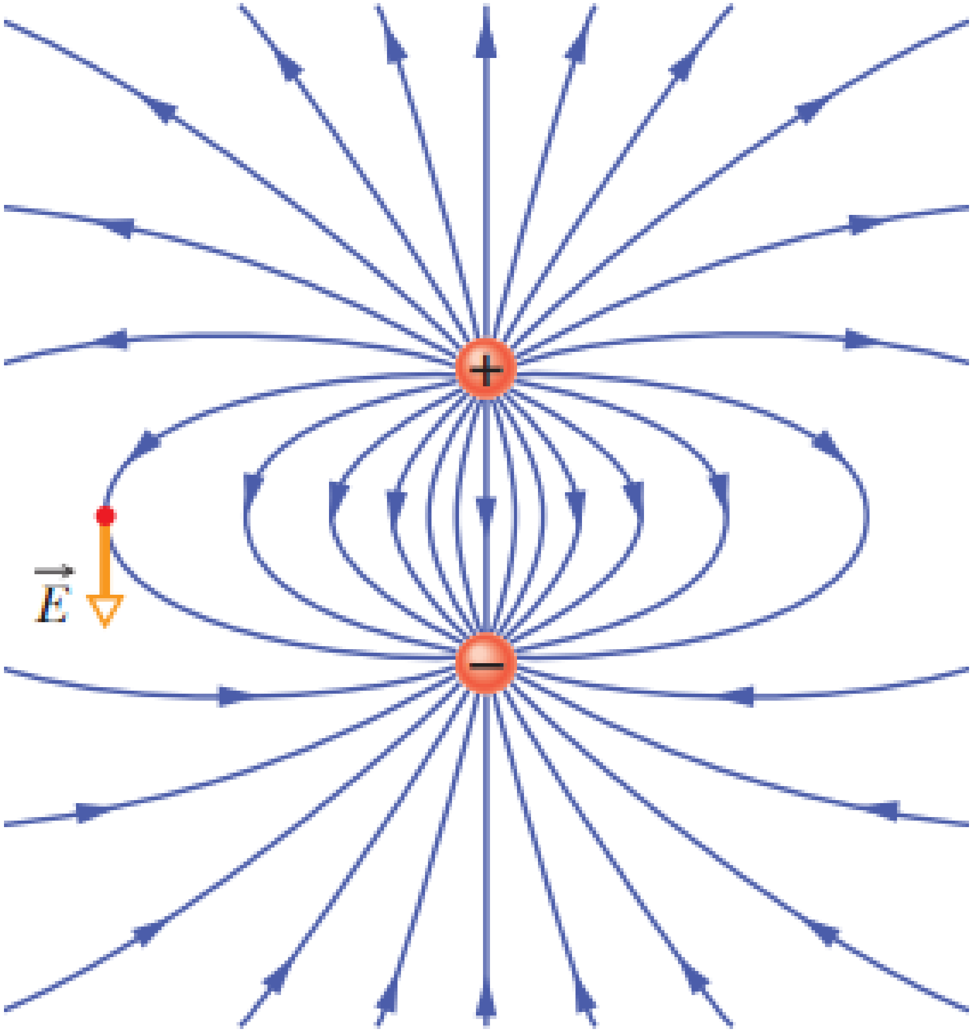


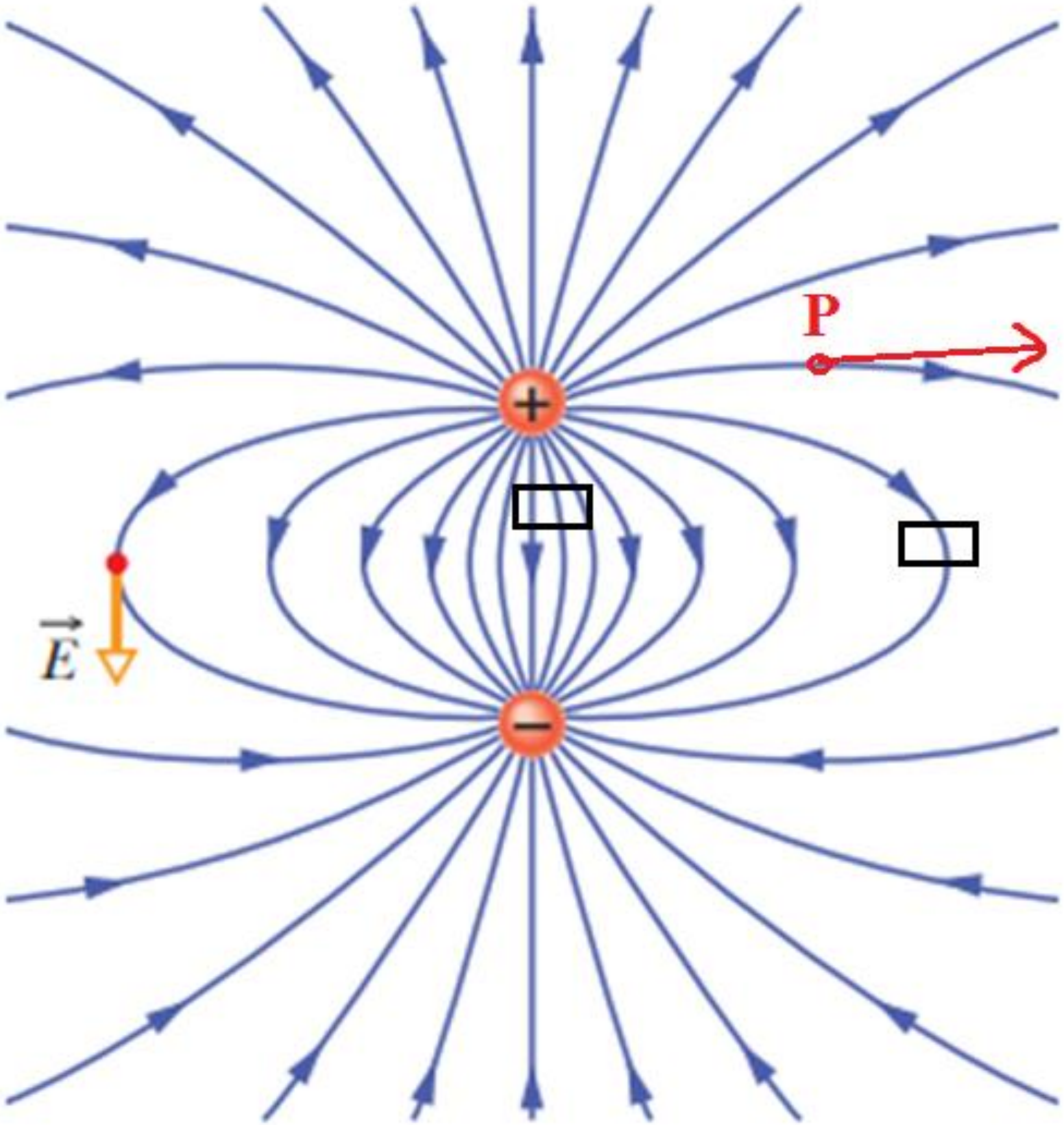
Electric field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate).

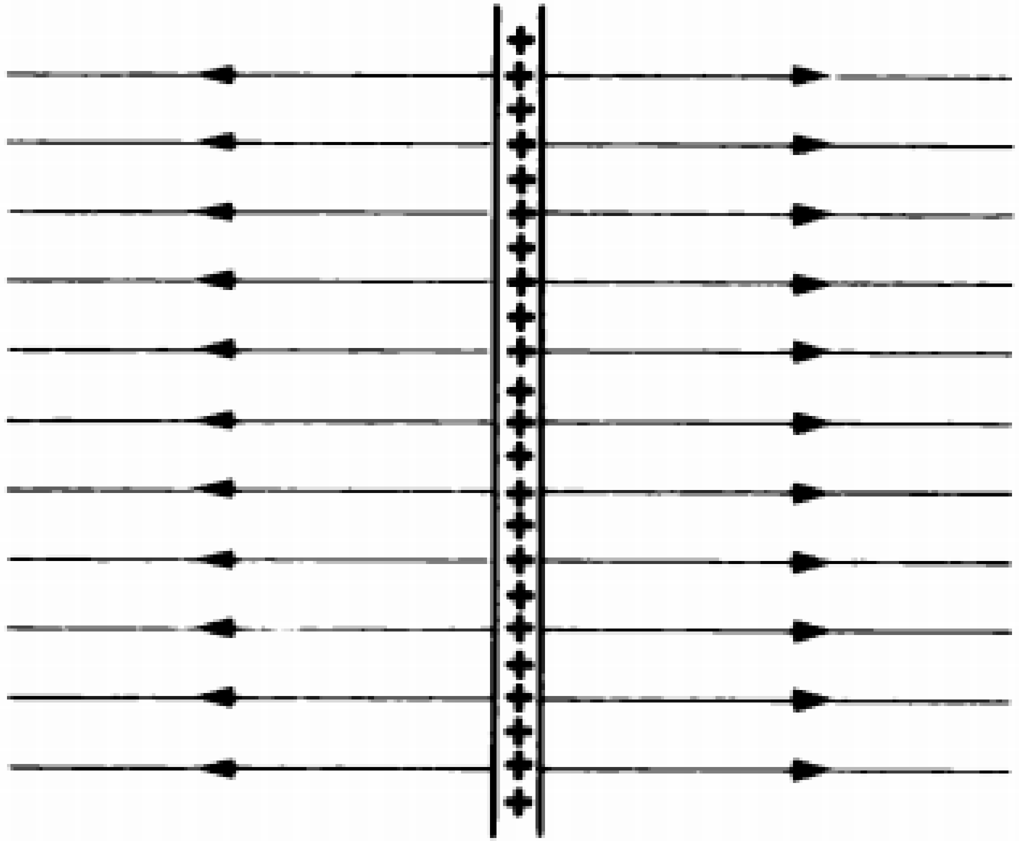



N
S
N
S
S
N


$\vec{E}$


+
−
$\vec{E}$


P
$\vec{E}$



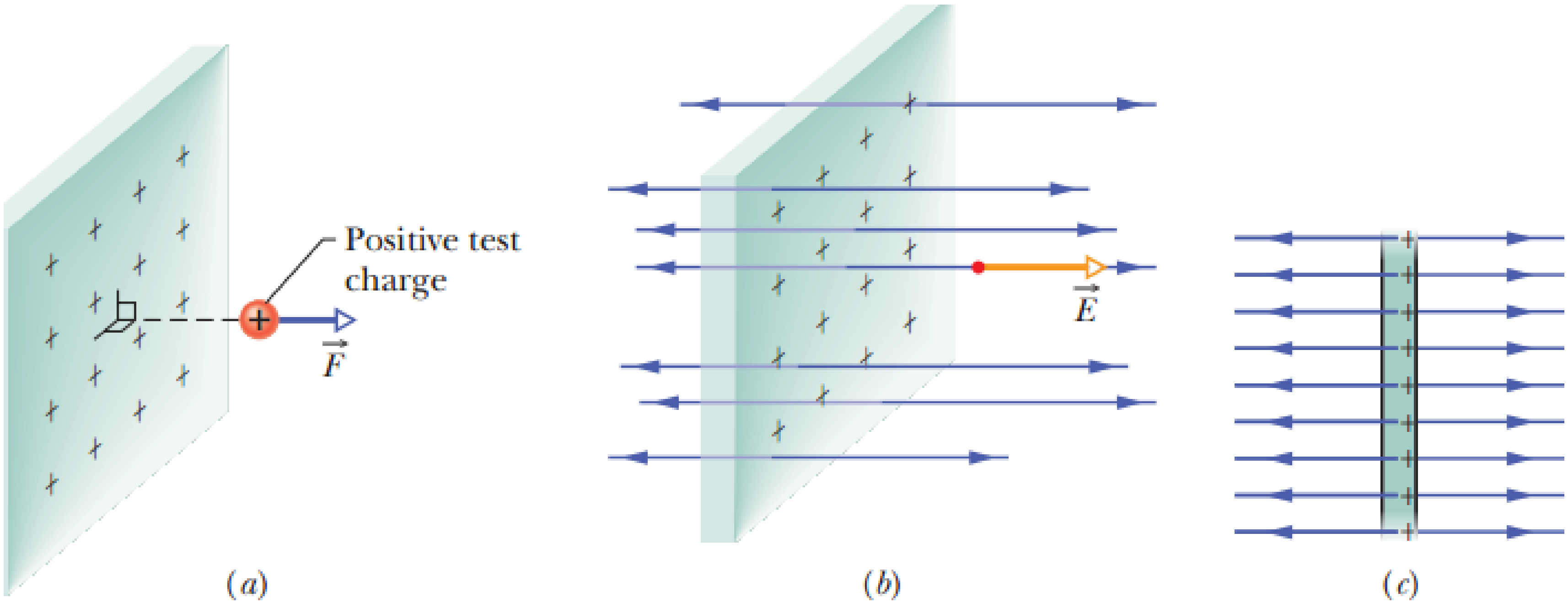
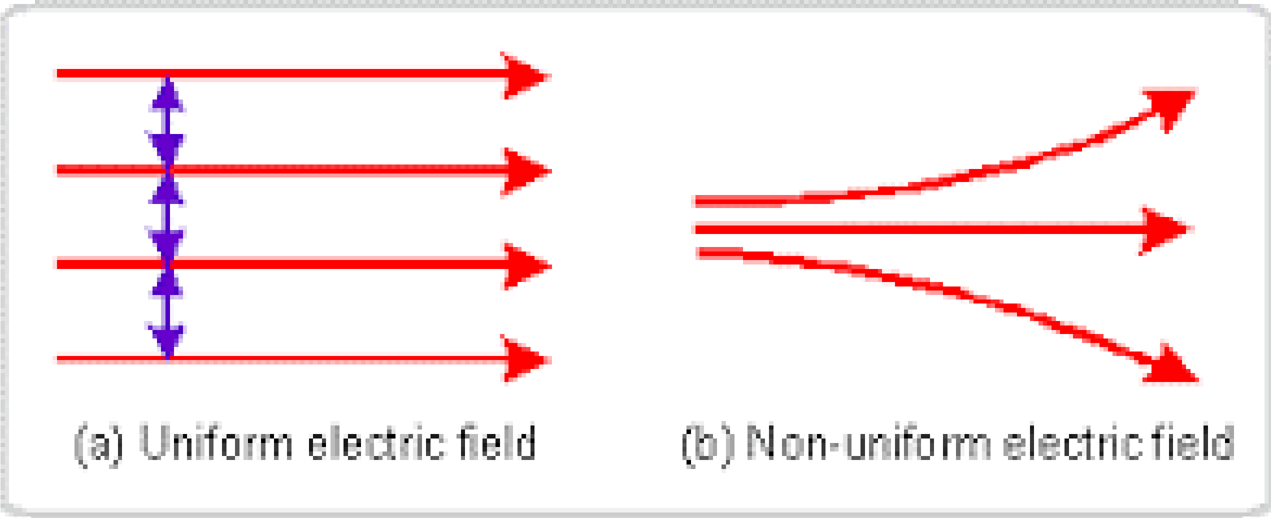


Figure 22-4 (*a*) The force on a positive test charge near a very large, nonconducting sheet with uniform positive charge on one side. (*b*) The electric field vector $\vec{E}$ at the test charge's location, and the nearby electric field lines, extending away from the sheet. (*c*) Side view.


(a) Uniform electric field
(b) Non-uniform electric field

Assignment # 2

PROBLEMS

Section 28-2 The Electric Field E

1. An electron is accelerated eastward at $1.84 \times 10^9\ m/s^2$ by an electric field. Determine the magnitude and direction of the electric field.
2. Humid air breaks down (its molecules become ionized) in an electric field of 3.0×10^6 N/C. What is the magnitude of the electric force on (*a*) an electron and (*b*) an ion (with a single electron missing) in this field?
3. An alpha particle, the nucleus of a helium atom, has a mass of 6.64×10^{-27} kg and a charge of $+2e$. What are the magnitude and direction of the electric field that will balance its weight?
4. In a uniform electric field near the surface of the Earth, a particle having a charge of -2.0×10^{-9} C is acted on by a downward electric force of 3.0×10^{-6} N. (*a*) Find the mag-

nitude of the electric field. (*b*) What is the magnitude and direction of the electric force exerted on a proton placed in this field? (*c*) What is the gravitational force on the proton? (*d*) What is the ratio of the electric force to the gravitational force in this case?

Section 28-3 The Electric Field of Point Charges

5. What is the magnitude of a point charge chosen so that the electric field 75.0 cm away has the magnitude 2.30 N/C?

6. Calculate the dipole moment of an electron and a proton 4.30 nm apart.

7. Calculate the magnitude of the electric field, due to an electric dipole of dipole moment 3.56×10^{-29} C·m, at a point 25.4 nm away along the bisector axis.

8. Find the electric field at the center of the square of Fig. 21. Assume that $q = 11.8$ nC and $a = 5.20$ cm.

8. Find the electric field at the center of the square of Fig. 21. Assume that $q = 11.8$ nC and $a = 5.20$ cm.

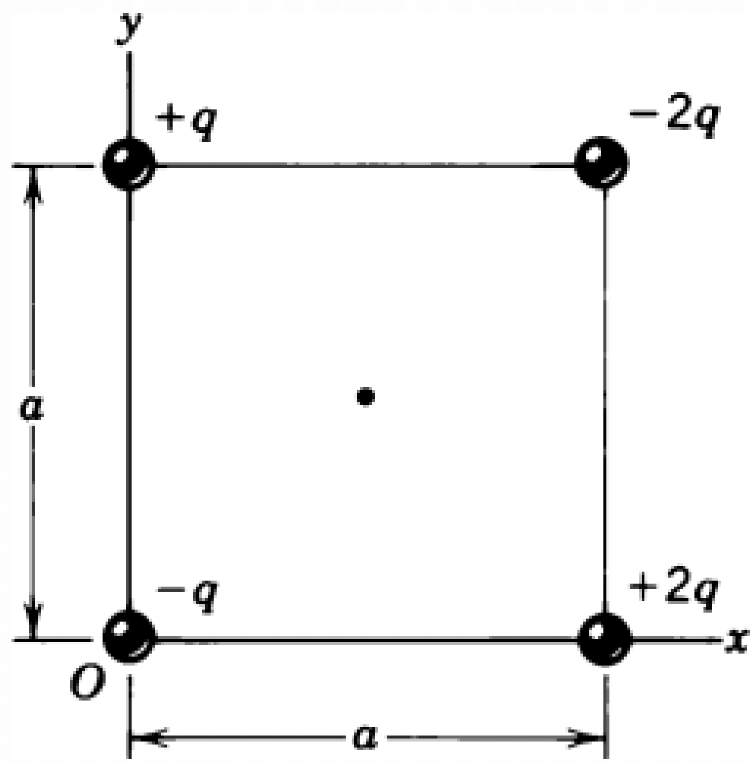


Figure 21 Problem 8.