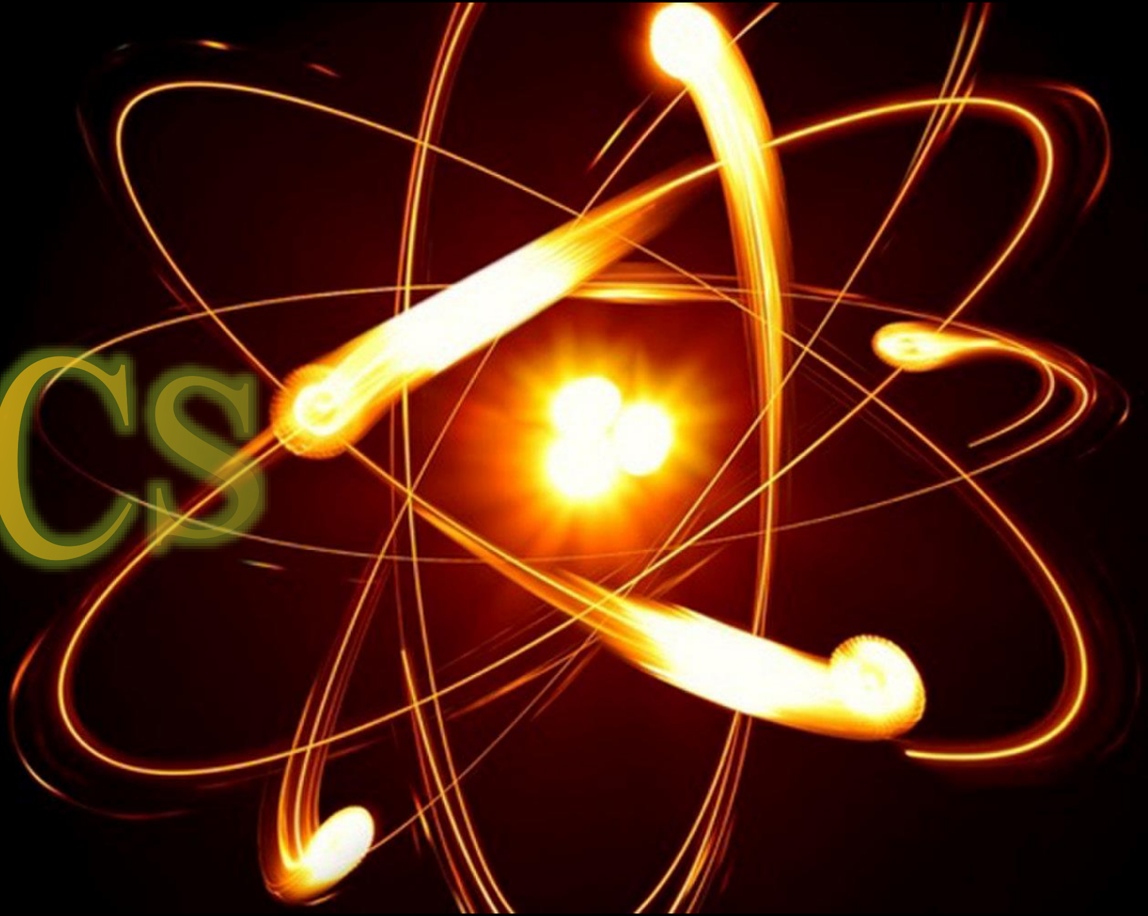
PHYSICS



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

Week 2 – Electrostatics

2023.9

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TRY TO RECALL

What have we learned LAST WEEK ?

- 1.
- 2.
- 3.

Is there anything that we still need to spend more time to get understood?

- 1.
- 2.

What are we going to do after the lecture?

TRY TO RECALL

What is the equation for the electric field?

Where does the charge go after rubbing?

Is electric field a scalar or vector?

What is the electric field inside a capacitor?

What are the four characteristics of the electric field lines?

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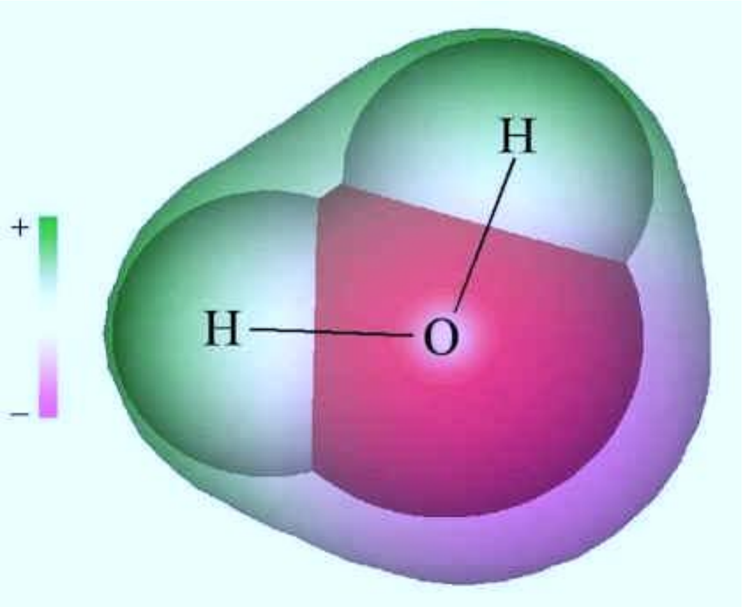
OUTLINE

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

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.

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?

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

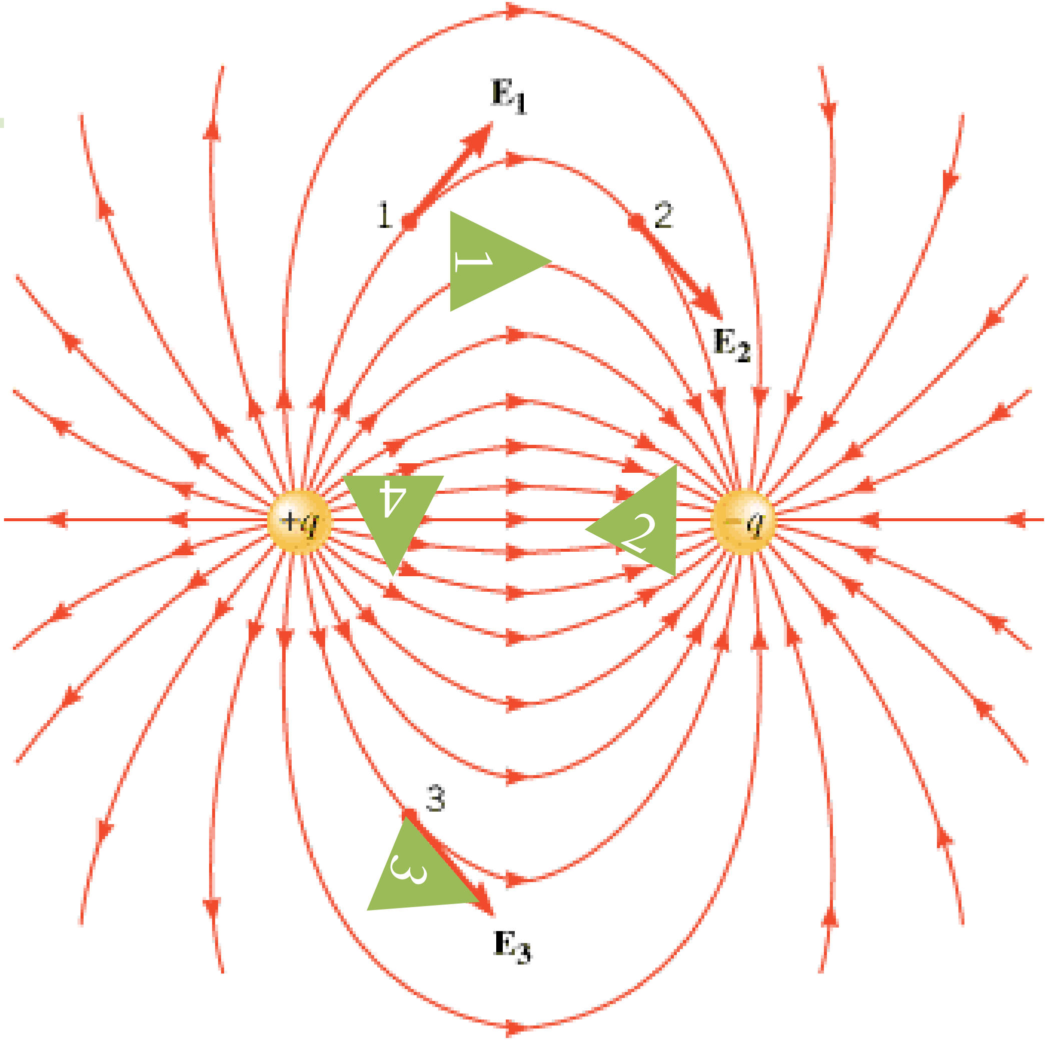
$$\varepsilon_0 = 8.85 * 10^{-12}\ \mathrm{C}^2/(\mathrm{N\ m}^2)$$

(Permittivity of free space)

Electric field line

Characteristics:

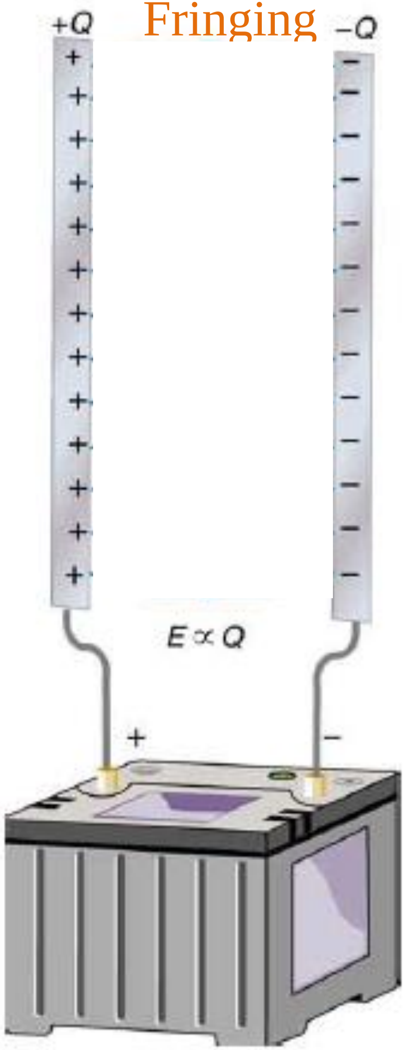
1. Direction
2. Magnitude
3. Direction of *E*
4. Never cross



Electric field line

Nearly uniform field

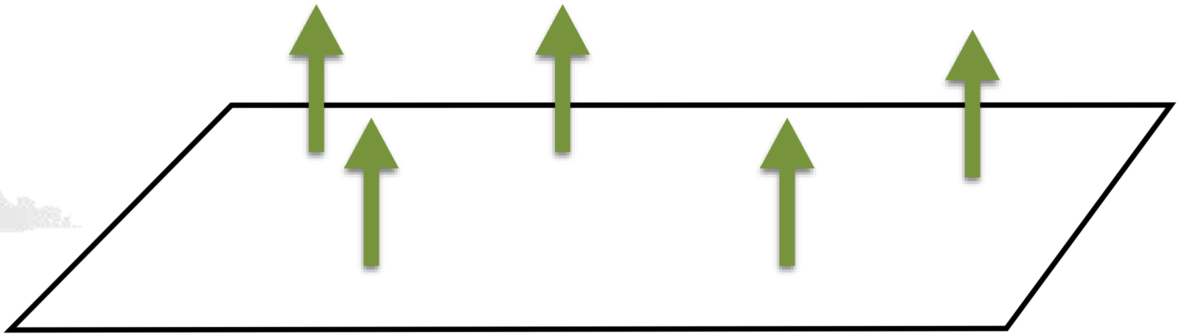
between parallel plates



Electric field from an infinite charged plate

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

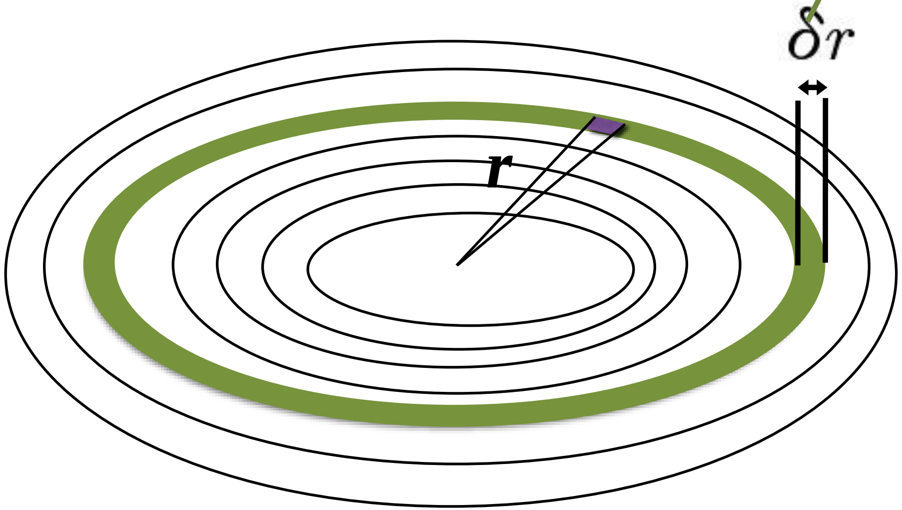
$$E_{plate} = \text{PREDICT}$$

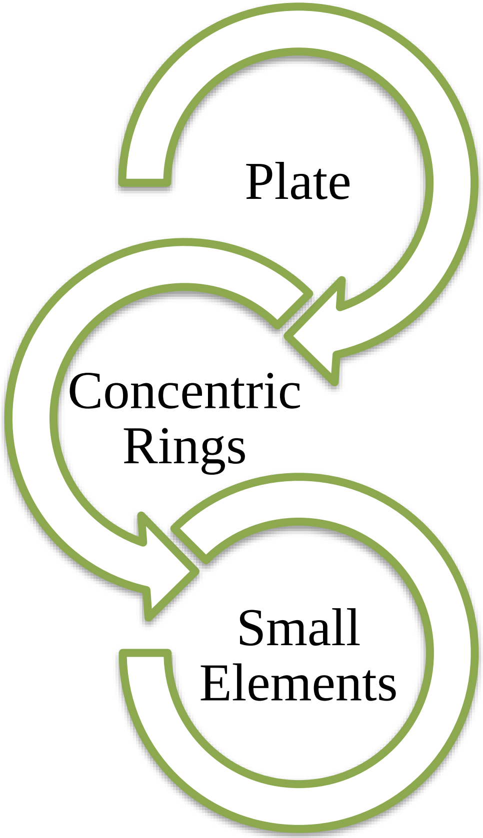


Electric field from an infinite charged plate

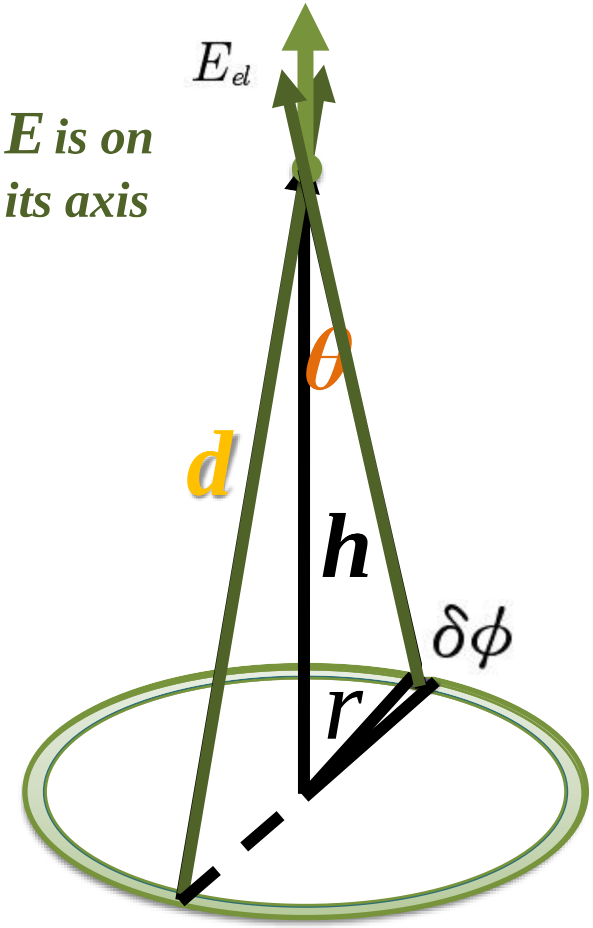
With equal width

From r = 0 to infinity





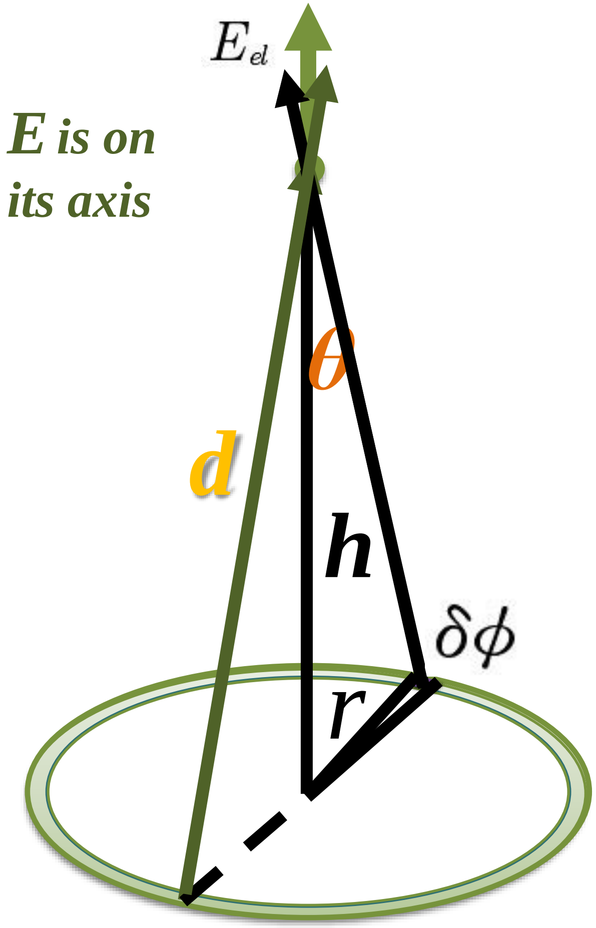
Electric field from a uniformly charged ring



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?

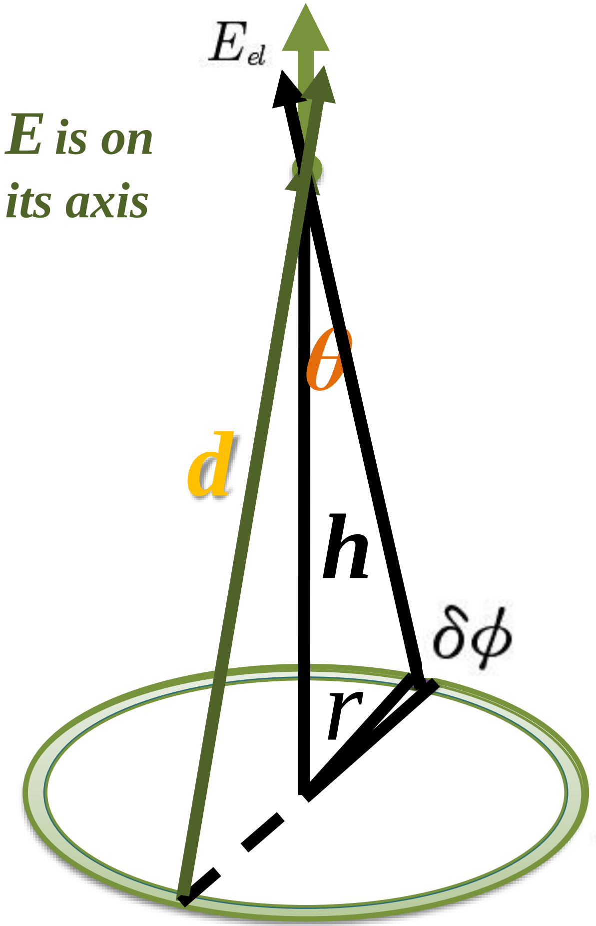
Electric field from a uniformly charged ring



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



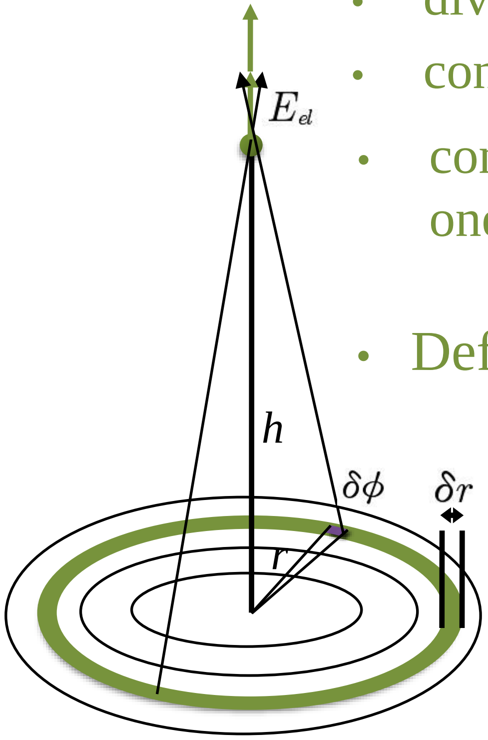
- area of each element: $A_{el} = r\delta\phi\ \delta r$
- charge of each element: $Q_{el} = \sigma r\delta\phi\ \delta r$
- number of elements in a circle: $\dfrac{2\pi r}{r\delta\phi} = \dfrac{2\pi}{\delta\phi}$
- field from one element:

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

- 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*):

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

- 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*

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

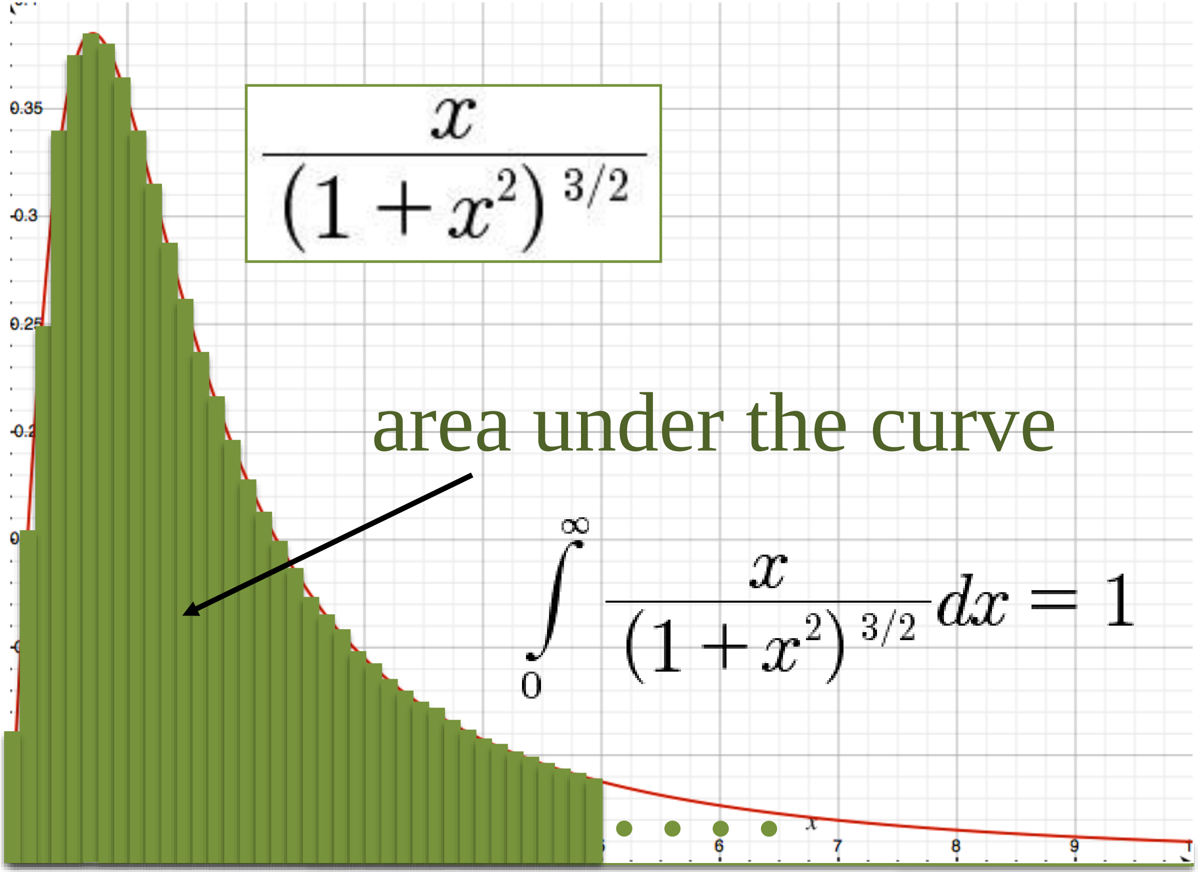
Electric field from an infinite charged plate

Add all Fields from

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

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

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



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

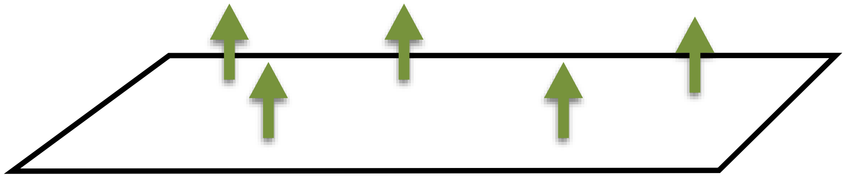
area under the curve

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

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

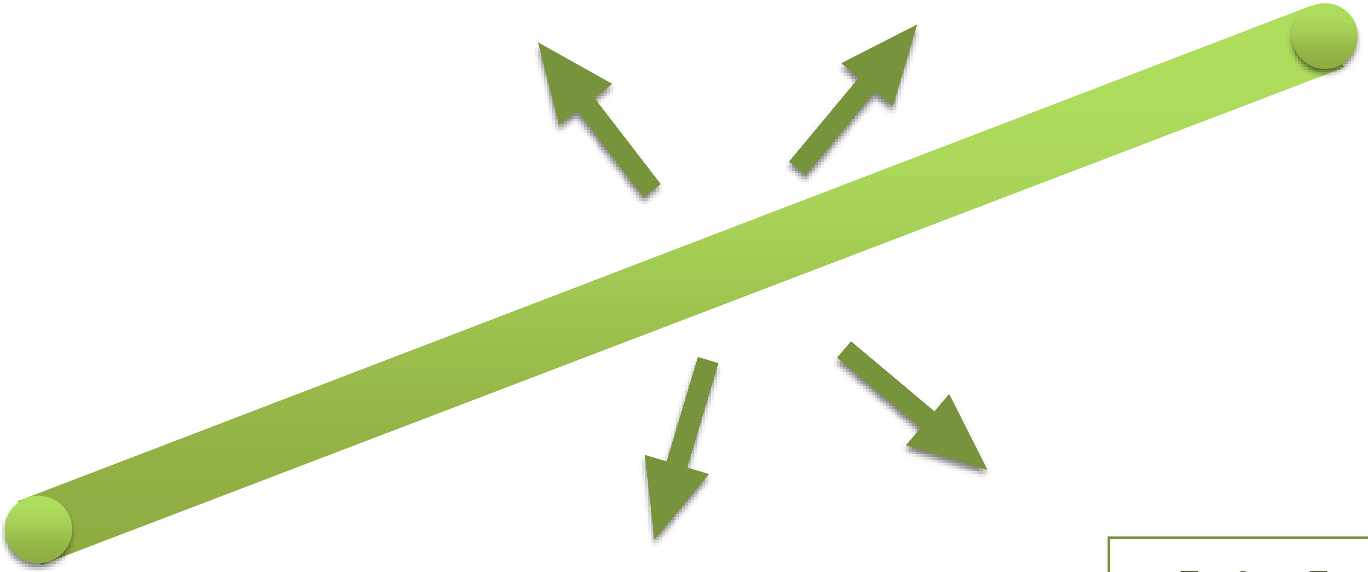
- **But of course, no plate can be infinite**
- **This is only an approximation**

Plate is large

or

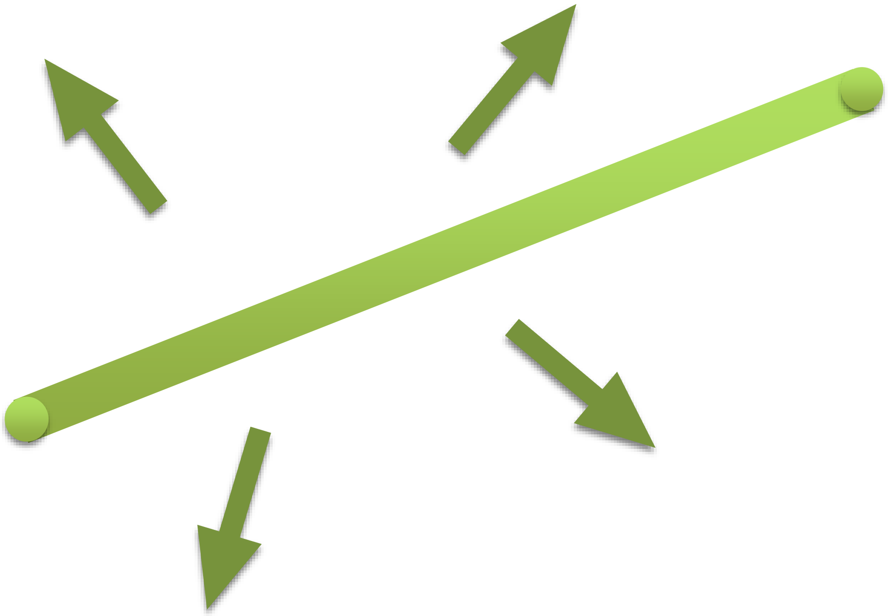
Close to the plate

Electric field from an infinite charged wire



Think about it!

Electric field from an infinite charged wire



Related to the distance?

How?

Think about it!

Gravitational field

Definition: Force per unit mass

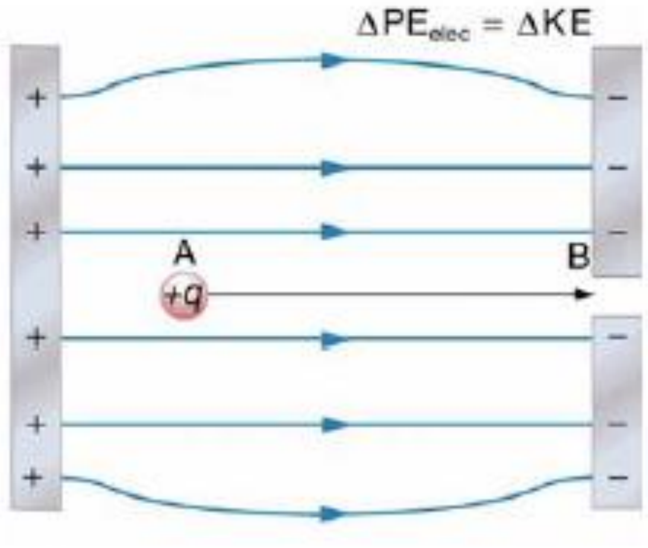
Magnitude above Earth surface:

$$GM_E/r^2$$

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

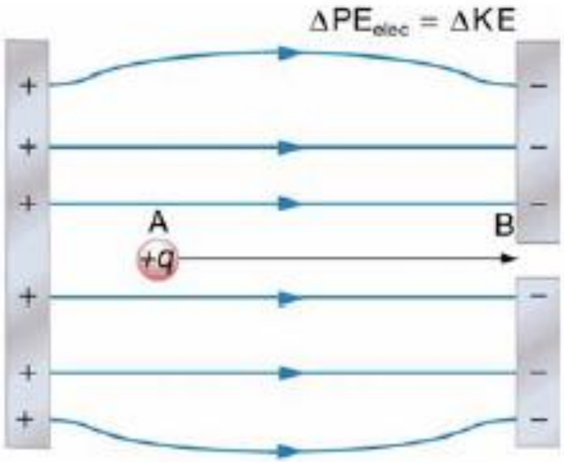
In a gravitational field.

Potential Energy

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

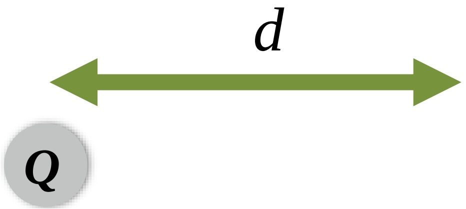
The electrostatic force is a conservative force

Corresponding potential energy

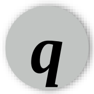


Potential energy of a charge

Zero potential - infinitely far away



$$v = 0$$



Change in potential energy = - work done

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

Potential energy of a charge

$$W = F\,x$$

d

Q

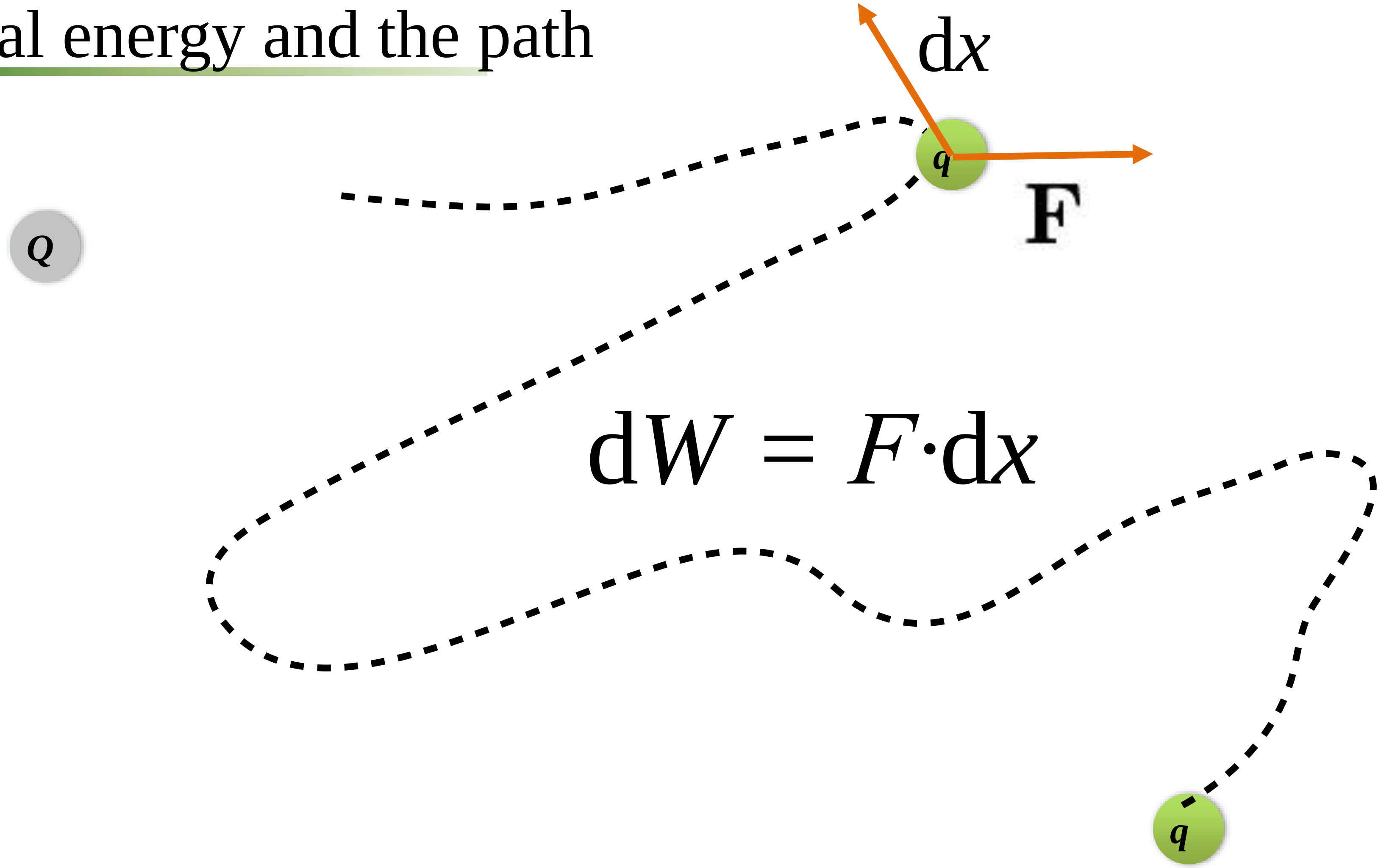
q

Potential energy of a charge

$$W = F\,x$$

F depends on *x*

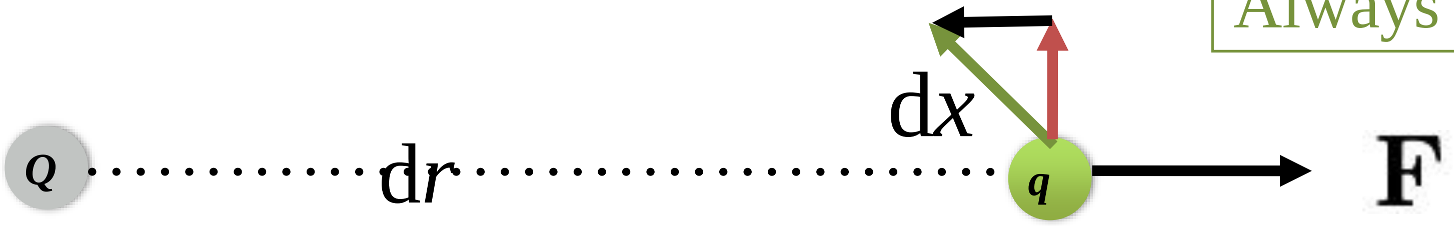
Potential energy and the path



$$dW = F \cdot dx$$

Potential energy and the path

Always radial



$r\mathrm{d}\theta$

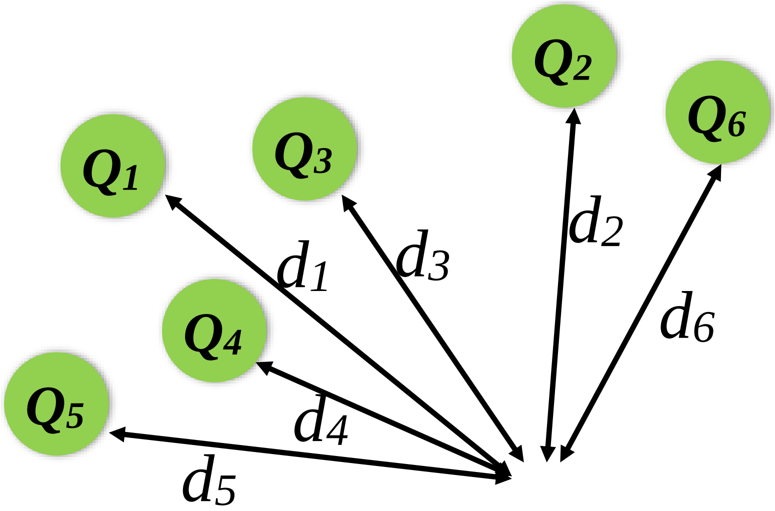
$\mathrm{d}x$

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

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

***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)

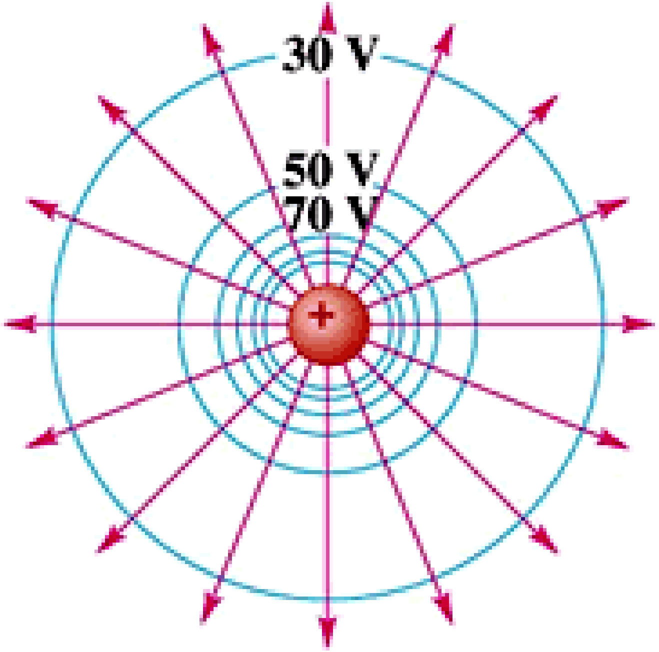
also called "Voltage"

Example

$V = ?$ $Q = -3\ \text{nC}$

Equipotential lines

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

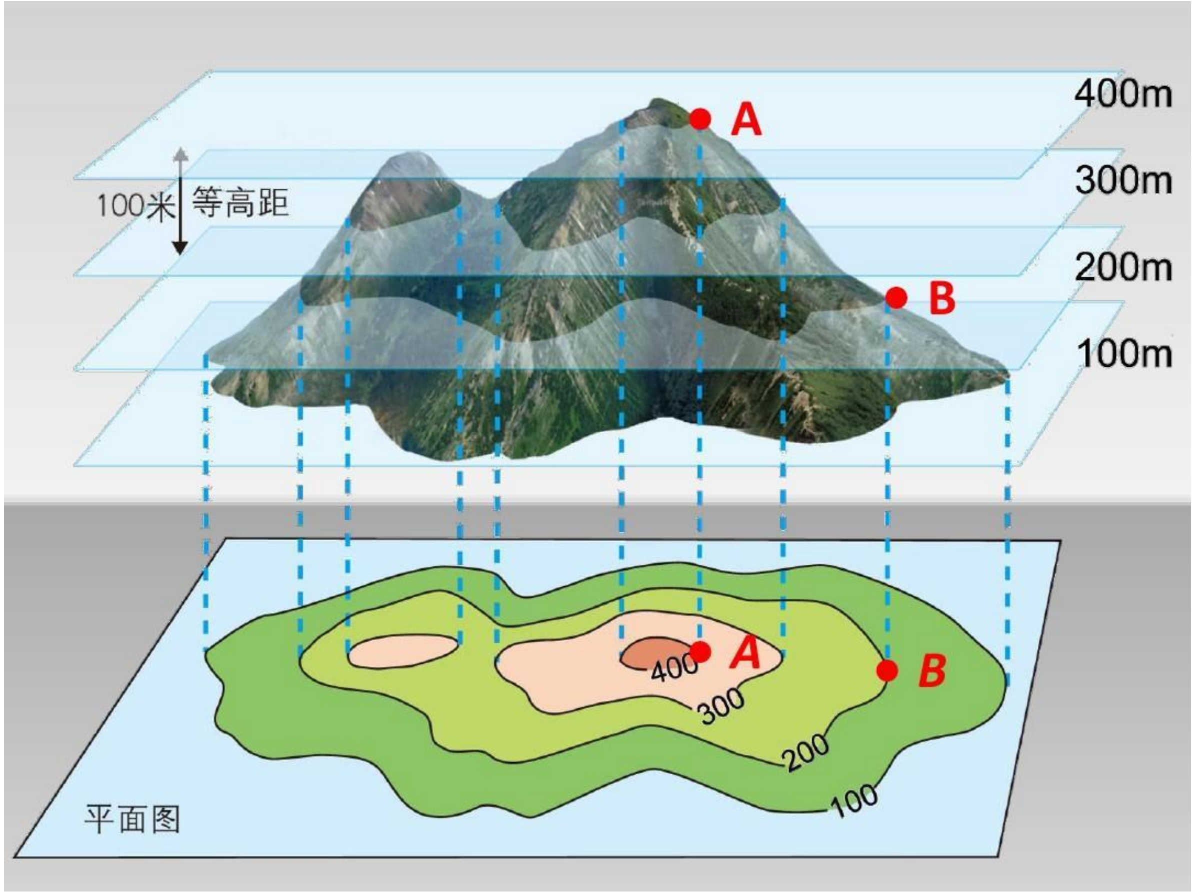


Potential at distance '*r*' from a point charge is the same

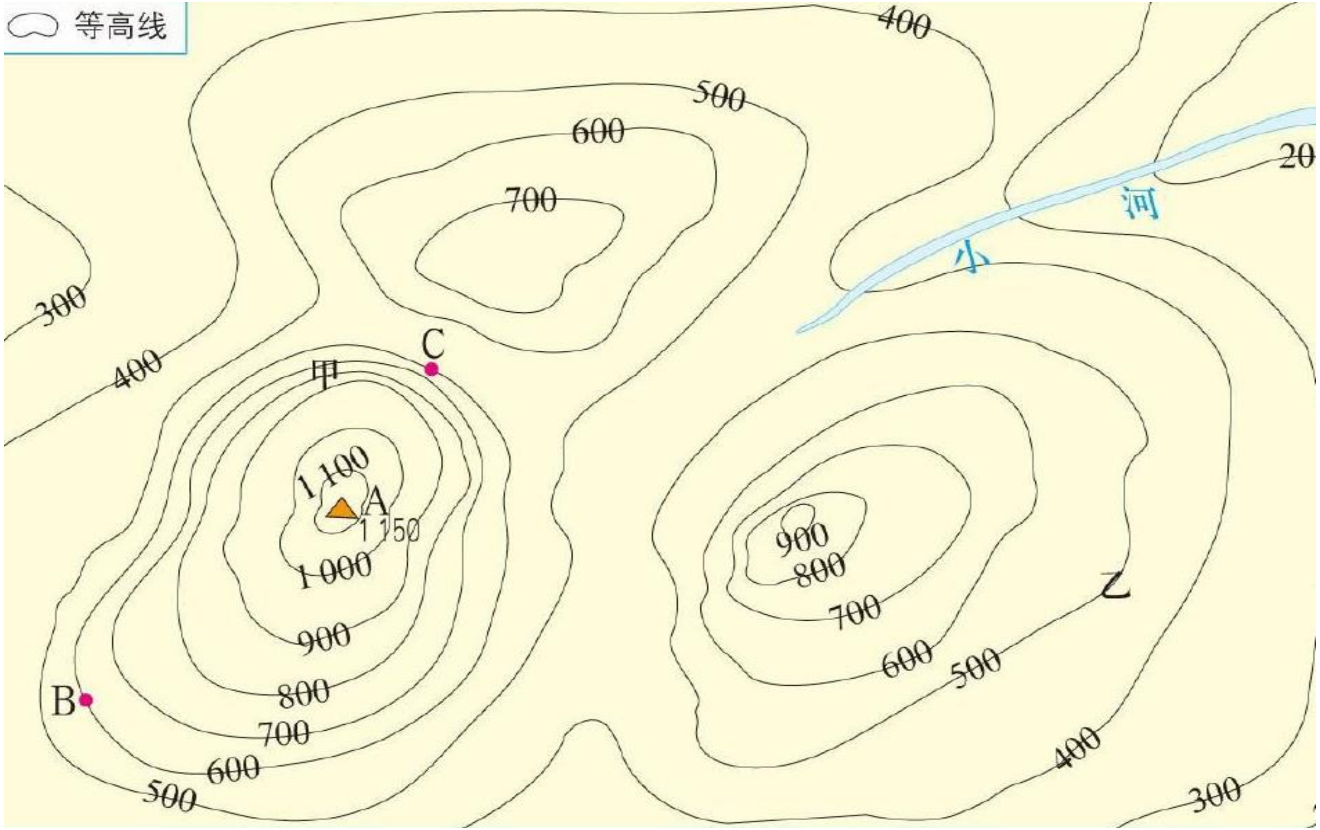
We can draw "**equipotential lines**" where potential is the same

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

Equipotential lines



Equipotential lines



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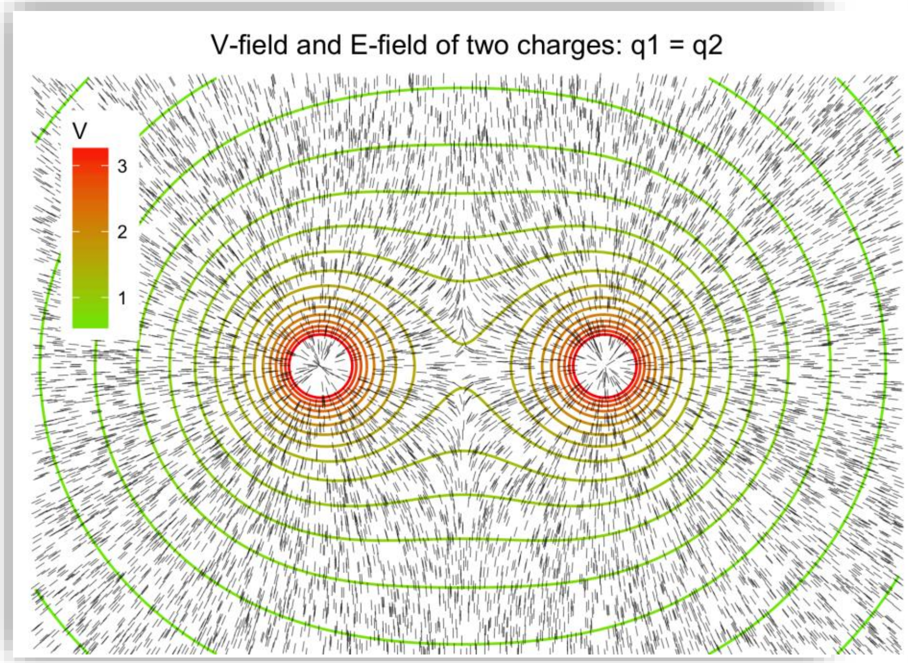

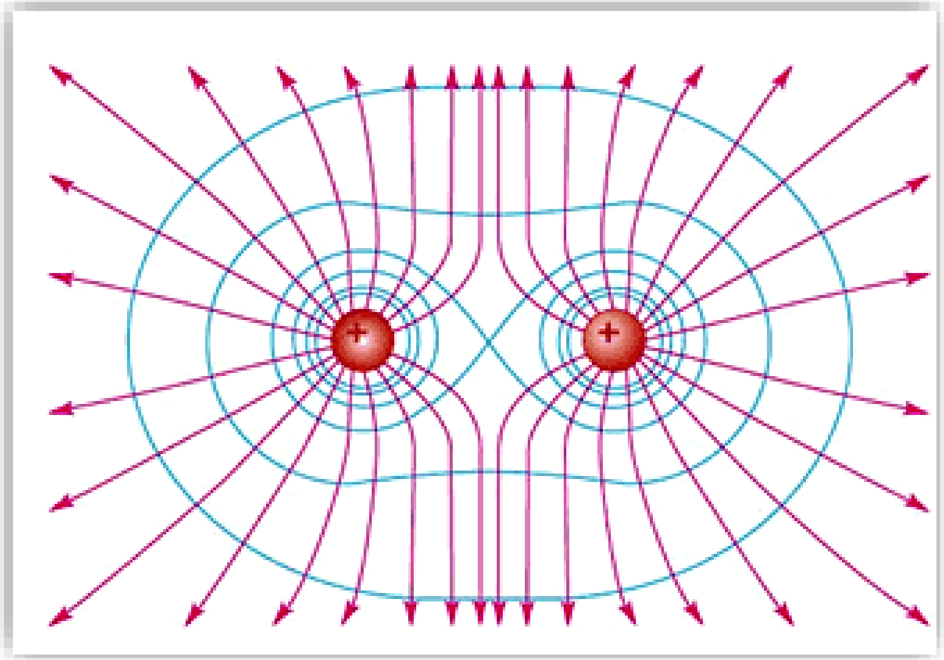

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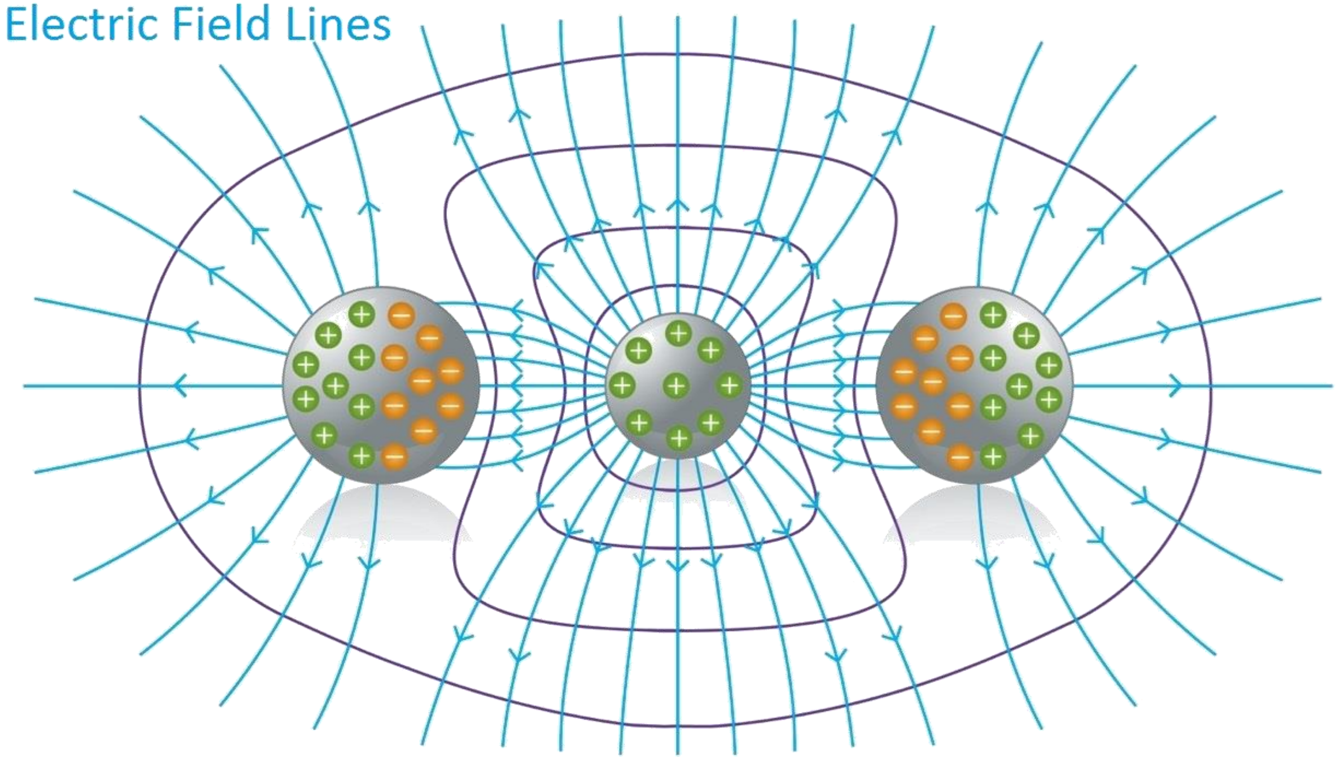
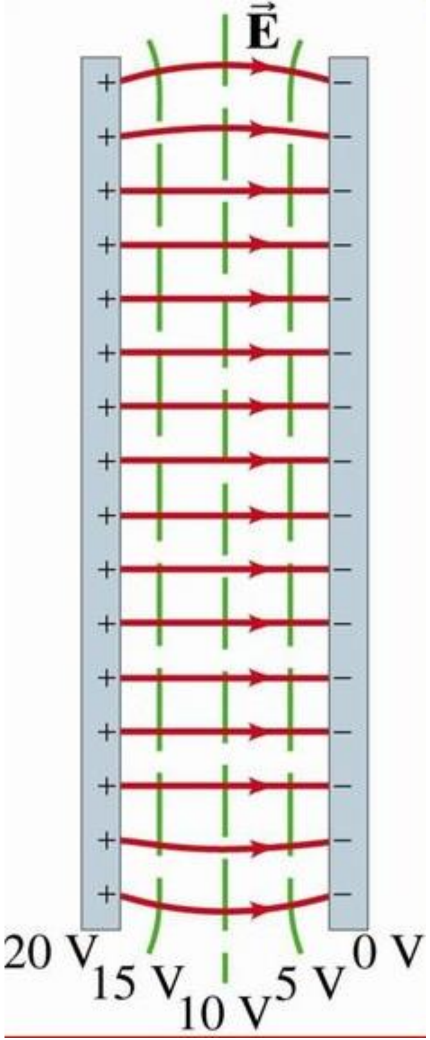




Differences between

Electric field line

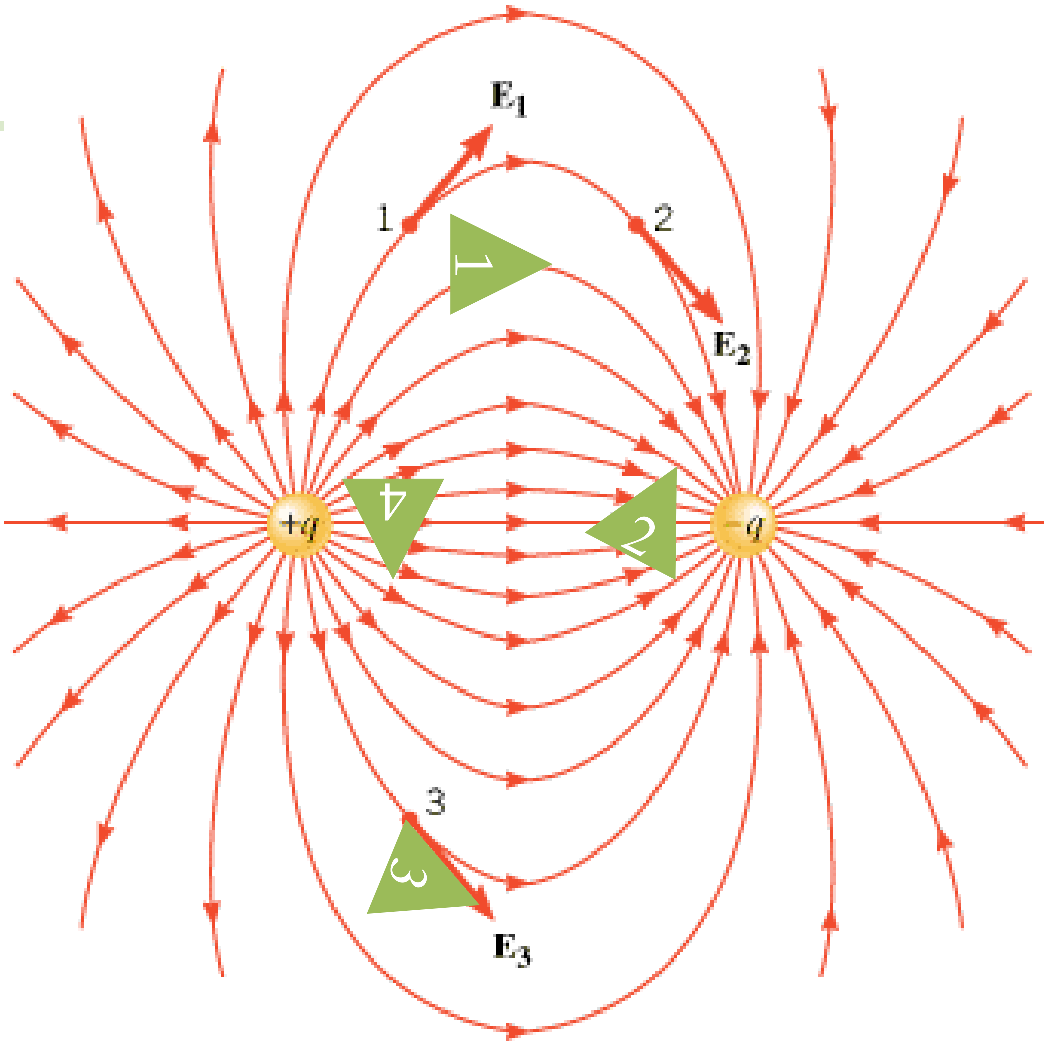
&

equipotential line

Electric field line

Characteristics:

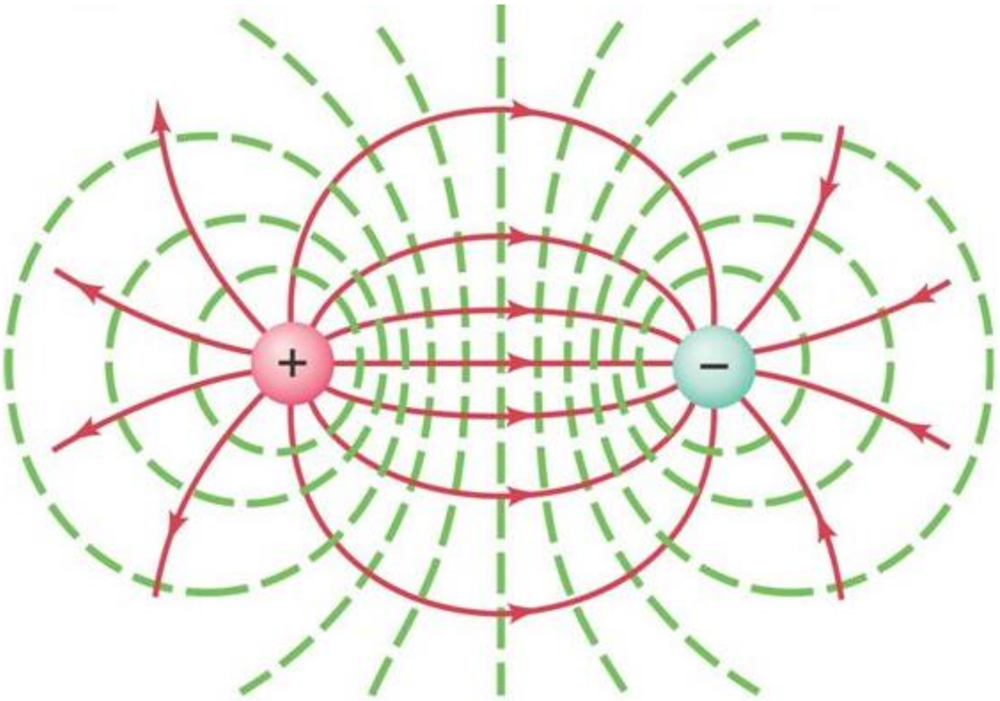
1. Direction
2. Magnitude
3. Direction of *E*
4. Never cross



Equipotential lines

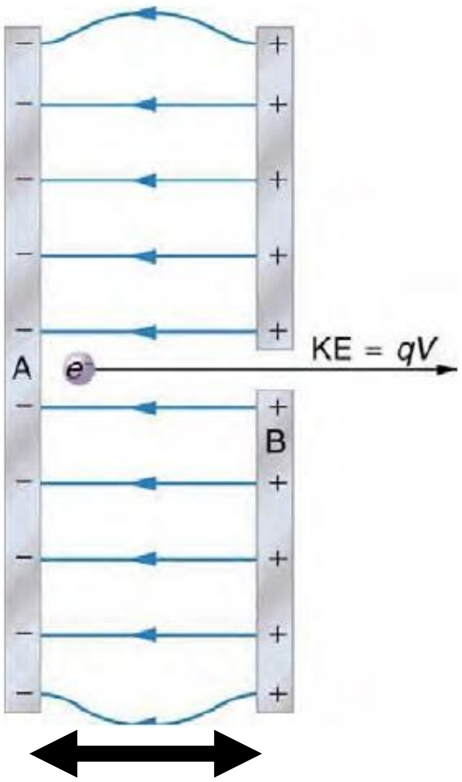
Characteristics:

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



Similar in the Gravitational potential lines/Conservation of mechanical Energy

Example

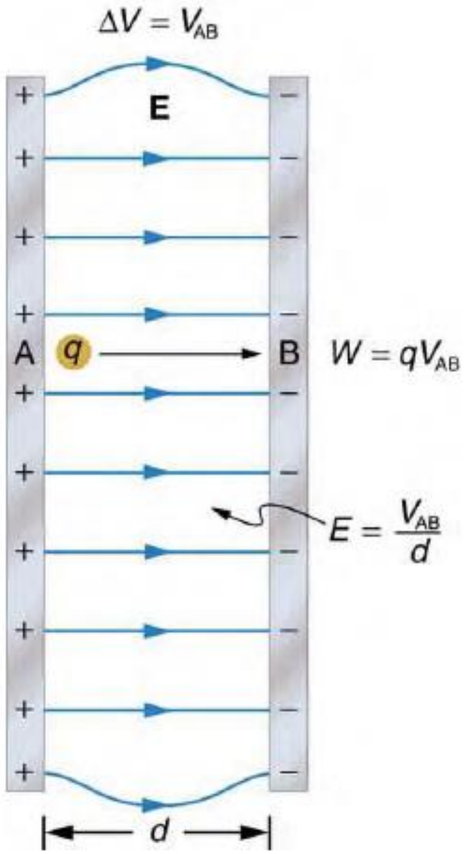


100 Volts

The speed of the electron?

$$\Delta E_p + \Delta E_k = 0$$

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

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

$\boxed{\textbf{\textit{gradient}}}$

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

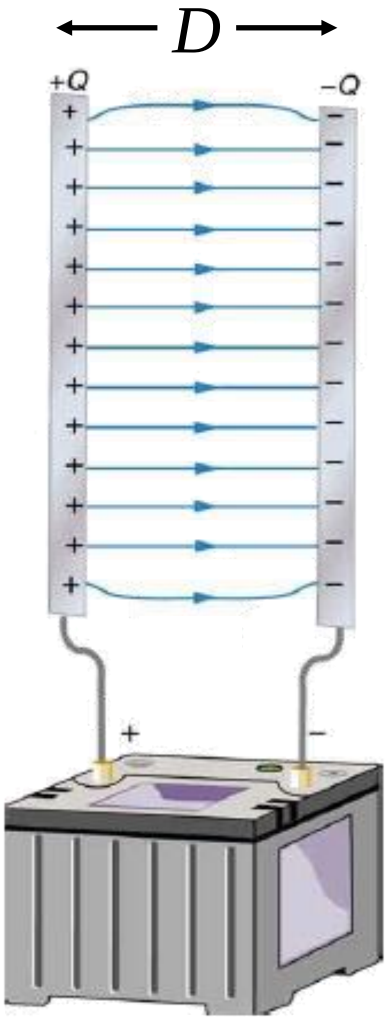
Parallel metal plates charged by a constant voltage source.

What is the charge on the plate(s) ?

Voltage of the battery = potential difference

Distance between plates - *D*

Surface area of plates - *A*



Example

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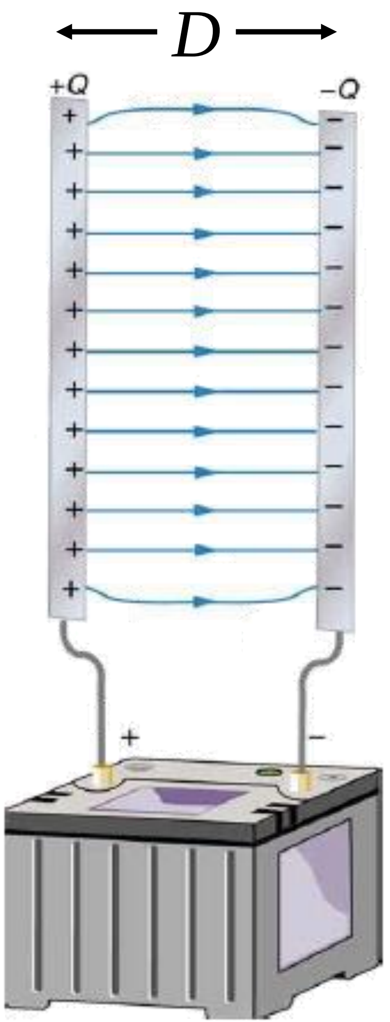

ΔV	E	σ	**Q**
Potential difference	Electric field	surface charge density	

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

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.

TRY TO RECALL

What have we learned this WEEK ?

- 1.
- 2.
- 3.

Is there anything that we still need to spend more time to get understood?

- 1.
- 2.

What are we going to do after the lecture?

Week 2

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**