1. Charges, fields and potential for electrostatic systems with conductors
2. Capacitance of an isolated conductor
3. Capacitance of a pair of conductors = “capacitor”

Reading: 3.1, 3.2, 3.5
Next Monday: 3.6, 3.7, 1.14, 3.3 and 3.4
BEFORE CLASS: Play with toys – how is the energy stored?

SET TIME FOR FIRST HOUR EXAM: WED FEB 21 EVENING?
DO WARM-UP PROBLEMS BEFORE RECITATIONS THIS WEEK
3rd HOMEWORK ASSIGNMENT IS DUE IN CLASS NEXT MONDAY

class web site
http://www.physics.rutgers.edu/ugrad/272
Systems with conductors are DIFFERENT

Charges in conductor move if electric force they feel would move them within the object

Charges rearrange until all charges feel zero electric force for motion within the object

Example: Neutral conductor in uniform external field

GENERAL NOTE: when reading the problem, look for word “conducting” vs “fixed”
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points in the material of 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 in the material of a conductor

Gauss’ law: electric fields determine charge distribution

\[ \nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \]

So fact #1 + Gauss’ Law =
Net charge is ZERO at all points in the material of a conductor
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Fact #1: electric field is ZERO at all points in the material of a conductor

Gauss’ law: electric fields determine charge distribution

\[ \nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0} \]

So fact #1 + Gauss’ Law =
Net charge is ZERO at all points in the material of a conductor
Rules for charges and electric fields in electrostatic systems with CONDUCTORS

Net charge is ZERO at all points IN THE MATERIAL of a conductor
BUT
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

Net charge is ZERO at all points IN THE MATERIAL of a conductor
BUT
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 in the material 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 in the material 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?
What is the field OUTSIDE the conductor?
Electric fields are zero inside conductors
All excess charge is on the surface

Field at the surface of a conductor

It is perpendicular to the surface
Surface is an equipotential
All points in the material are at the same potential as the surface

Magnitude of the field at the surface is $\sigma/\varepsilon_0$
(Use Gauss’s Law!)
Rules for charges, fields & potential in electrostatic systems with conductors

Charges go to the surface (includes exterior and interior surfaces)
No net charge at any point in the material
Field in the material is zero
Field at surface is perpendicular to the surface
Potential is the same at all points in the conductor
Field at surface is $\sigma/\varepsilon_0$

True for an isolated conductor
True for a conductor in the presence of other charges, conductors
Rule for conductors with cavities:
IF the cavity is empty then the field is zero
IF the cavity contains charges, then field is not zero in the cavity
But the net charge on the surface of the cavity = -net charge inside
Isolated conductor, charge $Q$, potential $\phi$

What happens if I double the charge?

If $Q$ doubles, E field doubles so potential doubles

Ratio $Q/\phi$ is independent of $Q$

**Capacitance $C$**

Property only of the “geometry” of the conductor

“geometry” = size and shape

**UNITS:** $1 \text{ C/V} = 1$ farad (F)
Capacitance of sphere of radius R

Capacitance of disk of radius R – see Purcell p.142
System of two conductors $q$ and $-q$

Charges on surfaces produce electric fields. Fields are zero inside the conductors. Fields are perpendicular to surface just outside surface of each conductor is an equipotential.

Value of potential on surface of left conductor $= \phi_L$

Value of potential on surface of right conductor $= \phi_R$

"Potential difference between conductors" $\phi = |\phi_L - \phi_R|$
Capacitor, charges $q$ and $-q$, potential difference $\phi$

What happens if I double the charge on each conductor, to $2q$ and $-2q$?
Capacitor, charges $q$ and $-q$, potential difference $\phi$

What happens if I double the charge on each conductor?

If $q$ doubles, E field doubles so potential difference doubles

Ratio $q/\phi$ is independent of choice of $q$

**Capacitance** $C$ of a capacitor

Property only of the “geometry” of the two conductors! “geometry” = size, shape, arrangement in space
The two metal objects in the figure have net charges of +72 pC and -72 pC. The potential difference between them is 18 V. What is the capacitance?

(A) 0.13 pF  
(B) 0.25 pF  
(C) 4.0 pF  
(D) 8.0 pF  
(E) Need more information to answer
The two metal objects in the figure have net charges of +72 pC and -72 pC. The potential difference between them is 18 V. What is the capacitance?

(A) 0.13 pF
(B) 0.25 pF
(C) 4.0 pF
(D) 8.0 pF
(E) Need more information to answer

Answer for this particular “geometry”– changes if I move or rotate one of the objects
For simple cases, we can find the potential difference when the two conductors have charge $q$ and $-q$.
Capacitance of two parallel plates with area $A$ & separation $d$

Assume charge $q$ is uniform on plate: $\sigma = \pm q/A$

Compute $E$ of plate (neglect fringing field) $q/(2\varepsilon_0 A)$ from each plate.

Compute $V = qd/(2\varepsilon_0 A)$

Divide $q/V$ to get $C = q/(qd/(2\varepsilon_0 A)) = \varepsilon_0 A/d$

Depends only on geometry (size, shape, arrangement)
For simple cases, we can find the potential difference when the two conductors have charge $q$ and $-q$

Concentric spheres: $R_1$ and $R_2$ – see Purcell p. 146-147