Electric Fields

Chapter 22

Major Topics of Chapter 22

- What is a Field?
- The Electric Field
- Electric Field Lines
- The Electric Field Due to a Point Charge
- The Electric Field Due to an Electric Dipole
- A Point Charge in an Electric Field
- A Dipole in an Electric Field

test charge

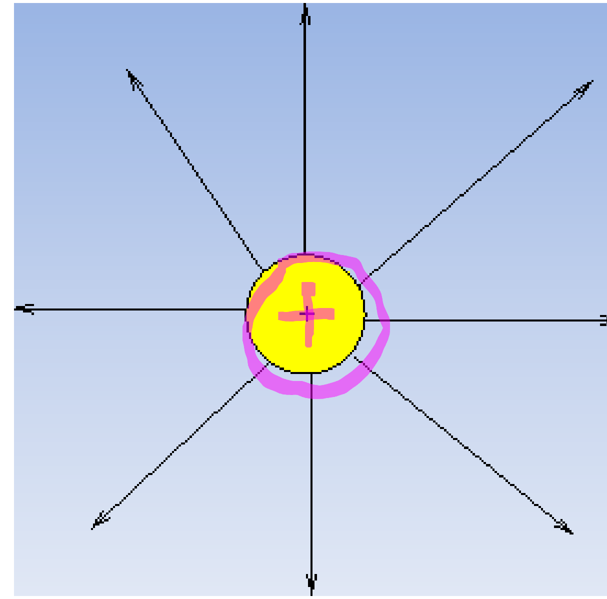
q_0

+

Point charge

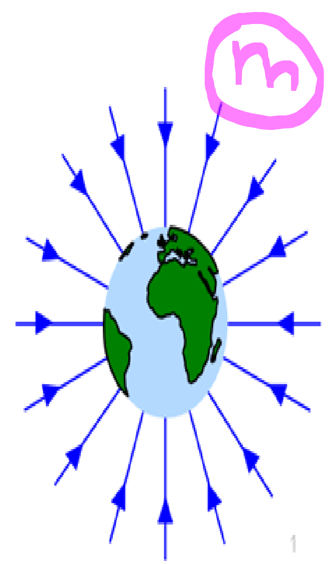
+ −

Analogy



The electric field is the space around an **electrical charge**

just like

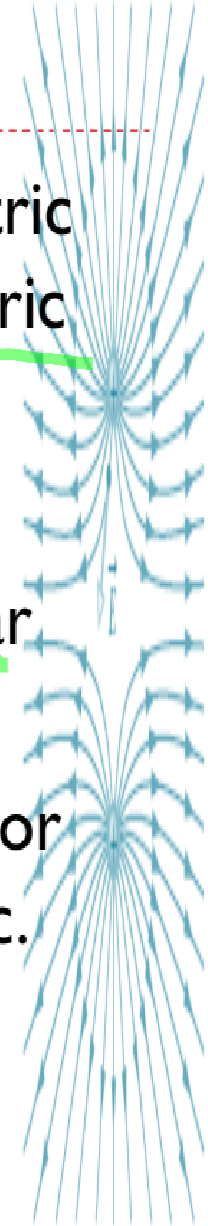


(resourcefulphysics.org)

a gravitational field is the space around a **mass**.

1. The Electric Field

- The space or region around a charge where the Electric force can be felt/ effected or experienced is the Electric Field
- The field can be scalar or vector
- The field due to scalar quantity is categorized in Scalar field. Eg; temperature field or pressure field etc.
- The field due to Vector quantity is categorized in Vector Field. Eg; Earth's Gravitational field or Electric field etc.



- Mathematically,

$$\text{Electric Field} = \text{Electric Force} / \text{ charge}$$

$$\vec{E} = \vec{F} / q_o$$ Magnitude

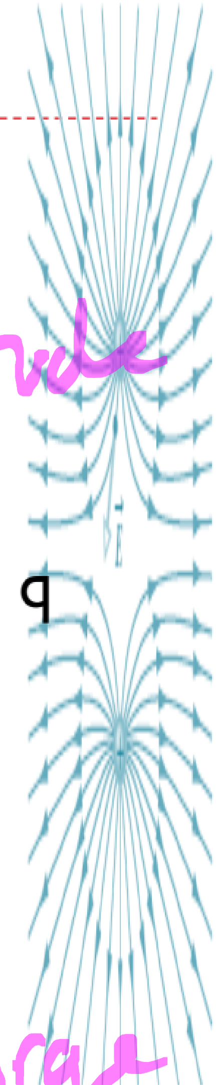
- Its unit is Newton/ Coulombs (N/C)
- Once $\vec{E}$ is found at a point using a test body; the $\vec{F}$ on q can be determined;

$$\vec{F} = q\vec{E}$$

$\vec{F}$ direction

$\vec{E}$?

$q_o \rightarrow$ test charge



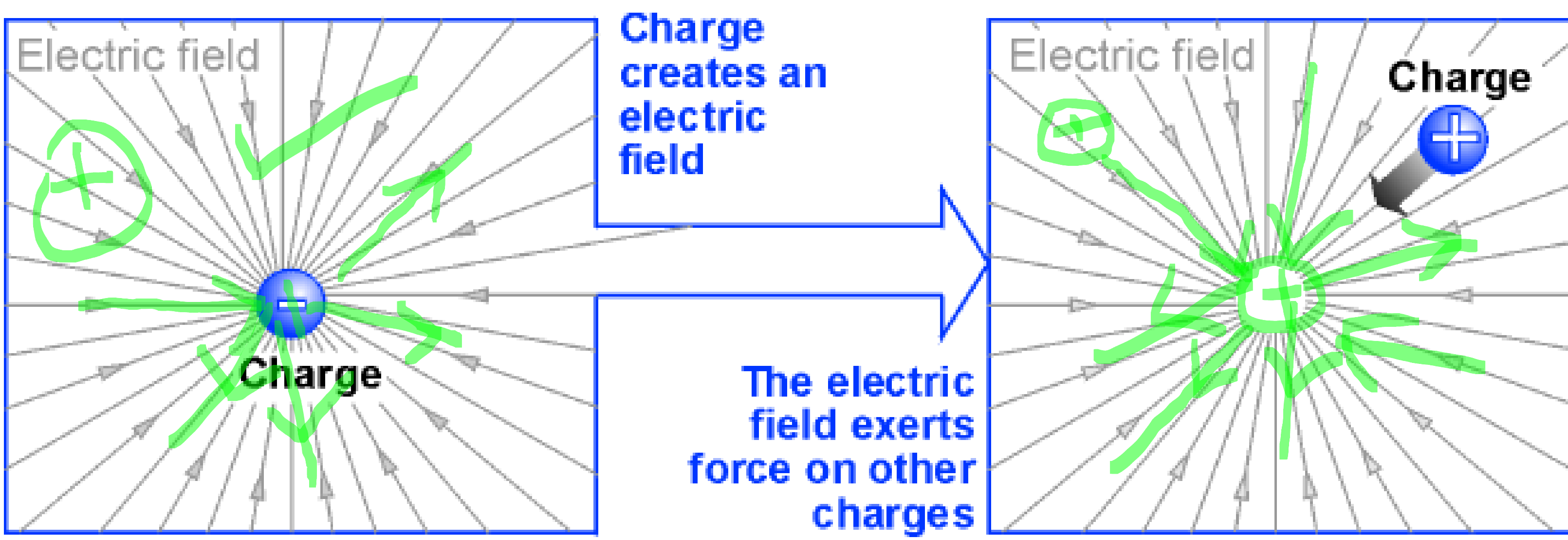
Fields and forces

charge ↔ ch

- The concept of a field is used to describe any quantity that has a value for all points in space.
- You can think of the field as the *way* forces are transmitted between objects.

charge →

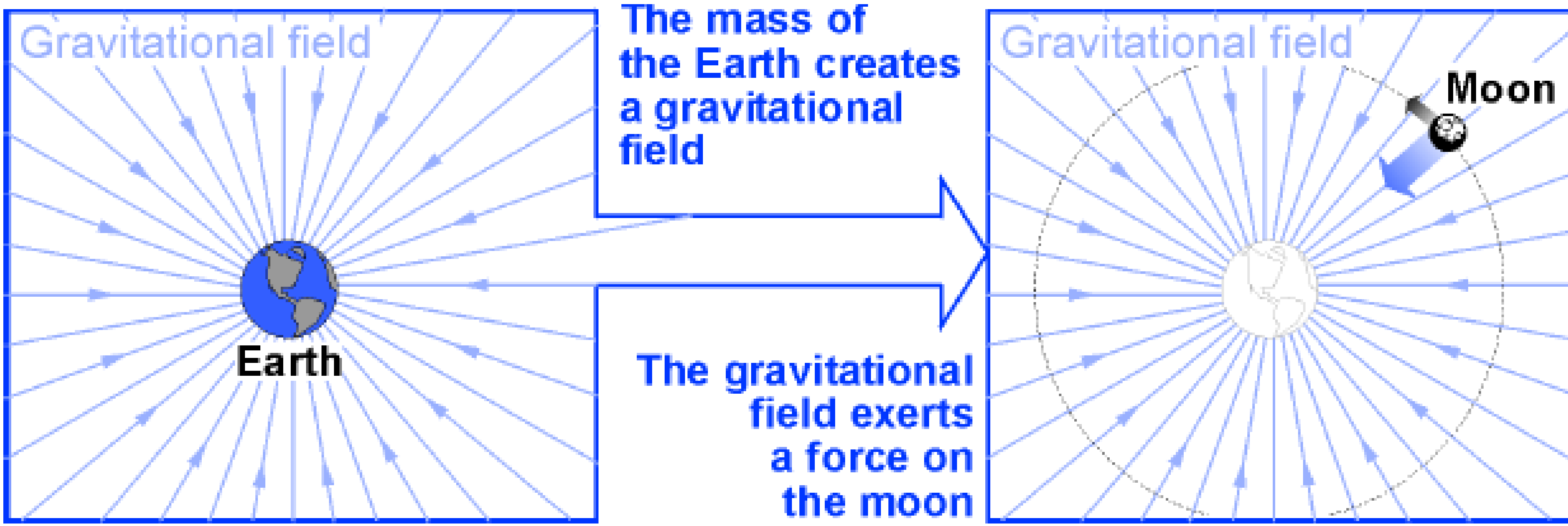
- Charge creates an electric field that creates forces on other charges.



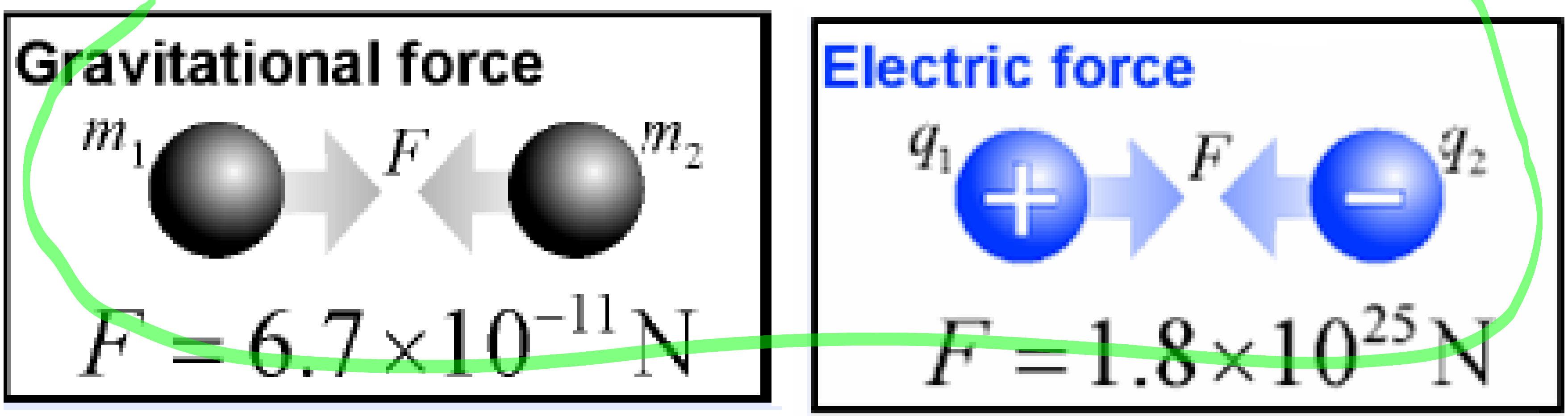
Typical Electric Field Values

Field Location or Situation	Value (N/C)
At the surface of a uranium nucleus	3×10^{21}
Within a hydrogen atom, at a radius of 5.29×10^{-11} m	5×10^{11}
Electric breakdown occurs in air	3×10^{6}
Near the charged drum of a photocopier	10^{5}
Near a charged comb	10^{3}
In the lower atmosphere	10^{2}
Inside the copper wire of household circuits	10^{-2}

- Mass creates a gravitational field that exerts forces on other masses.



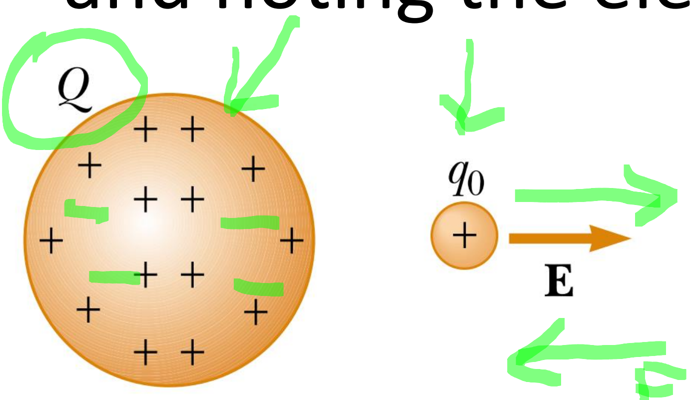
Gravitational forces are far weaker than electric f



Electric Field

- Concept evolved by Michael Faraday (1791–1867) in the context of electric forces
- An electric field is said to exist in the region of space around a charged object, the source charge or point charge $q = -e$
- The presence of the electric field can be detected by placing a test charge in the field and noting the electric force on it

$$E = \frac{F_0}{|q_0|}$$



$$\vec{E} = \frac{\vec{F}_0}{q_0}$$ (definition of electric field as electric force per unit charge)

Electric Field - 2

+ + + +

Continuous Charge

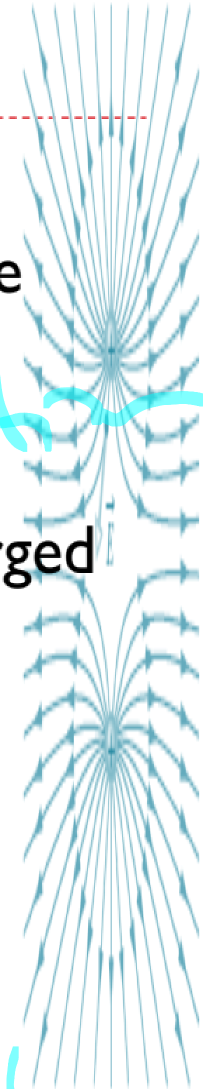
- E = F/q relation is valid only for a point charge
- For a charged object of finite size in an electric field, the field may vary in magnitude and direction over the size of the object, so the corresponding force equation may be more complicated
- Analyzing electric field in the interaction between charged objects involves two tasks:
  1. calculating the electric field produced by a given distribution of charge and
  2. calculating the force that a given field exerts on a charge placed in it

Do-it !!

1. An electron (q = - e) placed near a charged body experiences a force in the +y direction of magnitude $3.60 * 10^{-8}$N.

(a) What is the electric field at that location? Dirn

(b) What would be the force exerted by the same charged body on an alpha particle (q = +2e) placed at the location formerly occupied by the electron?



(a) $E_y = F_y/q = \dfrac{3.60 \times 10^{-8} N}{-1.60 \times 10^{-19}} = -2$

$\overline{F}_y = q\overline{E}_y$

$q = +2e$

$= 2(1.60\times10^{-19}$

$\overline{F}_y = q\overline{E}_y = -7.20\times1$

Do-it !!

1. An electron ($q = -e$) placed near a charged body experiences a force in the +y direction of magnitude $3.60*10^{-8}$N.

(a) What is the electric field at that location?

(b) What would be the force exerted by the same charged body on an alpha particle ($q = +2e$) placed at the location formerly occupied by the electron?

ANSWER: a) Ey = -2.25 exp 11 N/C

b) Fy = -7.2 exp -8 N

5. Electric Field Lines

- The concept of Electric field was introduced by Michael Faraday in 19th Century
- He imagined the space around an electric charge to be filled with lines of force
- These imaginary lines are now referred as the *electric field lines*

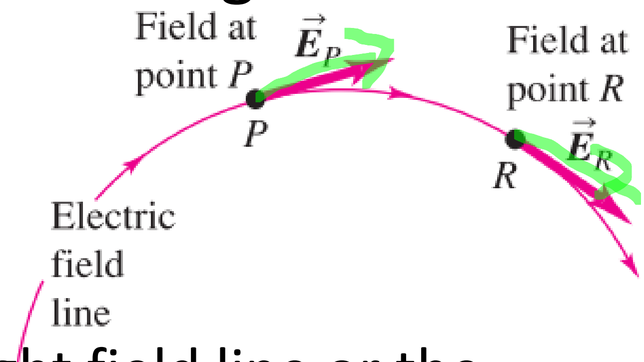
+q_0

Property of Electric Field lines

1. The tangent to the electric field line passing through any point in space gives the direction of the electric field or that point.
2. The electric field lines start on positive charges and end on negative charges
3. For a positive charge, the lines point radially outward, so that at any point P the field is radial.
4. For a negative charge, the lines point radially inward
5. The magnitude of the electric filed at any point is proportional to the number of field lines per unit cross-sectional area perpendicular to the lines.

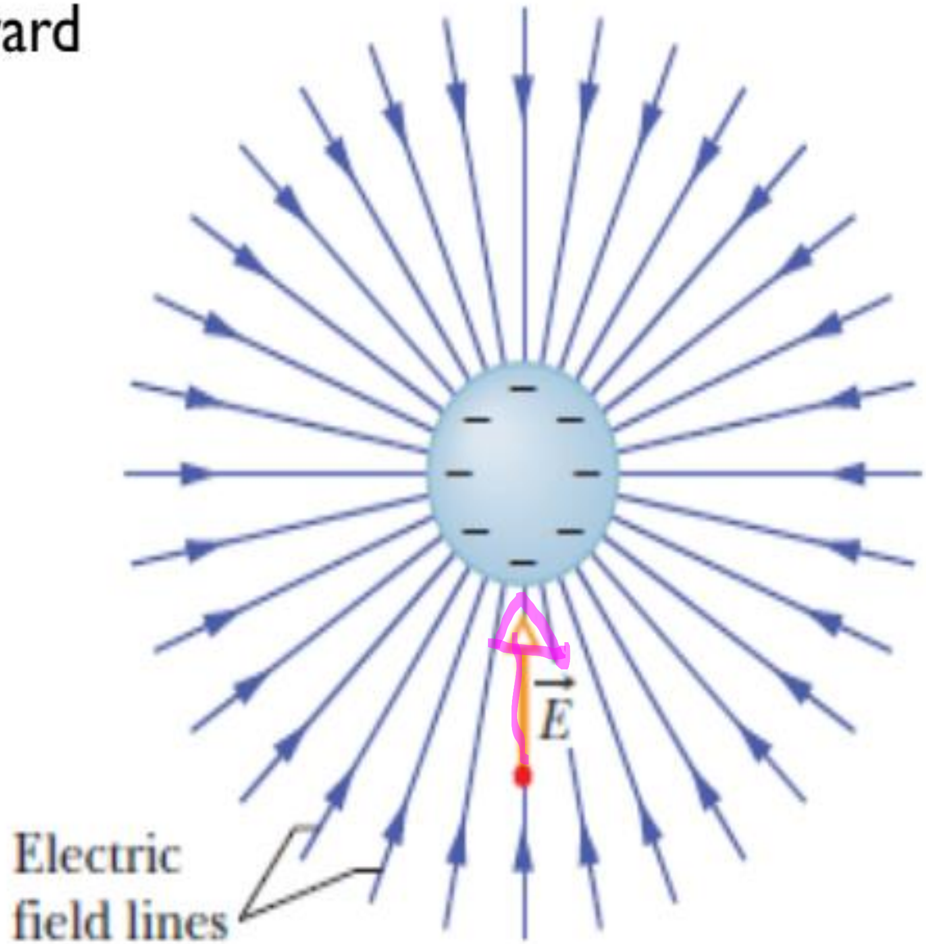
Electric Field Lines

- Space around a charged body can be thought of filled with lines of force
- Relation between the field lines and electric field vectors is;

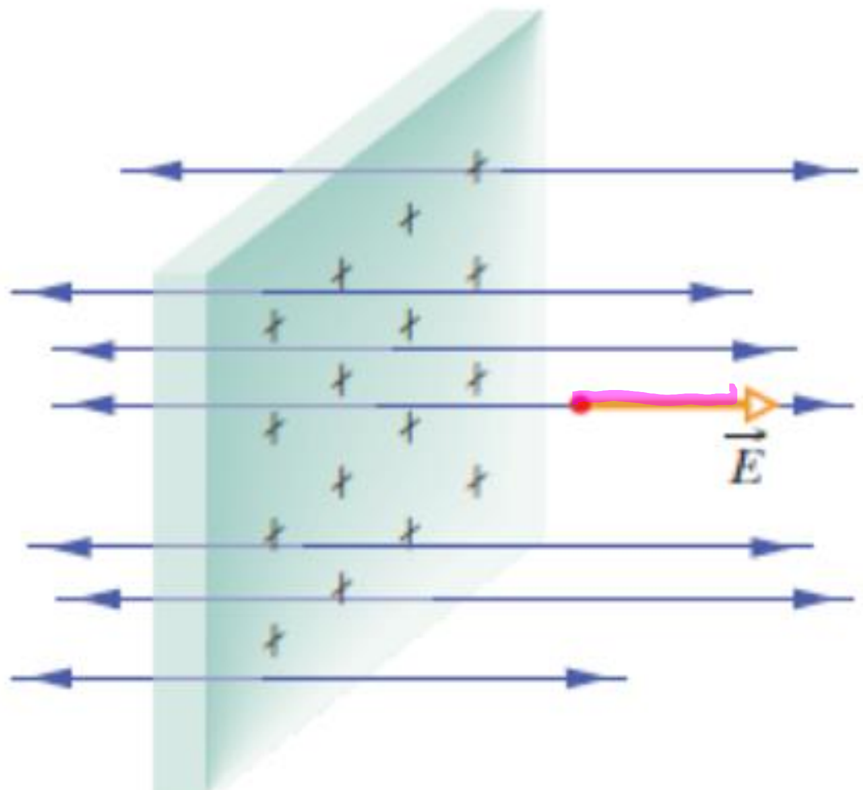


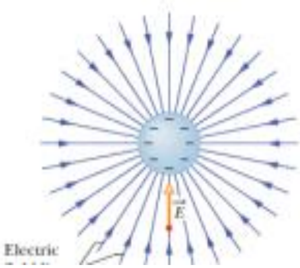
1. At any point, the direction of a straight field line or the direction of the tangent to a curved field line gives the direction of E at that point
2. Field lines are drawn so that the number of lines per unit area, measured in a plane that is perpendicular to the lines, is proportional to the magnitude of E
3. Field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate)

1. For a negative charge, the Electric lines point radially inward

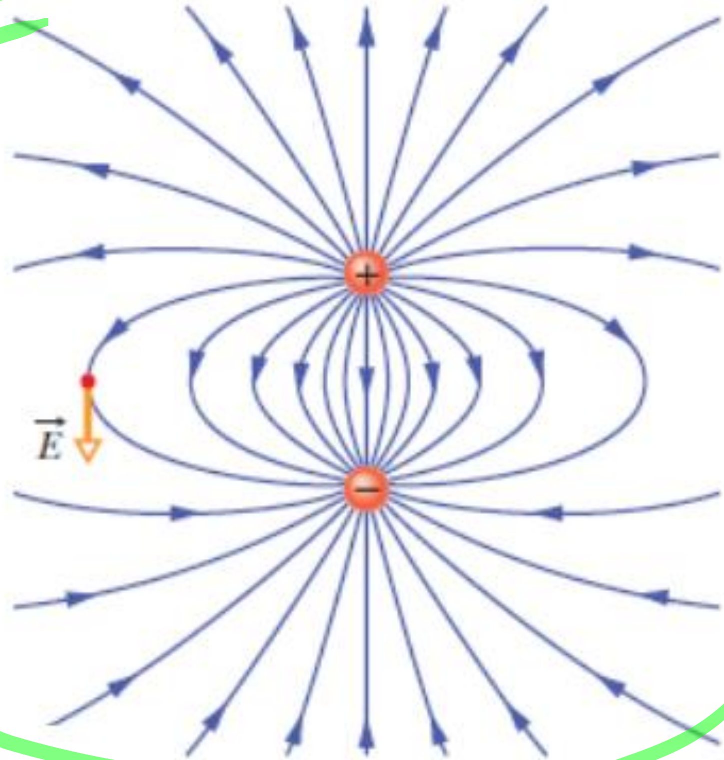


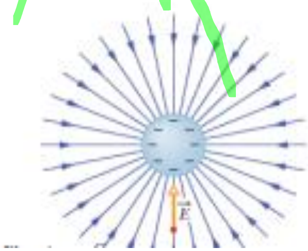
2. Electric Field lines near a thin uniform sheet of charge
As the charges are positive, so the Electric lines are radially outward

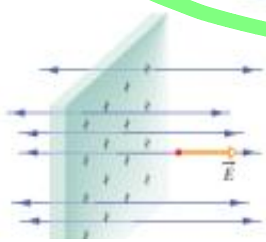




3. Electric Field lines of an Electric Dipole

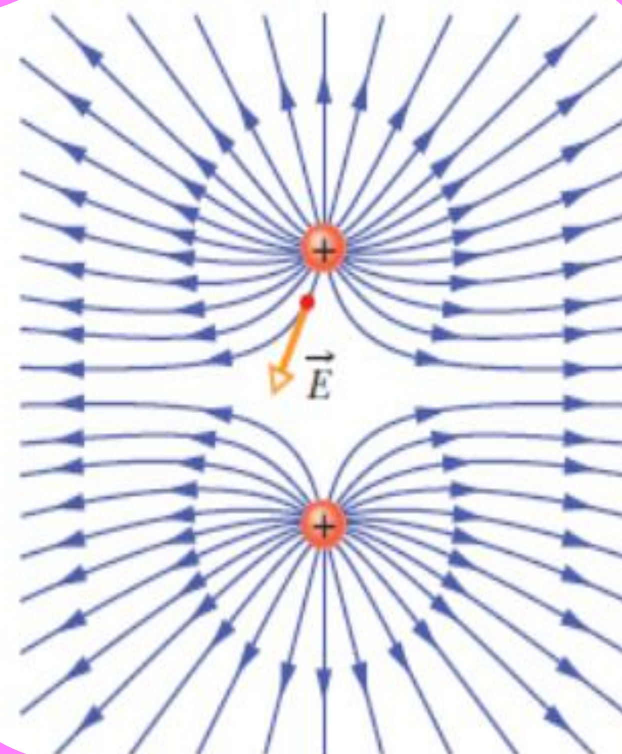


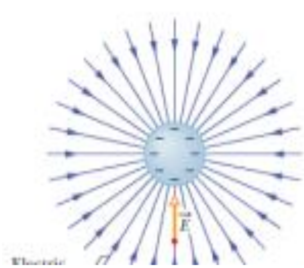


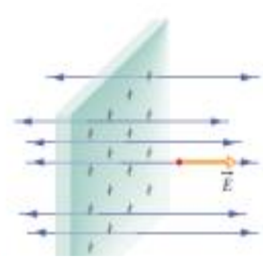


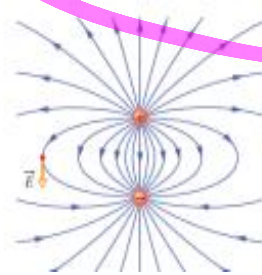
4. Electric Field lines for two equal positive charges

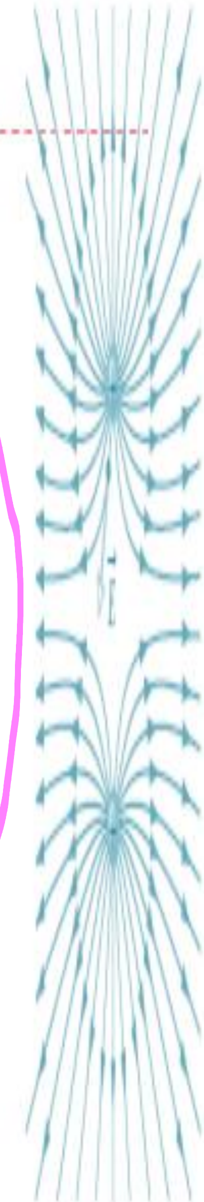
HW Electr. 2 Field lines



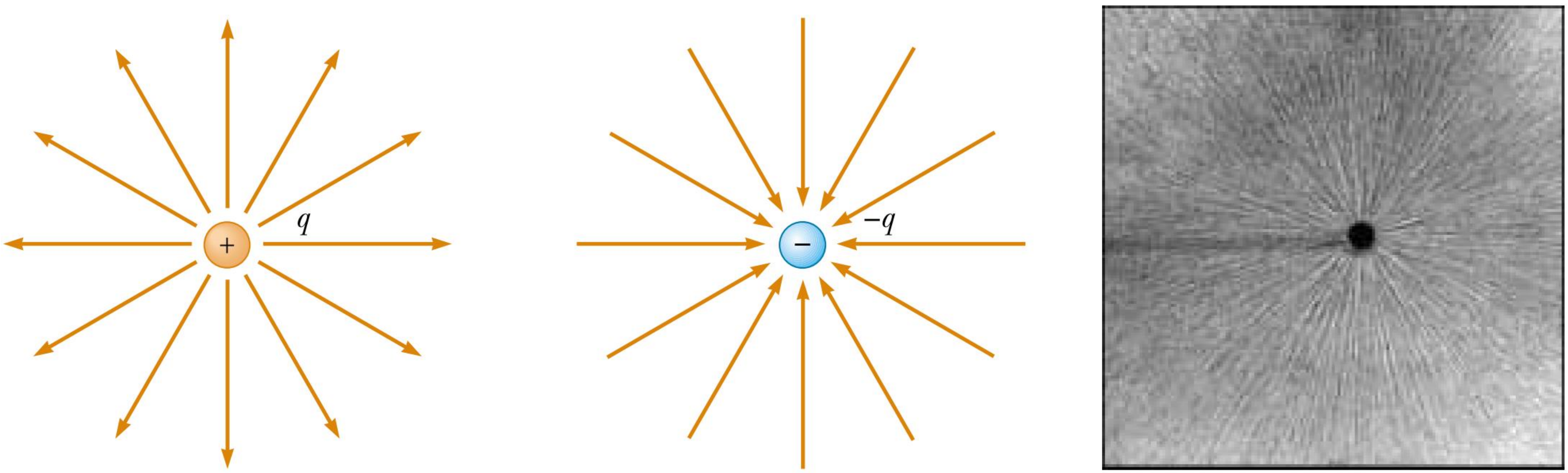






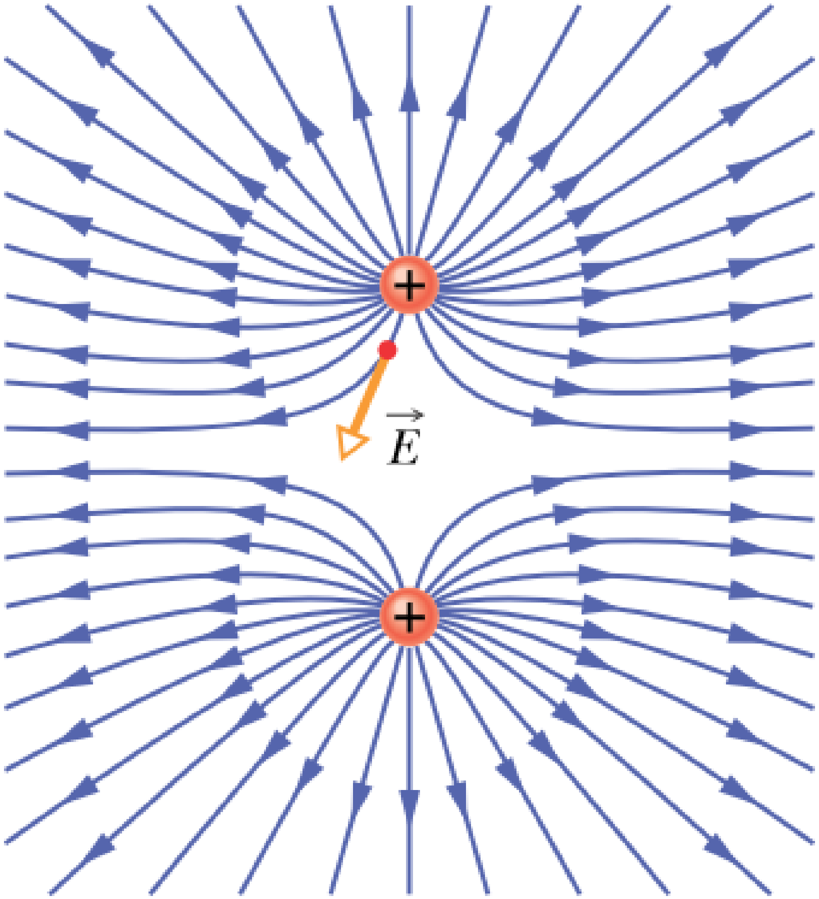


Electric Field Lines for a Point Charge

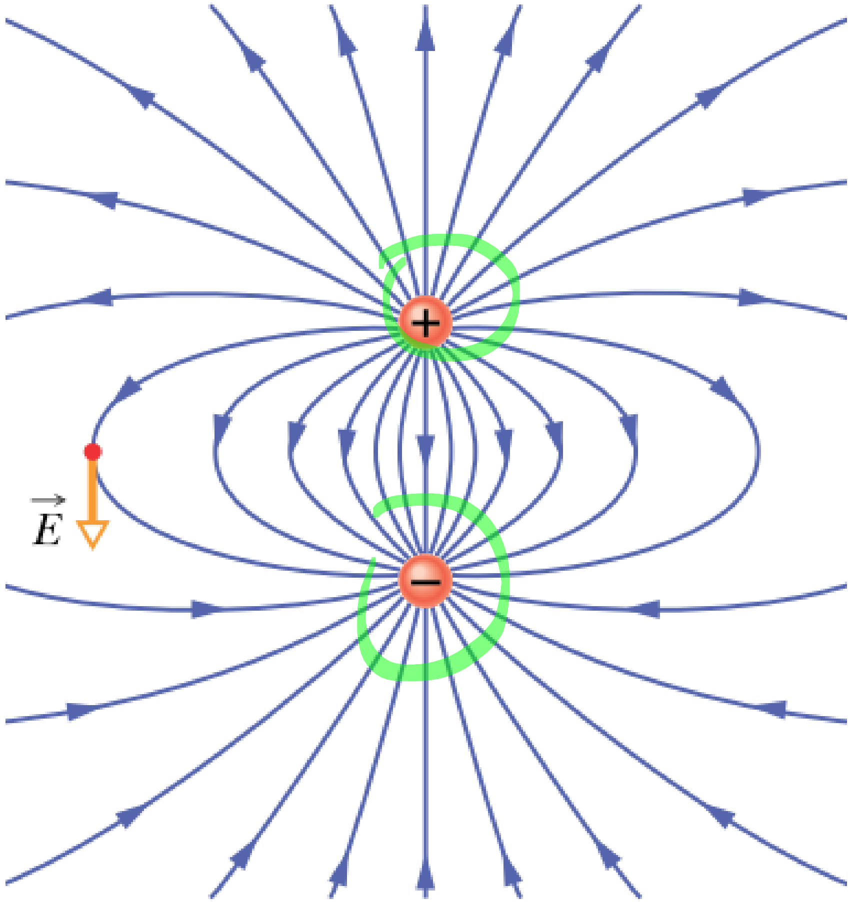


(a) (b) (c)

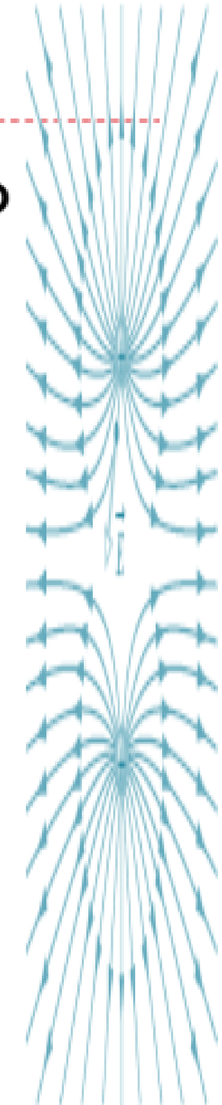
Electric Field Lines for 2 Point Charges



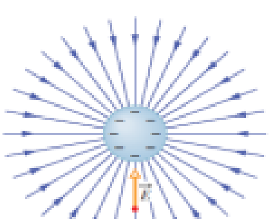
Electric Dipole

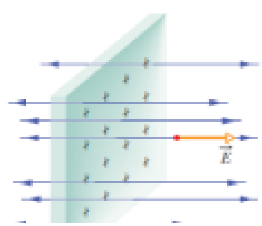


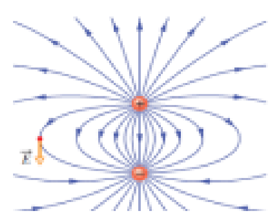
Do – it !!

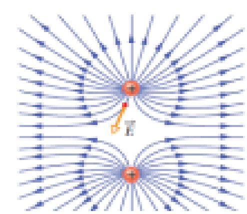


8. Sketch qualitatively the field lines associated with two separated point charges +q and -2q.





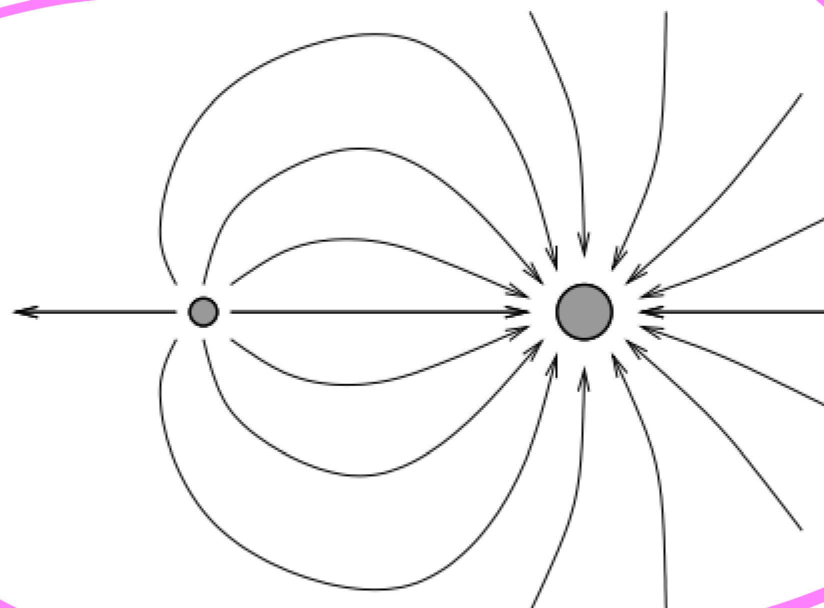


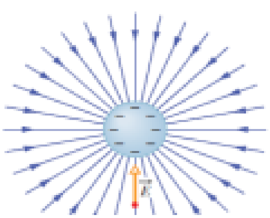


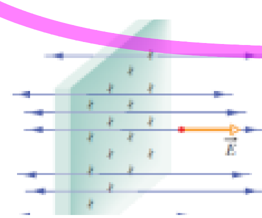
Do – it !!

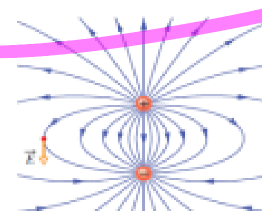
8. Sketch qualitatively the field lines associated with two separated point charges +q and -2q.

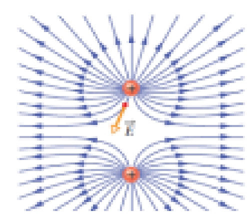
Electric Dipole

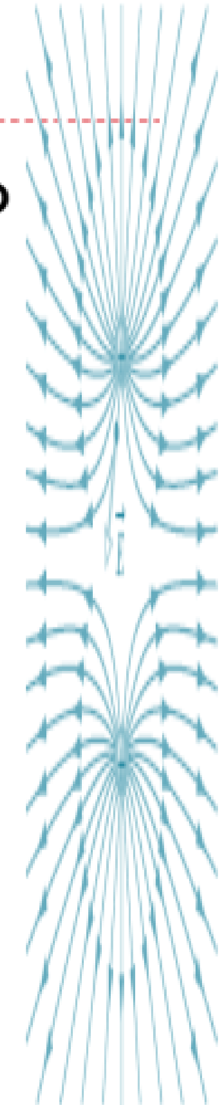






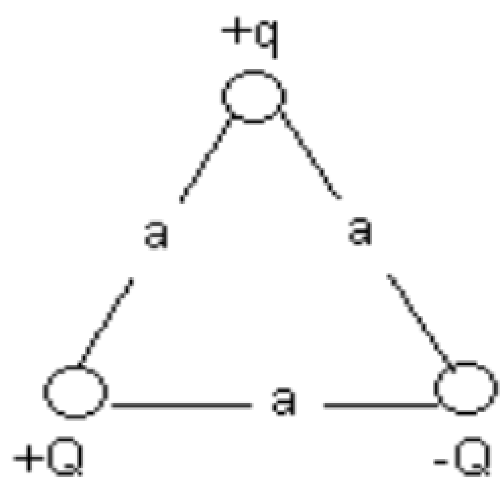






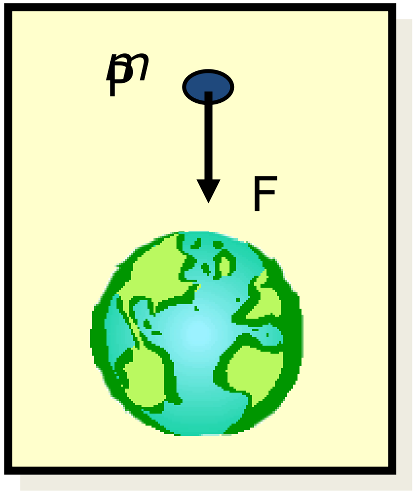
Do – it !! Homework

9. Three charges are arranged in an equilateral triangle as shown in Figure 2 below. Consider the field lines due to +Q and –Q, and from them identify the direction of the force that acts on +q because of the presence of the other two charges.



The Concept of a Field

A field is defined as a property of space in which a material object experiences a force.



Above earth, we say there is a gravitational field at P.

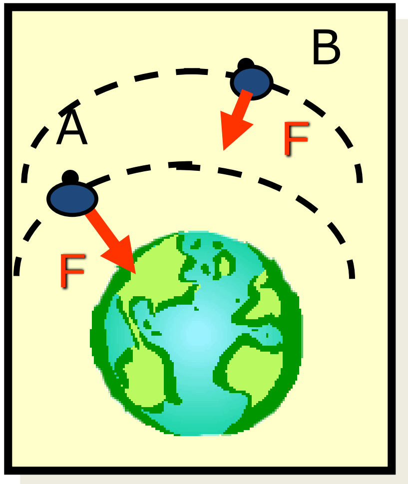
Because a mass *m* experiences a downward force at that point.

No force, no field; No field, no force!

The direction of the field is determined by the force.

The Gravitational Field

Consider points A and B above the surface of the earth—just points in space.



Note that the force F is real, but the field is just a convenient way of describing space.

The field at points A or B might be found from:

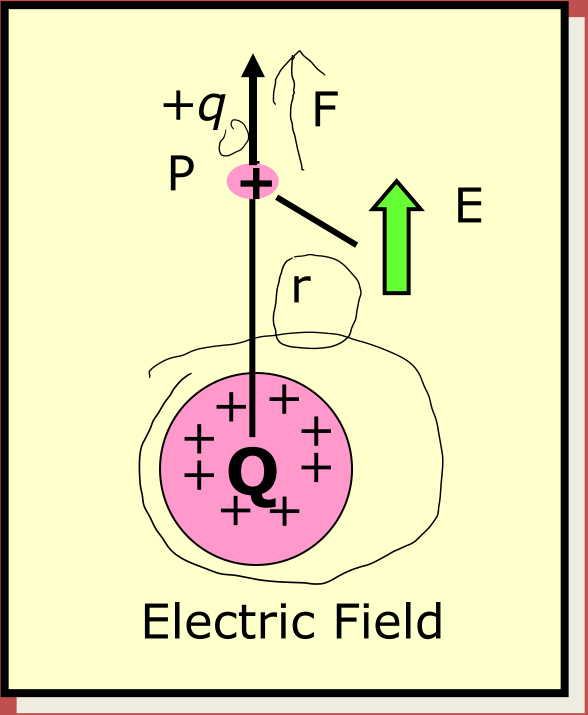
$$g = \frac{F}{m}$$

If g is known at every point above the earth then the force F on a given mass can be found.

The magnitude and direction of the field g is depends on the weight, which is the force F.

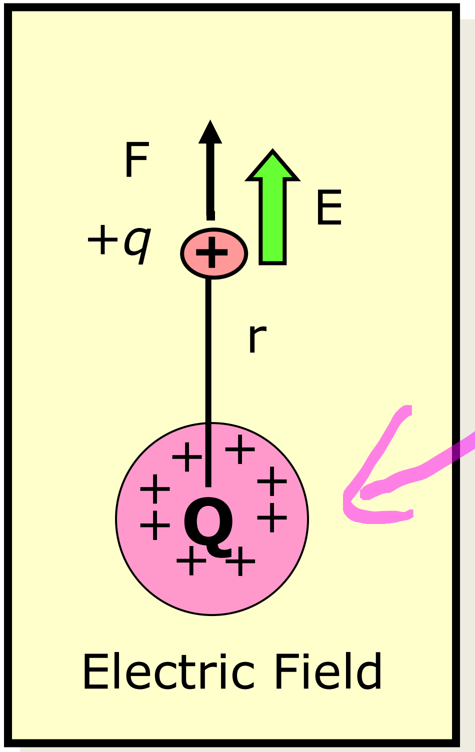
The Electric Field

1. Now, consider point P a distance r from +Q.
2. An electric field E exists at P if a test charge +q has a force F at that point.
3. The direction of the E is the same as the direction of a force on + (pos) charge.
4. The magnitude of E is given by the formula:

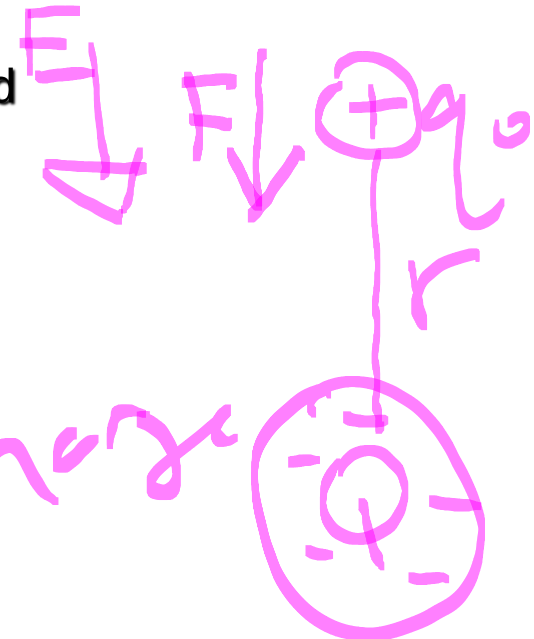


$$E = \frac{F}{q}; \text{ Units } \frac{N}{C}$$

Field is Property of Space



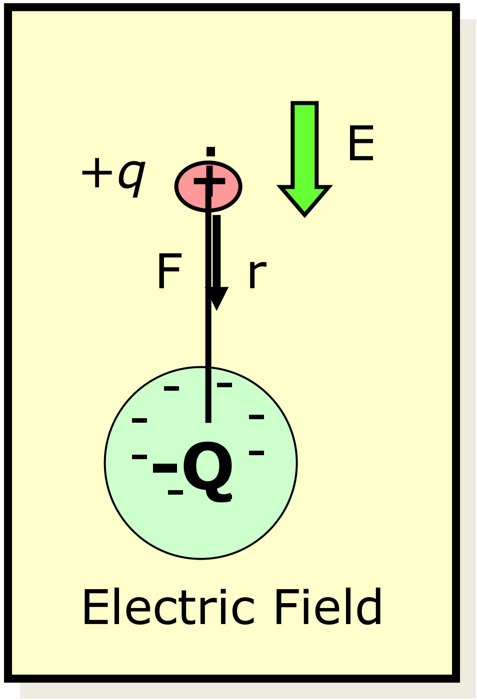
Force on +q is with field direction.



point charge
or
source

The field E at a point exists whether there is a charge at that point or not. The direction of the field is away from the +Q charge.

Field Near a Negative Charge



Force on +q is with field direction.

Note that the field E in the vicinity of a negative charge –Q is toward the charge—the direction that a +q test charge would move.

Relationship Between F and E

- If q is placed in electric field , then we have
  - This is valid for a point charge only $\vec{\mathbf{F}}_e = q\vec{\mathbf{E}}$
  - For larger objects, the field may vary over the size of the object
- If q is positive, the force and the field are in the same direction
- If q is negative, the force and the field are in opposite directions

22-4 The Electric Field Due to a Point Charge

To find the electric field due to a point charge q (or charged particle) at any point a distance r from the point charge, we put a positive test charge q_0 at that point. From Coulomb's law (Eq. 21-1), the electrostatic force acting on q_0 is

$$\vec{F} = \boxed{\frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}}\,\hat{r}. \qquad (22\text{-}2)$$

← unit vector

The direction of $\vec{F}$ is directly away from the point charge if q is positive, and directly toward the point charge if q is negative. The electric field vector is, from Eq. 22-1,

Vector form

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r} \quad \text{(point charge).} \qquad (22\text{-}3)$$

$\hat{r} = \frac{\vec{r}}{|\vec{r}|}$

The direction of $\vec{E}$ is the same as that of the force on the positive test charge: directly away from the point charge if q is positive, and toward it if q is negative.

Because there is nothing special about the point we chose for q_0, Eq. 22-3 gives the field at every point around the point charge q. The field for a positive point charge is shown in Fig. 22-6 in vector form (not as field lines).

We can quickly find the net, or resultant, electric field due to more than one point charge. If we place a positive test charge q_0 near n point charges $q_1, q_2, \ldots, q_n$, then, from Eq. 21-7, the net force $\vec{F}_0$ from the n point charges acting on the test charge is

$$\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \cdots + \vec{F}_{0n}.$$

Therefore, from Eq. 22-1, the net electric field at the position of the test charge is

$$\begin{aligned}\vec{E} &= \frac{\vec{F}_0}{q_0} = \frac{\vec{F}_{01}}{q_0} + \frac{\vec{F}_{02}}{q_0} + \cdots + \frac{\vec{F}_{0n}}{q_0} \\ &= \vec{E}_1 + \vec{E}_2 + \cdots + \vec{E}_n. \qquad (22\text{-}4)\end{aligned}$$

Point Charge

+ −

- A point charge is a hypothetical charge located at a single point in space with no dimensions
- While an electron can for many purposes be considered a point charge, its size can be characterized by length scale known as the electron radius.

test $+q_0$

Any field

→ positive

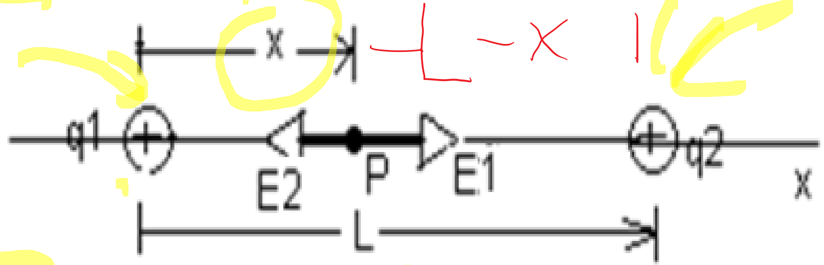
→ imaginary

→ E intensity

Do it !!

$\times 10^{-6}$

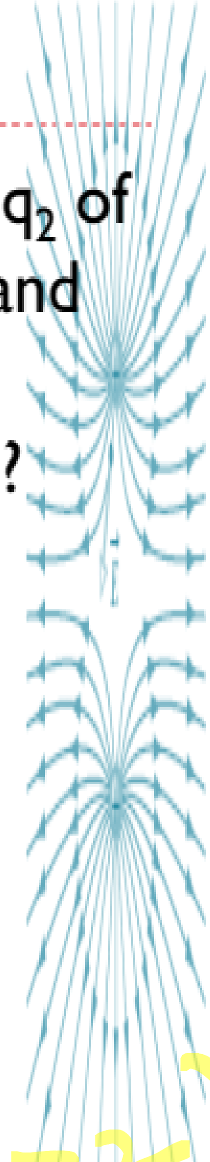
2. Figure shows a charge q_1 of +1.5 μC and a charge of q_2 of +2.3 μC. the first charge is at the origin of an x-axis, and the second is at a position x = *L*, where *L* = 13 cm. at what point *P* along the x-axis is the electric field zero?



$E_1 = E_2$

$$\frac{1}{4\pi\varepsilon_0}\frac{q_1}{x^2} = \frac{1}{4\pi\varepsilon_0}\, q_2/(L-x)^2$$

13 cm



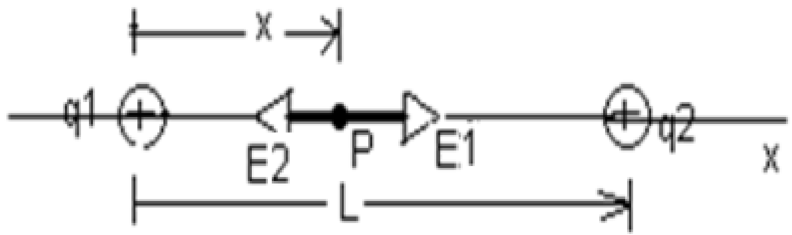
$$x = \frac{L}{1 \pm \sqrt{q_2/q_1}}$$

where is the coordinate of point P

$$\boxed{x = 5.8\,cm}$$

$$\boxed{x = \cancel{-54.6\,cm}}$$

Do it !!



2. ANS: x = 5.8cm, ~~54.6 cm~~

Electric Field magnitude for a point charge(Homework)

What is the magnitude of the electric field $\vec{E}$ at a field point 2.0 m from a point charge $q = 4.0$ nC?

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

$$= \frac{(9.0\times10^{9}\,N\cdot m^2/C^2)\,4.}{}$$

$$\boxed{E = 9.0\,N/C}$$

Electric Field Vector for a point charge

A point charge $q = -8.0$ nC is located at the origin. Find the electric-field vector at the field point $x = 1.2$ m, $y = -1.6$ m.

$$\vec{E} = k\frac{q}{r^2}\hat{r} \quad \left(\therefore \hat{r} = \frac{\vec{r}}{|r|} \right)$$

$$|r| = \sqrt{1.2^2 + (-1.6)^2} = 2.0m$$

r

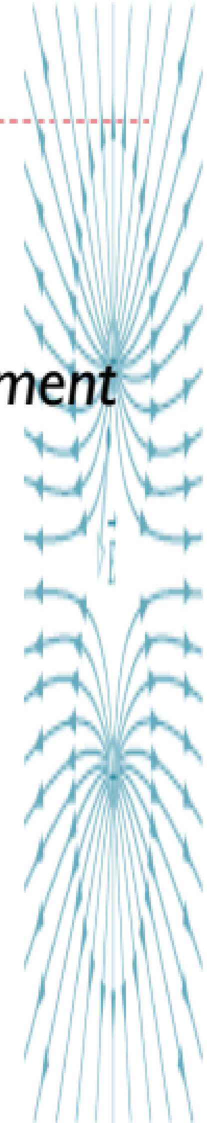
3. The Electric Dipole

- The configuration of two equal and opposite charges separated by a distance is called an *electric dipole*
- It can be measured quantitatively by *electric dipole moment p*, given by;

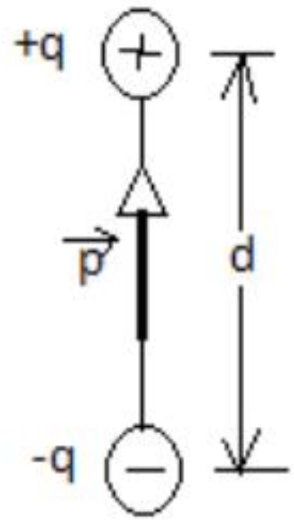
$$\text{Dipole moment} = \text{charge} * \text{distance}$$

$$p = q*d$$

- Its unit is Coulombs.meter (C.m)



- Dipole moment is a vector quantity and its direction is from -ve charge towards +ve charge.

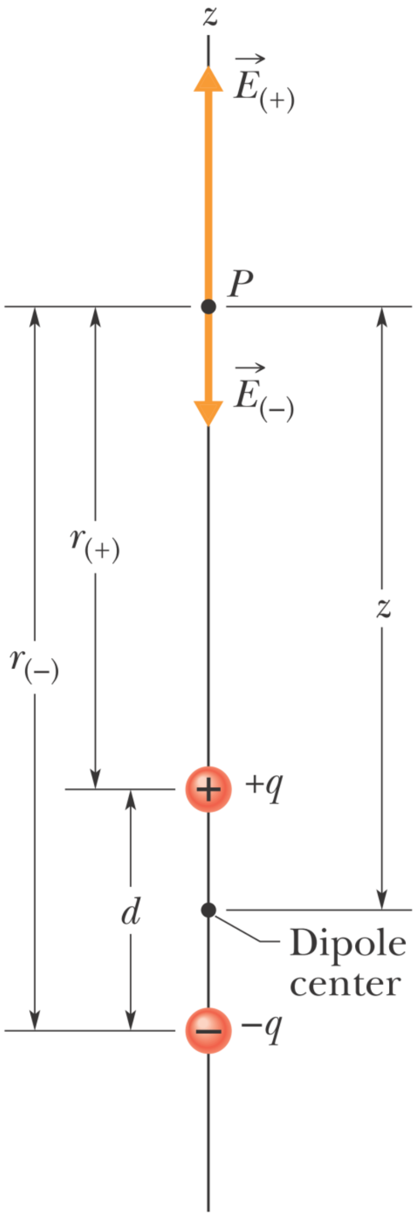


Do – it !!

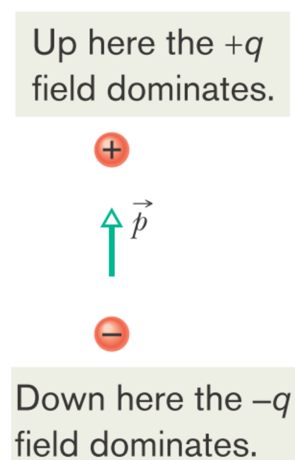
3. Calculate the dipole moment of an electron and a proton that are 4.30 nm apart.

$$p = qd = (1.60\times 10^{-19}\mathrm{C})(4.30\times 10^{-9}) = 6.88\times 10^{-28}\mathrm{C}\cdot\mathrm{m}.$$

Electric Field of a Dipole



- Electric dipole is defined as a positive charge q and a negative charge -q separated by some distance
- Good model of many molecules such as hydrochloric acid (HCl)



$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3}$$

$$E = E_{(+)} - E_{(-)}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(+)}^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{r_{(-)}^2}$$

$$= \frac{q}{4\pi\varepsilon_0(z - \frac{1}{2}d)^2} - \frac{q}{4\pi\varepsilon_0(z + \frac{1}{2}d)^2}.$$

After a little algebra, we can rewrite this equation as

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\left(\frac{1}{\left(1 - \frac{d}{2z}\right)^2} - \frac{1}{\left(1 + \frac{d}{2z}\right)^2}\right).$$

After forming a common denominator and multiplying its terms, we con

$$E = \frac{q}{4\pi\varepsilon_0 z^2}\frac{2d/z}{\left(1 - \left(\frac{d}{2z}\right)^2\right)^2} = \frac{q}{2\pi\varepsilon_0 z^3}\frac{d}{\left(1 - \left(\frac{d}{2z}\right)^2\right)^2}.$$

$$E = \frac{1}{2\pi\varepsilon_0}\frac{qd}{z^3}.$$

$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3} \qquad \text{(electric dipole).}$$

Summary

Electric Field To explain the electrostatic force between two charges, we assume that each charge sets up an electric field in the space around it. The force acting on each charge is then due to the electric field set up at its location by the other charge.

Definition of Electric Field The *electric field* $\vec{E}$ at any point is defined in terms of the electrostatic force $\vec{F}$ that would be exerted on a positive test charge q_0 placed there:

$$\vec{E} = \frac{\vec{F}}{q_0}. \tag{22-1}$$

Electric Field Lines *Electric field lines* provide a means for visualizing the direction and magnitude of electric fields. The electric field vector at any point is tangent to a field line through that point. The density of field lines in any region is proportional to the magnitude of the electric field in that region. Field lines originate on positive charges and terminate on negative charges.

Field Due to a Point Charge The magnitude of the electric field $\vec{E}$ set up by a point charge q at a distance r from the charge is

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}. \tag{22-3}$$

The direction of $\vec{E}$ is away from the point charge if the charge is positive and toward it if the charge is negative.

Field Due to an Electric Dipole An *electric dipole* consists of two particles with charges of equal magnitude q but opposite sign, separated by a small distance d. Their **electric dipole moment** $\vec{p}$ has magnitude qd and points from the negative charge to the positive charge. The magnitude of the electric field set up by the dipole at a distant point on the dipole axis (which runs through both charges) is

$$E = \frac{1}{2\pi\varepsilon_0}\frac{p}{z^3}, \tag{22-9}$$

where z is the distance between the point and the center of the dipole.

Force on a Point Charge in an Electric Field When a point charge q is placed in an external electric field $\vec{E}$, the electrostatic force $\vec{F}$ that acts on the point charge is

$$\vec{F} = q\vec{E}. \tag{22-28}$$

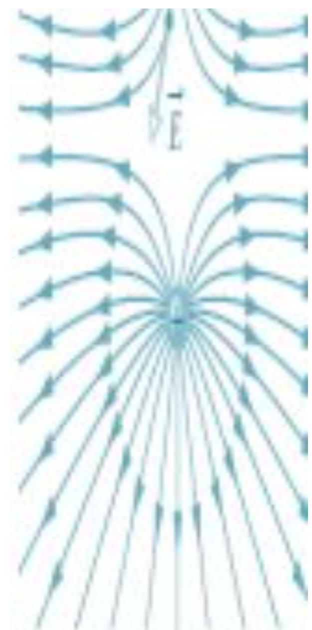
Dipole in an Electric Field When an electric dipole of dipole moment $\vec{p}$ is placed in an electric field $\vec{E}$, the field exerts a torque $\vec{\tau}$ on the dipole:

$$\vec{\tau} = \vec{p} \times \vec{E}. \tag{22-34}$$

The dipole has a potential energy U associated with its orientation in the field:

$$U = -\vec{p} \cdot \vec{E}. \tag{22-38}$$

This potential energy is defined to be zero when $\vec{p}$ is perpendicular to $\vec{E}$; it is least ($U = -pE$) when $\vec{p}$ is aligned with $\vec{E}$ and greatest ($U = pE$) when $\vec{p}$ is directed opposite $\vec{E}$.



What next ?

- Chapter 23 : Gauss’ Law