Chapter 23: Electrostatic Energy & Capacitance
Chapter 24: Electric Current & Ohm's law
Tuesday September 27th

- Review of Mini Exam 2
- Review of Capacitance and Electrostatic Energy
- Capacitors in series and parallel
    - Demonstration and example
- Dielectrics and capacitance
    - Demonstration and explanation
- Conductors under dynamic conditions
    - Current, current density, drift velovity
- Ohm's law

Reading: up to page 410 in the text book (Ch. 24)

Capacitors

- The transfer of charge from one terminal of the capacitor to the other creates the electric field.
- Where there is an electric field, there must be a potential difference, leading to the following definition of capacitance *C*:

$$C = \frac{Q}{\Delta V} \qquad \text{or} \qquad Q = C\Delta V$$

- *Q* represents the magnitude of the excess charge on either plate. Another way of thinking of it is the charge that was transferred between the plates.

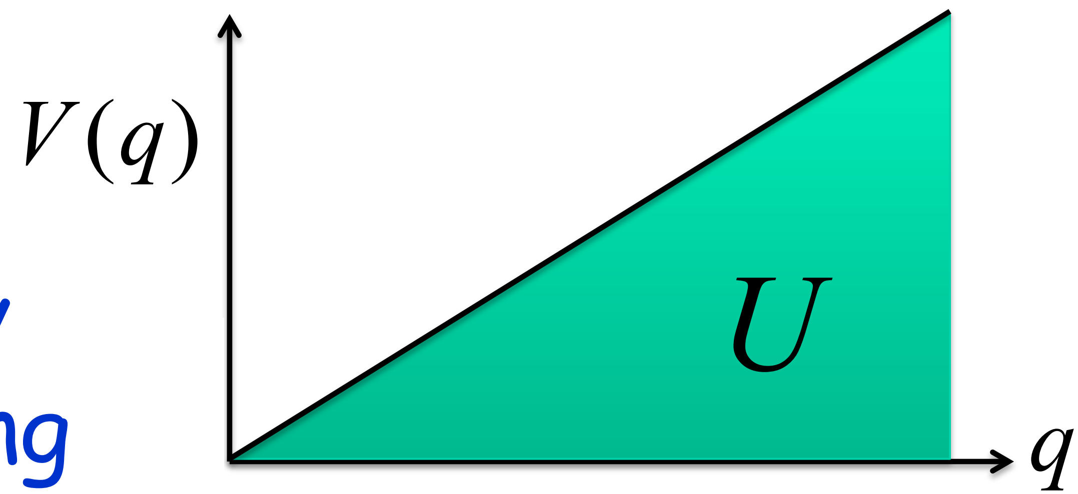
SI unit of capacitance: 1 farad (F) = 1 coulomb/volt

(after Michael Faraday)

Energy stored in a Capacitor

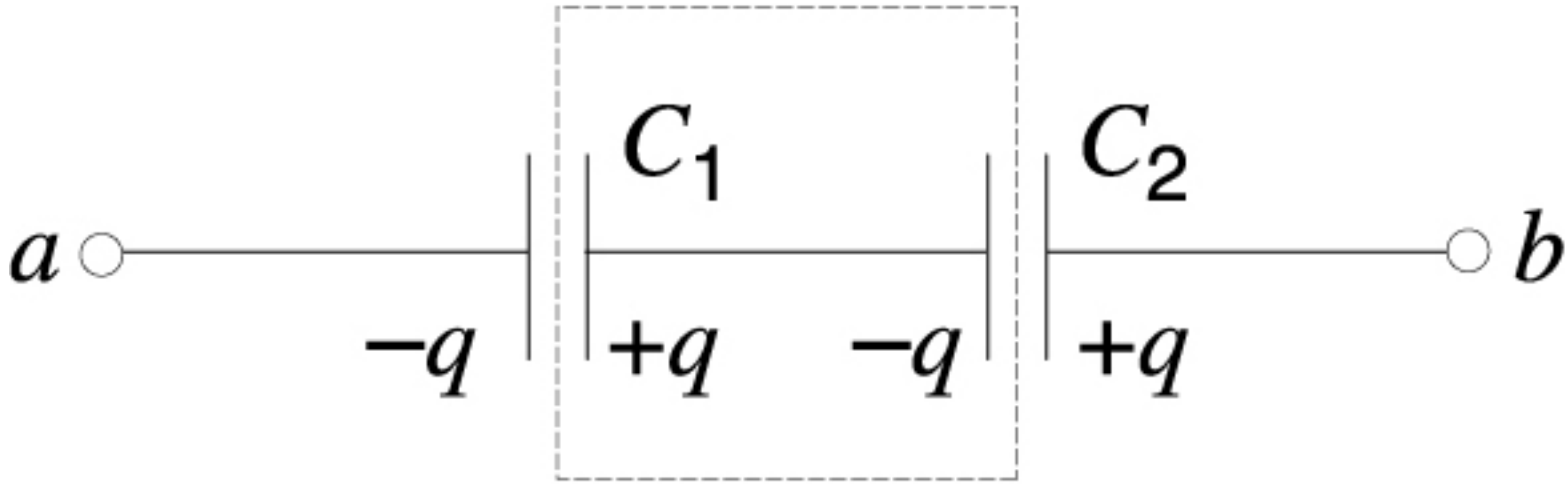
$$U = \frac{q^2}{2C} = \frac{(CV)^2}{2C} = \tfrac{1}{2}CV^2$$

$$= \frac{q^2}{2C} = \tfrac{1}{2}\frac{q}{C}q = \tfrac{1}{2}qV$$



Just like energy stored in a spring

Capacitors connected in series

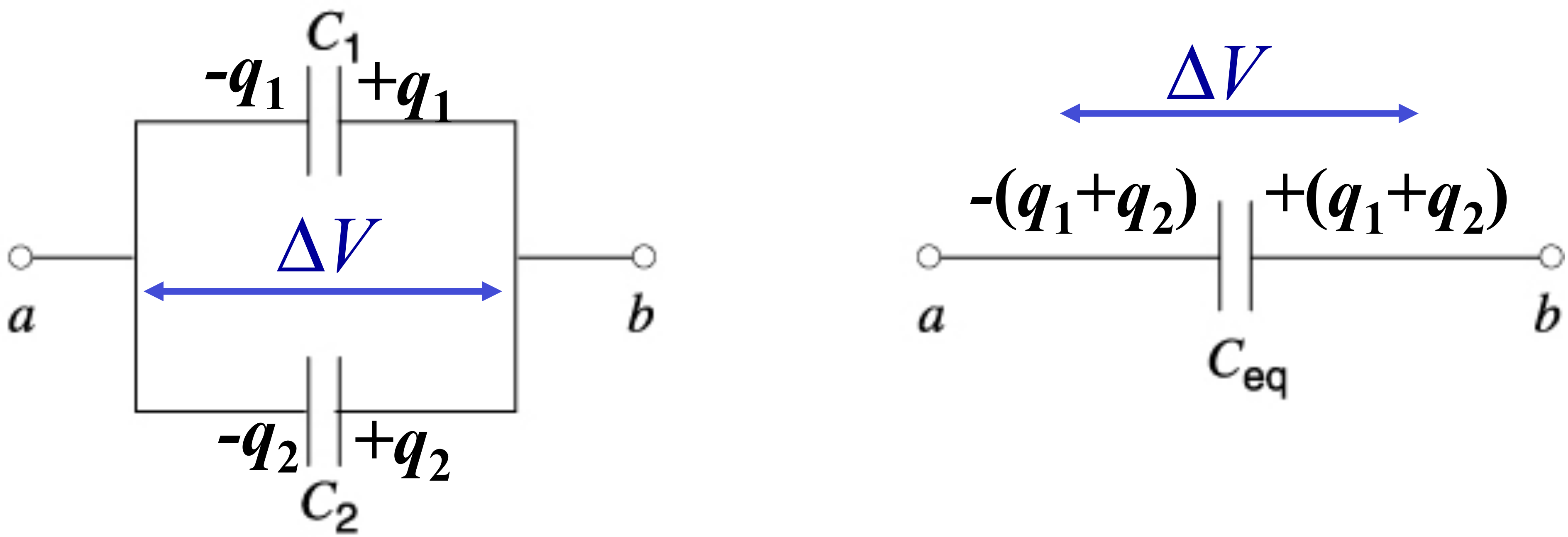


$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

In fact:

$$\frac{1}{C_{eq}} = \sum_n \frac{1}{C_n}$$

Capacitors connected in parallel



$$q_1 = C_1 \Delta V$$

$$q_2 = C_2 \Delta V$$

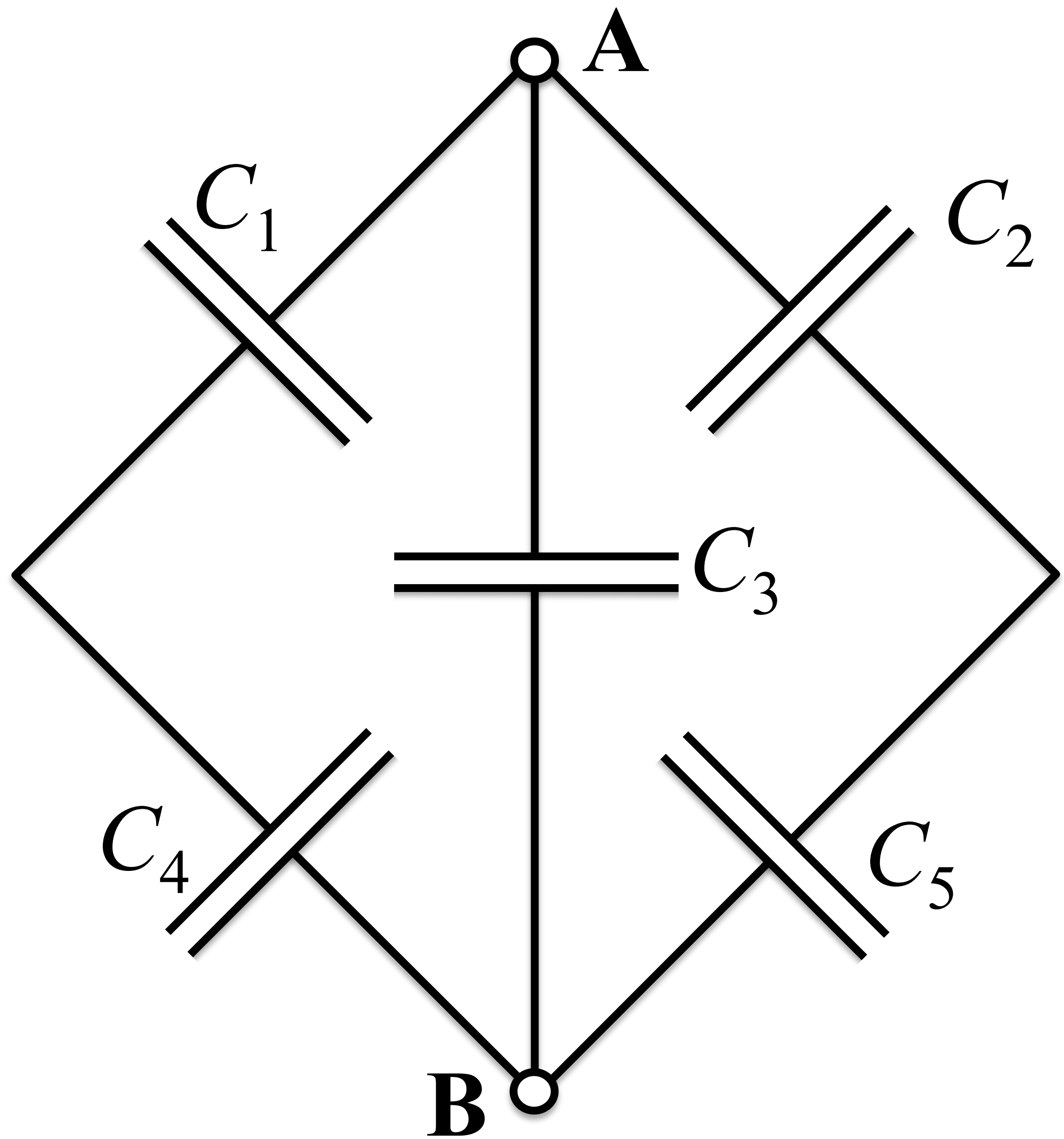
$$q_1 + q_2 = C_{eq} \Delta V$$

$$(C_1 + C_2)\Delta V = C_{eq} \Delta V$$

$$C_{eq} = C_1 + C_2$$

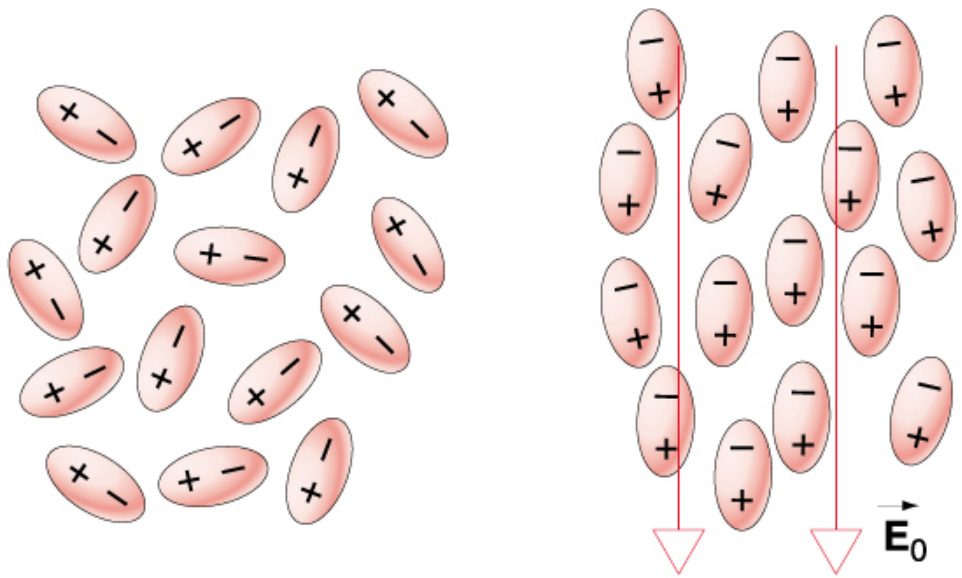
More Challenging Example

What is capacitance between points **A** and **B**

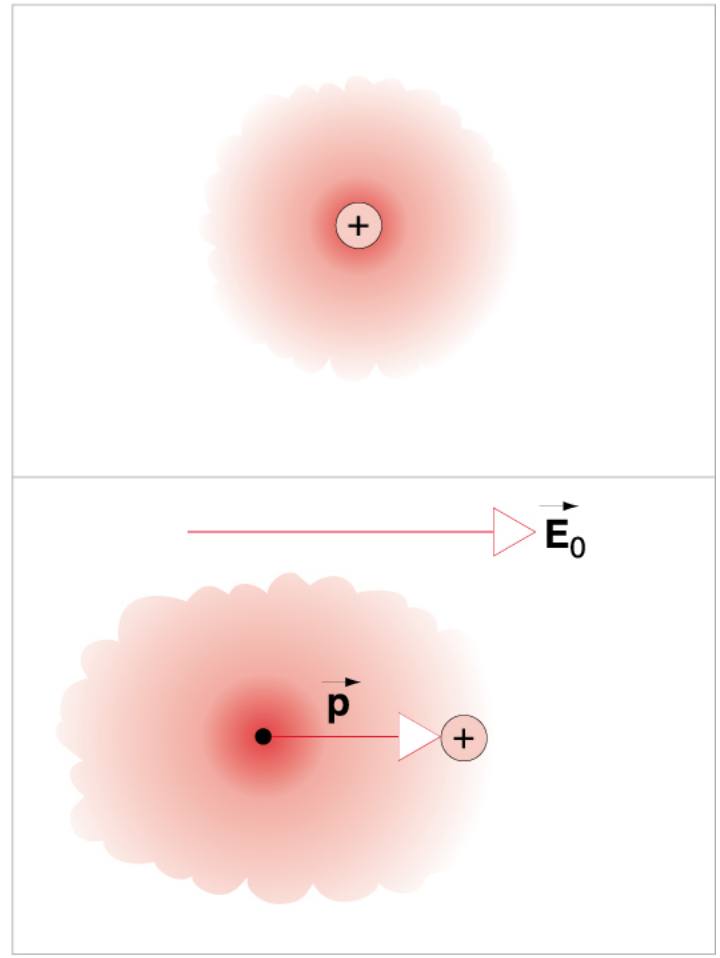


A dielectric in an electric field

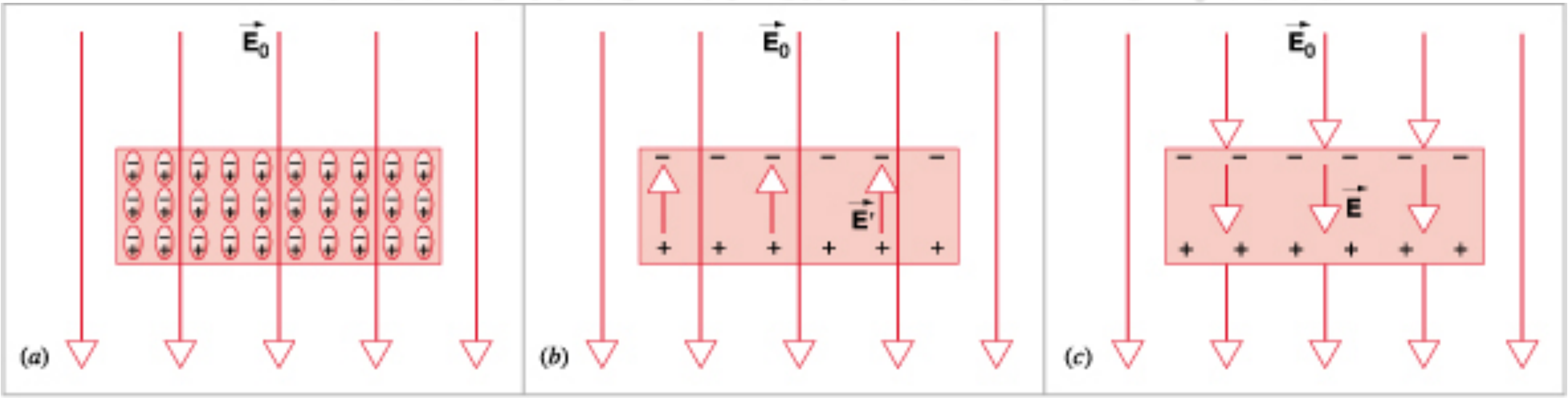
Electric dipoles in an electric field



Non-polar atoms in an electric field



A dielectric in an electric field



$$\vec{\mathbf{E}} = \vec{\mathbf{E}}_0 + \vec{\mathbf{E}}'$$

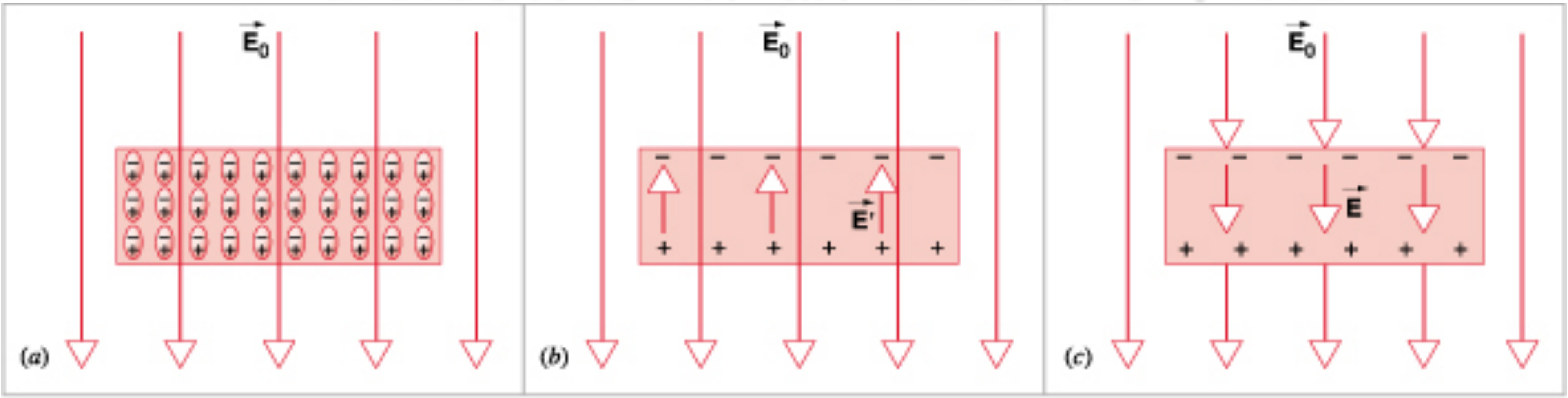
$$E = E_0 - E' \longleftarrow E' \text{ opposes } E_0$$

Linear materials: $E' \propto E$, or $E' = \chi_e E$

$$\Rightarrow E = E_0 - \chi_e E, \text{ or } E_0 = (1 + \chi_e) E$$

χ_e is the electric susceptibility (dimensionless)

A dielectric in an electric field



Linear materials: $E_0 = \left(1+\chi_e\right) E$

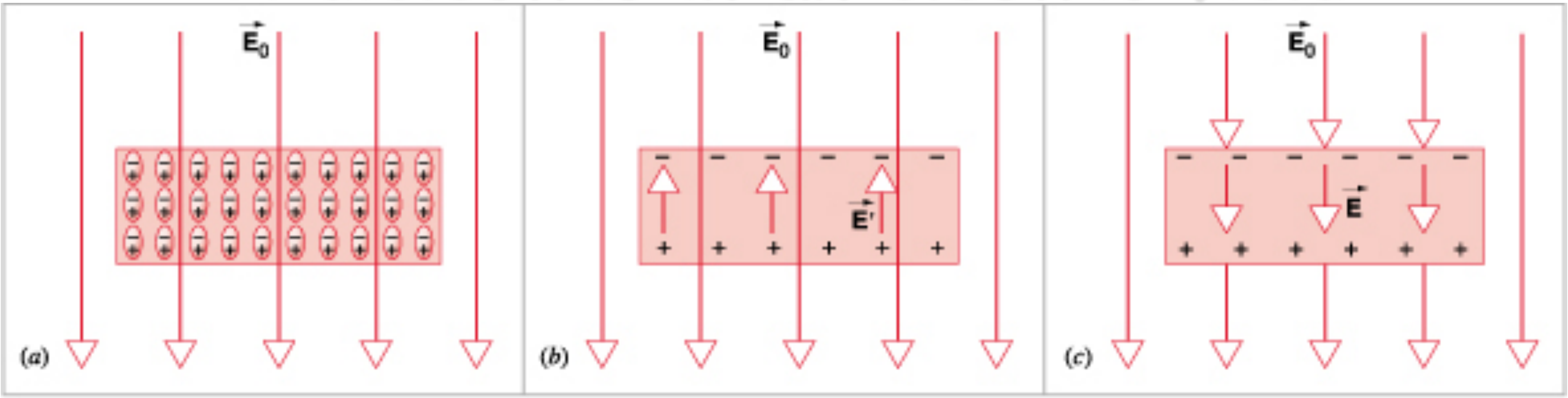
$$\Rightarrow E = \frac{1}{1+\chi_e} E_0 = \frac{1}{\kappa_e} E_0 \qquad (\kappa_e = 1+\chi_e)$$

χ_e is the electric susceptibility (dimensionless)

κ_e is the dielectric constant (dimensionless)

$\varepsilon = \kappa_e \varepsilon_o$ is the permittivity

A dielectric in an electric field



Linear materials: $$E_0 = (1+\chi_e)E$$

Isolated capacitor:

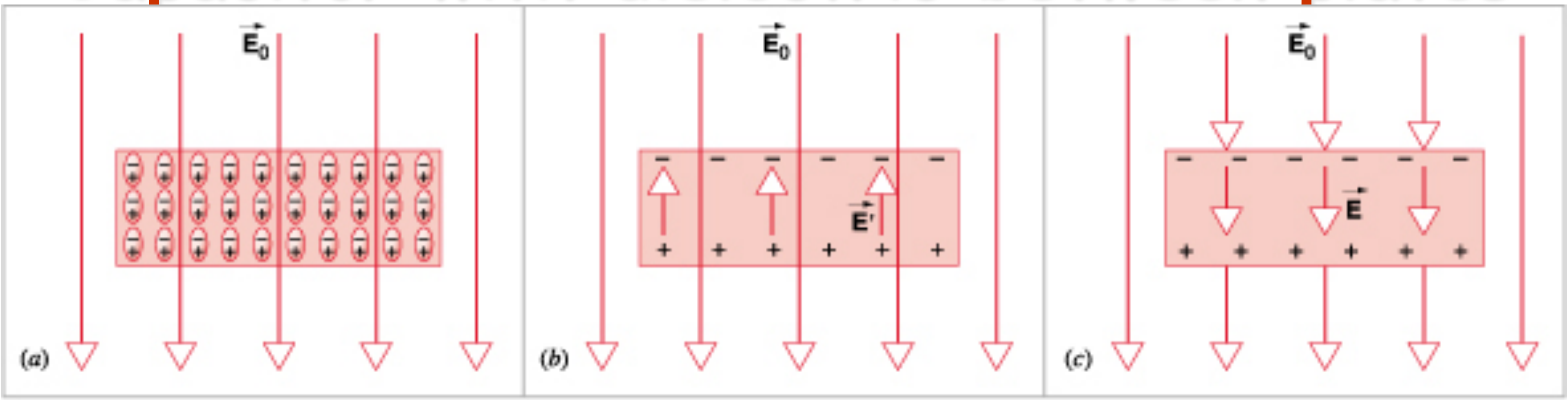
Potential difference without dielectric

$$\text{If } E = \frac{E_0}{\kappa_e}, \quad \text{then } \Delta V = \frac{\Delta V_0}{\kappa_e} = \frac{1}{\kappa_e}\frac{Qd}{A\varepsilon_o}$$

Actual potential difference with dielectric

Potential decreases due to screening of field by surface charge

Capacitor with dielectric between plates



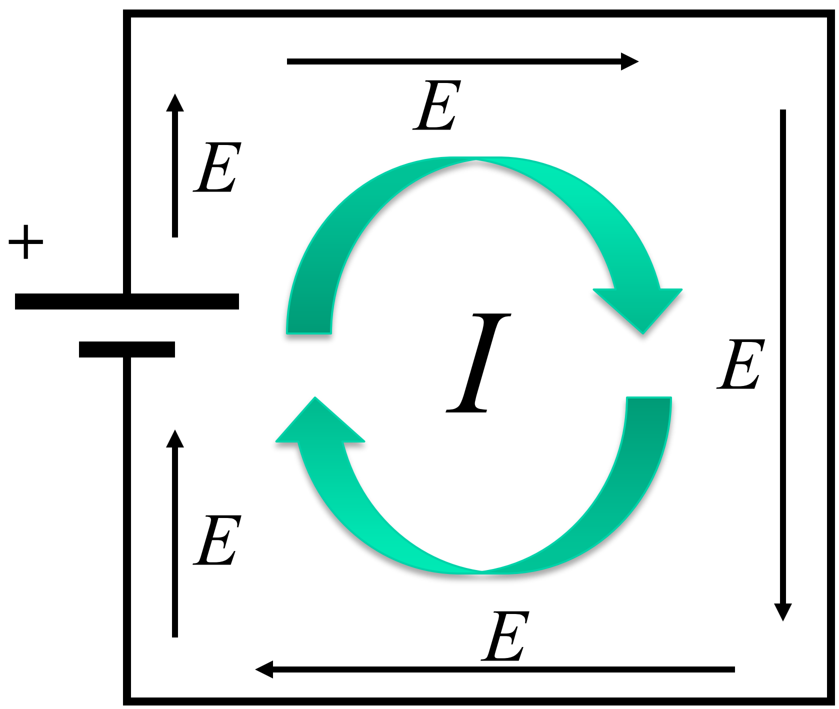
Linear materials: $$E_0 = (1 + \chi_e) E$$

Isolated capacitor: $$\Delta V = \frac{\Delta V_0}{\kappa_e} = \frac{1}{\kappa_e} \frac{Qd}{A\varepsilon_o}$$

Capacitance increases:

$$\Rightarrow \qquad C_{eff} = \frac{Q}{\Delta V} = \kappa_e \frac{\varepsilon_o A}{d} = \kappa_e C$$

Conductors in E-fields: dynamic conditions



- ***If the E-field is maintained, then the dynamics persist, i.e., charge continues to flow indefinitely.***
- ***This is no longer strictly the domain of electrostatics.***
- ***Note the direction of flow of the charge carriers (electrons).***

Electrical current: $$I = \frac{dQ}{dt} \approx \frac{\Delta Q}{\Delta t}$$

SI unit: 1 ampere (A) = 1 coulomb per second (C/s)