PHY294H

- Professor: Joey Huston
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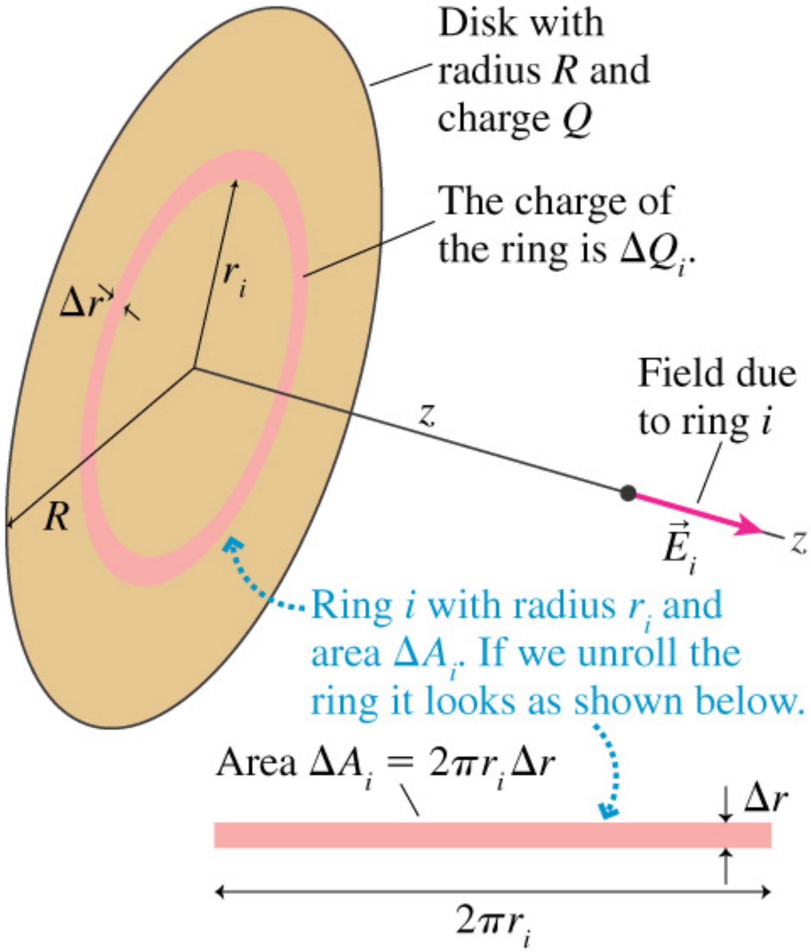
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **2nd MP assignment due Wed Jan. 27; second hand-written problem (27.51) as well; I'll add it on to the MP assignment for convenience, but it still needs to be turned in with a complete solution**
  - **Help-room hours: 12:40-2:40 Tues; 3:00-4:00 PM Friday**
- Quizzes by iclicker (sometimes hand-written)
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

What if the plane of charge is not infinite?



- Consider a disk of radius R containing a total charge Q

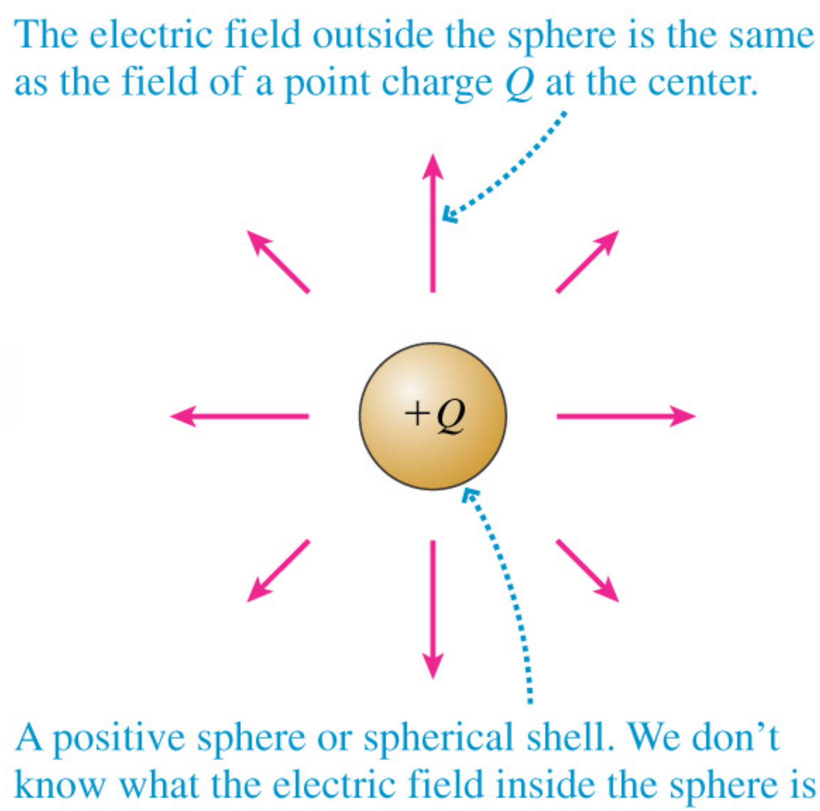
$$\left(E_{disk}\right)_z = \frac{\eta}{2\varepsilon_o}\left[1 - \frac{z}{\sqrt{z^2 + R^2}}\right]$$

Derivation in book

Electric field due to sphere of charge

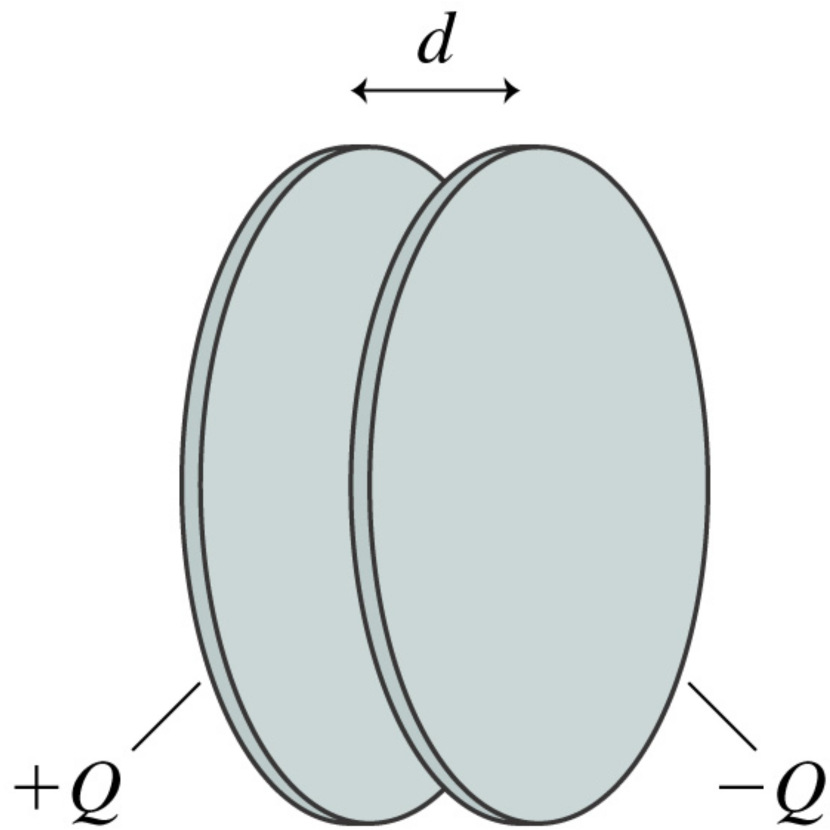
- Won't do the derivation (3 dimensional integral) but can state that electric field due to charged sphere looks like that due to a point charge

$$\vec{E}_{\text{sphere}} = \frac{Q}{4\pi\epsilon_0 r^2}\hat{r} \qquad \text{for } r \geq R$$



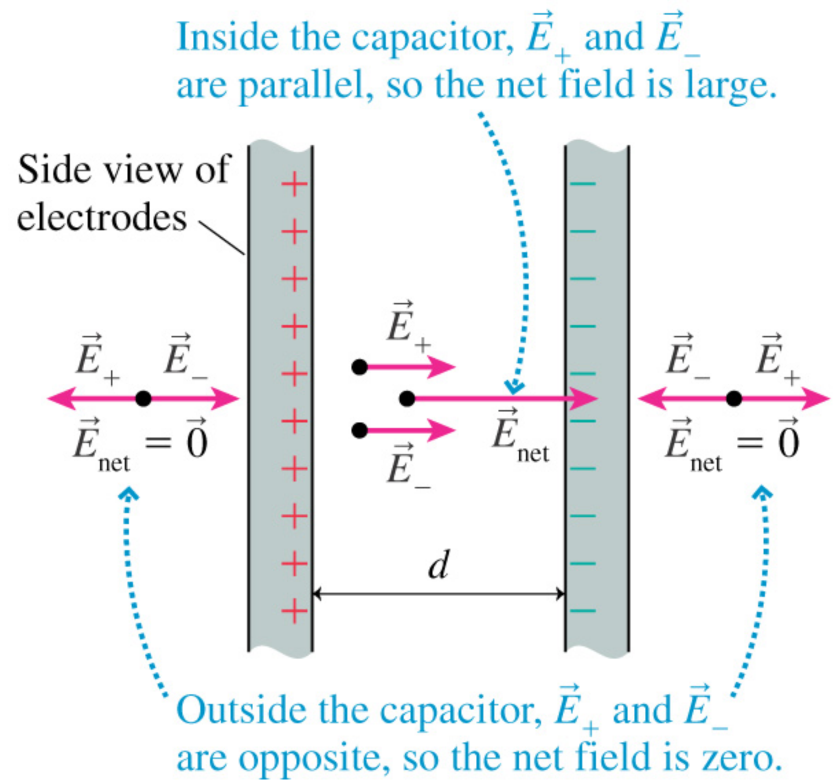
Capacitors

- Let's take 2 disks a distance d apart, put a charge of +Q on one plate and a charge of -Q on the other plate
- We have a parallel plate capacitor
  - note that the total charge on the capacitor is zero
  - what does the electric field look like?
  - remember our previous results for a plane of charge



Electric field

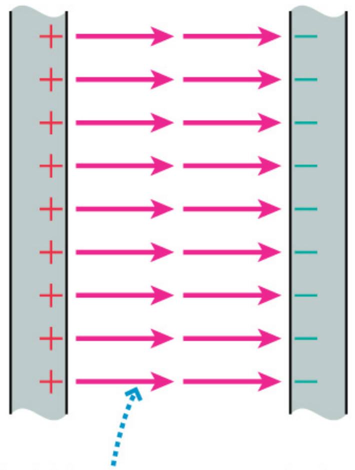
- Because opposite signs attract (and these are conducting plates), charge resides on inner surfaces
- Electric field inside the capacitor is doubled, zero outside
- Inside:
  - $E_+ = \eta/(2\varepsilon_o)$
  - $E_- = \eta/(2\varepsilon_o)$
  - both fields in same direction
  - $E_{tot} = \eta/\varepsilon_o$
  - note factor of 2



Uniform electric fields

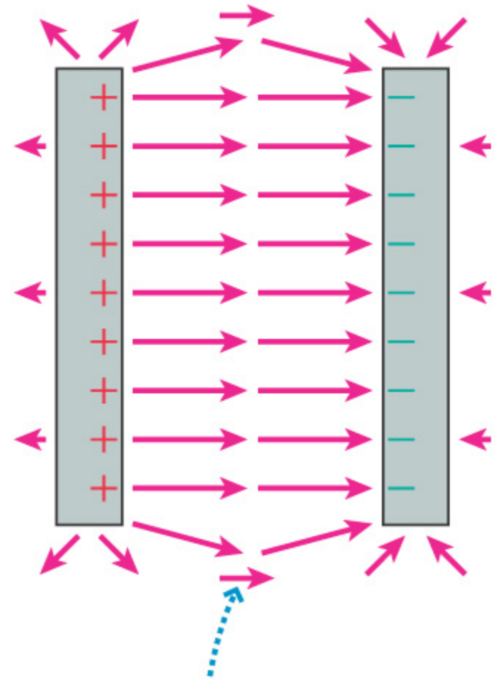
- A capacitor is a good way of producing a uniform electric field
- Of course in reality, a capacitor has a finite extent so there are fringe fields at edge
  - but we' ll ignore those for the first part

(a) Ideal capacitor



The field is constant, pointing from the positive to the negative electrode.

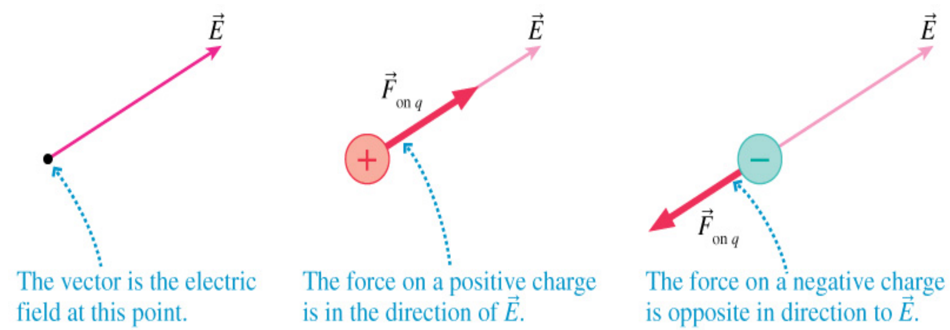
(b) Real capacitor



A weak fringe field extends outside the electrodes.

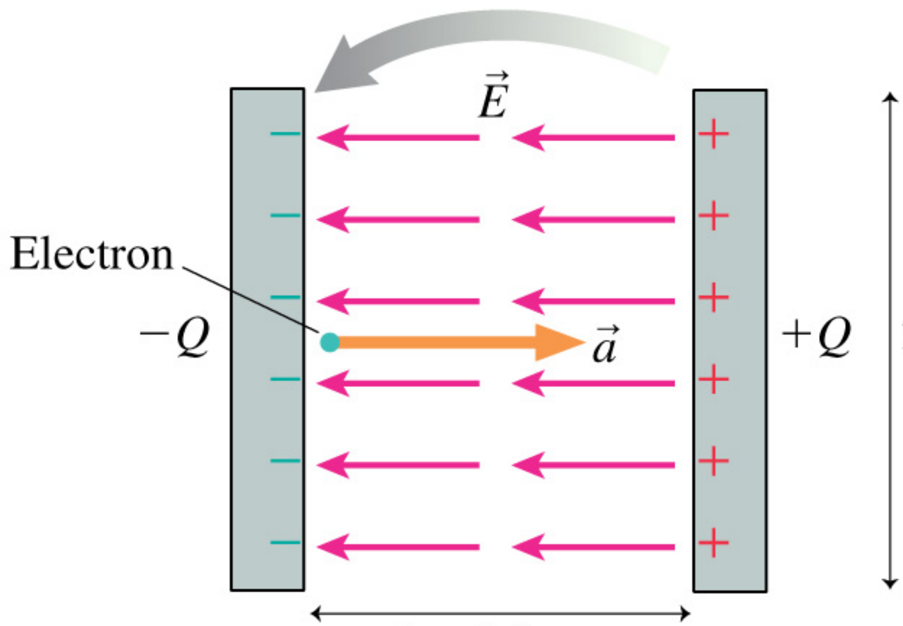
Motion of a charged particle in an electric field

- If I put a charge in an electric field, it will experience a force given by $\vec{F}_{on\ q} = q\vec{E}$ and an acceleration = $\vec{F}_{on\ q}/m = q\vec{E}/m$
- If the electric field is uniform, then F will be uniform and thus a will be uniform
  - $\vec{a} = q\vec{E}/m$ = constant
  - this we can handle



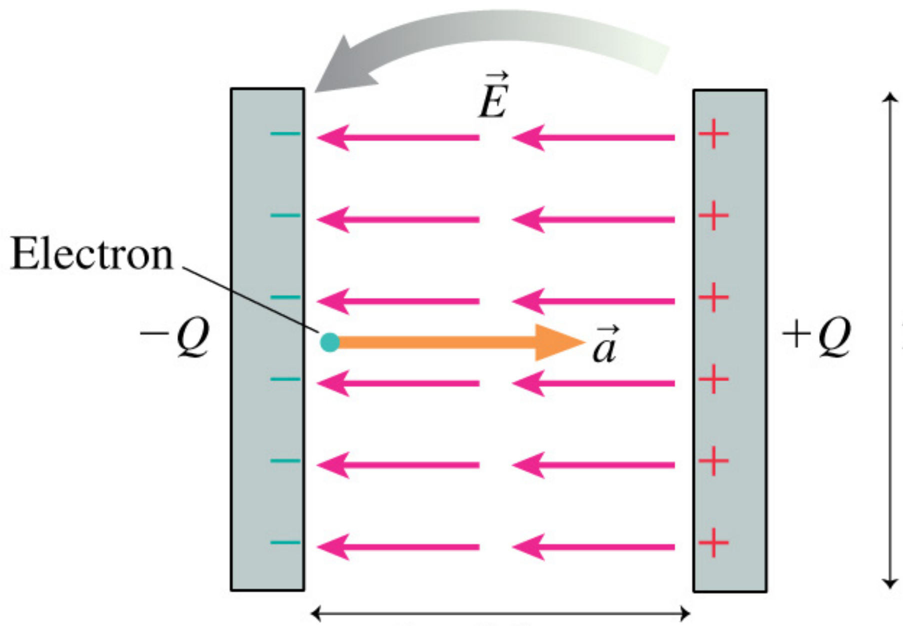
Let's take an example

- Let's take 2 disks 10 cm in radius separated by 1 cm
- Move 10^{12} electrons from right disk to left disk
- What is the electric field set up inside the capacitor?



Let's take an example

- Suppose I place an electron next to the left plate and let the electric field act on it? What is the acceleration it experiences?
- How long does it take to move across the gap?
- How fast is it moving when it gets there?

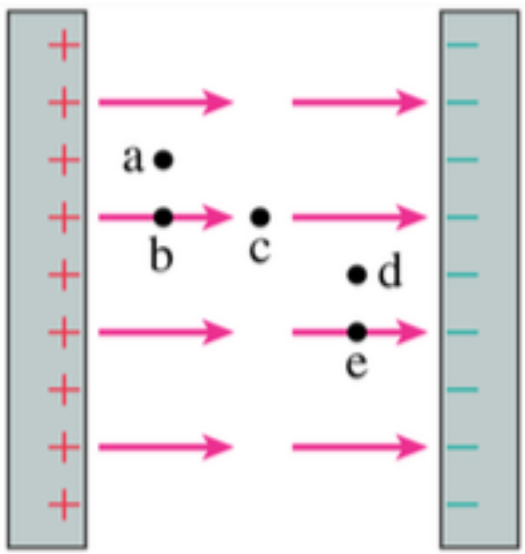


iclicker question

Rank in order, from **largest to smallest**, the forces F_a to F_e a proton would experience if placed at points a – e in this parallel-plate capacitor.

$$E_{capacitor} = \frac{\eta}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$

A. $F_a = F_b = F_d = F_e > F_c$
B. $F_a = F_b > F_c > F_d = F_e$
C. $F_a = F_b = F_c = F_d = F_e$
D. $F_e = F_d > F_c > F_a = F_b$
E. $F_e > F_d > F_c > F_b > F_a$



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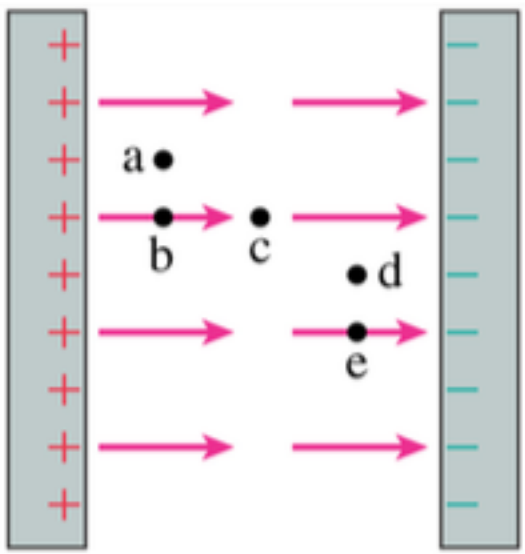
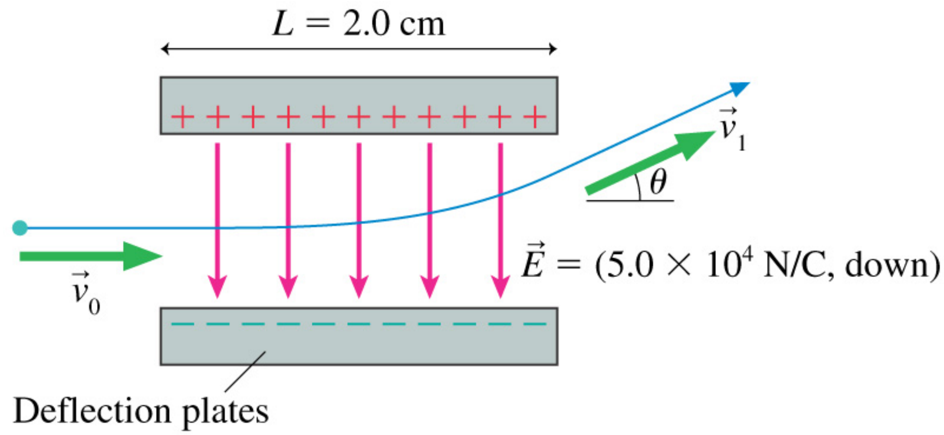
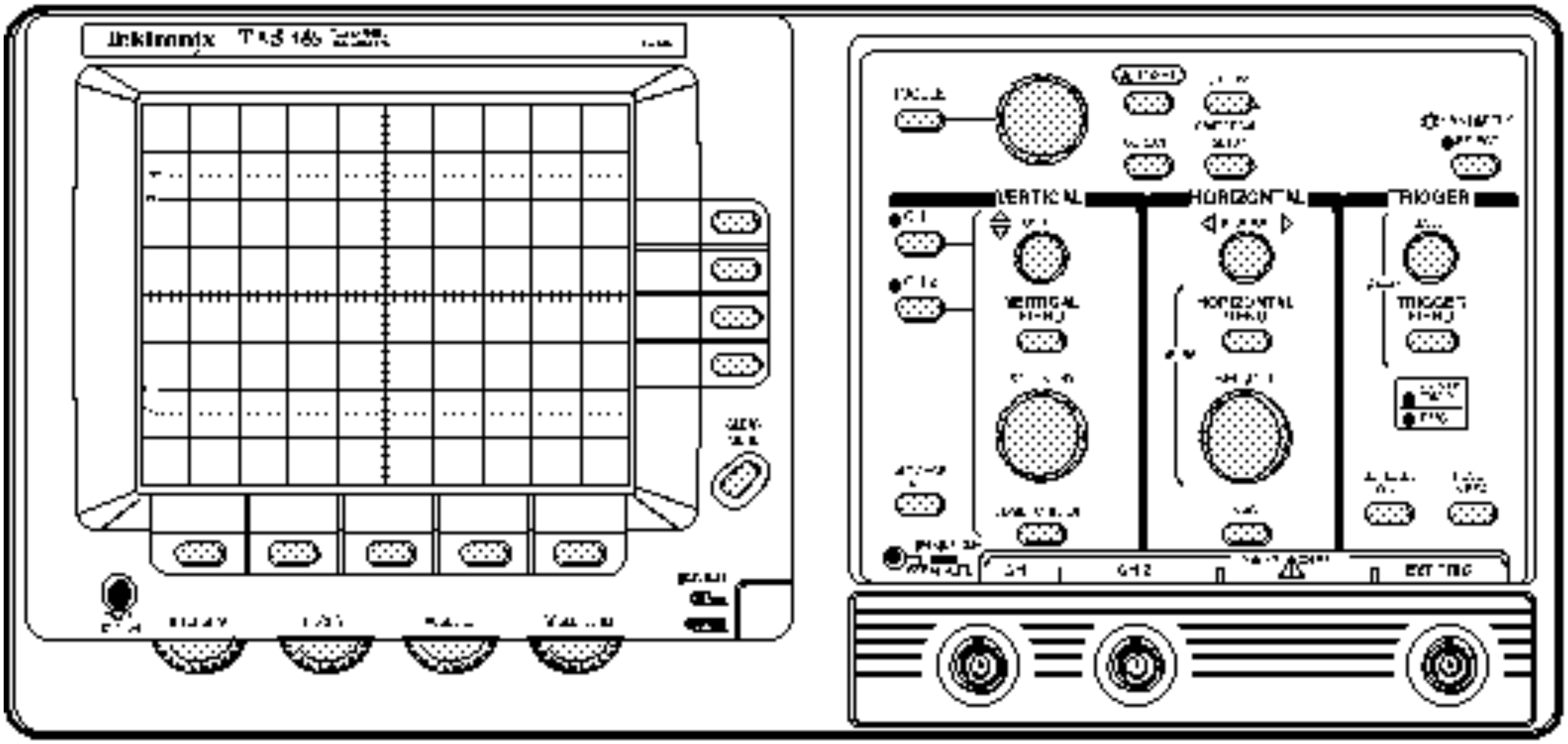


Turn the capacitor around

- An electron moving through an electric field perpendicular to its (original) motion will be deflected
- Like what happens in an oscilloscope

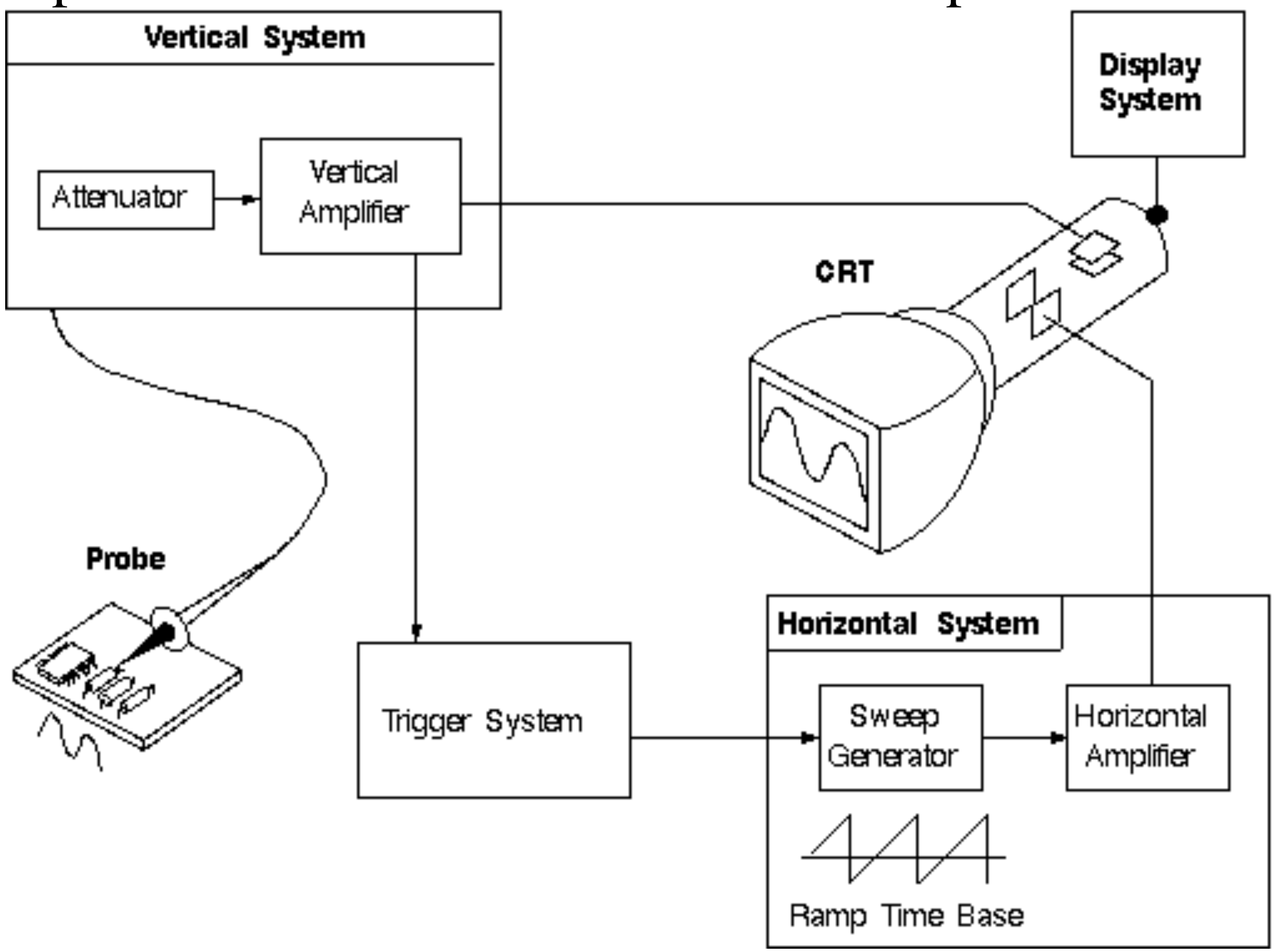


Oscilloscope

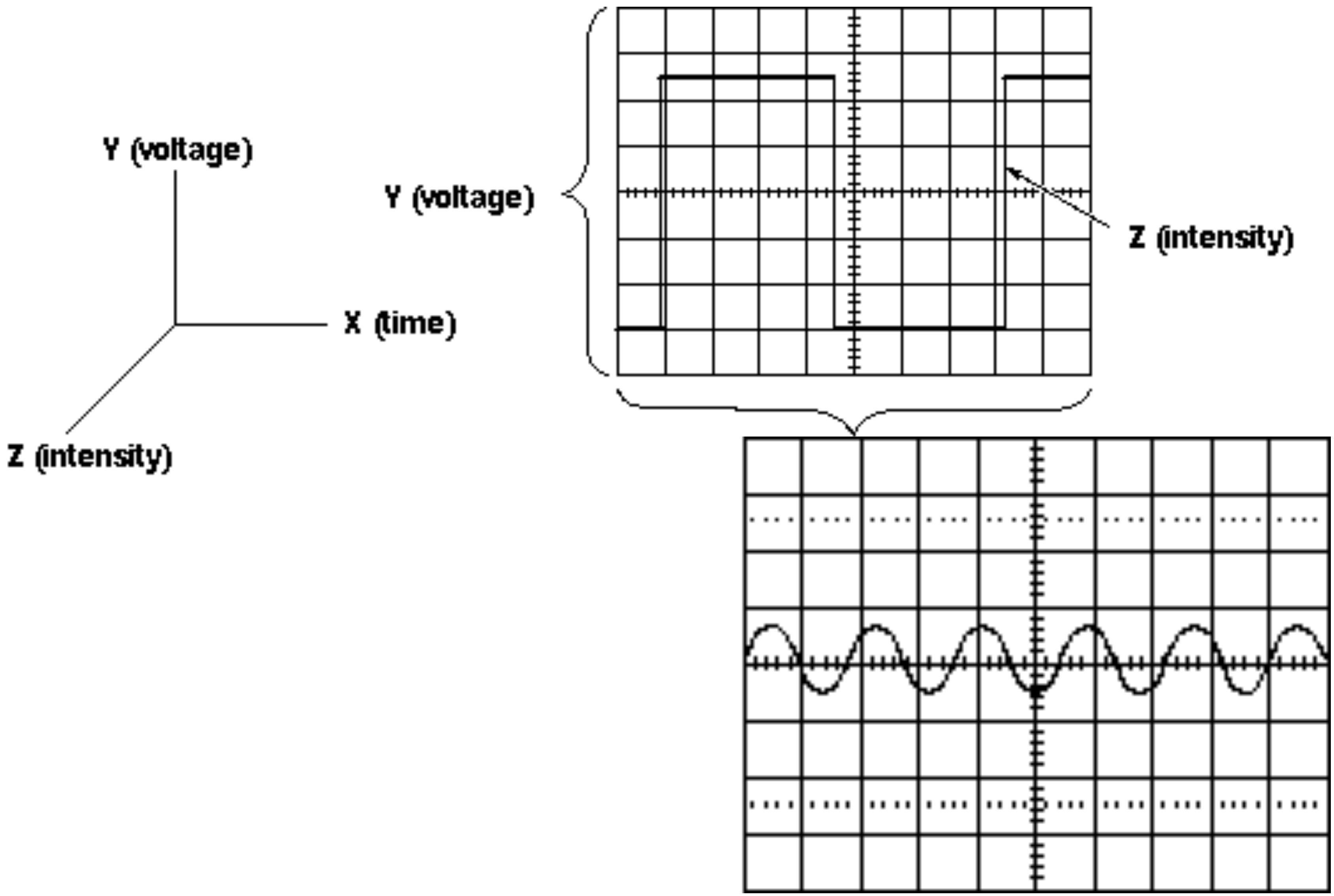


How it works

There's a cathode ray tube, much like in a TV. An electron beam hits a phosphor screen. The electron beam sweeps across the screen.

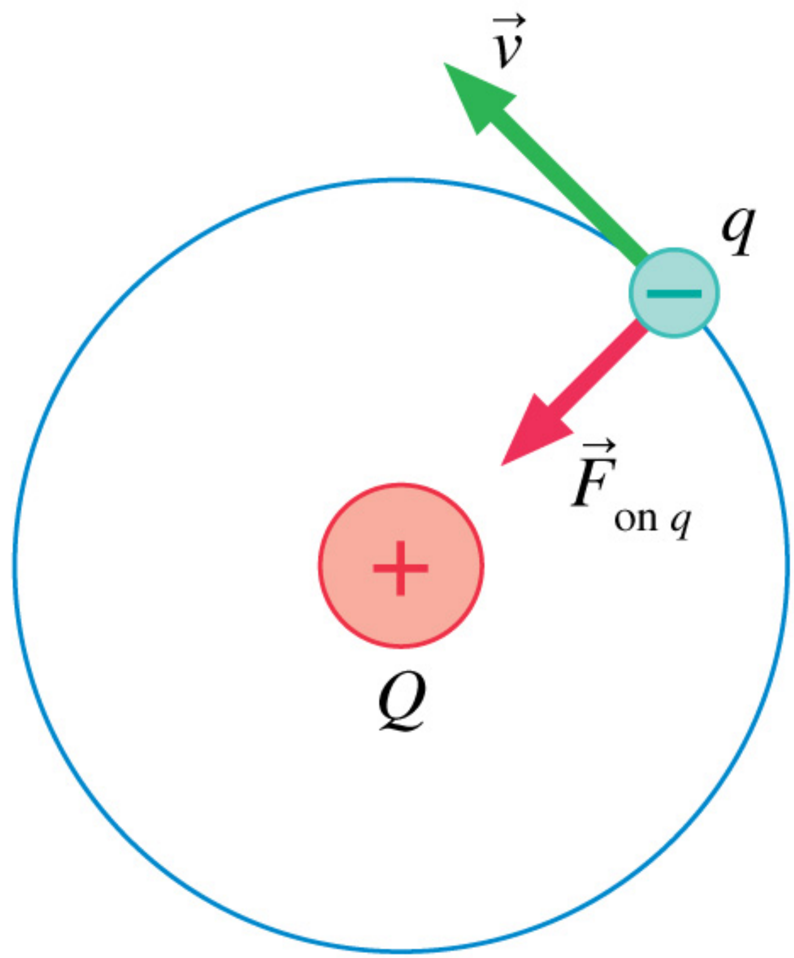


Waveforms



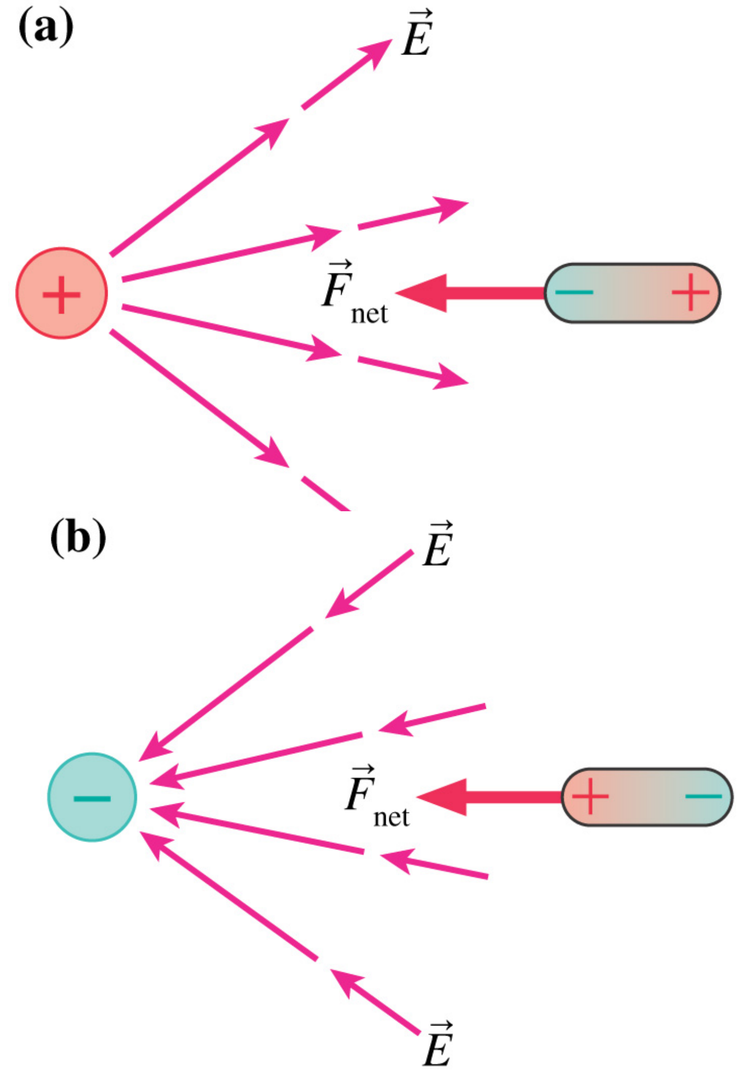
Motion in a non-uniform electric field

- This could be for example an electron orbiting a proton in a hydrogen atom
- $(F_{net})_r = mv^2/r$
  - …or $|q|E=mv^2/r$
  - $a = |q|E/m$
- We'll find out later in this course what's wrong with this simple description of a hydrogen atom
  - accelerating charges radiate, and the electron is accelerating



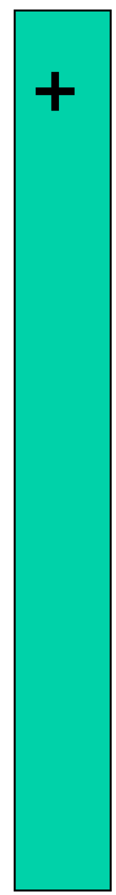
Dipole in a non-uniform electric field

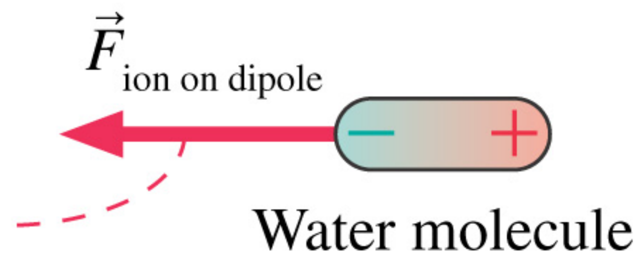
- The trick is that the electric field from the charged rod was not a uniform electric field
- So the net force is non-zero, no matter the direction of the electric field (or another way of saying it, the sign of the charge creating the electric field)



Force on a water molecule

- Let's consider the force of our charged rod acting on a water molecule from the stream
- Treat the rod as a point charge
  - only the end is charged
- We can calculate the difference in the force on the negative end and the positive end of the water molecule
- Or since $F_{\text{rod on molecule}} = F_{\text{molecule on the rod}}$, we can calculate the electric field from the water molecule and the resultant force on the rod





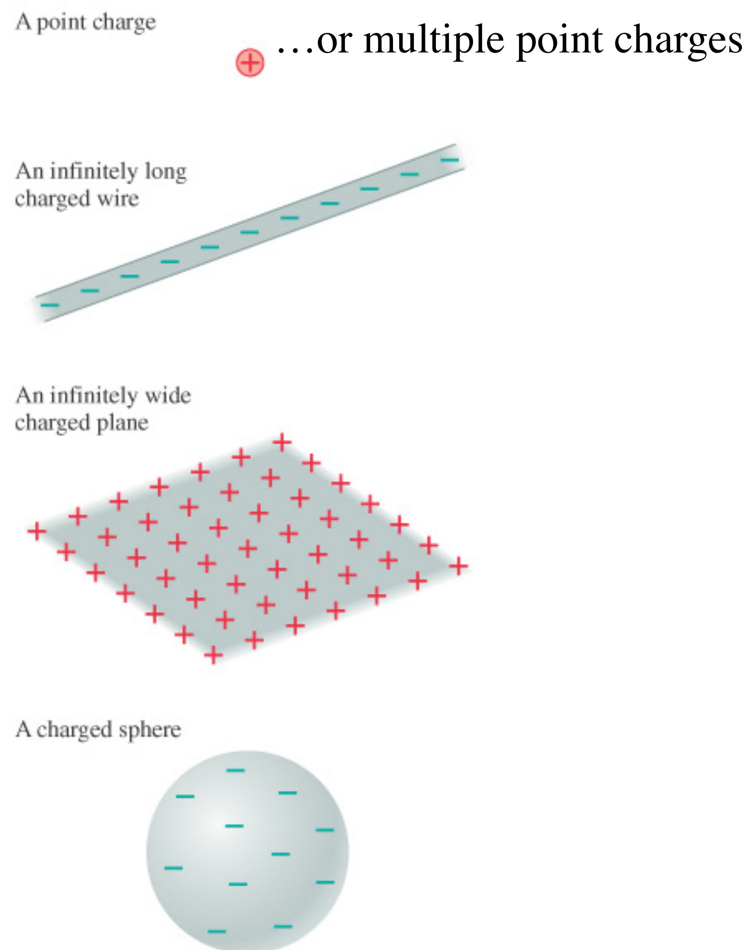
take q on rod as 10^9 +e charge

$r = 2$ cm

$|p| = 6.2 \times 10^{-30}$ C·m

Calculating electric fields

- In this last chapter, we calculated the electric fields for situations with more than one charge
  - either multiple point charges, or continuous charge distributions
  - we were able to calculate the electric field using the principle of superposition
    - $\vec{E}_{tot} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$
    - and this will always work
- But for situations in which there is a lot of symmetry, there's another very powerful and neat technique that we can use



Gauss' law

- This also allows us to introduce the first of Maxwell's equations, Gauss' law

$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\epsilon_0} \qquad (27.18)$$

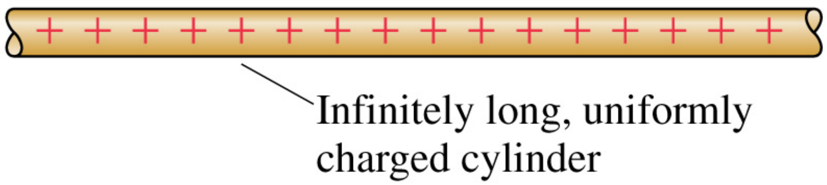
- …as well as Karl Gauss

- Note the introduction of a surface integral, something you probably haven't encountered in calculus yet
- Gauss' law states that the electric field flux integrated around any closed surface equals the charge enclosed by the surface divided by ε_o

Symmetry

- Let's step back from the ideas of electric flux and surface integrals and first think about symmetry
- Very powerful argument in all of physics
- For example, we can state that the symmetry of an electric field should match the symmetry of the electric charges that create the field

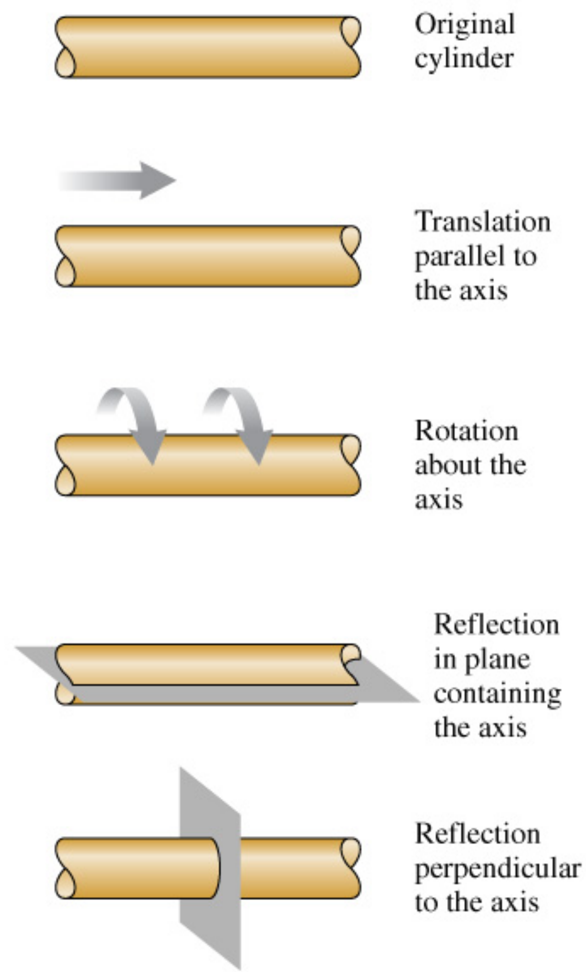
Consider the case of an infinitely long uniform charged cylinder



We already know what the electric field looks like, but what can we argue on the basis of the symmetry of the charge distribution

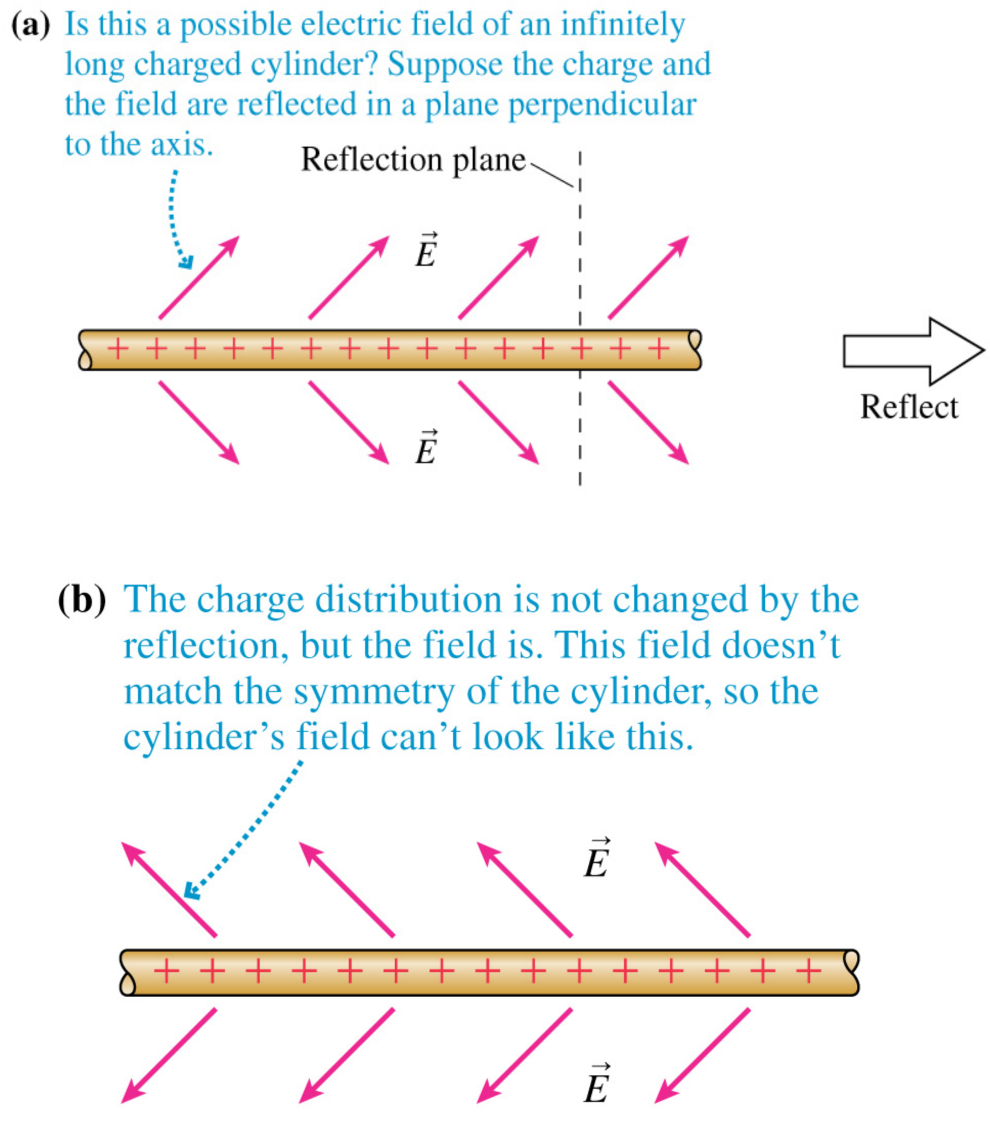
Symmetry of cylindrical charge distribution

- The charge distribution looks unchanged if
  - you perform a translation parallel to the axis
  - a rotation about the axis
  - a reflection in the plane containing the axis
  - a reflection perpendicular to the axis



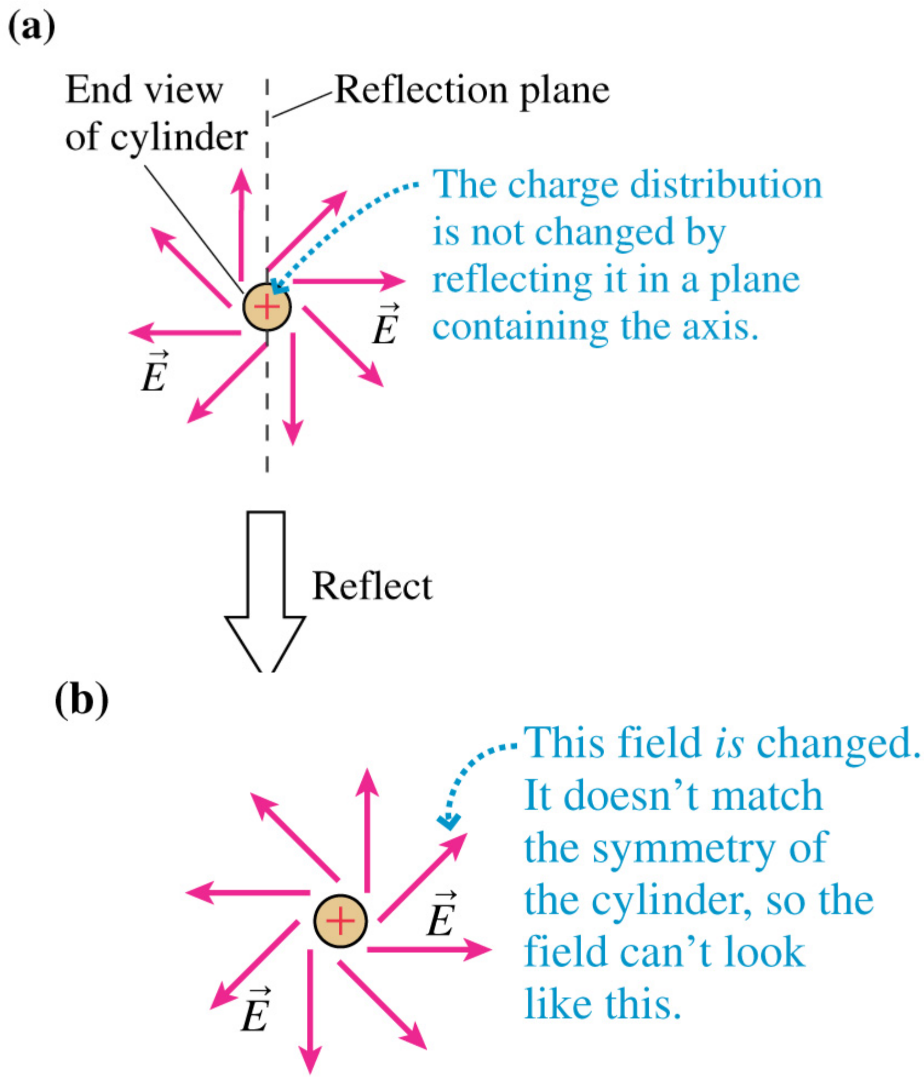
Field symmetries: possible field

- This field looks the same upon translation, rotation, reflection in a plane containing the axis but not in a plane perpendicular the axis
- The field then doesn't match the symmetry of the charge distribution, so this field configuration can't be right
- The electric field of a cylindrically symmetric charge distribution can not have a component parallel to the cylinder axis



Field symmetries: possible field

- This field configuration doesn't work with reflection in a plane containing the axis
- The electric field of a cylindrically symmetric charge distribution can not have a component tangent to the circular cross section



Goldilocks and the 3 field distributions

- This field distribution is just right
- The electric field is radial, pointing straight out from the wire
- Convince yourself that it matches the symmetry of the charge distribution
- Note that these arguments don't tell us whether the field falls off as $1/r^2$ or $1/r$ (the latter which we already had calculated); just that it has a cylindrical symmetry