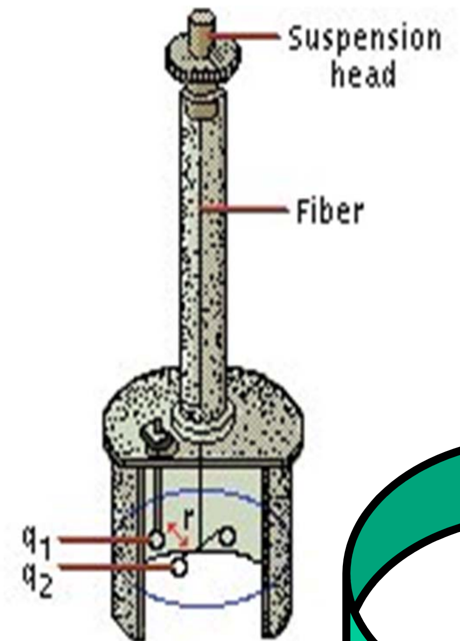
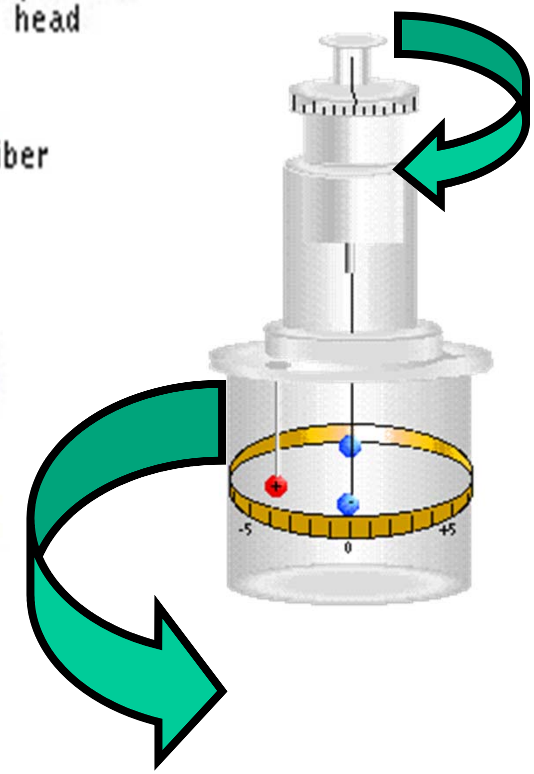
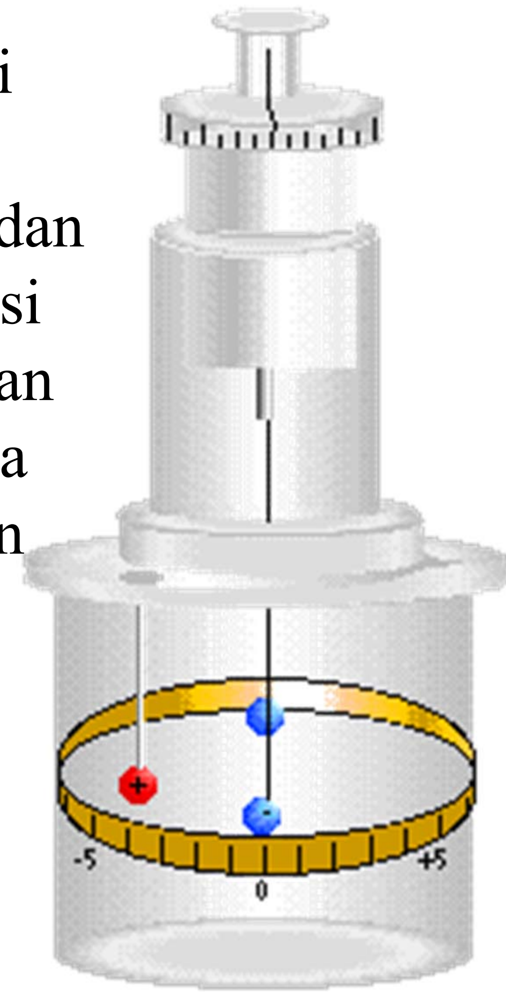
Hukum Coulomb

Keseimbangan Torsi Coulomb



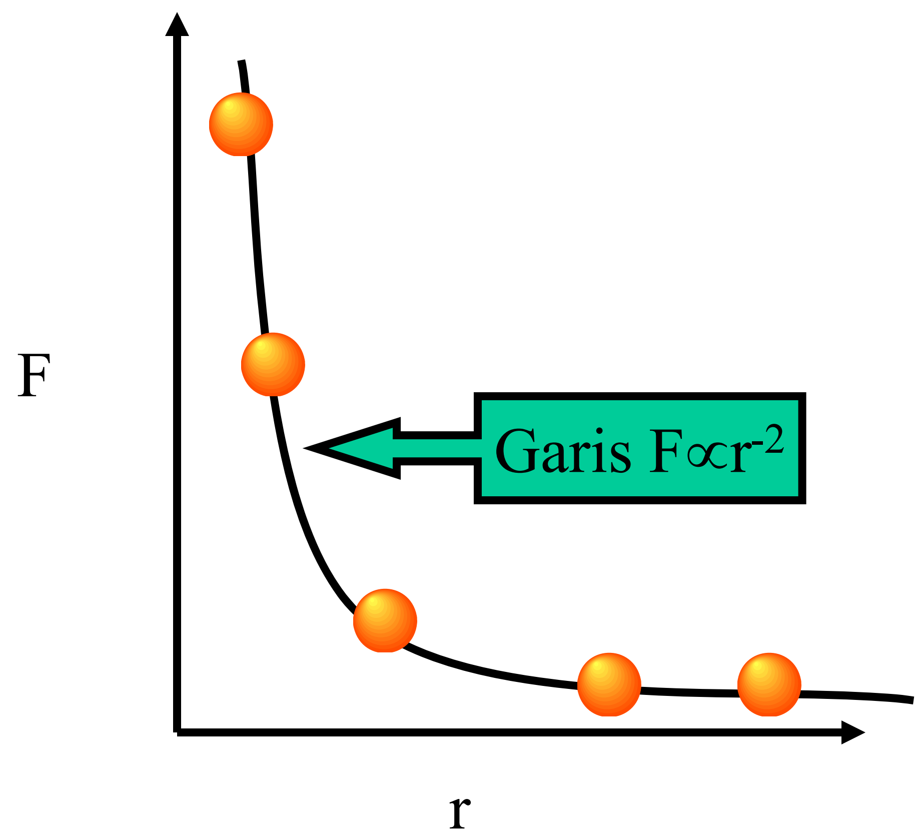


Perputaran ini untuk mencocokan dan mengukur torsi dalam serat dan sekaligus gaya yang menahan muatan



Skala dipergunakan untuk membaca besarnya pemisahan muatan

Percobaan Coulomb



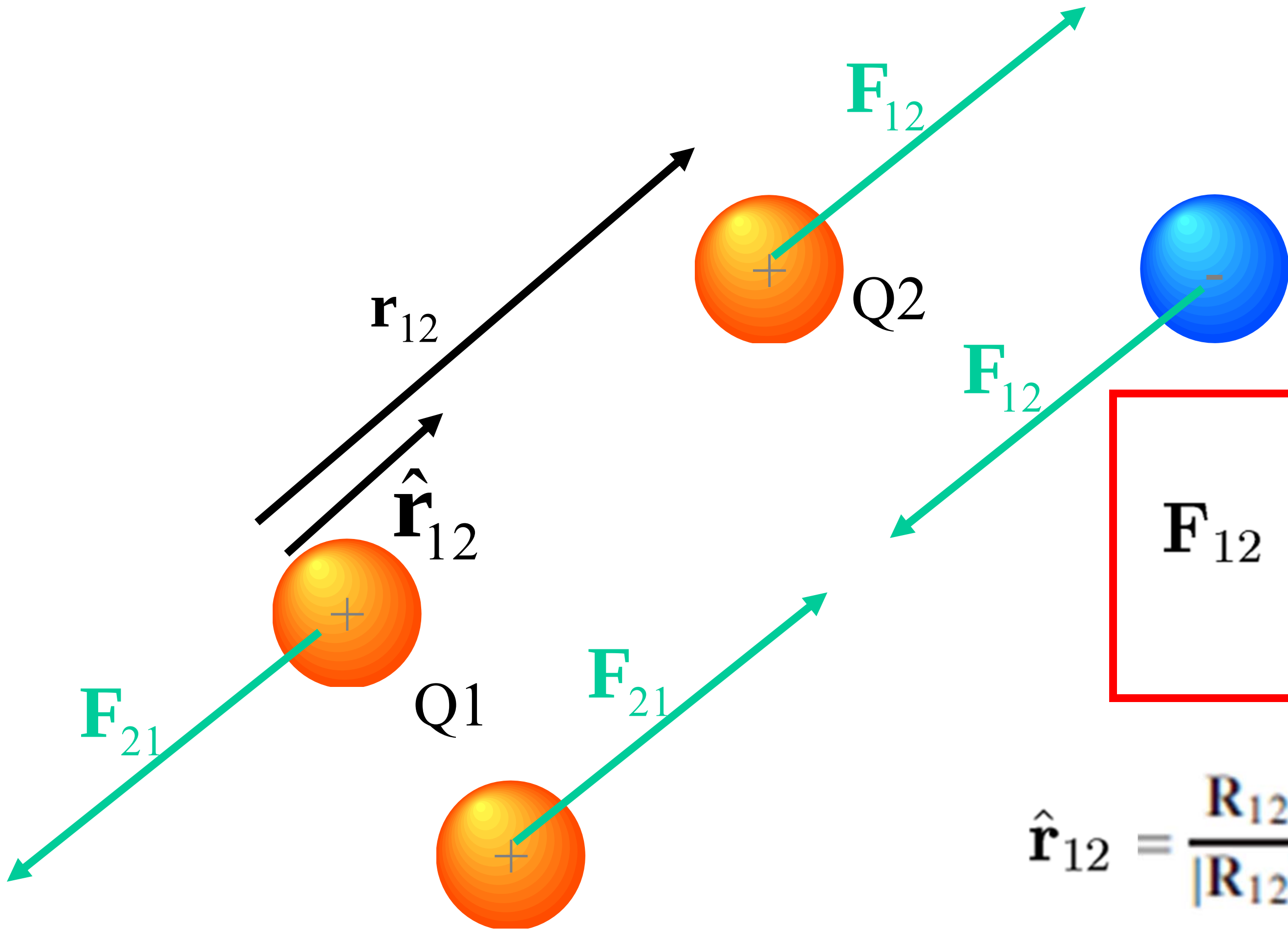
Hukum Coulomb

- Penentuan Coulomb
  - Gaya tarik menarik jika muatan berbeda tanda
  - Gaya sebanding dengan perkalian muatan q_1 dan q_2 sepanjang garis lurus yang menghubungkannya
  - Gaya berbanding terbalik dengan kuadrat jarak
- I.e.
  - $|F_{12}| \propto |Q_1|\,|Q_2| / r_{12}^2$
  - atau
  - $|F_{12}| = k\,|Q_1|\,|Q_2| / r_{12}^2$

Hukum Coulomb

- Satuan untuk konstanta ditentukan dari hukum Coulomb
- Coulomb telah menentukan konstanta ini dalam satuan SI
  - $k = 8.987.5x10^9\ Nm^2C^{-2}$
- k secara normal dinyatakan sebagai $k = 1/4\pi\varepsilon_0$

Bentuk vektor hukum Coulomb

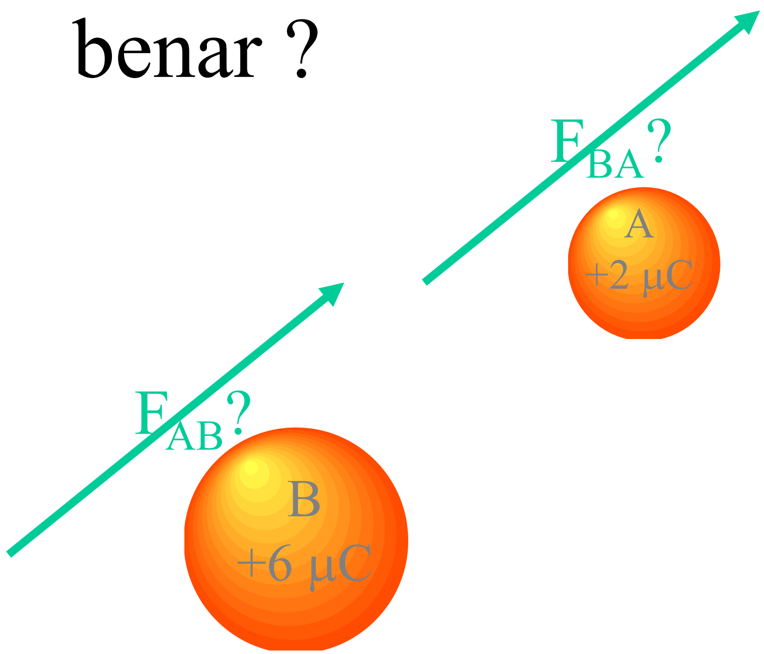


$$\mathbf{F}_{12} = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r_{12}^2}\hat{\mathbf{r}}_{12},$$

$$\hat{\mathbf{r}}_{12} = \frac{\mathbf{R}_{12}}{|\mathbf{R}_{12}|} = \frac{\mathbf{R}_{12}}{R_{12}} = \frac{\mathbf{r}_2 - \mathbf{r}_1}{|\mathbf{r}_2 - \mathbf{r}_1|}$$

Kuis

Objek A bermuatan +2 μC dan Objek B bermuatan +6 μC. Pernyataan manakah yang benar ?



- **A:** $\mathbf{F}_{AB}=-3\mathbf{F}_{BA}$
- **B:** $\mathbf{F}_{AB}=-\mathbf{F}_{BA}$
- **C:** $\mathbf{3F}_{AB}=-\mathbf{F}_{BA}$
- **D:** $\mathbf{F}_{AB}=12\mathbf{F}_{BA}$

Contoh Soal (Penerapan Vektor dalam Hk. Coulomb)

Let us illustrate the use of the vector form of Coulomb's law by locating a charge of $Q_1 = 3 \times 10^{-4}$ C at $M(1, 2, 3)$ and a charge of $Q_2 = -10^{-4}$ C at $N(2, 0, 5)$ in a vacuum. We desire the force exerted on Q_2 by Q_1.

Solution. We shall make use of (3) and (4) to obtain the vector force. The vector $\mathbf{R}_{12}$ is

$$\mathbf{R}_{12} = \mathbf{r}_2 - \mathbf{r}_1 = (2-1)\mathbf{a}_x + (0-2)\mathbf{a}_y + (5-3)\mathbf{a}_z = \mathbf{a}_x - 2\mathbf{a}_y + 2\mathbf{a}_z$$

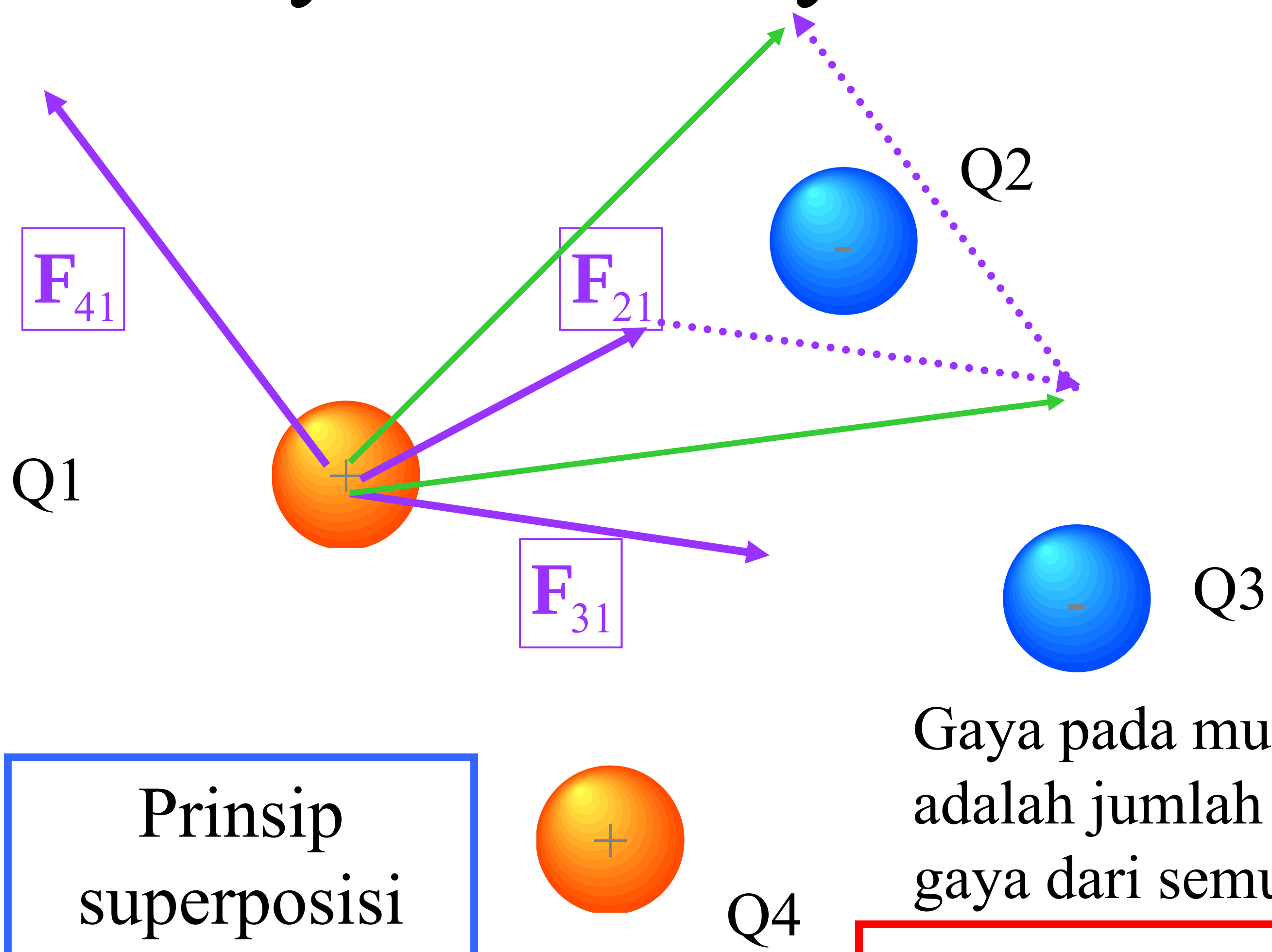
leading to $|\mathbf{R}_{12}| = 3$, and the unit vector, $\mathbf{a}_{12} = \frac{1}{3}(\mathbf{a}_x - 2\mathbf{a}_y + 2\mathbf{a}_z)$. Thus,

$$\begin{aligned}\mathbf{F}_2 &= \frac{3 \times 10^{-4}(-10^{-4})}{4\pi(1/36\pi)10^{-9} \times 3^2}\left(\frac{\mathbf{a}_x - 2\mathbf{a}_y + 2\mathbf{a}_z}{3}\right)\\ &= -30\left(\frac{\mathbf{a}_x - 2\mathbf{a}_y + 2\mathbf{a}_z}{3}\right) \text{ N}\end{aligned}$$

Gaya dari banyak muatan

Superposisi

Gaya dari banyak muatan



Prinsip superposisi

Gaya pada muatan adalah jumlah vektor gaya dari semua muatan

$$\boxed{\mathbf{F}_1 = \mathbf{F}_{21} + \mathbf{F}_{31} + \mathbf{F}_{41}}$$

The Electric Field

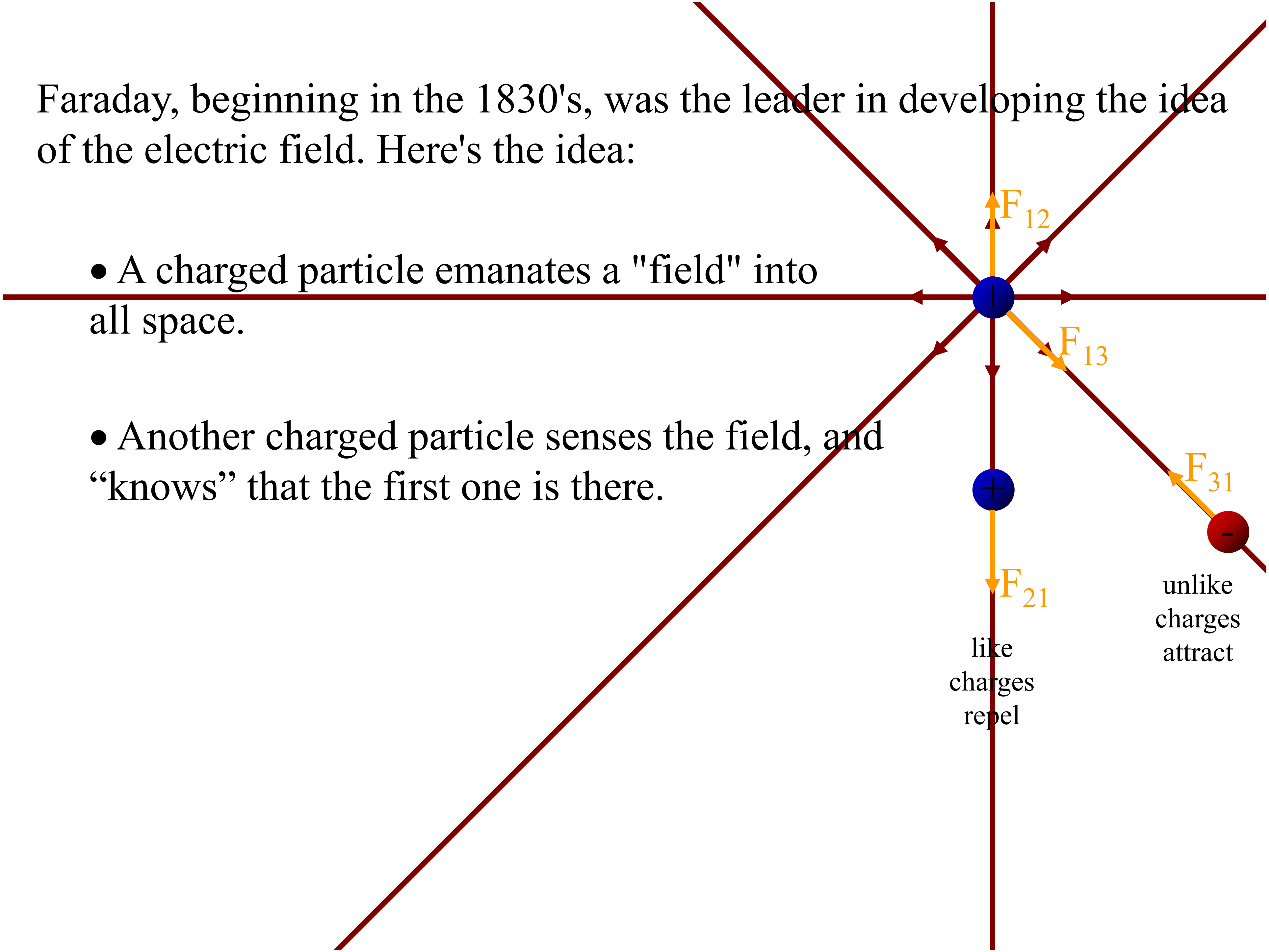
Coulomb's Law (demonstrated in 1785) shows that charged particles exert forces on each other over great distances.

How does a charged particle "know" another one is “there?”

Faraday, beginning in the 1830's, was the leader in developing the idea of the electric field. Here's the idea:

- A charged particle emanates a "field" into all space.

- Another charged particle senses the field, and “knows” that the first one is there.



We define the electric field by the force it exerts on a test charge q_0:

$$\boxed{\vec{E} = \frac{\vec{F}_0}{q_0}}$$

This is your second starting equation. By convention the direction of the electric field is the direction of the force exerted on a POSITIVE test charge. The absence of absolute value signs around q_0 means you must include the sign of q_0 in your work.

If the test charge is "too big" it perturbs the electric field, so the "correct" definition is

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}_0}{q_0}$$

You won't be required to use this version of the equation.

Any time you know the electric field, you can use this equation to calculate the force on a charged particle in that electric field. $\vec{F} = q\vec{E}$

The units of electric field are Newtons/Coulomb.

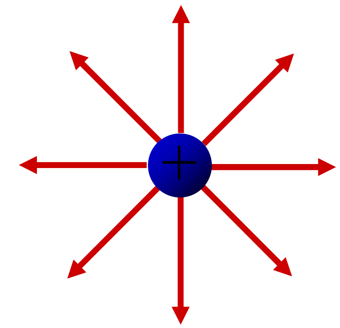
$$\left[\vec{E}\right] = \frac{\left[\vec{F}_0\right]}{\left[q_0\right]} = \frac{N}{C}$$

Later you will learn that the units of electric field can also be expressed as volts/meter:

$$\left[E\right] = \frac{N}{C} = \frac{V}{m}$$

The electric field exists independent of whether there is a charged particle around to “feel” it.

Remember: the electric field direction is the direction a + charge would feel a force.



A + charge would be repelled by another + charge.

Therefore the direction of the electric field is away from positive (and towards negative).

The Electric Field
Due to a Point Charge

Coulomb's law says

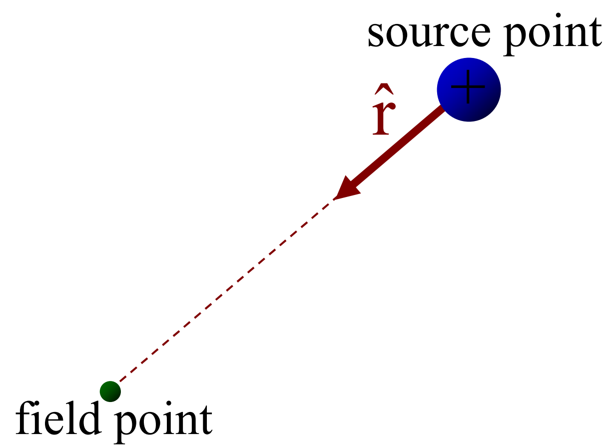
$$F_{12} = k\frac{|q_1 q_2|}{r_{12}^2},$$

... which tells us the electric field due to a point charge q is

$$\vec{E}_q = k\frac{|q|}{r^2} \text{, away from +} \qquad \ldots\text{or just}\ldots \qquad \boxed{E = k\frac{|q|}{r^2}}$$

This is your third starting equation.

We define $\hat{r}$ as a unit vector from the source point to the field point:



The equation for the electric field of a point charge then becomes:

$$\boxed{\vec{E}=k\frac{q}{r^2}\hat{r}}$$

You may start with either equation for the electric field (this one or the one on the previous slide). But don't use this one unless you REALLY know what you are doing!

Writing these expressions in cartesian coordinates for a charge Q at the origin, we have $\mathbf{R} = \mathbf{r} = x\mathbf{a}_x + y\mathbf{a}_y + z\mathbf{a}_z$ and $\mathbf{a}_R = \mathbf{a}_r = (x\mathbf{a}_x + y\mathbf{a}_y + z\mathbf{a}_z)/\sqrt{x^2 + y^2 + z^2}$; therefore,

$$\mathbf{E} = \frac{Q}{4\pi\epsilon_0(x^2 + y^2 + z^2)}\left(\frac{x}{\sqrt{x^2 + y^2 + z^2}}\mathbf{a}_x + \frac{y}{\sqrt{x^2 + y^2 + z^2}}\mathbf{a}_y + \frac{z}{\sqrt{x^2 + y^2 + z^2}}\mathbf{a}_z\right)$$

If we consider a charge which is *not* at the origin of our coordinate system, the field no longer possesses spherical symmetry (nor cylindrical symmetry, unless the charge lies on the z axis), and we might as well use cartesian coordinates. For a charge Q located at the source point $\mathbf{r}' = x'\mathbf{a}_x + y'\mathbf{a}_y + z'\mathbf{a}_z$, as illustrated in Fig. 2.2, we find the field at a general field point $\mathbf{r} = x\mathbf{a}_x + y\mathbf{a}_y + z\mathbf{a}_z$ by expressing $\mathbf{R}$ as $\mathbf{r} - \mathbf{r}'$, and then

$$\mathbf{E}(\mathbf{r}) = \frac{Q}{4\pi\epsilon_0|\mathbf{r} - \mathbf{r}'|^2}\frac{\mathbf{r} - \mathbf{r}'}{|\mathbf{r} - \mathbf{r}'|} = \frac{Q(\mathbf{r} - \mathbf{r}')}{4\pi\epsilon_0|\mathbf{r} - \mathbf{r}'|^3} = \frac{Q[(x - x')\mathbf{a}_x + (y - y')\mathbf{a}_y + (z - z')\mathbf{a}_z]}{4\pi\epsilon_0[(x - x')^2 + (y - y')^2 + (z - z')^2]^{3/2}}$$

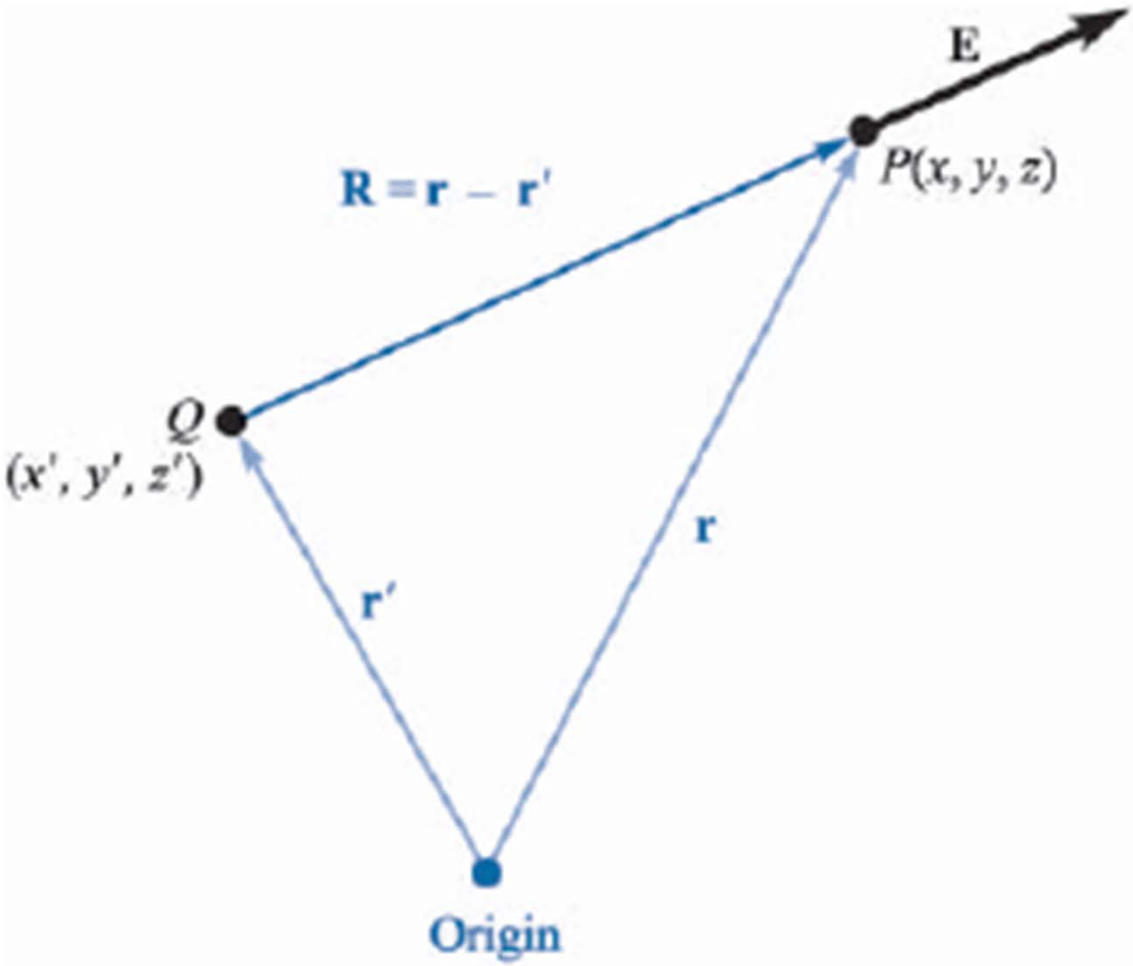


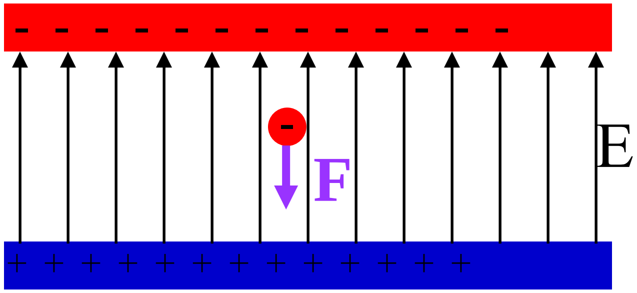
FIGURE 2.2
The vector $\mathbf{r}'$ locates the point charge Q, the vector $\mathbf{r}$ identifies the general point in space $P(x, y, z)$, and the vector $\mathbf{R}$ from Q to $P(x, y, z)$ is then $\mathbf{R} = \mathbf{r} - \mathbf{r}'$.

Motion of a Charged Particle in a Uniform Electric Field

A charged particle in an electric field experiences a force, and if it is free to move, an acceleration.

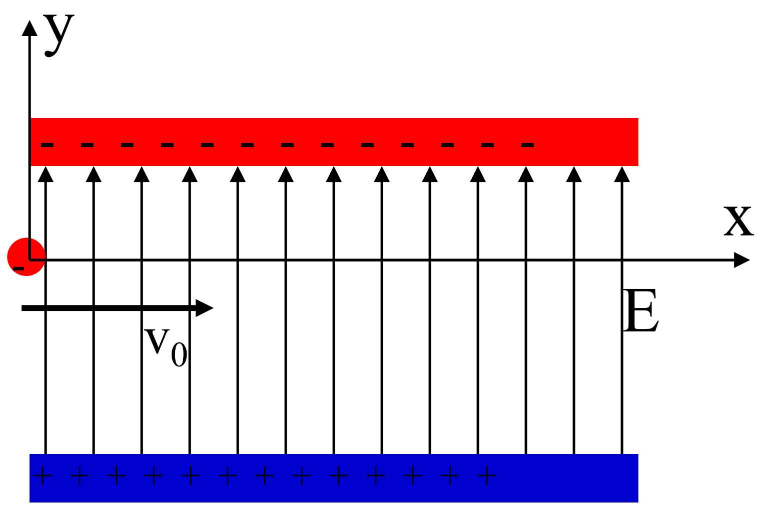
If the only force is due to the electric field, then

$$\sum \vec{F} = m\vec{a} = q\vec{E}.$$

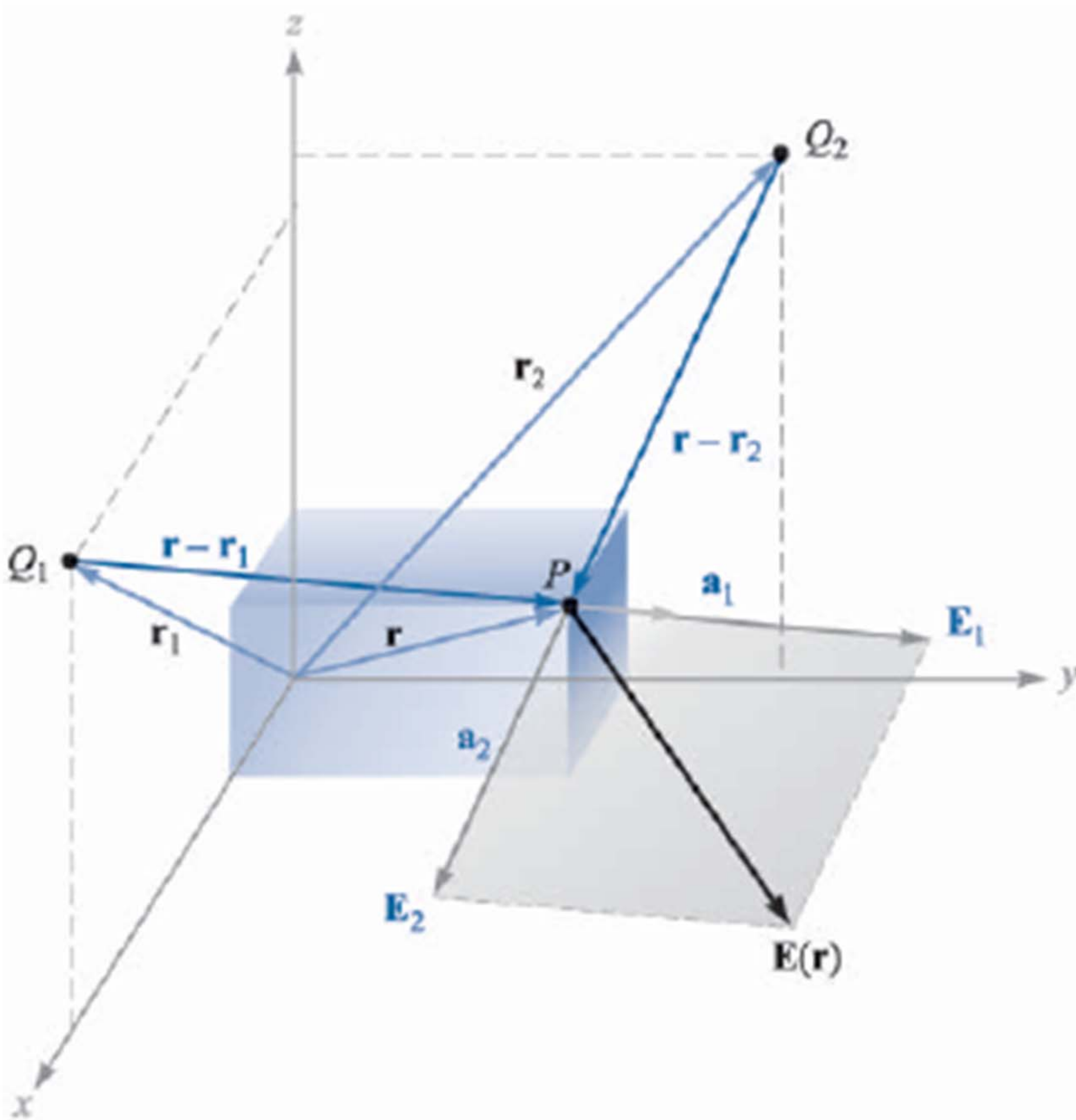


If $\vec{E}$ is constant, then $\vec{a}$ is constant, and you can use the equations of kinematics.

Example: an electron moving with velocity v_0 in the positive x direction enters a region of uniform electric field that makes a right angle with the electron's initial velocity. Express the position and velocity of the electron as a function of time.



The Electric Field
Due to a Collection of Point Charges



The electric field due to a small "chunk" Δq of charge is

$$\Delta\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{\Delta q}{r^2}\hat{r}$$

unit vector from Δq to wherever you want to calculate $\Delta\vec{E}$

The electric field due to collection of "chunks" of charge is

$$\vec{E} = \sum_i \Delta\vec{E}_i = \frac{1}{4\pi\varepsilon_0}\sum_i \frac{\Delta q_i}{r_i^2}\hat{r}_i$$

As $\Delta q \rightarrow dq \rightarrow 0$, the sum becomes an integral.

unit vector from Δq_i to wherever you want to calculate $\vec{E}$

Contoh soal:

In order to illustrate the application of (13) or (14), let us find $\mathbf{E}$ at $P(1, 1, 1)$ caused by four identical 3-nC (nanocoulomb) charges located at $P_1(1, 1, 0)$, $P_2(-1, 1, 0)$, $P_3(-1, -1, 0)$, and $P_4(1, -1, 0)$, as shown in Fig. 2.4.

Solution. We find that $\mathbf{r} = \mathbf{a}_x + \mathbf{a}_y + \mathbf{a}_z$, $\mathbf{r}_1 = \mathbf{a}_x + \mathbf{a}_y$, and thus $\mathbf{r} - \mathbf{r}_1 = \mathbf{a}_z$. The magnitudes are: $|\mathbf{r} - \mathbf{r}_1| = 1$, $|\mathbf{r} - \mathbf{r}_2| = \sqrt{5}$, $|\mathbf{r} - \mathbf{r}_3| = 3$, and $|\mathbf{r} - \mathbf{r}_4| = \sqrt{5}$. Since $Q/4\pi\epsilon_0 = 3 \times 10^{-9}/(4\pi \times 8.854 \times 10^{-12}) = 26.96\ \mathrm{V \cdot m}$, we may now use (13) or (14) to obtain

$$\mathbf{E} = 26.96\left[\frac{\mathbf{a}_z}{1}\frac{1}{1^2} + \frac{2\mathbf{a}_x + \mathbf{a}_z}{\sqrt{5}}\frac{1}{(\sqrt{5})^2} + \frac{2\mathbf{a}_x + 2\mathbf{a}_y + \mathbf{a}_z}{3}\frac{1}{3^2} + \frac{2\mathbf{a}_y + \mathbf{a}_z}{\sqrt{5}}\frac{1}{(\sqrt{5})^2}\right]$$

or

$$\mathbf{E} = 6.82\mathbf{a}_x + 6.82\mathbf{a}_y + 32.8\mathbf{a}_z\ \mathrm{V/m}$$