Unit - I
1.7 Electrostatics

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Smart Grid

Grid → Smart

↳ digitisation ✓ ✓

ATC → 26%

Aggregated Technical Commercial losses

Grid + Communication + automation → Smart grid

ATC → Technical loss
→ Inefficient billing
→ Theft

Commercial
→ Payment default

Syllabus

UNIT – I **10 Periods**

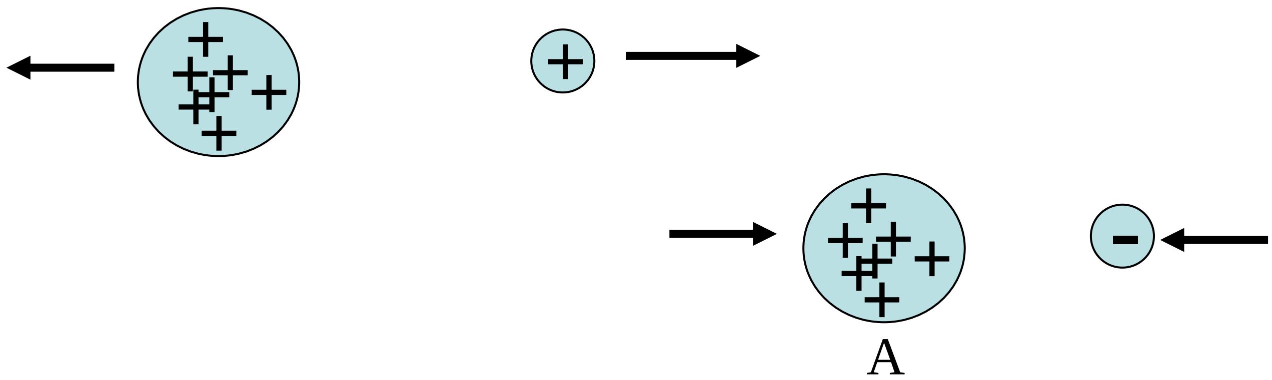
Introduction and Basic Concepts: Concept of Potential difference, voltage, current - Fundamental linear passive and active elements to their functional current-voltage relation - Terminology and symbols in order to describe electric networks - Concept of work, power, energy and conversion of energy- Principle of batteries and application.

Principles of Electrostatics: Electrostatic field - electric field intensity - electric field strength - absolute permittivity - relative permittivity - capacitor composite – dielectric capacitors - capacitors in series & parallel - energy stored in capacitors - charging and discharging of capacitors.

The Electric Field

Unit positive charge

Between two charged bodies there is a force, F, of attraction or repulsion:



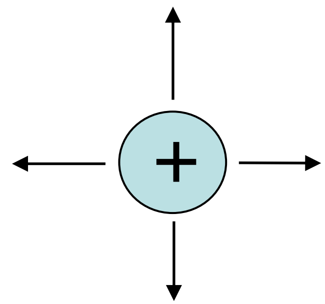
We don't understand why; we can only say this is what happens.

We can think of a charged body as *changing the nature of the space surrounding it*.

SASTRA
ENGINEERING · MANAGEMENT · LAW · SCIENCES · HUMANITIES · EDUCATION
DEEMED TO BE UNIVERSITY
(U/S 3 OF THE UGC ACT, 1956)
THINK MERIT | THINK TRANSPARENCY | THINK SASTRA

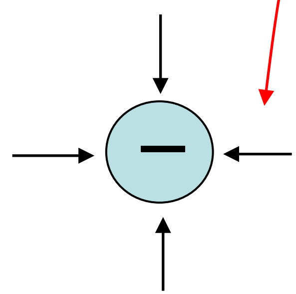
Direction of the Electric Field

Outward (away) from a positive charge



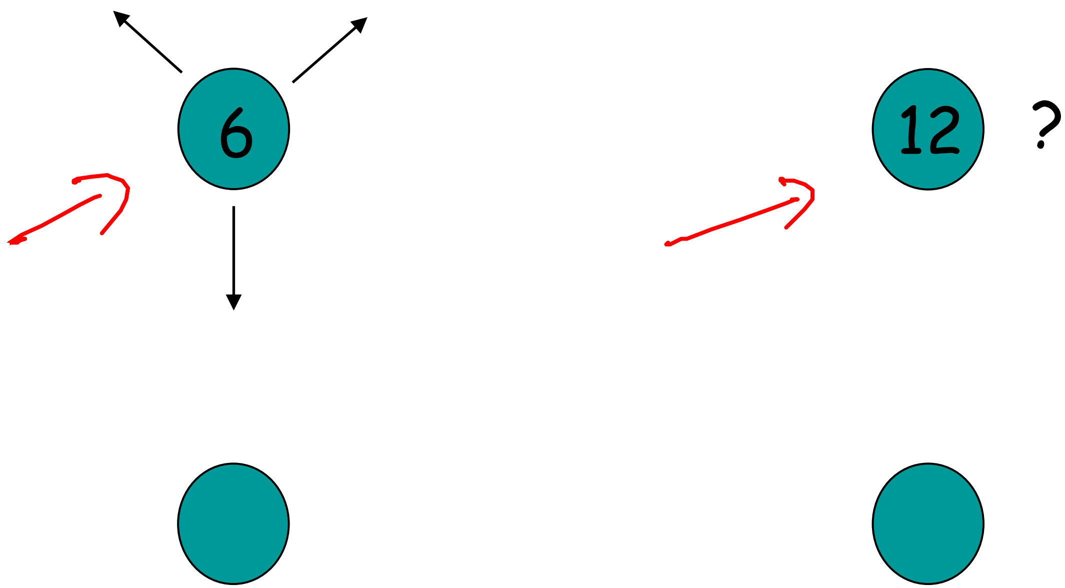
These are called "field arrows"

Inward (towards) a negative charge



Direction of the Electric Field

We draw the number of arrows proportional to the charge…more charge, more arrows. Say the charges are in “μCoulombs” (that’s micro-coulombs, or 10^{-6} Coulombs)



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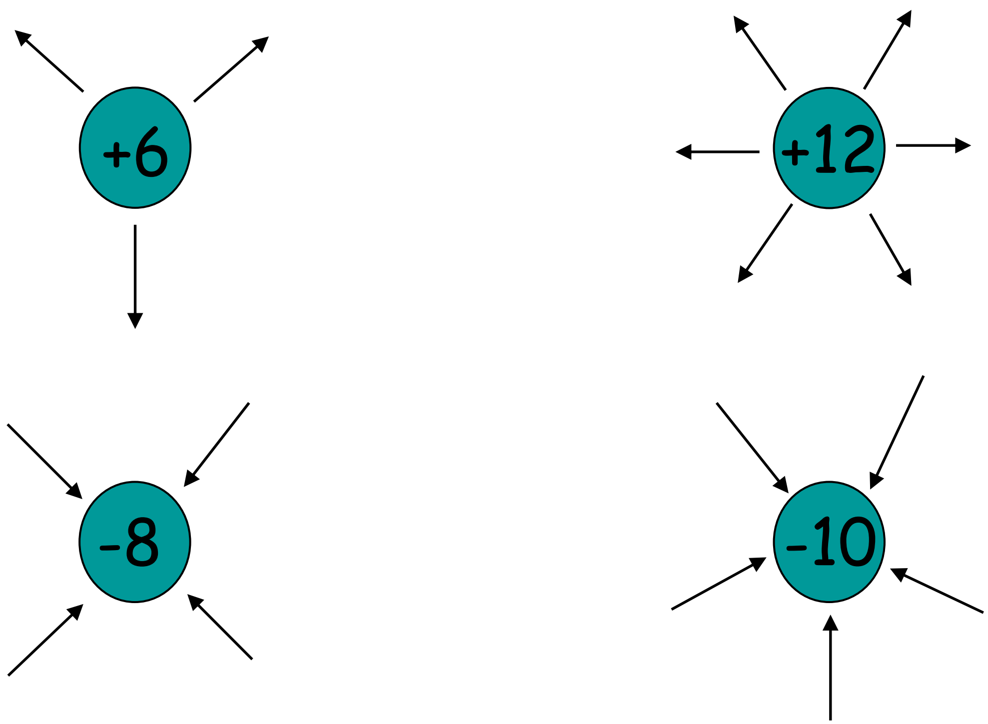
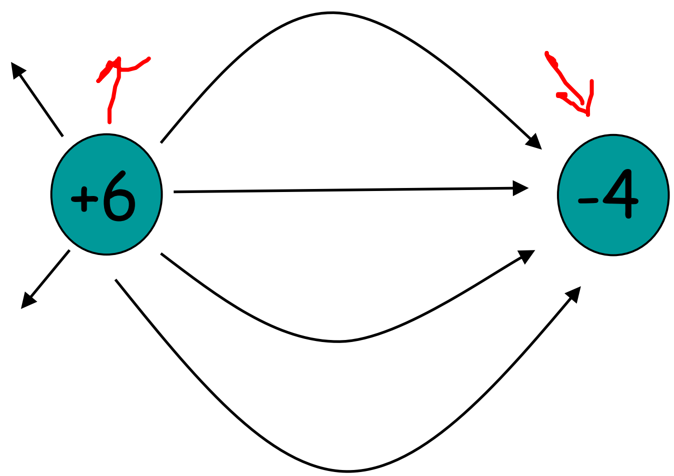


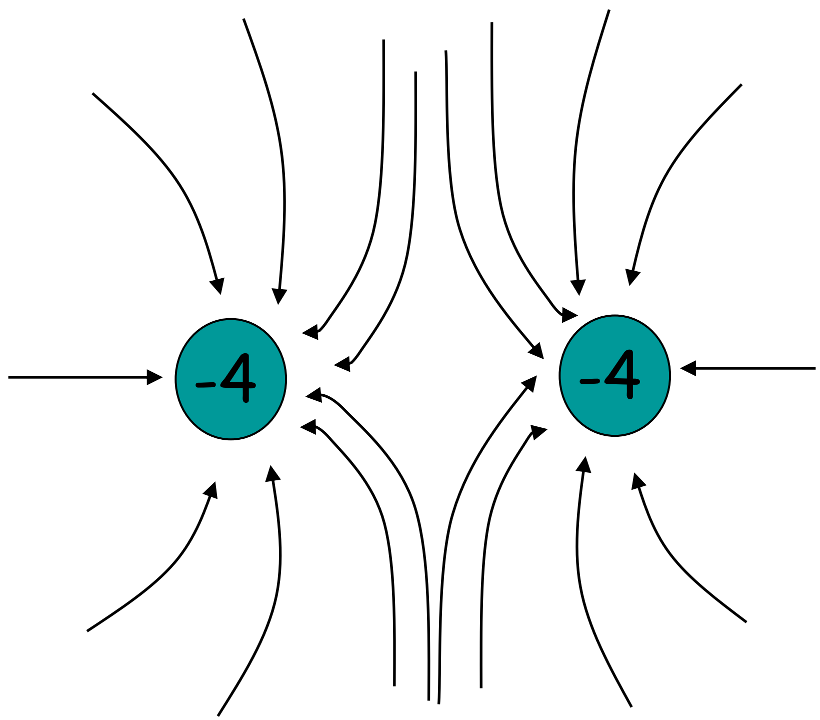
Direction of the Electric Field

When charges get near each other, these fields interact

For unlike charges, the arrows go from the positive charge to the negative charge:



For like particles the arrows are repelled:



The field arrows never cross in either case

Electric Field Intensity (Cont'd)

It becomes convenient to define electric field intensity $\mathbf{E}_1$ or force per unit charge as:

$$\mathbf{E}_1 = \frac{\mathbf{F}_{12}}{Q_2}$$

This field from charge Q_1 fixed at origin results from the force vector $\mathbf{F}_{12}$ for any arbitrarily chosen value of Q_2

Electric Field Intensity (Cont'd)

Coulomb's law can be rewritten as

$$\boxed{\mathbf{E} = \frac{Q}{4\pi\varepsilon_0 |\mathbf{R}|^2}\mathbf{a}_R}$$

to find the <u>**electric field intensity**</u> at any point in space resulting from a fixed charge Q.

Example 2

Find **E** at (0,3,4) m in cartesian coordinates due to a point charge Q =0.5μC at the origin.

Solution to Example 2

$$R = 3a_y + 4a_z \qquad a_R = (3a_y + 4a_z)/5$$

$$R = 5 \qquad \boxed{= 0.6a_y + 0.8a_z}$$

$$E = \frac{0.5\times10^{-6}}{4\pi\left(10^{-9}/36\pi\right)(5)^2}\left(0.6a_y + 0.8a_z\right)$$

Thus $[E] = 180V/m$ in the direction $a_R = 0.6a_y + 0.8a_z$

Example 3

Let a point charge Q_1 = 25nC be located at P_1 (4,-2,7).

If $\varepsilon = \varepsilon_0$, find electric field intensity at P_2 (1,2,3).

Insulation

↓

printers

Ash precipitator

Solution to Example 3

By using the electric field intensity,

$$\mathrm{E} = \frac{Q}{4\pi\varepsilon_o|\mathrm{R}|^2}\mathrm{a}_R$$

This field will be:

$$\mathrm{E} = \frac{25\times10^{-9}}{4\pi\varepsilon_o|\mathrm{R}|}\mathrm{a}_R$$

Solution to Example 3 (Cont'd)

Where, $\mathbf{R}_{12} = \mathbf{r}_2 - \mathbf{r}_1 = -3\mathbf{a}_x + 4\mathbf{a}_y - 4\mathbf{a}_z$

and $|\mathrm{R}| = \sqrt{41}$

$$\mathrm{E} = \frac{Q}{4\pi\varepsilon_o |\mathrm{R}|^2}\mathrm{a}_R = \frac{Q}{4\pi\varepsilon_o |\mathrm{R}|^3}\mathrm{R}$$

$$= \frac{25\times10^{-9}}{4\pi\left(8.854\times10^{-12}\right)(41)^{3/2}}\left(-3\mathrm{a}_x + 4\mathrm{a}_y - 4\mathrm{a}_z\right)$$

$$= ??$$

Electric Field Intensity (Cont'd)

If there are N charges, $Q_1, Q_2 \ldots Q_N$ located respectively at point with position vectors $r_1, r_2 \ldots r_N$ the electric field intensity at point r is:

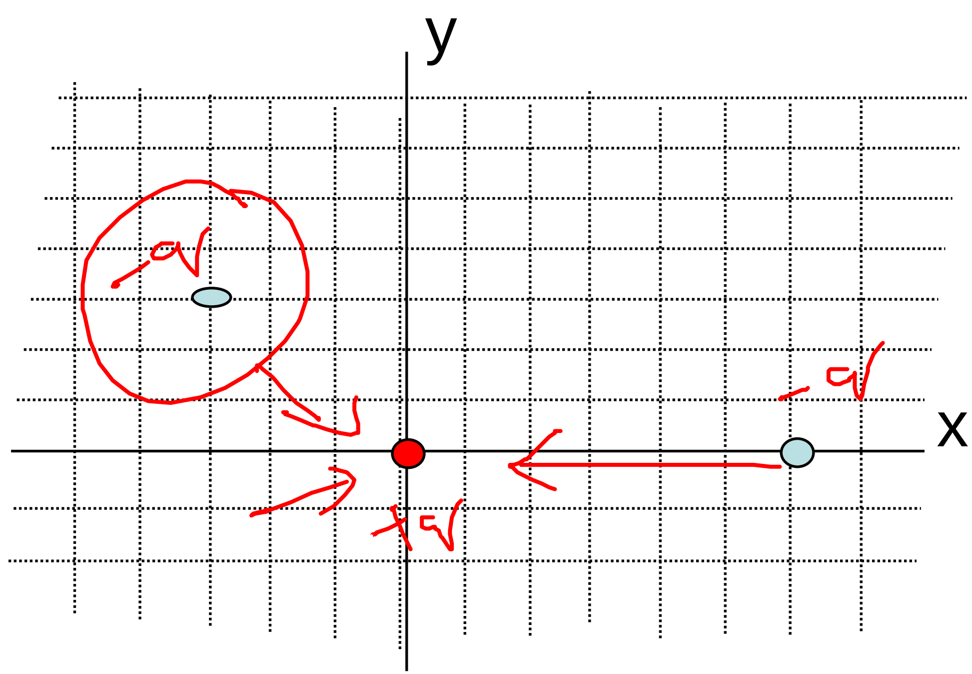
$$\mathbf{E} = \frac{Q_1}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}_1|^2} \frac{(\mathbf{r} - \mathbf{r}_1)}{|\mathbf{r} - \mathbf{r}_1|} + .. \frac{Q_N}{4\pi\varepsilon_0 |\mathbf{r} - \mathbf{r}_N|^2} \frac{(\mathbf{r} - \mathbf{r}_N)}{|\mathbf{r} - \mathbf{r}_N|}$$

$$\boxed{\mathrm{E} = \frac{1}{4\pi\varepsilon_0} \sum_{k=1}^{N} \frac{Q_k (\mathrm{r} - \mathrm{r}_k)}{|\mathrm{r} - \mathrm{r}_k|^3}}$$

Superposition of forces from two charges

Blue charges fixed , negative, equal charge (-q)

What is force on positive red charge +q ?



Superposition of forces from two charges

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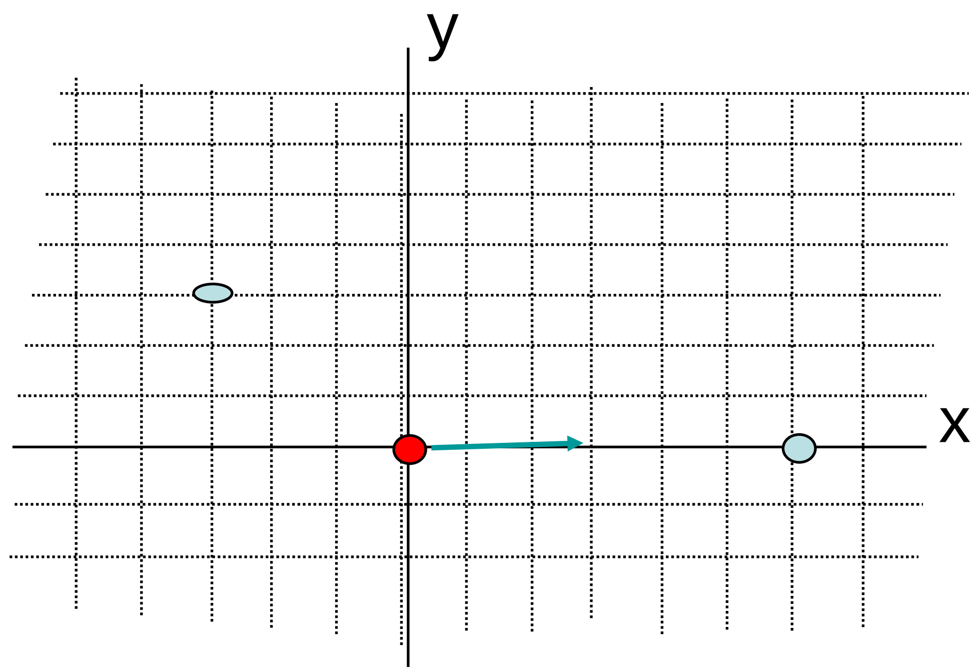
What is force on positive red charge +q ?

Consider effect of each charge separately:



Superposition of forces from two charges

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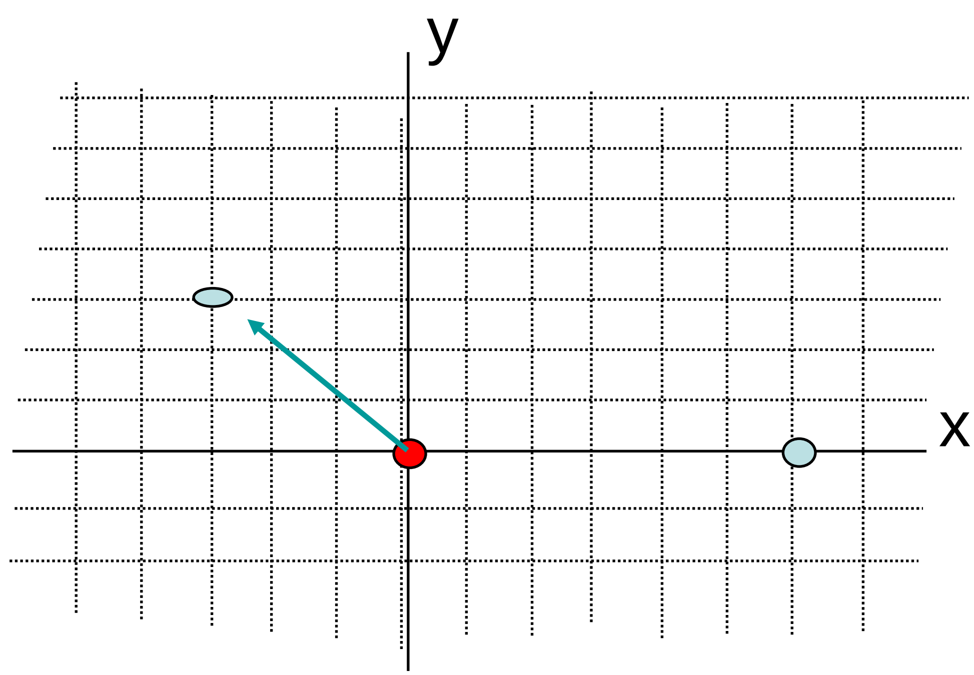
What is force on positive red charge +q ?

Take each charge in turn:



Superposition of forces from two charges

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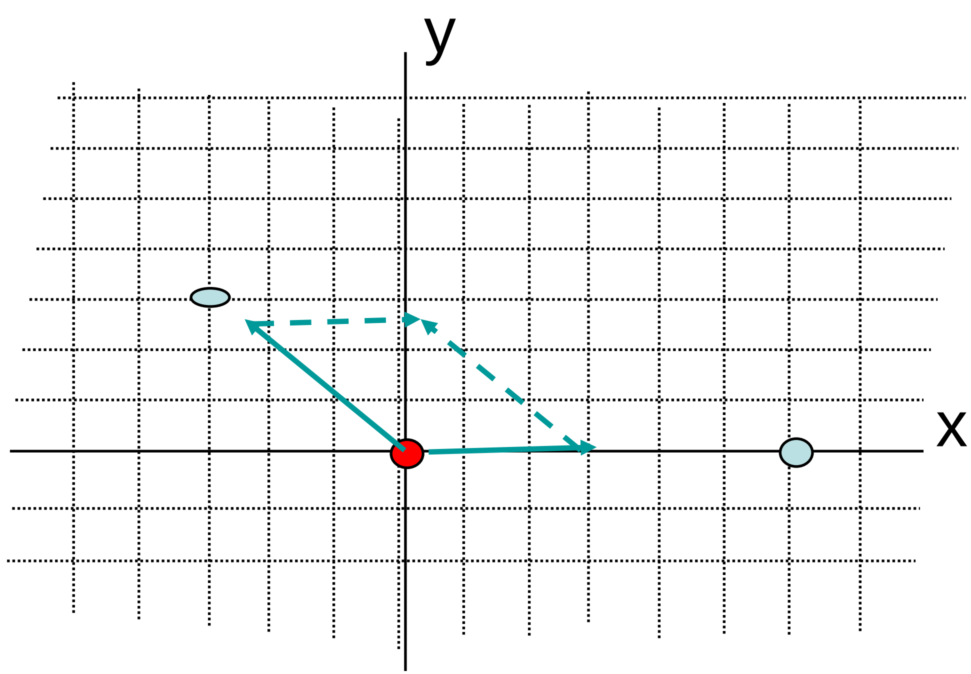
What is force on positive red charge +q ?

Create vector sum:



Superposition of forces from two charges

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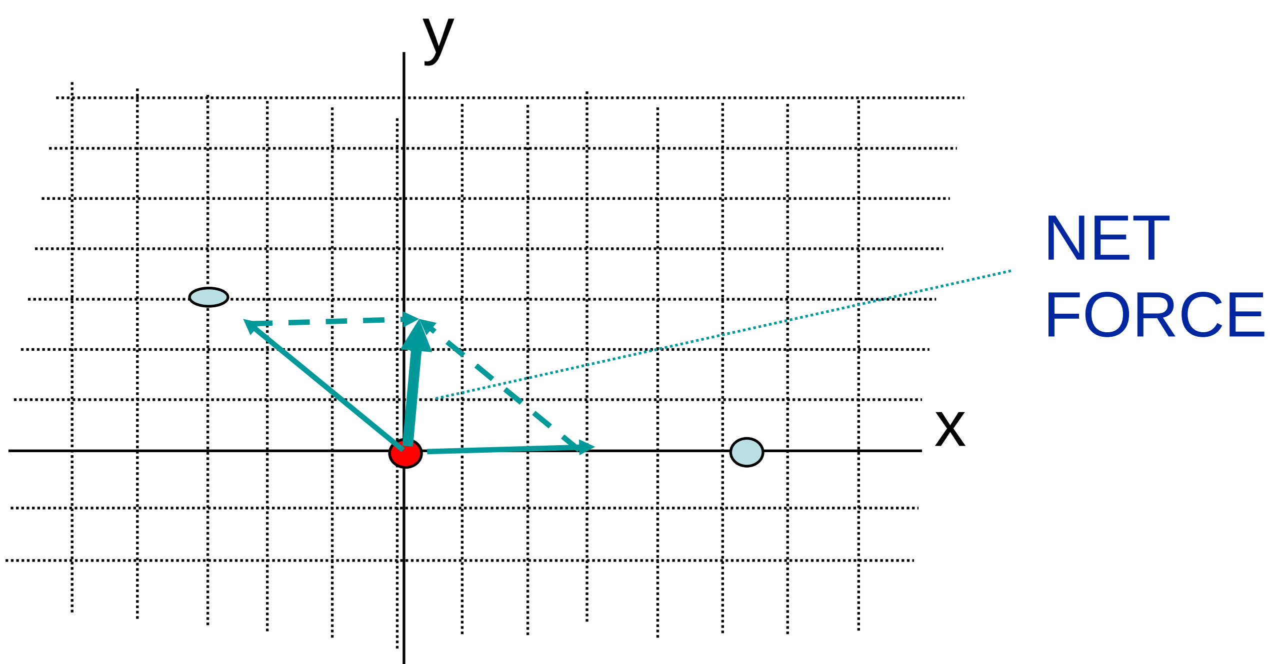
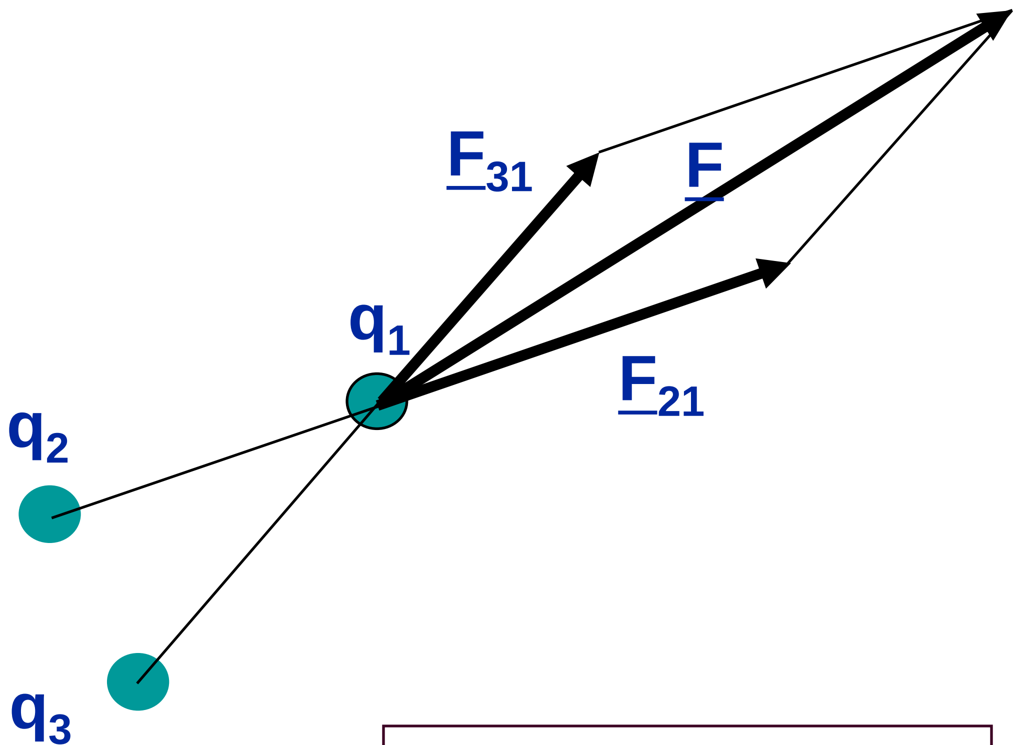
What is force on positive red charge +q ?

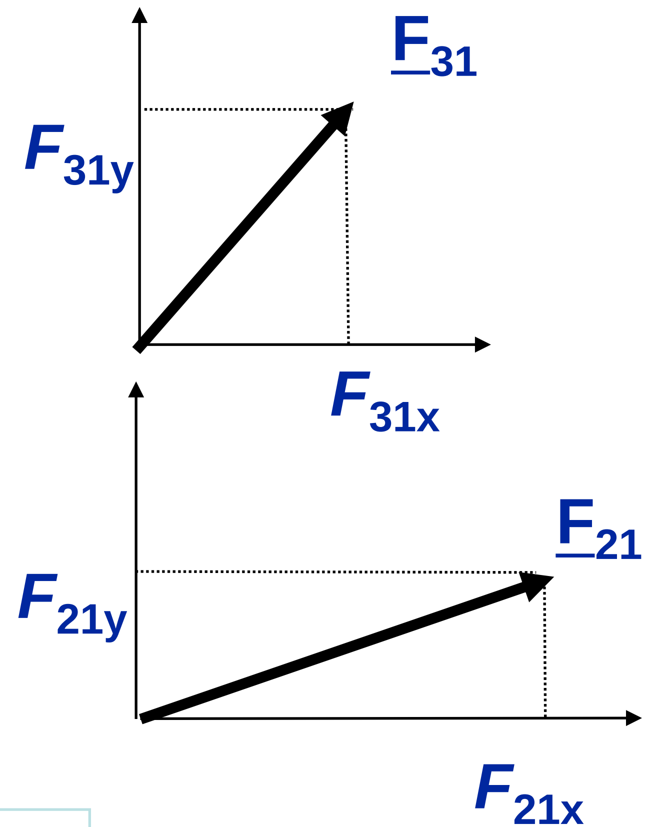
Find resultant:



When a number of charges are present, the total force on a given charge is equal to the vector sum of the forces due to the remaining other charges on the given charge.

Superposition Principle





Forces add vectorially

$$\underline{F} = (F_{21x} + F_{31x})\,\underline{x} + (F_{21y} + F_{31y})\,\underline{y}$$

Just as we defined a gravitational field, we define an "electric field" in a similar manner:

$$F = \frac{GmM}{r^2}$$

$$mg = \frac{GmM}{r^2}$$

$$g = \frac{GM}{r^2}$$

This is the gravitational field (Earth = 9.8 m/s^2 or 9.8 N/kg)

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$$\cancel{m}g = \frac{G\cancel{m}M}{r^2}$$

$$g = \frac{GM}{r^2}$$

$$F = \frac{k|qQ|}{r^2}$$

$$\cancel{q}(E) = \frac{k|\cancel{q}Q|}{r^2}$$

This is the gravitational field (Earth = 9.8 m/s^2 or 9.8 N/kg)

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

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The general equation for an ELECTRIC FIELD is:

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

$$\frac{Newtons}{Coulomb} = \frac{N}{C}$$

(compare this to the equation for the gravitational field)

Notice that for gravity, $F = mg$

We see that in electrostatics, $F = qE$

$$F = \frac{GmM}{r^2}$$

$$\downarrow$$

$$mg = \frac{GmM}{r^2}$$

$$g = \frac{GM}{r^2}$$

$$F = \frac{k|qQ|}{r^2}$$

$$\downarrow$$

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

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

Summary

Electrostatics

- → Coulomb's law
- → Field intensity
  - → Single
  - → multiples → force
- → gravitional field