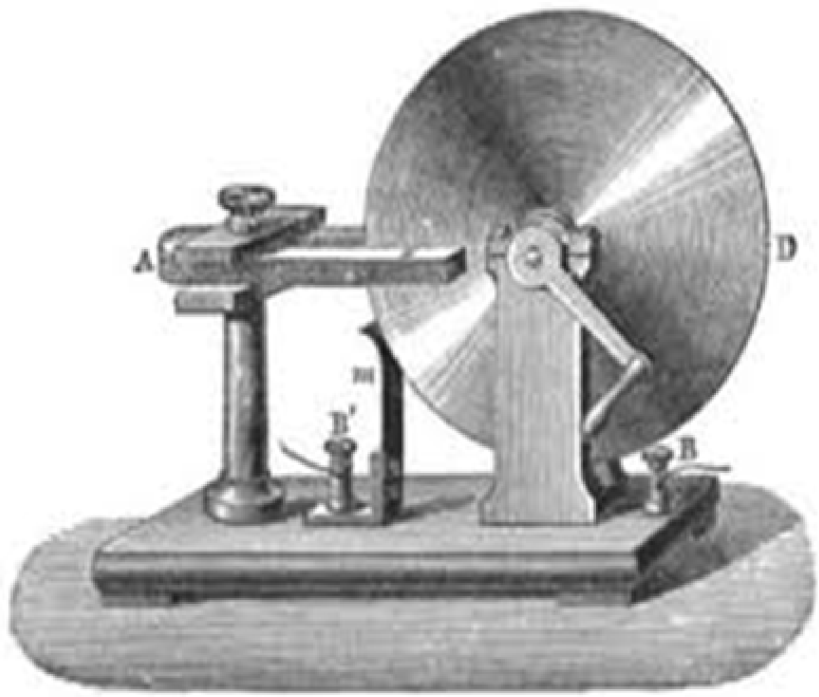
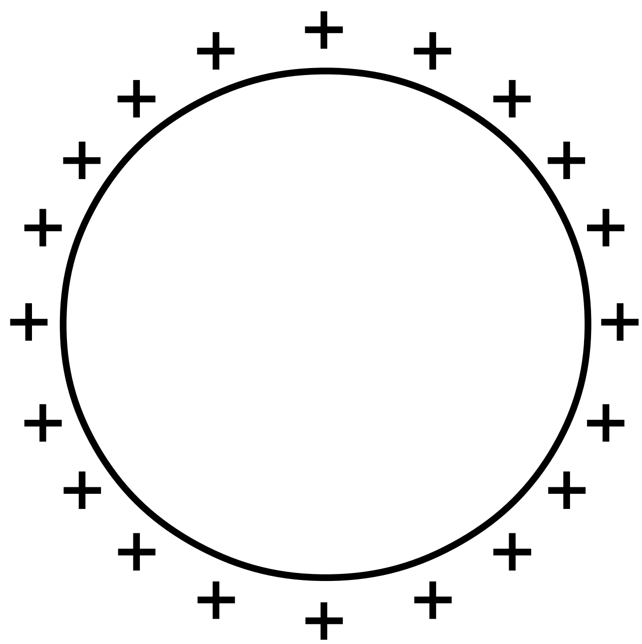
Electromagnetic Induction



A spherical body has a uniform positive charge density on its surface. There are no other charges around. What can be known about the electric field inside the sphere?



A. $E = 0$ everywhere inside

B. $E = 0$ only at the very center, but E can be non-zero elsewhere inside the sphere.

C. E is non-zero everywhere inside the sphere

D. Not enough info given

ANS: **A** — $E = 0$ everywhere inside the sphere.

Because the charge is distributed symmetrically over the surface of the sphere, any field inside and outside the object must be spherically symmetric: it must point inward or outward radially, and its magnitude can only depend at most on the distance from the sphere's center.

Place a spherical Gaussian surface of radius r inside the sphere. By spherical symmetry the net flux through this surface must be the field strength multiplied by the surface area, or $\Phi = 4\pi r^2 E$.

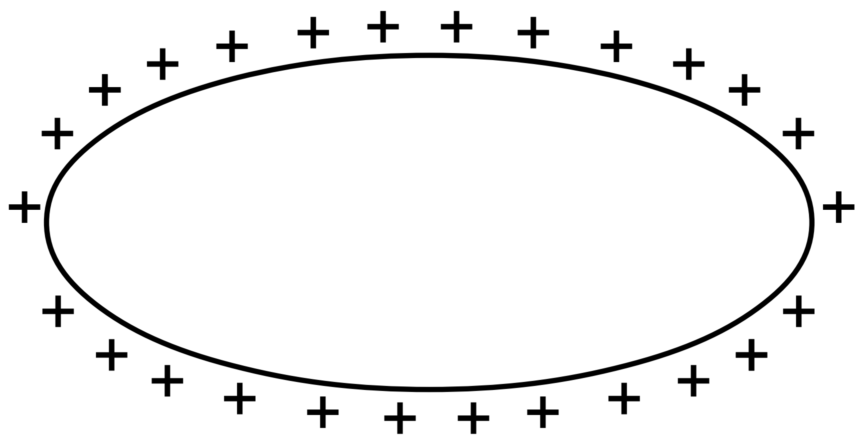
Regardless of the Gaussian sphere's radius r, as long as it is less than the radius of the sphere (R), there will be no charge contianed within the surface. Therefore, by Gauss's law, the flux through the Gaussian surface must be zero. This is only possible if the field itself is $E = 0$ for every Gaussian surface with $r < R$. Therefore, $E = 0$ everywhere inside the sphere.

But wait, there's more! Outside the sphere the total charge contained within the Gaussian surface is Q. Therefore, the total flux through the Gaussian surface is $\Phi = 4\pi r^2 E(r) = Q/\epsilon_0$. Solving for E, we get

$$E(r) = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2},$$

the field for a point charge Q at the origin. Now you know why I told you that the field outside a spherical charge is the same as if all of the charge were located at the center!

An oblong body has a uniform positive charge density on its surface. There are no other charges around. What can be known about the electric field inside the sphere?



A. $E = 0$ everywhere inside

B. $E = 0$ only at the very center, but E can be non-zero elsewhere inside the sphere.

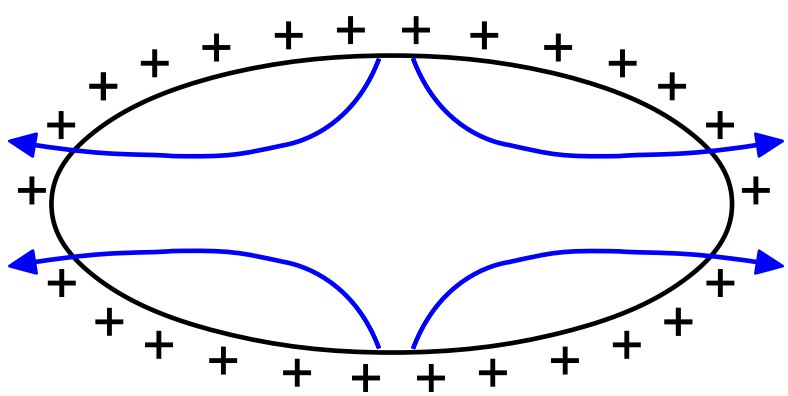
C. E is non-zero everywhere inside the sphere

D. Not enough info given

ANS: **B** — $E = 0$ at the center, but can be non-zero elsewhere inside the sphere.

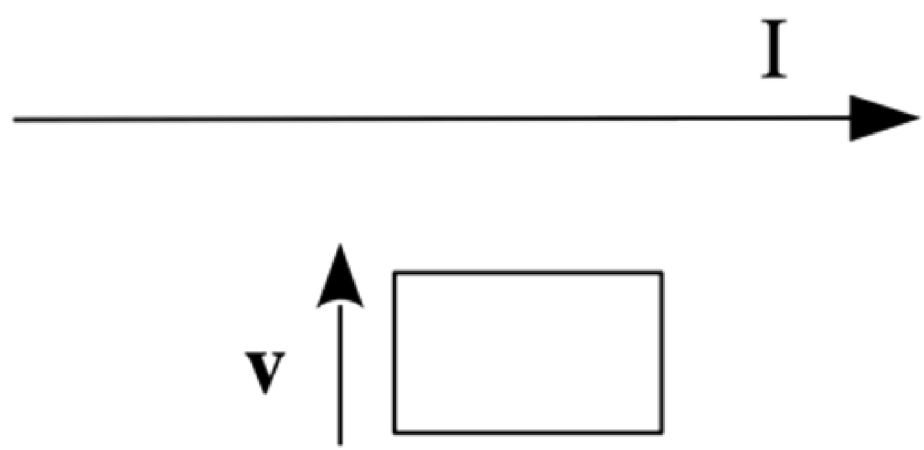
By symmetry it's easy to see that $E = 0$ at the center. At that point the field from charge near the top will be down, while the field from charge near the bottom will be up, and equal in magnitude. The same goes for the field at the center created by charges to the left and right, and other directions. For any given charge location, you can find another charge the same distance from the center in the opposite direction.

However, the charge is not distributed symmetrically over the surface of the sphere, so we cannot expect the field to be exactly zero inside. All we can require is that the net flux through a Gaussian surface inscribed within the body must be zero. This simply means that field lines entering the Gaussian surface must also leave the Gaussian surface. The internal field might look like the diagram below.



Note: For a conductor, the field would be exactly zero inside. This means that the charge must distribute itself on the surface to make the field be exactly zero inside. Such a charge distribution will not be uniform, so we know the object above cannot be a conductor.

A long, straight wire carries a steady current to the right. A rectangular conducting loop lies in the same plane as the wire, with two sides parallel to the wire and two sides perpendicular. Suppose the loop is pushed toward the wire. The induced current in the loop is



A. Clockwise
B. Counterclockwise
C. There is no current.
D. Need more information

ANS: **B** — The induced current in the loop flows *counterclockwise*.

Step 1: The current in the wire creates a magnetic field in the region bounded by the wire loop. From a right-hand rule, we know that this field points into the page.

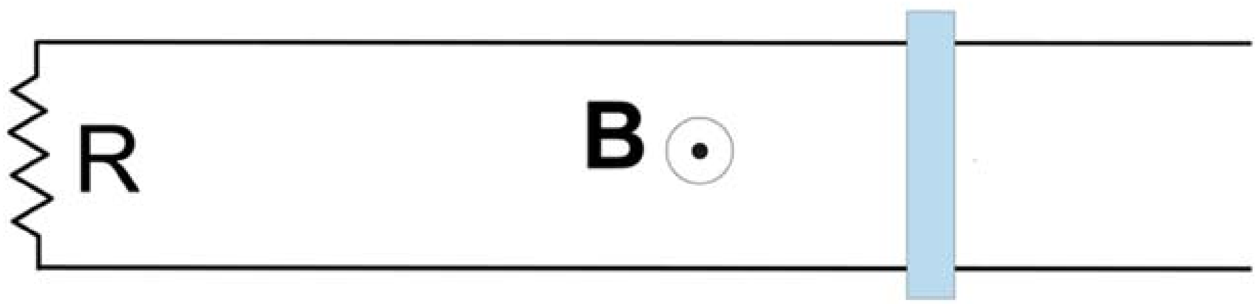
Step 2: As the loop approaches the wire, the field inside the loop due to the current I will *increase*. Therefore, the into-page-directed flux inside the loop will increase as the loop moves to regions of increasing magnetic field strength.

Step 3: From Faraday's law, we know that a changing magnetic flux through a closed wire loop will induce a current in that loop. From Lenz's law, this induced current will oppose the change in flux. Because the flux is increasing into the page, the flux created by the induced current must point *out of the page*.

Step 4: From another right-hand rule, a current in the loop that will create a flux out of the page will be directed *counterclockwise*.

Question: What if the loop is pulled away from the wire?
ANS: The induced current in the loop will flow *clockwise*. Can you follow the steps above to explain this answer?

A conducting rod lies across a pair of conducting wires in the presence of an externally imposed magnetic field out of the page. The rod is initially stationary. If the imposed magnetic field strength is increased, the rod



A. remains stationary
B. slides to the right
C. slides to the left
D. moves up
E. moves down
F. moves out of page
G. moves into page
H. none of the above

ANS: C — The rod slides to the left.

The systematic way is to answer in a series of steps:

Step 1: The outward-pointing (out of page) field is increasing. Therefore, the closed loop formed by the rod, resistor, and two horizontal wires will enclose a magnetic flux that is increasing outward.

Step 2: The changing flux will induce a current in the loop. This current will *oppose* the increasing outward flux. Therefore, the induced current will flow *clockwise* to create an inward (into page) flux.

Step 3: This clockwise current will flow downward through the rod. From a right-hand rule, the force on a downward current due to an outward field will point *to the left*.

Simpler Argument: The upward flux through the wire loop increases because the field increases. To counteract this change, the area bounded by the loop must *decrease*. In other words, the loop must shrink by sliding the rod to the left.