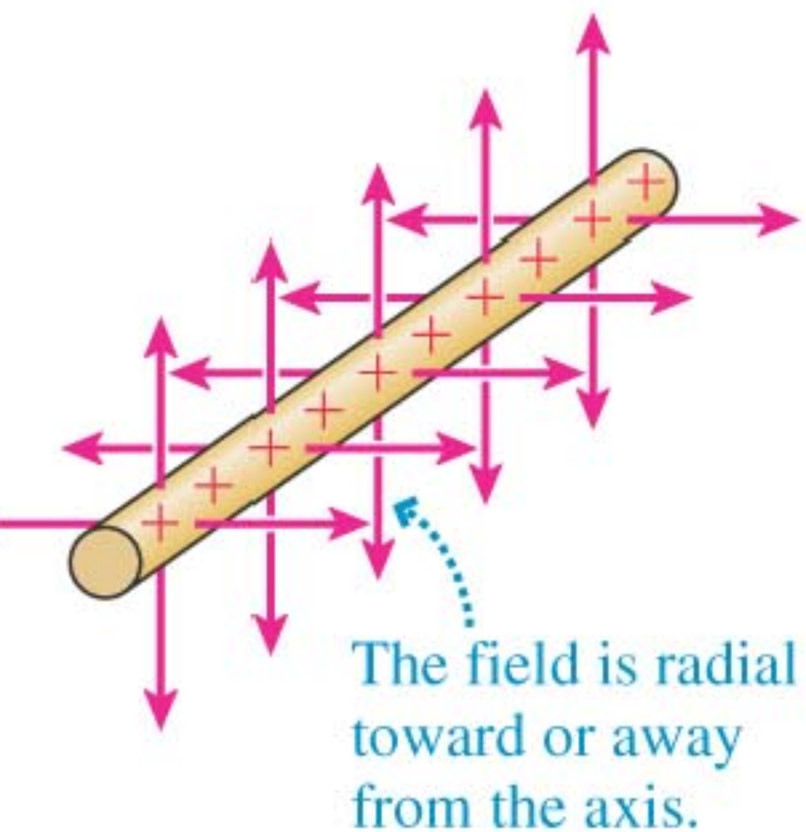
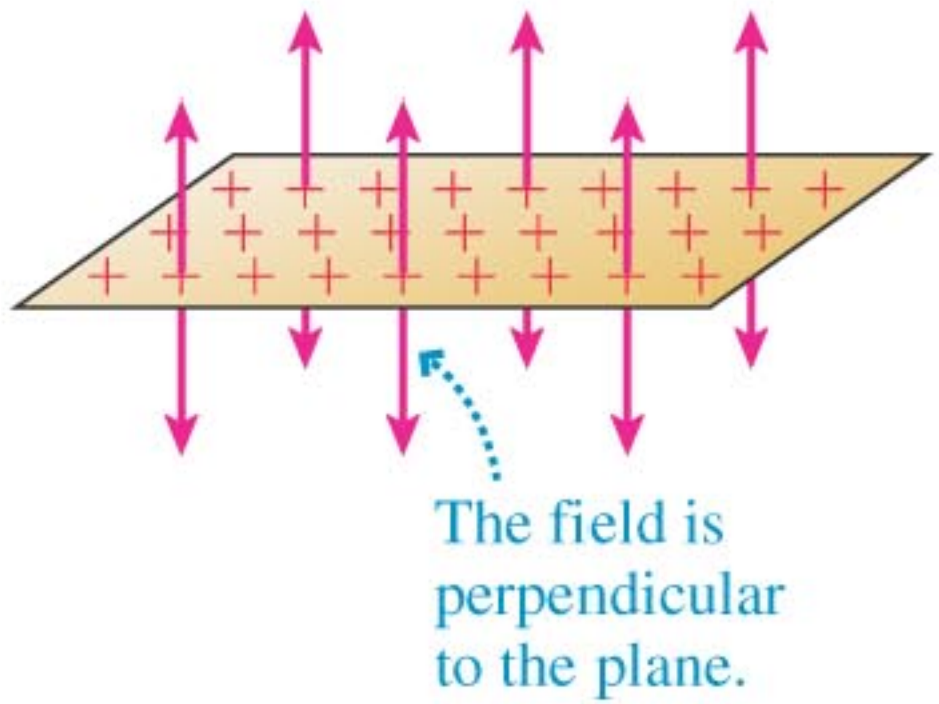
Three Basic Charge Distributions

infinite line of charge



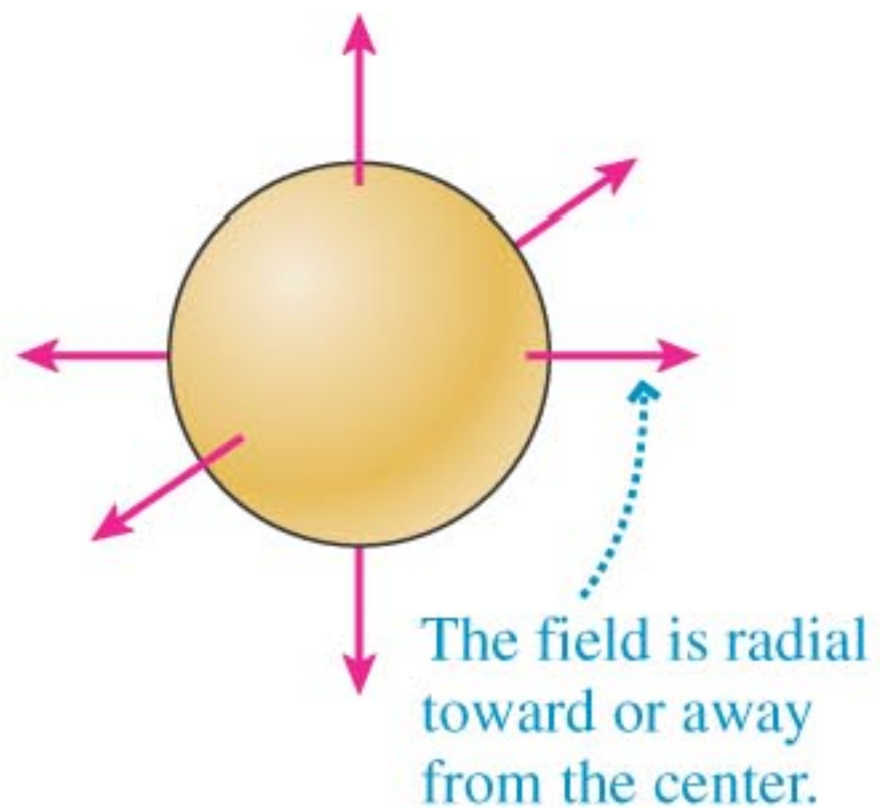
$$E_{\text{line}} = \frac{1}{2\pi\epsilon_0}\frac{\lambda}{r}$$

infinite plane of charge



$$E_{\text{plane}} = \frac{\eta}{2\epsilon_0}$$

sphere of charge (same as point charge)

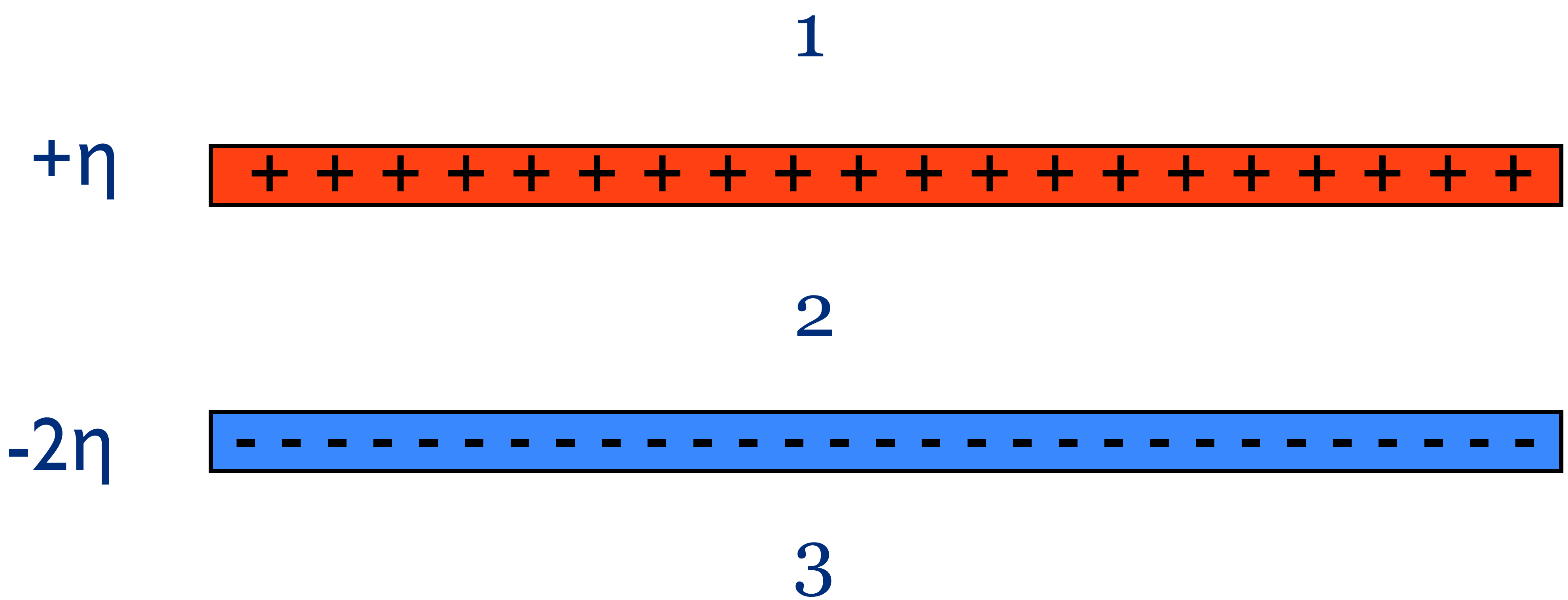


$$E_{\text{sphere}} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$

$$\lambda = \frac{Q}{\ell} = \text{ linear charge density}$$

$$\eta = \frac{Q}{A} = \text{ surface charge density}$$

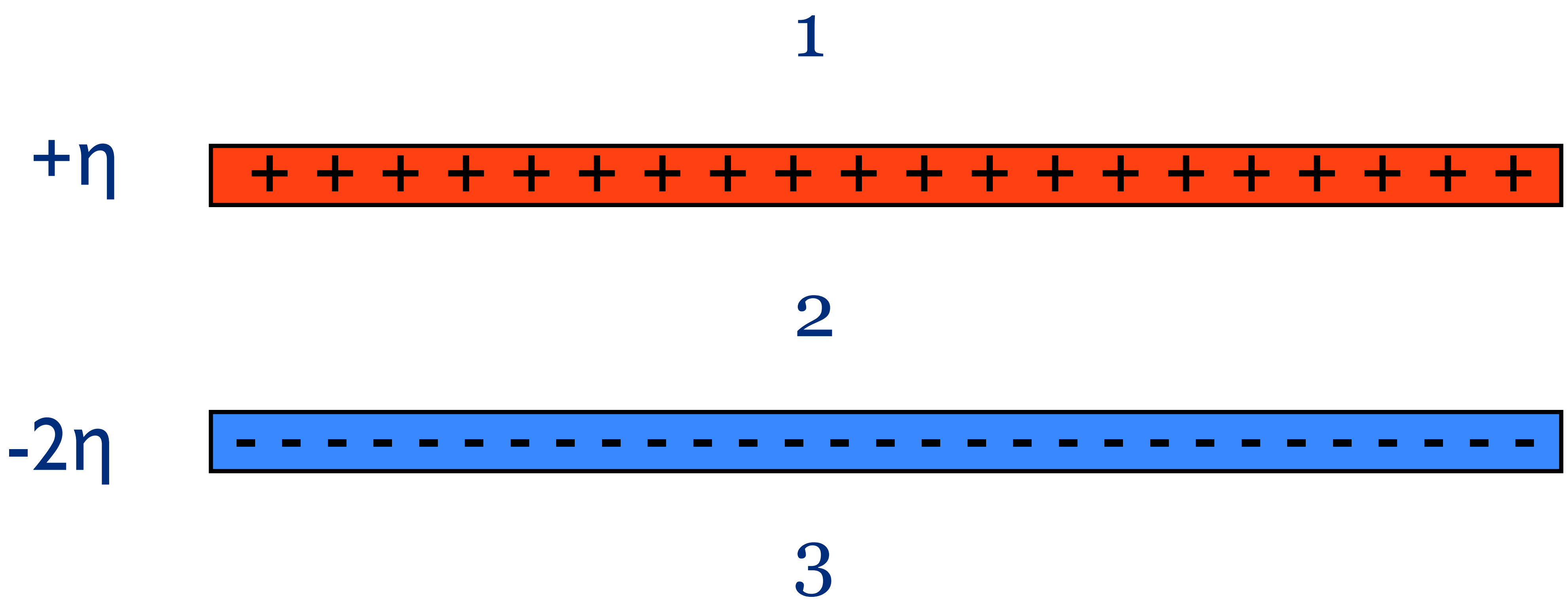
Unevenly charged planes



On a piece of paper, both draw and determine the strength of the electric fields in each the regions labelled 1, 2, and 3.

(assume they are infinite planes)

Unevenly charged planes

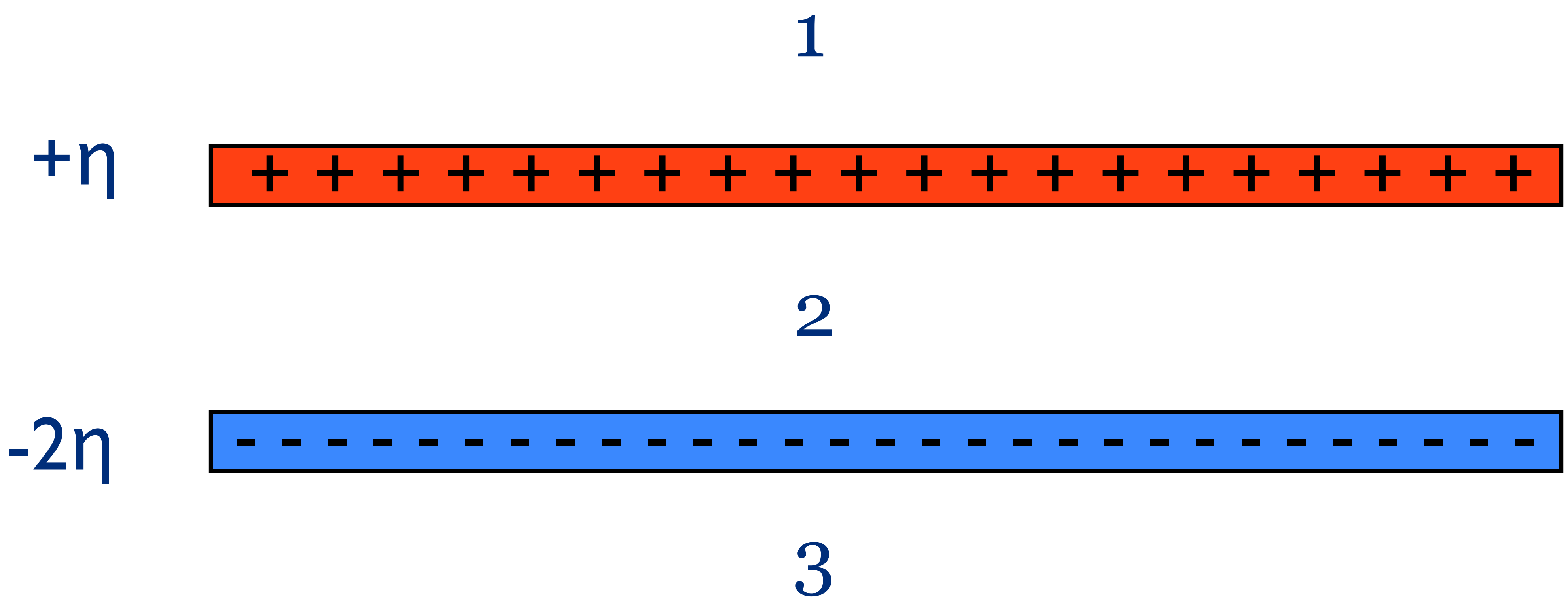


Which is true about the electric field in the regions 1 and 3?

a) $E_1 < E_3$, opposite directions
b) $E_1 < E_3$, same direction
c) $E_3 = E_1$, opposite directions
d) $E_3 = E_1$, same direction
e) $E_1 > E_3$, opposite directions
f) $E_1 > E_3$, same direction*

*stand to answer f)

Unevenly charged planes



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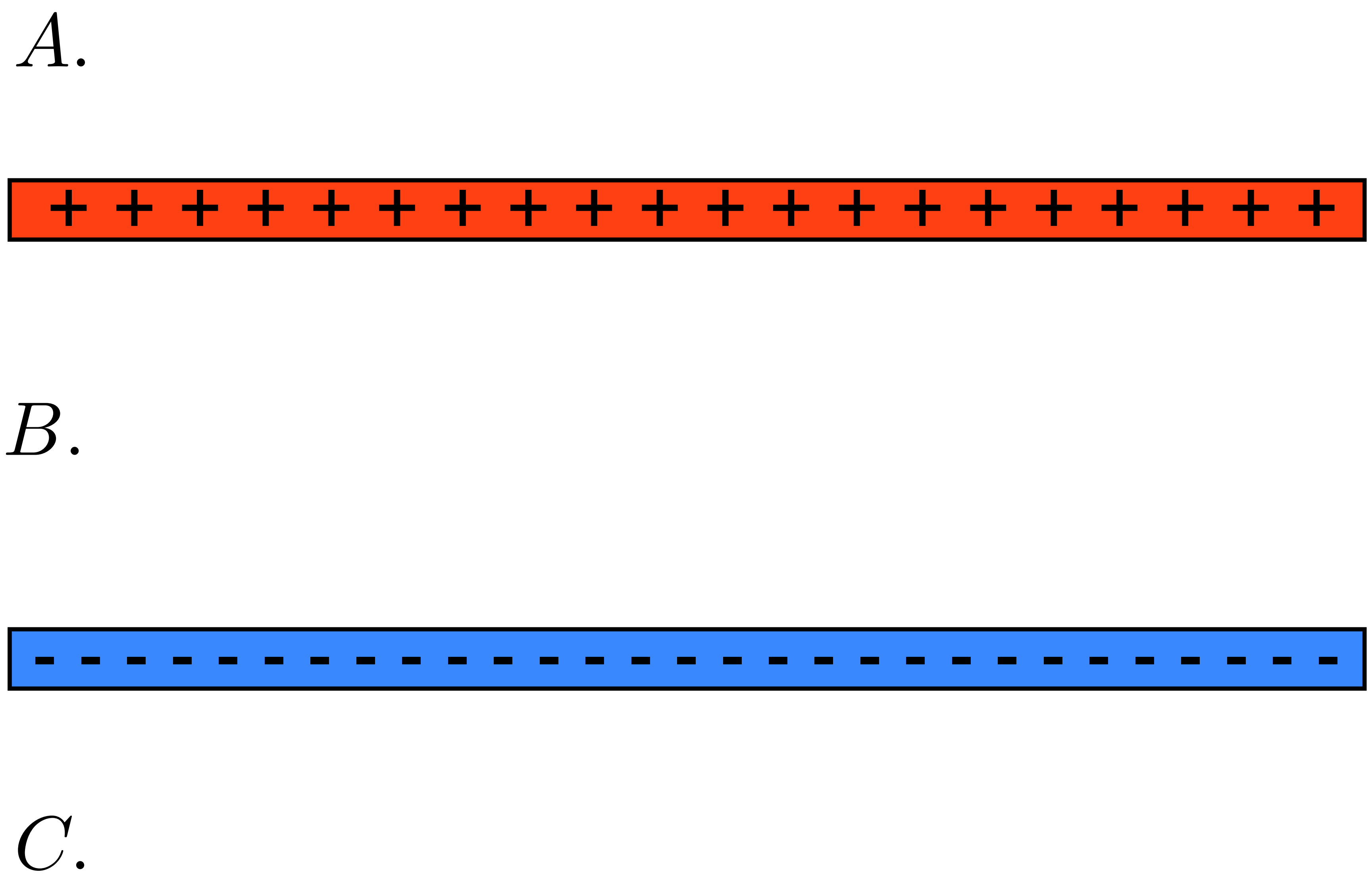
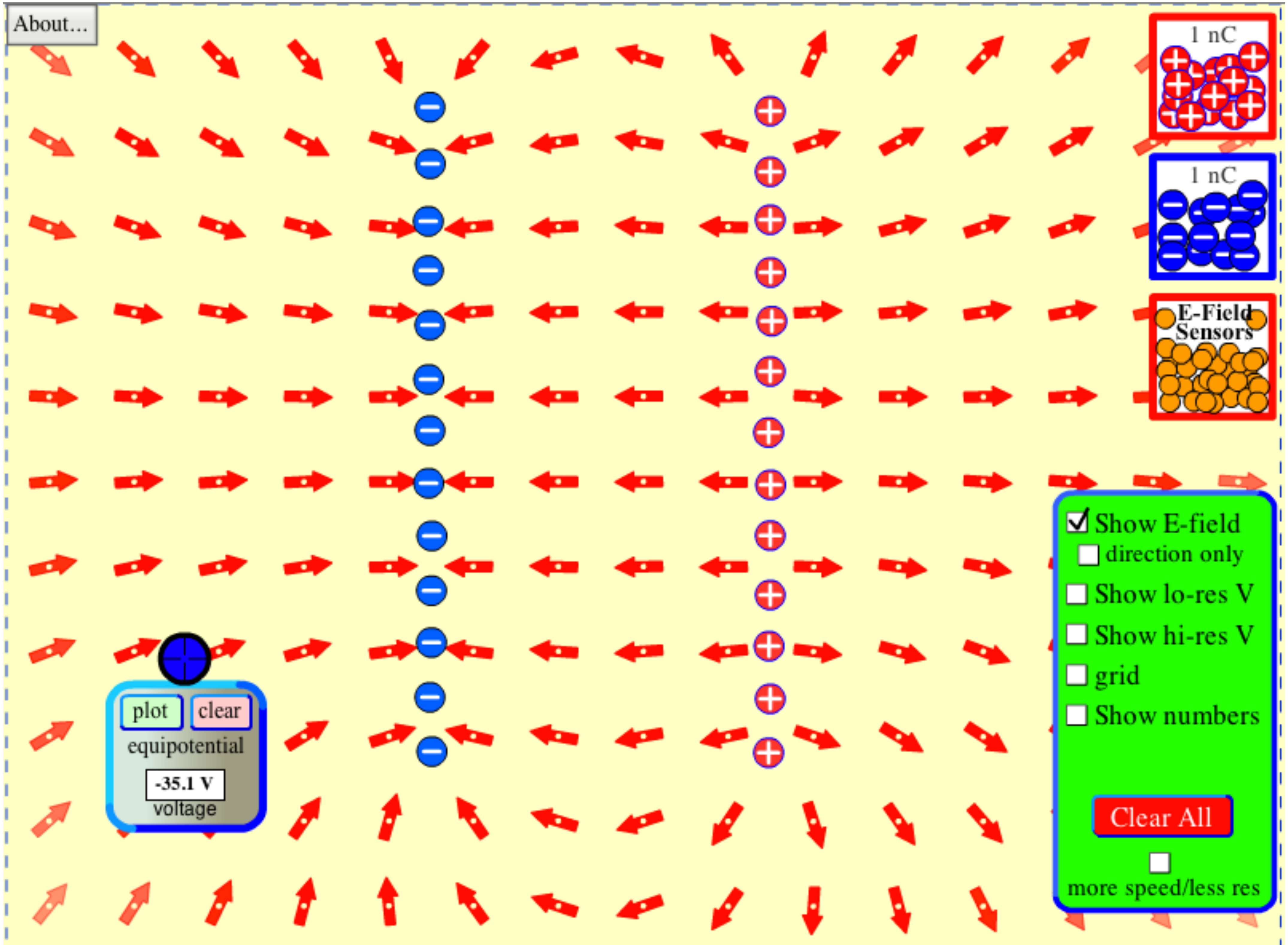
The Capacitor

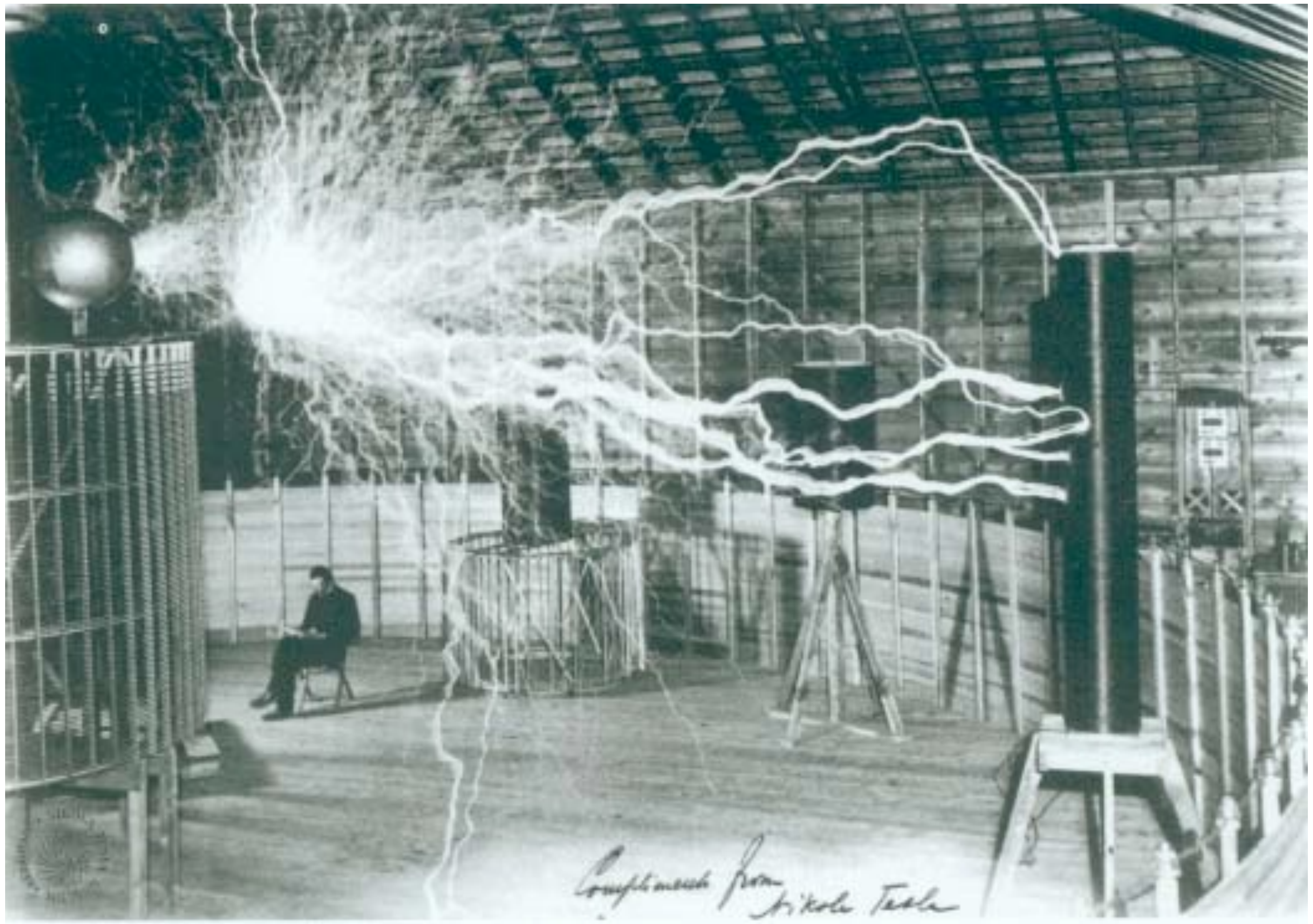


Imagine two planes of equal charge. What is the field in between, above, and below the planes?

Capacitor field



Motion of Charges in Electric Fields

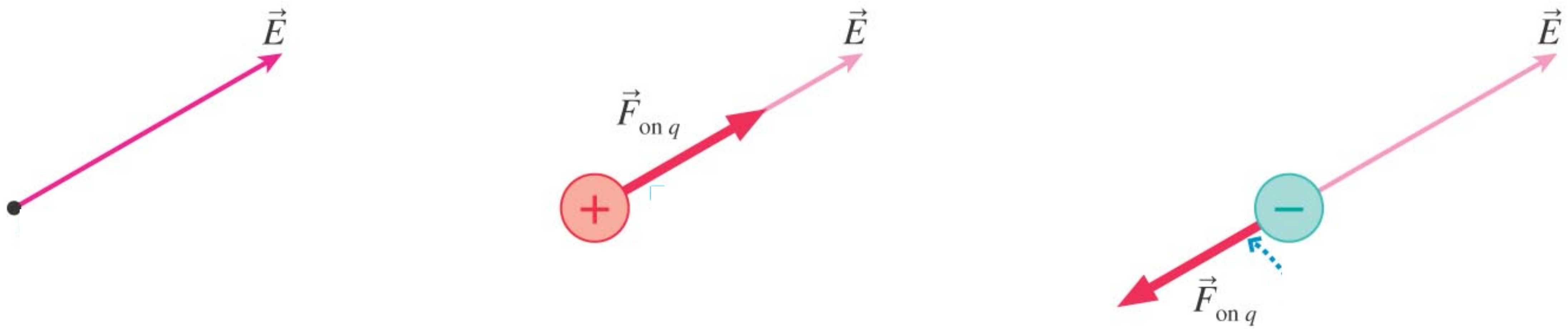


Charge in an Electric Field

The force on a charge *q* in an electric field *E* is given by

$$\vec{F} = q\vec{E}$$

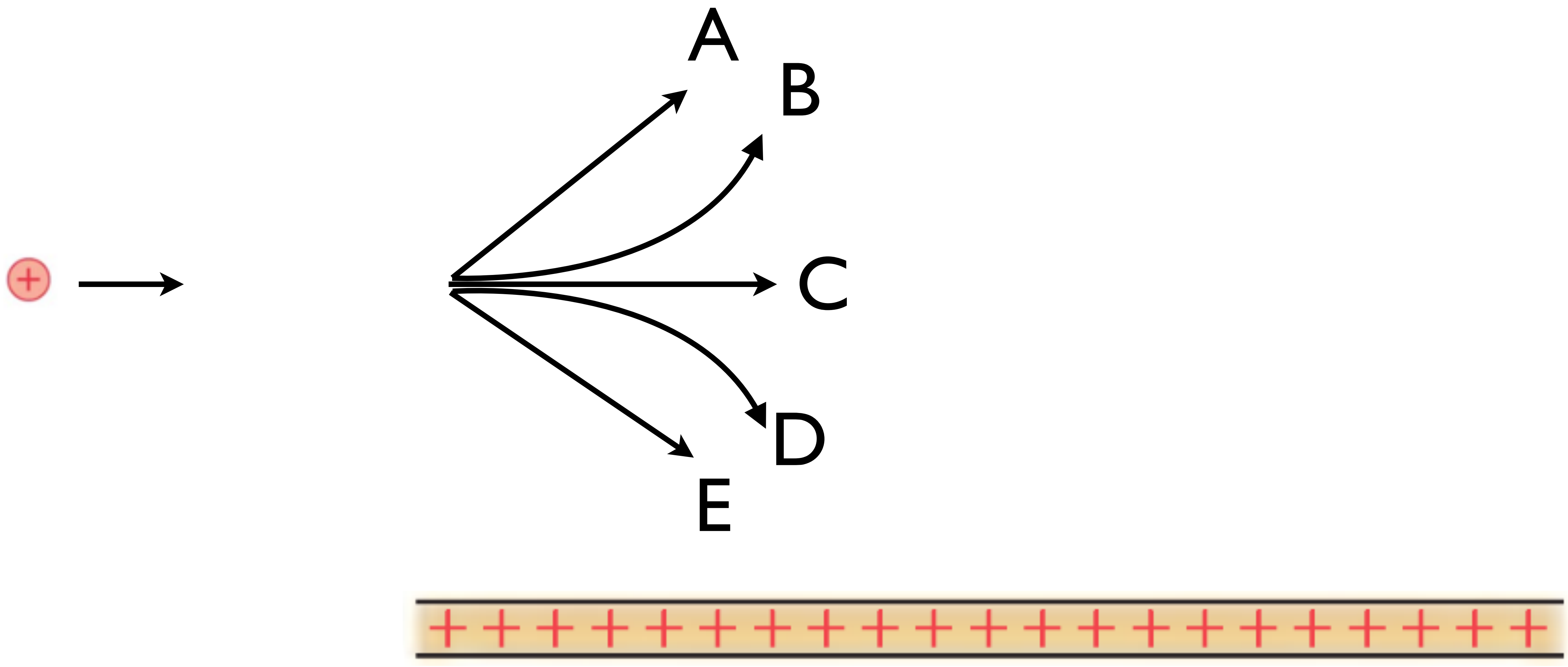
$$\vec{a} = \frac{q}{m}\vec{E}$$



Electric Field Hockey PhET

Charge in a field

A proton is moving to the right with some velocity.
Which best describes the path the proton will take?



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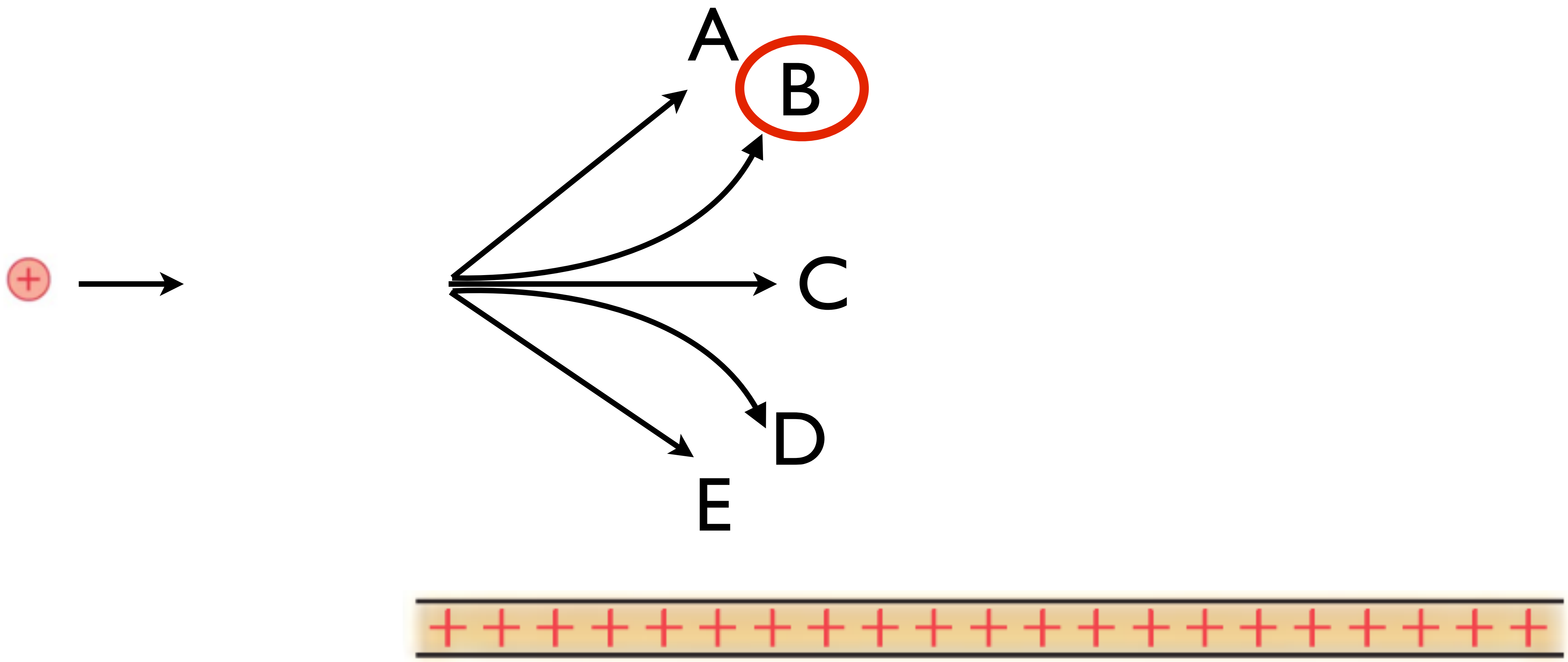
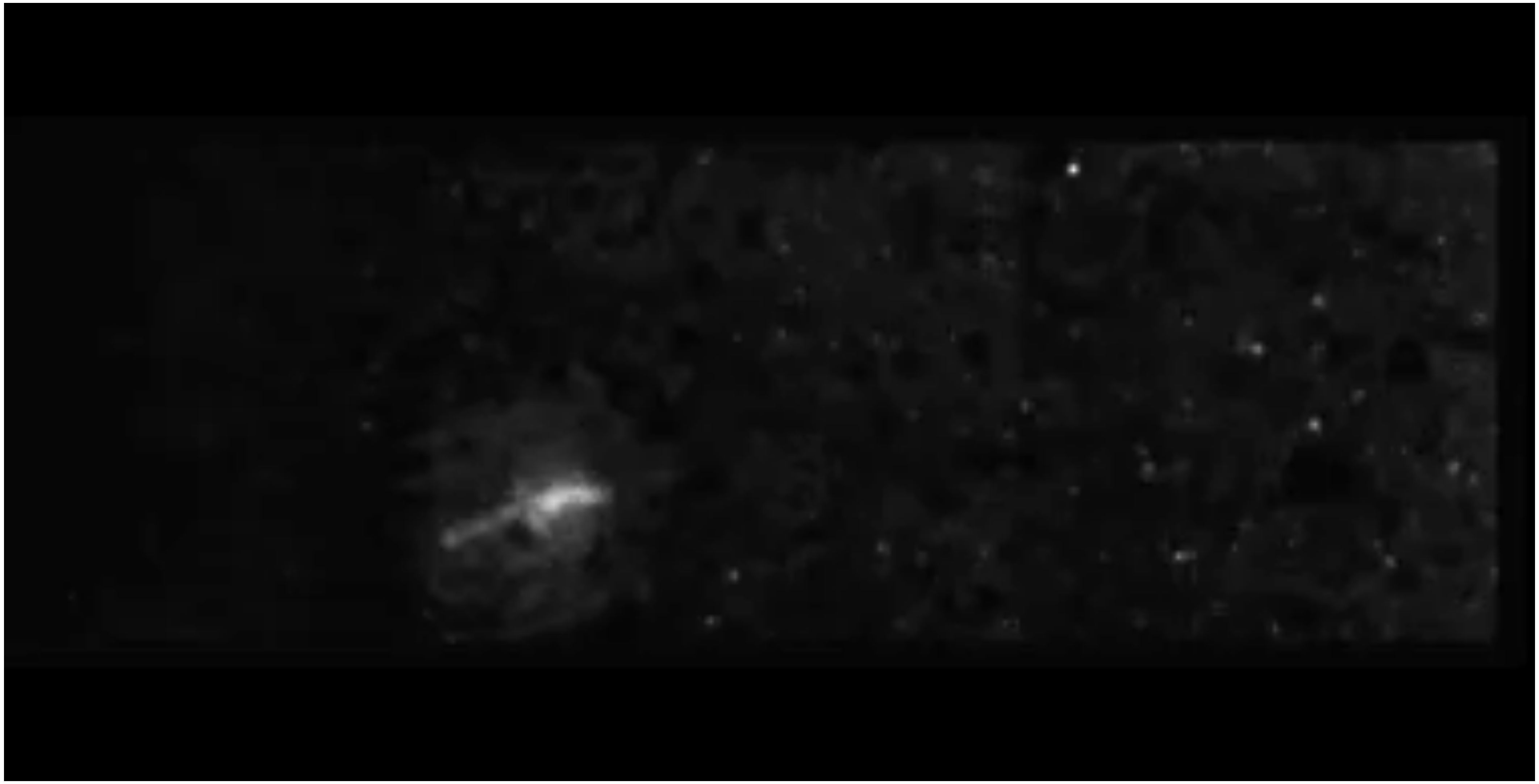


Electrophoresis



Electrophoresis

The electric field pushes the DNA, but the fluid slows it.
The drag force at low Reynolds number is

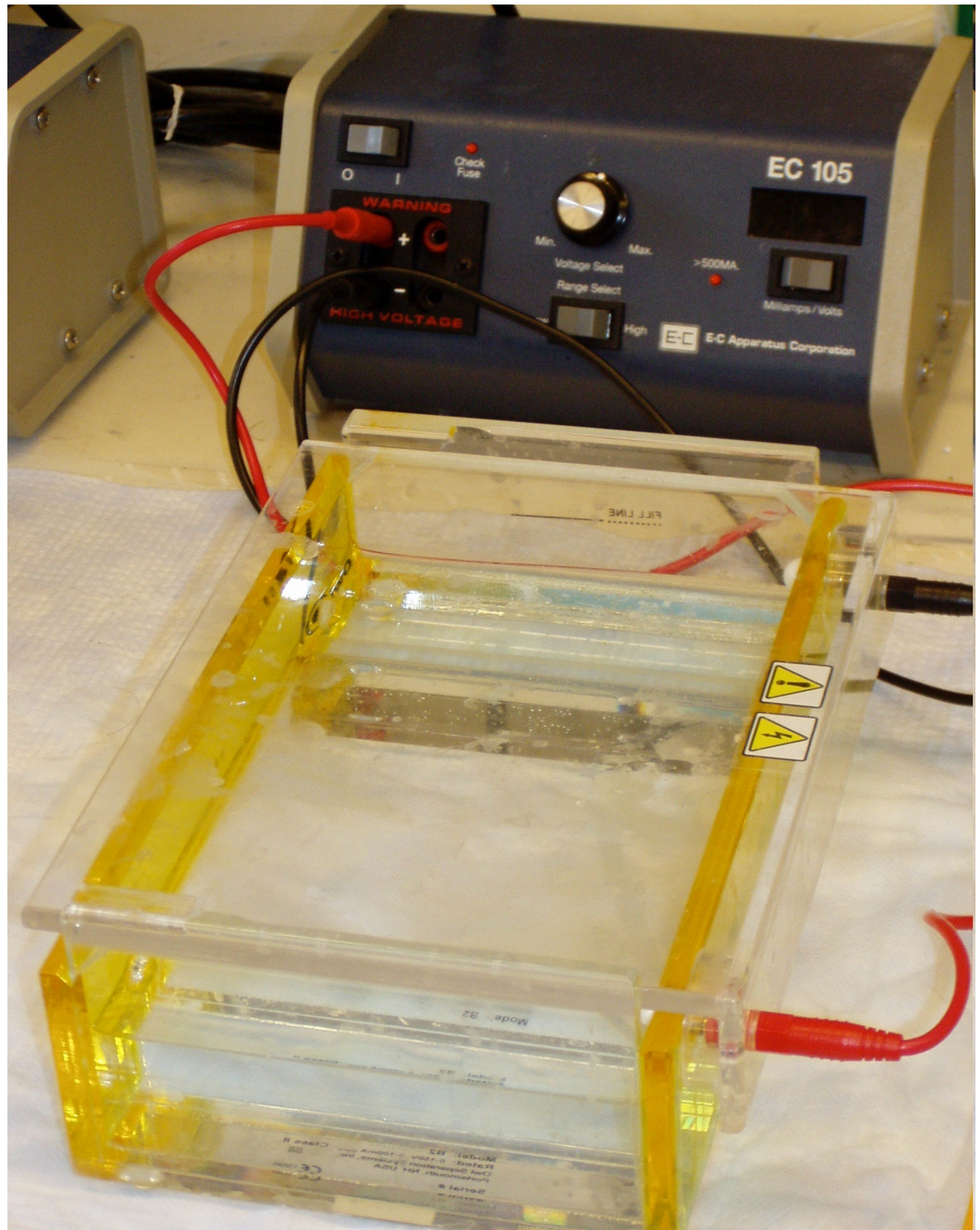
$$\vec{F}_{\mathrm{D}} = -b\vec{v}$$

Adding this to the electrostatic force yields and equilibrium at

$$\vec{v} = \frac{q}{b}\vec{E}$$

The speed the DNA moves depends on the electric field strength.

Electrophoresis



Clicker Question

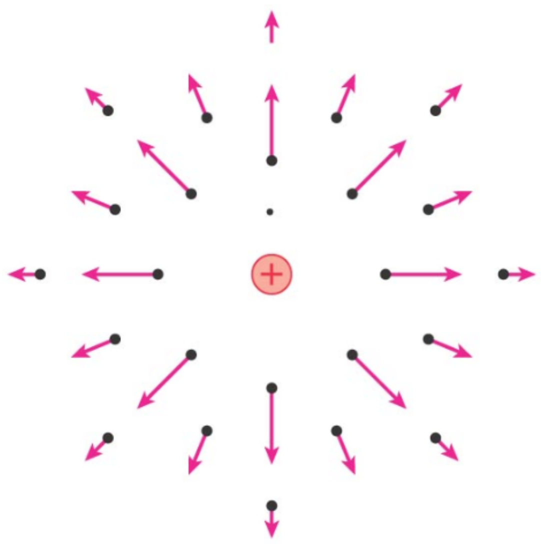
How does the force between a dipole and a positive charge depend on distance?

a) r
b) 1/r
c) $1/r^2$
d) $1/r^3$
e) $1/r^6$

Extra: How about two dipoles?

Clicker Question

How does the force between a dipole and a positive charge depend on distance?

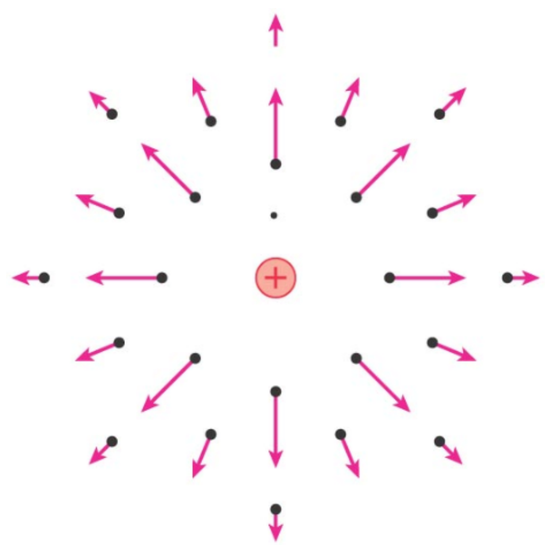


a) r
b) 1/r
c) $1/r^2$
d) $1/r^3$
e) $1/r^6$

$$F = qE = k\frac{qQp}{r^3}$$

The Electric Dipole

A dipole is held next to a positive charge.



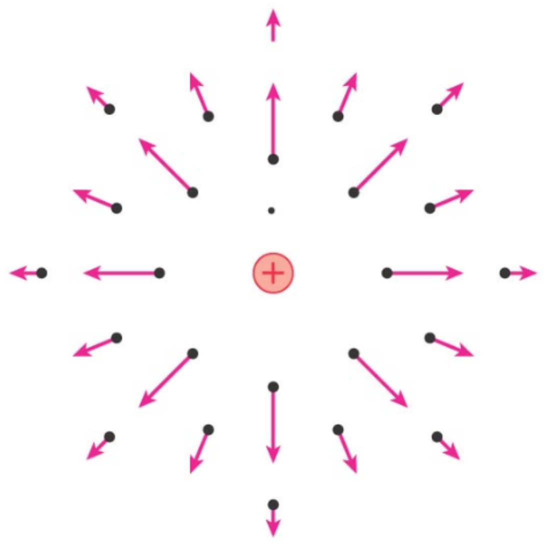
Which best describes what happens when the dipole is released?

a) rotate counterclockwise
b) rotate counterclockwise and move left
c) rotate counterclockwise and move right
d) rotate clockwise
e) rotate clockwise and move left
f) rotate clockwise and move right*

*stand to answer f)

The Electric Dipole

A dipole is held next to a positive charge.



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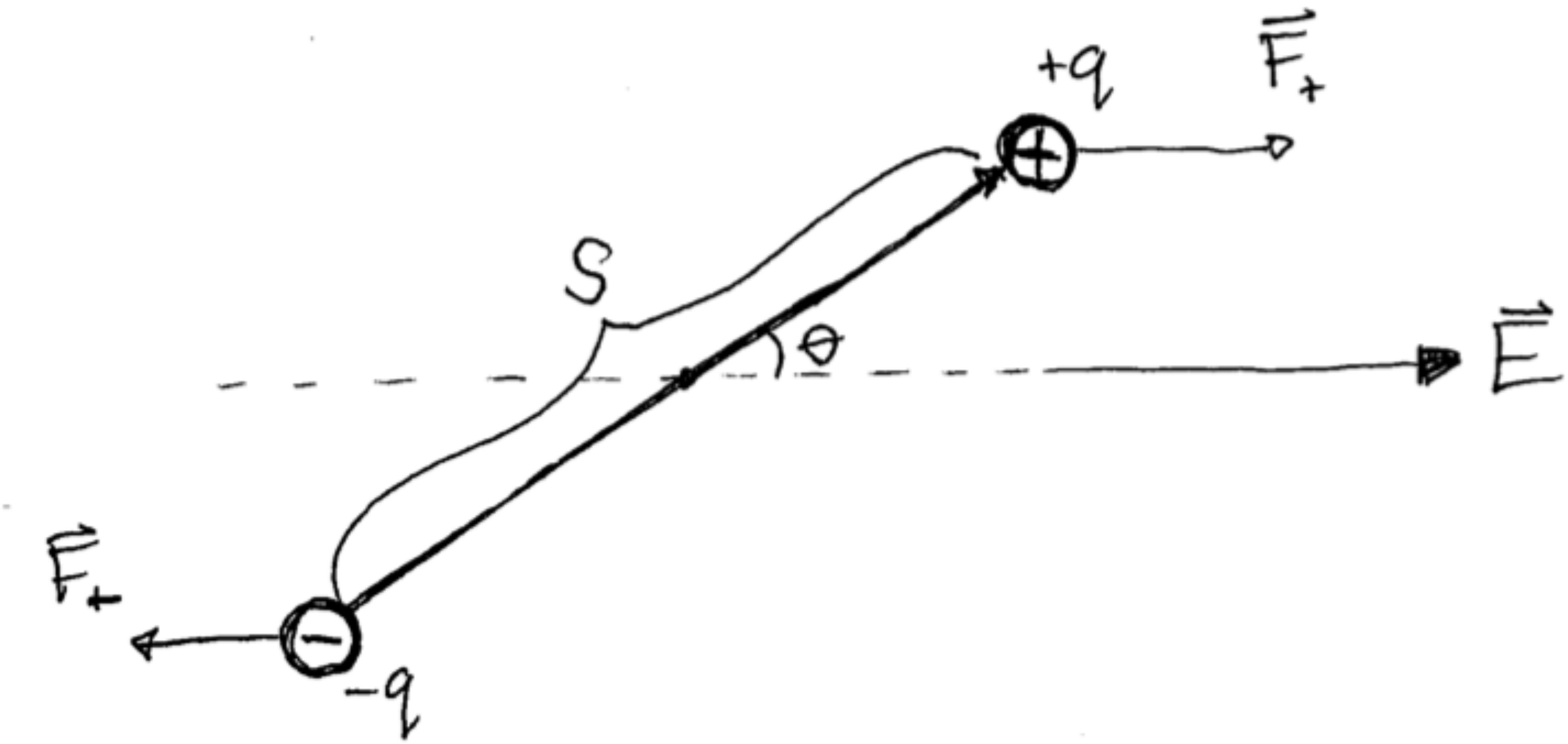
Torque on a Dipole

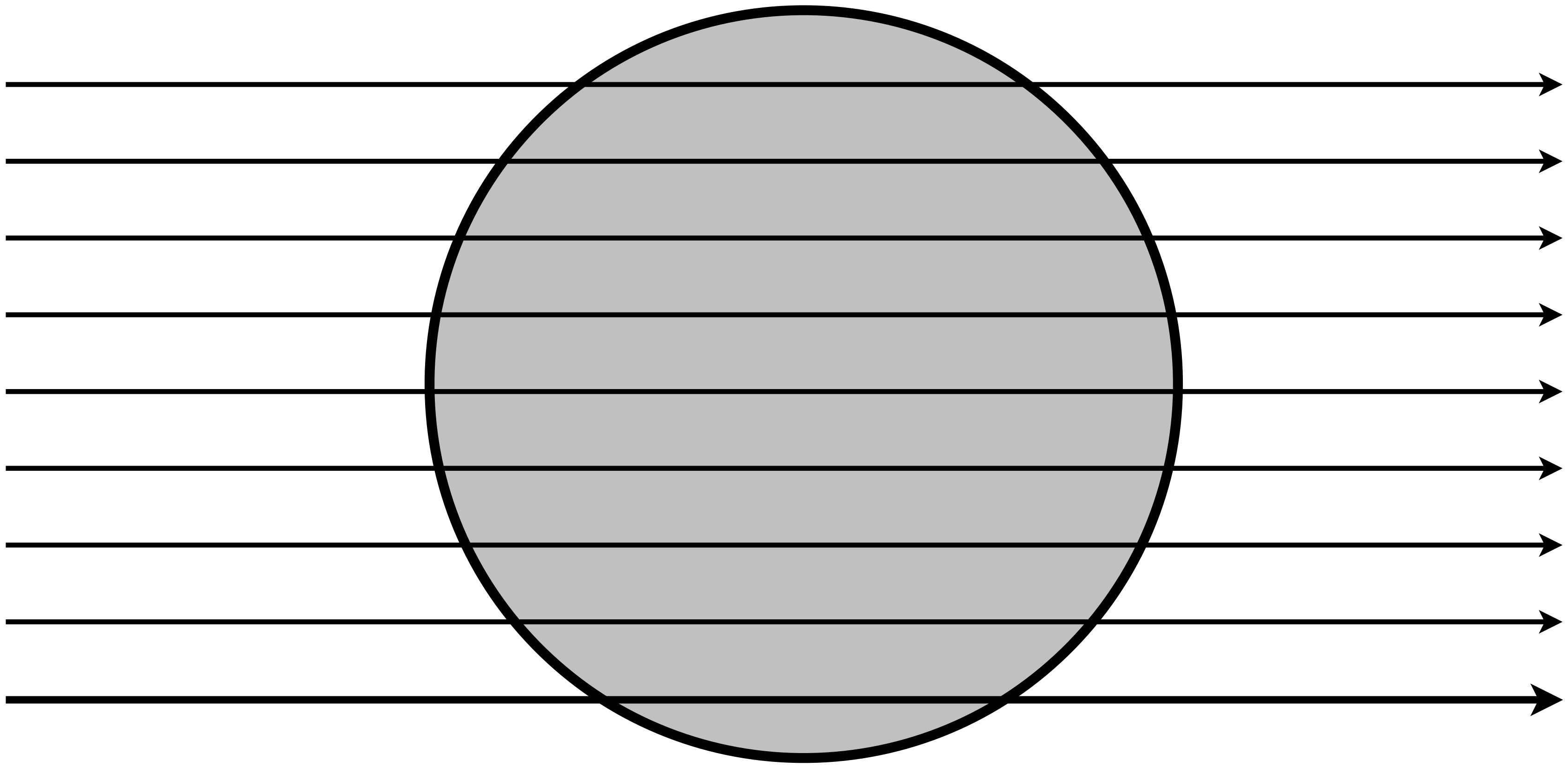
A dipole in a electric field feels a torque.



$$\tau = pE\sin\theta, \quad p = qs$$

E = 0 in a Conductor

The electric field in a conductor in electric static equilibrium is zero. Why?

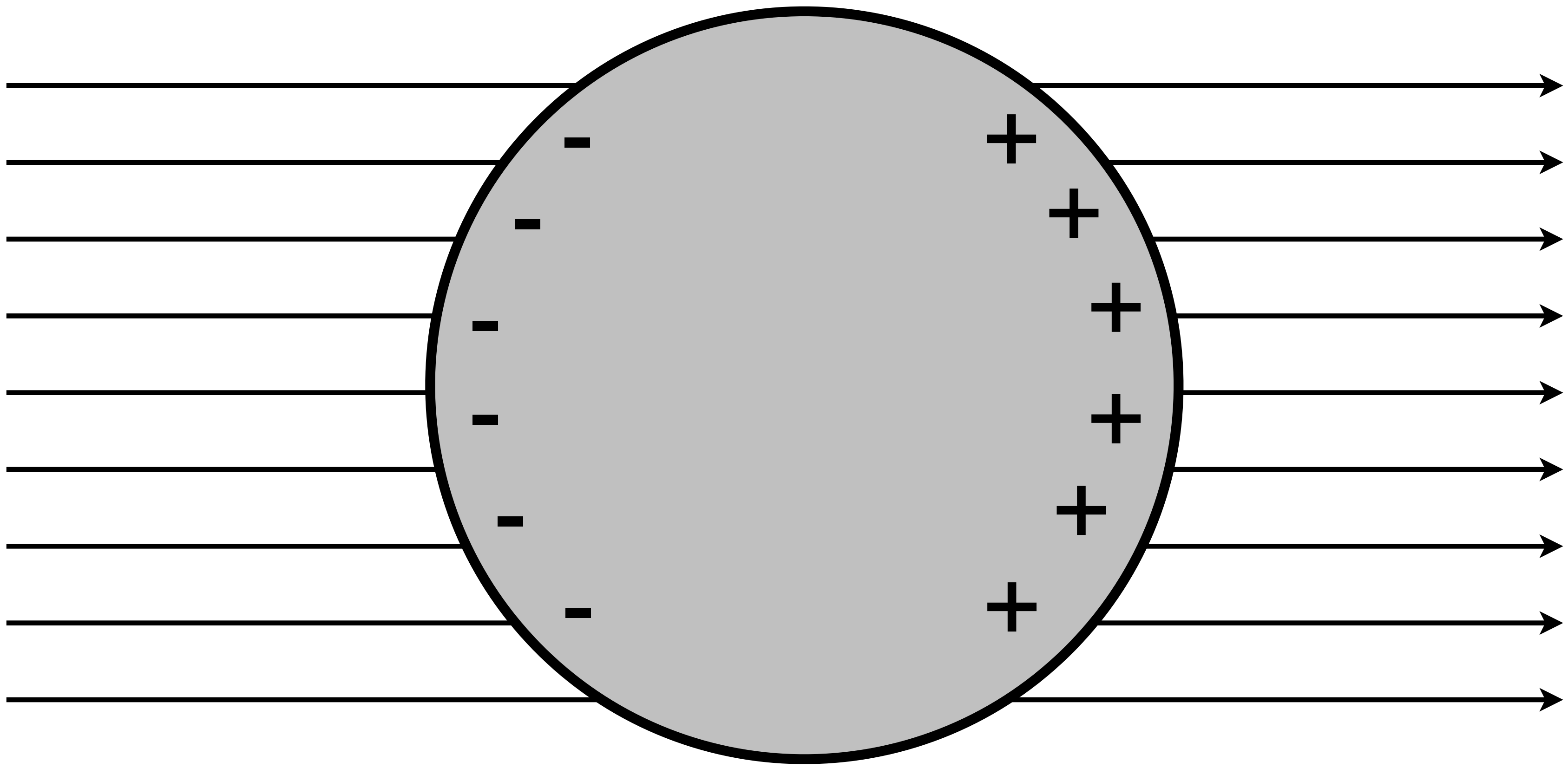


Exercise: Assume that E ≠ 0 inside the conductor.
What happens to free electrons?
What field gets created?

$$\vec{F} = q\vec{E}$$

E = 0 in a Conductor

The charges arrange themselves such that the field they generate completely cancels the field inside the conductor.

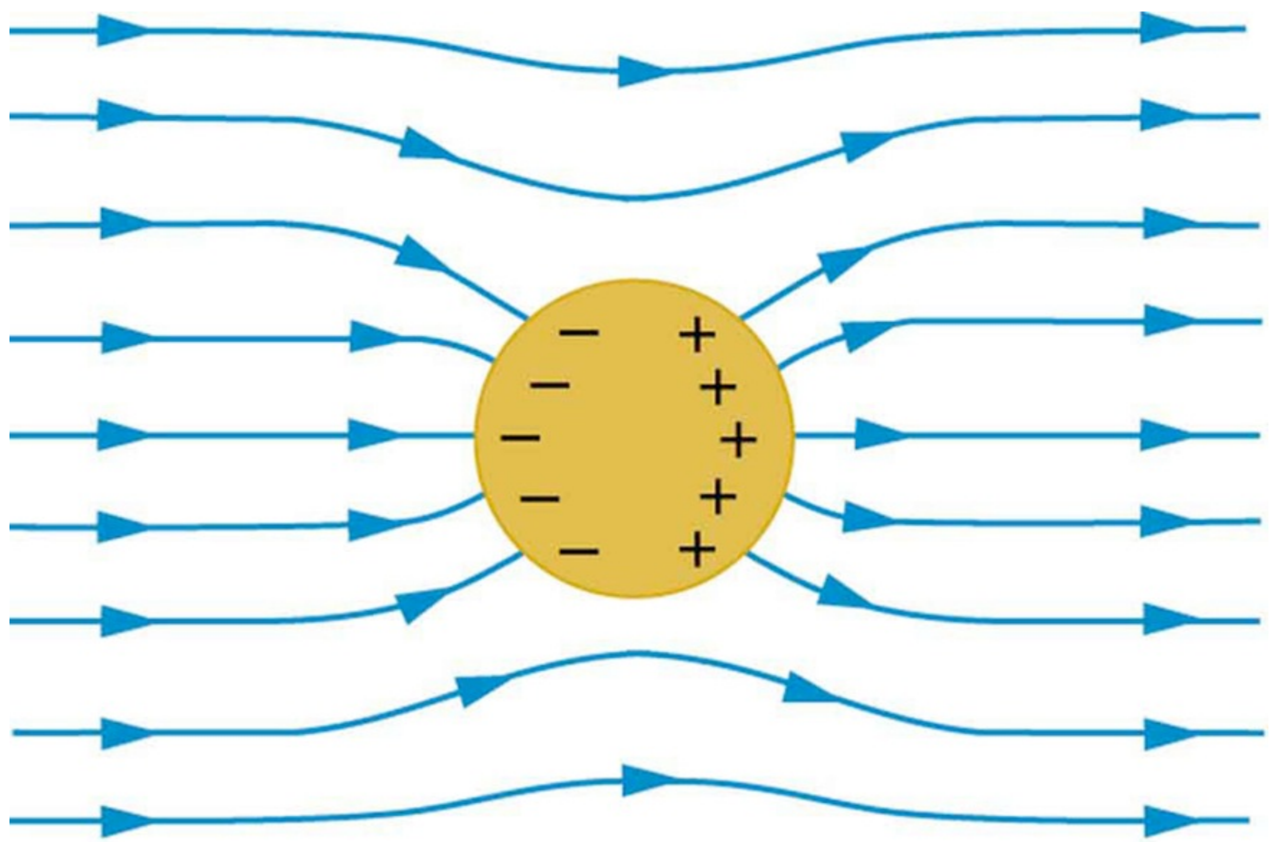


Reminder: charge sits on the surface of a conductor

Note: the electric field gives you another way to explain polarization in a metal

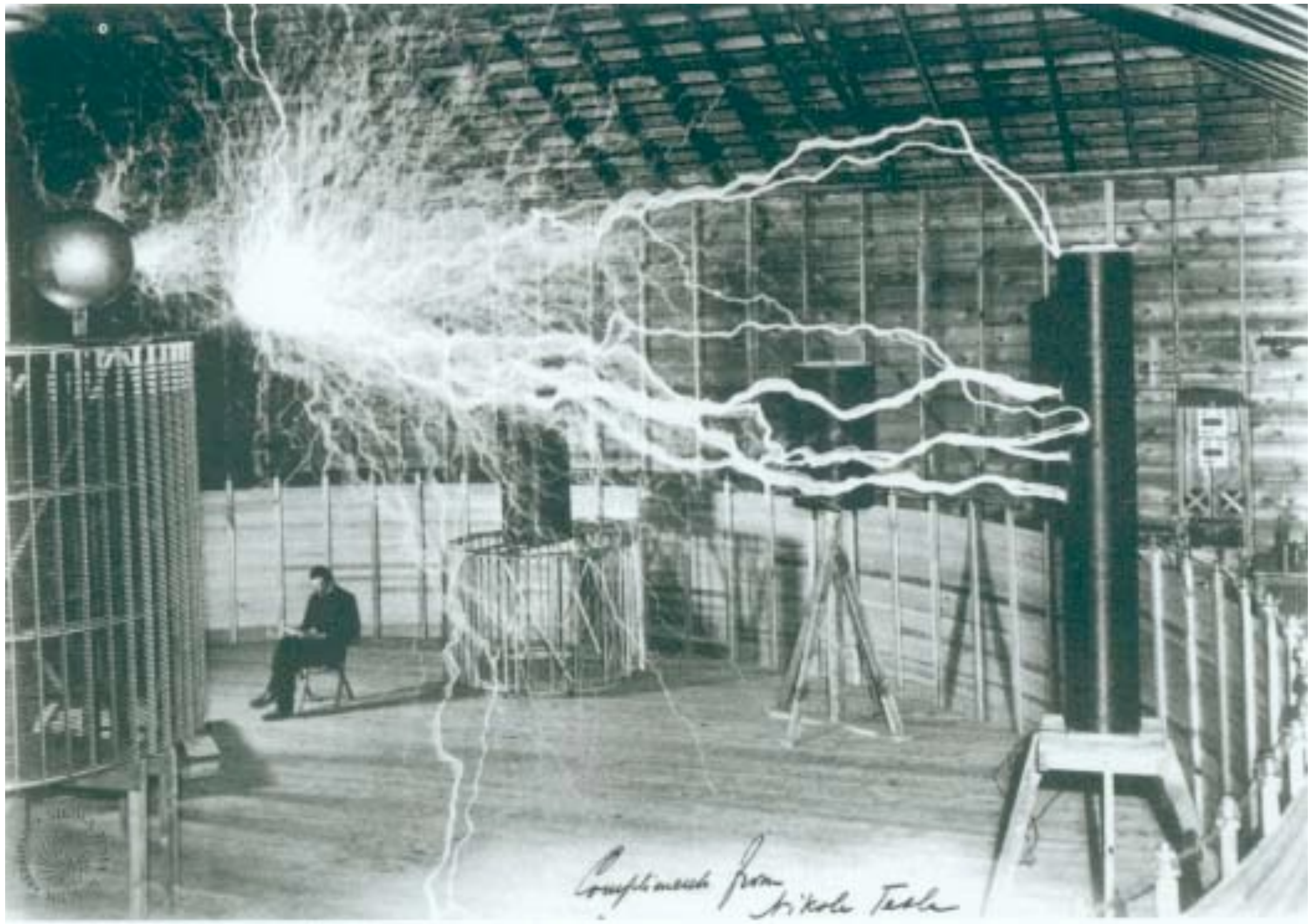
E = 0 in a Conductor

In reality the field lines look more more like this.

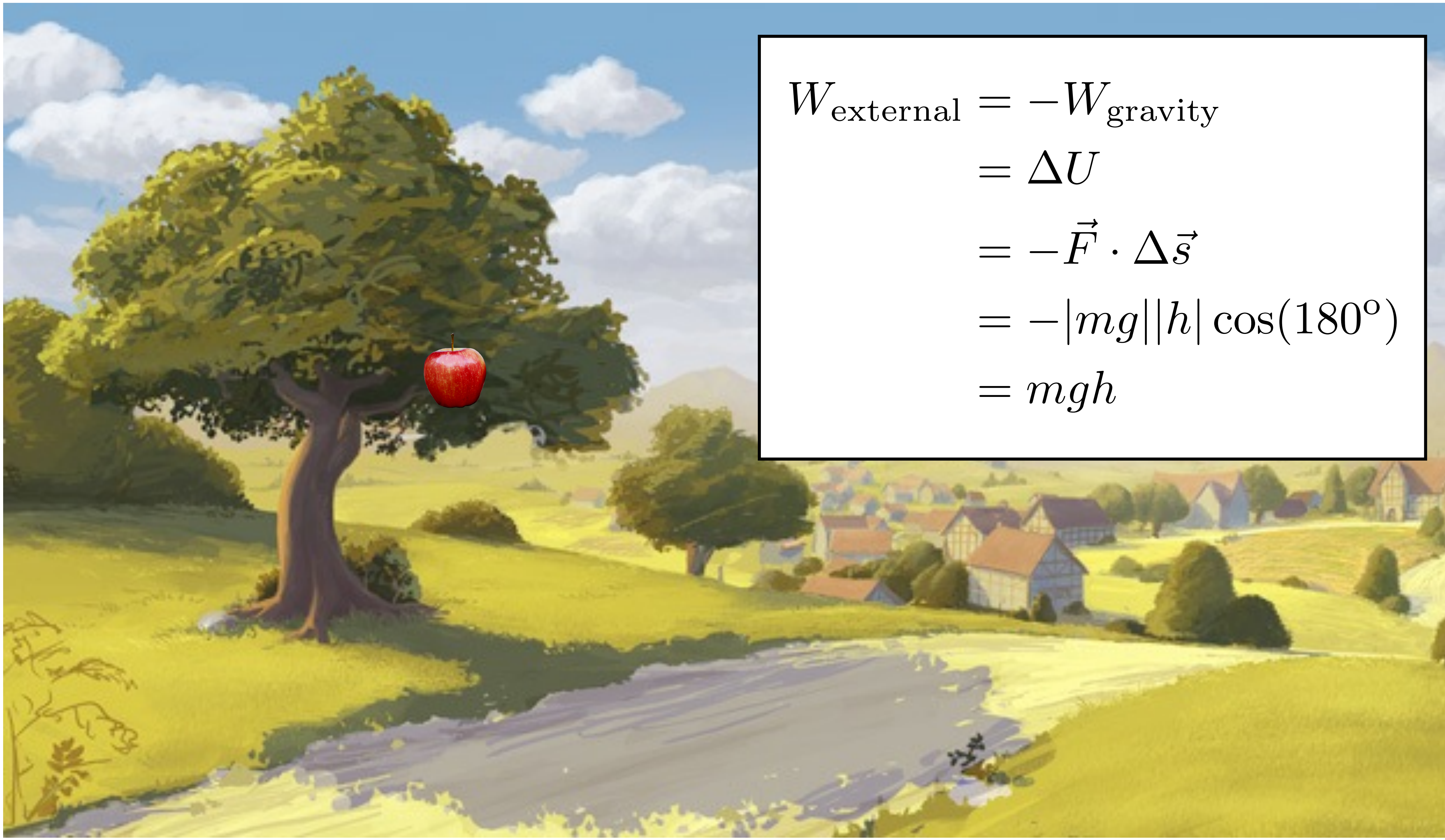


Note: Electric field is perpendicular to surface of the conductor.

Fields and Potentials

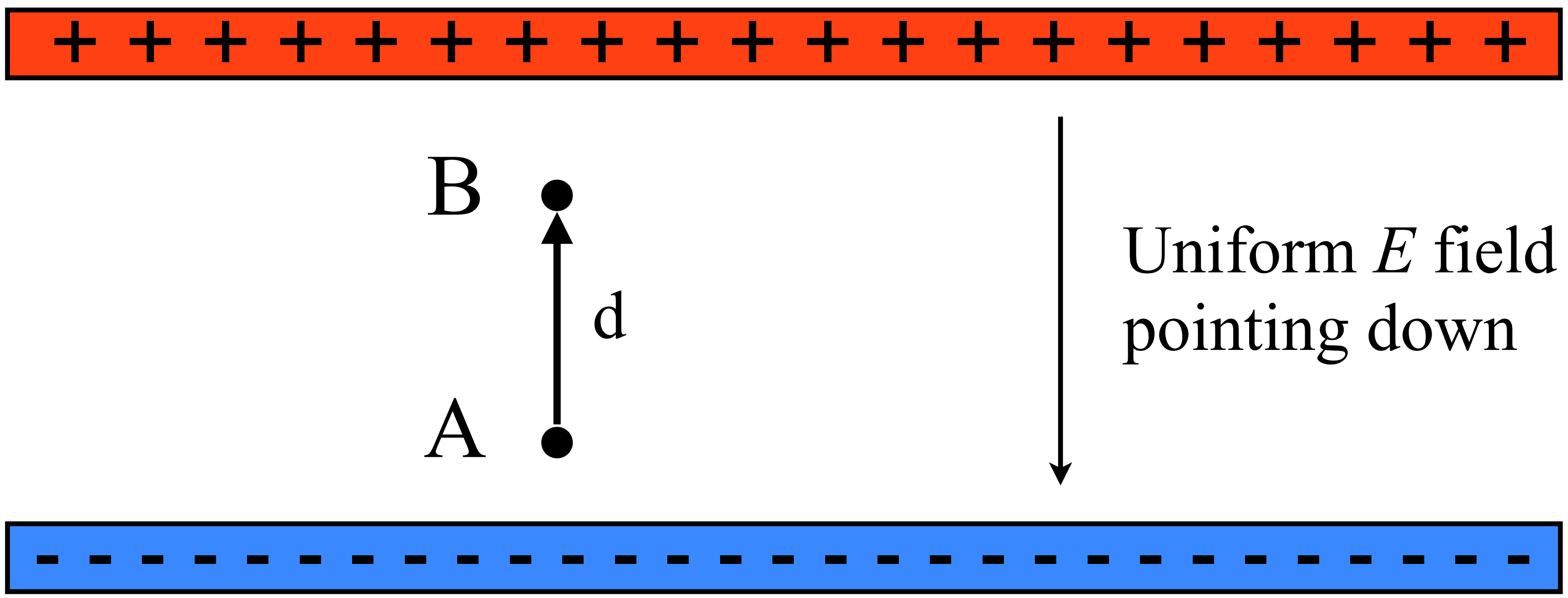


Gravity



$$
\begin{aligned}
W_{\text{external}} &= -W_{\text{gravity}} \\
&= \Delta U \\
&= -\vec{F} \cdot \Delta \vec{s} \\
&= -|mg||h| \cos(180^{\circ}) \\
&= mgh
\end{aligned}
$$

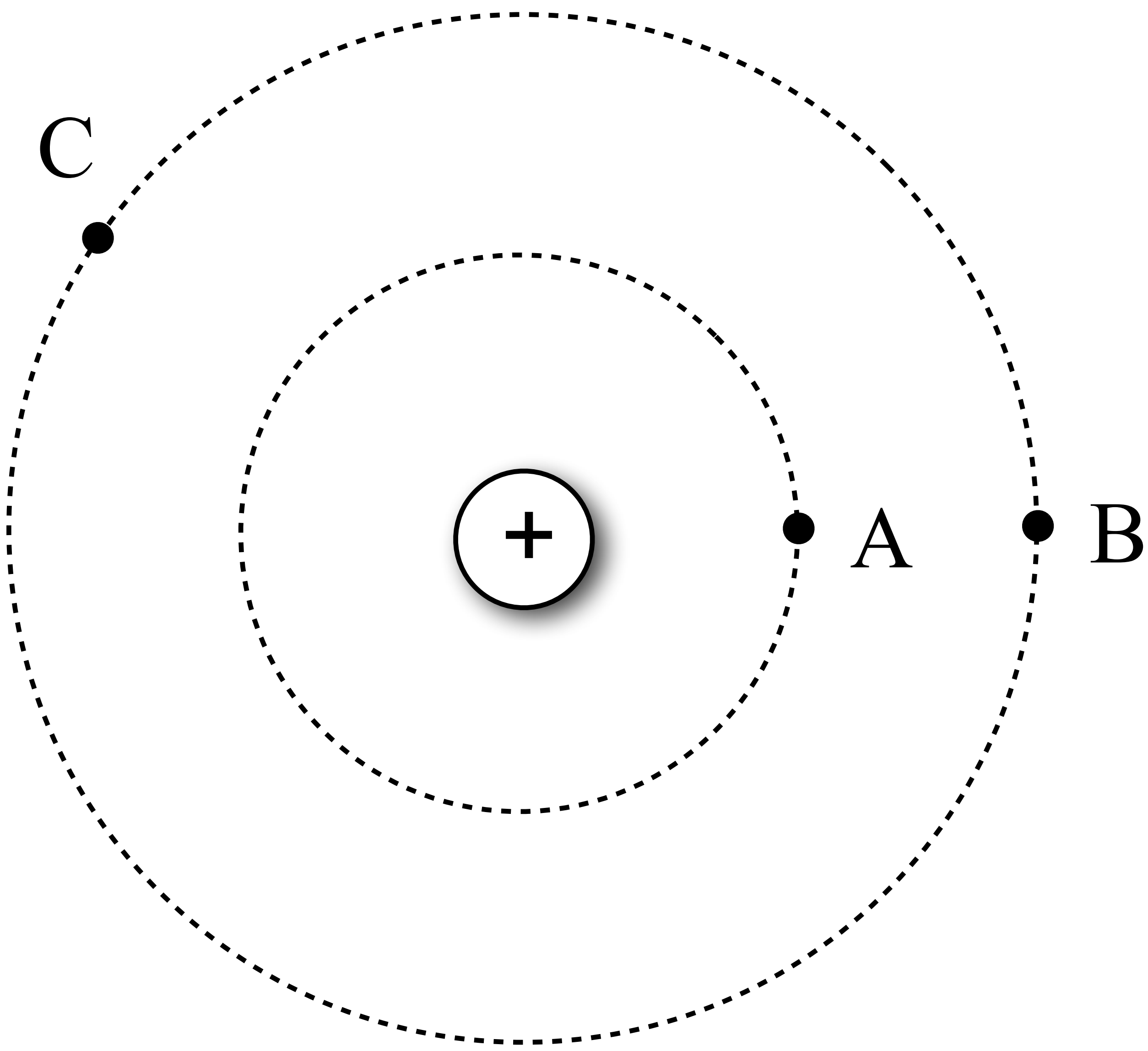
Potential Energy



Moving a charge +*q* from point A to point B.

$$W_{\text{ext}} = \Delta U = -\vec{F} \cdot \Delta\vec{s}$$
$$= qEd$$

Clicker Question

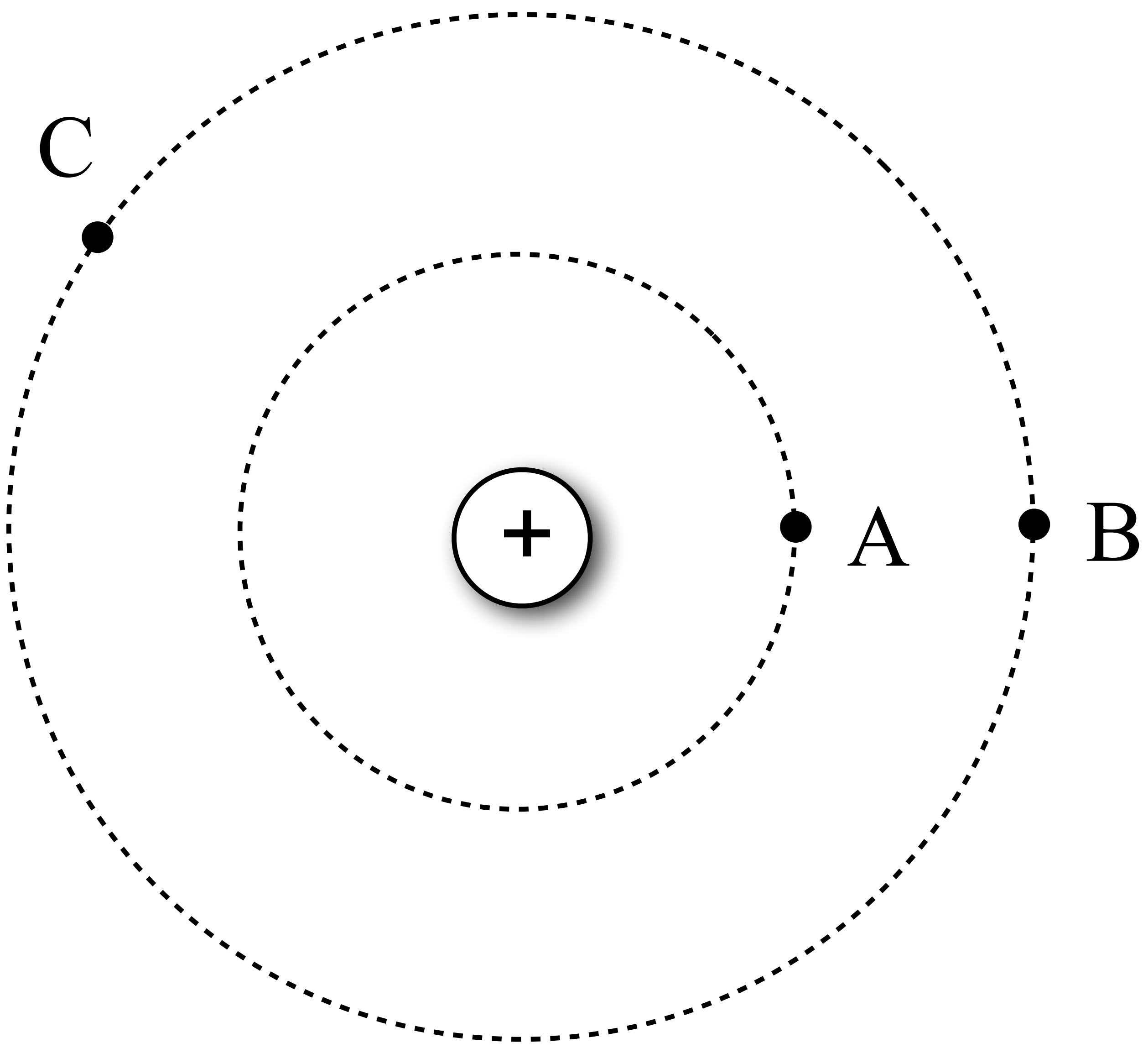


Moving a positive charge from A to B requires

A) more work
B) less work
C) the same work

than moving a positive charge from A to C.

Clicker Question



Moving a positive charge from A to B requires

A) more work
B) less work
C) the same work

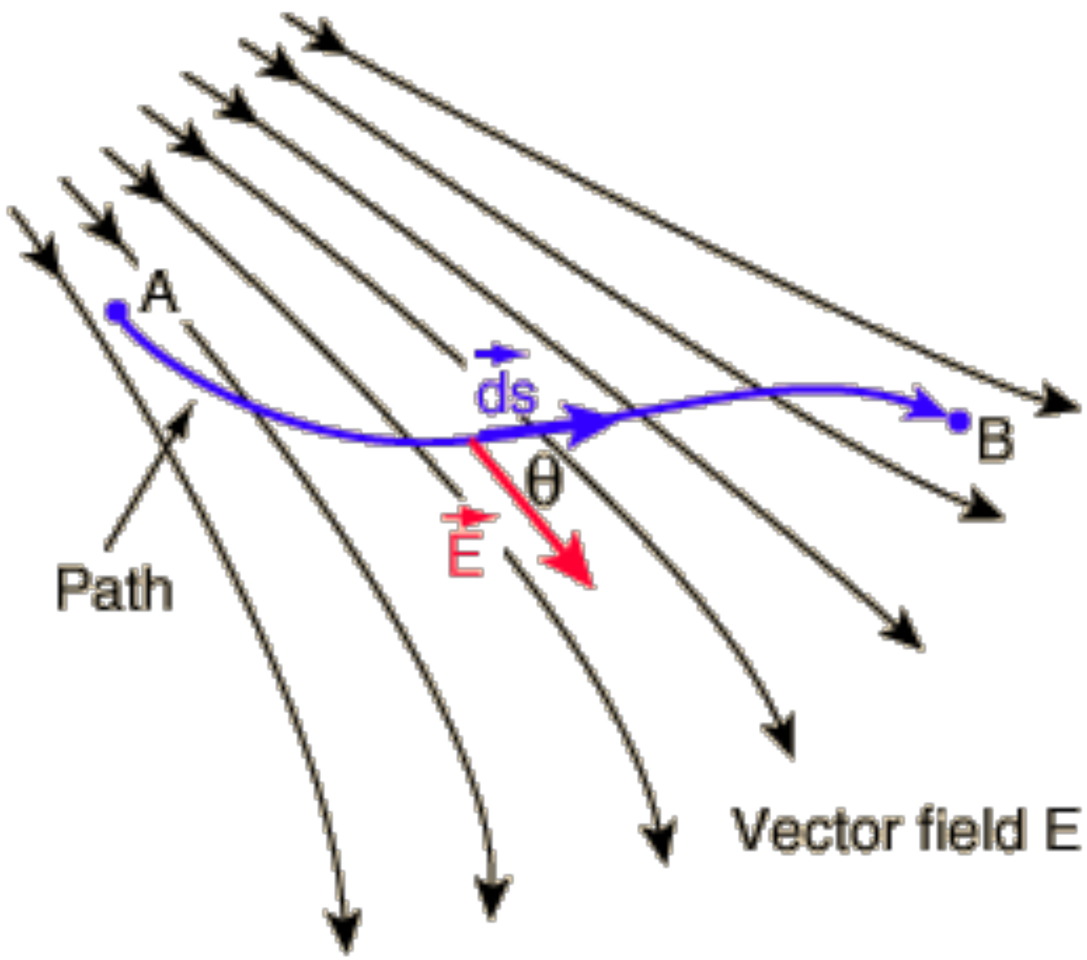
than moving a positive charge from A to C.

There is no change in potential energy when moving a charge along the dotted line. This is because the force and path are perpendicular.

$$dU = -\vec{F} \cdot \vec{ds}$$

Line Integral

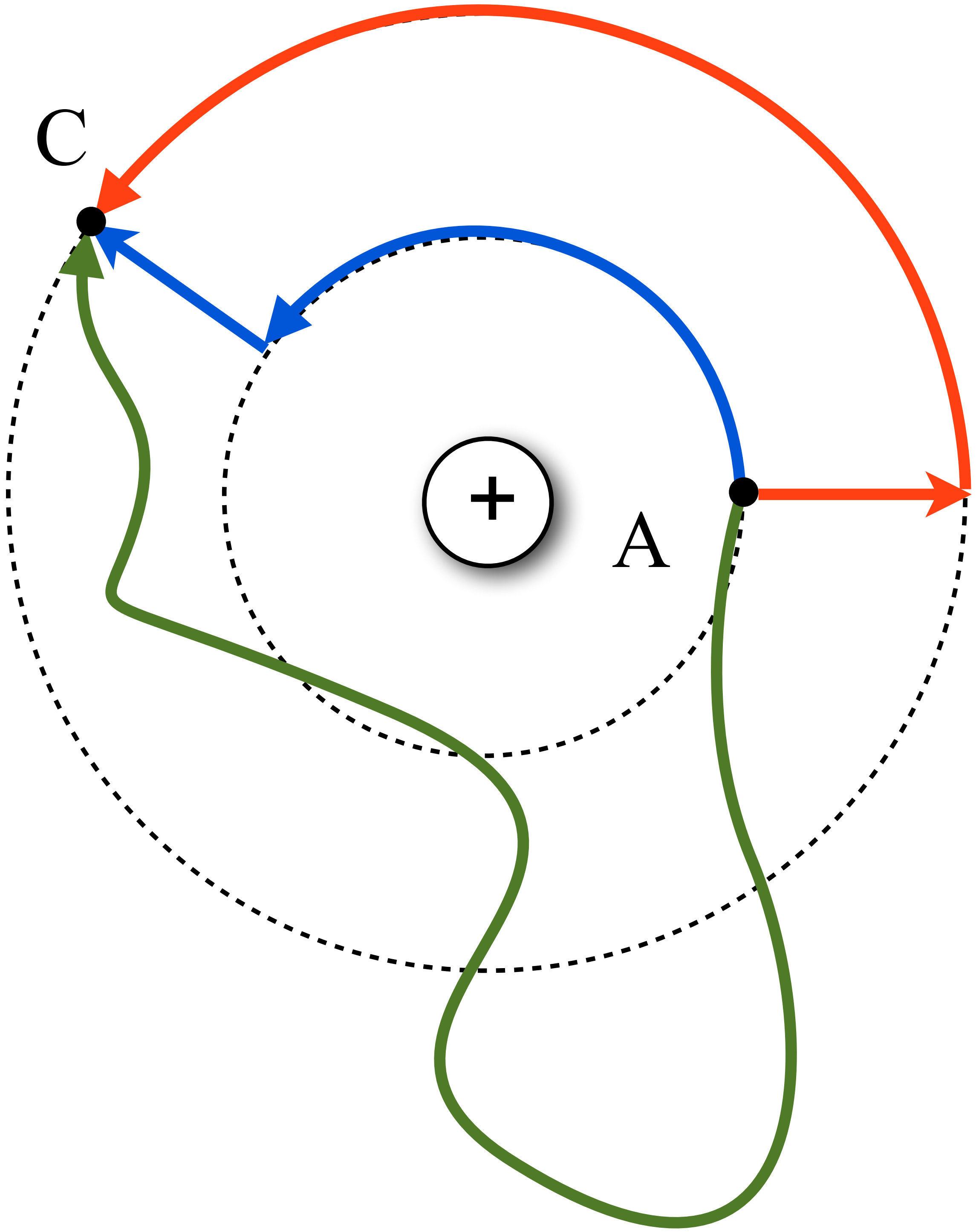
The potential energy can be determined using a **line integral**!



$$\Delta U = -\sum_i F_i \Delta s_i \cos(\theta_i)$$
$$= -\int_s \vec{F} \cdot d\vec{s}$$

To get the total change in energy, you **add up all the small changes** in energy.

Path Independence

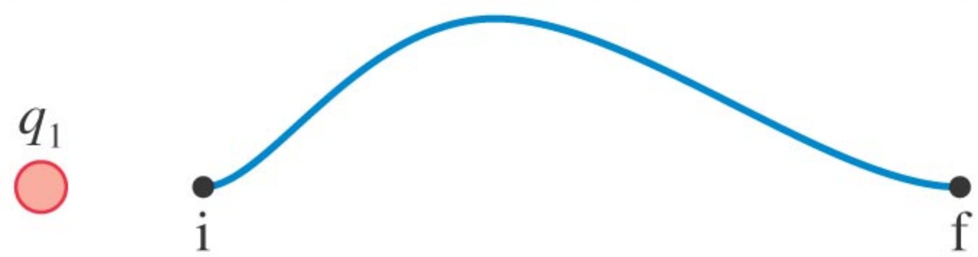


$$\Delta U = -\int_s \vec{F} \cdot \vec{ds}$$

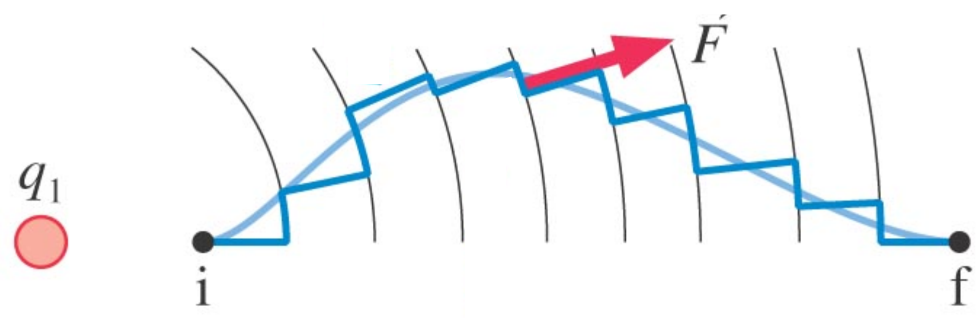
The Blue Path, the Red Path, and the Green Path all have the same change in potential energy. The path does not matter.

Conservative Force

The work done along this path can be simplified to a straight line. This is called **path independence**.



Path independence is a **quality of conservative forces**.



Conservative forces can always be written in terms of a potential.

$$F_s = -\frac{dU}{ds}$$

U for two charges?