Electricity and Magnetism

lecture Three

Electric field, A point charge in an electric field, A dipole in an electric field

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2021- 2022

Outline

1. The Electric Field
2. Relationship between Force and Electric Field
3. Electric Field Direction
4. A Point Charge in an Electric Field
5. A Dipole in an Electric Field
6. References

1. The Electric Field

Electric field is defined as the electric force per unit charge, is a vector field because. The direction of the field is taken to be the direction of the force it would exert on a positive test charge.

- The electric force is a field force.
- Field forces can act through space, producing effect even with no physical contact between interacting objects.
- An electric field is said to exist in the region of space around a charged object.
- When another charged object (test charge), enters this electric field, an electric force acts on it.
- The electric field is defined as the electric force on the test charge per unit charge.

The electric field vector E at a point in space is defined as the electric force F acting on a positive test charge q0 placed at that point divided by the test charge:

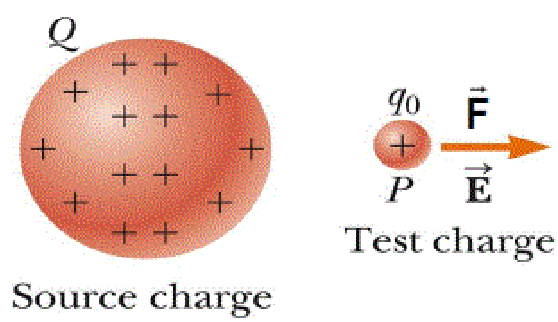
$$\vec{E} = \frac{\vec{F}}{q_0} \quad \text{.....................} \quad (1)$$

The SI units of E are N/C.

Note that E is the field produced by some charge or charge distribution separate from the test charge; it is not the field produced by the test charge itself.

Also, note that the existence of an electric field is a property of the source charge; the presence of the test charge is not necessary for the field to exist.

- The test charge serves as a detector of the field.



- The direction of E is that of the force on a positive test charge.

- We can also say that an electric field exists at a point if a test charge at that point experiences an electric force.

2. Relationship between F and E

Equation 1 can be rearranged as

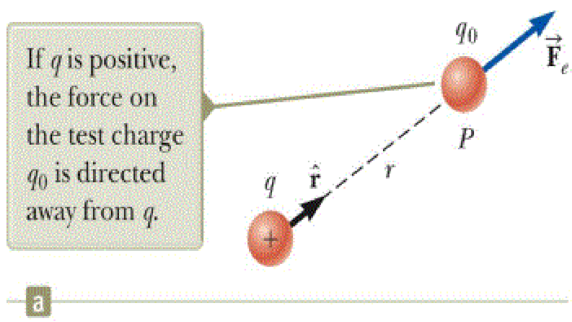
$$\overrightarrow{F} = q\overrightarrow{E}$$

This equation gives us the force on a charged particle placed in an electric field.

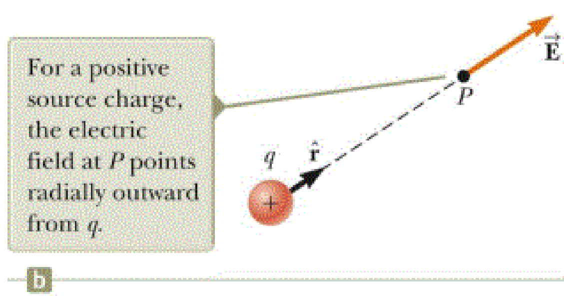
- This is valid for a point charge only.
- For larger objects, the field may vary over the size of the object.
- If test charge, q_0, is positive, the force and the field are in the same direction.
- If test charge, q_0, is negative, the force and the field are in opposite directions.

3. Electric Field Direction

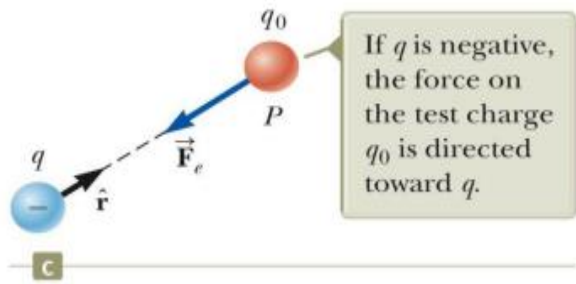
a) If q is positive, then the force on the test charge is directed away from q.



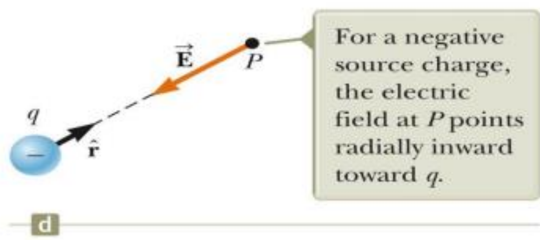
b) The direction of the electric field at P points is also away from the positive source charge.



c) If q is negative, then the force on the test charge is directed toward q.



d) The electric field at P points is also toward the negative source charge



Electric Field, Vector Form According to Coulomb's law, the force exerted by source charge q on the test charge q_o, can be expressed as: where r̂ is a unit vector directed from q toward q_o. The electric field at P, the position of the test charge is defined by ($E = Fe / q_o$):

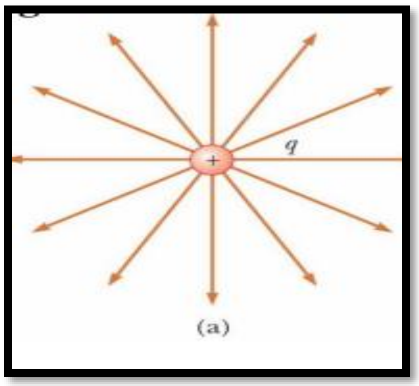
$$\vec{F} = \frac{1}{4\pi\varepsilon_0}\frac{qq_0}{r^2}\hat{r}. \quad \vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$$

$$\vec{E} = K\frac{q}{r^2}\hat{r} \qquad \text{.....................} (3)$$

4. The electric field lines for a point charge

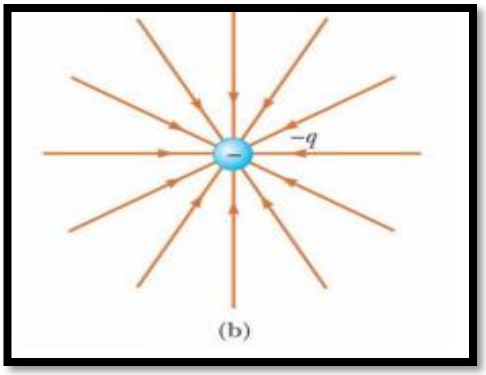
a) The electric field lines for a Positive Point Charge

- The field lines radiate outward in all directions.
- In three dimensions, the distribution is spherical.
- The lines are directed away from the source charge.
- A positive test charge would be repelled away from the positive source charge.



b) The electric field lines for a Negative Point Charge

- The field lines radiate inward in all directions.
- In three dimensions, the distribution is spherical.
- The lines are directed toward the source charge.
- A positive test charge would be attracted toward the negative source charge.



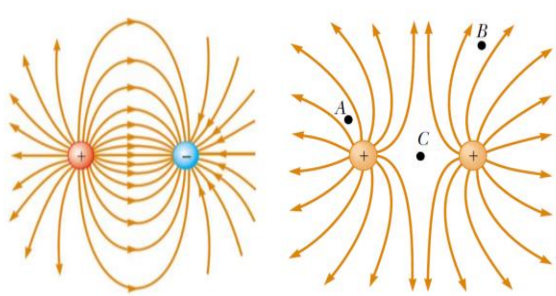
5. **The electric field lines for two point charges (an electric dipole)**

a) **Unlike charges**

- The charges are equal and opposite.
- The number of field lines leaving the positive charge equals the number of lines terminating on the negative charge.

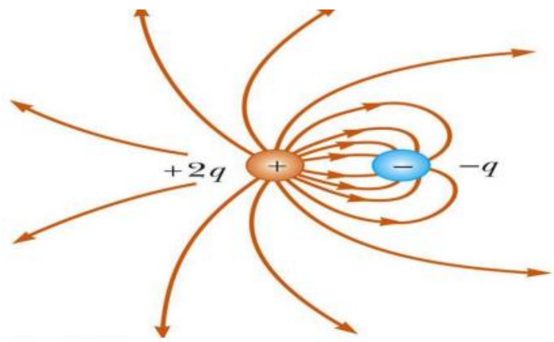
b) Like charges

- The charges are equal and positive.
- The same number of lines leaves each charge since they are equal in magnitude.
- At a great distance, the field is approximately equal to that of a single charge of 2q.



c) Unequal Charges

- The positive charge is twice the magnitude of the negative charge.
- Two lines leave the positive charge for each line that terminates on the negative charge.
- At a great distance, the field would be approximately the same as that due to a single charge of +q



6. A Point Charge in an Electric Field

What happens is that an electrostatic force $\vec{F}$ acts on the particle, as given by external electrical field $\vec{E}$, as given by:

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

in which q is the charge of the particle (including its sign)

The electrostatic force $\vec{F}$ acting on a charged particle located in an external electric field $\vec{E}$ has the direction of $\vec{E}$, if the charge q of the particle is positive and has the opposite direction if q is negative.

7. A Dipole in an Electric Field

1. Electrostatic forces act on the charged ends of the dipole.
2. Because the electric field is uniform, those forces act in opposite directions and with the same magnitude F = qE.

3. The net force on the dipole from the field is zero and the center of mass of the dipole does not move.
4. A dipole experiences a rotating effect.
5. The rotating effect is also called torque on the dipole.

We can write the magnitude of the net torque as:

$$\tau = q\,E\,d\,\sin\theta$$