Your Questions

I do not think I understand the difference between the electric field and the electric potential. They seem to be the same equation to me. I see that electric field is derived using the force between the charges while the electric potential is derived using the electrical energy between the charges, however I do not understand what you mean when you say that electric field is the gradient of the electric potential.

Since V is the change in potential energy, would another way to calculate it be \( V = \Delta PE = \Delta \text{ugh} \)?

What is the electron volt?

Does the model of a line for charge always apply? Can the charge move down the line and not be equally?

I know the electric field above the plane points up, but what does the electric field look like below the plane?

"A sheet of charge" is too theoretical for me. What's an actual example of this in nature?
Electrostatic Potential
Foothold ideas: Electrostatic potential energy and potential

• The potential energy between two charges is

• The potential energy of many charges is

• The potential energy added by adding a test charge $q$ is

$$U_{12}^{\text{elec}} = \frac{k_{\text{C}} Q_1 Q_2}{r_{12}}$$

$$U_{12\ldots N}^{\text{elec}} = \sum_{i<j=1}^{N} \frac{k_{\text{C}} Q_i Q_j}{r_{ij}}$$

$$\Delta U_{q}^{\text{elec}} = \sum_{i=1}^{N} \frac{k_{\text{C}} q Q_i}{r_{iq}} = qV$$
Forces and Fields

\[ \vec{F}_q = \sum_{i=1}^{N} \frac{k_c q Q_i}{r_{iq}^2} \hat{r}_{iq} \]

Potential Energy and Potential

\[ \Delta U_{q}^{elec} = \sum_{i=1}^{N} \frac{k_c q Q_i}{r_{iq}} \]

\[ V = \frac{\Delta U_{q}^{elec}}{q} \]
Foothold ideas:
Electrostatic Potential energy and Electrostatic Potential

• Again we focus our attention on a test charge!
• Usual definition of “electrostatic potential energy”: How much does the energy of our system change if we add the test charge

It’s really a change in potential energy!

\[ U_{q_0}^{\text{elec}}(\vec{r}_0) = \frac{k_c q_0 q_1}{r_{01}} + \frac{k_c q_0 q_2}{r_{02}} + \ldots + \frac{k_c q_0 q_N}{r_{0N}} = \sum_{i=1}^{N} \frac{k_c q_0 q_i}{r_{0i}} \]

• We ignore the electrostatic potential energies of all other pairs (since we assume the other charges do not move)
• We can pull the test charge magnitude out of the equation and obtain en electrostatic potential

\[ V(\vec{r}_0) = \frac{U_{q_0}^{\text{elec}}(\vec{r}_0)}{q_0} = \frac{k_c q_1}{r_{01}} + \frac{k_c q_2}{r_{02}} + \ldots + \frac{k_c q_N}{r_{0N}} = \sum_{i=1}^{N} \frac{k_c q_i}{r_{0i}} \]
Positive test charge with positive source

Potential energy of a positive test charge near a positive source.

\[ U = \frac{kqQ}{r} \]

Electric Potential of a positive test charge near a positive source.

\[ V = \frac{kQ}{r} \]
What happens when I change the sign of the test charge?

A. Potential energy graph changes
B. Electrostatic potential graph changes
C. Both change
D. Neither of the graphs changes
Negative test charge

Potential energy of a negative test charge near a positive source.

Electric Potential of a negative test charge near a positive source.

\[ U = \frac{kqQ}{r} \]

\[ V = \frac{kQ}{r} \]
Two test charges are brought separately into the vicinity of a charge $+Q$. First, test charge $+q$ is brought to point $A$ a distance $r$ from $+Q$. Next, $+q$ is removed and a test charge $+2q$ is brought to point $B$ a distance $2r$ from $+Q$. Compared with the electrostatic potential energy of the charge at $A$, that of the charge at $B$ is

A. greater
B. smaller
C. the same
D. You can’t tell from the information given
Two test charges are brought separately into the vicinity of a charge $+Q$. First, test charge $+q$ is brought to point A a distance $r$ from $+Q$. Next, $+q$ is removed and a test charge $+2q$ is brought to point B a distance $2r$ from $+Q$. Compared with the electrostatic potential of the charge at A, that of the charge at B is

A. greater

B. smaller

C. the same

D. You can’t tell from the information given
Your Questions

Where does π come from? \( k_c \) is actually a combination of fundamental constants

\[
k_c = \frac{1}{4\pi\varepsilon_0}
\]

π comes from spherical symmetry

Where does the \( \frac{1}{2} \) come from? From the relationship between electric potential and electric potential energy and capacitance:

\[
dU = dqV = dq \left( \frac{q}{C} \right) \rightarrow \int_0^U dU = \frac{1}{C} \int_0^Q q dq \rightarrow U = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} CV^2 = \frac{1}{2} QV
\]

What are some examples of capacitors in biology?
A massive object might be placed at one of three spots in a region where there is a uniform gravitational field. How do the gravitational potentials, $V = gh$, on the masses at positions 1, 2, and 3 compare?

A. $V$ is greatest at 1

B. $V$ is greatest at 2

C. $V$ is greatest at 3

D. $V = 0$ at all three spots

E. $V \neq 0$ but same at all three spots

F. Not enough information
A positive charge might be placed at one of three spots in a region. It feels the same force (pointing to the left) in each of the spots.
How does the electric potential, $V_{\text{elec}}$, on the charge at positions 1, 2, and 3 compare?

A. $V$ is greatest at 1
B. $V$ is greatest at 2
C. $V$ is greatest at 3
D. $V = 0$ at all three spots
E. $V \neq 0$ but same at all three spots
F. Not enough information
Graphical representations of the Electric Field and Potential
At which point is the force downhill strongest?

A. A

:B. B

C. C

D. none

Topography map = gravitational PE graph (2D)
Topography map = gravitational PE graph (2D)

At which point is the force downhill pointing to the east? (North is up)

A. A
B. B
C. C
D. none

เผย jabon jabon jabon jabon
Model of PE for 2 line charges (3D)
Where would a test charge feel the strongest electric force?

A. A
B. B
C. C
D. A&B
Where would a test charge feel the strongest electric force?

A. A
B. B
C. C
D. A&B
Model of PE for 2 line charges

Where would a test charge feel the strongest electric field?

A. A
B. B
C. C
D. A&B
Where would a test charge feel the largest potential energy?

A. A
B. B
C. C
D. A&B
E. Depends on whether the test charge is positive or negative
Where would a test charge feel the strongest electric force?

A. A  
B. B  
C. C  
D. D  
E. E  
F. More than one
The sheet of charge

• Field is constant, pointing away from positive sheet, towards negative sheet.

• Constant!!?
  How can that be?
Two sheets of charge
Two sheets of charge
Result

The fields of the two plates cancel each other on the outside.

The fields of the two plates add on the inside, producing double the field of a single plate.

The fields of the two plates cancel each other on the outside.
The figure shows a capacitor *just after* it has been connected to a battery.

Current will flow in this manner for a nanosecond or so until the capacitor is fully charged.

The charge escalator moves charge from one plate to the other. $\Delta V_C$ increases as the charge separation increases.
- The figure shows a fully charged capacitor.
- Now the system is in electrostatic equilibrium.
- Capacitance always refers to the charge per voltage on a fully charged capacitor.
The ratio of the charge $Q$ to the potential difference $\Delta V_C$ is called the **capacitance** $C$:

$$C \equiv \frac{Q}{\Delta V_C} = \frac{A}{4\pi k_C d} \quad \text{(parallel-plate capacitor)}$$

Capacitance is a purely *geometric* property of two electrodes because it depends only on their surface area and spacing.

The SI unit of capacitance is the **farad**:

$$1 \text{ farad} = 1 \text{ F} \equiv 1 \text{ C/V}$$

The charge on the capacitor plates is directly proportional to the potential difference between the plates:

$$Q = C \Delta V_C \quad \text{(charge on a capacitor)}$$
What is the capacitance of these two electrodes?

A. 8 nF  
B. 4 nF  
C. 2 nF  
D. 1 nF  
E. Some other value
Capacitors are important elements in electric circuits. They come in a variety of sizes and shapes.

The keys on most computer keyboards are capacitor switches. Pressing the key pushes two capacitor plates closer together, increasing their capacitance.
Charging a capacitor

The spacing between the plates of a 1.0 μF capacitor is 0.050 mm.

a. What is the surface area of the plates?
b. How much charge is on the plates if this capacitor is attached to a 1.5 V battery?

MODEL Assume the battery is ideal and the capacitor is a parallel-plate capacitor.
- The figure shows two arbitrary electrodes charged to $\pm Q$.
- It might appear that the capacitance depends on the amount of charge, but the potential difference is proportional to $Q$.
- Consequently, the capacitance depends only on the geometry of the electrodes.
- The figure shows a capacitor being charged.

- As a small charge $dq$ is lifted to a higher potential, the potential energy of the capacitor increases by:
  \[
dU = dq \Delta V = \frac{q dq}{C} \]

- The total energy transferred from the battery to the capacitor is:
  \[
  U_C = \frac{1}{C} \int_0^Q q dq = \frac{Q^2}{2C}
  \]
- Capacitors are important elements in electric circuits because of their ability to store energy.
- The charge on the two plates is $\pm q$ and this charge separation establishes a potential difference $\Delta V = q/C$ between the two electrodes.
- In terms of the capacitor’s potential difference, the potential energy stored in a capacitor is:

$$U_C = \frac{Q^2}{2C} = \frac{1}{2} C(\Delta V_C)^2$$
A capacitor can be charged slowly but then can release the energy very quickly.

An important medical application of capacitors is the *defibrillator*.

A heart attack or a serious injury can cause the heart to enter a state known as *fibrillation* in which the heart muscles twitch randomly and cannot pump blood.

A strong electric shock through the chest completely stops the heart, giving the cells that control the heart’s rhythm a chance to restore the proper heartbeat.
A capacitor charged to 1.5 V stores 2.0 mJ of energy. If the capacitor is charged to 3.0 V, it will store

A. 1.0 mJ  
B. 2.0 mJ  
C. 4.0 mJ  
D. 6.0 mJ  
E. 8.0 mJ