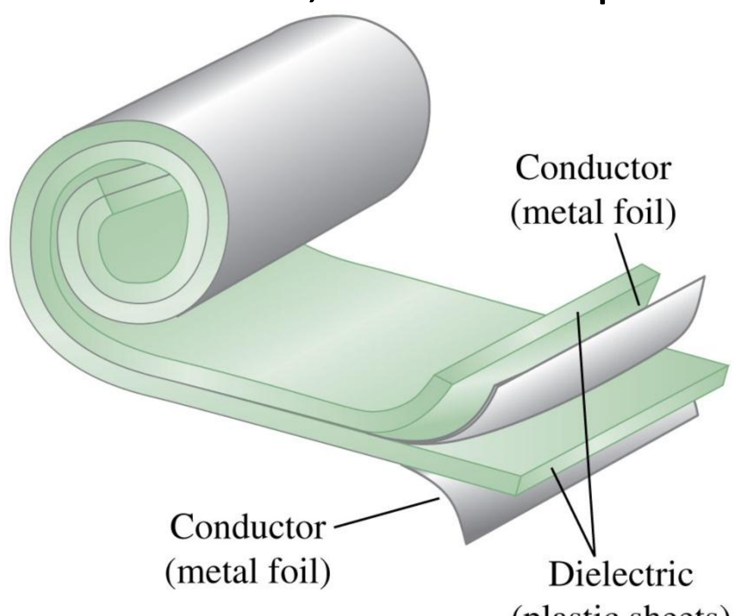
Lecture 21
(Dielectrics)

Physics 161-01 Spring 2012

Douglas Fields

Why Dielectrics

- There are three reasons why dielectrics are used in capacitors:
  - They act to give a solid separation between plates of a capacitor (which are usually large, thin sheets of metal separated by a small distance).
  - They increase the dielectric breakdown of the capacitor by increasing the voltage that can be applied before a spark occurs.
  - They increase the capacitance!
- The first of these is self evident, but let's explore the other two.



Dielectric Breakdown

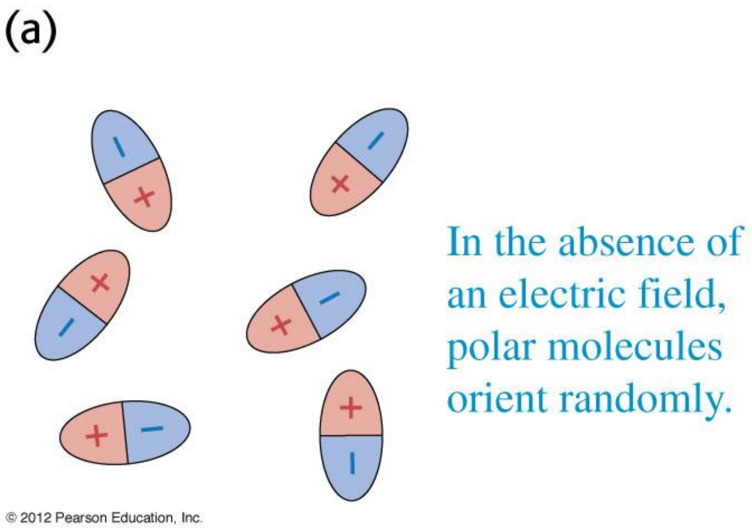
- An insulator has no free electrons to allow charges to move, but they do have electrons.
- These electrons are bound in the atomic or molecular potentials.
- If a sufficiently large electric force acts on them, they can be pulled free from their atoms or molecules, transforming the insulator into a conductor.
- By choosing a material with a higher dielectric strength, once can avoid dielectric breakdown.
- Dry air has a dielectric strength of ~3×10^6V/m.

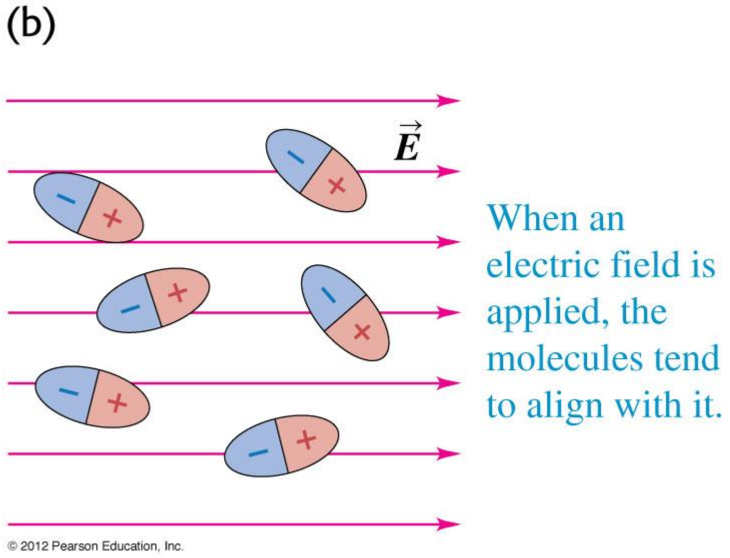
Table 24.2 Dielectric Constant and Dielectric Strength of Some Insulating Materials

Material	Dielectric Constant, K	Dielectric Strength, E_m (V/m)
Polycarbonate	2.8	3×10^7
Polyester	3.3	6×10^7
Polypropylene	2.2	7×10^7
Polystyrene	2.6	2×10^7
Pyrex glass	4.7	1×10^7

Dielectric Constant

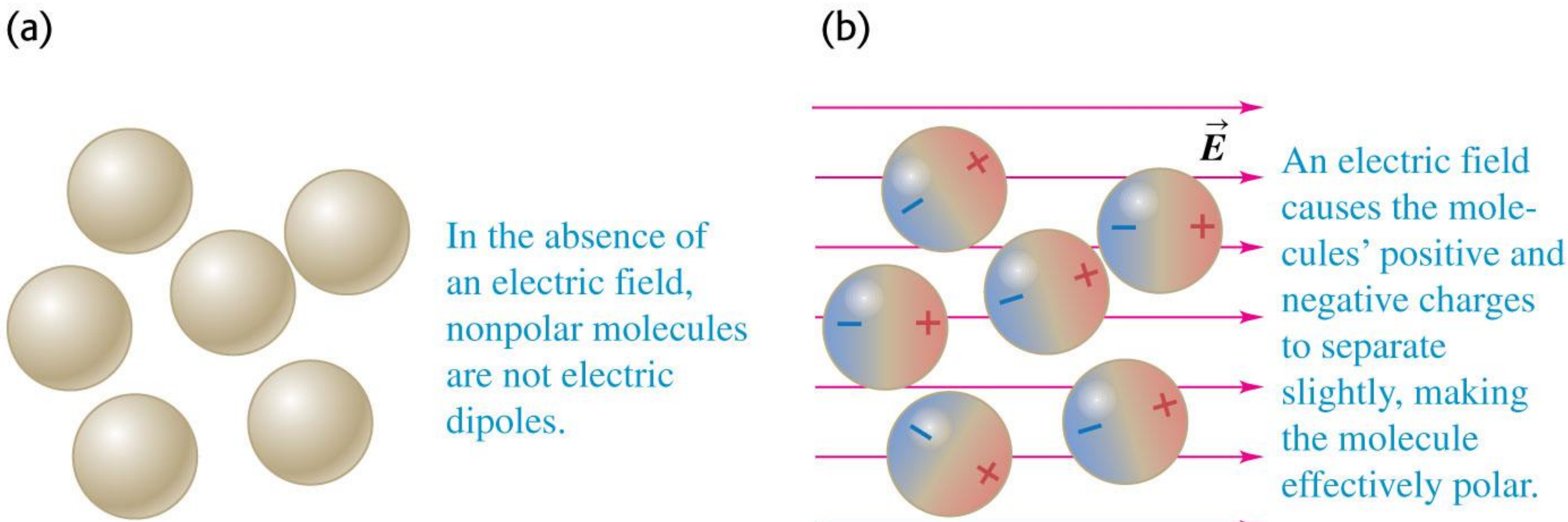
- Remember what happens when we put a dipole in an electric field?





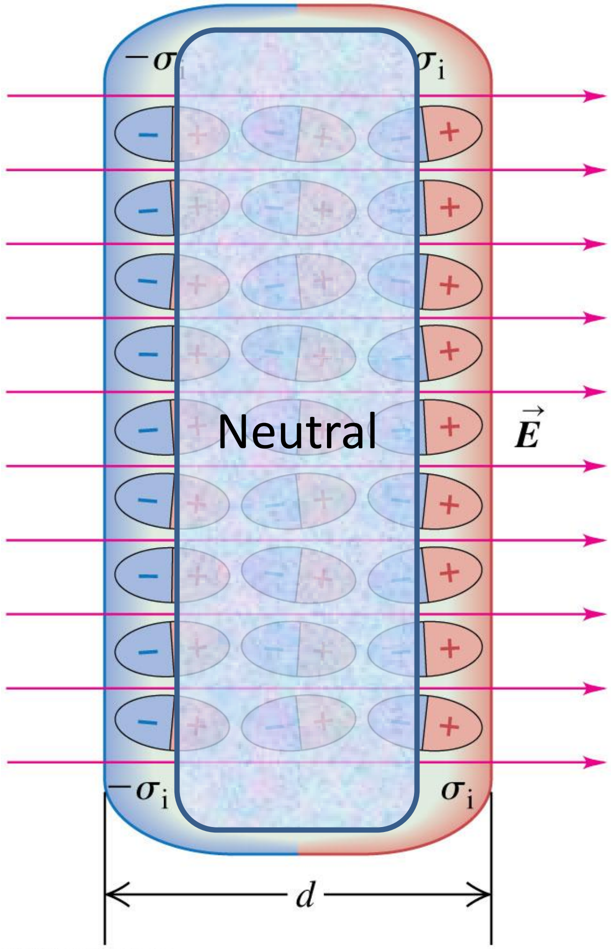
Dielectric Constant

- Even if the molecule has no inherent dipole moment, an electric field can cause one:



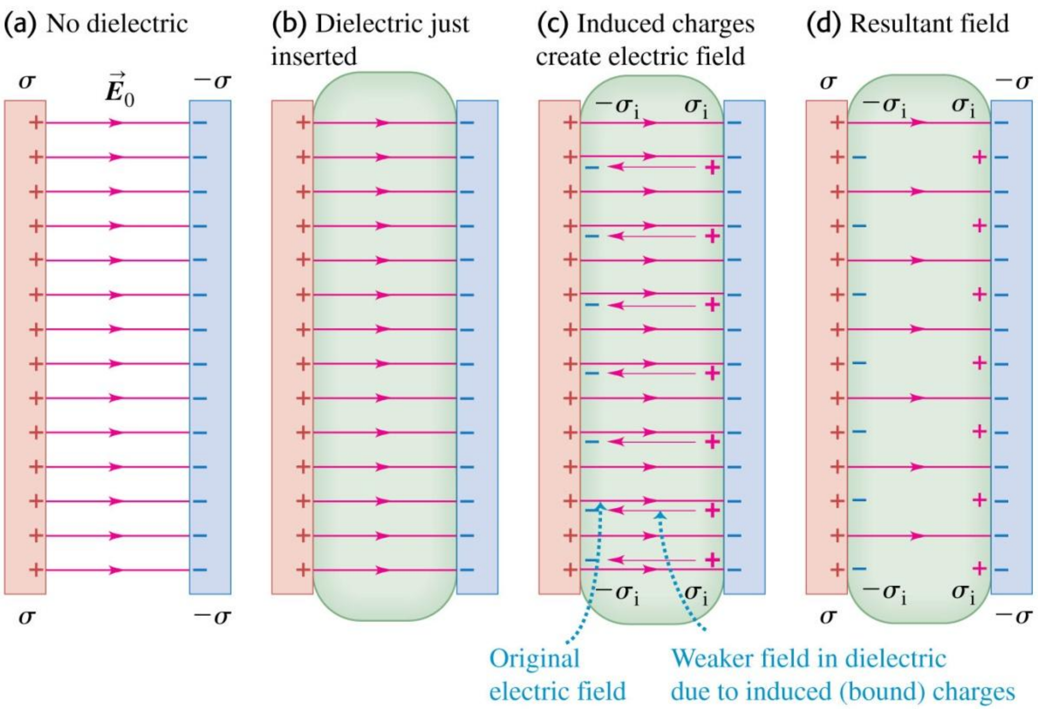
Dielectric Constant

- Now, let’s look at what happens when we put a block of dielectric material into an electric field.
- While the entire object remains neutral, there are induced surface charges created on the opposing surfaces.



Dielectric Constant

- Those surface charges create an electric field that opposes (points in the opposite direction to) the electric field in which it is placed.
- The net result is a reduction in the electric field between the plates.



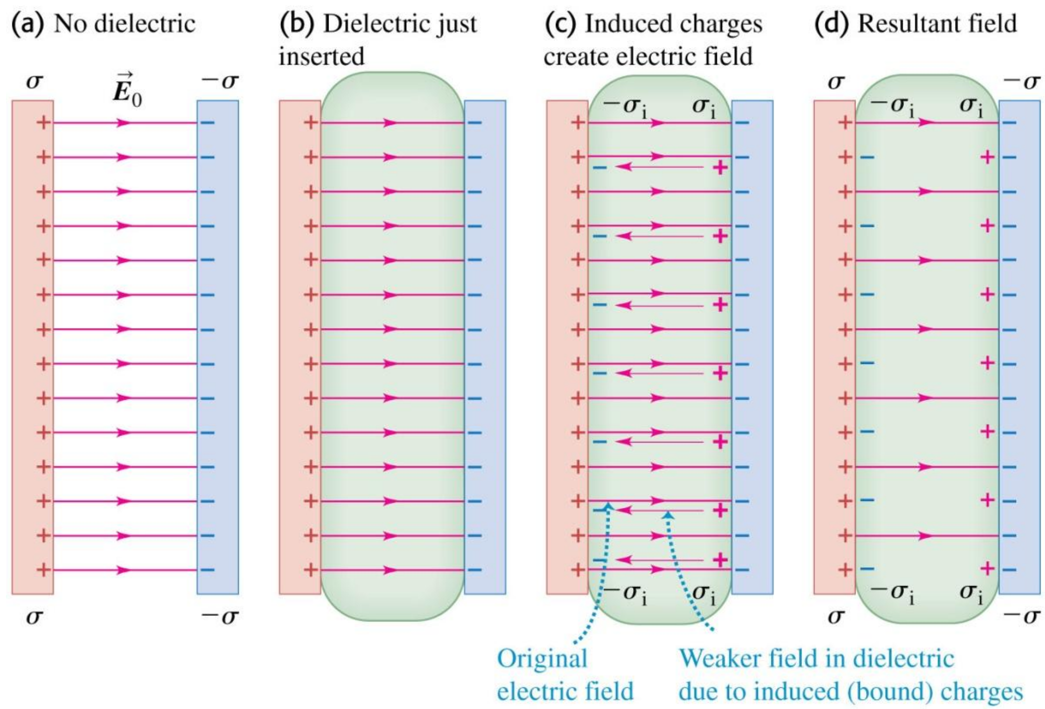
Dielectric Constant

- This reduces the potential across the plates, since the potential is determined by:

$$\Delta V = -\int_0^d \vec{E} \cdot d\vec{l}$$

- And, since the charge on the capacitor hasn't changed, the capacitance goes up:

$$C = \frac{Q}{V}$$



Dielectric Constant

- The amount that the electric field (and thus, the potential) is reduced, and the capacitance is increased, depends upon the material used:

$$C = KC_0$$

$$E = \frac{E_0}{K}$$

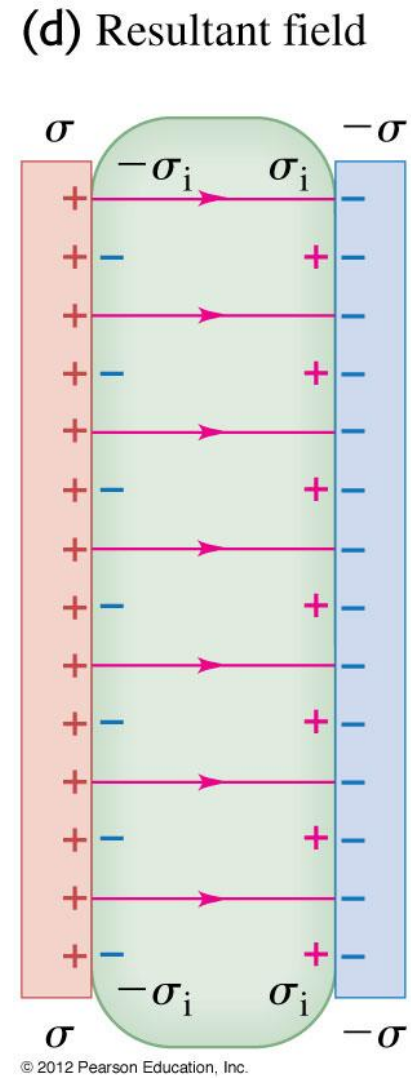
$$V = \frac{V_0}{K}$$

Table 24.1 Values of Dielectric Constant K at 20°C

Material	K	Material	K
Vacuum	1	Polyvinyl chloride	3.18
Air (1 atm)	1.00059	Plexiglas	3.40
Air (100 atm)	1.0548	Glass	5–10
Teflon	2.1	Neoprene	6.70
Polyethylene	2.25	Germanium	16
Benzene	2.28	Glycerin	42.5
Mica	3–6	Water	80.4
Mylar	3.1	Strontium titanate	310

Permittivity

- For a parallel plate capacitor which is completely filled with a dielectric of dielectric strength K, the capacitance is now:



$$C = \frac{Q}{V} = \frac{\sigma A}{\frac{E_0}{K} d} = \frac{K\sigma A}{E_0 d} = \frac{K\sigma A}{\frac{\sigma}{\varepsilon_0} d} = \frac{K\varepsilon_0 A}{d}$$

$$C = \frac{\varepsilon A}{d}$$

CPS 21-1

You slide a slab of dielectric between the plates of a parallel-plate capacitor. As you do this, the *charges* on the plates remain constant.

What effect does adding the dielectric have on the *potential difference* between the capacitor plates?

A. The potential difference increases.

B. The potential difference remains the same.

C. The potential difference decreases.

D. not enough information given to decide

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CPS 21-2

You slide a slab of dielectric between the plates of a parallel-plate capacitor. As you do this, the *charges* on the plates remain constant.

What effect does adding the dielectric have on the *energy stored* in the capacitor?

A. The stored energy increases.

B. The stored energy remains the same.

C. The stored energy decreases.

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CPS 21-2

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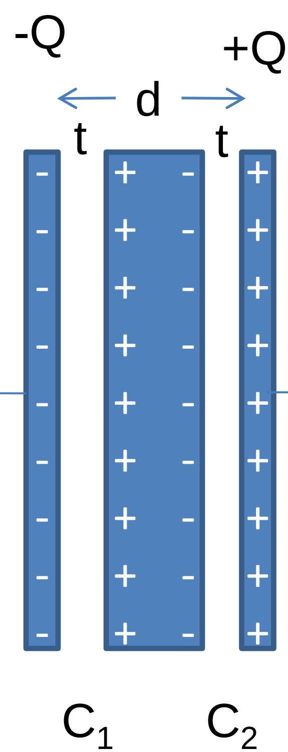
The Perfect Dielectric?

- In order to better understand dielectrics by taking the effect to the extreme, let's look at what happens if we put a piece of conductor between the plates of a parallel plate capacitor:

$$1)\,V_0 = -\int_l^r \vec{E}\cdot d\vec{l} = Ed$$

$$2)\,E = \frac{\sigma}{\varepsilon_0}$$

$$3)\,C_0 = \frac{Q}{V_0} = \frac{\sigma A}{Ed} = \frac{\varepsilon_0 A}{d}$$



$$1)\,V = -\int_l^r \vec{E}\cdot d\vec{l} = E\left(d-t\right)$$

$$2)\,E = \frac{\sigma}{\varepsilon_0}$$

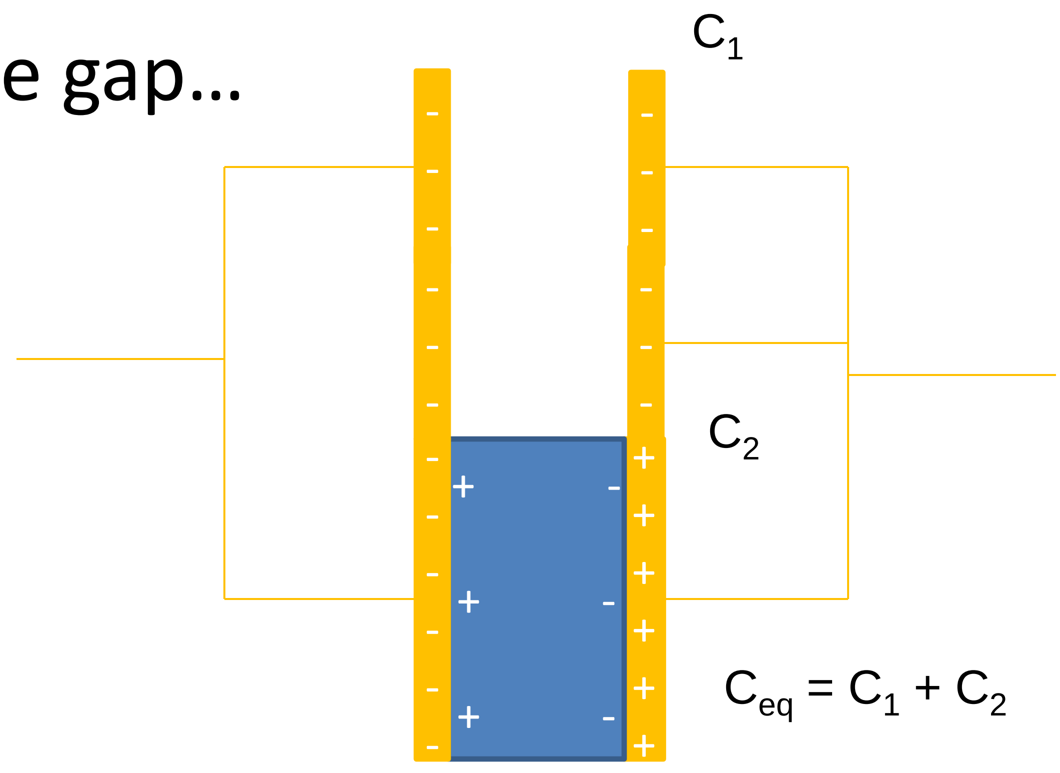
$$2)\,C_{\text{eqv}} = \frac{Q}{V} = \frac{\sigma A}{\frac{\sigma}{\varepsilon_0}\left(d-t\right)} = \frac{\varepsilon_0 A}{\left(d-t\right)}$$

$$\text{or})\,\frac{1}{C_{\text{eqv}}} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{\frac{1}{2}\left(d-t\right)}{\varepsilon_0 A} + \frac{\frac{1}{2}\left(d-t\right)}{\varepsilon_0 A} = \frac{\left(d-t\right)}{\varepsilon_0 A} \Rightarrow$$

$$C_{\text{eqv}} = \frac{\varepsilon_0 A}{\left(d-t\right)}$$

Capacitor in Parallel

- If you are given a capacitor where the dielectric doesn't completely fill the gap…



Gauss's Law for Dielectrics

- Gauss's Law now has to take into account all of the charge, induced and free:

$$\Phi_{\text{E,Net}} = \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} = \frac{\sigma A - \sigma_i A}{\varepsilon_0} = \frac{(\sigma - \sigma_i) A}{\varepsilon_0} \Rightarrow$$

$$\Phi_{\text{E,Net}} = \oint \vec{E} \cdot d\vec{A} = \frac{\sigma A}{K \varepsilon_0} \Rightarrow$$

$$\Phi_{\text{E,Net}} = \oint K\vec{E} \cdot d\vec{A} = \frac{q_{\text{enc, free}}}{\varepsilon_0}$$