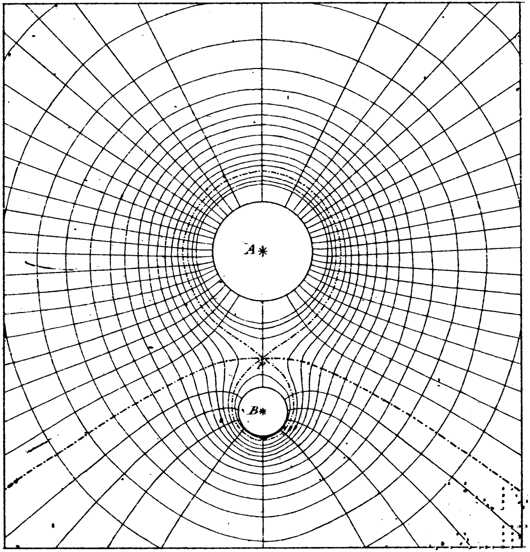
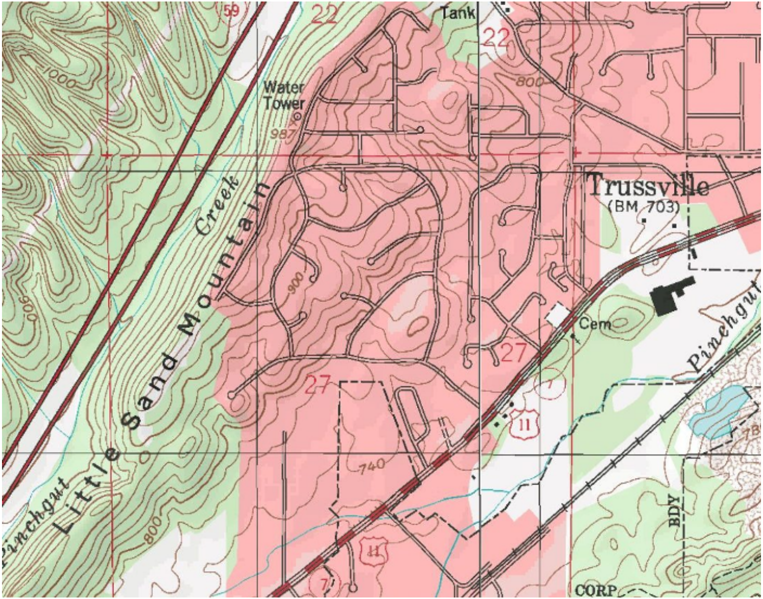
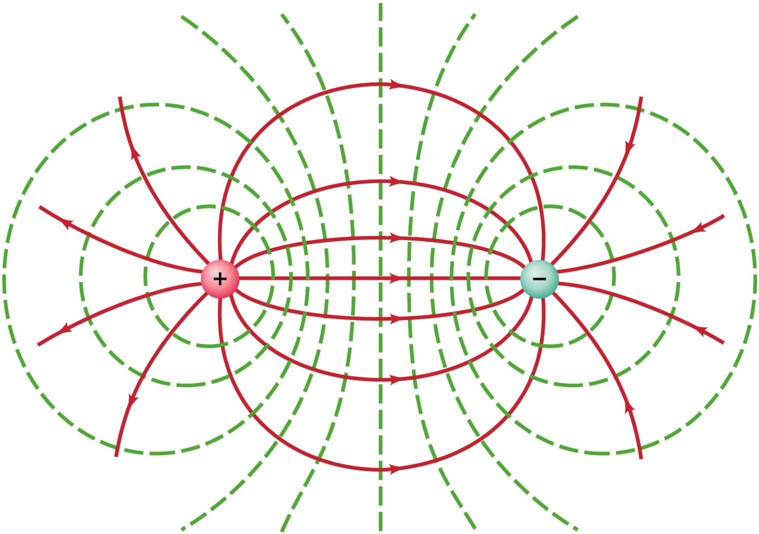
Potentials and Fields



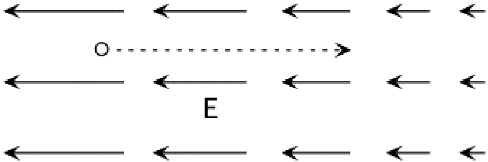
Gravitational Equipotential Lines



Electric Equipotential Lines



A test particle is pushed through an electric field that gets gradually weaker along the particle's path (the dashed line shown below).



The electric potential at the location of the test particle

A. increases.
B. decreases.
C. stays the same.
D. depends on the sign of the test charge.

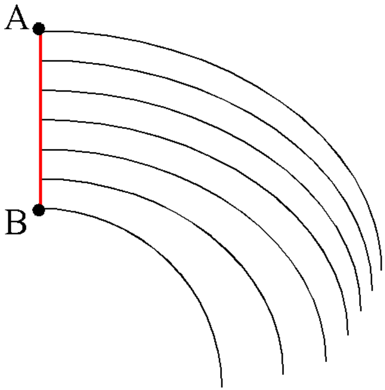
ANS: A—The electric potential increases as the charge moves to the right.

The electric field always points from regions of high potential to regions of low potential. The field always points to the left in the diagram, so the potential is higher on the right than it is on the left. The potential at the location of the charge increases as we move to the right.

The field strength is decreasing as we move to the right, but don't let that confuse you. The field strength tells us how the potential changes over a specific distance. Therefore, the rate of increase in potential decreases as we move to the right, but the potential continues to increase, nontheless.

Can you answer this question by reasoning about the direction of increasing or decreasing potnetial energy? Try it and ask me questions if you get stuck.

The figure below shows a pattern of equipotential curves (in black). The difference in potential between neighboring contours is the same for all curves. A particle moves from point A to B along the red path. What can you say about the electric potential along its path?



A. It is constant and zero

B. It is constant and nonzero

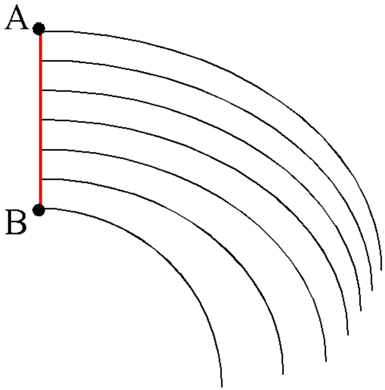
C. It is steadily changing in magnitude

D. None of the above

ANS: C—The electric potential is steadily changing in magnitude.

The equipotential lines are lines of constant potential, separated by a fixed value of ΔV between successive lines. You cannot tell whether the potential is increaseing or decreasing as the charge moves from A to B, but you can certainly tell that it is changing. Furthermore, because the spatial separation between the successive equipotential lines is the same along this particular path, we can say that the potential is steadily changing.

The figure below shows a pattern of equipotential curves (in black). The difference in potential between neighboring contours is the same for all curves. A particle moves from point A to B along the red path. What can you say about the electric field along its path?



A. It is constant and zero

B. It is constant and nonzero

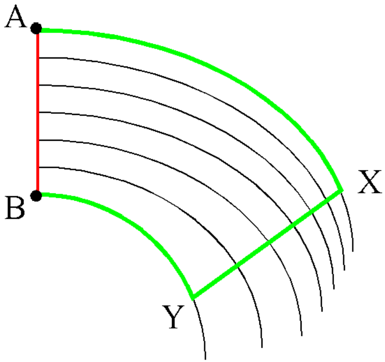
C. It is steadily changing in magnitude

D. None of the above

ANS: B—The electric field is constant and nonzero along the path.

There is definitely an electric field at all points along this path because the potential is changing. The electric field will point perpendicular to the equipotential lines, and therefore along or against the path. The magnitude of the electric field is $E = \Delta V/\Delta s$, so with equal changes in potential (ΔV) in equal separations (Δs), we see that the field is constant.

The figure below shows a pattern of equipotential curves (in black). The difference in potential between neighboring contours is the same for all curves. A particle moves from point A to B along the green path. What can you say about the electric field along its path?



A. It is constant and zero

B. It is constant and nonzero

C. It is steadily changing in magnitude

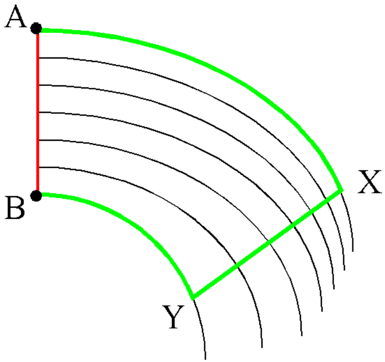
D. None of the above

ANS: D—None of the above statements are correct.

The field is definitely not constant along the green path. It is smallest at point Y and greatest at point X. Moreover, since the field is always perpendicular to the equipotential lines, the direction of the field changes as we follow the green path.

The field is also not steadily changing in magnitude. The fields at point A and B are equal. As we move from A to X, the field increases in magnitude because the equipotential lines are getting closer together. As we move from X to Y, the field decreases in magnitude because the equipotential lines are getting farther apart. Finally, as we move from Y to B, the field increases in magnitude because the equipotential lines are getting closer together again.

The figure below shows a pattern of equipotential curves (in black). The difference in potential between neighboring contours is the same for all curves. What can you say about the change in electric potential along the green path vs. the red path?



A. The change is greater along the green path than the red
B. The change is greater along the red path than the green
C. The net change is equal along both paths
D. None of the above

ANS: C—The net change in potential is equal along both paths.

The potential difference between two points is independent of the path. It only depends on the values of potential at the starting and ending points.

Warmup Question

Can there be a non-zero electric potential at a position in space where there is no electric charge?

Can there be a charge at a position where the potential is zero? Discuss thoroughly.

ANS: Yes, there can be a non-zero potential at a position in space where there is no electric charge. In fact, you can have a non-zero potential at a position in space even if there are no electric charges anywhere in the universe! All a non-zero potential means is that the potential at that point is different from some point(s) at which potential is defined to be zero.

In fact, we can define potential to be zero wherever we want. The potential at all other points in space is then defined in terms of that reference point and the distribution of charges in space.

You can have a charge at a position in space where the potential is zero if we define the potential to be zero there.

Warmup Question

A television set accelerates electrons ($m = 9.11 \times 10^{-31}\,\text{kg}$, $q = -1.6 \times 10^{-19}\,\text{C}$) into a beam by sending them through an electric potential difference. They then excite the phosphor on your TV screen and show you strange pictures of strange people. Anyway, you know that the speed each electron has when it hits your screen is about one quarter of the speed of light, right? (The speed of light is $3 \times 10^{8}\,\text{m/s}$.) Find the potential difference through which they are accelerated. (Note to physics nerds: you don't need to worry about relativistic effects for this estimate.)

ANS: The electron gains a kinetic energy of

$$\begin{aligned}
\frac{1}{2}mv^2 &= \frac{1}{2}\left(9.11\times10^{-31}\,\text{kg}\right)\left(\frac{3}{4}\times10^{8}\,\text{m/s}\right)^2 \\
&= \frac{1}{2}\left(10^{-30}\,\text{kg}\right)\left(\frac{3}{4}\times10^{8}\,\text{m/s}\right)^2 \\
&= \frac{1}{2}\left(10^{-30}\,\text{kg}\right)\left(\frac{1}{2}\times10^{16}\,\text{m}^2/\text{s}^2\right) \\
&= \left(\frac{1}{4}\right)\times10^{-14}\,\text{J} \\
&= 2.5\times10^{-15}\,\text{J}\,.
\end{aligned}$$

Therefore, the electron *loses* that much potential energy. Knowing that $\Delta U = q\Delta V$, we know that the potential difference changes by an amount

$$\Delta V = \frac{\Delta U}{q} = \frac{-2.5\times10^{-15}\,\text{J}}{-1.6\times10^{-19}\,\text{C}} = 1.5\times10^{4}\,\text{V} = 15\,\text{kV}\,.$$

Around 15000 Volts! That's not at all trivial, but it's doable. There's a reason why you needed to make sure that the TV was unplugged and given time for capacitors discharged before you worked on one of those old TVs!

Warmup Question

If you move in the direction of the electric field, the electric potential must

A. increase

B. decrease

C. stay the same

D. depends on the charge being moved

ANS: B—The electric potential decreases as you move in the direction of electric field. Putting it differently, and more easily to remember, electric field always points in the direction of decreasing electric potential.