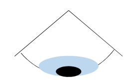
From Course Handbook:

Regrade policy. Requests for regrades must be submitted no later than the end of the second recitation meeting after the general return of the graded material, …

Electric Current
(rate of charge flow)

Average Current:

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



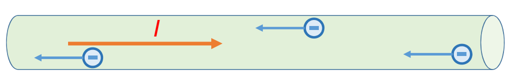
(Counting charge that passes in a given time.)

Electric Current
(rate of charge flow)

Average Current:

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

Positive current refers to flow of positive charges. If moving charges are negative (electrons), the current is in the opposite "direction".

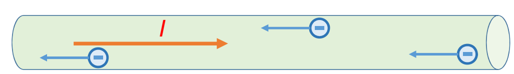


Electric Current
(rate of charge flow)

Average Current:

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

It is odd to speak of direction associated with current. Current is a scalar, but it does have a sign.



Electric Current
(rate of charge flow)

Average Current:

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

Instantaneous Current:

$$I = \frac{dQ}{\text{d}t}$$

Unit of current is ampere (A) or amp. 1A = $\frac{1\text{C}}{1\text{s}}$

Electric Current
(rate of charge flow)

Typical Currents:

• 100W light bulb	1A
• Automobile starter motor	200A
• Electronics	nA - mA

Current and Current Density

The current in a wire is the sum of all the charge per time passing through a cross-section of the wire.

$$\text{Current} = \frac{\text{charge}}{(\text{area})(\text{time})}(\text{area})$$

$$I = \int \vec{J} \cdot d\vec{A}$$

$\vec{J}$ is current density.

Current and Current Density

$$I = \int \vec{J} \cdot d\vec{A}$$

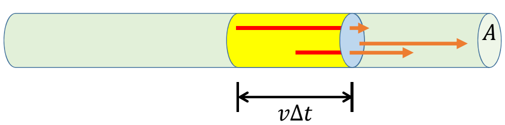
In many applications,
$\vec{J}$ is uniform and parallel to $d\vec{A}$.

$$I = \int \vec{J} \cdot d\vec{A} = J \int dA = JA$$

or

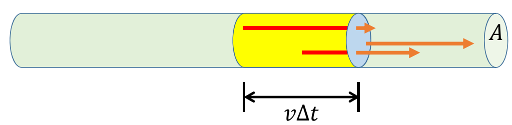
$$J = \frac{I}{A}$$

Current
A microscopic view



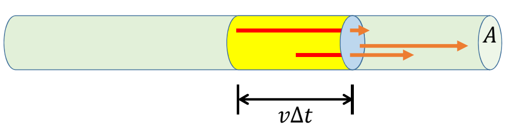
- Charges passing a given point in time, Δt, are those initially in a volume, $(v\Delta t)A$.

Current
A microscopic view



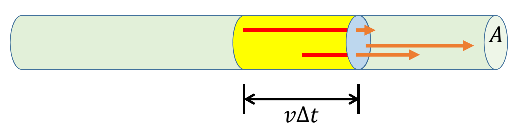
- Charges passing a given point in time, Δt, are those initially in a volume, $(v\Delta t)A$.
- The number of passing charges depends on the charge density, *n*. $N = n(v\Delta tA)$

Current
A microscopic view



- Charges passing a given point in time, Δt, are those initially in a volume, $(v\Delta t)A$.
- The number of passing charges depends on the charge density, *n*. $N = n(v\Delta tA)$
- The amount of passing charge depends on the charge per carrier, *q*. $\Delta Q = q(nv\Delta tA)$

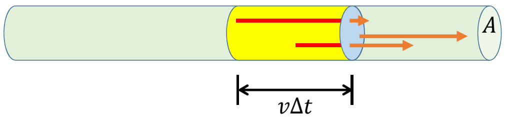
Current
A microscopic view



$$I = \frac{\Delta Q}{\Delta t} = nqvA$$

- The amount of passing charge depends on the charge per carrier, *q*. $\Delta Q = q(nv\Delta tA)$

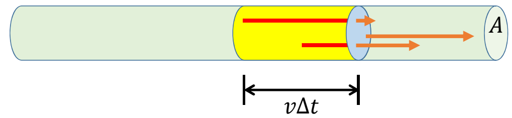
Current
A microscopic view



$$I = \frac{\Delta Q}{\Delta t} = nqvA \qquad J = \frac{I}{A} = nqv$$

(not quite correct)

Current Density Corrected



$$I = \frac{\Delta Q}{\Delta t} = nqvA \qquad \vec{J} = nq\vec{v}_d$$

$\vec{v}_d$ is the average velocity, called drift velocity.

Current Density Corrected

$$\vec{J} = nq\vec{v}_d$$

Some free electron densities:
- Silver $n = 5.86 \times 10^{28}\ /\text{m}^3$
- Gold $n = 5.90 \times 10^{28}\ /\text{m}^3$
- Copper $n = 8.47 \times 10^{28}\ /\text{m}^3$
- Aluminum $n = 18.1 \times 10^{28}\ /\text{m}^3$

Example: 12-guage copper wire (common in home wiring) has a cross-sectional area of $3.31 \times 10^{-6}\text{m}^2$ and carries a current of 10A. Determine the drift speed of the electrons. [Free electron density in copper is $8.47 \times 10^{28}\text{m}^3$.]

Ohm's Law

Current caused by electric field in conductor

Amount of current depends on
- Strength of field
- How conductive the conductor is

$$\vec{J} = \sigma\vec{E}$$

σ is electrical conductivity

Ohm's Law

$$\vec{J} = \sigma\vec{E}$$

σ is electrical conductivity

Alternatively written as

$$\vec{J} = \frac{1}{\rho}\vec{E}$$

ρ is electrical resistivity

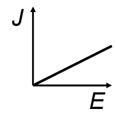
Either version may be referred to as Ohm's Law

(In this context, σ and ρ are NOT charge densities.)

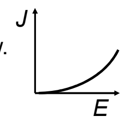
Ohm's Law

$$\vec{J} = \frac{1}{\rho}\vec{E}$$

Some materials follow Ohm's Law.
Ohmic materials



Other materials do not follow Ohm's Law.
Non-Ohmic materials



(Ohm's Law is not a Law of Nature.)

Example: An 8m long 12-guage copper wire ($A = 3.31 \times 10^{-6}\text{m}^2$) carries a current of 10A when connected across a potential difference of 0.406V.

a) Determine the current density in the wire.
b) Determine the electric field in the wire.
c) Determine the resistivity of the wire.

Ohm's Law

$$\vec{J} = \frac{1}{\rho}\vec{E}$$

Resistivity depends on temperature.

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

α is the temperature coefficient and ρ_0 is the resistivity at T_0.

Example: A wire is connected across a constant potential difference. It is noted that as the wire heats up from $20°\text{C}$ to $50°\text{C}$, the current drops from 0.500A to 0.443A. Determine the temperature coefficient of the material.

Material	Conductivity ($\times 10^7$ /Ωm)	Resistivity ($\times 10^{-8}$ Ωm)	Temperature Coefficient (/°C)
Aluminum	3.77	2.65	0.00429
Gold	4.1	2.44	0.0034
Copper	5.95	1.68	0.00386
Silver	6.29	1.59	0.0038
Silicon*	1.56×10^{-3} /Ωm	6.4×10^{2} Ωm	-0.075 /°C

*Silicon values depend strongly on impurities.

Microscopic vs. Macroscopic View

Microscopic
- Material
- Resistivity
- Current Density

$\vec{E} = \rho\vec{J}$

Macroscopic
- Device
- Resistance
- Current

$V = IR$

Connections $\quad J = \frac{I}{A} \quad R = \rho\frac{L}{A}$

Resistance

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

Resistance
- Proportional to length
- Inversely proportional to area
- Unit is Ohm (Ω)

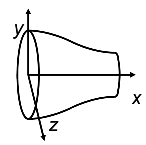
Applications: Jumper cables and holiday lights.

Resistance

Resistance depends on the material (resistivity) and the geometry of the device.

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

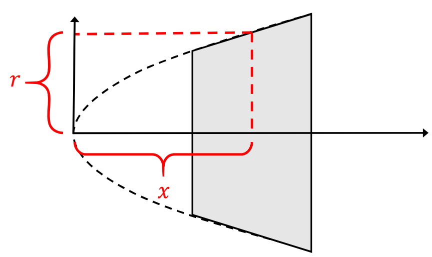
Integrate if the cross-section is not uniform.



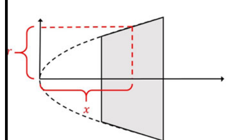
$$R = \int_0^L \rho \frac{dx}{A}$$

(*A* is a function of *x*.)

Example: The radius of a conductor is given by $r = \frac{1}{4}x^2$ between $x = 2\text{mm}$ and $x = 4\text{mm}$. Determine the resistance of the conductor for a current flowing in the x-direction.



Example: The radius of a conductor is given by $r = \frac{1}{4}x^2$ between $x = 2\text{mm}$ and $x = 4\text{mm}$. Determine the resistance of the conductor for a current flowing in the x-direction.



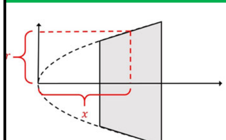
$$R = \rho \frac{L}{A} \rightarrow R = \int \rho \frac{dx}{A}$$

$$R = \int_{r_0}^{r_f} \rho \frac{dx}{\pi r^2}$$

$$R = \int_{r_0}^{r_f} \rho \frac{dx}{\pi \left(\frac{1}{4}x^2\right)^2} = \int_{r_0}^{r_f} \rho \frac{16dx}{\pi x^4}$$

$$R = -\frac{16\rho}{3\pi}\left(\frac{1}{r_f^3} - \frac{1}{r_0^3}\right)$$

Example: The radius of a conductor is given by $r = \frac{1}{4}x^2$ between $x = 2\text{mm}$ and $x = 4\text{mm}$. Determine the resistance of the conductor for a current flowing in the x-direction.



$$R = \rho \frac{L}{A} \rightarrow R = \int \rho \frac{dx}{A}$$

$$R = \int_{r_0}^{r_f} \rho \frac{dx}{\pi r^2}$$

$$R = \int_{r_0}^{r_f} \rho \frac{dx}{\pi \left(\frac{1}{4}x^2\right)^2} = \int_{r_0}^{r_f} \rho \frac{16dx}{\pi x^4}$$

Be careful to enter limits in meters.

$$R = -\frac{16\rho}{3\pi}\left(\frac{1}{r_f^3} - \frac{1}{r_0^3}\right)$$