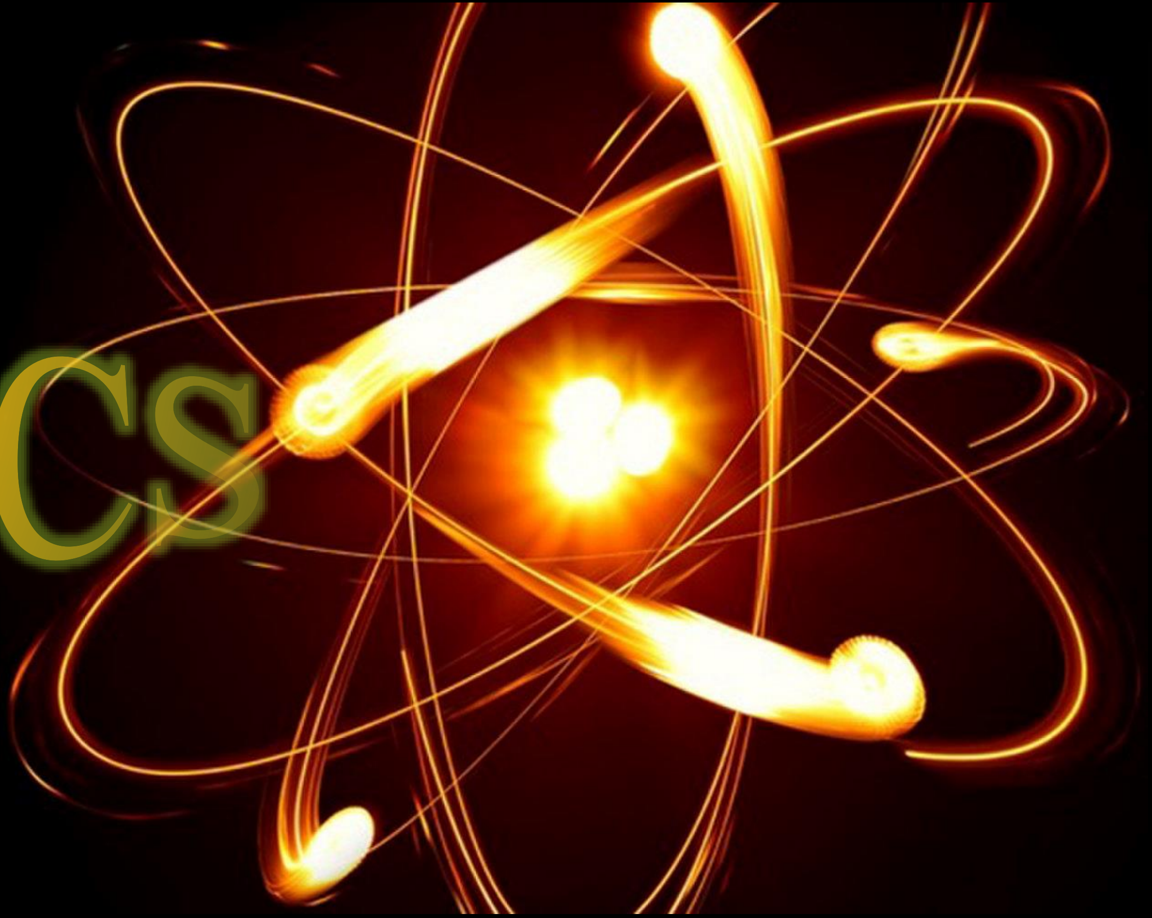
PHYSICS



西南交通大學
Southwest Jiaotong University

Physics 2: **Electricity , Optics and Quanta**

2023.9

QQ group: 776916994

cyjing@swjtu.edu.cn

Schedules

Week	Topic	Number of sessions	Note
1	Electrostatics	3	
2	Electrostatics & DC Electricity	3	
3	DC Electricity	3	
4	Capacitors	3	
5	Magnetism	3	
6	Electromagnetic Induction	3	
7	Generators, Motors	3	
8	Generators, Motors & Back Emf	3	

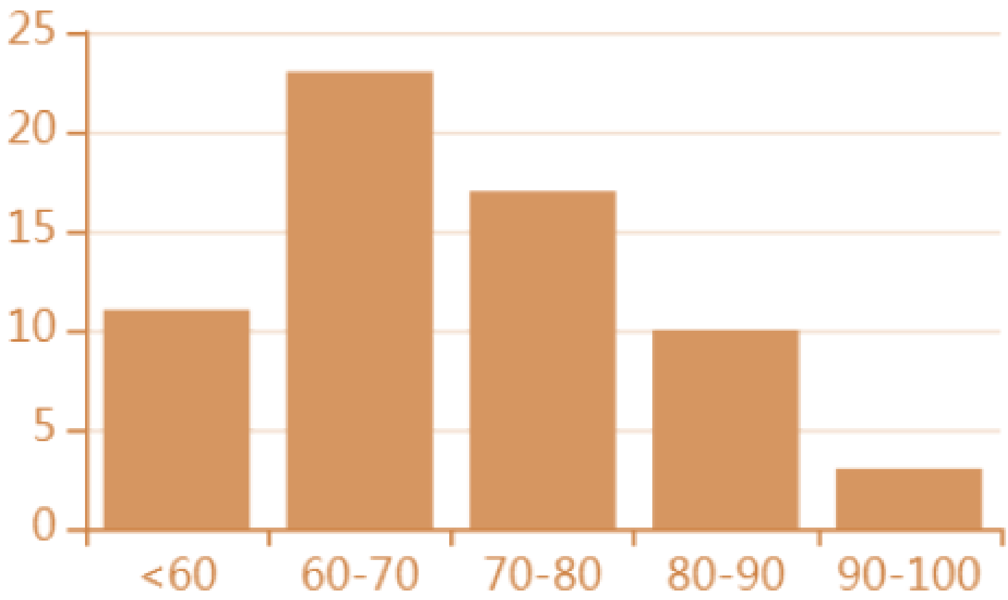
Schedules

Week	Topic	Number of sessions	Note
9	Self inductance & Midterm Exam	3	
10	Self inductance & AC Electricity	3	
11	AC Electricity	3	
12	AC Electricity	3	
13	Electromagnetic waves	3	
14	Optics	3	
15	Wave optics	3	
16	Quanta & Quanta waves	3	
17	Matter wave & REVISION	3	

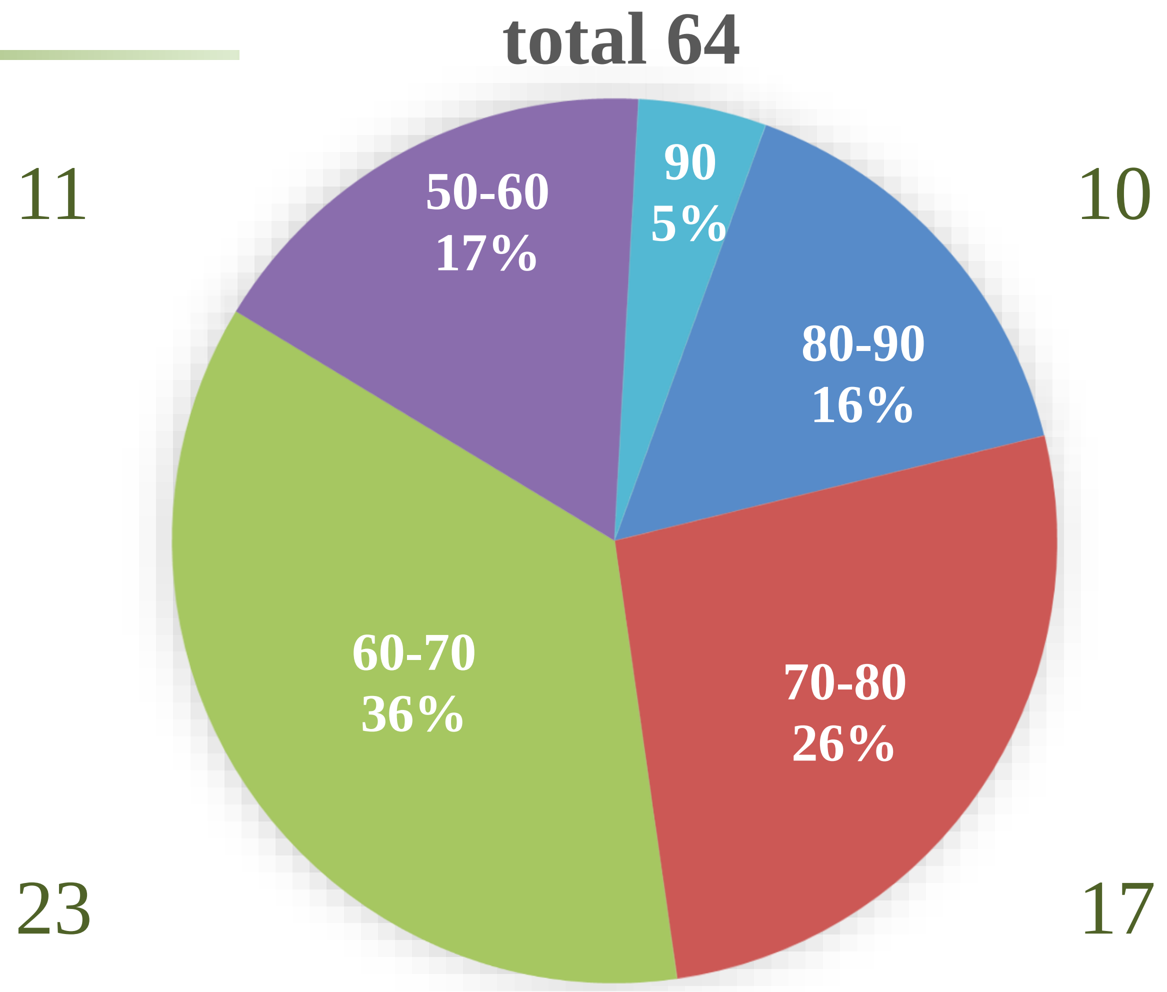
Looking back

AVERAGE

68.62



Looking back



Your final grade

Assessment type	% of module
Lab Report	**10**
Homework	**10**
Mid-term test	**10**
End of module Exam	**70**

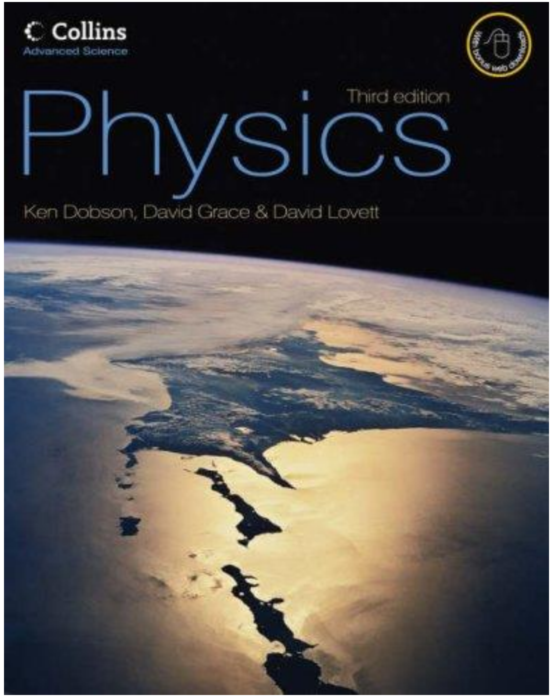
Two tips

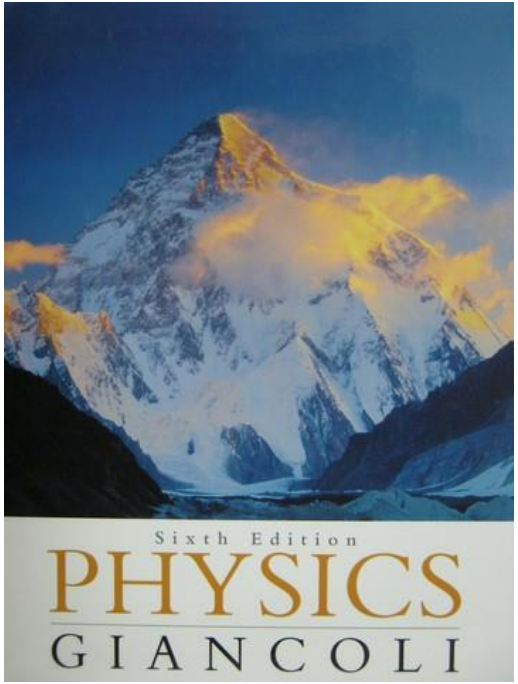
Two tips

Textbook

Physics

by Dobson, Grace and Lovett





Physics

by Giancoli

As a reference book

Week 1

Electrostatics				***Equilibrium System* (electrostatic, no current!)**	
Electric charge	Electric force	Electric field	Electric Potential	**Conductor in Electric field**	**non-conductor in Electric field**
Q	F	E	V		**Dielectrics**

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Physics 2: **Electricity , Optics and Quanta**

Week 1 – Electrostatics

2023.9

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Floating of the plastic rope

Static electricity

What type of charge?

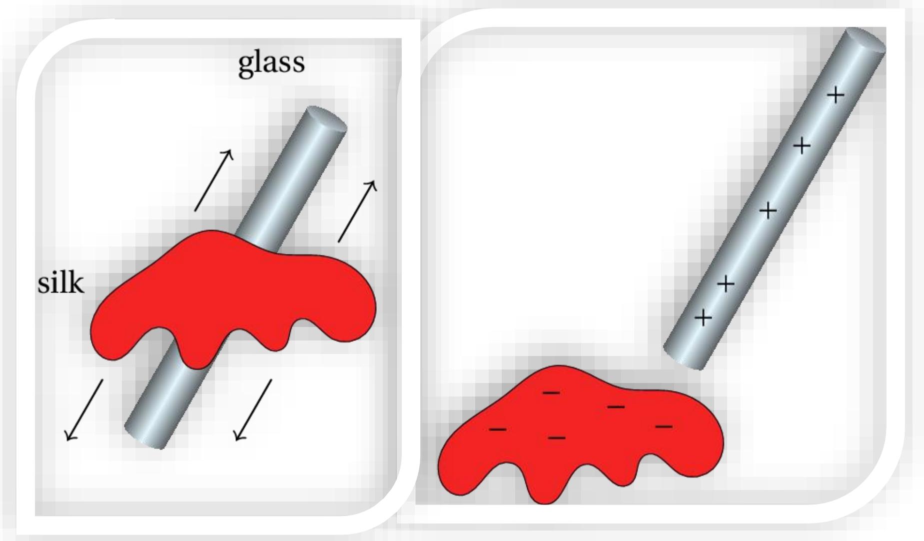
Hold a net charge for long?

Where does the charge go?

Static electricity

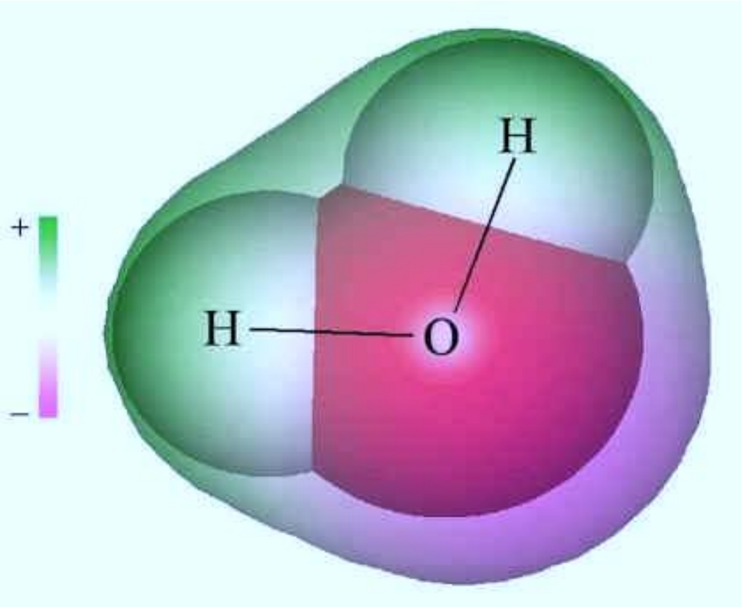
Benjamin Franklin
1706-1790

What type of charge?



Net electric charge ?

Static electricity



Polar – neutral, but charge is not distributed uniformly

Hold a net charge for long?

Hold their charge for a limited time and return to neutral state.

Where does the charge go?

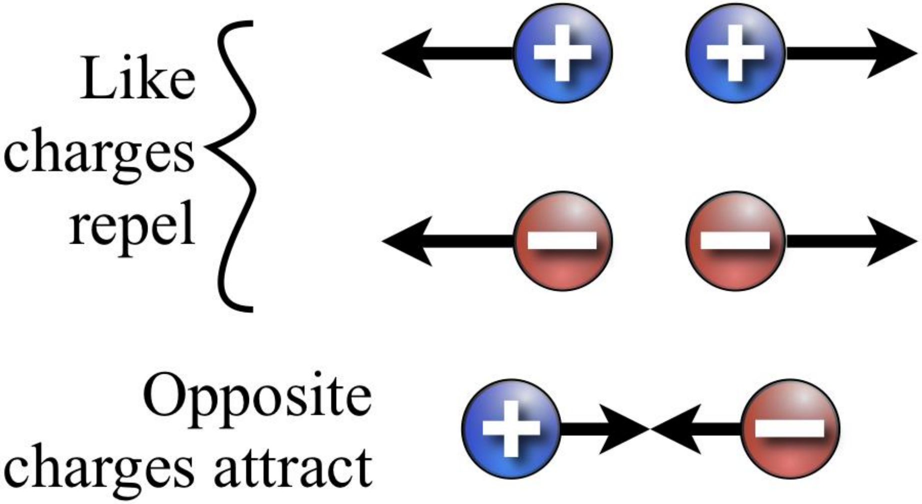
Excess charge “leaks off” on to water molecules in the air.

Electric Charge, Force and Field

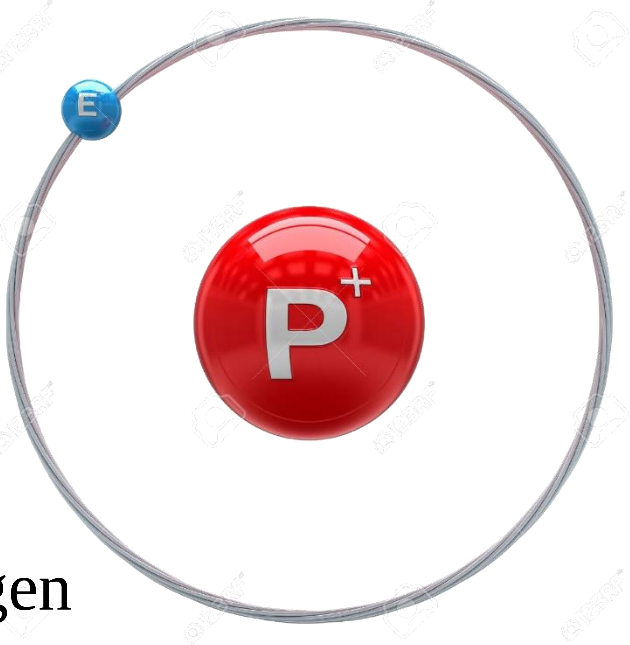
Definition

- matter
- experience a force
- placed in an ***electromagnetic field***.

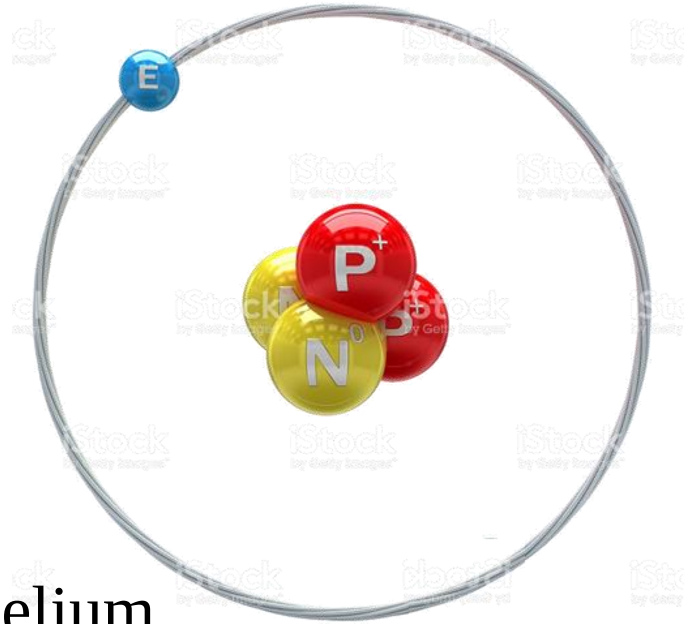
Types



Electric force



Hydrogen



Helium

Compare the electric forces that the two electrons experience.

(given the same distance between electrons and nuclei)

Electrostatic Force – Coulomb's law

2 ***point*** charges q_1 and q_2 :

Vector! $$\mathbf{F}_{21} = k\frac{q_1 q_2}{{r_{21}}^2}\hat{\mathbf{r}}_{21} = \frac{q_1 q_2}{4\pi\varepsilon_0 {r_{21}}^2}\hat{\mathbf{r}}_{21}$$

unit vector

(to show the direction)

q_1 on q_2?

q_2 on q_1?

$$k = 9 \times 10^9\ Nm^2C^{-2}$$

$$\varepsilon_0 = 8.85 * 10^{-12}\ \mathrm{C}^2/(\mathrm{N\,m}^2)$$

(Permittivity of free space)

"quantized" Electric charge

$$q = \pm ne$$

$$e = 1.6 \times 10^{-19}\ \text{C}$$

$$= 1.6021766208(98) \times 10^{-19}\ \text{C}$$

Elementary/subatomic particles carry elementary charge:

●	electron	$-e$	$m_e = 9.11 \times 10^{-31}$ kg
●	proton	e	$m_p = 1.6726 \times 10^{-27}$ kg
●	neutron	0	$m_n = 1.6749 \times 10^{-27}$ kg

Unit of electric charge

coulomb (unit symbol: C)

charge (symbol: *Q or q*) transported

$$1\,\mathrm{C} = 1\,\mathrm{A} \cdot 1\,\mathrm{s}$$

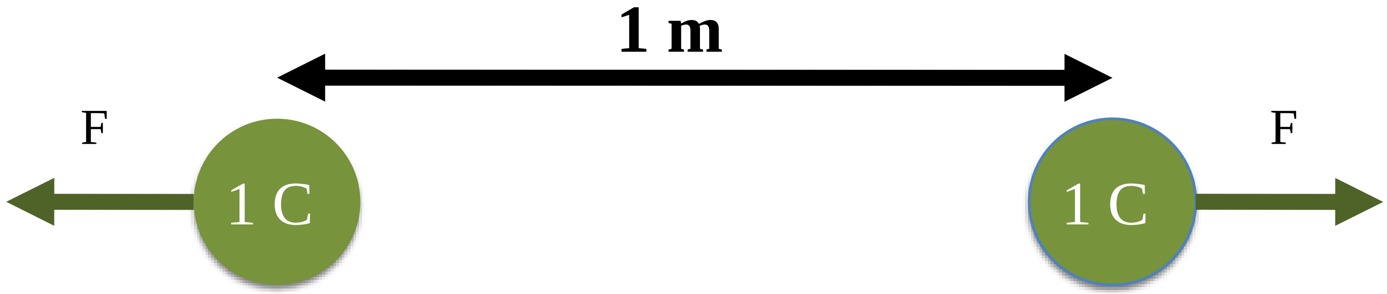
Thus, it is also the amount of excess charge on a capacitor of one **farad** charged to a potential difference of one **volt**:

$$1\,\mathrm{C} = 1\,\mathrm{F} \cdot 1\,\mathrm{V}$$

Charles-Augustin de Coulomb
(1736 –1806)

Unit of electric charge

Force on two 1 Coulomb charges separated by 1 m



$F = 9 \times 10^{9}$ N equivalent to the weight of 920,000 metric tons!

So : 1 C is a very big charge!

Coulombs in everyday life

Static electricity by rubbing materials :

a few micro-coulombs

($\mu C = 10^{-6}$ C)

A lightning bolt:

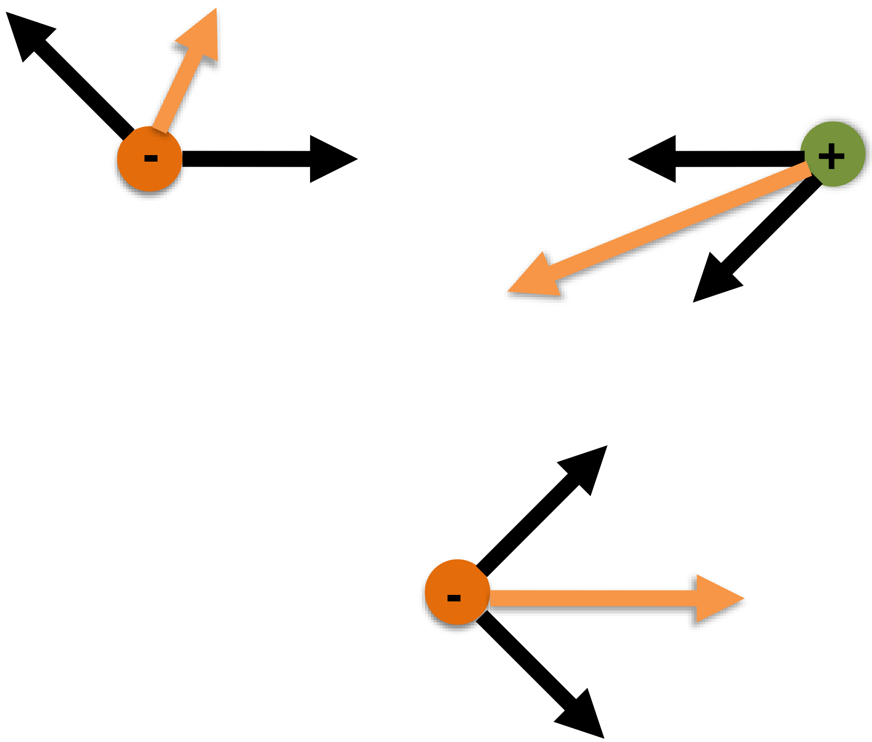
about 15 C

Total charge from AA battery from fully charged to discharged:

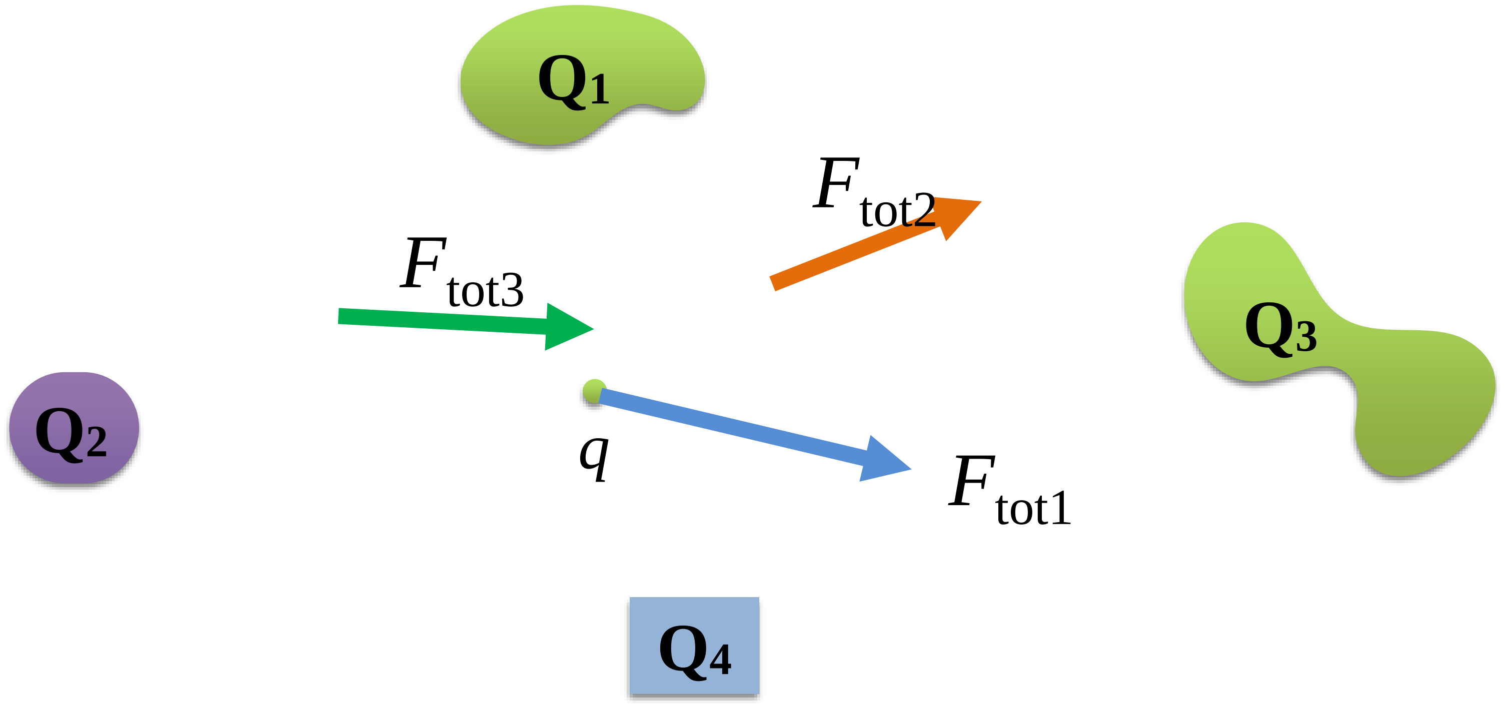
5 kC = 5000 C

Superposition of electric forces

Electrostatic force



Force on a small "test" charge q



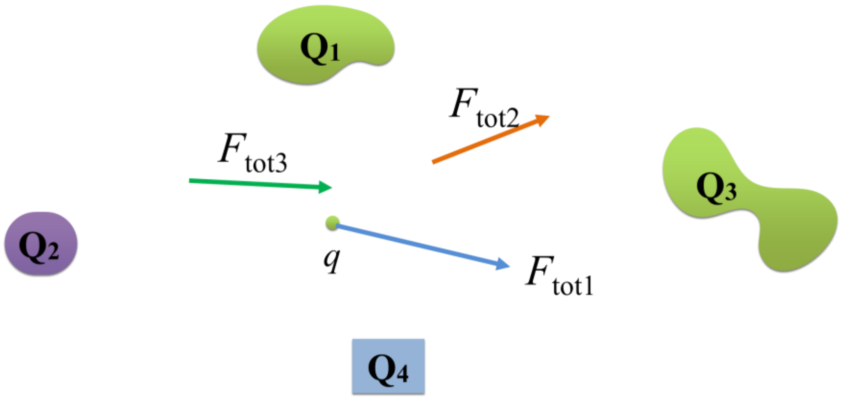
What if the test charge becomes $2q$? How about the forces?

Force on a small “test” charge q

What if the test charge becomes 2q?
How about the forces?

$$F \propto Q_{test}$$

$$F/Q_{test} = \text{constant}$$



Electric field

Electrostatic force

Define through the electric force

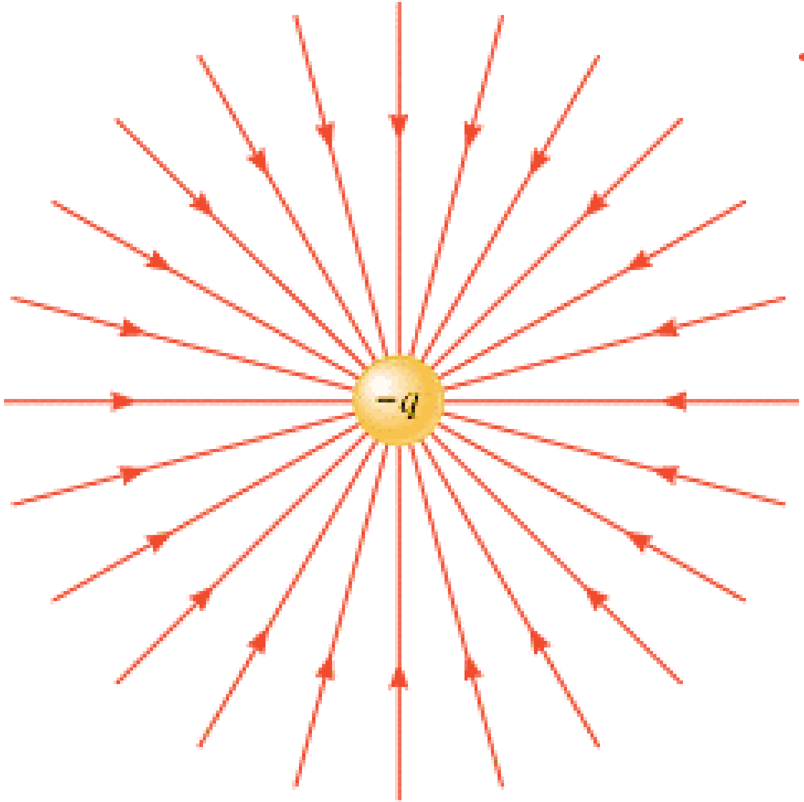
At any point in space, we can define : $E = \frac{F_{\text{tot}}}{q} = ?$

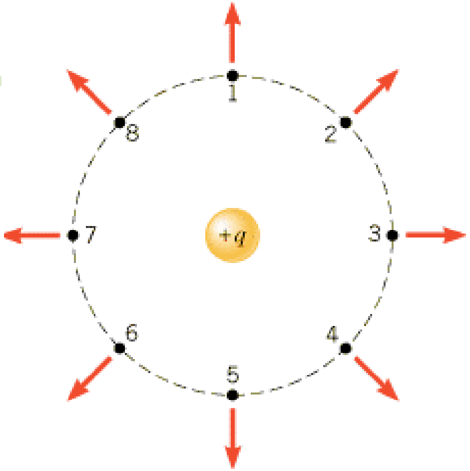
E **is the Electric Field.**

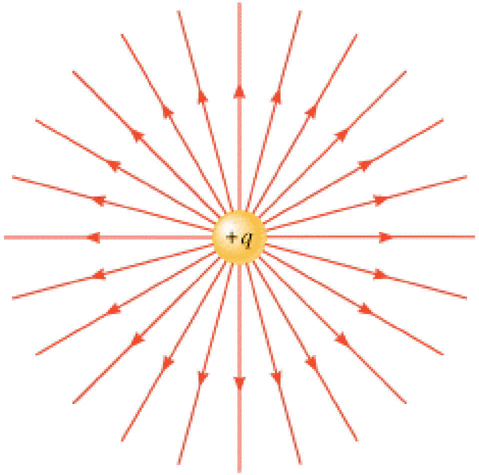
It is a field that surrounds electric charges.

vectors

Electric field line







Direction?

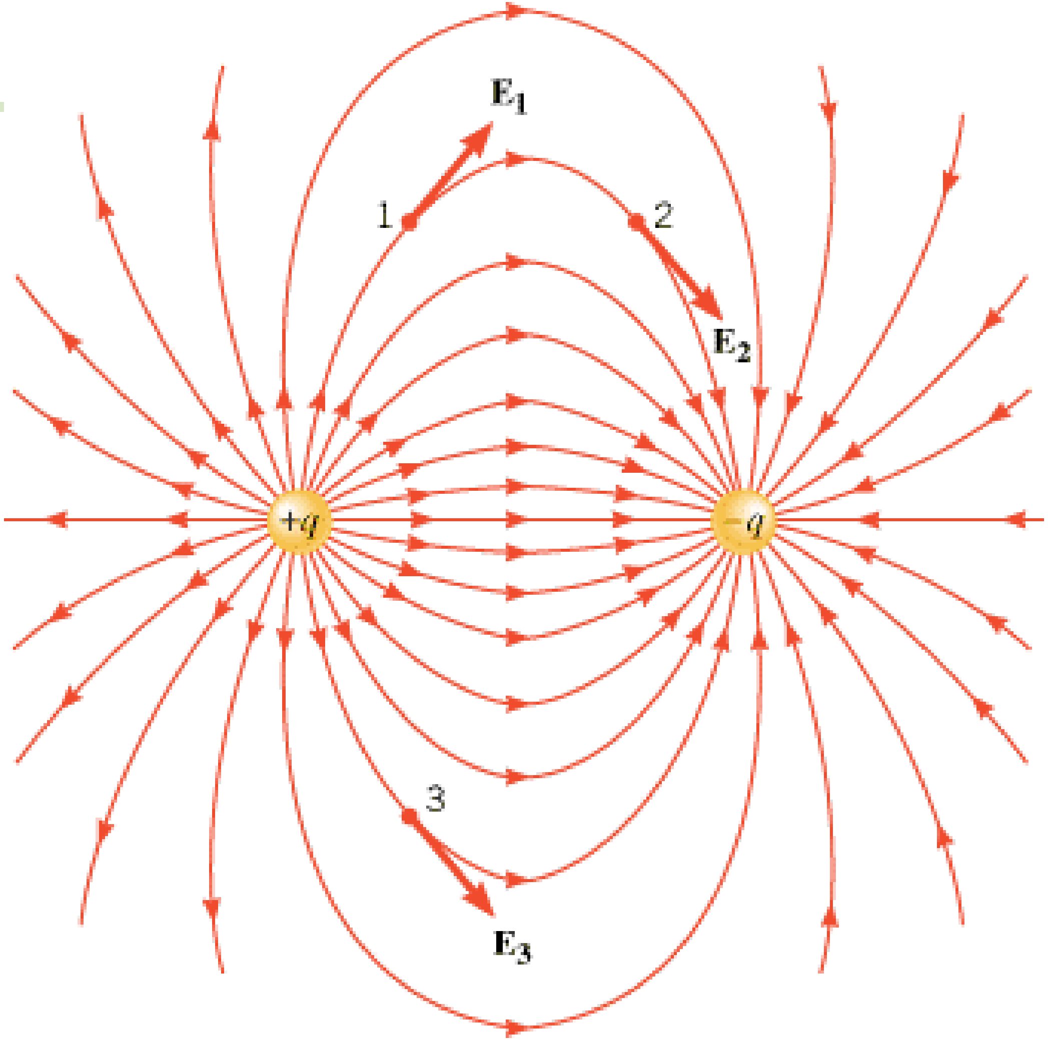
Magnitude?

Electric field line

1 positive and 1 negative charges (dipole)

Direction of E ?

Tangential
to
the field line

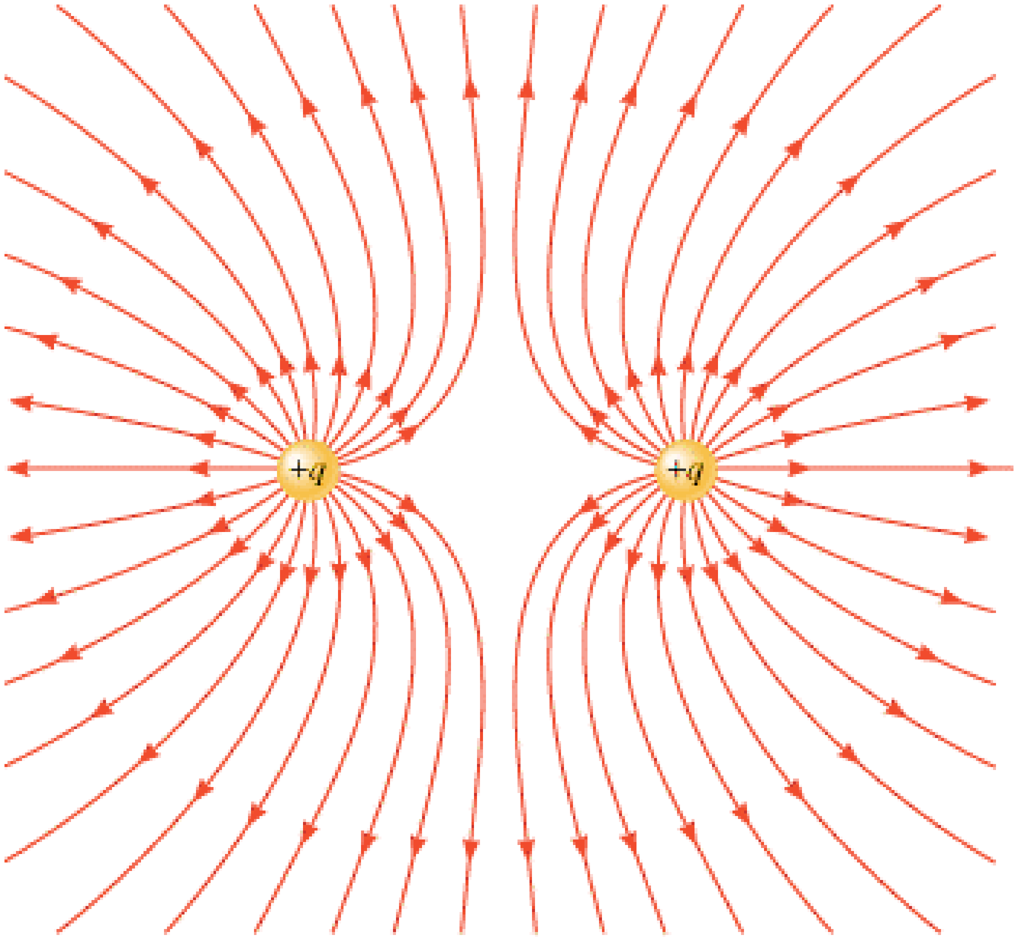


Electric field line

Electric field lines

never cross

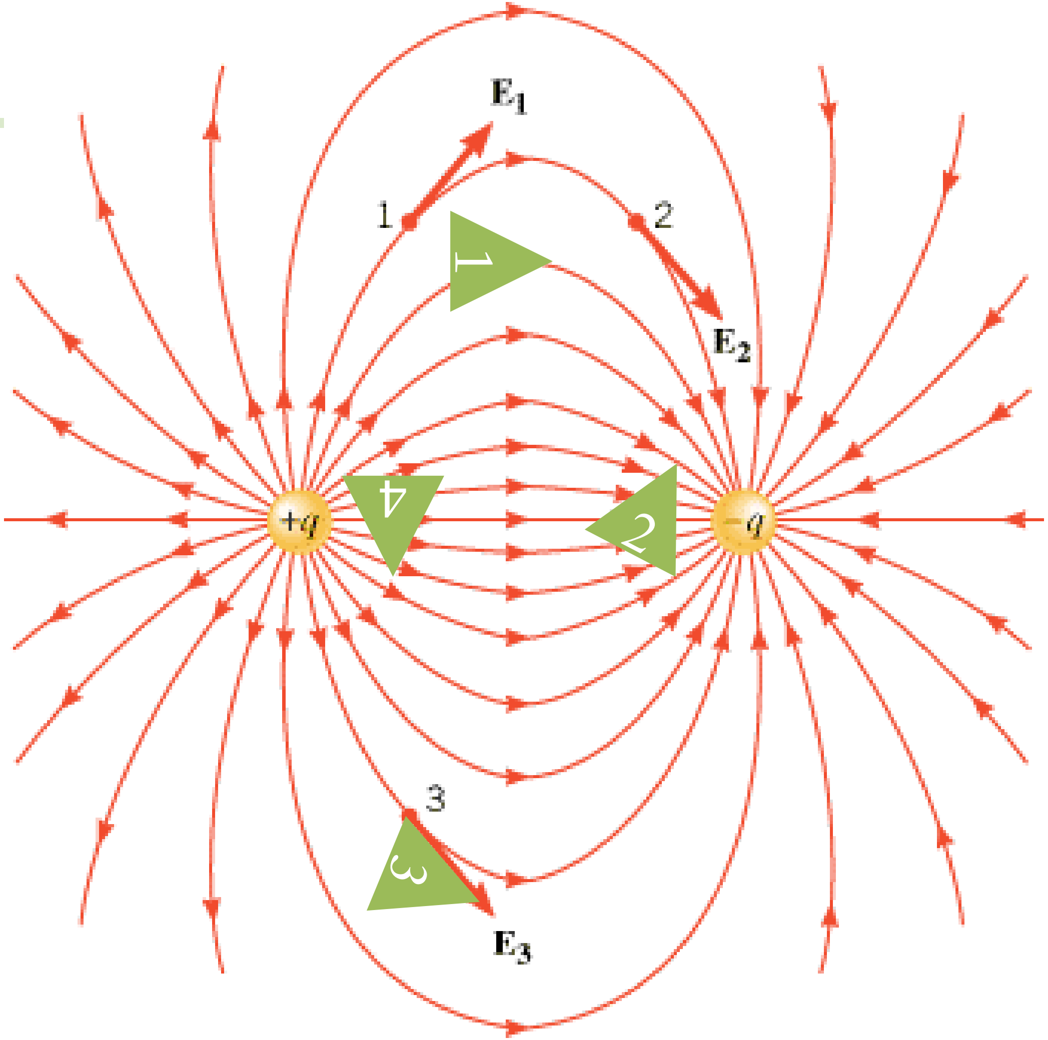
each other !



Electric field line

Characteristics:

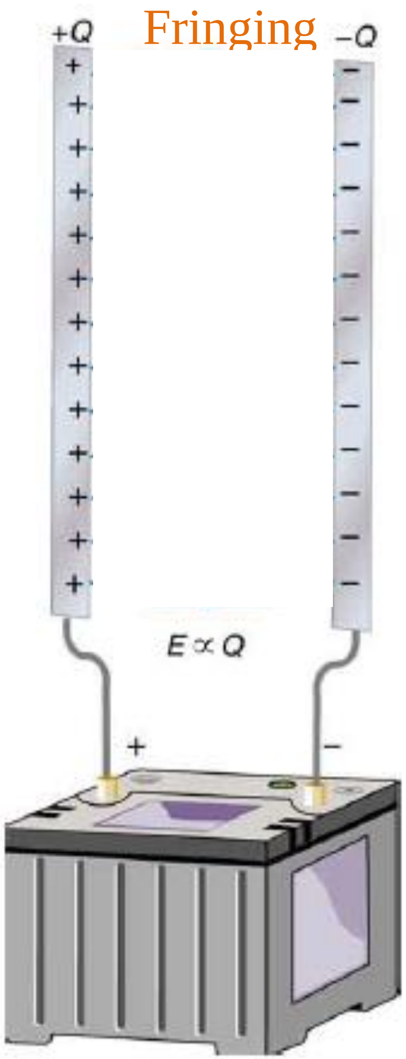
1. Direction
2. Magnitude
3. Direction of *E*
4. Never cross



Electric field line

Nearly uniform field

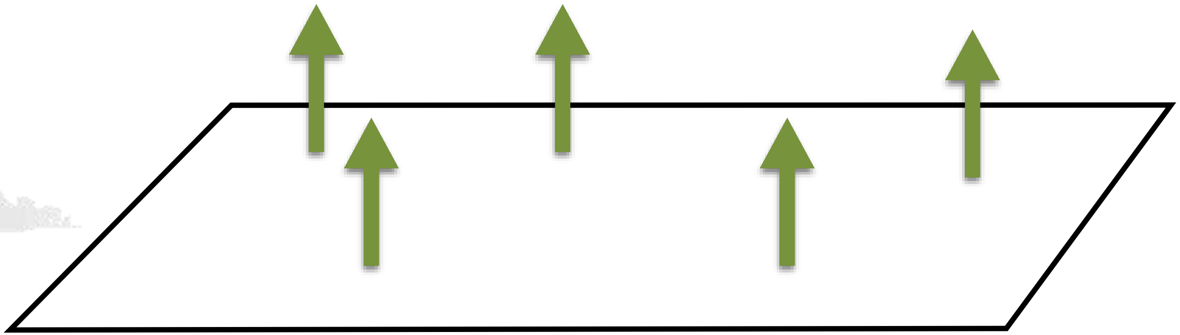
between parallel plates



Electric field from an infinite charged plate

with a uniform surface density of charge $\boldsymbol{\sigma}$:

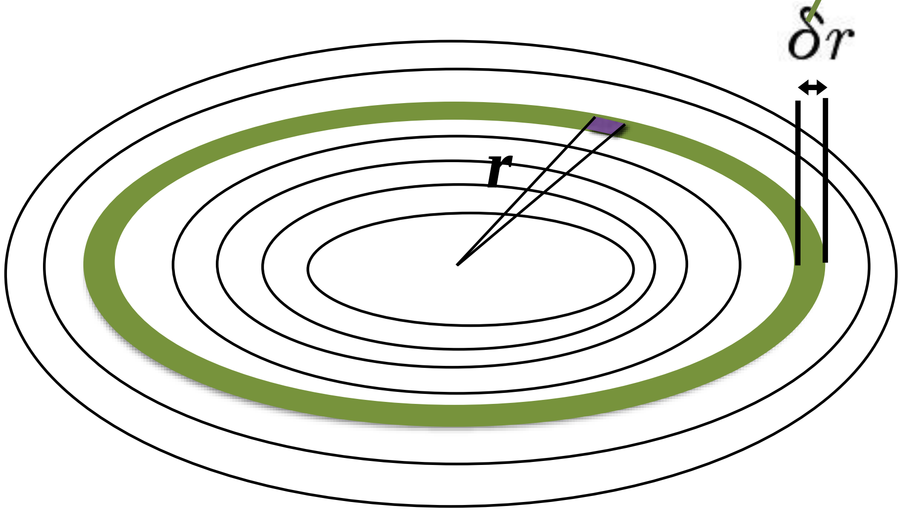
$$E_{plate} = \text{PREDICT}$$

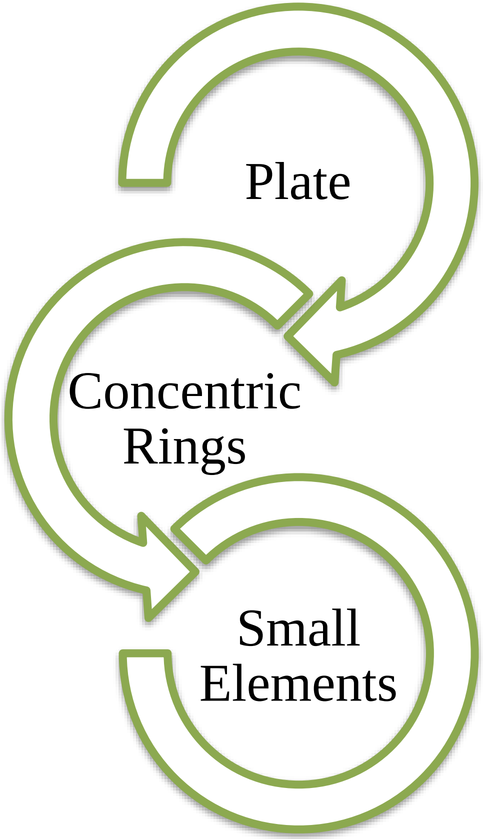


Electric field from an infinite charged plate

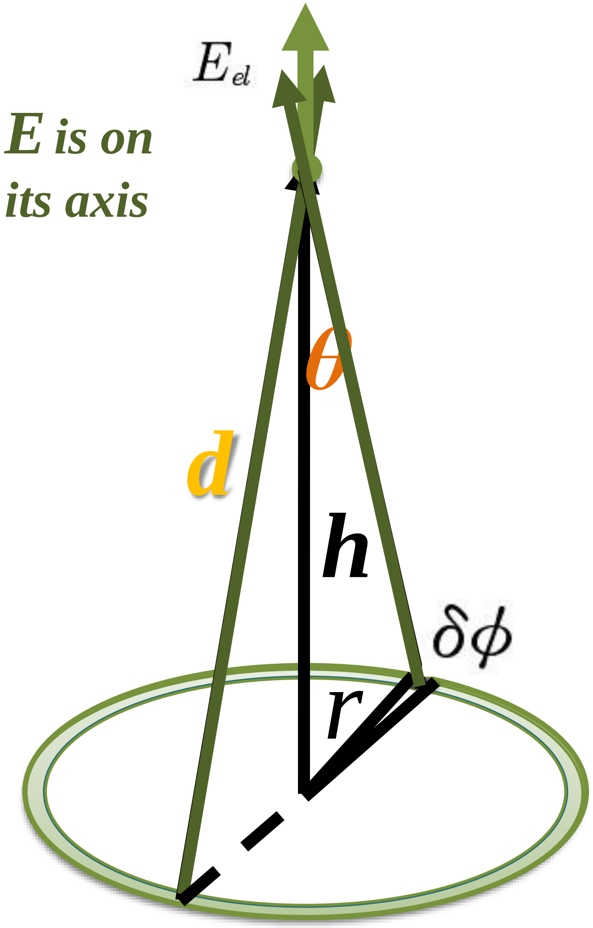
With equal width

From r = 0 to infinity





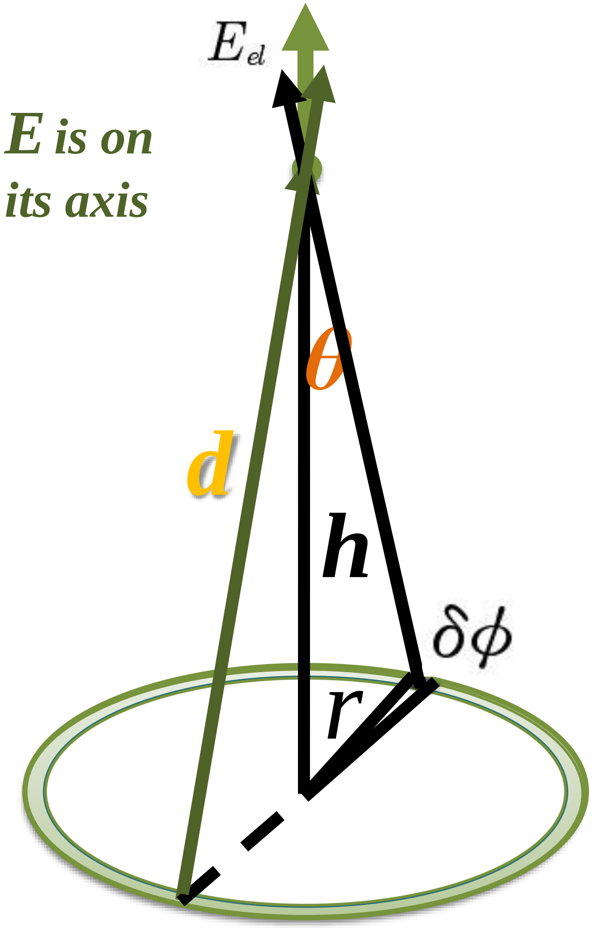
Electric field from a uniformly charged ring



Surface charge density $\boldsymbol{\sigma = Q/A}$

- divide the circle into small elements
- Direction of electric field of the small elements?
- Direction of total E?

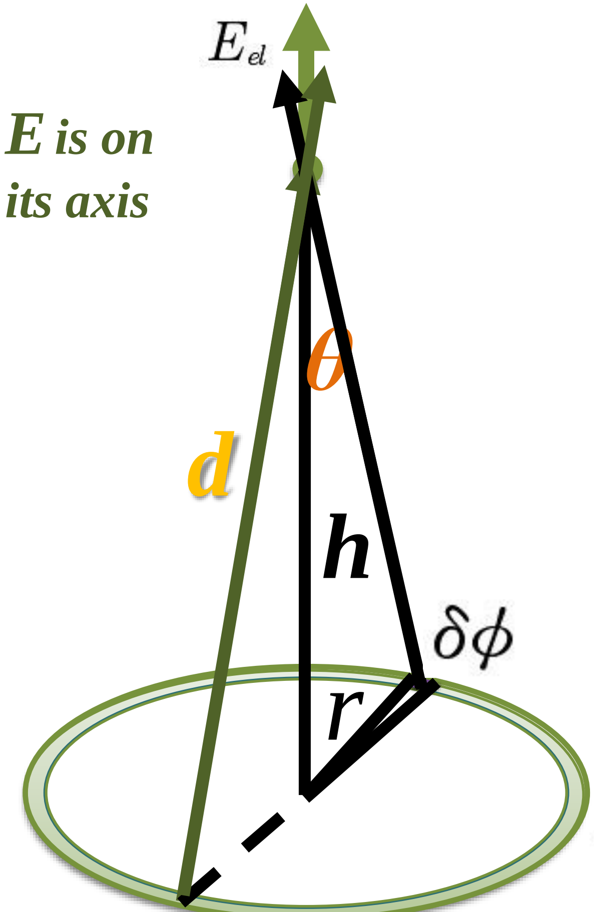
Electric field from a uniformly charged ring



Surface charge density $\boldsymbol{\sigma = Q/A}$

- divide the circle into small elements
- the *horizontal* components from elements on opposite sides of the circle cancel out
- all the small elements give a same amount of electric field in the *vertical* direction

Electric field from a uniformly charged ring



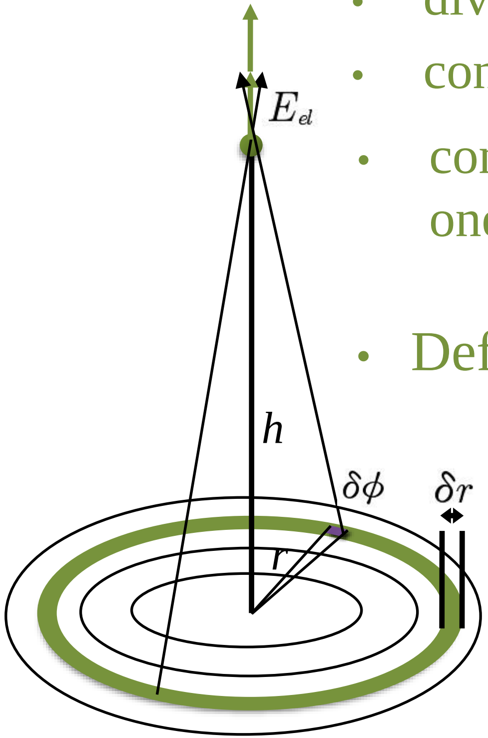
- area of each element: $A_{el} = r\delta\phi\ \delta r$
- charge of each element: $Q_{el} = \sigma r\delta\phi\ \delta r$
- number of elements in a circle: $\dfrac{2\pi r}{r\delta\phi} = \dfrac{2\pi}{\delta\phi}$
- field from one element:

$$E_{el} = \frac{Q_{el}}{4\pi\varepsilon_0 d^2}\cos\theta = \frac{\sigma r\delta\phi\,\delta r\cos\theta}{4\pi\varepsilon_0 d^2}$$

- total field from the circle

$$E_{tot}(r) = \frac{2\pi}{\delta\phi}\frac{\sigma r\delta\phi\ \delta r}{4\pi\varepsilon_0 d^2}\cos\theta = \frac{\sigma r\,h\,\delta r}{2\varepsilon_0(r^2+h^2)^{3/2}}$$

Electric field from an infinite charged plate



- divide the plane into *concentric rings* with equal width
- contributions from rings, from *r* = 0 to infinity
- contribution from one ring (*r*):

$$E_{tot}(r) = \frac{2\pi}{\delta\phi}\frac{\sigma r\delta\phi\ \delta r}{4\pi\varepsilon_0 d^2}\cos\theta = \frac{\sigma r\, h\, \delta r}{2\varepsilon_0 (r^2 + h^2)^{3/2}}$$

- Define a new variable *x* :

$$x = \frac{r}{h} \qquad \delta x = \frac{\delta r}{h}$$

$$E_{tot}(r) = \frac{\sigma\left(\frac{r}{h}\right)\left(\frac{\delta r}{h}\right)}{2\varepsilon_0\left(\left(\frac{r}{h}\right)^2 + 1\right)^{3/2}}$$

- Field from charges at radius *r* = *hx*

$$E_{tot}(x) = \frac{\sigma\, x\, \delta x}{2\varepsilon_0 (x^2 + 1)^{3/2}}$$

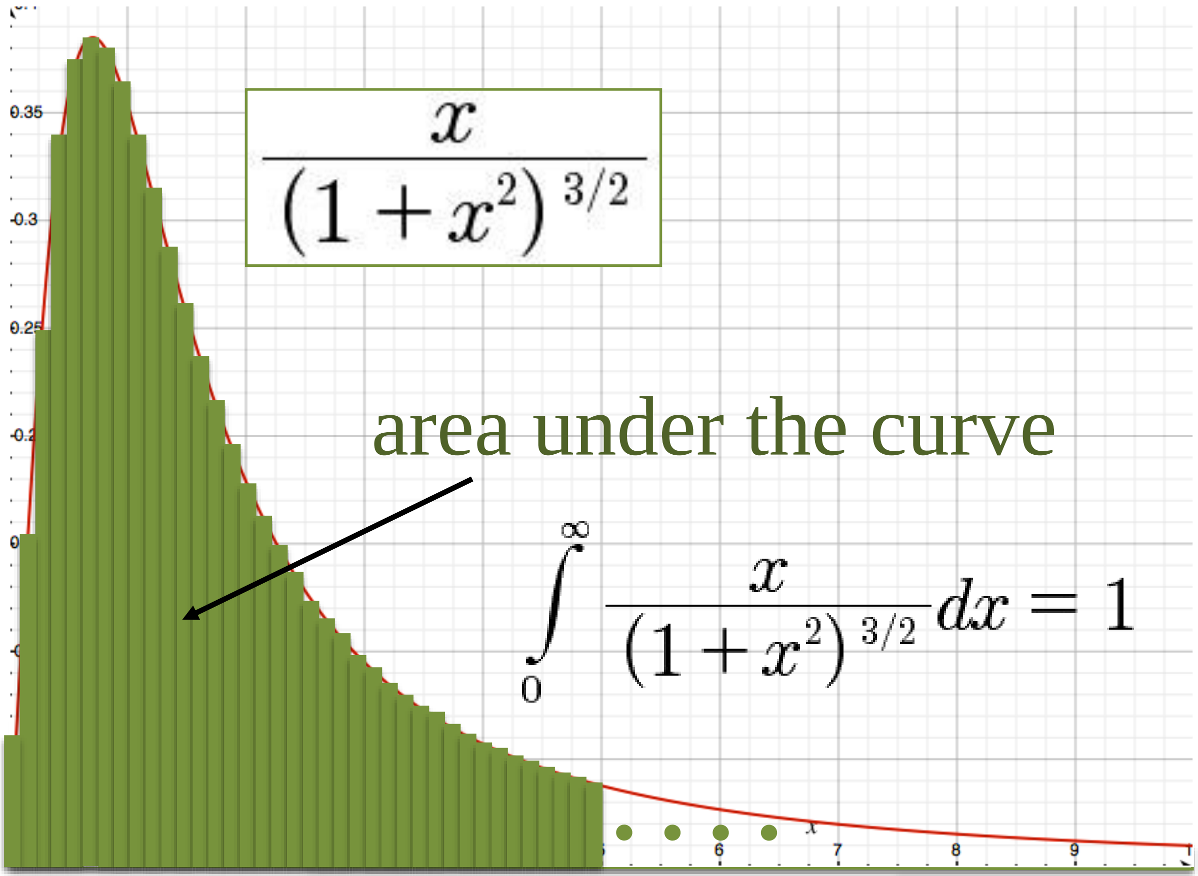
Electric field from an infinite charged plate

Add all Fields from

$x = 0$ to $x = \infty$

$$E_{plate} = \frac{\sigma}{2\varepsilon_0}\int_0^{\infty} \frac{x}{(1+x^2)^{3/2}}\,dx$$

$$\boxed{E_{plate} = \frac{\sigma}{2\varepsilon_0}}$$



$$\boxed{\frac{x}{(1+x^2)^{3/2}}}$$

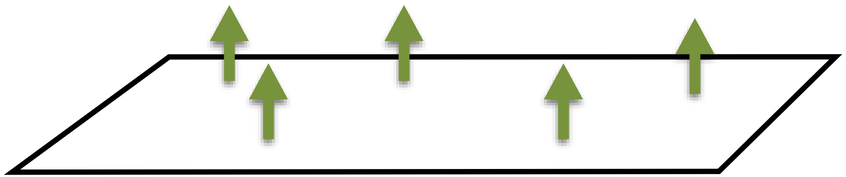
area under the curve

$$\int_0^{\infty} \frac{x}{(1+x^2)^{3/2}}\,dx = 1$$

Electric field from an infinite charged plate

with a uniform surface density of charge $\boldsymbol{\sigma}$:

$$E_{plate} = \frac{\sigma}{2\varepsilon_0}$$



Direction	Up/down	Distance
vertical	depend on the charge	indep-endent

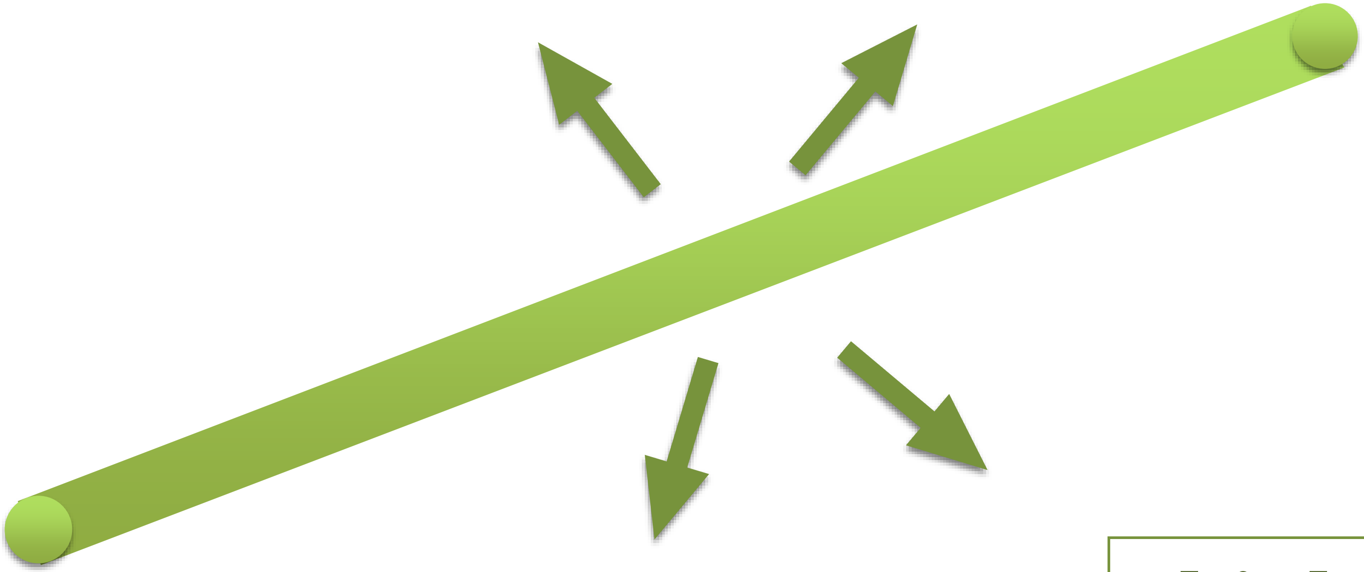
- **But of course, no plate can be infinite**
- **This is only an approximation**

Plate is large

or

Close to the plate

Electric field from an infinite charged wire



Think about it!

Gravitational field

Definition: Force per unit mass

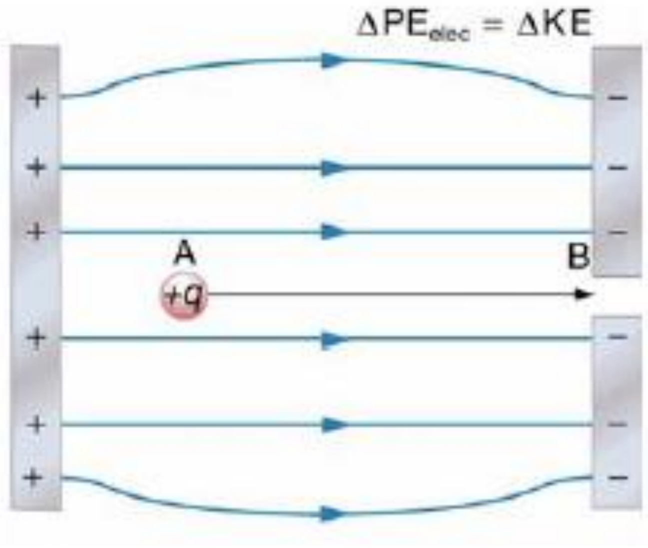
Magnitude above Earth surface:

$$GM_E/r^2$$

At the earth surface, magnitude

$$g = GM_E/r^2$$

Charge accelerated in an electric field



Potential Energy U

Charge accelerated in an electric field

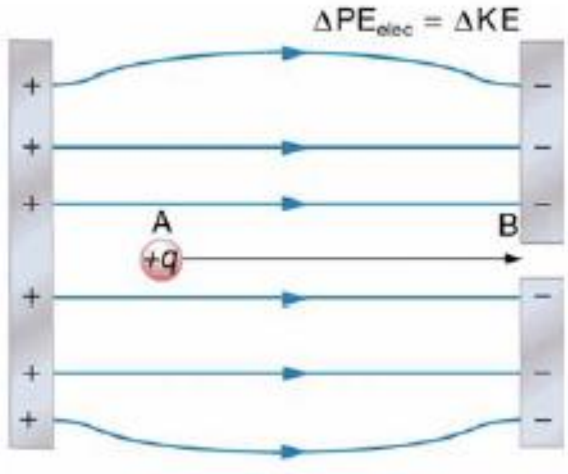
In a gravitational field.

Potential Energy

$$\Delta KE = -\Delta PE = Work$$

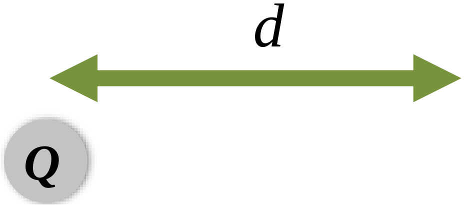
The electrostatic force is a conservative force

Corresponding potential energy



Potential energy of a charge

Zero potential - infinitely far away



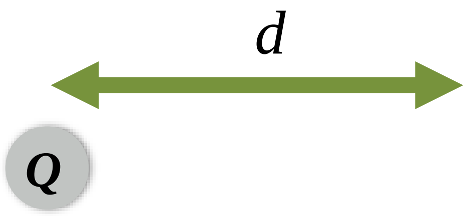
$$v = 0$$

Change in potential energy = - work done

$$W = Fx = -\Delta U$$

Potential energy of a charge

$$W = F\,x$$



Potential energy of a charge

$$W = F\,x$$

F depends on *x*

Potential energy of a charge

For each small interval : $\Delta W = F(x)\,\Delta x$

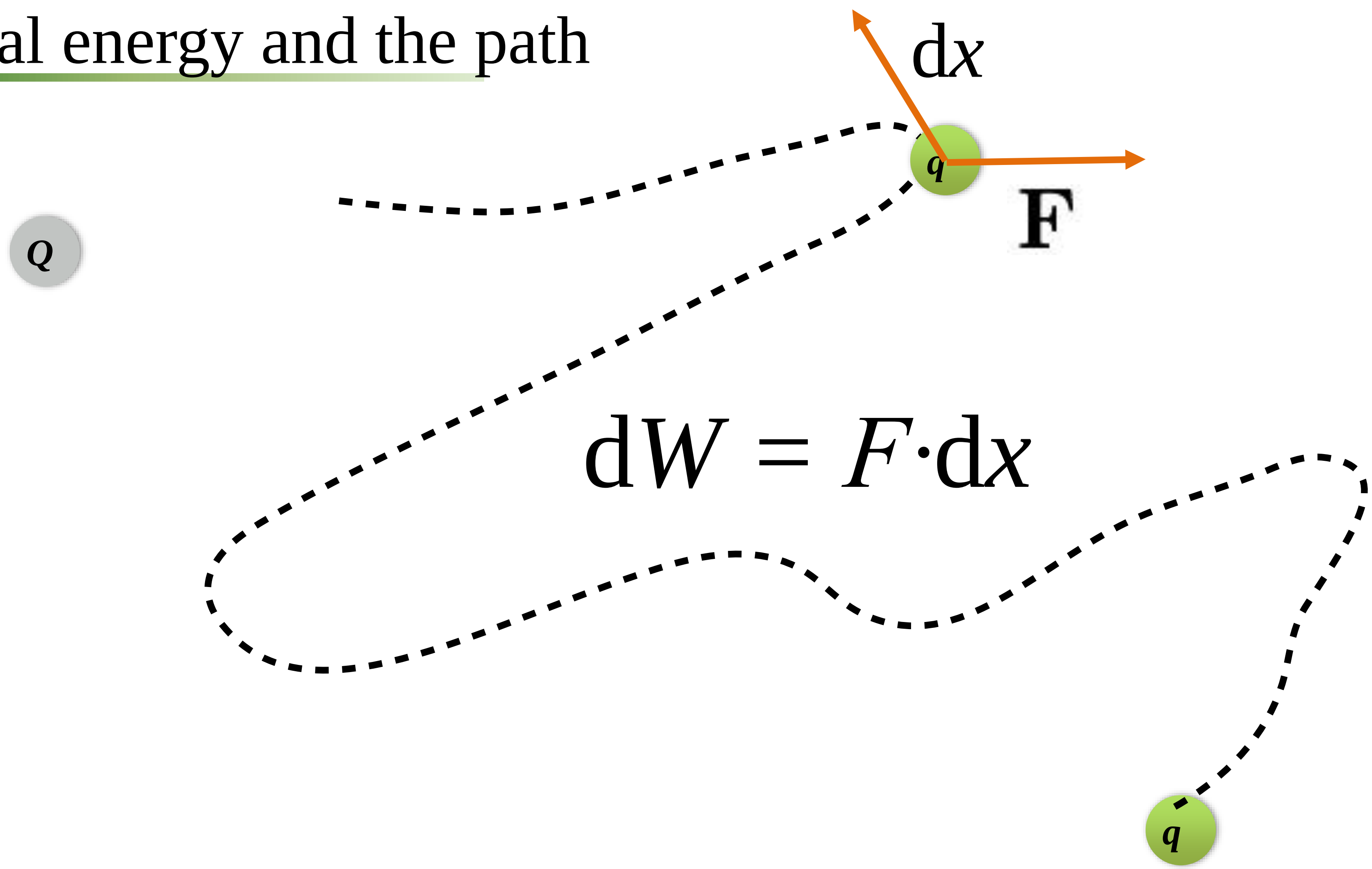
The total work is the sum of all those small intervals: $W = \int_{\infty}^{d} F(x)\,dx$

$$F(x) = \frac{Qq}{4\pi\varepsilon_0 x^2} \Longrightarrow W = \frac{Qq}{4\pi\varepsilon_0}\int_{\infty}^{d} \frac{1}{x^2}\,dx = \frac{Qq}{4\pi\varepsilon_0}\left[\frac{-1}{x}\right]_{\infty}^{d} = \frac{-Qq}{4\pi\varepsilon_0 d} + 0$$

So the potential energy is: $\boxed{U = \frac{Qq}{4\pi\varepsilon_0 d}}$

path?

Potential energy and the path



$$dW = F \cdot dx$$

Potential energy and the path

Always radial

r

$r\mathrm{d}\theta$

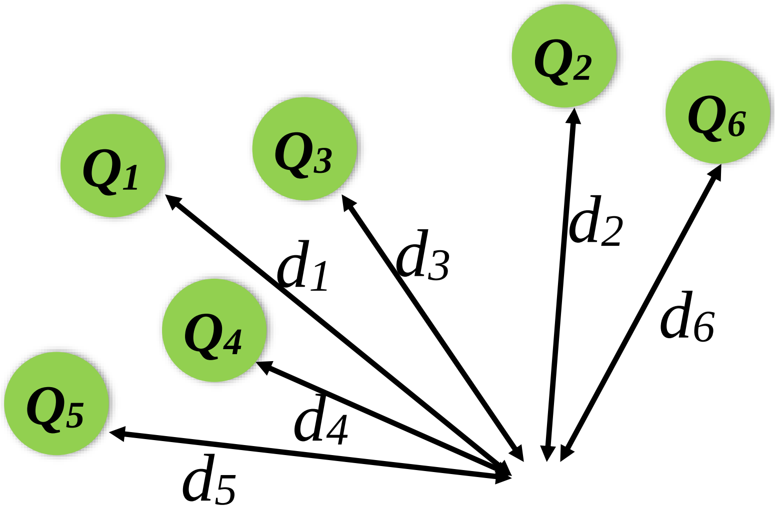
d

$$W = \int^{X} F \cdot \mathrm{d}r$$

W only depends on movement in the radial direction

So the work does not depend on the path!

U and multiple charges



Total U is the sum of potential energy due to all charges

$$U = \sum_{i=1}^{6} \frac{Q_i q}{4\pi\varepsilon_0 d_i}$$

- Potential energy is always proportional to *q*
- Define: $$V = \frac{U}{q} = \sum_{i=1}^{6} \frac{Q_i}{4\pi\varepsilon_0 d_i}$$

***V* is the "potential"**

Electric potential

$$V = \frac{U}{q}$$

V is the ‘**electric potential**’, or just ‘**potential**’

Change in potential between points A and B is:

$$\Delta V = V_B - V_A = \frac{\Delta U_{BA}}{q}$$

(Joules/Coulomb = Volt)

also called “Voltage”

Example

$V = ?$ $\quad Q$ = -3 nC

$$V = \frac{U}{q}$$

$$U = \frac{kQq}{r}$$

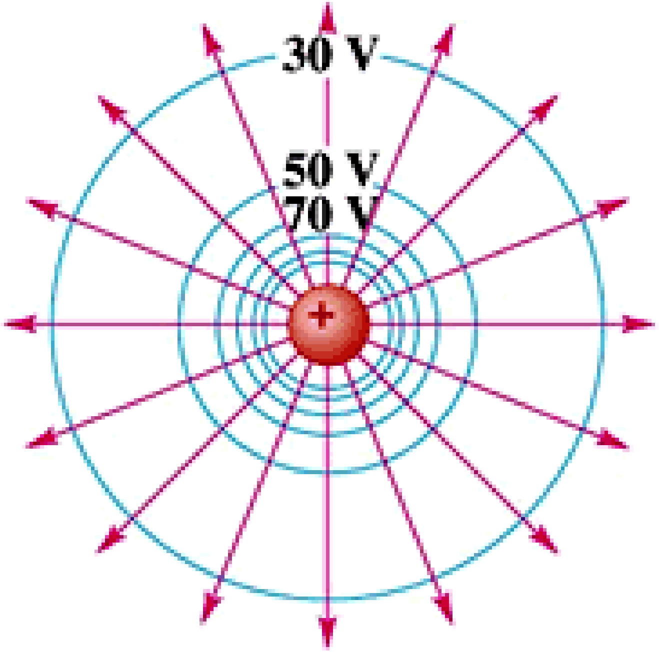
$$V = \frac{kQ}{r} = \frac{(9.0 * 10^{9}\ \mathrm{Nm^2/C^2})(-3 * 10^{-9}\ \mathrm{C})}{0.05\ \mathrm{m}} = -539\ \mathrm{V}$$

Equipotential lines

$$V = \frac{kQ}{r}$$

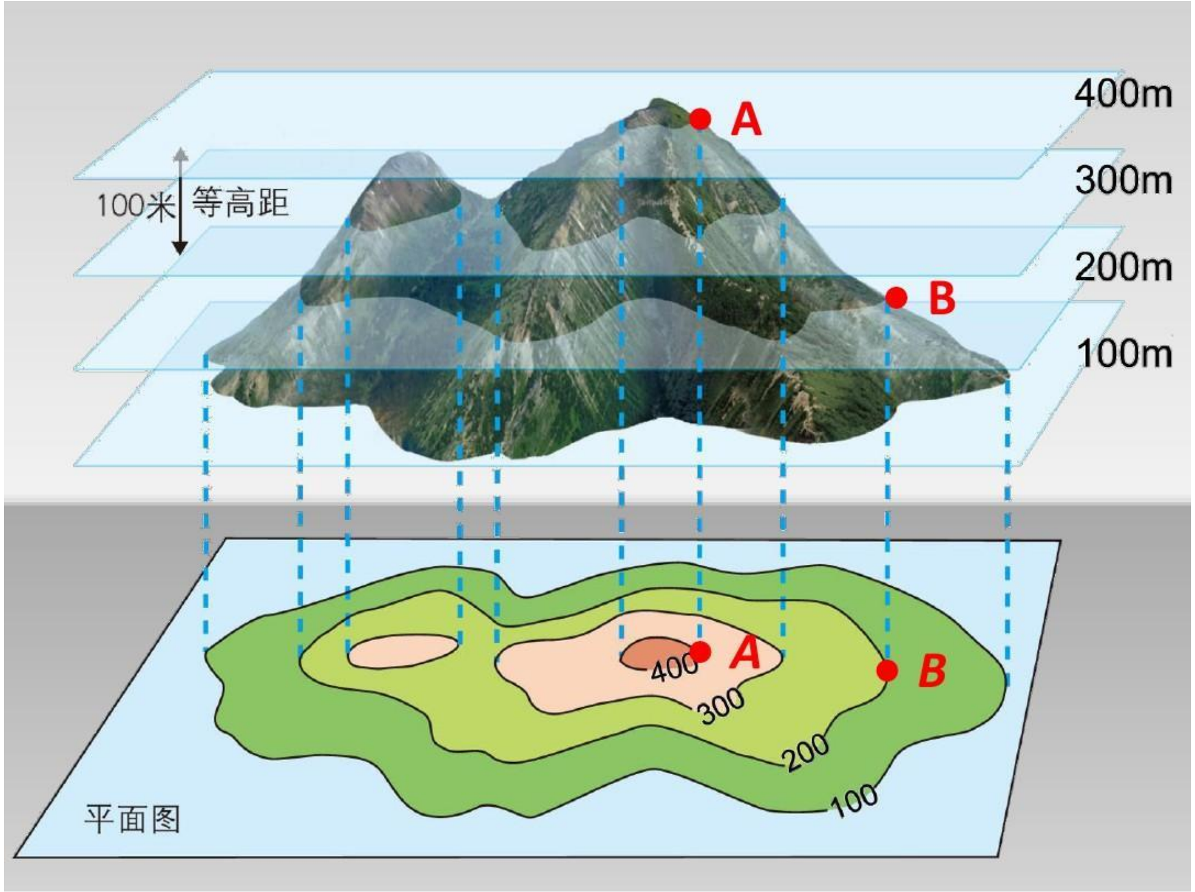
Potential at distance '*r*' from a point charge is the same

We can draw "**equipotential lines**" where potential is the same

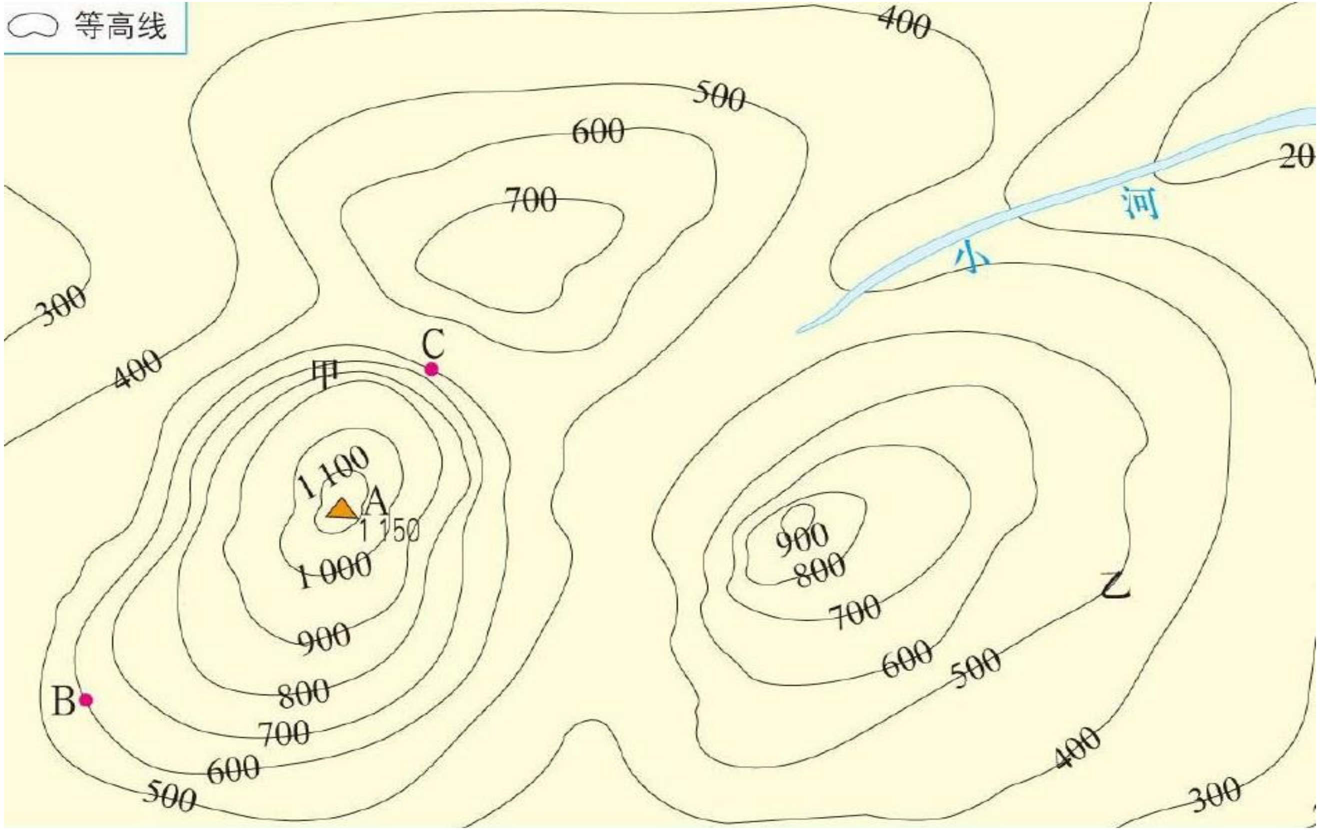


Equipotential lines/surfaces are **perpendicular** to *Electric Field lines*

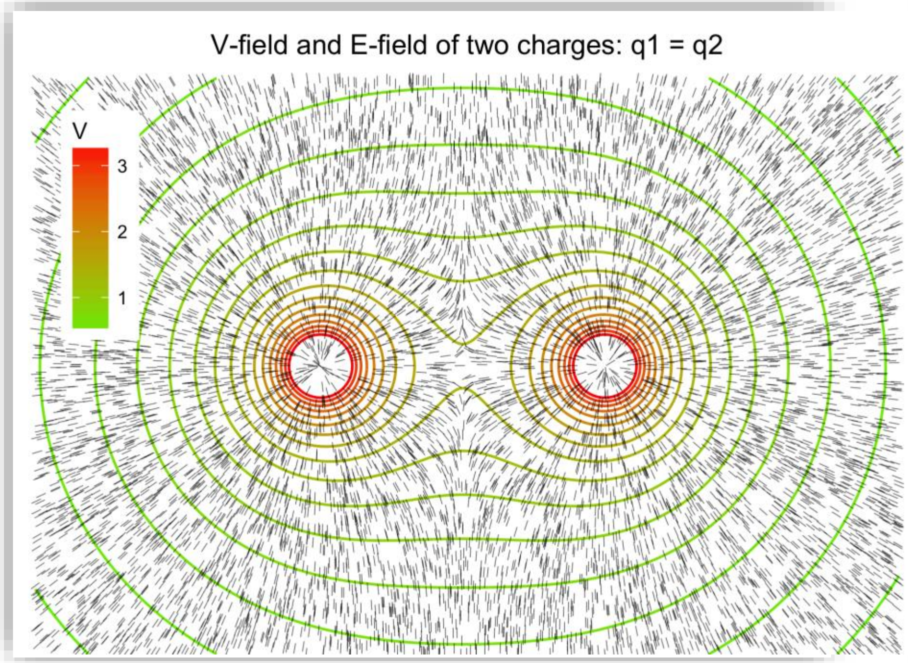
Equipotential lines

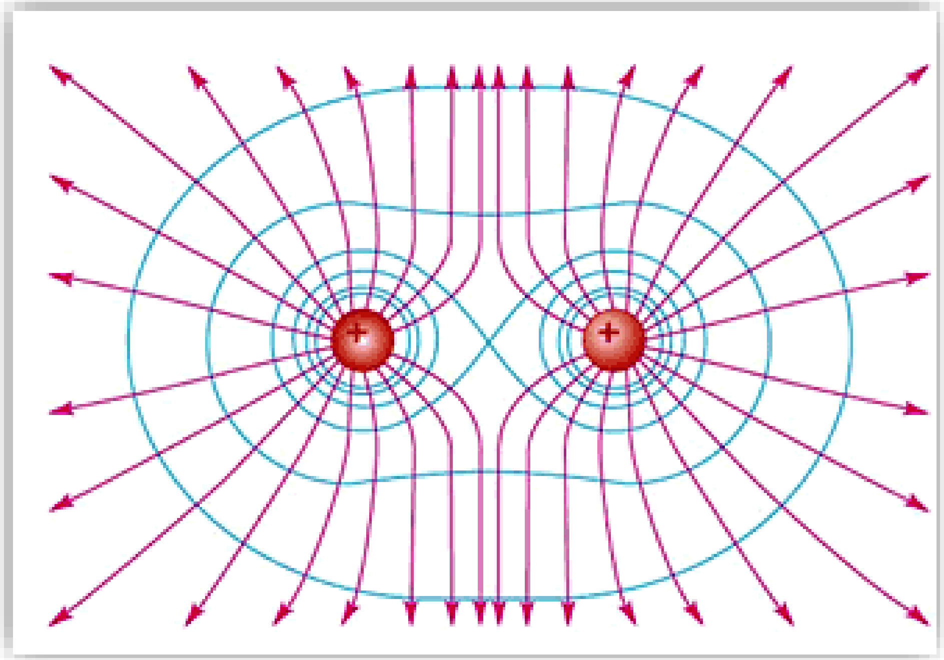


Equipotential lines

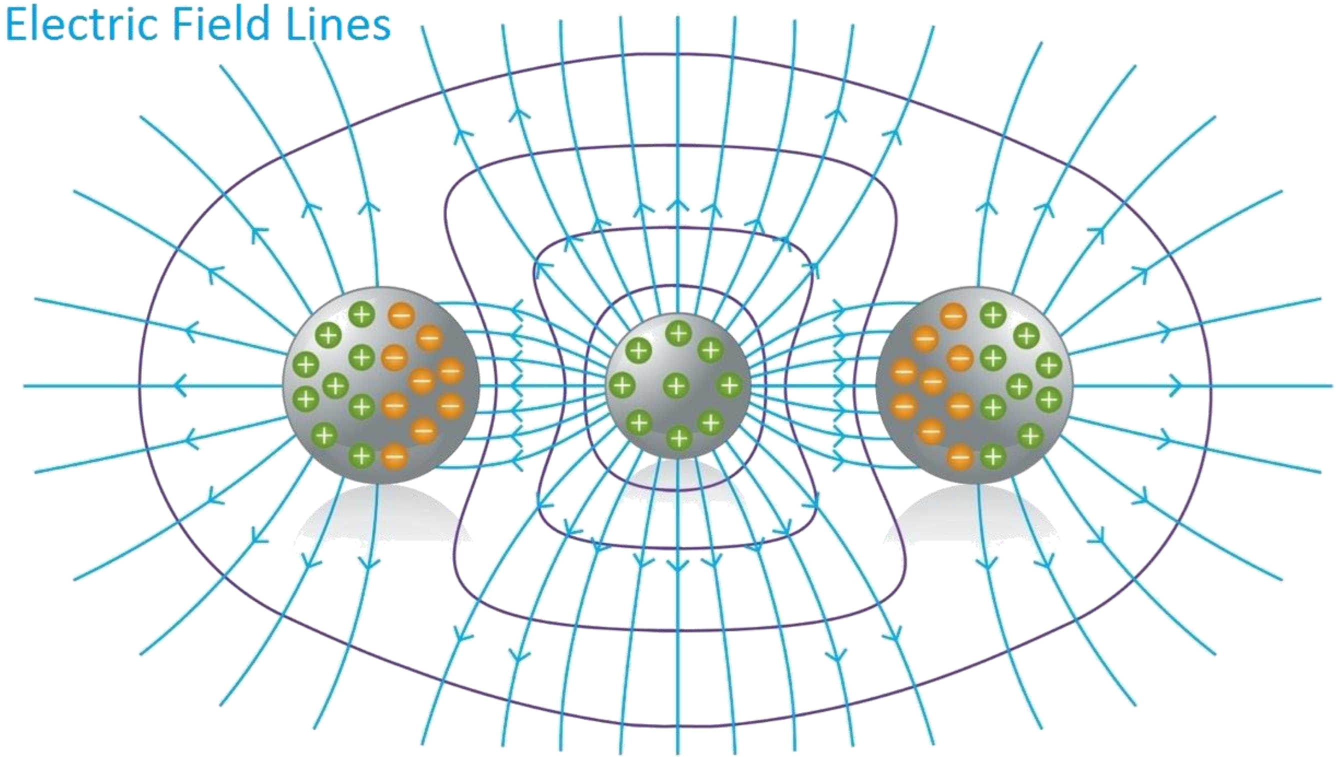


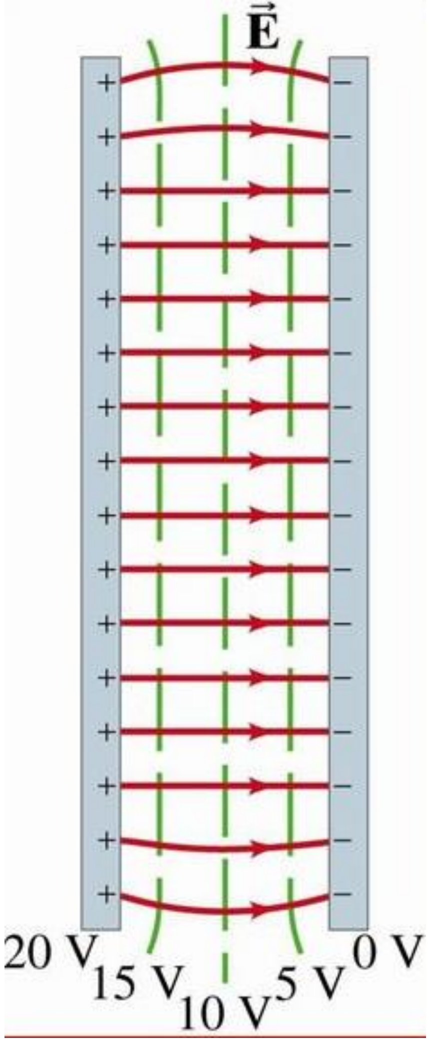
Equipotential lines





Equipotential lines

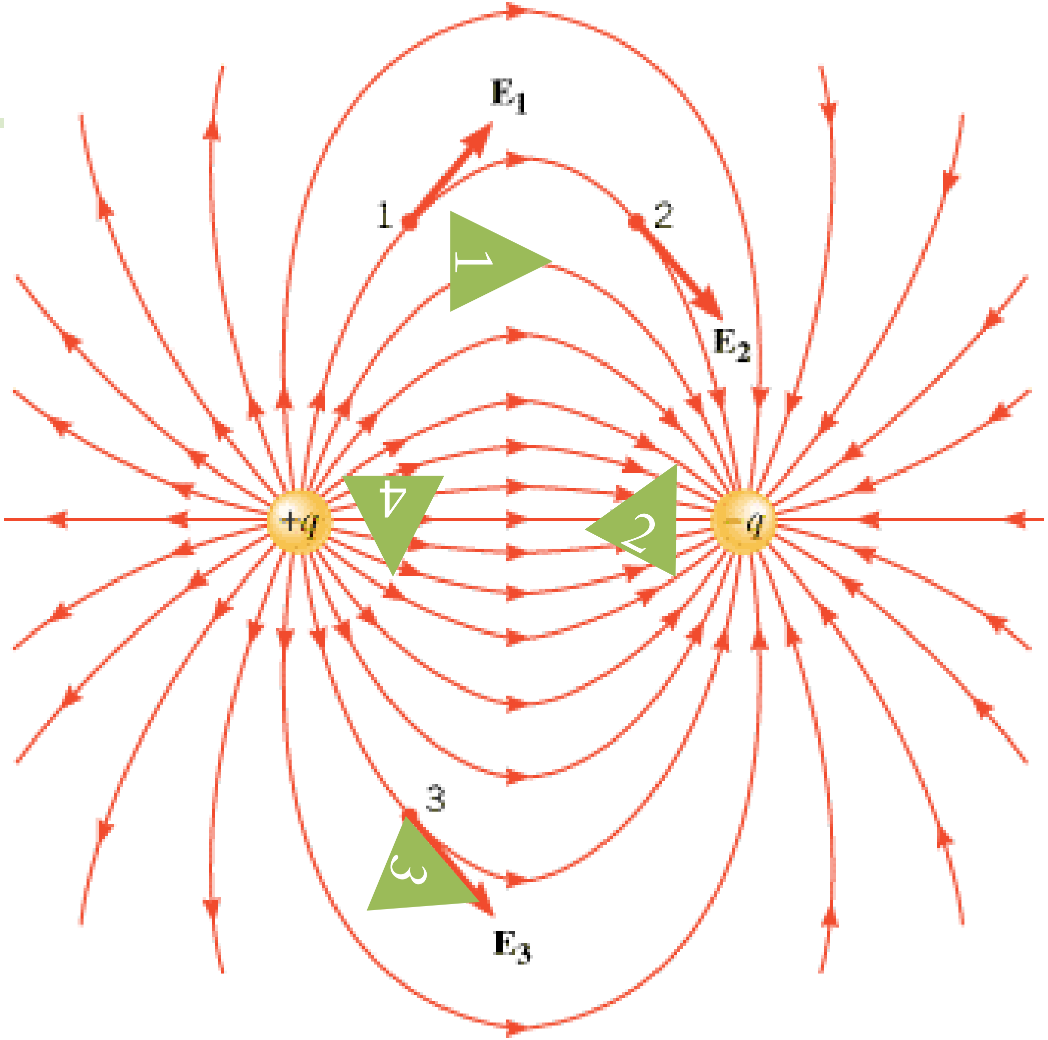




Electric field line

Characteristics:

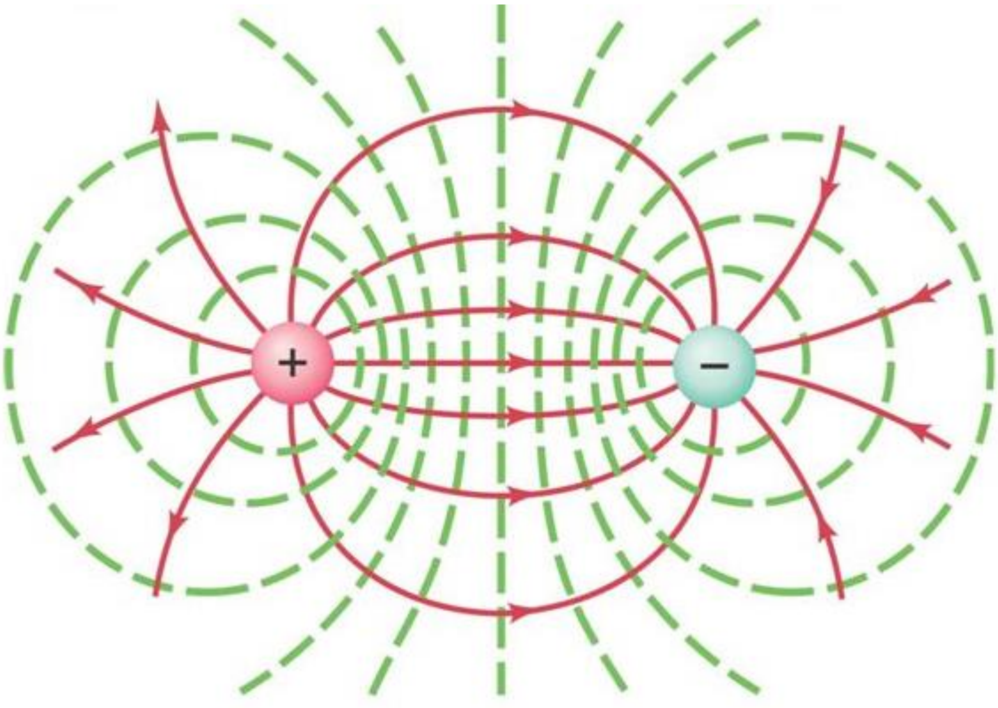
1. Direction
2. Magnitude
3. Direction of *E*
4. Never cross



Equipotential lines

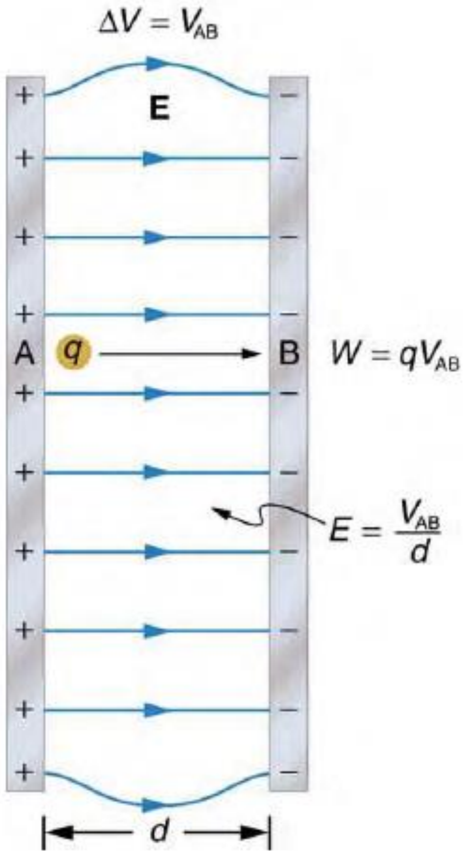
Characteristics:

1. Direction to E
2. Shape
3. Shortest way



Similar in the Gravitational potential lines/Conservation of mechanical Energy

V and E



How to relate potential to electric field?

In a constant electric field

$$W = qV_{AB} = F_E\, d = qEd$$

$$E = \frac{V_{AB}}{d} \qquad 1\,\mathrm{N/C} = 1\,\mathrm{V/m}$$

In general

$$E = -\frac{dV}{dr} \quad \text{or} \quad \vec{E} = -\nabla V \quad \boxed{\textbf{\textit{gradient}}}$$

Example

Four identical point charges are arranged at the corners of a square [*Hint*: Draw a figure]. The electric field E and potential V at the center of the square are

(a) $E = 0,\ V = 0.$

(b) $E = 0,\ V \neq 0.$

(c) $E \neq 0,\ V \neq 0.$

(d) $E \neq 0,\ V = 0.$

(e) $E = V$ regardless of the value.

Example

Which of the following statements is valid?

(a) If the potential at a particular point is zero, the field at that point must be zero.

(b) If the field at a particular point is zero, the potential at that point must be zero.

(c) If the field throughout a particular region is constant, the potential throughout that region must be zero.

(d) If the potential throughout a particular region is constant, the field throughout that region must be zero.

Example

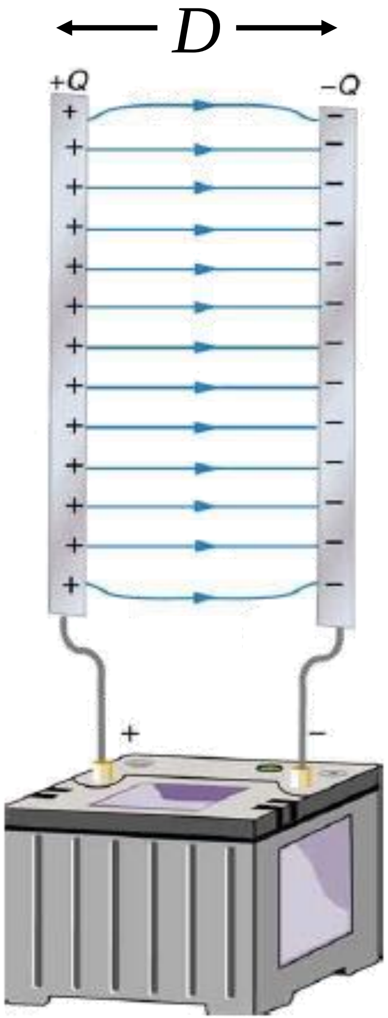
Parallel metal plates charged by a constant voltage source.

What is the charge on the plate(s) ?

Voltage of the battery = potential difference

Distance between plates - D

Surface area of plates - A



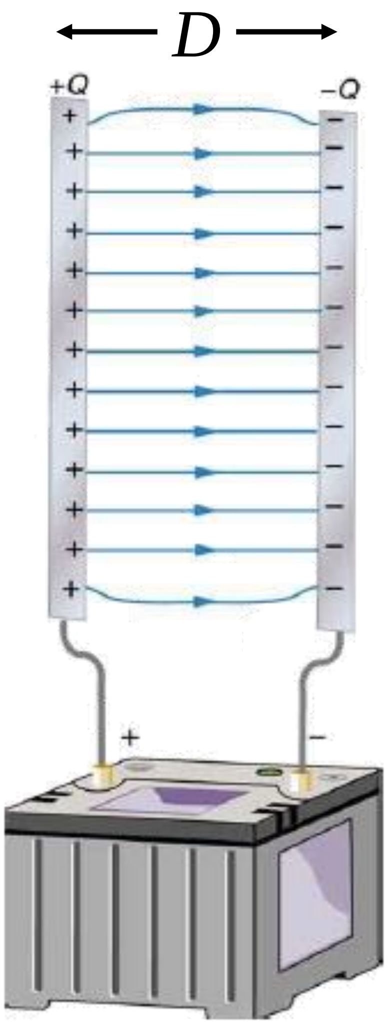
Example

Parallel metal plates charged by a constant voltage source.

What is the charge on the plate(s) ?

ΔV	E	σ	**Q**
Potential difference	Electric field	surface charge density	

$$E_{plate} = \frac{\sigma}{2\varepsilon_0}$$



Example

8. Which of the following do not affect capacitance?

(*a*) Area of the plates.
(*b*) Separation of the plates.
(*c*) Material between the plates.
(*d*) Charge on the plates.
(*e*) Energy stored in the capacitor.

Week 1

Electrostatics				***Equilibrium System*** **(electrostatic, no current!)**	
Electric charge	Electric force	Electric field	Electric Potential	**Conductor in Electric field**	**non-conductor in Electric field**
Q	F	E	V		**Dielectrics**