3rd Homework is due tonight at 11:59PM
1st Hour Exam is two weeks from today
Monday Feb 27th 9:40PM-11PM in ARC 103.
 Chapters 14, 16, 17, 21 and 22 are included in the exam.
(Multiple choice 16 questions; make single-sided formula sheet)
Students needing special accommodation (re)contact me
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CONGRATS FOR 4/4 TO: 62 students!
but why not 118? or 150?
Gauss’ Law: REVIEW

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \]

For a particular surface:
relates values of field on surface to the net charge inside
True for any closed surface:
relates electric field and charge distribution

What does it mean if the right hand side is zero?
Gauss’ Law: REVIEW

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \]

What does it mean if the right hand side is zero?

It DOESN’T mean that the field on the surface is zero

[Diagram of electric field lines]
Review of proof that Gauss’ law follows from Coulomb’s law

Last time; for sphere of radius \( R \)
Did the integral to show that

\[
\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}
\]

Flux line counting
Electric flux through outer surface
= electric flux through sphere

\[
\oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0}
\]
Review of proof that Gauss’ law follows from Coulomb’s law

Flux line counting
Electric flux through surface not enclosing the charge = zero

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \]
Add another charge

\[ E = E_1 + E_2 \]
\[ \Phi = \Phi_1 + \Phi_2 \]

If \( q_1 \) and \( q_2 \) are both inside \( \Phi = \frac{q_1}{\varepsilon_0} + \frac{q_2}{\varepsilon_0} = \frac{q_{\text{enc}}}{\varepsilon_0} \)

If \( q_1 \) inside and \( q_2 \) outside \( \Phi = \frac{q_1}{\varepsilon_0} = \frac{q_{\text{enc}}}{\varepsilon_0} \)

If \( q_1 \) outside and \( q_2 \) inside \( \Phi = \frac{q_2}{\varepsilon_0} = \frac{q_{\text{enc}}}{\varepsilon_0} \)

If \( q_1 \) and \( q_2 \) are both outside \( \Phi = 0 = \frac{q_{\text{enc}}}{\varepsilon_0} \)

**Gauss law is confirmed**
Clicker:

What is the flux integral for a spherical surface of radius R with point charge q a distance R/2 away from the center?

(A) 0
(B) \(q/(2\varepsilon_0)\)
(C) \(q/\varepsilon_0\)
(D) \(2q/\varepsilon_0\)
(E) Need to do a nasty integral to evaluate this
Clicker:

What is the flux integral for a spherical surface of radius $R$ with point charge $q$ a distance $R/2$ away from the center?

(A) $0$
(B) $q/(2\varepsilon_0)$
(C) $q/\varepsilon_0$
(D) $2q/\varepsilon_0$
(E) Need to do a nasty integral to evaluate this.
Starting from Gauss’s law, we can derive Coulomb’s law
Find field of a point charge \( E(r) \)
rotate
flip
charge distribution

electric field?
flip

NO!
flip

OK!
rotate

Same magnitude
Evaluate the flux integral on sphere of radius $R$

$$\mathbf{E}(r) = E(r) \hat{r}$$

$$\oint \mathbf{E} \cdot d\mathbf{A}$$

Gauss Law:
$$E(r) A = \frac{q}{\varepsilon_0}$$

$$E(r) = \frac{q}{(4\pi R^2 \varepsilon_0)} = \frac{kq}{R^2}$$

direction is radial
= Coulomb’s law!
same argument works for any spherically symmetric charge distribution $\vec{E}(\vec{r}) = E(r) \vec{r}$

Use Gauss’ law to prove the shell theorems

- Field outside a uniformly charged spherical shell is the same as if the charge were concentrated at a point at the center

- Field inside a uniformly charged spherical shell is zero

$q_{\text{enc}} = Q$  \hspace{1cm}  $q_{\text{enc}} = 0$
Symmetry of a uniformly charged infinite wire $\lambda$
Symmetry of a uniformly charged infinite wire $\lambda$
Field of uniformly charged wire
Points directly away from the wire
Magnitude depends only on distance \( r \) from wire

Flux through cylinder
\[ E(r) = 2 \pi r h \]

Gauss’ law
\[ E(r) 2 \pi r h = (\lambda h) / \varepsilon_0 \]

so
\[ E(r) = \lambda / (2\pi \varepsilon_0 r) \]
Same argument about the form of the field works for
• uniform cylindrical shell of radius $R$, charge density $\sigma$
• cylinder of radius $R$, charge density $\rho$
• hollow tube of inner radius $R_1$, outer radius $R_2$, charge density $\rho$
Field of uniformly charged sheet $\sigma$
Field of uniformly charged sheet $\sigma$

Flux through box = $2 \mathbf{E} \mathbf{A}$

Gauss’ law $2 \mathbf{E} \mathbf{A} = \frac{\sigma \mathbf{A}}{\varepsilon_0}$

So

$\mathbf{E} = \frac{\sigma}{2\varepsilon_0}$ away from the sheet
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points inside a conductor

A nonzero field would result in a nonzero force on the free charges at that point and they would move

They are not moving (electrostatics) so there is no force acting on them and the field must be zero.
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points inside a conductor

Gauss’ law: electric fields determine charge distribution
So fact #1 + Gauss’ Law =
Net charge is ZERO at all points inside a conductor
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points inside a conductor

Gauss’ law: electric fields determine charge distribution
So fact #1 + Gauss’ Law =
Net charge is ZERO at all points INSIDE a conductor

Charge can be nonzero at points on surface of a conductor
surface charge density $\sigma(r)$ (charge/area)
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points inside a conductor

Charge can be nonzero at points on surface of a conductor

surface charge density $\sigma(r)$ (charge/area)

Charge at the surface arranges itself so that the electric field inside is zero

(electric field of outside charges + electric field of surface charges)
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Charge at the surface arranges itself so that the electric field inside is zero

Spherical conductor with a concentric spherical cavity
Put a point charge at the center of the cavity
How is the charge arranged on surface of the conductor?
Surface charge density can be nonzero
Charge moves freely on surface
Charge arranges itself on surface to cancel out fields inside = fact #3

Spherical conductor with a concentric spherical cavity
Put a point charge at the center of the cavity
How is the charge arranged on surface of the conductor?

Relate the fields at the surface to the surface charge density
Surface charge density can be nonzero
Charge moves freely on surface
Charge arranges itself on surface to cancel out fields inside = fact #3

Spherical conductor with a point charge outside
Field outside still related to the surface charge density
Field inside hollow cavity is zero
Hollow conductor with an empty cavity

Electric field inside the cavity is ZERO

True for any shape!