Electricity and Magnetism

- Recap:
  - Confirmation of inverse square law
  - Superposition principle
  - Induction demo
- Electric field

Q: Is $F_{21} \sim 1/r^2$?

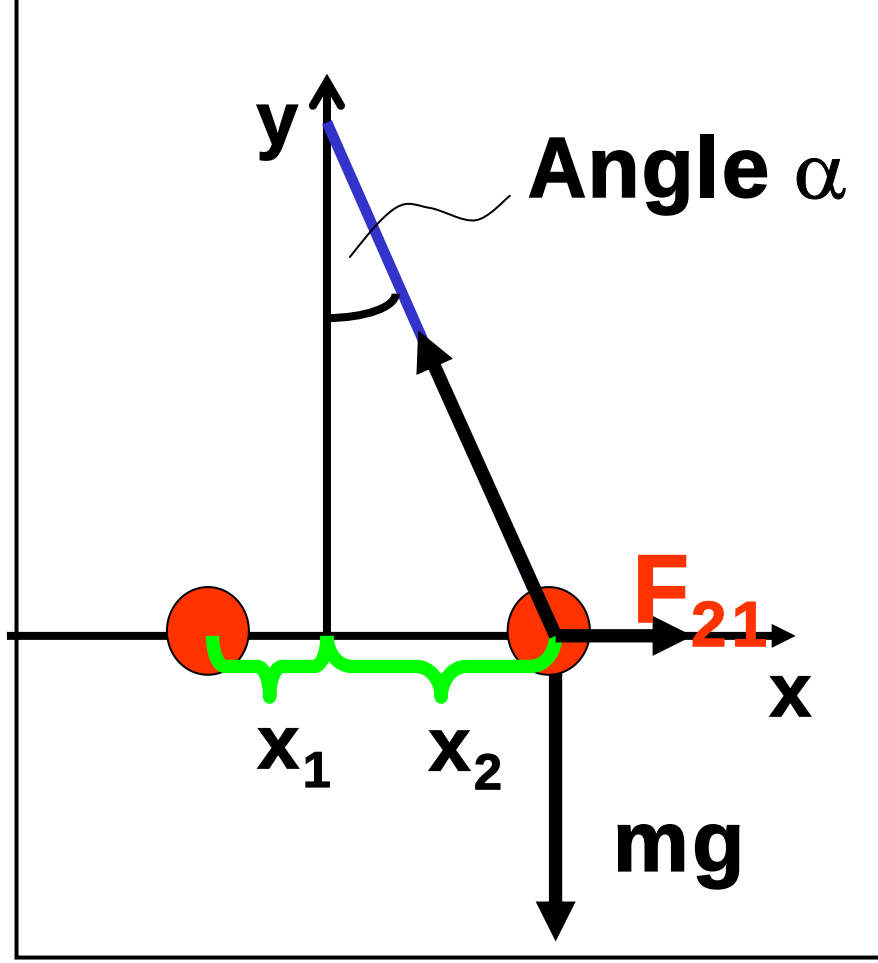
$F_{21} \sim x_2$

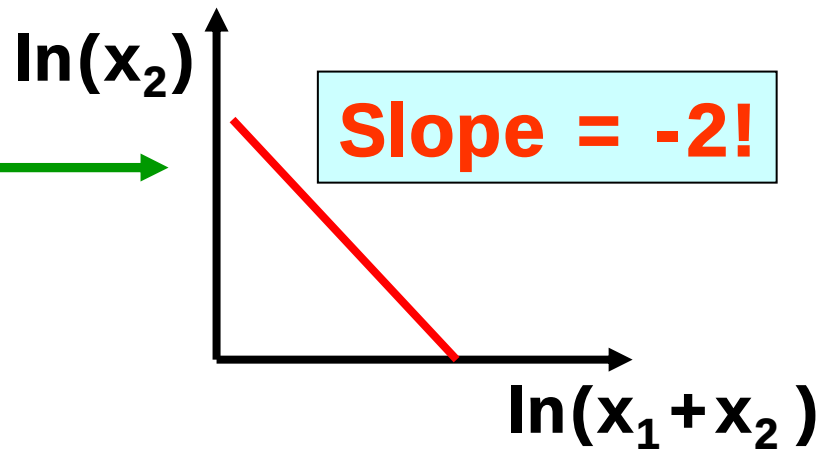
$r = x_1 + x_2$

$x_2 \sim 1/(x_1 + x_2)^2$

Check:

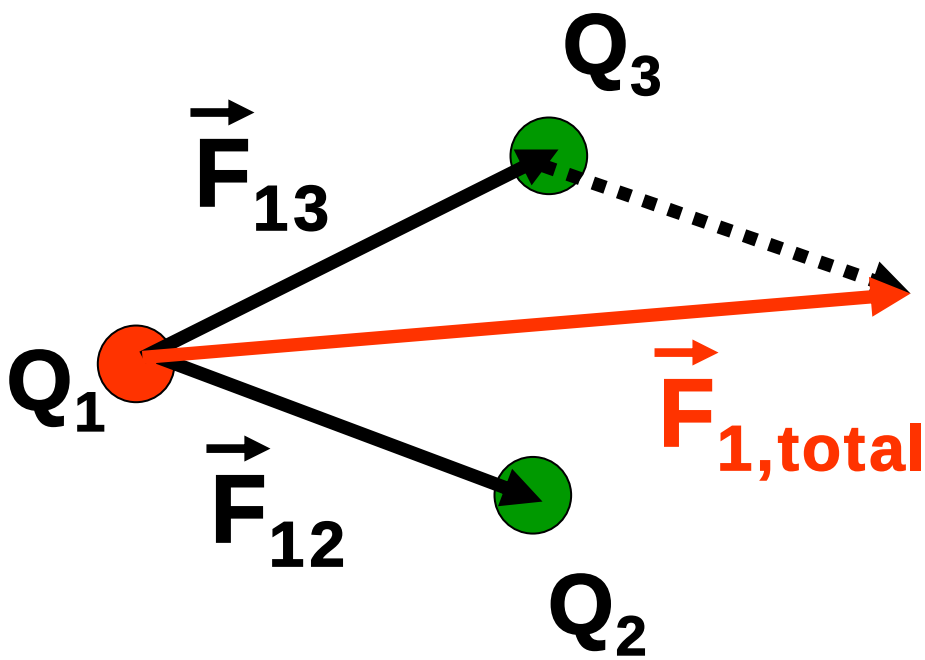
$\ln(x_2) \sim -2 \ln(x_1 + x_2)$





Superposition principle

- Just add the forces on Q_1 (as vectors)



Superposition principle

- Just add the forces on Q_1!
- Works for arbitrary number of charges:

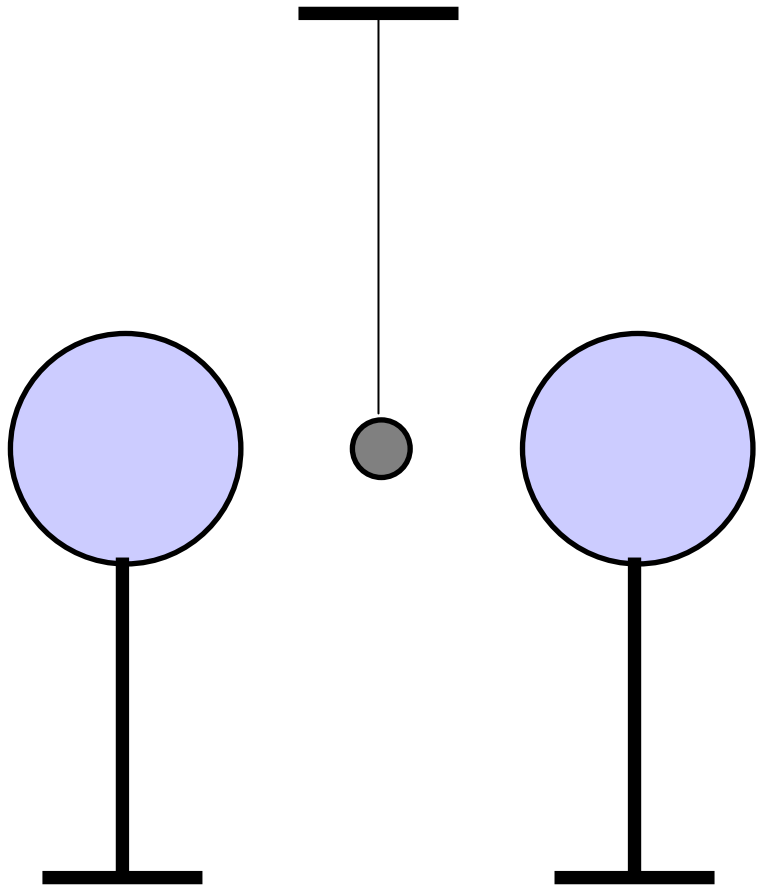
$$\vec{F}_{0,total} = \sum \vec{F}_{0,i} = \sum k \cdot \frac{Q_0 Q_i}{r_{i0}^2} \hat{r}_{i0}$$

Superposition principle

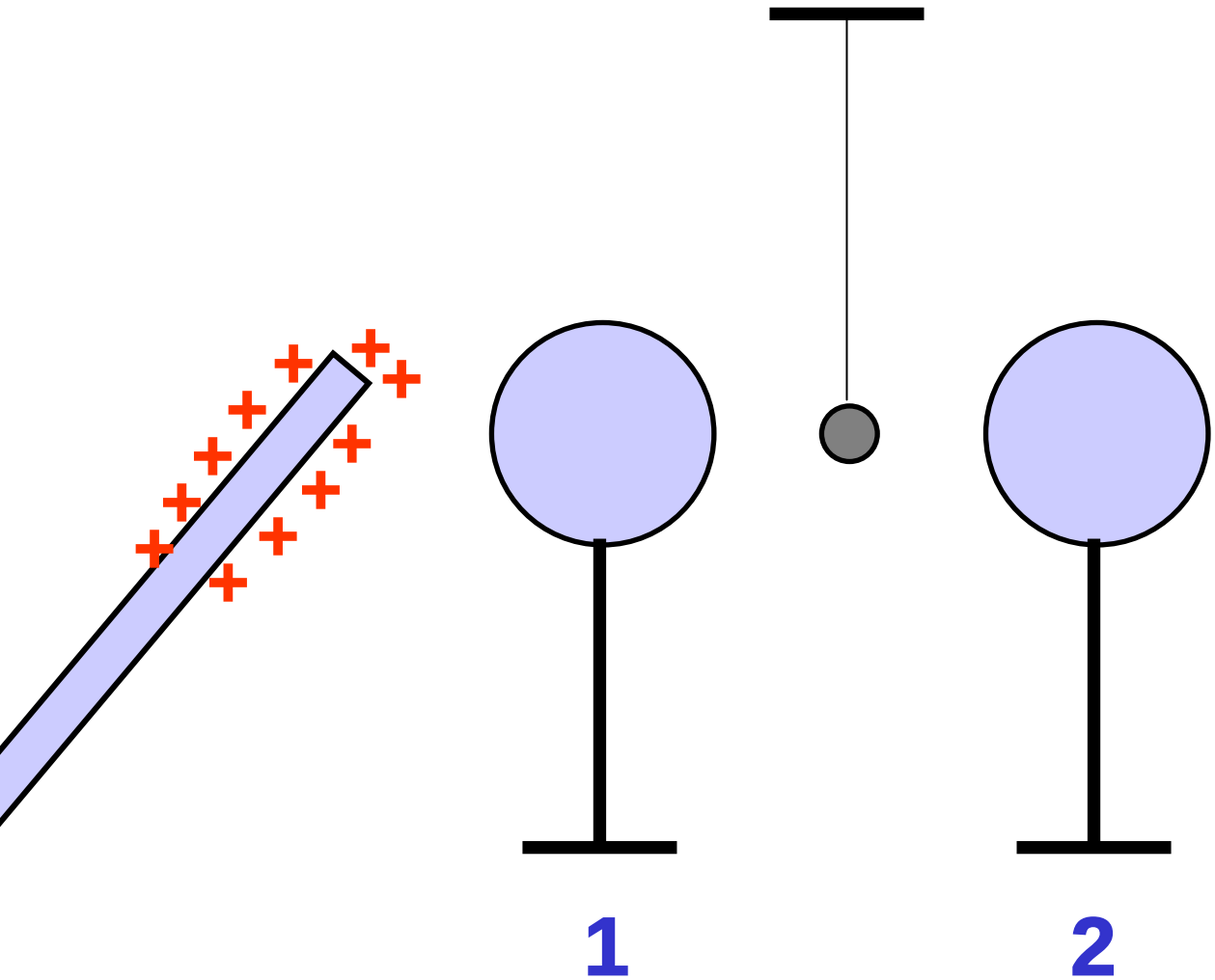
- What to do for many, many charges?
  - 10^9 e^- on glass rod...
- Replace sum with integral!

$$\vec{F}_{0,total} = \int d\vec{F}_0 = \int k \cdot \frac{Q_0 dQ}{r^2} \hat{r}$$

- Two spheres, 1 ping-pong ball
- All conducting, neutral



- Approach with charged glass rod
- Charges are induced on spheres



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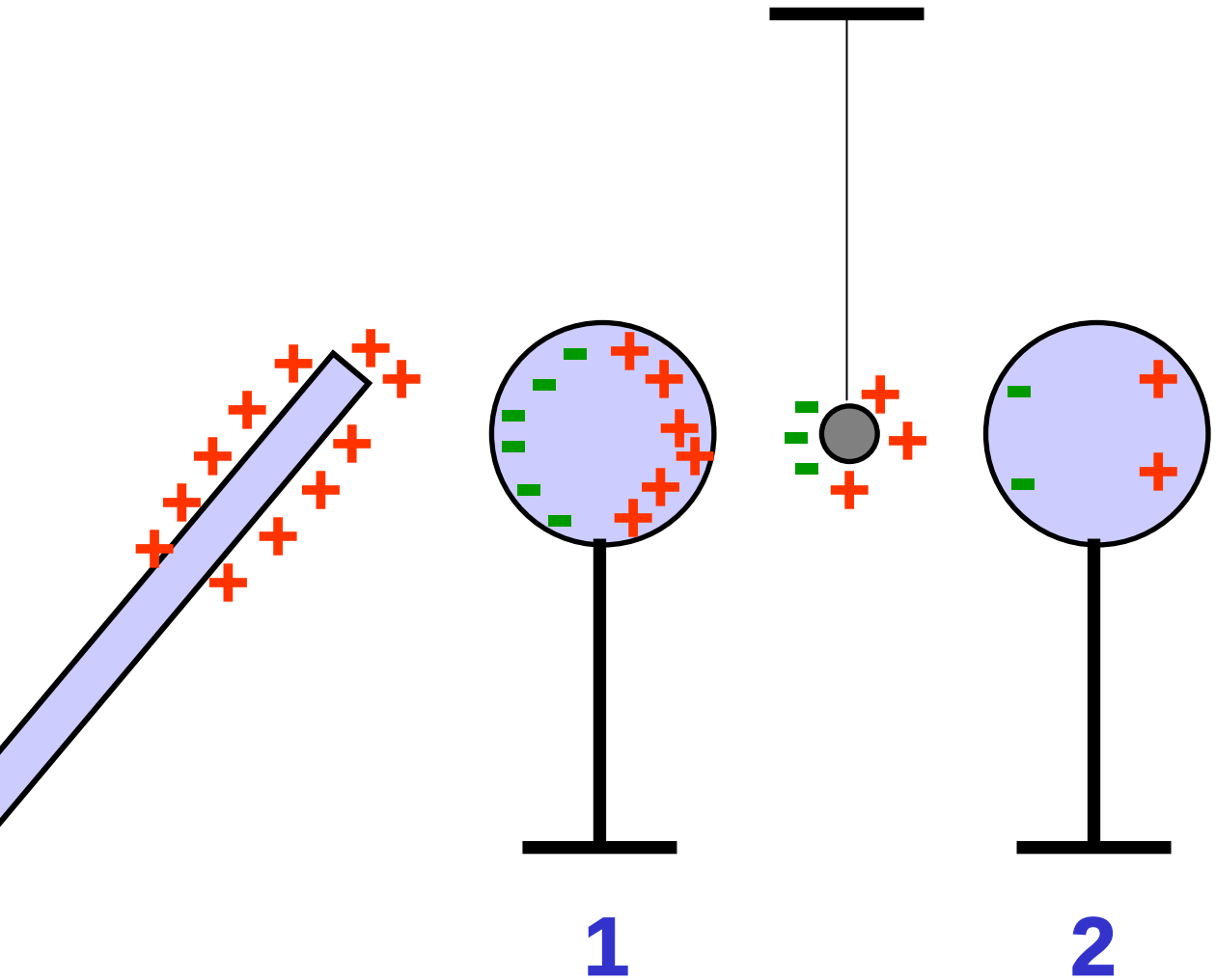
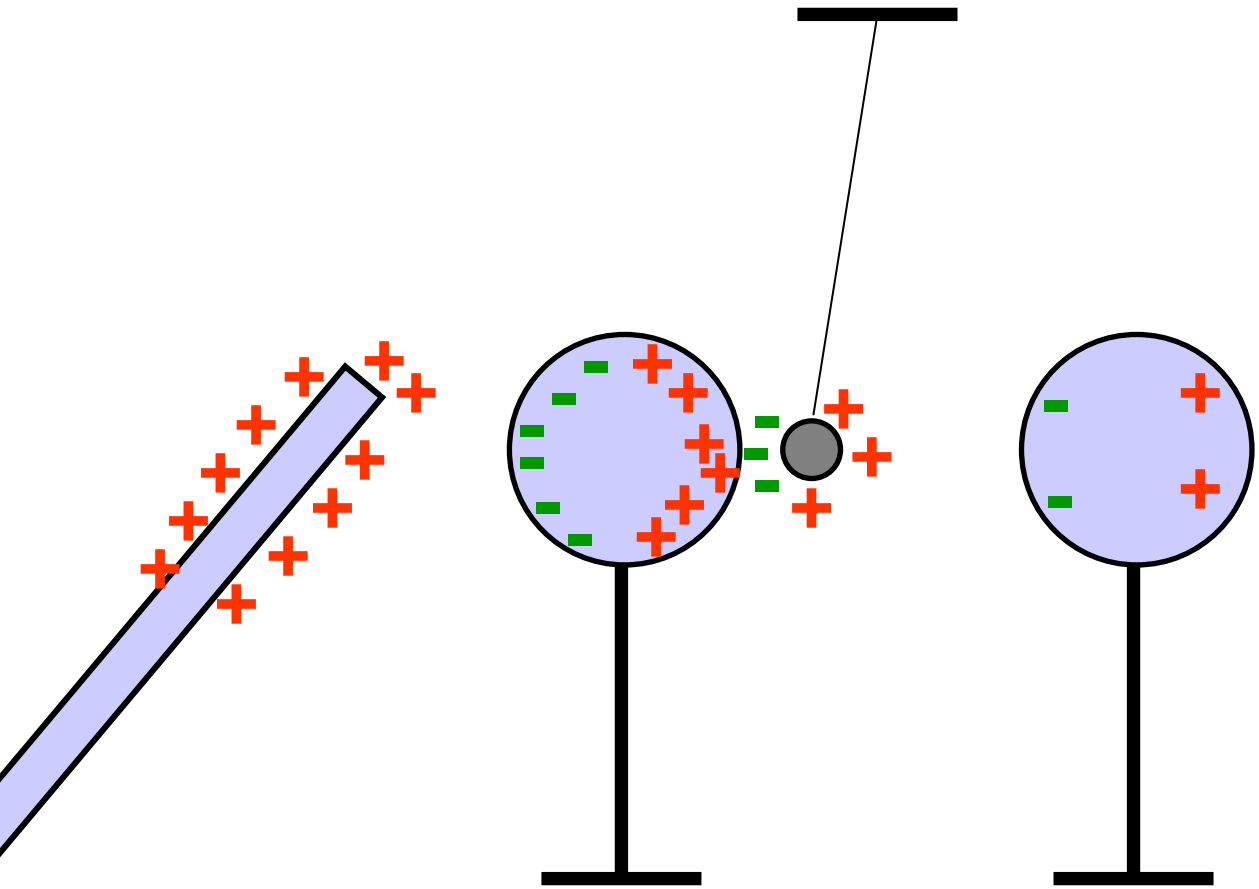
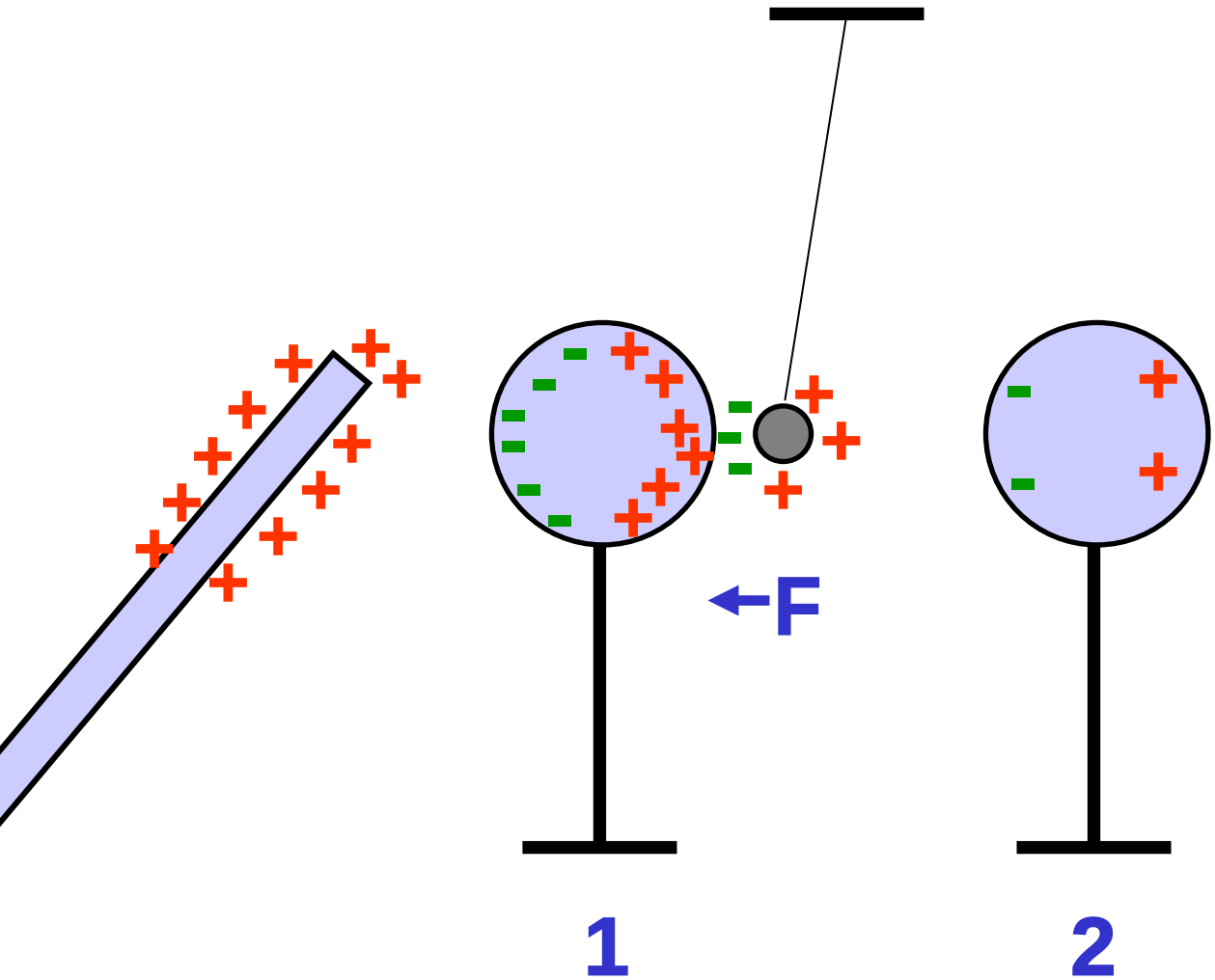


➢Net Force on ping-pong ball

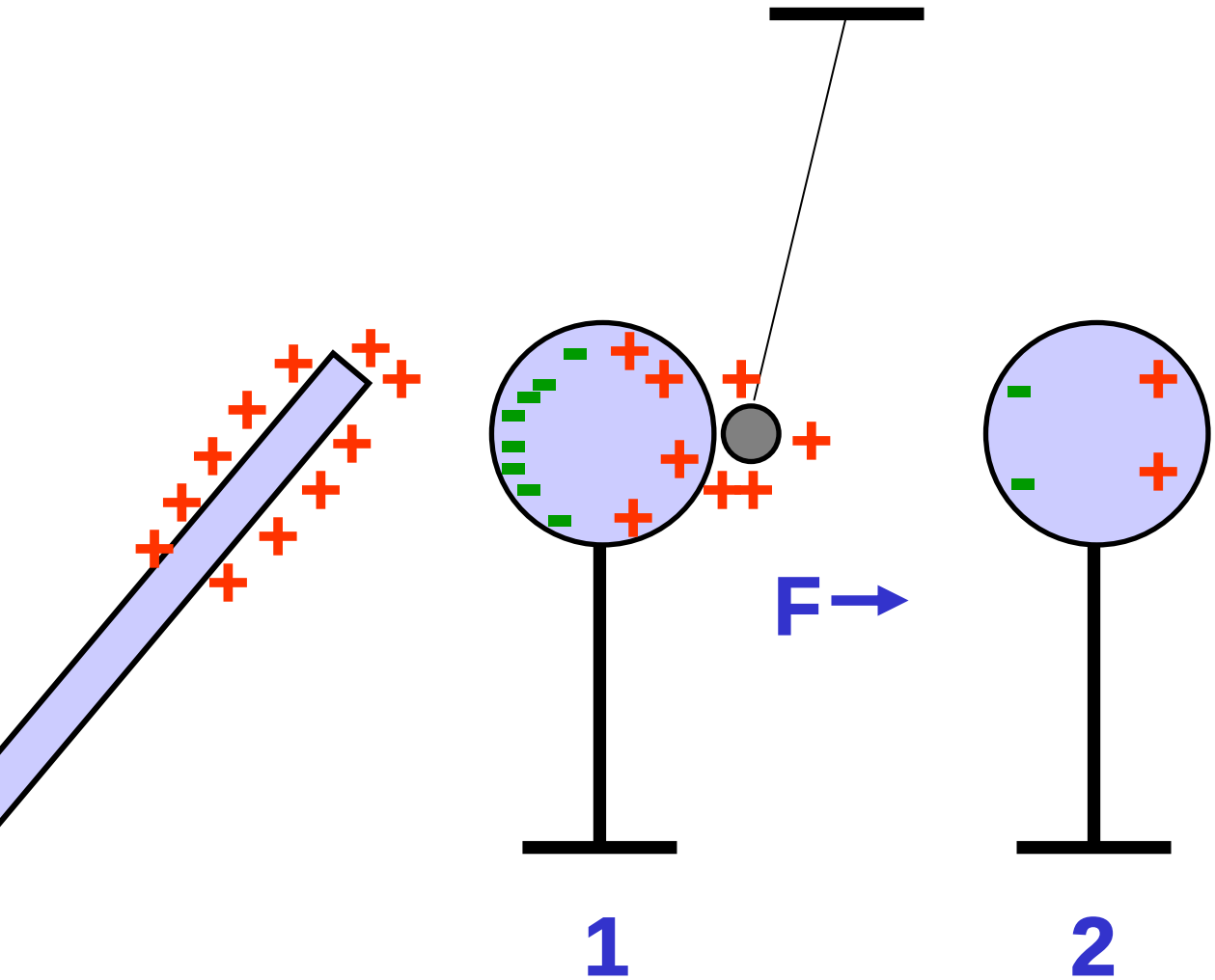


1 2

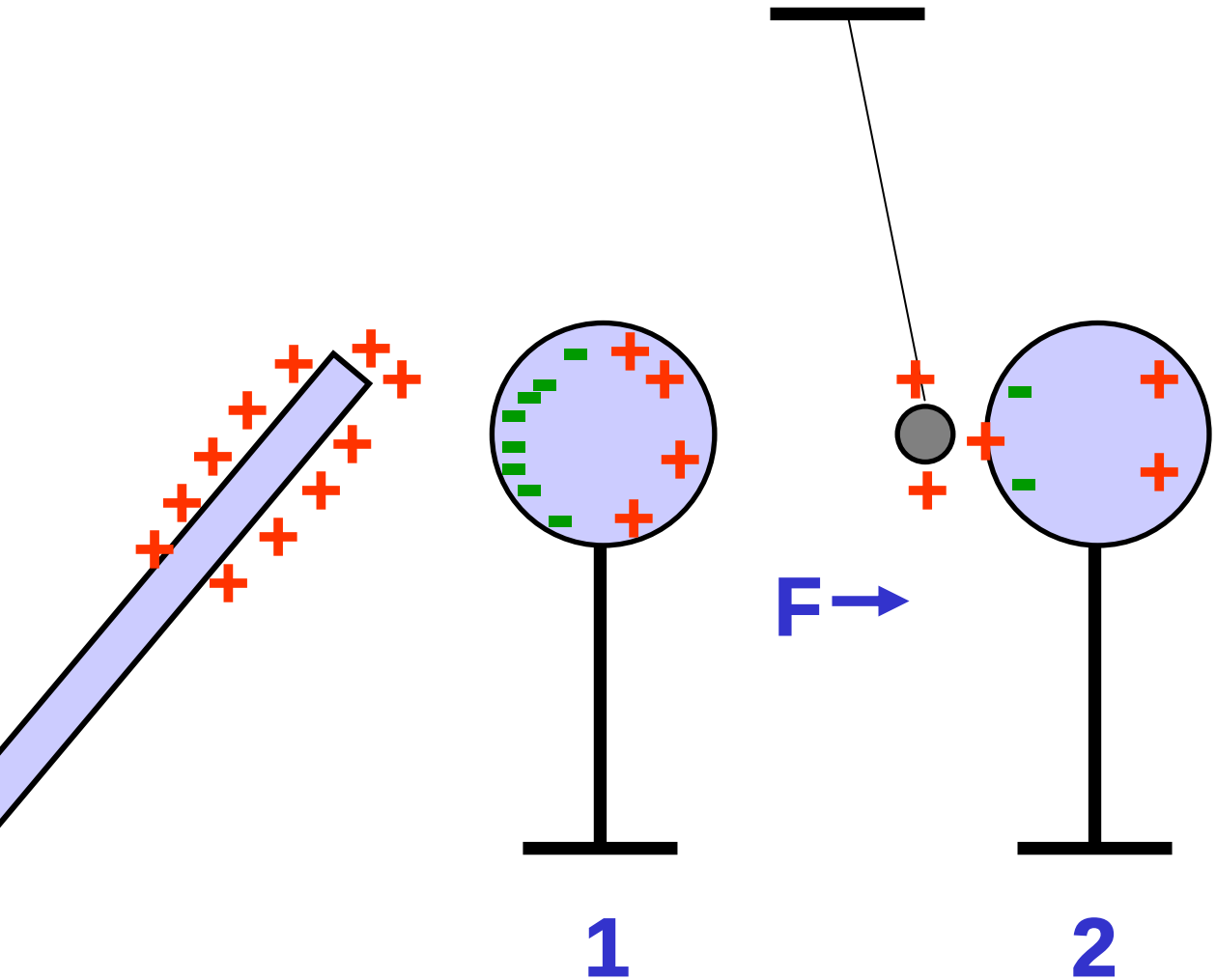
- Net Force on ping-pong ball
- Attracted to sphere 1



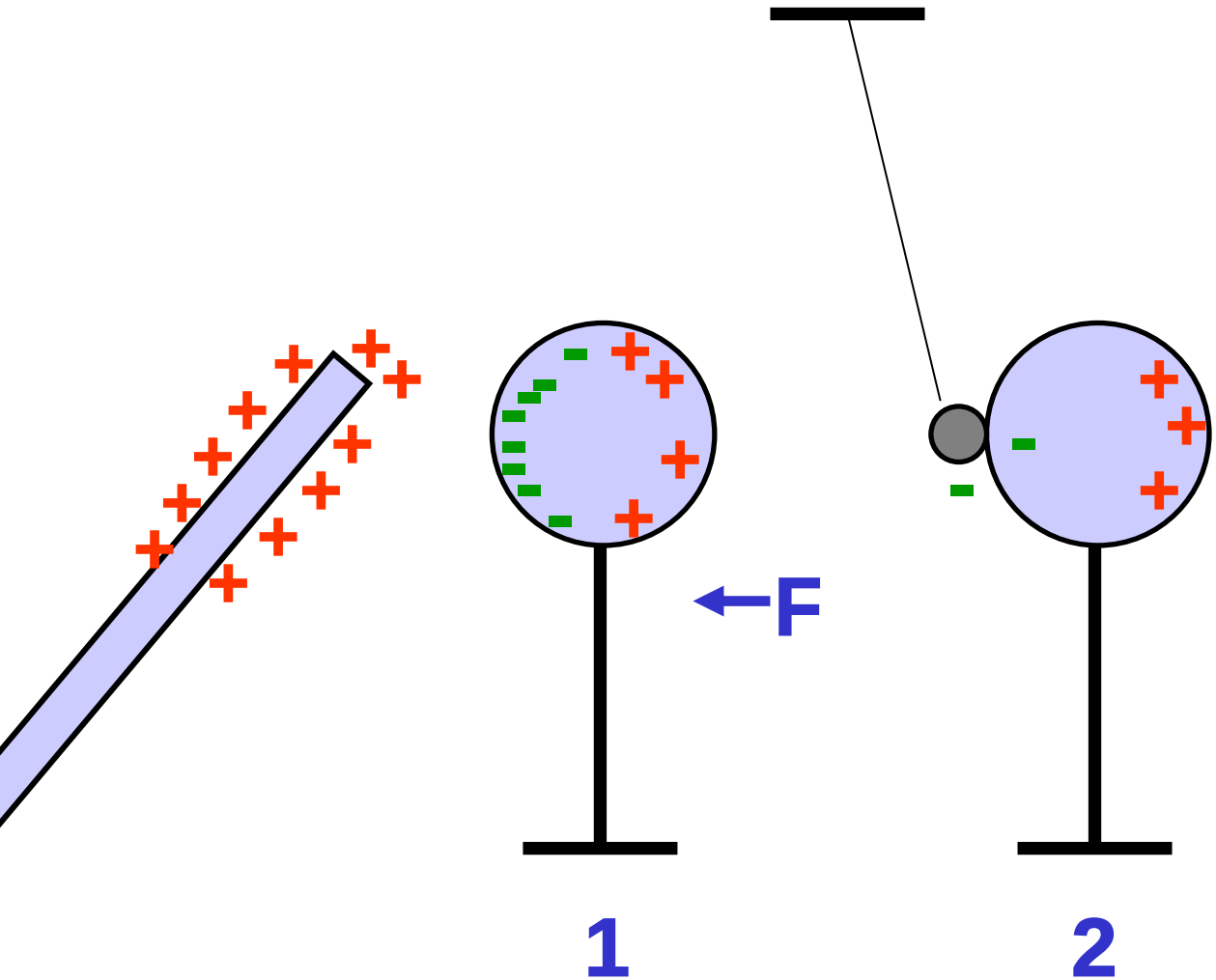
- Ping-pong ball touches sphere 1
- Picks up positive charge!



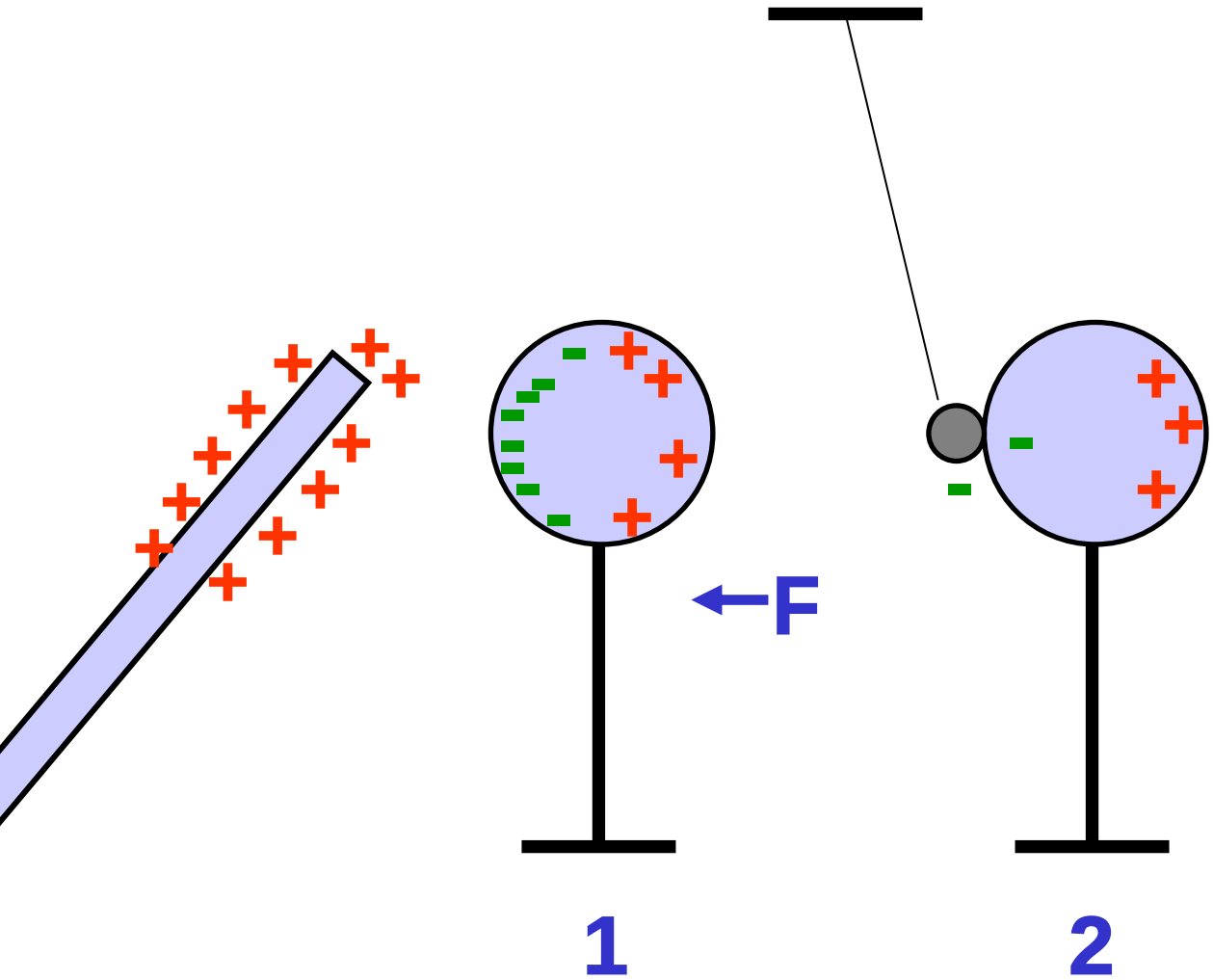
➢Ping-pong now attracted to sphere 2



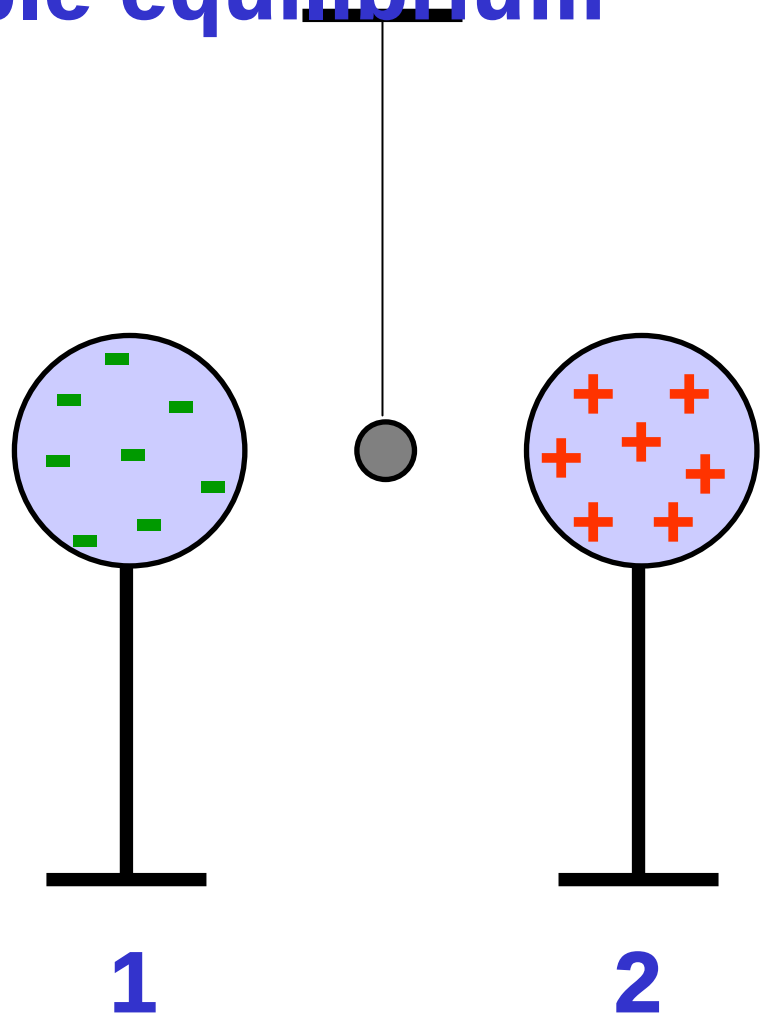
- Ping-pong touches sphere 2
- Picks up negative charge



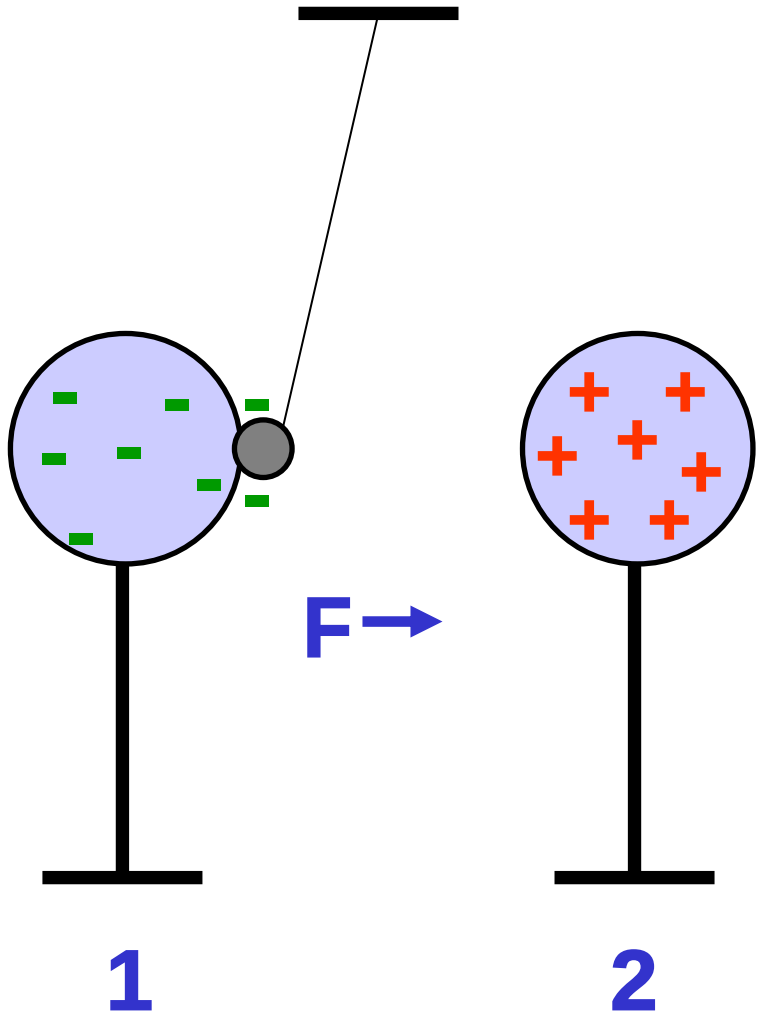
- Each time, there's less charge to pick up
- Eventually, process comes to a halt



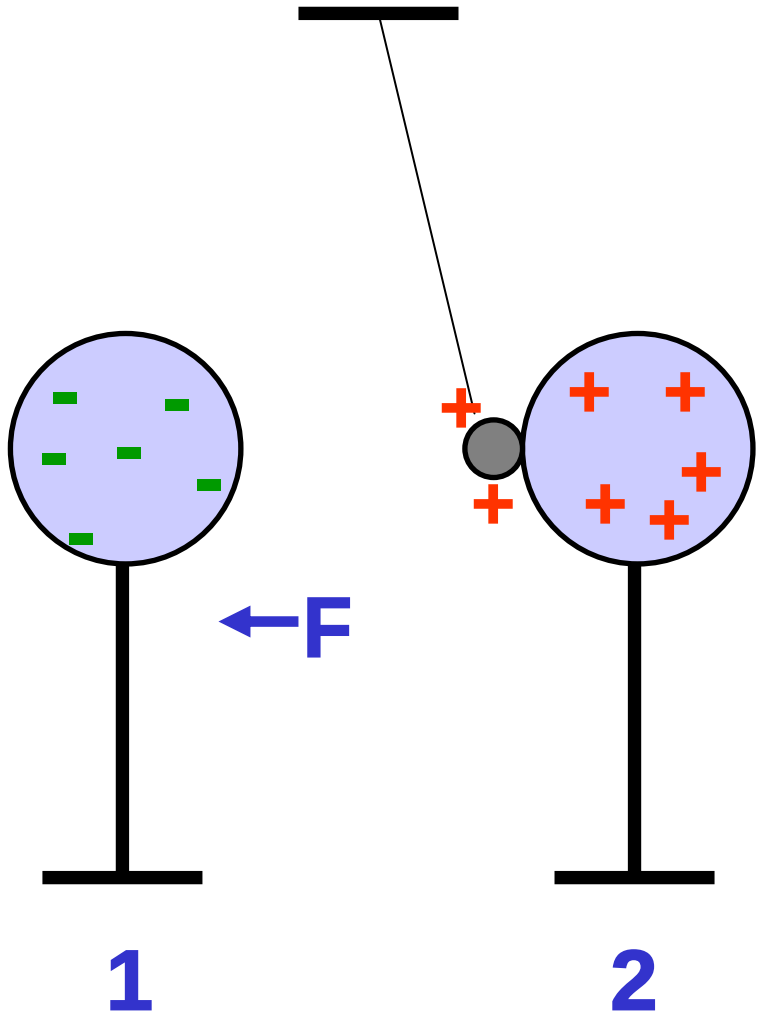
- Now remove rod
- Charge on 1 and 2 equal, opposite
- Unstable equilibrium



- One side wins, attracts ball
- Ball picks up charge -> Repulsion



- Touches other sphere
- Continue until both spheres neutral

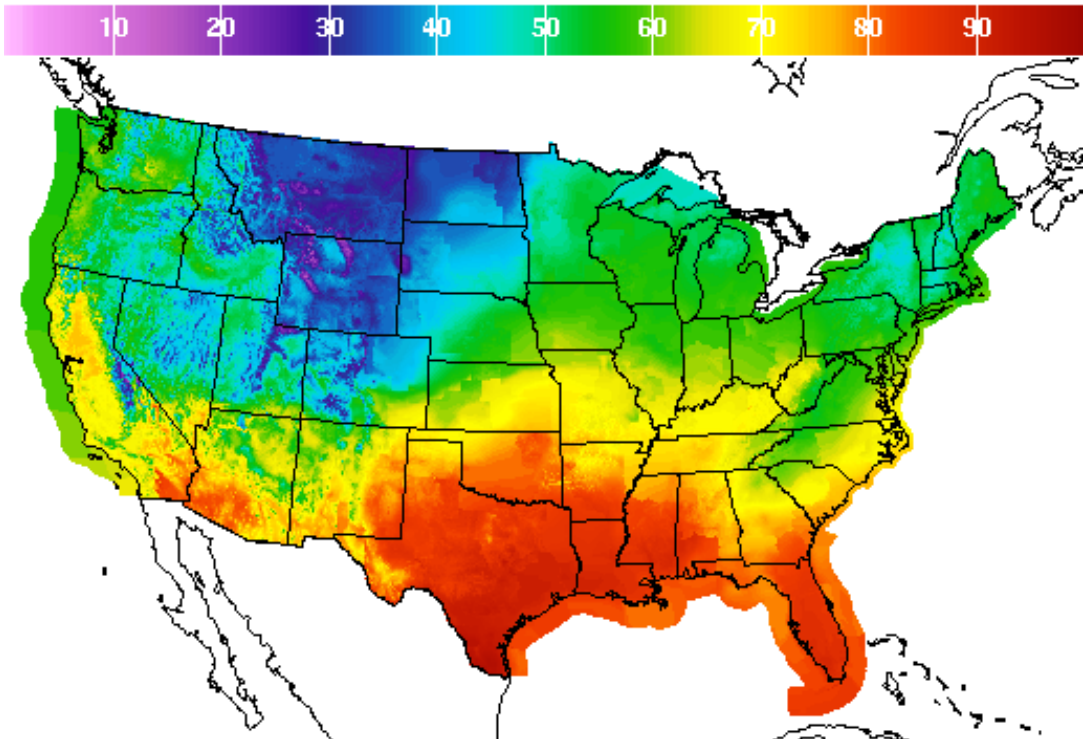


The Electric Field

- What's a field?
- How's the electric field defined?
- Is it real?

Example of Scalar Field

- Each Location $\vec{X}$ connected to a Number: $T(\vec{X})$



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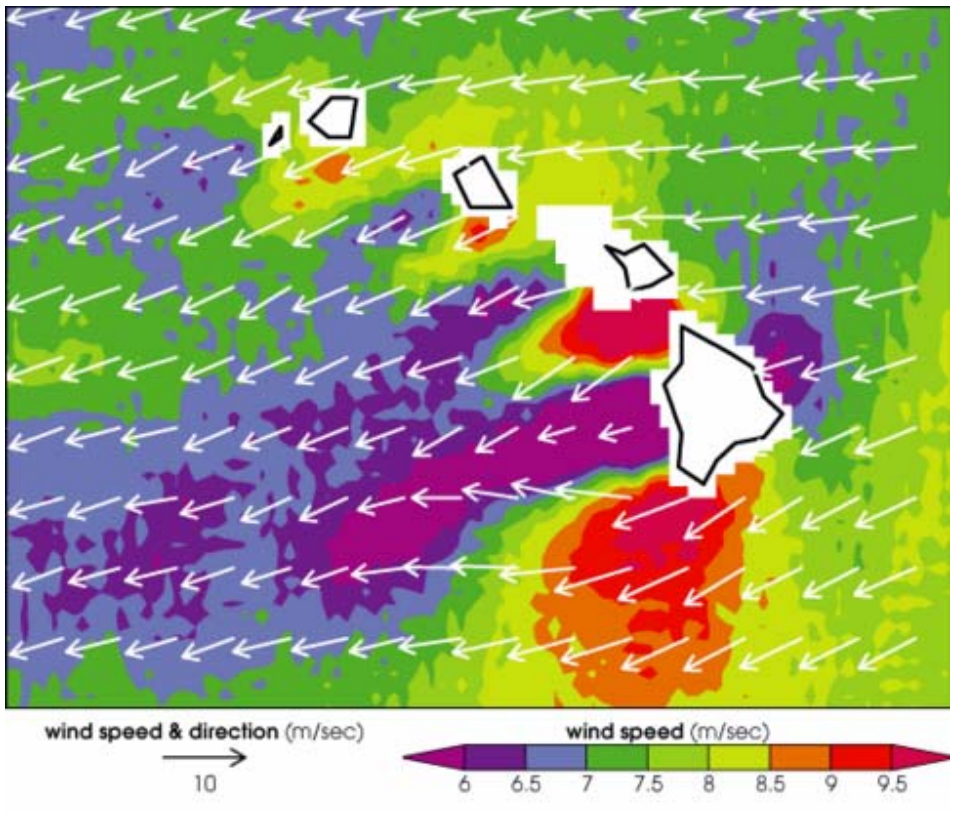
Example of Vector Field

- Each Location $\vec{X}$ connected to a vector: $\vec{v}(X)$



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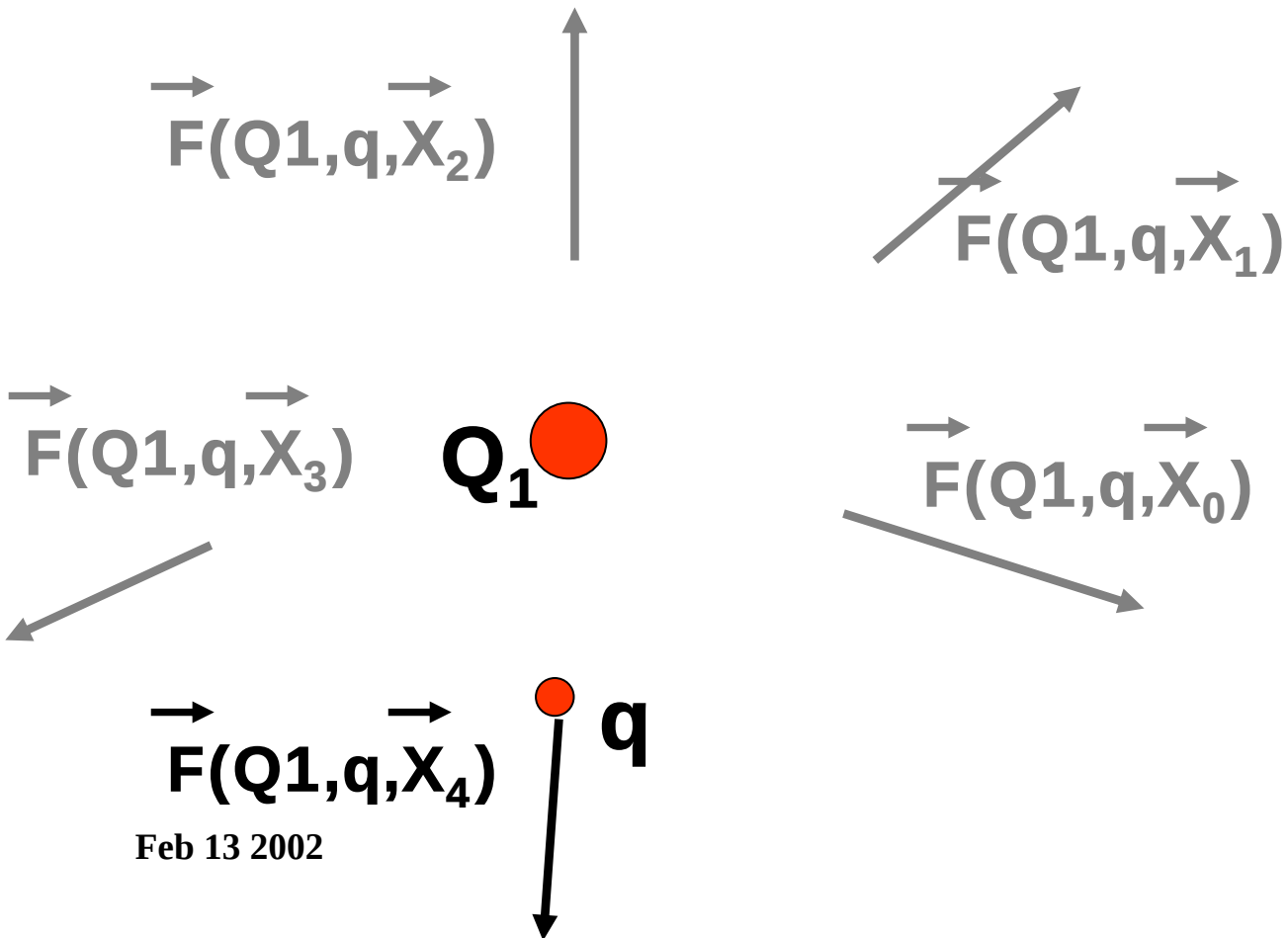
The Electric Field



The Electric Field

- Electric field is a Vector Field:

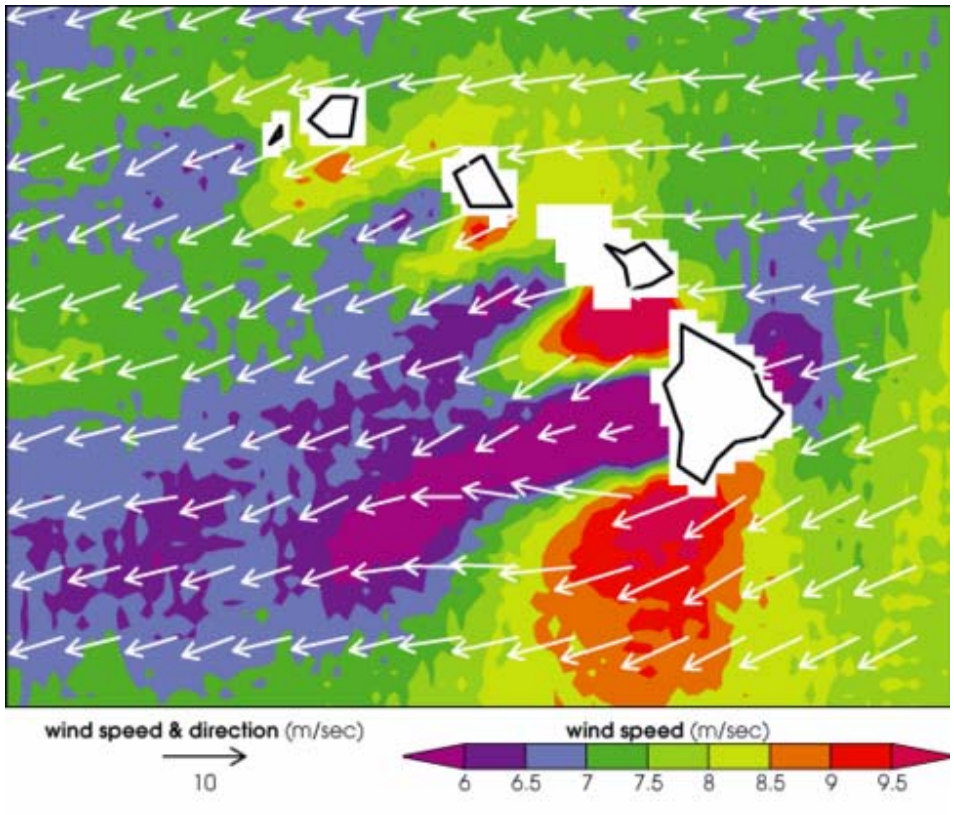
$$\vec{E}(\vec{x}) \stackrel{\text{def}}{=} \vec{F}(\vec{x}) / q$$

- For each location x, E gives Force on a ‘test charge’ q
- We can say: Space around charge Q is modified, such that ‘test charge’ q feels a force **F=Eq**

The Electric Field

- Superposition principle for Forces
  - also true for Electric field (from Definition)
- Field from many charges is vector sum of individual fields
  - integral in limit of continous distributions

Visualizing Fields



- One way to do it
  - Color: Speed
  - Line orientation, arrow: Direction

Visualizing the Electric Field

- Electric field ‘lines’
  - Michael Faraday, 1791-1867
- Cartoon of Strength and Direction of Field
- Line Density: Strength
- Line Orientation: Direction (for positive test charge q)