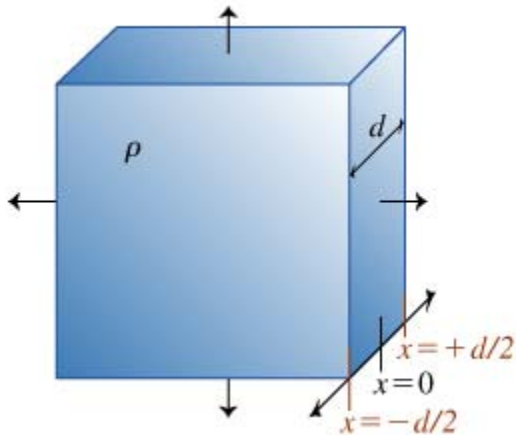


Problem discussed in the videos:

Videos (13) – (17)

The Electric Field inside and outside a Charged Insulator



A slab of insulating material of uniform thickness d , lying between $-d/2$ to $+d/2$ along the x axis, extends infinitely in the y and z directions, as shown in the figure. The slab has a uniform charge density ρ . The electric field is zero in the middle of the slab, at $x=0$.

Part A

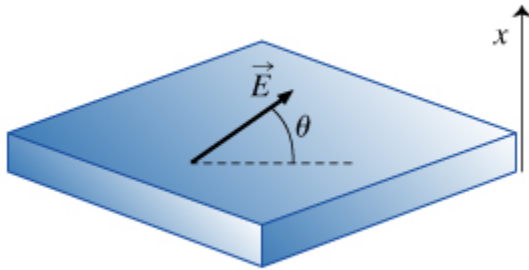
Which of the following statements is true of the electric field \vec{E} at the surface of one side of the slab?

ANSWER:

- The direction of \vec{E} is constant but its magnitude varies across the surface.
- Both the magnitude and the direction of \vec{E} are constant across the entire surface.
- The direction of \vec{E} varies across the surface but its magnitude is constant.
- Both the magnitude and the direction of \vec{E} vary across the surface.

Correct

Part B



What is the angle θ that the field \vec{E} makes with the surface of the slab, which is perpendicular to the x direction? Express your answer in radians, in terms of π .

ANSWER: $\theta = 1.57 \text{ rad}$
= Correct

Part C

What is E_{out} , the magnitude of the electric field outside the slab?

As implied by the fact that E_{out} is not given as a function of x , this magnitude is constant everywhere outside the slab, not just at the surface.

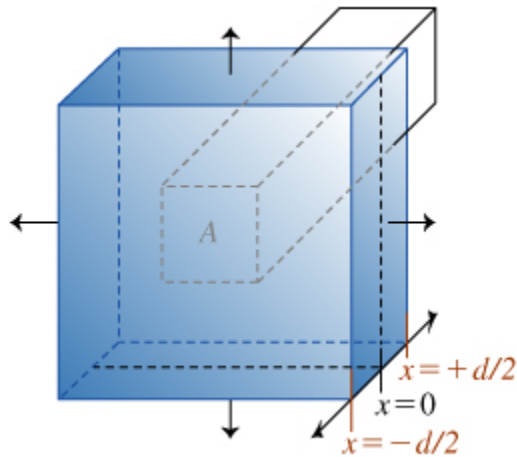
Hint C.1 How to approach the problem

Apply Gauss's law. You already know, by symmetry, that the electric field is perpendicular to the slab, and that it has constant magnitude across the surface of the slab. Use this information to choose an appropriate Gaussian surface.

Hint C.2 Gauss's law

Gauss's law can be written as $\Phi_E = q/\epsilon_0$, where Φ_E is the electric flux through a Gaussian surface (which depends on E_{out}), and q is the total charge enclosed by the surface.

Hint C.3 A Gaussian surface for this problem



Construct a Gaussian surface that is a rectangular box with sides oriented parallel to the electric field. There are two equally good choices for where to place the ends of the box:

- Put one end of the box outside the slab, perpendicular to the electric field, and the other end exactly in the middle of the slab (where the electric field is zero).
- Put one end of the box outside the slab and the other end an equal distance on the other side of the slab, both perpendicular to the electric field. By symmetry, the field at both ends of the box must be equal in magnitude and opposite in direction.

Both choices will lead to the correct answer, but the remaining hints will assume that you have chosen a Gaussian surface with one end in the middle of the slab.

Hint C.4 Calculate the enclosed charge

Hint not displayed

Hint C.5 Compute the electric flux

Hint not displayed

Express your answer in terms of d , ρ , and ϵ_0 .

ANSWER:

$$E_{\text{out}} = \frac{d\rho}{2\epsilon_0}$$

Correct

Part D

What is $E_{\text{in}}(x)$, the magnitude of the electric field inside the slab as a function of x ?

Hint D.1 How to approach the problem

Hint not displayed

Hint D.2 A Gaussian surface for this problem

Hint not displayed

Hint D.3 Calculate the enclosed charge

Hint not displayed

Hint D.4 Compute the flux

Hint not displayed

ANSWER:

$$E_{in}(x) = \frac{\rho x}{\epsilon_0}$$

Correct

Basic models of diodes and transistors (which are components used in more complex circuits, like those on computer chips) treat regions inside them as slabs of charge. In this example you found that

the electric field points in opposite directions on the two sides of $x = 0$. However, if a slab with

$$x = \frac{d}{2} \quad \text{to} \quad x = \frac{3d}{2}$$

negative charge were added behind this slab, i.e., from $x = \frac{d}{2}$ to $x = \frac{3d}{2}$, you can check that the electric field would be zero in the regions where there is no charge, because the fields due to the positive and negative charges cancel, and that the electric field in the regions where there is charge is always in the positive x direction.

Such a setup (usually called a PN junction) can be used as an electric "one-way street," since it supports the flow of positive charge only in the positive direction, i.e., along the electric field, and severely inhibits the flow of current in the opposite direction.