ENGI-1500
Physics -2

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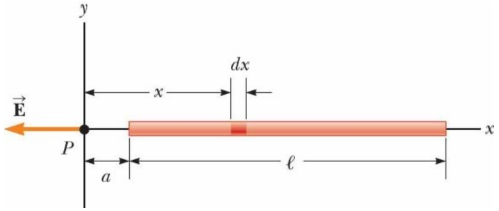
Faculty of Applied Sciences & Technology
Humber Institute of Technology and Advanced Learning
Winter 2023

HUMBER

Reminder of the previous week

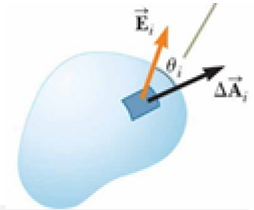
Continuous Charge Distributions

- E field of cont. charge dist.



$$E = k_e \frac{Q}{\ell}\left(\frac{1}{a} - \frac{1}{\ell + a}\right) = \boxed{\frac{k_e Q}{a(\ell + a)}}$$

- Electric flux

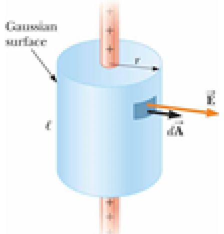


$$\Phi_E \equiv \int_{\text{surface}} \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}}$$

- Gauss's Law

$$\Phi_E = \oint \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0}$$

- Net flux through any closed surface surrounding a point charge ***q*** is given by q/ε_0.
- Net electric flux through closed surface that surrounds no charge = 0



$$E = \frac{\lambda}{2\pi\epsilon_0 r} = 2k_e \frac{\lambda}{r}$$

Electric Potential

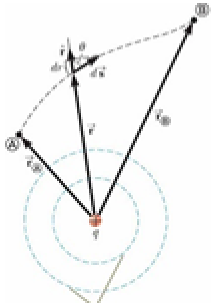
- Electric Potential Diff.

$$\Delta V = -\int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

$$V_B - V_A = -\int_A^B \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

- Electric potential due to a point charge

$$V = k_e \frac{q}{r}$$



- E field from E potential

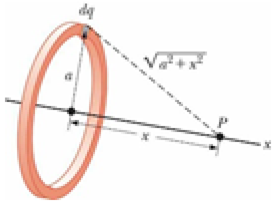
$$E_x = -\frac{\partial V}{\partial x}$$

$$E_y = -\frac{\partial V}{\partial y}$$

$$E_z = -\frac{\partial V}{\partial z}$$

- E potential of cont. charge dist.

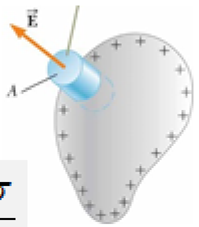
$$V = k_e \int \frac{dq}{r}$$

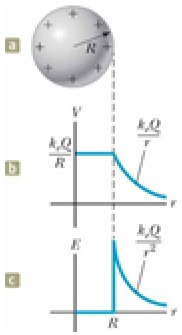


$$V = \frac{k_e}{\sqrt{a^2 + x^2}} \int dq = \boxed{\frac{k_e Q}{\sqrt{a^2 + x^2}}}$$

- E field of charged conductors

$$E = \frac{\sigma}{\varepsilon_0}$$





Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Week 3 / Class 3

- ❑ Capacitance and Dielectrics (Ch. 25)
- ❑ Current and Resistance (Ch. 26)

Outline of Week 3 / Class 3

- Reminder of the previous week

- Capacitance and Dielectrics (Ch. 25)
  - Definition and calculation of capacitance
  - Calculating Capacitance
  - Combination of capacitors
  - Energy stored in charge capacitors
  - Capacitors with dielectrics
  - Partially filled capacitors

- Current and Resistance (Ch. 26)
  - Electric current
  - Resistance
  - Resistance and temperature
  - Superconductors
  - Electrical power

- Examples
- Next week’s topic

Capacitance and Dielectrics (Ch. 25)

Definition of Capacitance

Definition of Capacitance

- We have a ***Capacitor*** when we have two charged conductors that
  1. carry equal magnitude and opposite sign charges
  2. and has a potential difference of ΔV between them.

- Experiments show that increasing the amount of charge on conductors increases the potential difference between them and this is a linear relationship:

$$Q = C\Delta V$$

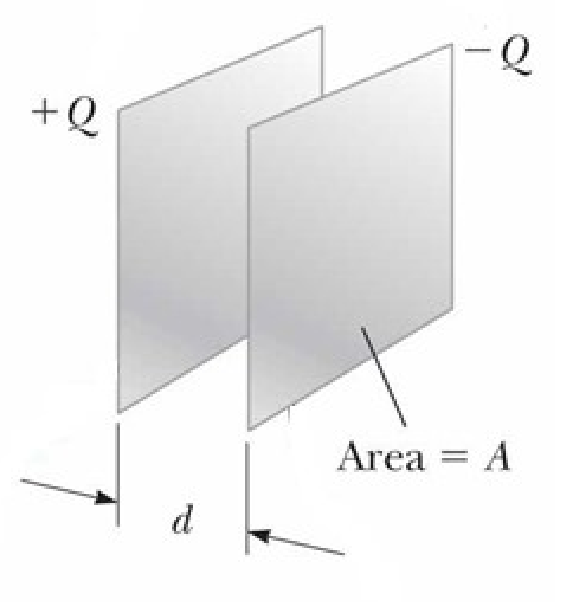
- The proportionality constant is defined as the ***Capacitance*** (***C***) and it depends on the shape and separation of the conductors.

- Capacitance is defined as the ratio of the magnitude of the charge on **<u>either conductor</u>** to the magnitude of the potential difference between the conductors:

$$C \equiv \frac{Q}{\Delta V}$$

- SI unit is ***Farad = Coulombs per Volt***

$$1\ \mathrm{F} = 1\ \mathrm{C/V}$$



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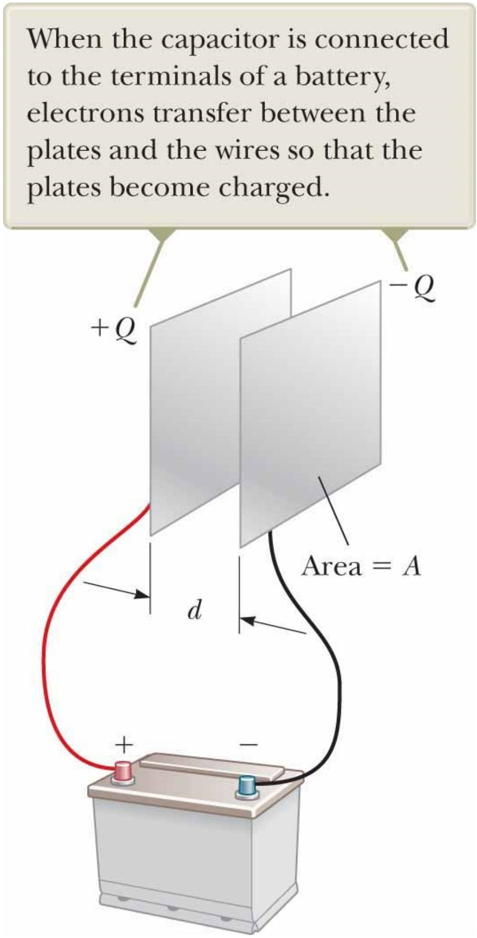
Definition of Capacitance

- In practice, how do we obtain charged conductors?

- If we connect the parallel plates to the terminals of a battery;
  - Electron movement continues until plate, wire, and terminals are all at the same electric potential

- Once equilibrium is attained, the potential difference between the capacitor plates is equal to the potential difference between the terminals of the battery.



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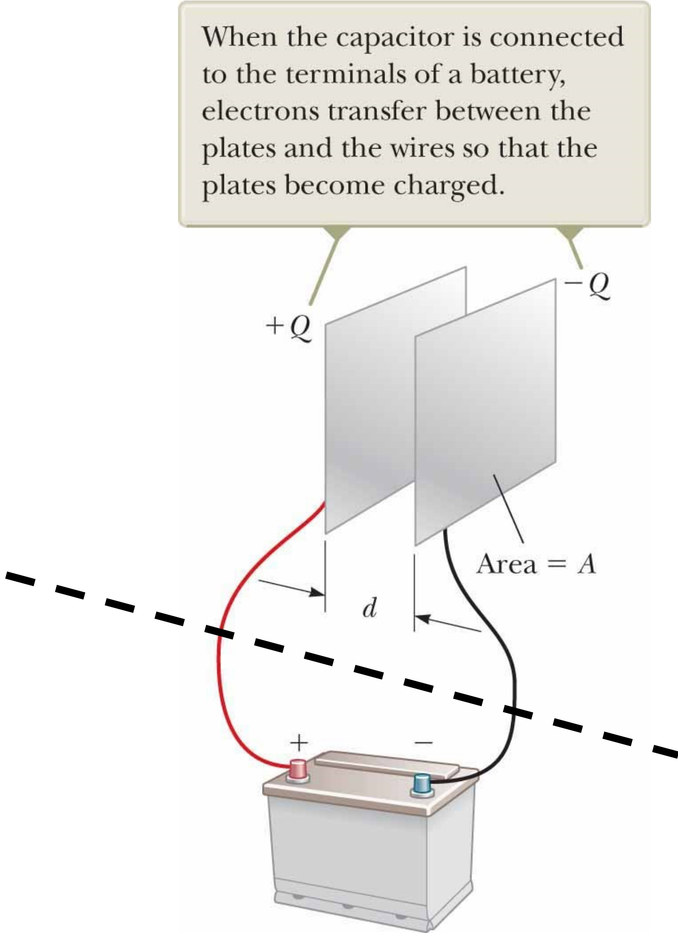
- Suppose we disconnect the battery from the plates:
  - Plates are not connected with wire to anything and they remain charged
  - Capacitor has stored charge
  - Also stored energy associated with the separation of charges



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Definition of Capacitance

Quick Quiz

A capacitor stores charge **Q** at a potential difference **ΔV**. What happens if the voltage applied to the capacitor by a battery is doubled to **2ΔV**?

(a) The capacitance falls to half its initial value, and the charge remains the same.
(b) The capacitance and the charge both fall to half their initial values.
(c) The capacitance and the charge both double.
(d) The capacitance remains the same, and the charge doubles.

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(b) The capacitance and the charge both fall to half their initial values.
(c) The capacitance and the charge both double.
True → **(d) The capacitance remains the same, and the charge doubles.**

The capacitance is a property of the physical system and does not vary with applied voltage.

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Capacitance and Dielectrics (Ch. 25)

Calculating the Capacitance

Calculating Capacitance

Parallel Plate

- Imagine two parallel, metallic plates of equal area **A**, separated by distance d (figure)
  - One plate carries charge **+Q**
  - Other carries charge **-Q**
- Surface charge density on each plate is **σ = Q/A**

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A}$$

Please review Example 23.8

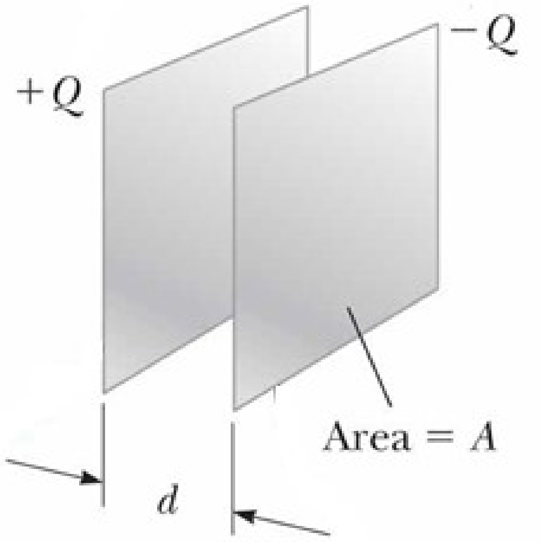
- For **d <<** plate dimensions, we can assume uniform electric field between plates. And we can calculate the potential difference for uniform E field:

$$\Delta V = Ed = \frac{Qd}{\varepsilon_0 A}$$

- Using the capacitance formula defined earlier, we can calculate the capacitance as:
  - Value depends entirely on the physical structure (A, d and dielectric constant)

$$C = \frac{Q}{\Delta V} = \frac{Q}{Qd/\varepsilon_0 A}$$

$$\boxed{C = \frac{\varepsilon_0 A}{d}}$$



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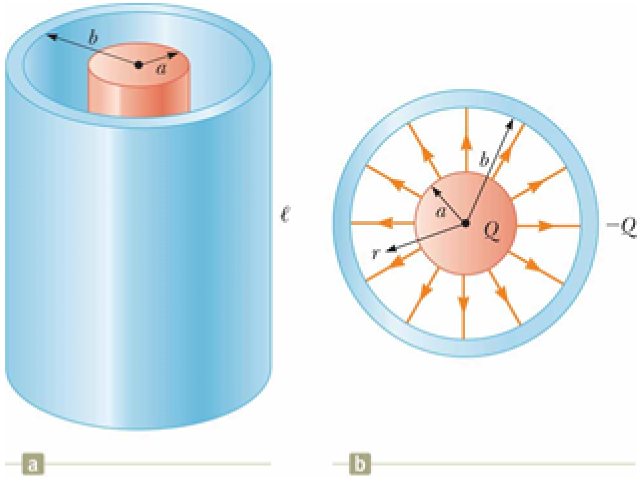
Calculating Capacitance

Cylindrical Capacitor

- Imagine a solid cylindrical conductor of radius ***a*** and charge ***Q*** is coaxial with a cylindrical shell of negligible thickness and radius ***b > a***. Find the capacitance of this cylindrical capacitor if its length is ℓ (figure).



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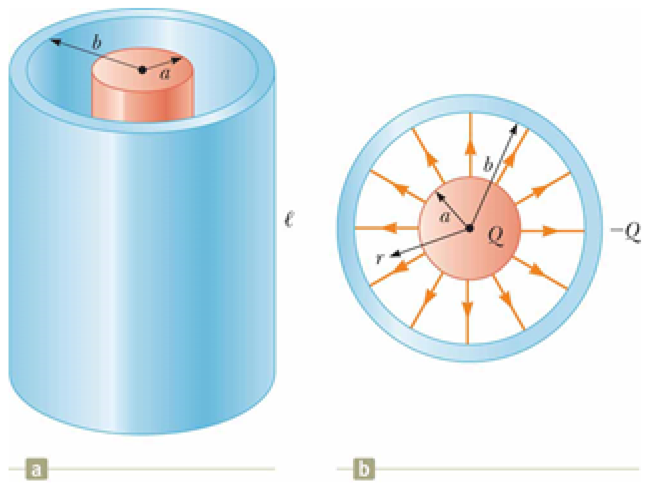
- Assuming ***ℓ*** is much greater than ***a*** and ***b***, we can neglect the end effects. The electric field is perpendicular to the long axis of the cylinders and is confined to the region between them.

- Potential difference between the cylinders:

$$V_b - V_a = -\int_a^b \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$



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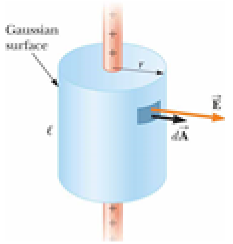
$$V_b - V_a = -\int_a^b \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}}$$

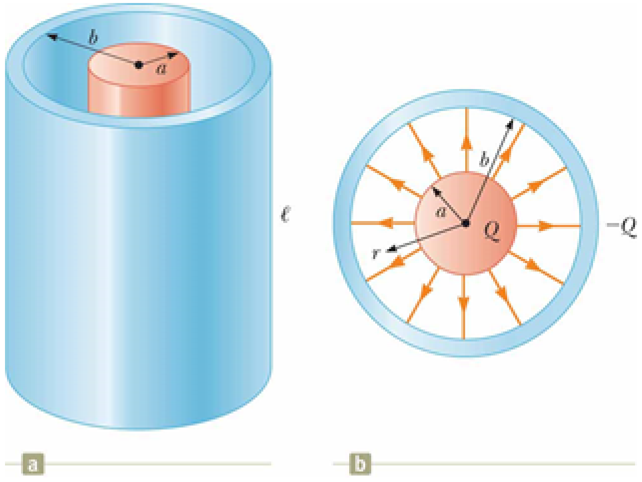
$$V_b - V_a = -\int_a^b E_r\,dr = -2k_e\lambda \int_a^b \frac{dr}{r} = -2k_e\lambda \ln\left(\frac{b}{a}\right)$$

From Example 23.7

$$E = \frac{\lambda}{2\pi\epsilon_0 r} = 2k_e\frac{\lambda}{r}$$

$$\boxed{k_e = 1/4\pi\varepsilon_0}$$





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$$C = \frac{Q}{\Delta V} = \frac{Q}{(2k_eQ/\ell)\ln(b/a)} = \boxed{\frac{\ell}{2k_e \ln(b/a)}}$$

Substitute the value of ΔV and use $\lambda = Q/\ell$.

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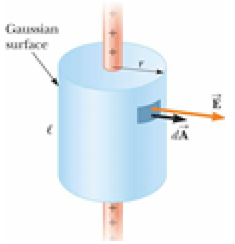

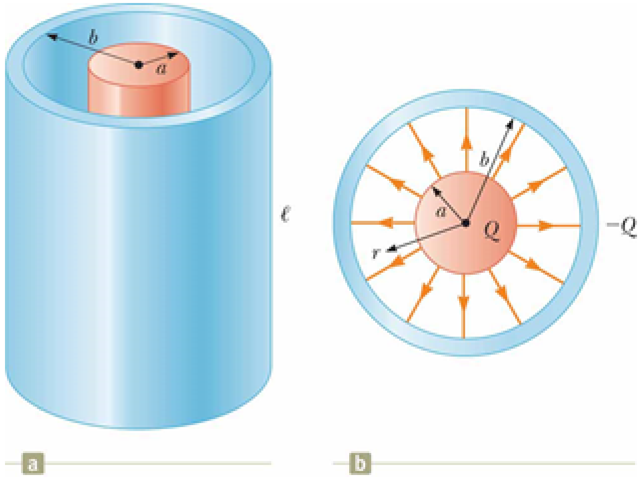

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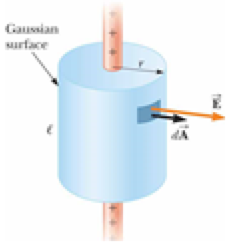

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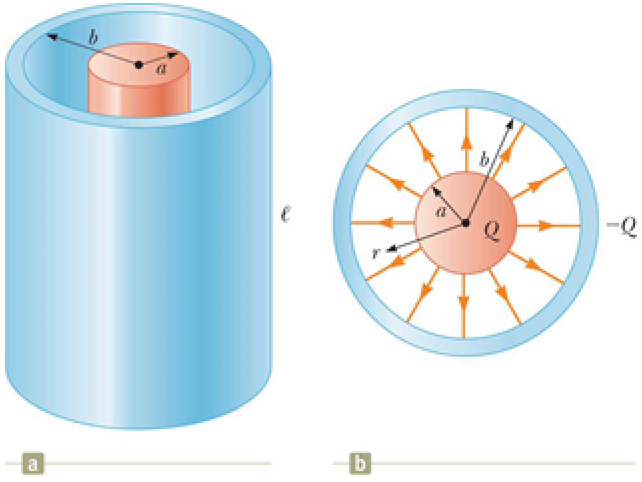

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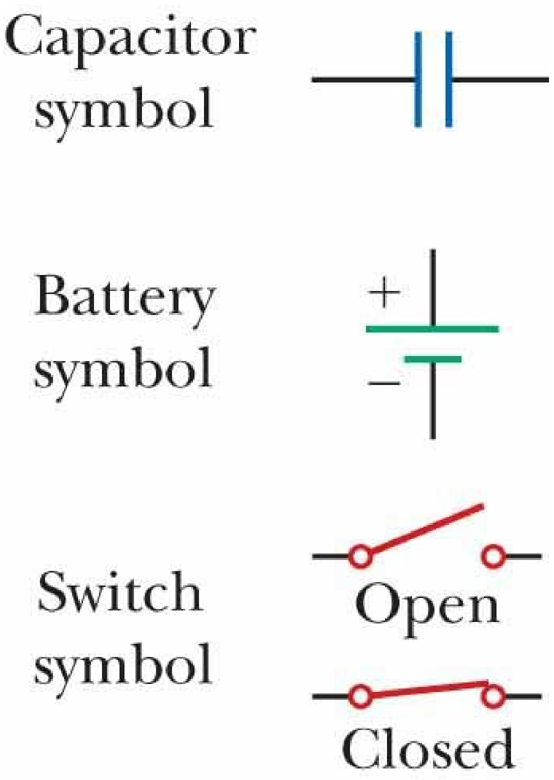
$$\frac{C}{\ell} = \frac{1}{2k_e \ln(b/a)}$$

Capacitance and Dielectrics (Ch. 25)

Combination of Capacitors

Circuit Symbols



Parallel Combination of Capacitors

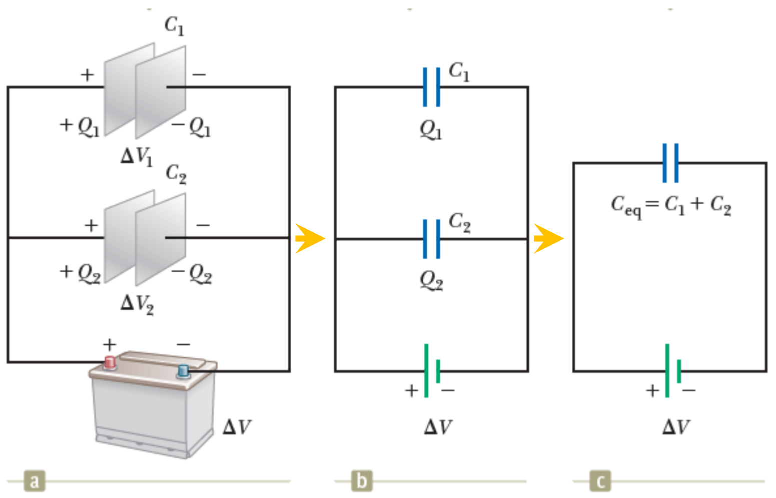
- Left plates of the capacitors are connected to the positive terminal of the battery by conducting wire – both are at the same electric potential as the positive terminal
- Right plates are connected to the negative terminal - both are at the same potential as the negative terminal

$$\Delta V_1 = \Delta V_2 = \Delta V$$

$$Q_{\text{tot}} = Q_1 + Q_2$$
$$= C_1 \Delta V_1 + C_2 \Delta V_2$$

$$Q_{\text{tot}} = C_{\text{eq}} \Delta V$$

$$C_{\text{eq}} \Delta V = C_1 \Delta V_1 + C_2 \Delta V_2$$
$$= \left(C_1 + C_2\right) \Delta V$$
$$\equiv C_{\text{eq}} \Delta V$$
$$C_{\text{eq}} = C_1 + C_2$$
$$\text{(parallel combination)}$$



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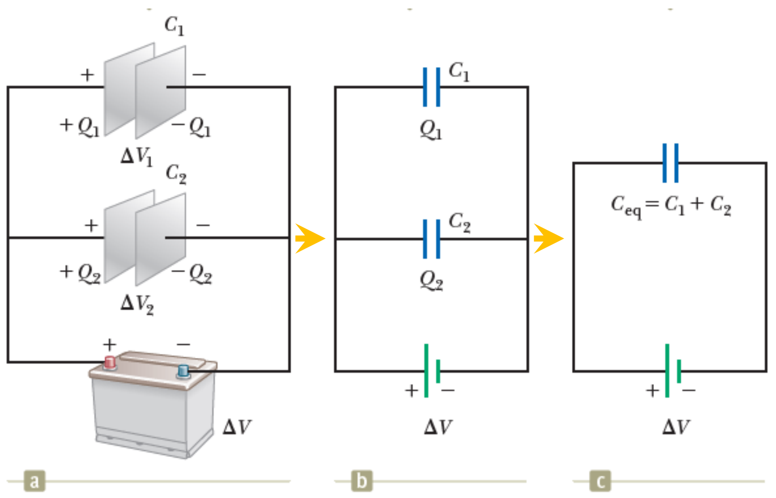

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$$\Delta V_1 = \Delta V_2 = \Delta V$$

$$\begin{aligned} Q_{\text{tot}} &= Q_1 + Q_2 \\ &= C_1 \Delta V_1 + C_2 \Delta V_2 \end{aligned}$$

$$Q_{\text{tot}} = C_{\text{eq}} \Delta V$$

$$\begin{aligned} C_{\text{eq}} \Delta V &= C_1 \Delta V_1 + C_2 \Delta V_2 \\ &= (C_1 + C_2) \Delta V \\ &\equiv C_{\text{eq}} \Delta V \end{aligned}$$

$$C_{\text{eq}} = C_1 + C_2 \quad (\text{parallel combination})$$

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \cdots \quad (\text{parallel combination})$$

Series Combination of Capacitors

- When the equilibrium is reached after the battery is connected; charges on the capacitors that are connected in series are the same: ***Q***.
- Total potential difference across any number of capacitors connected in series = sum of potential differences across individual capacitors

$$Q_1 = Q_2 = Q$$

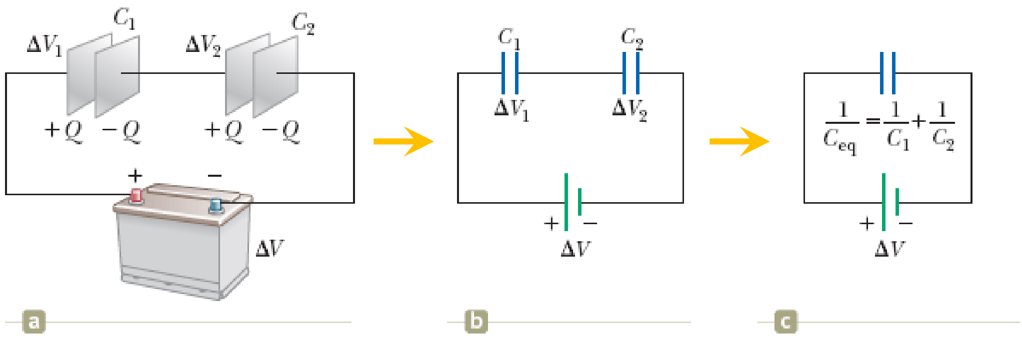
$$\Delta V_{\text{tot}} = \Delta V_1 + \Delta V_2$$

$$= \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$$

$$\Delta V_{\text{tot}} = \frac{Q}{C_{\text{eq}}}$$

$$\frac{Q}{C_{\text{eq}}} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$$

$$\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{(series combination)}$$



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$$\Delta V_{\text{tot}} = \frac{Q}{C_{\text{eq}}}$$

$$\frac{Q}{C_{\text{eq}}} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$$

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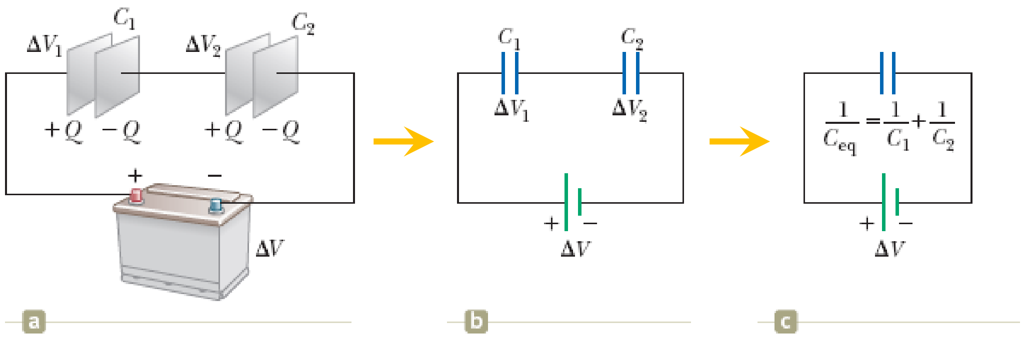

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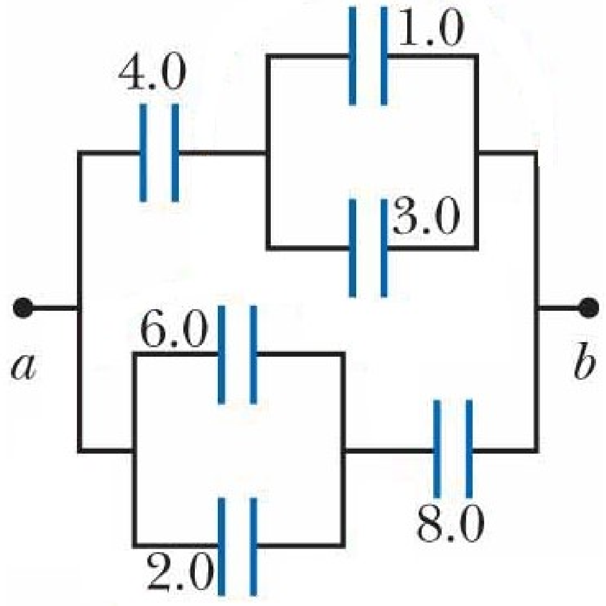
$$\boxed{\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots \quad (\text{series combination})}$$

Equivalent Capacitance

Example 25.3

Find the equivalent capacitance between ***a*** and ***b*** for the combination of capacitors shown in the figure. All capacitances are in microfarads (***μF***).



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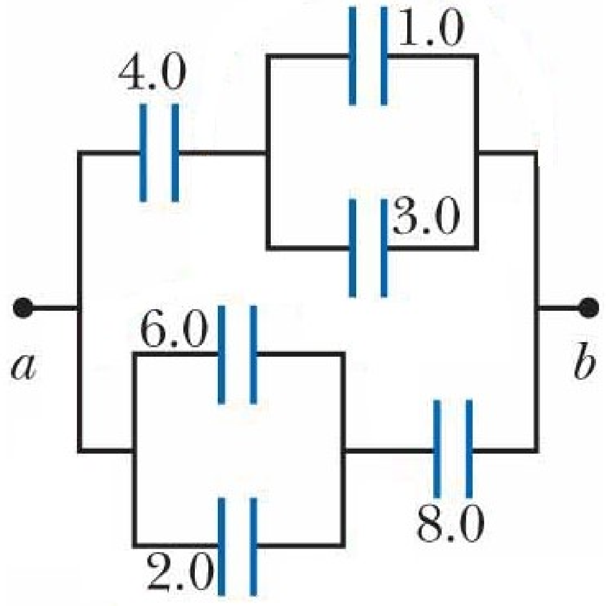

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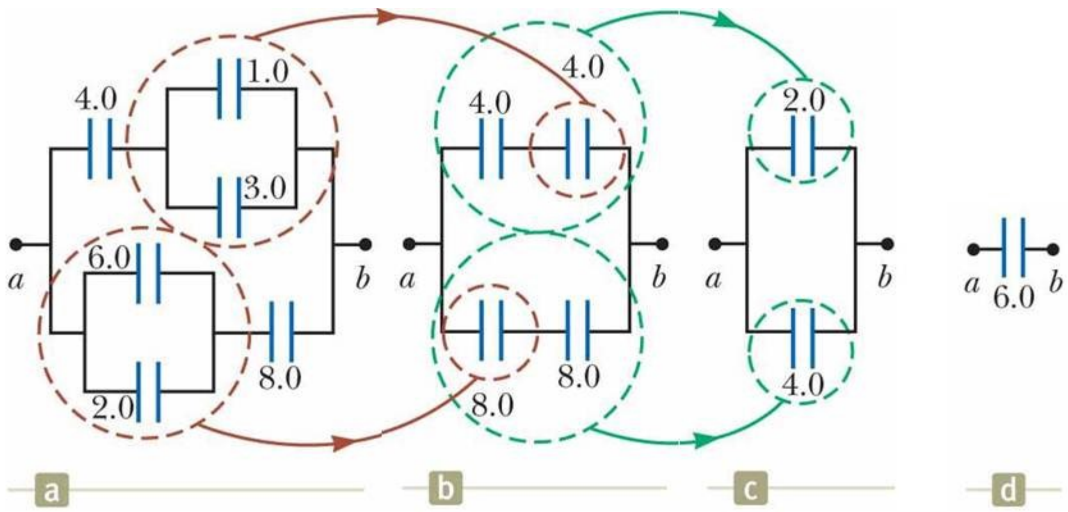
Solution



Capacitance and Dielectrics (Ch. 25)

Energy Stored in a Charged Capacitor

Energy Stored in a Charged Capacitor

- Work necessary to transfer increment of charge ***dq*** from the negatively charged plate to positively charged plate is (keeping in mind ΔV = q/C):

$$dW = \Delta V\, dq = \frac{q}{C}\, dq$$

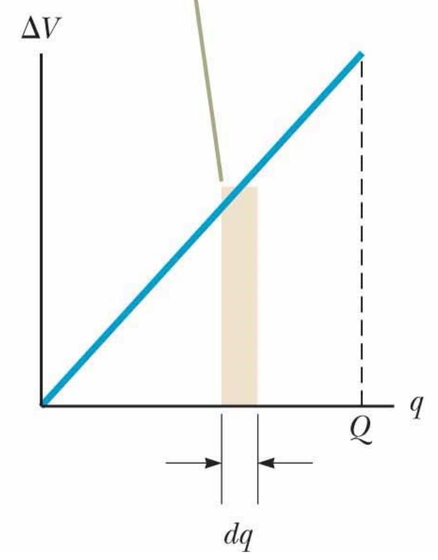
- The total work required to charge the capacitor from q = 0 to final charge q = Q is:

$$W = \int_0^Q \frac{q}{C}\, dq = \frac{1}{C}\int_0^Q q\, dq = \frac{Q^2}{2C}$$

- Work done in charging the capacitor appears as electric potential energy $\boldsymbol{U_E}$ stored in the capacitor:

$$\boxed{U_E = \frac{Q^2}{2C} = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2}$$

The work required to move charge dq through the potential difference ΔV across the capacitor plates is given approximately by the area of the shaded rectangle.



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Energy Stored in Charged Capacitors

Quick Quiz

You have three capacitors and a battery. In which of the following combinations of the three capacitors is the maximum possible energy stored when the combination is attached to the battery?

(a) series
(b) parallel
(c) no difference because both combinations store the same amount of energy

$$U_E = \frac{1}{2}CV^2$$

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(a) series

True → **(b) parallel**

(c) no difference because both combinations store the same amount of energy

Voltage is constant; to maximize the energy we need to maximize the capacitance (C)

<u>Source:</u> Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Capacitance and Dielectrics (Ch. 25)

Capacitors with Dielectrics

Capacitors with Dielectrics

- A dielectric is a non-conducting material (i.e., rubber, glass, or waxed paper)

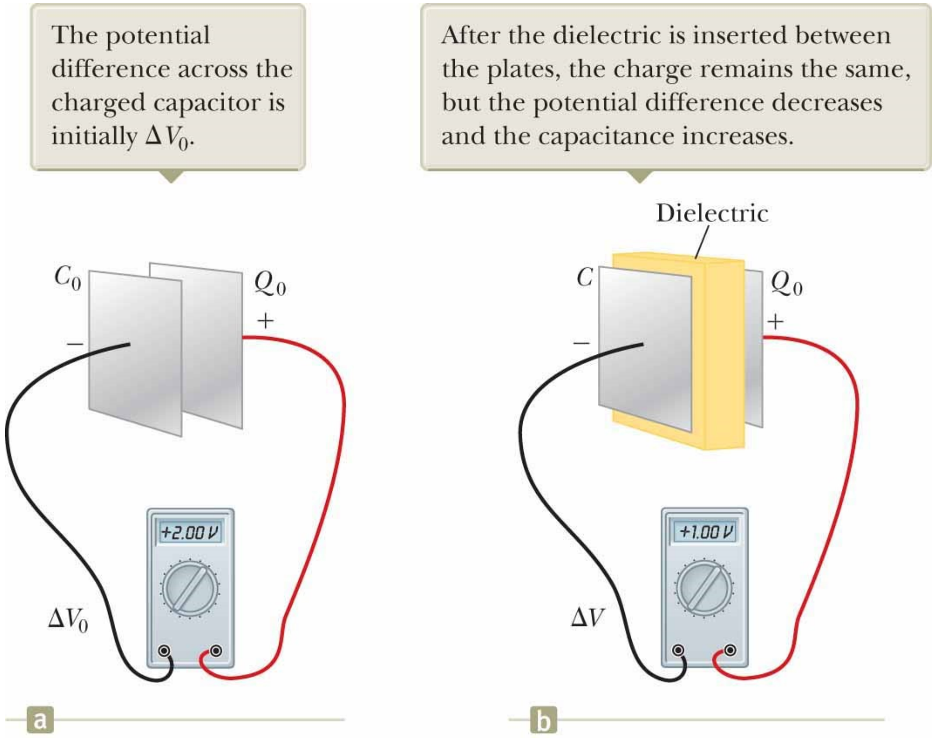
- Consider a parallel-plate capacitor with charge Q_0 and capacitance C_0
  - Potential difference across the capacitor is $\Delta V_0 = Q_0/C_0$ (figure (a))
  - Potential difference measured using **Voltmeter**

- If a dielectric layer is now inserted between the plates (figure (b)):
  - The Voltmeter indicates that voltage between plates **decreases** to ΔV

- Voltages with and without dielectric are related by factor $\boldsymbol{\kappa}$:

$$\Delta V = \frac{\Delta V_0}{\kappa} \qquad (\kappa > 1)$$

- ***K*** is the ***dielectric constant*** of the material and it varies from one material to another. Dielectric constant is also represented with $\boldsymbol{\varepsilon_r}$.



<u>Source:</u> Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

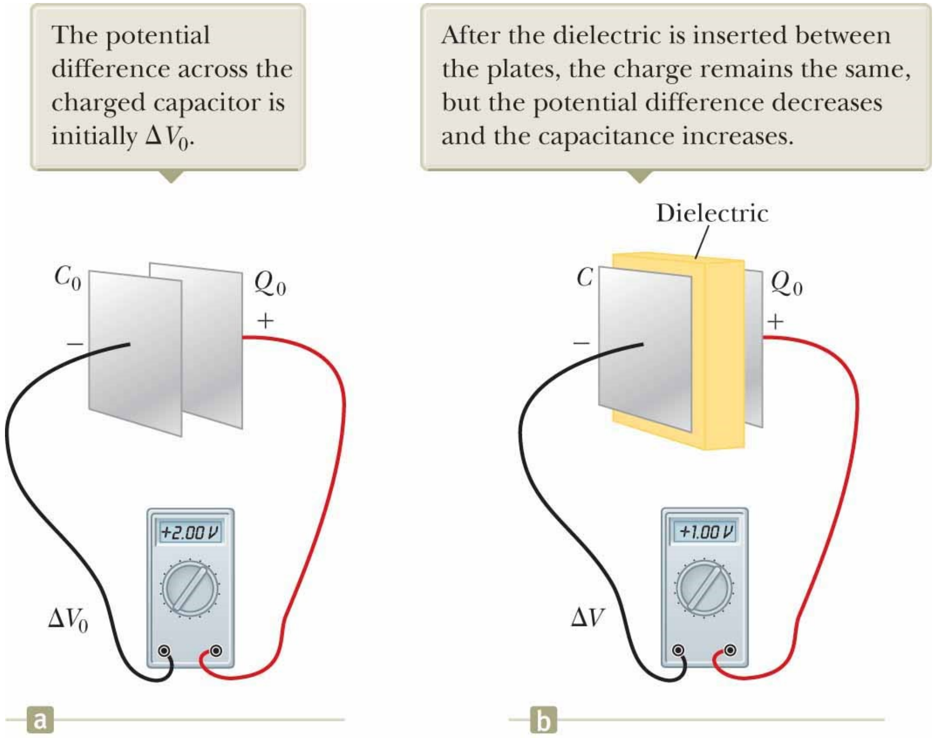
Capacitors with Dielectrics

- Because the charge $\boldsymbol{Q_0}$ on the capacitor does not change →
  - Capacitance must change:
  - Capacitance increases by **κ** when dielectric completely fills the region between the plates

$$C = \frac{Q_0}{\Delta V} = \frac{Q_0}{\Delta V_0/\kappa}$$

$$= \kappa \frac{Q_0}{\Delta V_0}$$

$$\boxed{C = \kappa C_0} \qquad \boxed{C = \varepsilon_r C_0}$$



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- Because $\mathbf{C_0 = \varepsilon_0 A/d}$ for parallel-plate capacitor → capacitance of a parallel-plate capacitor filled with dielectric can be calculated as:

$$C = \kappa \frac{\varepsilon_0 A}{d}$$

Capacitors with Dielectrics

$$C = \kappa \frac{\varepsilon_0 A}{d}$$

TABLE 25.1 Approximate Dielectric Constants and Dielectric Strengths of Various Materials at Room Temperature

Material	Dielectric Constant κ	Dielectric Strength[a] (10^6 V/m)
Air (dry)	1.000 59	3
Bakelite	4.9	24
Fused quartz	3.78	8
Mylar	3.2	7
Neoprene rubber	6.7	12
Nylon	3.4	14
Paper	3.7	16
Paraffin-impregnated paper	3.5	11
Polyethylene	2.30	18
Polystyrene	2.56	24
Polyvinyl chloride	3.4	40
Porcelain	6	12
Pyrex glass	5.6	14
Silicone oil	2.5	15
Strontium titanate	233	8
Teflon	2.1	60
Vacuum	1.000 00	—

[a]The dielectric strength equals the maximum electric field that can exist in a dielectric without electrical breakdown. These values depend strongly on the presence of impurities and flaws in the materials.

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Capacitors with Dielectrics

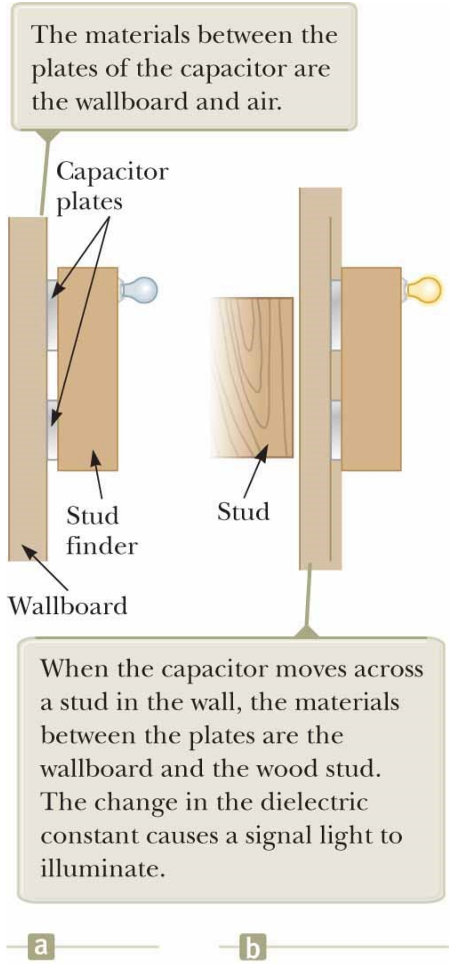
Quick Quiz

If you have ever tried to hang a picture or a mirror, you know it can be difficult to locate a wooden stud in which to anchor your nail or screw. A carpenter's stud finder is a capacitor with its plates arranged side by side instead of facing each other as shown in the figure. When the device is moved over a stud, does the capacitance

(a) increase or
(b) decrease?

The dielectric constant of wood is greater than 1;

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.



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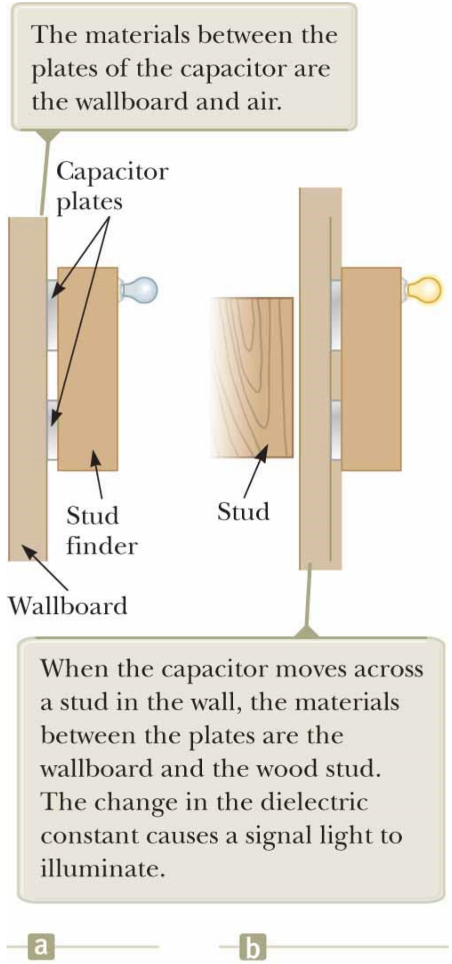
True → **(a) increase** or

(b) decrease?

The dielectric constant of wood is greater than 1; therefore, the capacitance increases ($C = \kappa C_0$). This increase is sensed by the stud finder's special circuitry, which causes an indicator on the device to light up.

<u>Source:</u> Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.



<u>Source:</u> Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

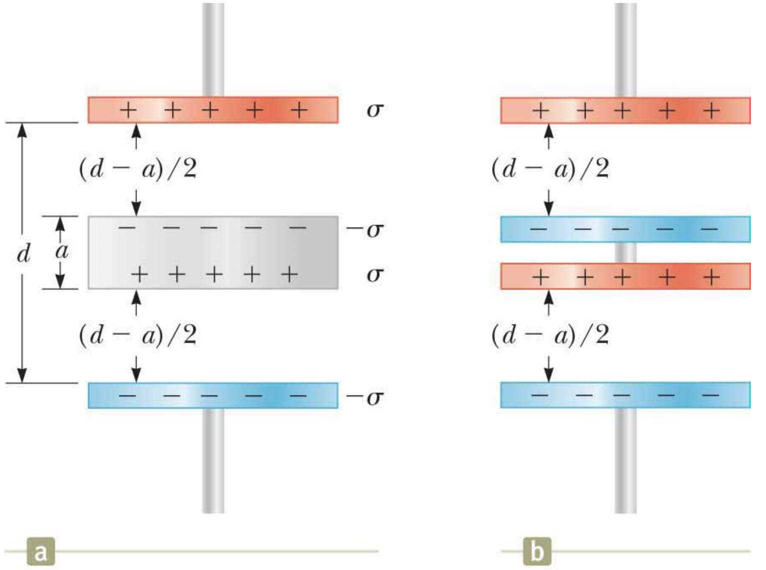
Capacitance and Dielectrics (Ch. 25)

Partially Filled Capacitors

Effect of a Metallic Slab

Example 25.7

A parallel-plate capacitor has a plate separation ***d*** and plate area ***A***. An uncharged metallic slab of thickness ***a*** is inserted midway between the plates. Find the capacitance of the device.



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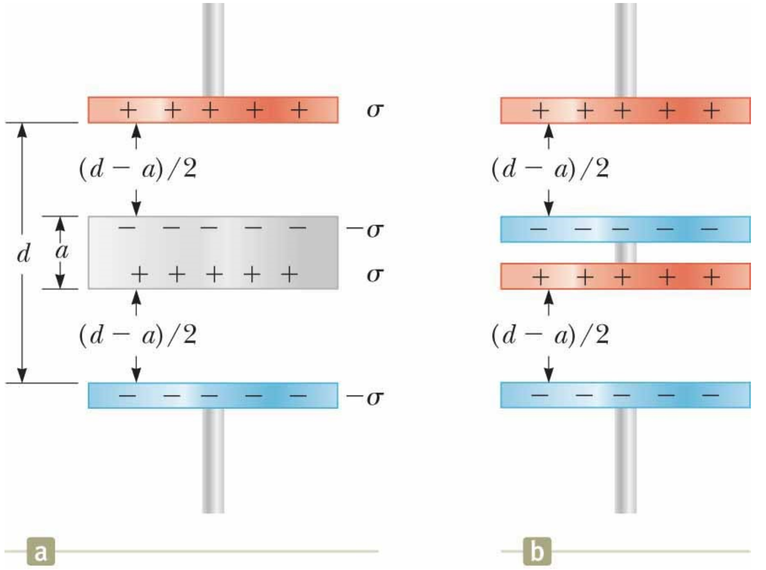

Conceptualize:

Any charge that appears on one plate of the capacitor must induce a charge of equal magnitude and opposite sign on the near side of the slab.

Categorize

We can model the edges of the slab as conducting planes and the bulk of the slab as a wire (since E field is zero inside the metal layer). As a result, the capacitor in the left is equivalent to two capacitors in series shown on the right.

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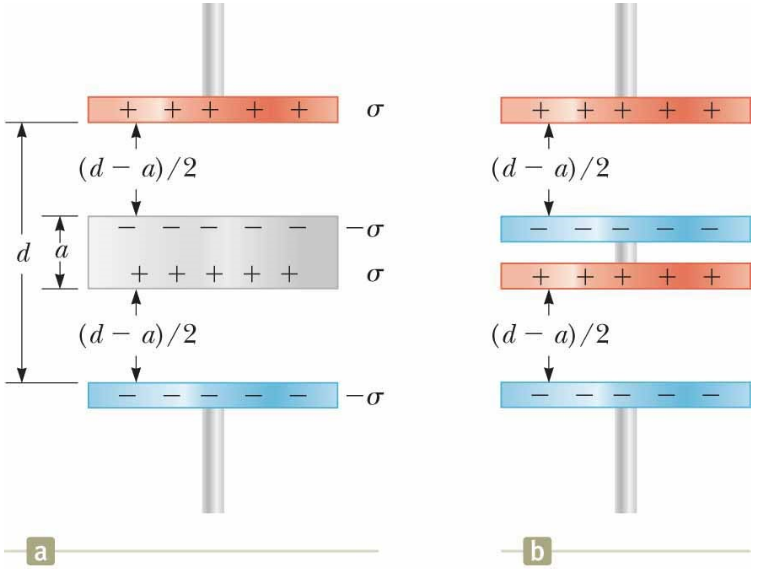

Solution

We can use the rule for adding two capacitors in series to find the equivalent capacitance:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

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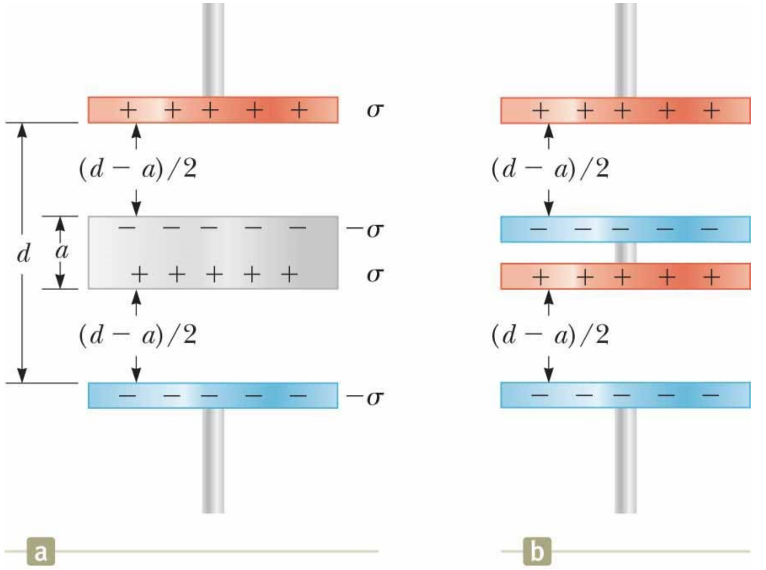
A parallel-plate capacitor has a plate separation ***d*** and plate area ***A***. An uncharged metallic slab of thickness ***a*** is inserted midway between the plates. Find the capacitance of the device.

Solution

We can use the rule for adding two capacitors in series to find the equivalent capacitance:

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{\dfrac{\epsilon_0 A}{(d-a)/2}} + \frac{1}{\dfrac{\epsilon_0 A}{(d-a)/2}}$$



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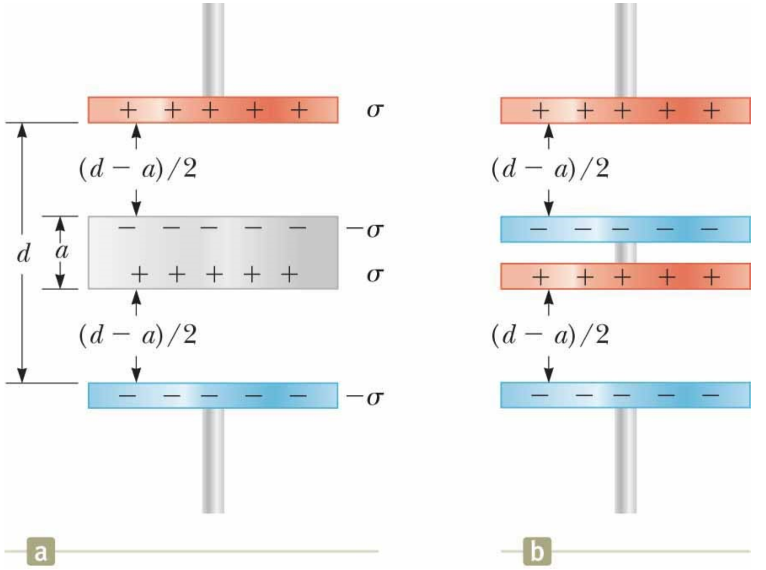
$$C = \boxed{\frac{\epsilon_0 A}{d-a}}$$



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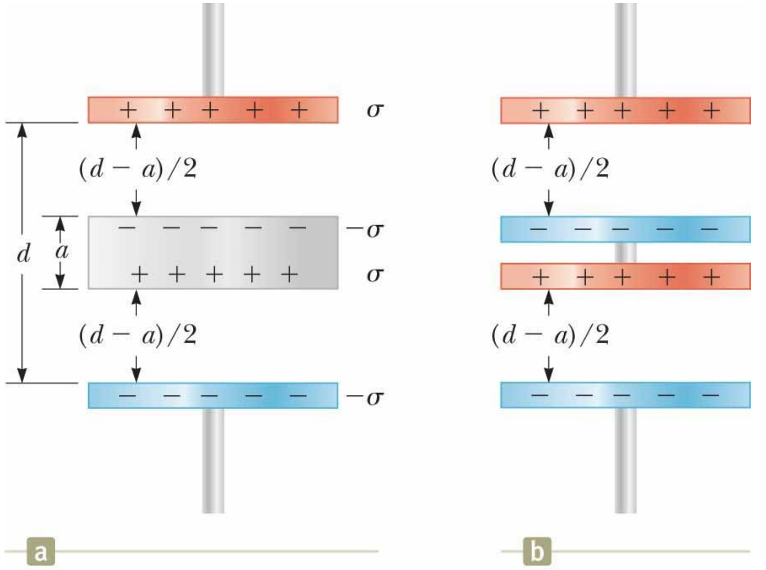

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$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{\dfrac{\epsilon_0 A}{(d-a)/2}} + \frac{1}{\dfrac{\epsilon_0 A}{(d-a)/2}}$$

$$C = \boxed{\frac{\epsilon_0 A}{d-a}}$$

The capacitance of the original capacitor is unaffected by the insertion of the metallic slab if the slab is infinitesimally thin.

$$C = \lim_{a \to 0}\left(\frac{\epsilon_0 A}{d-a}\right) = \frac{\epsilon_0 A}{d}$$

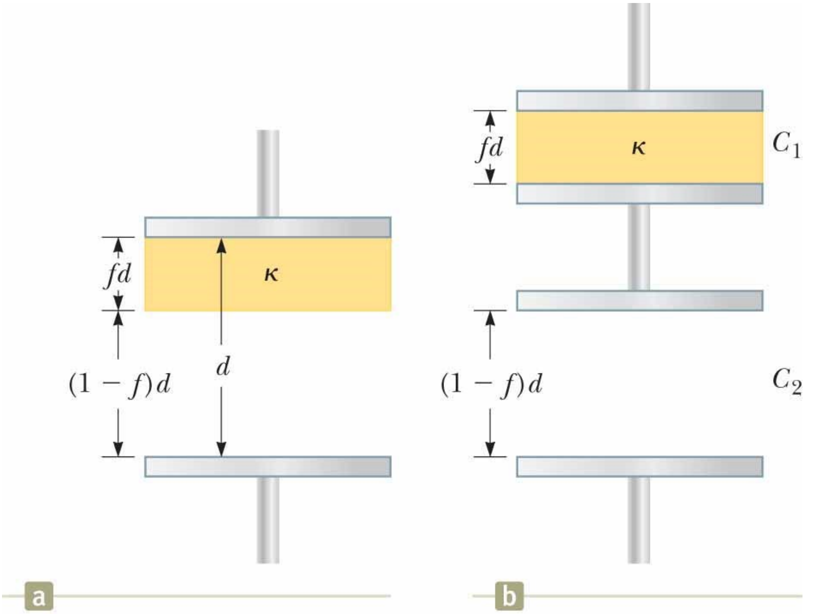
Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

A Partially Filled Capacitor

Optional

Example 25.8

A parallel-plate capacitor with a plate separation ***d*** has a capacitance $\boldsymbol{C_0}$ in the absence of a dielectric. What is the capacitance when a slab of dielectric material of dielectric constant $\boldsymbol{\kappa}$ and thickness ***fd*** is inserted between the plates, where ***f*** is a fraction between 0 and 1?



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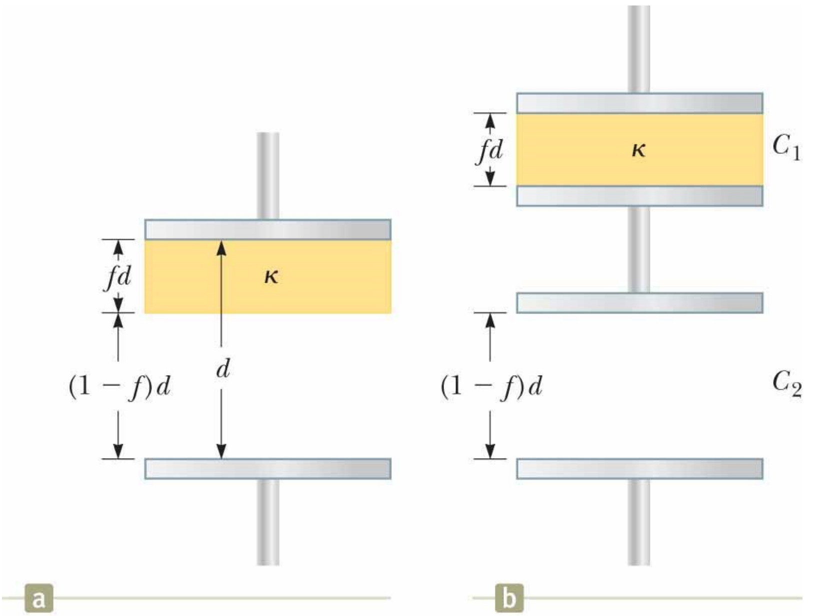
Conceptualize:

Similar to the previous example, we have two regions in the capacitor.

Categorize

We can model this system as a series combination of two capacitors. One capacitor has a plate separation ***fd*** and is filled with a dielectric; the other has a plate separation ***(1-f)d*** and has air between its plates.



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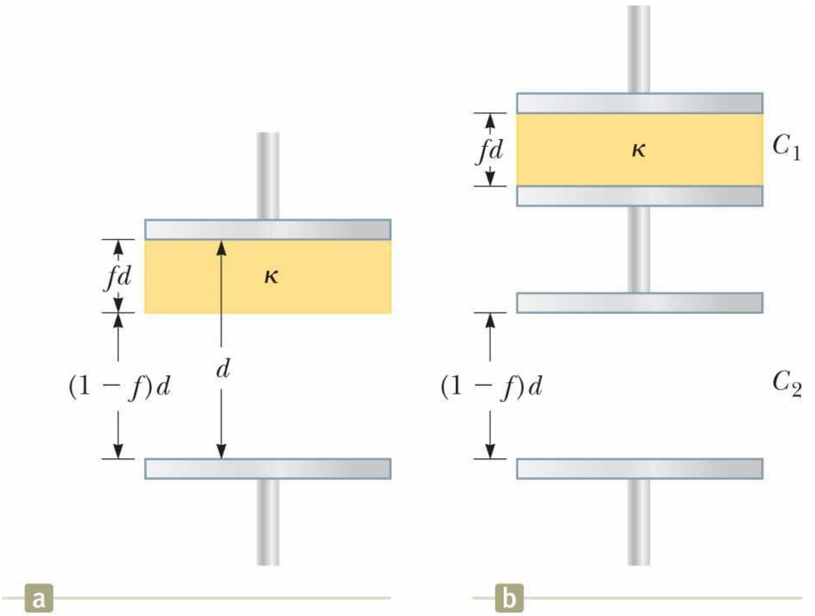
Solution

$$C_1 = \frac{\kappa\epsilon_0 A}{fd} \quad \text{and} \quad C_2 = \frac{\epsilon_0 A}{(1-f)d}$$



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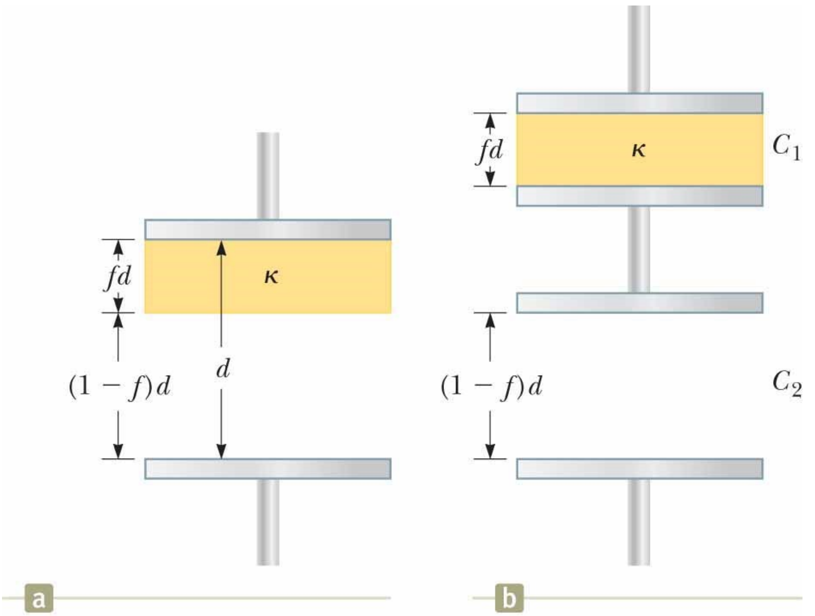

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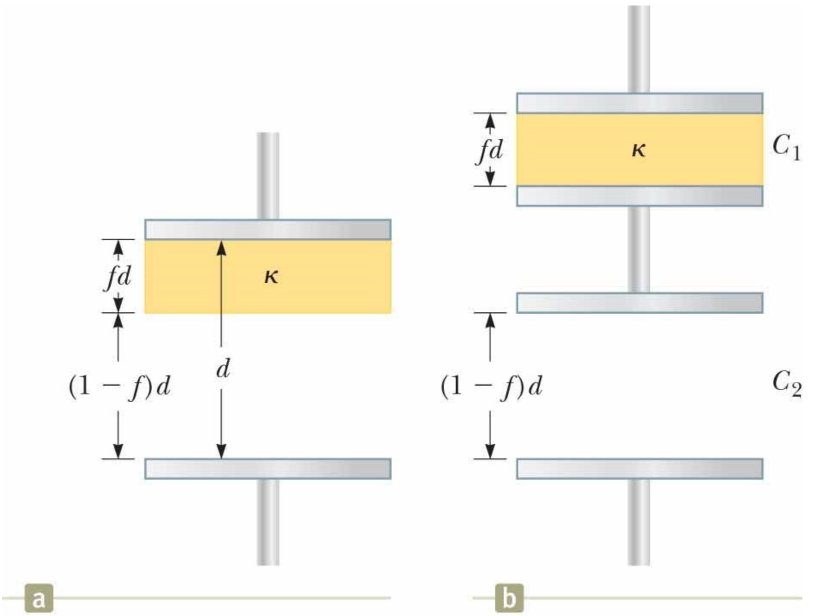
$$\frac{1}{C} = \frac{fd}{\kappa\epsilon_0 A} + \frac{\kappa(1-f)d}{\kappa\epsilon_0 A} = \frac{f+\kappa(1-f)}{\kappa}\,\frac{d}{\epsilon_0 A}$$



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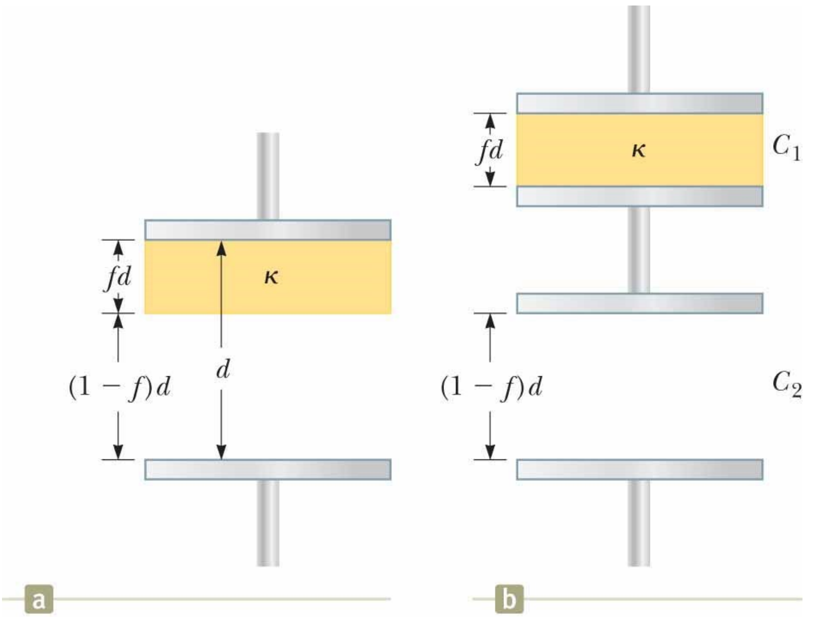
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{fd}{\kappa\epsilon_0 A} + \frac{(1-f)d}{\epsilon_0 A}$$

$$\frac{1}{C} = \frac{fd}{\kappa\epsilon_0 A} + \frac{\kappa(1-f)d}{\kappa\epsilon_0 A} = \frac{f+\kappa(1-f)}{\kappa}\frac{d}{\epsilon_0 A}$$

$$C = \frac{\kappa}{f+\kappa(1-f)}\frac{\epsilon_0 A}{d}$$

Recall $C_0=\varepsilon_0 A/d$



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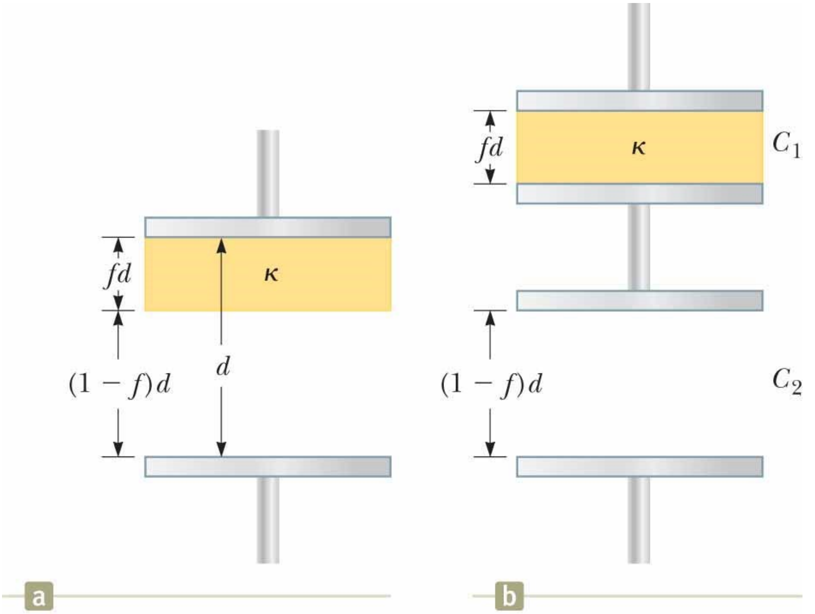

Solution

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$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{fd}{\kappa\epsilon_0 A} + \frac{(1-f)d}{\epsilon_0 A}$$

$$\frac{1}{C} = \frac{fd}{\kappa\epsilon_0 A} + \frac{\kappa(1-f)d}{\kappa\epsilon_0 A} = \frac{f+\kappa(1-f)}{\kappa}\,\frac{d}{\epsilon_0 A}$$

$$C = \frac{\kappa}{f+\kappa(1-f)}\,\frac{\epsilon_0 A}{d} = \boxed{\frac{\kappa}{f+\kappa(1-f)}C_0}$$

Test the result at f→0 and f→1

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Current and Resistance (Ch. 26)

Electric Current

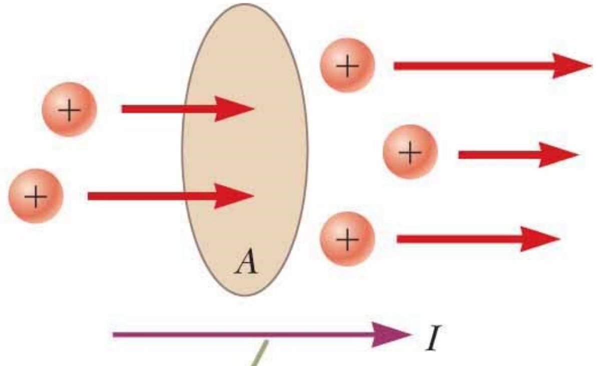
Electric Current

- In this section, we will study the ***flow of electric charges*** through a piece of material. The amount of flow depends on both the material and the potential difference across the material.

- Whenever there is a net flow of charge through some region, an electric current exists.

- To define current quantitatively, suppose charges are moving perpendicular to a surface of area ***A*** as shown in the figure.
  - This area could be the cross-sectional area of a wire

- The current is defined as the rate at which charge flows through this surface. If ***ΔQ*** is the amount of charge that passes through this surface in a time interval ***Δt,*** the average current I_{avg} is equal to the charge that passes through ***A*** per unit time:



The direction of the current is the direction in which positive charges flow when free to do so.

$$I_{\text{avg}} = \frac{\Delta Q}{\Delta t}$$

If the current varies in time, the instantaneous current is defined as:

$$I \equiv \frac{dQ}{dt}$$

The SI unit of current is the ampere (A):

$$1\ \text{A} = 1\ \text{C/s}$$

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Microscopic Model of Current

Optional

- Consider the current in a cylindrical conductor of cross-sectional area ***A*** (figure)
  - Volume of segment of conductor of length ***Δx = A Δx***

- ***n*** represents the number of mobile charge carriers per unit volume (charge carrier density) →
  - Number of carriers in segment = ***nA Δx***

- ***q*** = charge on each carrier and ΔQ is the total charge in this segment:

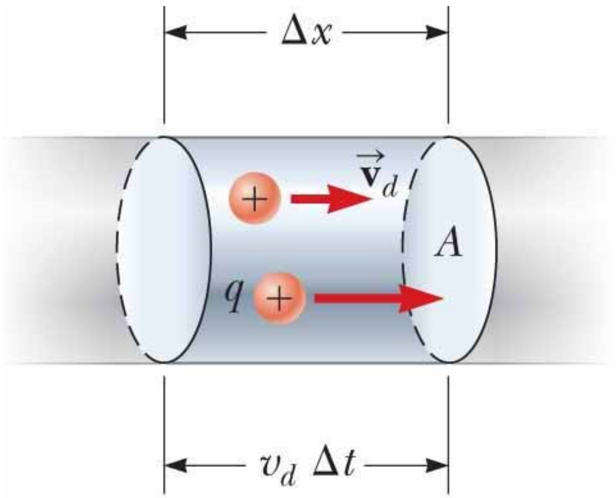
$$\Delta Q = (nA\,\Delta x)\,q$$

- If the carriers move with a velocity $\boldsymbol{v_d}$ parallel to the axis of the cylinder →
  - Magnitude of displacement in ***x*** direction in time interval ***Δt*** is $\boldsymbol{\Delta x = v_d \Delta t}$

- We can re-write the ***ΔQ*** as:

$$\Delta Q = (nA\,\Delta x)\,q \quad = (nAv_d\,\Delta t)\,q$$

- Now we can calculate the average current as: $$I_{\text{avg}} = \frac{\Delta Q}{\Delta t} = nqv_d A$$



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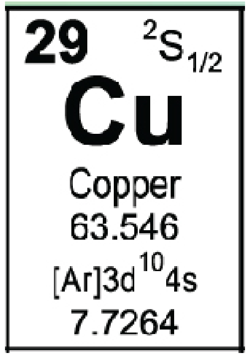
Drift Speed in a Copper Wire

Optional

Example 26.1

The 12-gauge copper wire in a typical residential building has a cross-sectional area of $\boldsymbol{A=3.31 \times 10^{-6}\ m^2}$. It carries a constant current of $\boldsymbol{I = 10.0\ A}$. What is the drift speed of the electrons in the wire ($\boldsymbol{v_d}$)? Assume each copper atom contributes one free electron to the current. The density of copper is $\boldsymbol{\rho = 8.92\ g/cm3}$.

<u>**Note:**</u> The periodic table of the elements shows that the molar mass of copper is $\boldsymbol{M = 63.5\ g/mol}$. Recall that 1 mol of any substance contains Avogadro's number of atoms ($\boldsymbol{NA = 6.02 \times 10^{23}\ mol^{-1}}$).



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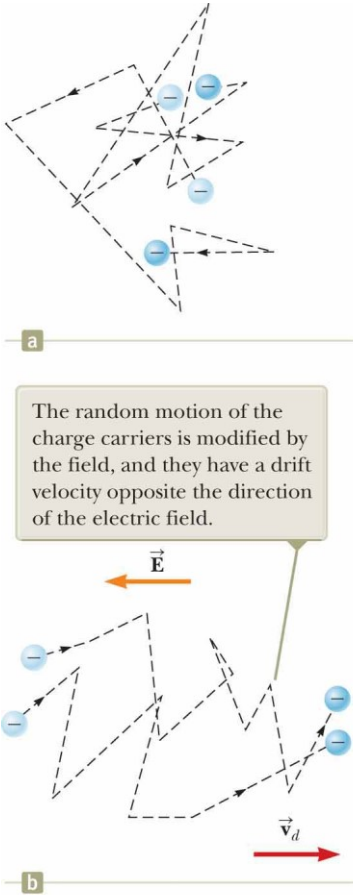

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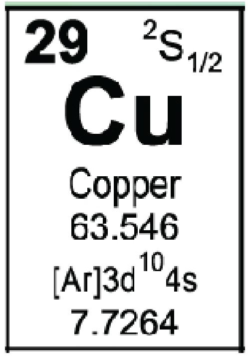
<u>Note:</u> The periodic table of the elements shows that the molar mass of copper is ***M = 63.5 g/mol.*** Recall that 1 mol of any substance contains Avogadro's number of atoms (***NA = 6.02 x 10^{23} mol^{-1}***).

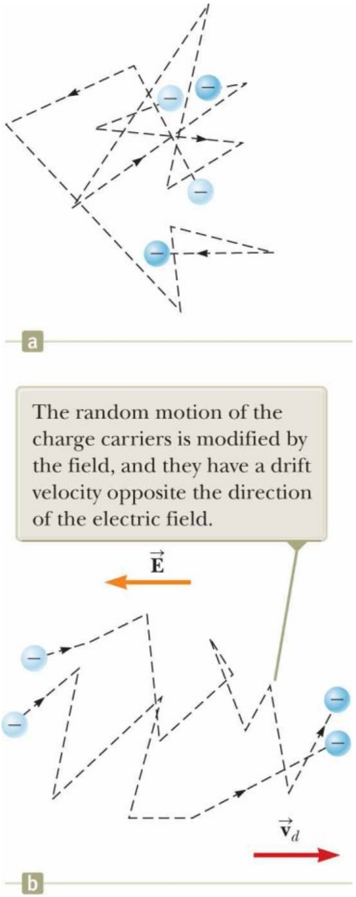
Solution

Use the molar mass and the density of copper to find the volume of 1 mole of copper:

$$V = \frac{M}{\rho}$$



$$I_{avg} = \frac{\Delta Q}{\Delta t} = nqv_d A$$



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<u>Note:</u> The periodic table of the elements shows that the molar mass of copper is ***M = 63.5 g/mol.*** Recall that 1 mol of any substance contains Avogadro's number of atoms (***NA = 6.02 x 10²³ mol⁻¹***).

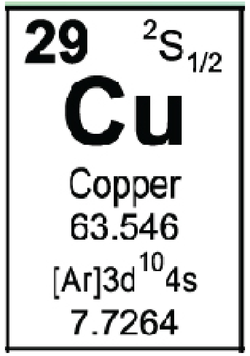
Solution

Use the molar mass and the density of copper to find the volume of 1 mole of copper:

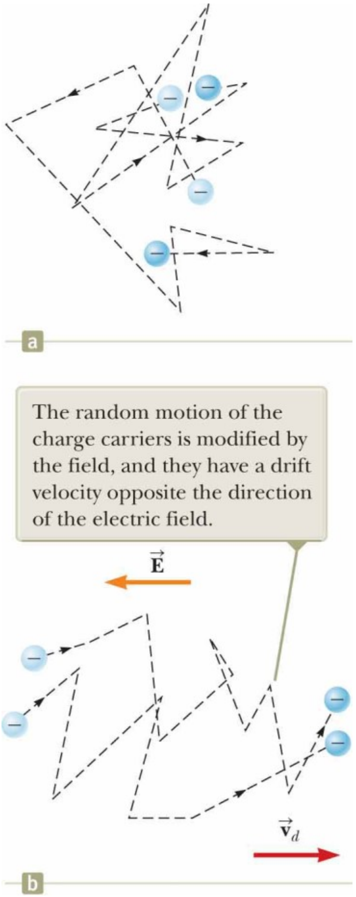
$$V = \frac{M}{\rho}$$

From the assumption that each copper atom contributes one free electron to the current, find the electron density in copper:

$$n = \frac{N_A}{V} = \frac{N_A \rho}{M}$$



$$I_{avg} = \frac{\Delta Q}{\Delta t} = nqv_d A$$



<u>Source:</u> Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Drift Speed in a Copper Wire

Optional

Example 26.1

The 12-gauge copper wire in a typical residential building has a cross-sectional area of ***A=3.31 x 10⁻⁶ m²***. It carries a constant current of ***I = 10.0 A***. What is the drift speed of the electrons in the wire (v_d)? Assume each copper atom contributes one free electron to the current. The density of copper is ***ρ = 8.92 g/cm3***.

<u>Note:</u> The periodic table of the elements shows that the molar mass of copper is ***M = 63.5 g/mol.*** Recall that 1 mol of any substance contains Avogadro's number of atoms (***NA = 6.02 x 10²³ mol⁻¹***).

29 $^2S_{1/2}$
Cu
Copper
63.546
$[Ar]3d^{10}4s$
7.7264

$$I_{avg} = \frac{\Delta Q}{\Delta t} = nqv_d A$$

Solution

Use the molar mass and the density of copper to find the volume of 1 mole of copper:

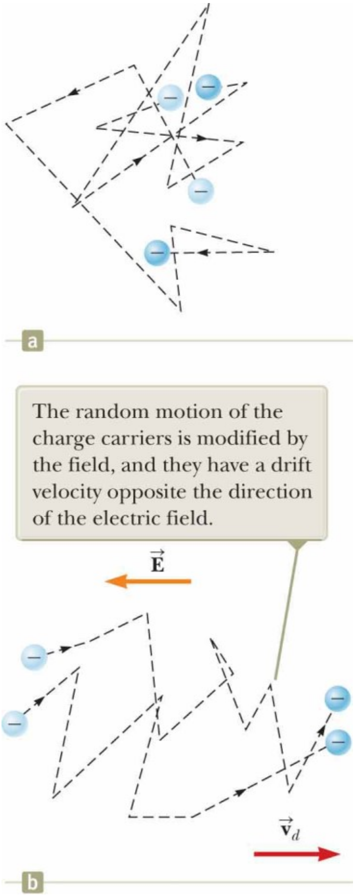
$$V = \frac{M}{\rho}$$

From the assumption that each copper atom contributes one free electron to the current, find the electron density in copper:

$$n = \frac{N_A}{V} = \frac{N_A \rho}{M}$$

Solve Equation 27.4 for the drift speed and substitute for the electron density:

$$v_d = \frac{I_{avg}}{nqA} = \frac{I}{nqA} = \frac{IM}{qAN_A\rho}$$



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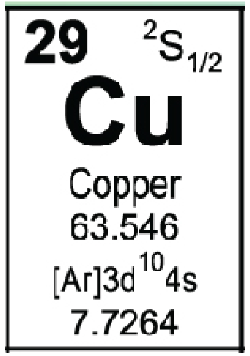

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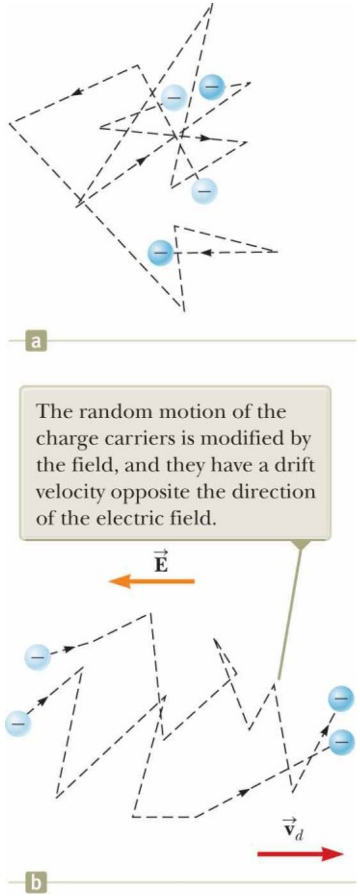

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Use the molar mass and the density of copper to find the volume of 1 mole of copper: $V = \frac{M}{\rho}$

From the assumption that each copper atom contributes one free electron to the current, find the electron density in copper: $n = \frac{N_A}{V} = \frac{N_A \rho}{M}$

Solve Equation 27.4 for the drift speed and substitute for the electron density: $v_d = \frac{I_{avg}}{nqA} = \frac{I}{nqA} = \frac{IM}{qAN_A\rho}$

Substitute numerical values:

$$v_d = \frac{(10.0\text{ A})(0.063\,5\text{ kg/mol})}{(1.60 \times 10^{-19}\text{ C})(3.31 \times 10^{-6}\text{ m}^2)(6.02 \times 10^{23}\text{ mol}^{-1})(8\,920\text{ kg/m}^3)}$$

$$= \boxed{2.23 \times 10^{-4}\text{ m/s}}$$

Current and Resistance (Ch. 26)

Resistance

Resistance

- Previously it was mentioned that the electric field inside a conductor is zero. This was true if the conductor was in equilibrium.

- When there is a non-zero E field in the conductor, ***electric current*** exists in the wire.

- Consider a conductor of cross-sectional area ***A*** carrying a current ***I***. The current density ***J*** in the conductor is defined as the current per unit area:

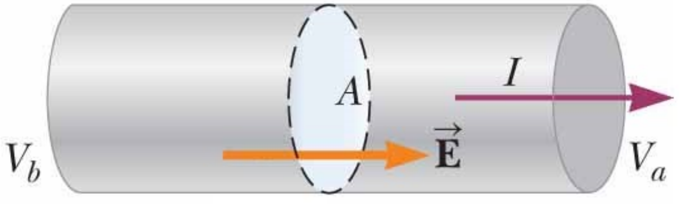
$$I = nqv_d A$$

$$J \equiv \frac{I}{A} = nqv_d$$

- SI units for ***J*** is ***Amperes per meter squared (A/m²)***

- In some materials, the current density is proportional to the electric field:

$$J = \sigma E$$



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Resistance

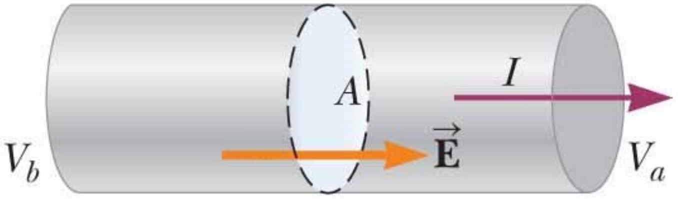
- In some materials, the current density is proportional to the electric field:

$$J = \sigma E$$

- where the constant of proportionality σ is called the ***conductivity*** of the conductor. Materials that obey this equation are said to follow ***Ohm's law***, named after Georg Simon Ohm.

- Ohm's Law states:

For many materials (including most metals), the ratio of the current density to the electric field is a constant σ that is independent of the electric field producing the current.



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

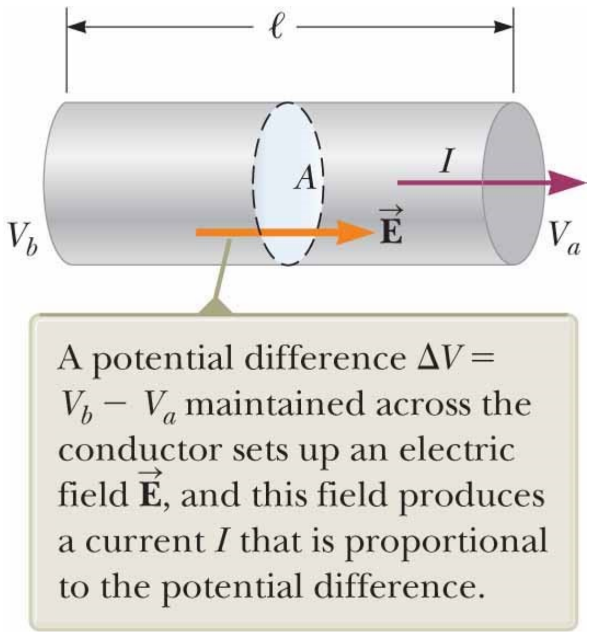
Resistance

Ohm's Law

- Consider a segment of straight wire of uniform cross-sectional area ***A*** and length ***l*** (figure)

- Magnitude of the potential difference across the wire can be found as:

$$\Delta V = E\ell \xrightarrow{J = \sigma E} \Delta V = \frac{\ell J}{\sigma} \xrightarrow{J = I/A} \Delta V = \left(\frac{\ell}{\sigma A}\right) I$$



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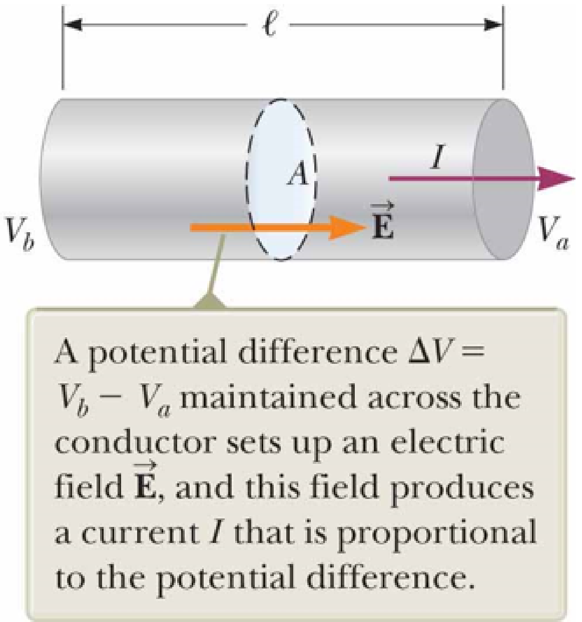
Will be defined as the ***Resistance (R)*** of the conductor



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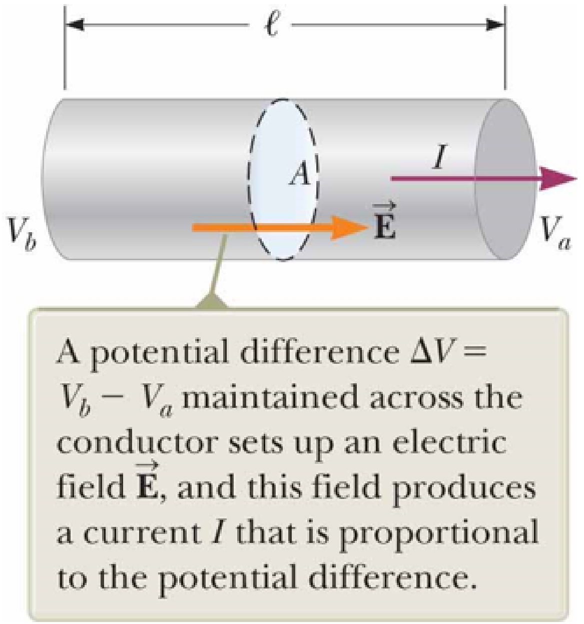
Will be defined as the ***Resistance (R)*** of the conductor

$$\boxed{R \equiv \frac{\Delta V}{I}}$$

- Or $\boxed{V = IR}$



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

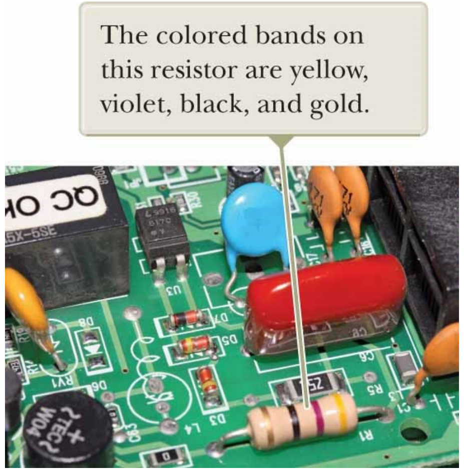
- The unit of Resistance is Ohm (Ω)
- 1 Ω = Volt / Ampere

Resistors

- Resistors are circuit elements that are used to control current in various parts of a circuit.
  - Many resistors are built into integrated circuit chips
  - Stand-alone resistors still available and widely used

- For large thru hole resistors, values are indicated by color coding
  - The first two colors give the first two digits in the resistance value
  - The third color represents the power of 10 for the multiplier
  - The last color is the tolerance of the resistance value.

- Example:



The four colors on the resistor in the picture are:
Yellow (=4), violet (=7), black (=10^0), and gold (=5%)

R = 47 x 10^0 with a tolerance +/- 5%

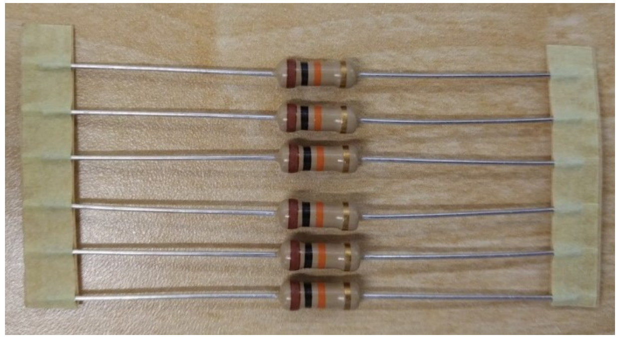
TABLE 26.1 Color Coding for Resistors

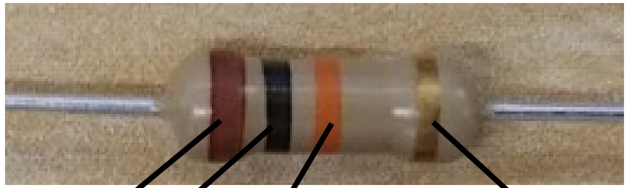
Color	Number	Multiplier	Tolerance
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
Gold		10^{-1}	5%
Silver		10^{-2}	10%
Colorless			20%

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10^{th} Edition. Cengage learning, 2018.

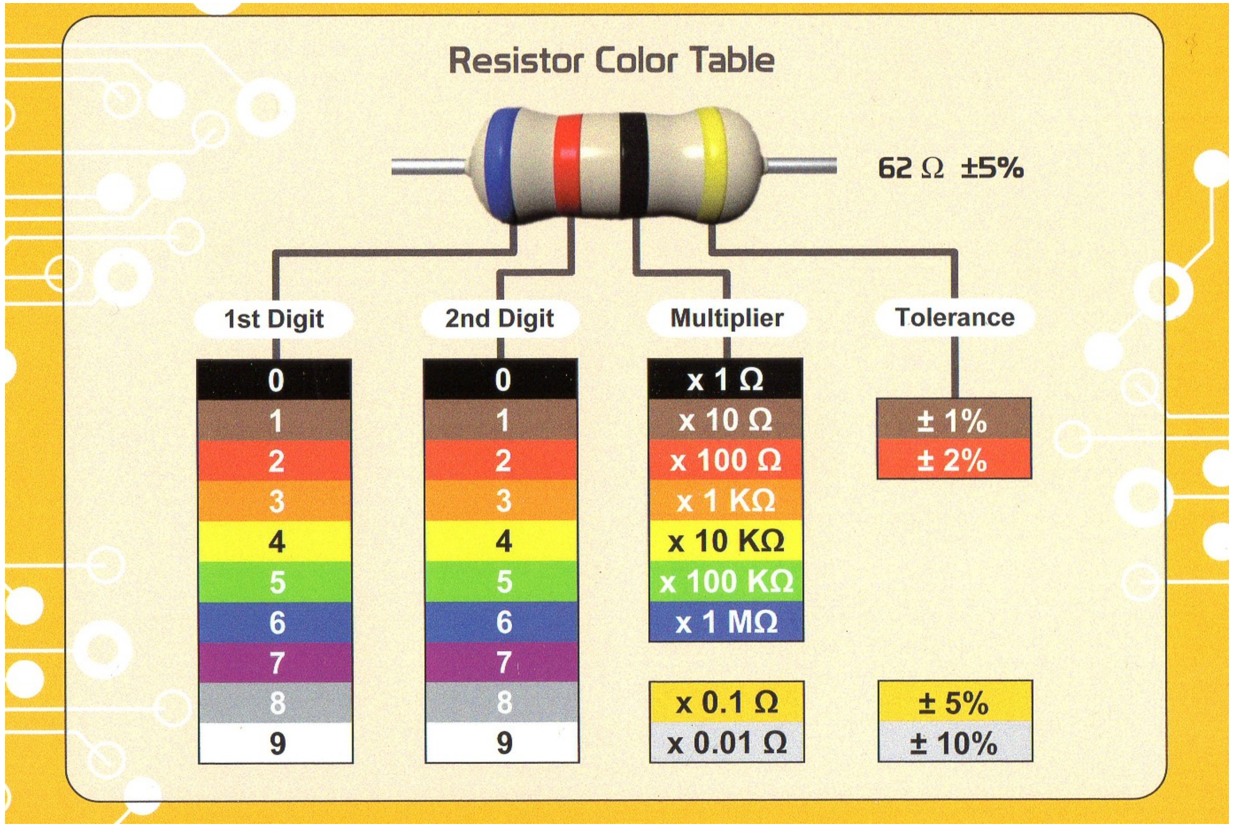
Resistors

10 kOhms





1 0 x 1000 = 10,000 +/- 5%



Source:
http://www.sysrecon.com/resources/4-band-resistor-color-code-calculator/

Resistivity

- We defined ***conductivity (σ)*** before.
- The inverse of conductivity is ***resistivity (ρ)***.

$$\rho = \frac{1}{\sigma}$$

ρ has units ohm . meters (Ω.m)

- Because ***R = l/σA***, we can express the resistance of a uniform block of material along the length ***l*** as:

$$R = \rho \frac{\ell}{A}$$

TABLE 26.2 Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient[b] α $[(°C)^{-1}]$
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon[d]	2.3×10^{3}	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C. All elements in this table are assumed to be free of impurities.
[b] See Section 26.4.
[c] A nickel–chromium alloy commonly used in heating elements. The resistivity of Nichrome varies with composition and ranges between 1.00×10^{-6} and 1.50×10^{-6} $\Omega \cdot m$.
[d] The resistivity of silicon is very sensitive to purity. The value can be changed by several orders of magnitude when it is doped with other atoms.

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Good insulators	Glass	10^{10} to 10^{14}	
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The Resistance of Nichrome Wire

Example 26.2

The radius of 22-gauge Nichrome wire is ***r = 0.32 mm***.

(A) Calculate the ***resistance per unit length*** of this wire.

(B) If a potential difference of ***10 V*** is maintained across a ***1.0-m*** length of the Nichrome wire, what is the ***current*** in the wire?

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Solution

(A) Resistance per unit length of 1m:

$$R = \rho \frac{\ell}{A} \rightarrow \frac{R}{\ell} = \frac{\rho}{A} = \frac{\rho}{\pi r^2} = \frac{1.0\times 10^{-6}\ \Omega\cdot\text{m}}{\pi\left(0.32\times 10^{-3}\ \text{m}\right)^2} = 3.1\ \Omega/\text{m}$$

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(B) Using Ohm's law (V=IR):

$$I = \frac{\Delta V}{(R/\ell)\ell} = \frac{10\ \text{V}}{(3.1\ \Omega/\text{m})(1.0\ \text{m})} = 3.2\ \text{A}$$

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The Radial Resistance of a Coax Cable

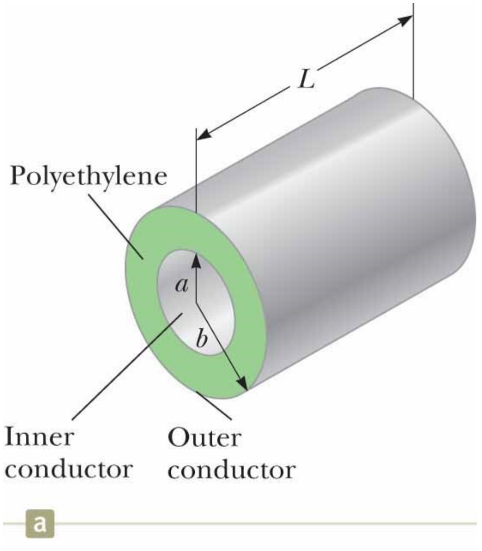
Optional

Example 26.3

Coaxial cables are used extensively for electronic applications.

A coaxial cable consists of two concentric cylindrical conductors. The region between the conductors is completely filled with polyethylene plastic as shown in the figure. Current leakage through the plastic, in the radial direction, is unwanted. (The cable is designed to conduct current along its length, but that is not the current being considered here.)

The radius of the inner conductor is ***a* = 0.500 cm**, the radius of the outer conductor is ***b* = 1.75 cm**, and the length is ***L* = 15.0 cm**. The resistivity of the plastic is $\boldsymbol{\rho = 1.0 \times 10^{13}\ \Omega \cdot m}$. Calculate the radial resistance of the plastic between the two conductors.



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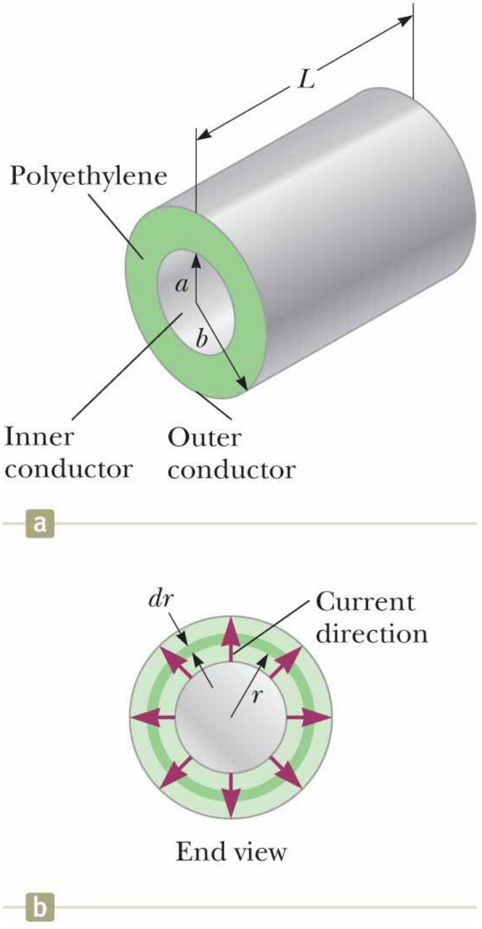

Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Solution

We can divide the plastic into concentric cylindrical shells of infinitesimal thickness ***dr*** (as shown in the bottom figure). Any charge passing from the inner to the outer conductor must move radially through this shell. We can use a differential form of our resistance equation, replacing ***l*** with ***dr*** for the length variable: ***dR = ρ dr/A***, where ***dR*** is the resistance of a shell of plastic of thickness ***dr*** and surface area ***A***.

$$R = \rho \frac{\ell}{A} \qquad dR = \frac{\rho\, dr}{A} = \frac{\rho}{2\pi r L} dr$$

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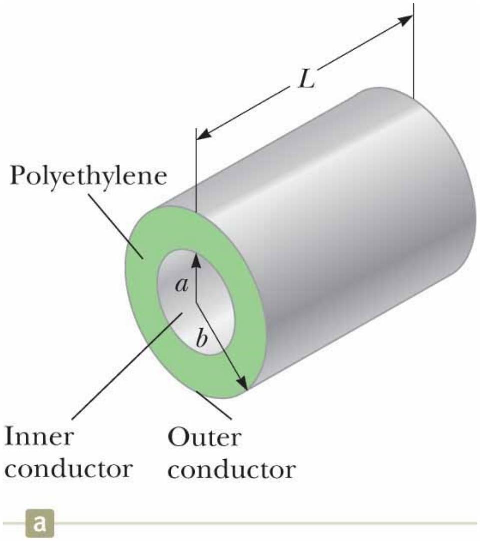
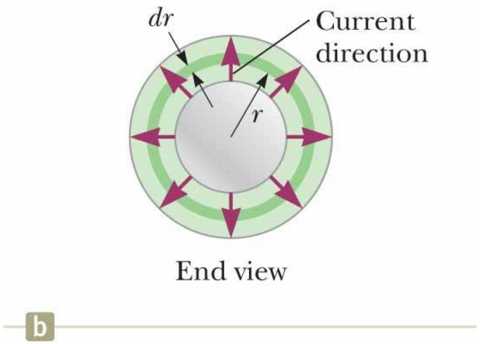
The radius of the inner conductor is ***a = 0.500 cm***, the radius of the outer conductor is ***b = 1.75 cm***, and the length is ***L = 15.0 cm***. The resistivity of the plastic is ***ρ = 1.0 x 10^{13} Ω·m***. Calculate the radial resistance of the plastic between the two conductors.





Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Solution

We can divide the plastic into concentric cylindrical shells of infinitesimal thickness ***dr*** (as shown in the bottom figure). Any charge passing from the inner to the outer conductor must move radially through this shell. We can use a differential form of our resistance equation, replacing ***l*** with ***dr*** for the length variable: ***dR = ρ dr/A***, where ***dR*** is the resistance of a shell of plastic of thickness ***dr*** and surface area ***A***.

$$R = \rho \frac{\ell}{A}$$

$$dR = \frac{\rho\, dr}{A} = \frac{\rho}{2\pi r L} dr$$

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The Radial Resistance of a Coax Cable

Optional

Example 26.3

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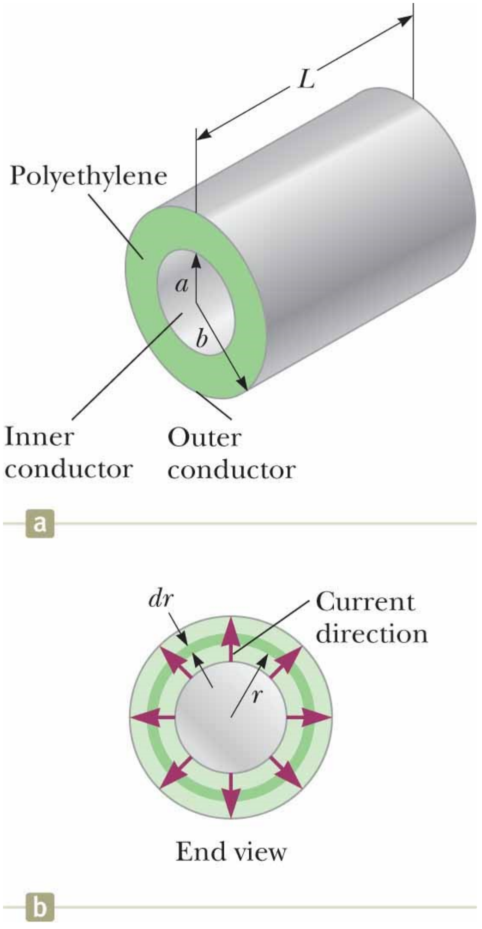

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$$R = \frac{1.0\times10^{13}\ \Omega\cdot\text{m}}{2\pi(0.150\ \text{m})}\ln\left(\frac{1.75\ \text{cm}}{0.500\ \text{cm}}\right) = \boxed{1.33\times10^{13}\ \Omega}$$

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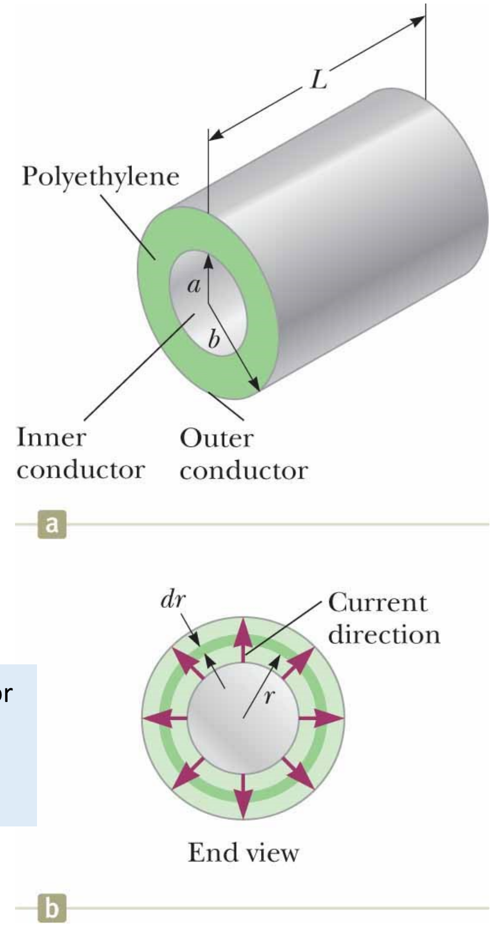
This is a very large resistance compared to the inner copper conductor (orders of magnitude). Therefore, almost all the current corresponds to charge moving along the length of the cable, with a very small fraction leaking in the radial direction.



Source: Serway, Raymond A., and John W. Jewett. *Physics for scientists and engineers*. 10th Edition. Cengage learning, 2018.

Current and Resistance (Ch. 26)

Resistance and Temperature

Resistance and Temperature

- Over a limited temperature range: resistivity of a conductor varies approximately linearly with temperature:

$$\rho = \rho_0\left[1+\alpha\left(T-T_0\right)\right]$$

  - ***ρ*** = the resistivity at some temperature T (in degrees Celsius)
  - $\boldsymbol{\rho_0}$ = the resistivity at some reference temperature T_0 (usually 20°C)
  - ***α*** = the temperature coefficient of resistivity:
    - $\boldsymbol{\Delta\rho = \rho - \rho_0}$ is the change in resistivity in temperature interval $\Delta T = T - T_0$

$$\alpha = \frac{\Delta\rho/\rho_0}{\Delta T}$$

- The table on the right provides the temperature coefficients of resistivity for various materials. Please note the unit for ***α = [(°C)–1]***

- Since resistance is proportional to the the variation of resistivity, the resistance of a sample is:

$$R = R_0\left[1+\alpha\left(T-T_0\right)\right]$$

TABLE 26.2 Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] (Ω · m)	Temperature Coefficient[b] α [(°C)$^{-1}$]
Silver	1.59×10^{-8}	3.8×10^{-3}
Copper	1.7×10^{-8}	3.9×10^{-3}
Gold	2.44×10^{-8}	3.4×10^{-3}
Aluminum	2.82×10^{-8}	3.9×10^{-3}
Tungsten	5.6×10^{-8}	4.5×10^{-3}
Iron	10×10^{-8}	5.0×10^{-3}
Platinum	11×10^{-8}	3.92×10^{-3}
Lead	22×10^{-8}	3.9×10^{-3}
Nichrome[c]	1.00×10^{-6}	0.4×10^{-3}
Carbon	3.5×10^{-5}	-0.5×10^{-3}
Germanium	0.46	-48×10^{-3}
Silicon[d]	2.3×10^{3}	-75×10^{-3}
Glass	10^{10} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

[a] All values at 20°C. All elements in this table are assumed to be free of impurities.
[b] See Section 26.4.
[c] A nickel–chromium alloy commonly used in heating elements. The resistivity of Nichrome varies with composition and ranges between 1.00×10^{-6} and 1.50×10^{-6} Ω · m.
[d] The resistivity of silicon is very sensitive to purity. The value can be changed by several orders of magnitude when it is doped with other atoms.

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Resistance and Temperature

- Precise temperature measurements can be made through careful monitoring of resistance of a particular material.
  - Example: widely used ***thermal resistors*** or ***thermistors***

- Note that some of the ***α*** values in table are negative → meaning the resistivity of these materials decreases with increasing temperature
  - Semiconductors
  - Increase in density of charge carriers at higher temperatures

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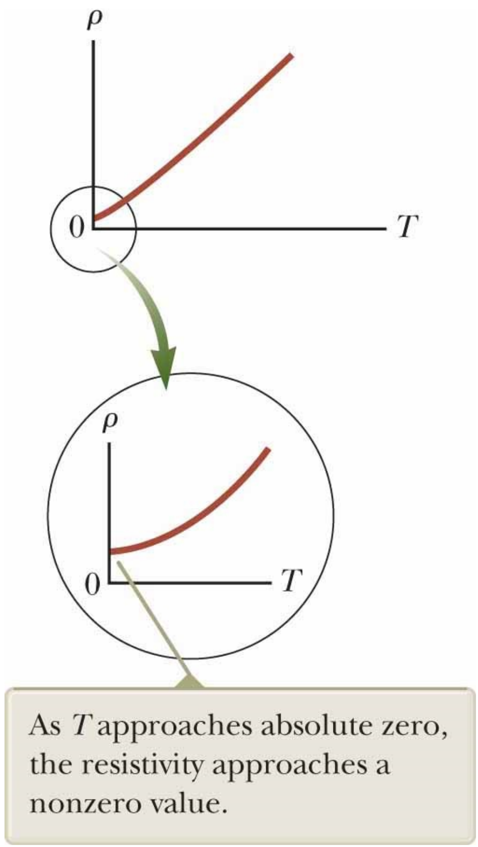
Resistance and Temperature

- For some metals (i.e., copper): the resistivity is nearly proportional to the temperature (figure)
    - Nonlinear region always exists at very low temperatures
    - Resistivity usually reaches some finite value as temperature approaches absolute zero
- Residual resistivity near absolute zero is caused primarily by collision of electrons with impurities and imperfections in metal
- High-temperature resistivity (linear region) is predominantly characterized by collisions between electrons and metal atoms



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Resistance and Temperature

Quick Quiz

When does an incandescent lightbulb carry more current?

(a) immediately after it is turned on and the glow of the metal filament is increasing
(b) after it has been on for a few milliseconds and the glow is steady?

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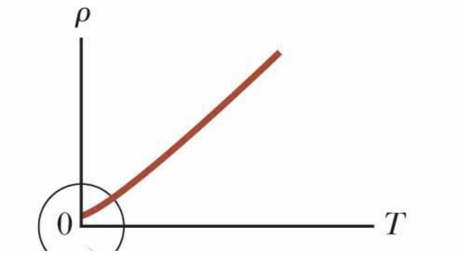
Resistance and Temperature

Quick Quiz

When does an incandescent lightbulb carry more current?

True → **(a) immediately after it is turned on and the glow of the metal filament is increasin**
(b) after it has been on for a few milliseconds and the glow is steady?

When the filament is at room temperature, its resistance is low and the current is therefore relatively large. As the filament warms up, its resistance increases and the current decreases. Older light bulbs often fail just as they are turned on because this large, initial current "spike" produces a rapid temperature increase and mechanical stress on the filament, causing it to break.



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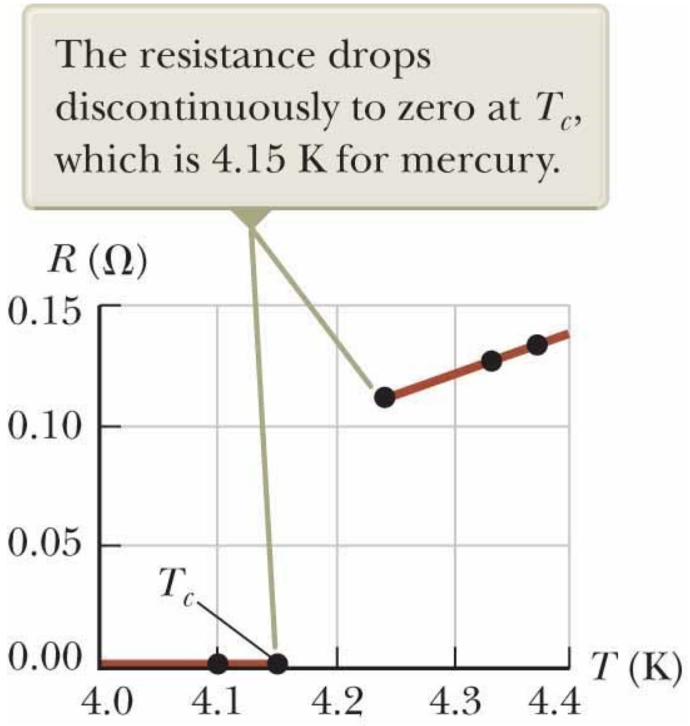
Current and Resistance (Ch. 26)

Superconductors

Superconductors

- There is a class of metals and compounds whose resistance decreases to zero when they are below a certain temperature ***Tc*** , known as the ***critical temperature***.
- These materials are known as ***superconductors***.
- The resistance–temperature graph for a superconductor follows that of a normal metal at temperatures above ***Tc*** (figure).
- When the temperature is at or below ***Tc*** , the resistivity drops suddenly to zero. This phenomenon was discovered in 1911 by Dutch physicist Heike Kamerlingh-Onnes (1853–1926) as he worked with mercury, which is a superconductor below 4.2 K.
- Resistivities of superconductors below their **Tc** values are less than **4×10^{-25} Ω·m**, or approximately **10^{17} times smaller than the resistivity of copper**. In practice, these resistivities are considered to be zero.



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Superconductors

- Today, thousands of superconductors are known, and as Table illustrates, the critical temperatures of recently discovered superconductors are substantially higher than initially thought possible.

- Two kinds of superconductors :
  - Ceramics with high critical temperatures (recent discoveries)
  - Metals (earlies observations)

- Copper, silver, and gold, which are excellent conductors, do not exhibit superconductivity.

- One truly remarkable feature of superconductors is that once a current is set up in them, it persists ***without any applied potential difference*** (because R=0). Steady currents have been observed to persist in superconducting loops for several years with no apparent decay!

- Current applications: ***powerful magnets used in MRI*** machines.

- If room-temperature superconductors are ever identified → tremendous effect on technology

TABLE 26.3 Critical Temperatures for Various Superconductors

Material	T_c (K)
$HgBa_2Ca_2Cu_3O_8$	134
Tl—Ba—Ca—Cu—O	125
Bi—Sr—Ca—Cu—O	105
$YBa_2Cu_3O_7$	92
Nb_3Ge	23.2
Nb_3Sn	18.05
Nb	9.46
Pb	7.18
Hg	4.15
Sn	3.72
Al	1.19
Zn	0.88

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Current and Resistance (Ch. 26)

Electrical Power

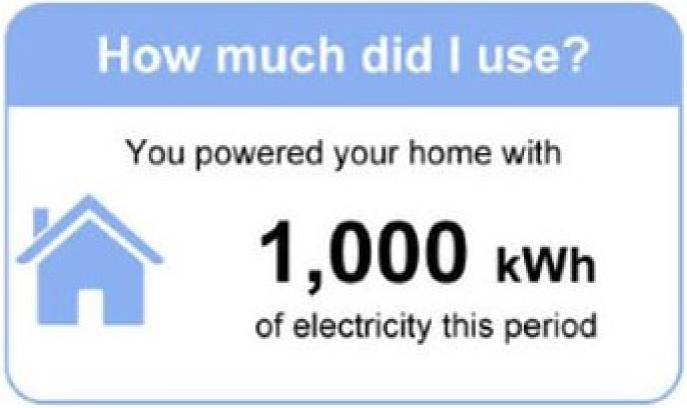
Electrical Power

- The unit on our electricity bill is kilowatt-hour (***kWh***). This is how we measure how much electricity we used.
  - Unit can be smaller like Wh or mWh, or larger like MWh or GWh.

- kWh is a measure of the amount of electrical energy used.

- Power is ***the rate of energy transfer*** (in this case rate of electrical energy usage)

- Rate of energy transfer means there is a time element
  → The amount of work done in a given time.



Electrical Power

- The figure shows a circuit consisting of a battery that is connected to a resistor.
    - we assume wires have negligible resistance

- The battery maintains a potential difference of magnitude ***ΔV*** across its own terminals
    - since wires have negligible resistance, same potential is maintained across the resistor as well

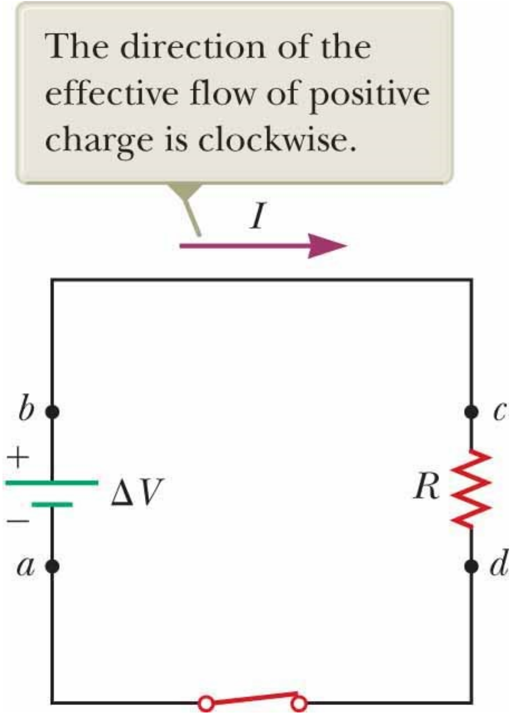
- There is a steady current ***I*** produced in the circuit, directed from terminal ***c*** to terminal ***d***.

- The amount of charge ***dq*** that moves between those terminals in time interval ***dt*** is equal to ***I dt***:

$$dq = Idt$$

- This charge ***dq*** moves through a decrease in potential of magnitude ***ΔV***, and thus its electric potential energy decreases in magnitude by the amount:

$$dU = dq\Delta V = (Idt)\Delta V$$



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Electrical Power

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$$dU = dq\Delta V = (Idt)\Delta V$$

- The principle of conservation of energy tells us that the decrease in electric potential energy from **b** to **a** is accompanied by a transfer of energy to some other form.

- The power ***P*** associated with that transfer is the ***rate of transfer dU/dt*** :

$$\mathrm{P} = \frac{dU}{dt} = \frac{d}{dt}(q\Delta V) = I\Delta V$$

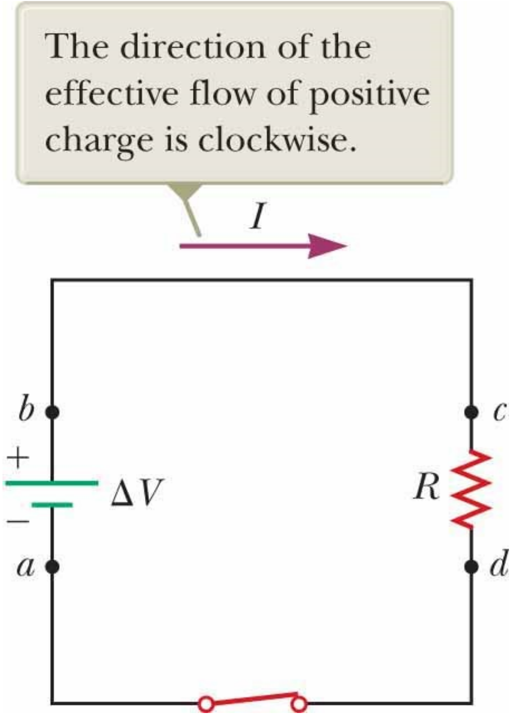
$$\mathrm{P} = IV$$

(in general, voltage source is given by ***V***)

$$\mathrm{P} = IV = I(IR) = I^2R = \frac{V^2}{R}$$

(using Ohms law: ***V=IR***)

$$\mathrm{P} = I^2R \qquad \mathrm{P} = \frac{V^2}{R}$$



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Power in an Electric Heater

Example 26.4

An electric heater is constructed by applying a potential difference of ***120 V*** across a Nichrome wire that has a total resistance of ***8.00 Ω***. Find the current carried by the wire and the power rating of the heater. ***[V=120V, R=8Ω, I=?]***

Source:
https://www.gopresto.com/product/heatdish-parabolic-electric-heater-0792401

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Solution

To find the current, we apply Ohm's law: V=IR

$120V = I \times 8\Omega \rightarrow I=15A$

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Solution

To find the current, we apply Ohm's law: V=IR

$120V = I \times 8\Omega \rightarrow I=15A$

Since we know V, I and R, we can find the power in various ways:

$P=VI \rightarrow P = 120 \times 15 = 1{,}800W$

$P=I^2R \rightarrow P = 15^2 \times 8 = 1{,}800W$

$P=V^2/R \rightarrow P = 120^2 / 8 = 1{,}800W$

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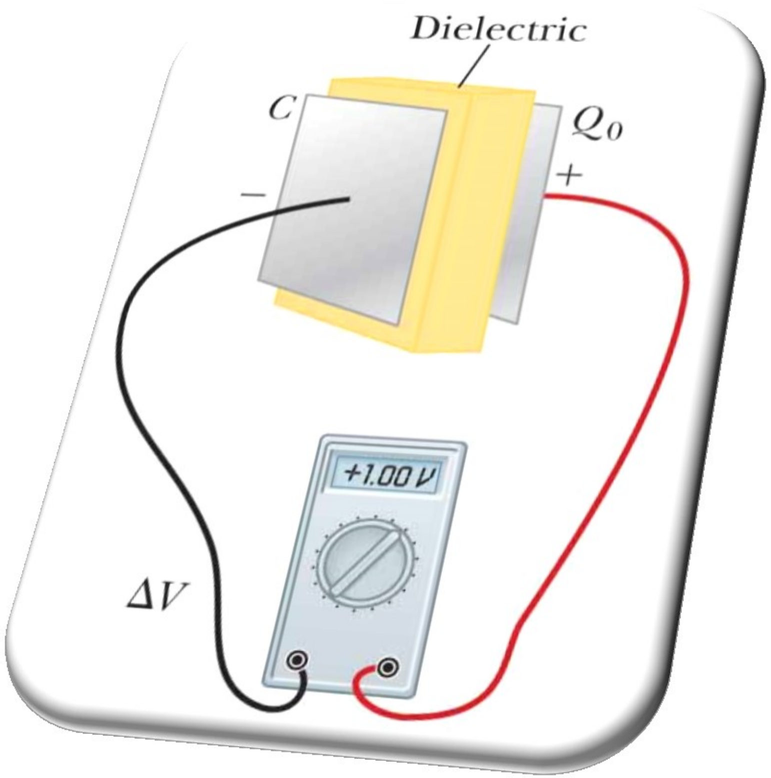
Summary of Week 3, Class 3

- Reminder of the previous week

- Capacitance and Dielectrics (Ch. 25)
    - Definition and calculation of capacitance
    - Calculating Capacitance
    - Combination of capacitors
    - Energy stored in charge capacitors
    - Capacitors with dielectrics
    - Partially filled capacitors

- Current and Resistance (Ch. 26)
    - Electric current
    - Resistance
    - Resistance and temperature
    - Superconductors
    - Electrical power

- Examples
- Next week's topic



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Reading / Preparation for Next Week

Topics for next week: Direct Current Systems (Ch.27)

Back-up Slides

Optional Content

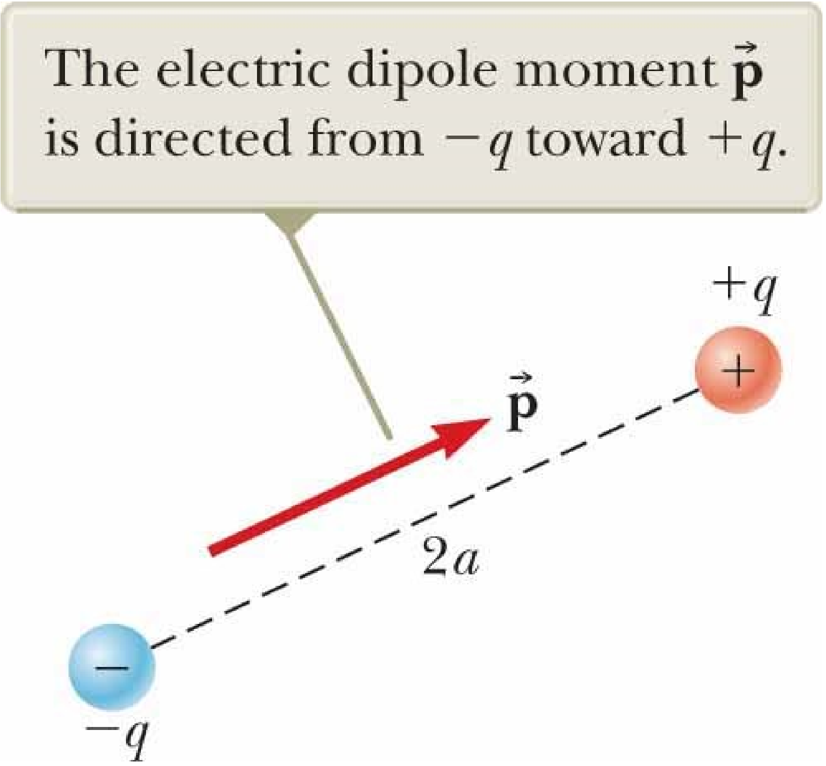
Capacitance and Dielectrics (Ch. 25)

Electric Dipole in an Electric Field

Electric Dipole in an Electric Field

- The electric dipole consists of two charges of equal magnitude and opposite sign separated by a distance ***2a*** as shown in figure.
- Electric dipole moment of this configuration is defined as the vector $\vec{p}$ directed from ***–q*** toward ***+q*** along the line joining the charges.
- The magnitude of $\vec{p}$ can be calculated as:

$$p \equiv 2aq$$



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Electric Dipole in an Electric Field

- Suppose now the electric dipole is placed in an external uniform electric field ***E*** and makes angle ϴ with the field (figure).

- Electric forces acting on charges are equal in magnitude (***F=qE***) and opposite in direction. Hence, the net force on the dipole is zero.

- But the two forces produce a net torque on the dipole.

- Torque due to the force on ***+q*** about the axis ***O*** has a magnitude:

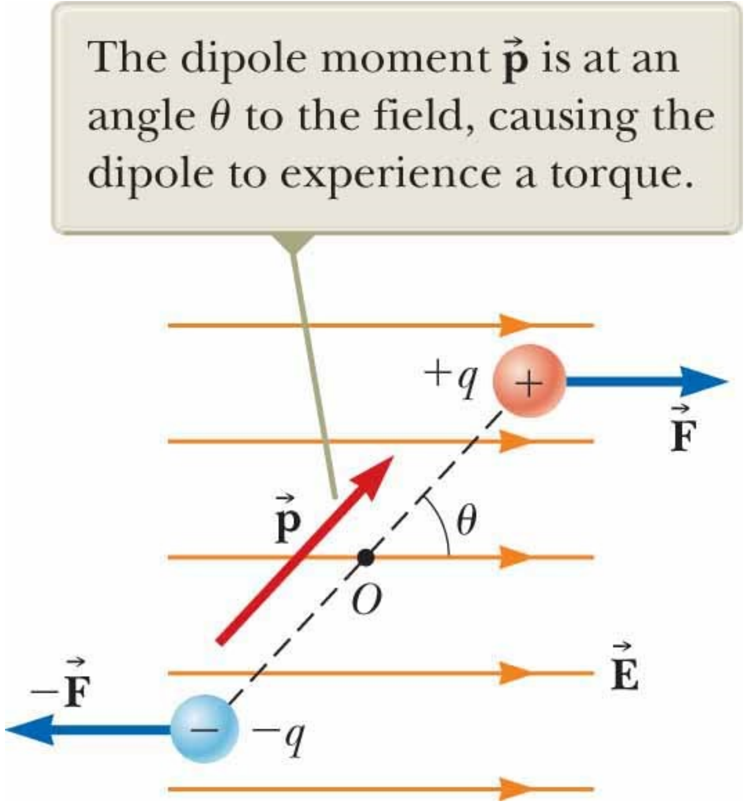
$$Fa\sin\theta$$

(*producing clockwise rotation*)

- Torque due to the force on -q about the axis O has the same magnitude.

- The magnitude of net total torque:

$$\tau = 2Fa\sin\theta$$



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Electric Dipole in an Electric Field

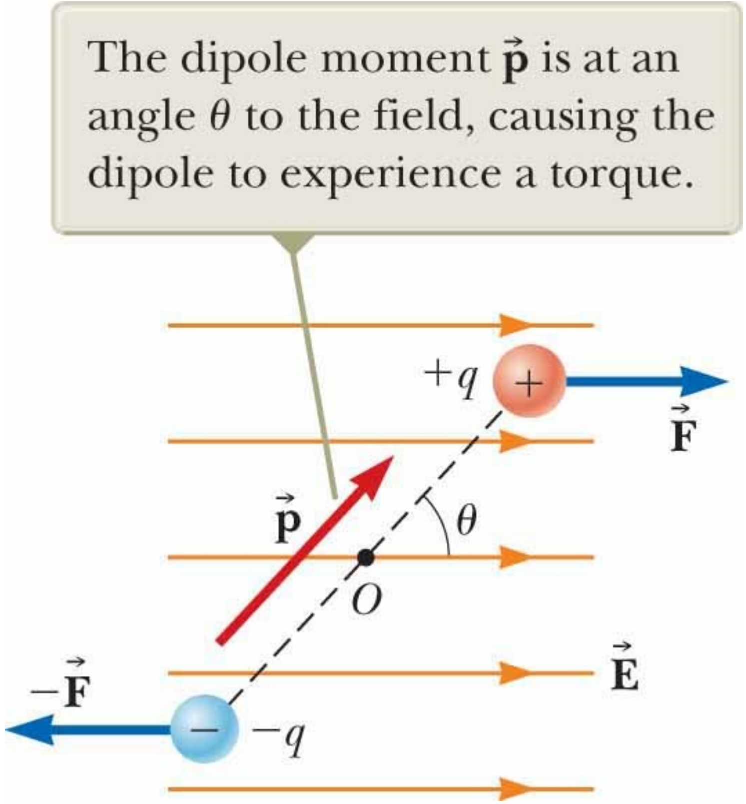
- The magnitude of net total torque:

$$\tau = 2Fa\sin\theta$$

  - We also have
    - F=qE
    - P=2aq

$$\tau = 2aqE\sin\theta = pE\sin\theta$$

$$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}$$



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Capacitance and Dielectrics (Ch. 25)

An Atomic Description of Dielectrics

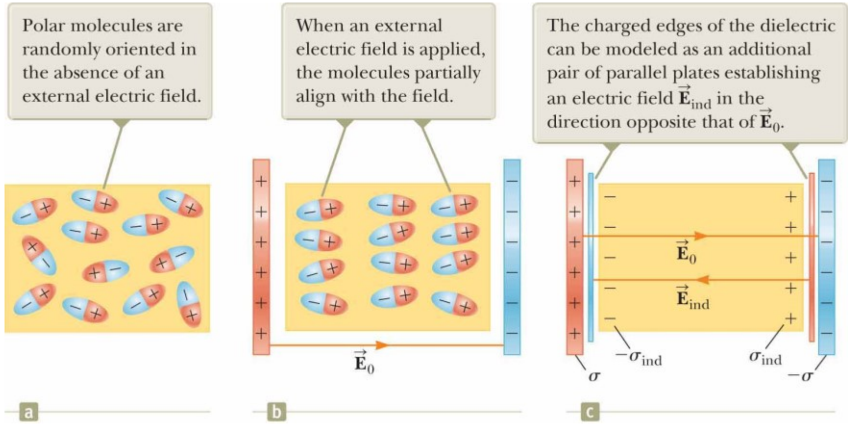
An Atomic Description of Dielectrics

- Recall: potential difference ΔV_0 between the plates of an empty capacitor was reduced to $\Delta V_0/\kappa$ when dielectric was introduced between the plates.

$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{E}}_0}{\kappa}$$

- When we place a slab of dielectric material between the plates of the capacitor; induced surface charges on the dielectric give rise to induced Electric field $\boldsymbol{E_{ind}}$ in a direction opposite to the external field $\boldsymbol{E_0}$ (figure b and c). Net $\boldsymbol{E}$ field magnitude in the dielectric can be written as:

$$E = E_0 - E_{\text{ind}}$$



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