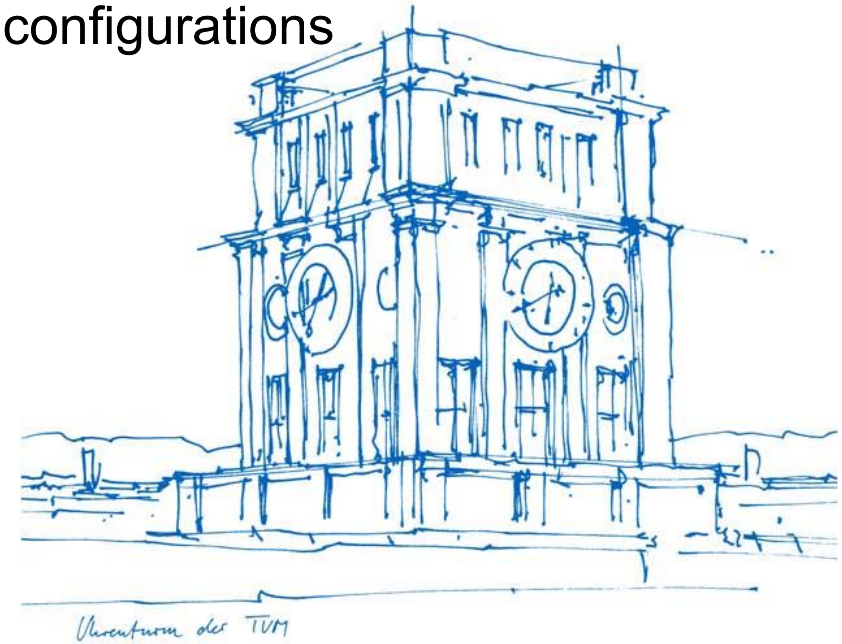
# Lecture

# Electricity and Magnetism

## Chapter 1 Electrostatics – 1.3. Electric Field

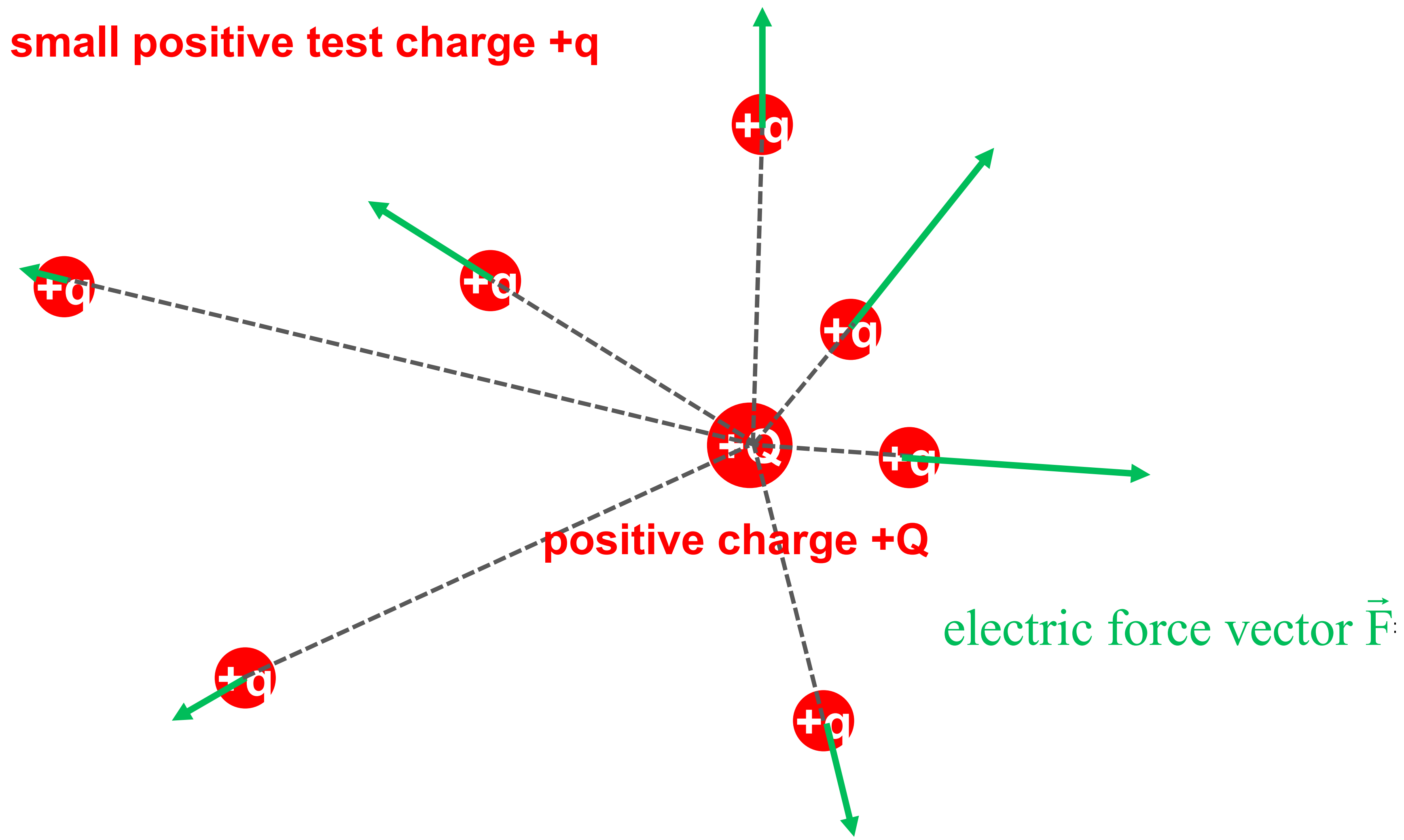
- Electric field - summary
- Electric fields for specific charge configurations



# 1.3 Summary electric field and specific cases

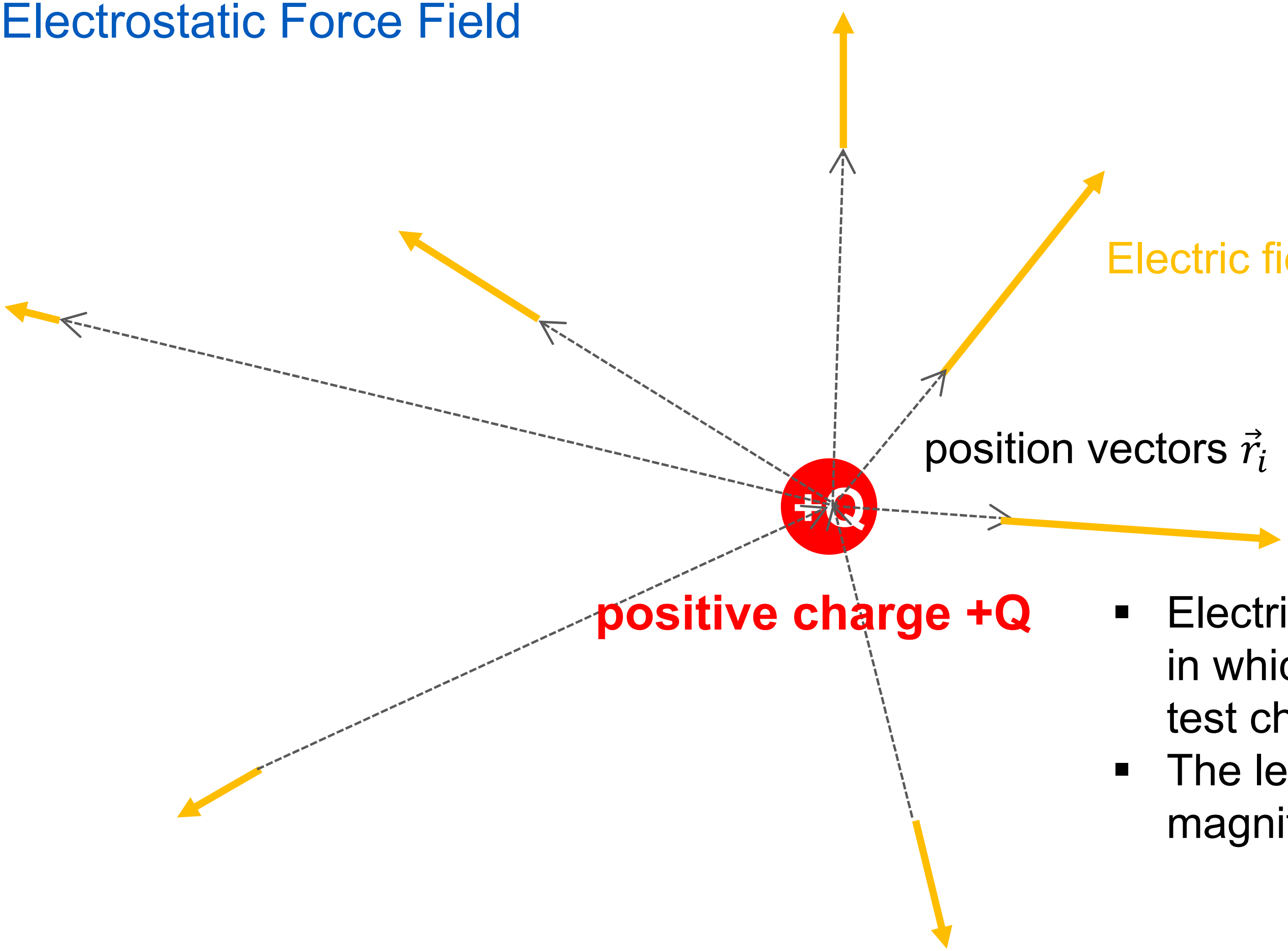
## Electrostatic Force Field

fixed charge +Q



# 1.3 Summary electric field and specific cases

## Electrostatic Force Field



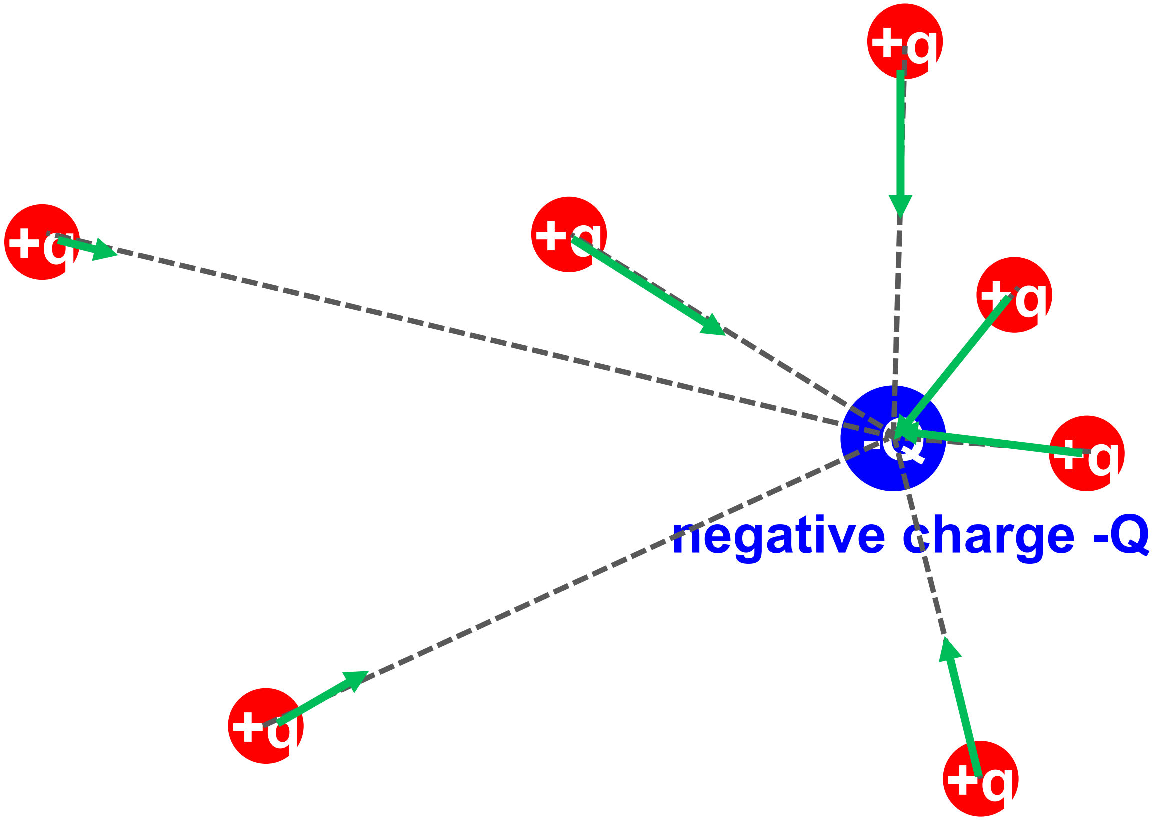

- Electric field vectors show, in which direction a positive test charge is moved.
- The lenght represents the magnitude of the force.

# 1.3 Summary electric field and specific cases

## Electrostatic Force Field

positive

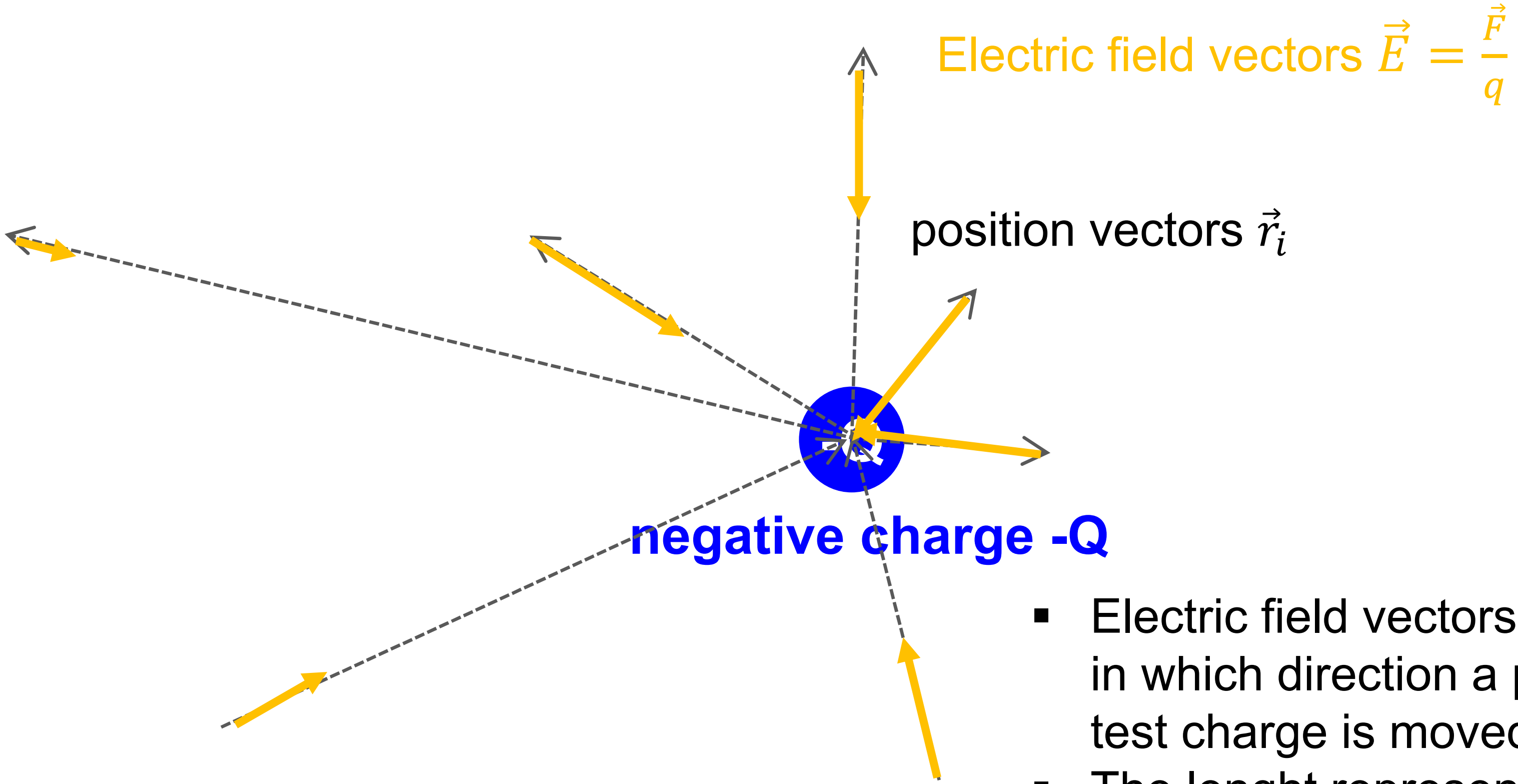
**small ~~negative~~ test charge -q**



# 1.3 Summary electric field and specific cases

## Electrostatic Force Field

**small negative test charge -q**




- Electric field vectors show, in which direction a positive test charge is moved.
- The lenght represents the magnitude of the force.

# 1.3 Summary electric field and specific cases

- Definition of electric field: force on test charge q

$$\boxed{\vec{E}(\vec{r}) = \frac{\vec{F}_q(\vec{r})}{q}}$$

- Electric field generated by N point charges $q_i$ at locations $\vec{r}_i$

$$\boxed{\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{\left|\vec{r}-\vec{r}_i\right|^3}\left(\vec{r}-\vec{r}_i\right)}$$

- Electric field is a vector field.

  At each location $\vec{r}$ in space it gives magnitude and direction of the force acting on a (positive) point charge q.

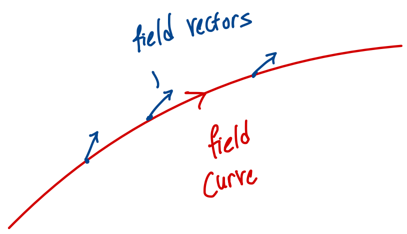
# 1.3 Summary electric field and specific cases

- Electric field
  - describes a force on an electric test charge q (charge per force), which is generated by a fixed electrical charge Q
  - force varies with location (magnitude and direction)
  - electric field is effective at any location in space
  - is a vector field : shows at each location in space which is the force on a positive test charge q (magnitude and direction!)

- Unit of electric field:

$$\left[\vec{E}\right] = \frac{\left[\vec{F}(\vec{r})\right]}{[q]} = \frac{N}{C} = \frac{N \cdot m}{A \cdot s \cdot m} = \frac{W \cdot s}{A \cdot s \cdot m} = \frac{V \cdot \cancel{A \cdot s}}{\cancel{A \cdot s} \cdot m} = \frac{V}{m}$$

# 1.3 Summary electric field and specific cases




- Vector fields are represented by vectors and field
- Field lines = tangents to the vectors of the vector field:
  - Direction of field lines $\longrightarrow$ direction of field quantity at respective location/position in space
  - Density of field linese $\longrightarrow$ strength of field = magnitude of field quantity

Electric field:

- Field lines point (per definition) in the direction of the force on a positive test charge $\longrightarrow$ start at positive charges and end at negative charges
- Field lines at an electric conductor „start“ under a right angle (90°/perpendicular to the surface)

## 1.3.2 Electric fields for special cases

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{\left|\vec{r}-\vec{r}_i\right|^3}(\vec{r}-\vec{r}_i)$$

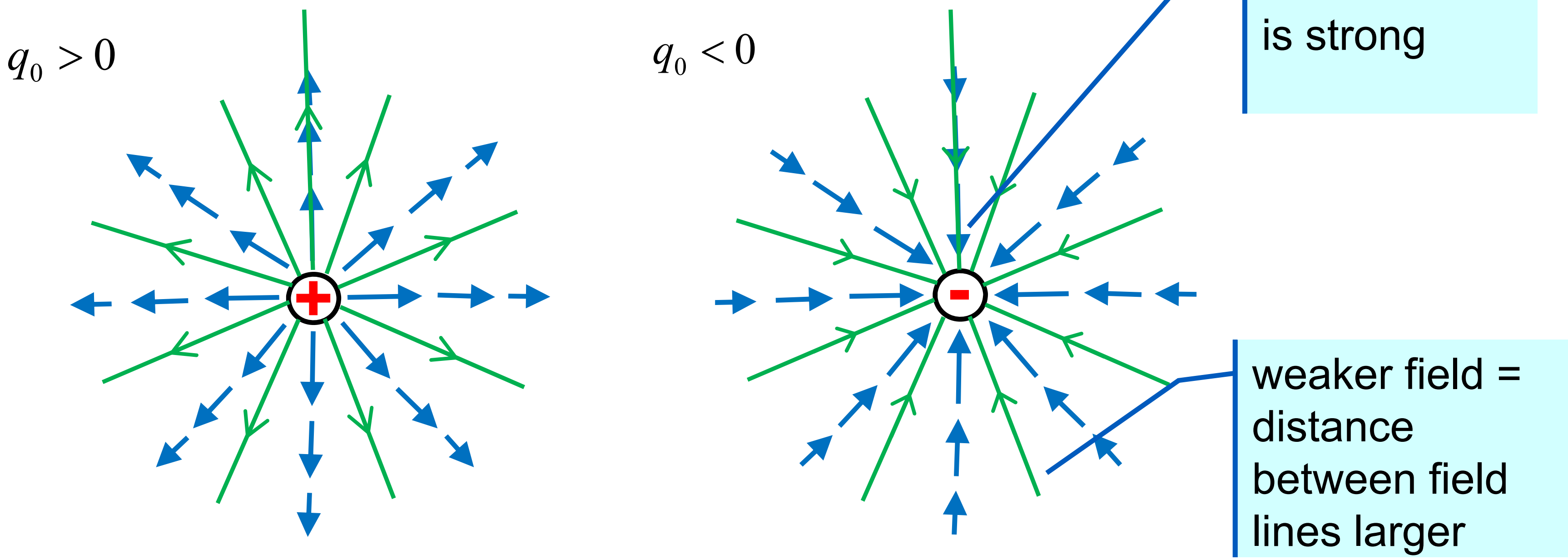
Charge at location

N=1, ~~Ladung~~ $q_0$ ~~am Ort~~ $\vec{r}_0$

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\frac{q_0}{\left|\vec{r}-\vec{r}_0\right|^3}(\vec{r}-\vec{r}_0)$$

for ~~für~~ $\vec{r}_0 = 0$: $\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\frac{q_0}{\left|\vec{r}\right|^3}\vec{r}$

$\longrightarrow$ monopole field



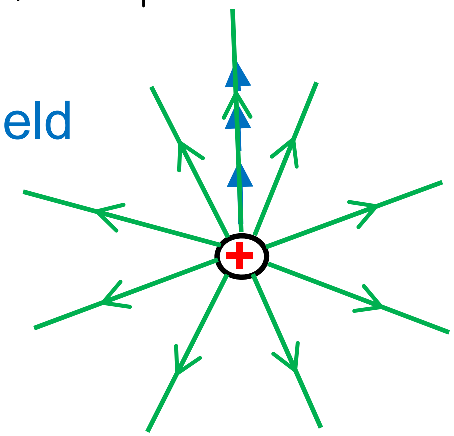
## 1.3.2 Electric fields for special cases

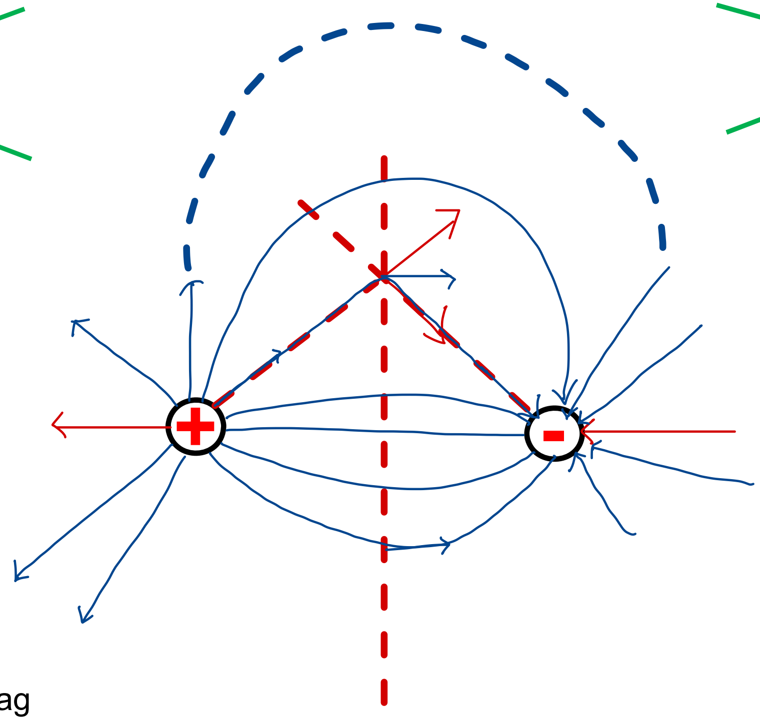
$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{\left|\vec{r}-\vec{r}_i\right|^3}\left(\vec{r}-\vec{r}_i\right)$$

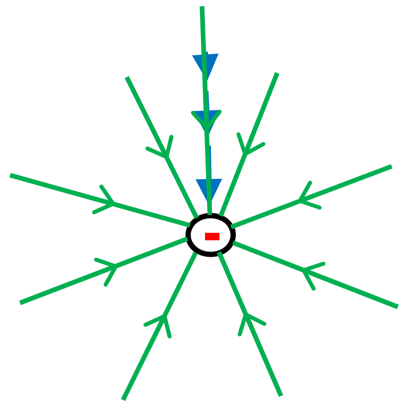
N=2: +q ~~am Ort~~ at location $\vec{r}_1$ ; -q ~~am Ort~~ at location $\vec{r}_2$

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\frac{q}{\left|\vec{r}-\vec{r}_1\right|^3}\left(\vec{r}-\vec{r}_1\right) - \frac{1}{4\pi\varepsilon_0}\frac{q}{\left|\vec{r}-\vec{r}_2\right|^3}\left(\vec{r}-\vec{r}_2\right)$$

$\longrightarrow$ dipole field



# 1.3.2 Electric fields for special cases - please solve!

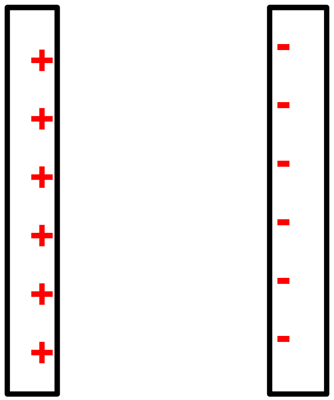
$$\boxed{\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i}{\left|\vec{r} - \vec{r}_i\right|^3} \left(\vec{r} - \vec{r}_i\right)}$$

Example 1

N=2: +q am Ort $\vec{r}_1$; +q am Ort $\vec{r}_2$

Examplel2

2 charged parallel plates



How does the electric field look like for both cases?

# 1.3.2 Electric fields for special cases - please solve!

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{\left|\vec{r}-\vec{r}_i\right|^3}\left(\vec{r}-\vec{r}_i\right)$$

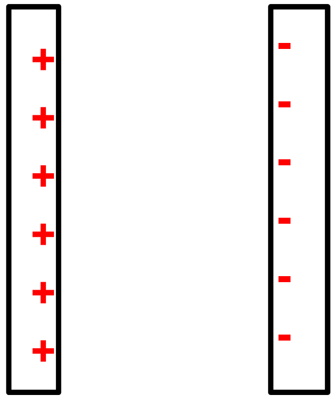
## Example 1

N=2: +q at $\vec{r}_1$; +q at $\vec{r}_2$

## 1.3.2 Electric fields for special cases - please solve!

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i}{\left|\vec{r} - \vec{r}_i\right|^3} \left(\vec{r} - \vec{r}_i\right)$$

### Example 2
2 charged parallel plates



# 1.3.2 Electric fields - Visualization

## (Experimental) Visualising Electrical Fields

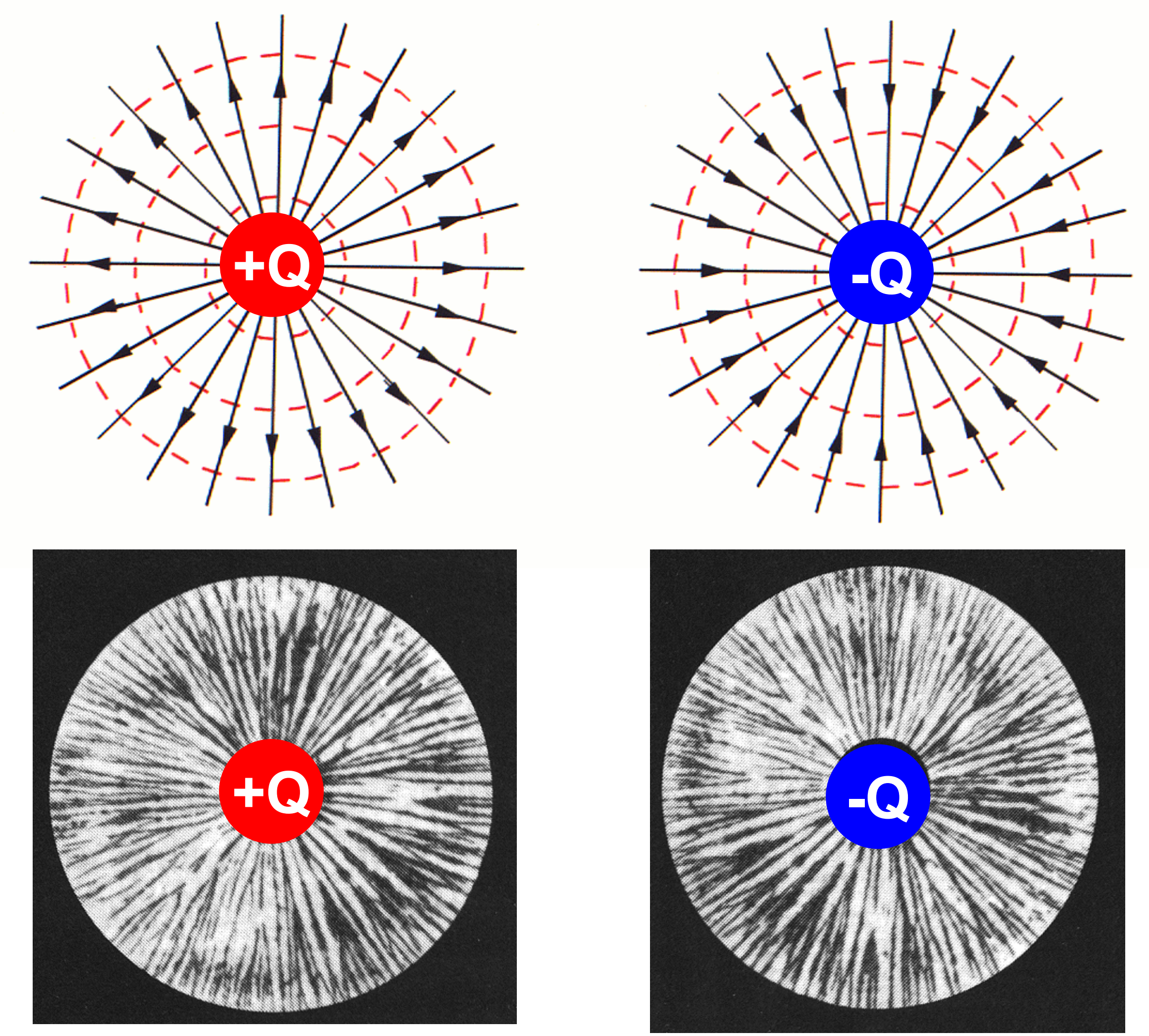
- To visualise electric field lines one can use – for example - small particles of semolina
- The semolina seeds in an electric field exhibit electric dipoles
- These small electric dipoles align in an electric field, as the positive part of the semolina grains are attracted by the negative sources of the electric field and the negative part of the semolina grains are attracted by the positive sources of the electric field lines.
- The resulting "picture" of all the aligned grains gives a visualisation of the electric field distribution.

# 1.3.2 Electric fields - Visualization

## (Experimental) Visualising Electrical Fields

# 1.3.2 Electric fields - Field Maps

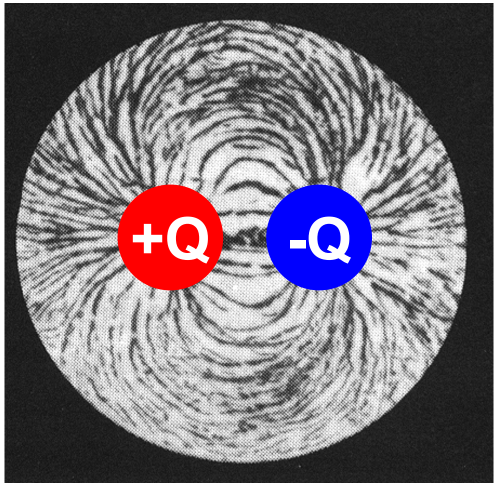
## Electrical Field of Monopoles



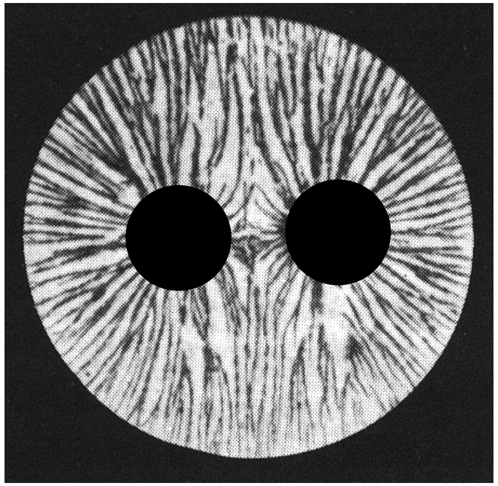
# 1.3.2 Electric fields - Field Maps

## Electrical Field of a Dipole and two like charges

an electric dipole

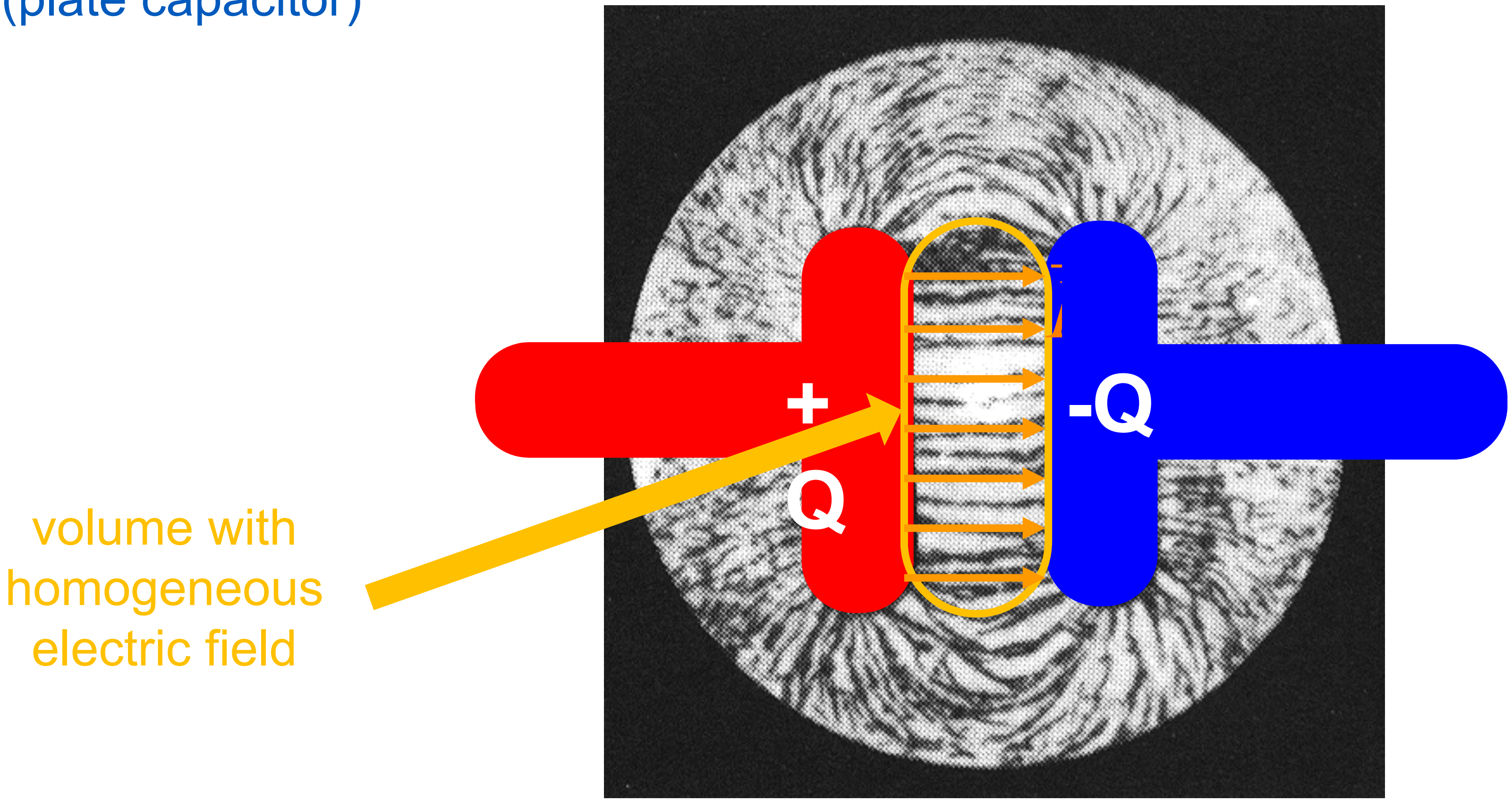



like charges



# 1.3.2 Electric Fields - Field Maps

Electric field lines generated by oppositely charged metal plates (plate capacitor)




Homogeneous field means: field does not depend on position (see next slide)

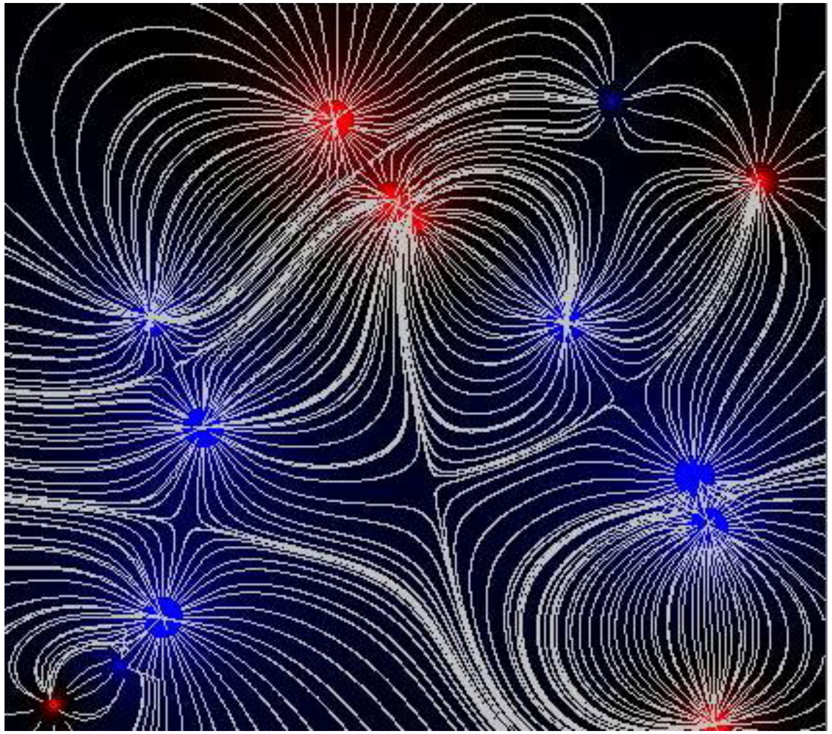
## Homogeneous Electric Field Lines

For a homogeneous electric field the electrical field at any position has the same magnitude and the same direction independent of position!

Schematically this represented by parallel and equidistant field lines (see below)

# 1.3.2 Electric Fields - Field Maps

## Electric field lines generated by a number of different electrical charges



The electric field lines – and thus the electric field strength as well – are distributed inhomogeneously in space.

There are also regions where the electrical field is nearly homogeneous.

The electric field lines visualised here are a superposition of the electric fields generated by all the charges located in that picture.