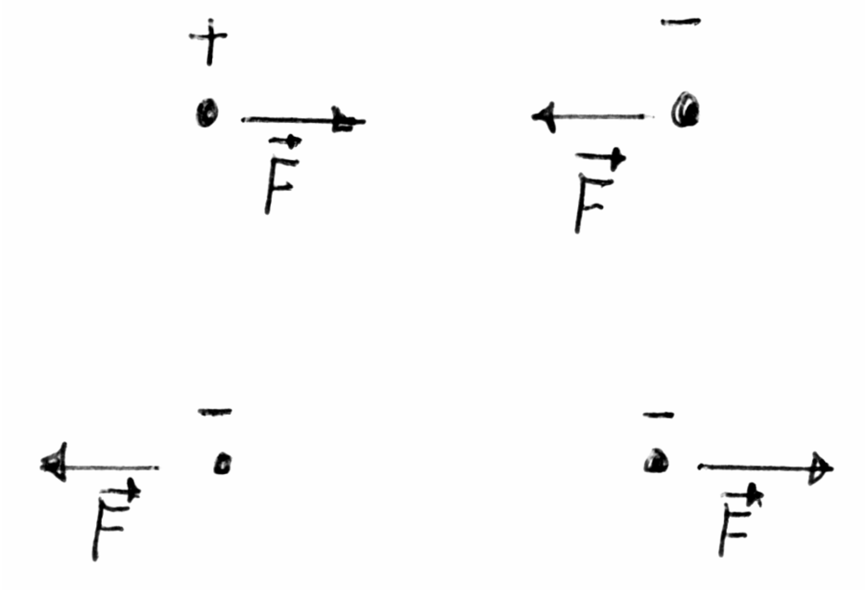
Review of Current, Voltage & Resistance: Lesson 2

Electrons and Charges (EC 1)

- Electricity is concerned with the flow of charged particles
- Basic particle: the Electron: negatively charged
- Electron charge: $q = -e = 1.602 \times 10^{-19}$ C (Coulombs)
- Mass of an electron $m_e = 9.1 \times 10^{-31}$ kg
- Like charges repel each other
- Unlike charges attract
- Electrons attracted by Positive,
  repelled by Negative charges



Electric Fields

- Electric Field ($\vec{E}$): The Force applied to a unit charge
- E is a vector quantity: has a direction and magnitude
- Units are N/C (Newtons per Coulomb)
- Positive charges move in the same direction as the E field
- Negative charges move: opposite direction to the E field
- The force on a charge is:

$$\vec{F} = q\vec{E}$$

Where q = the charge

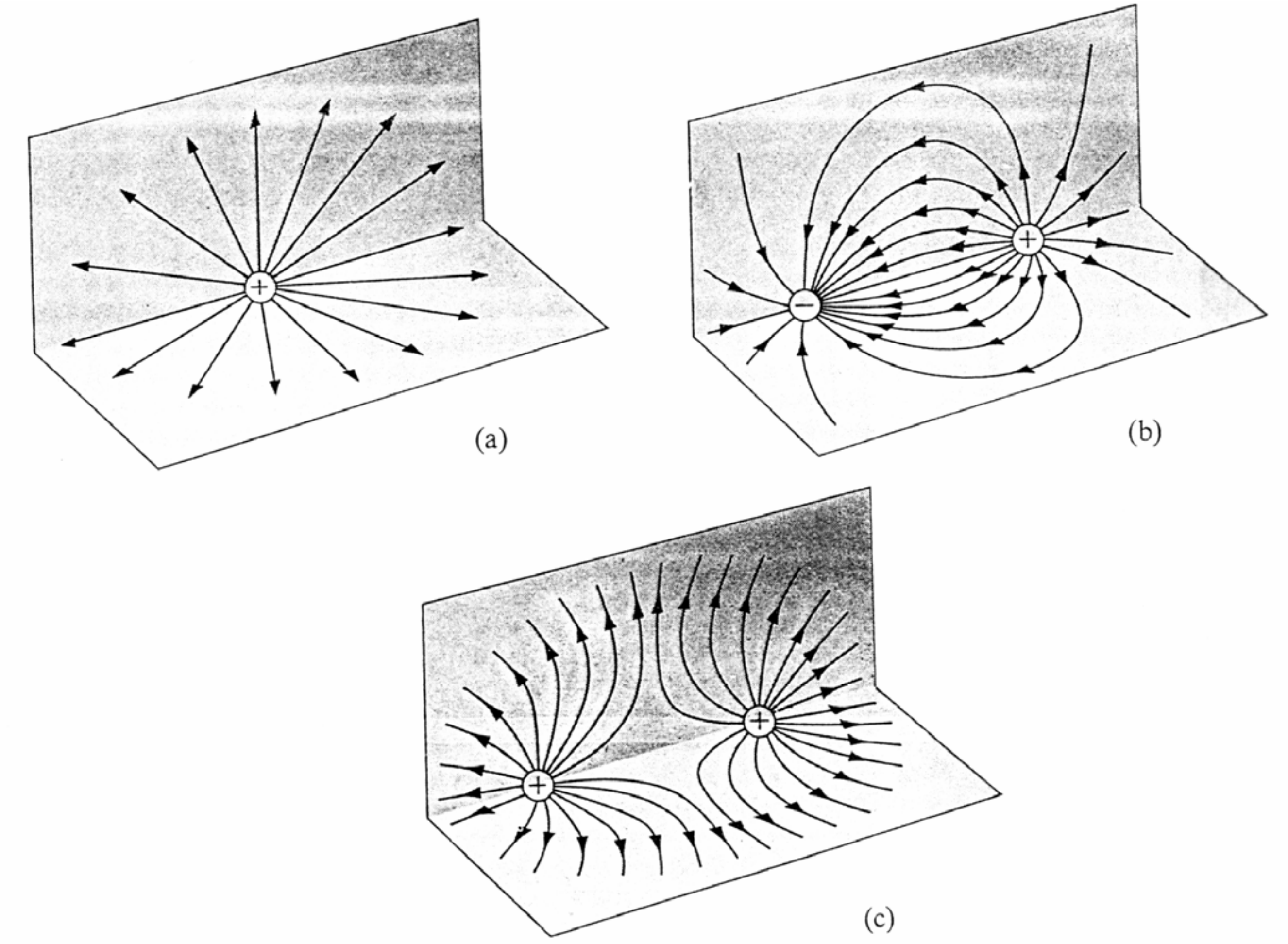


Fig. 25–8. The mapping of an electric field with the aid of lines of force.

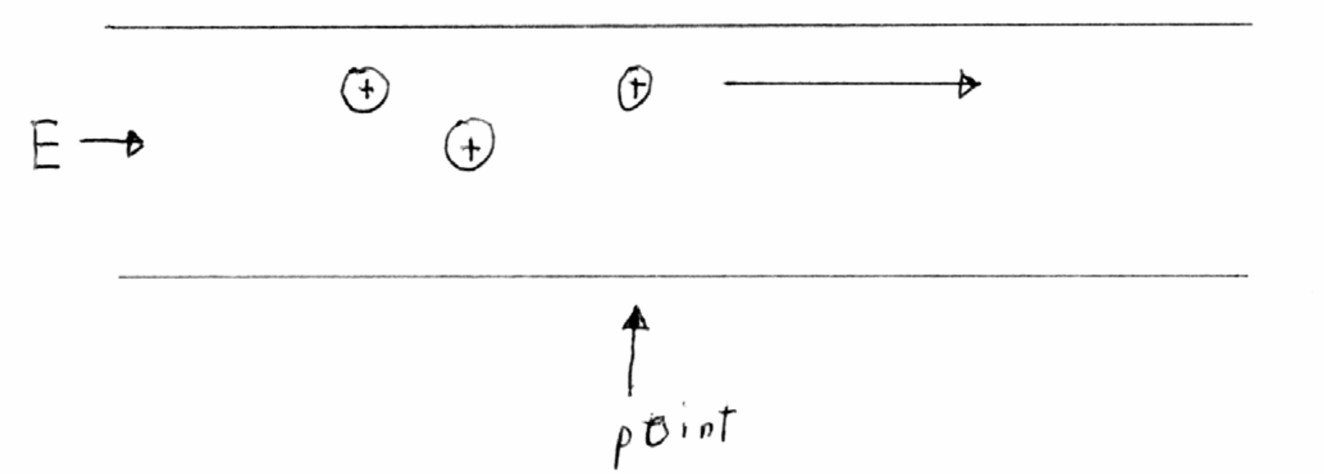
Charges and Current (EC 1)

- Electricity: the flow of charges within a confined volume
- Consider a wire with lots of free electrons
- An applied Electric field produces a flow of the electrons
- Electrons flow in the opposite direction of the E field
- Current (I): the rate of positive charge particle flow
- Units of Current: Amperes
- 1 Ampere = 1 Coulomb of charge passing a given point per second

$$I = \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

where

q = charge in coulombs
t = time in seconds



Current in a Wire

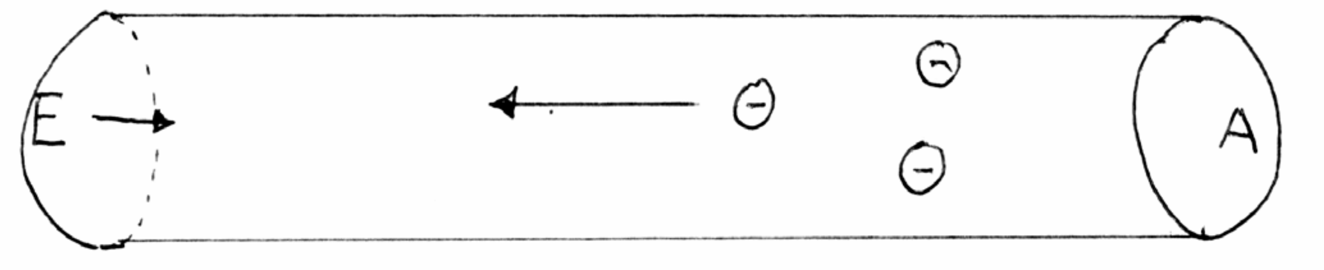
- Often current is calculated using the charge density
- Then the current is:

$$I = nqA\mu$$

Where

n = Charge density: charged particles per unit volume (cm^3)
μ: Velocity of the charges (cm/sec.)
A: Area of the wire (sq.cm)

- For copper n ~10^{22} cm^{-3}
  μ ~$9x10^{-4}$ cm/s
- Takes 18.5 minutes for electrons to cross 1 cm in copper!
- Electron velocity is slow but signal travels near speed of light
- Reason: all the electrons move at same time
- Since q = -e (negative charge)
- Hence current direction is **OPPOSITE** the flow of electrons



Positive & Negative Charge Currents

- Metals have only electron flow
- In Transistors/diodes (semiconductors) both positive and negative charges flow
- For both charge flow

$$I = \left(n_e e v_e + n_p e v_p\right)\mathrm{A}$$

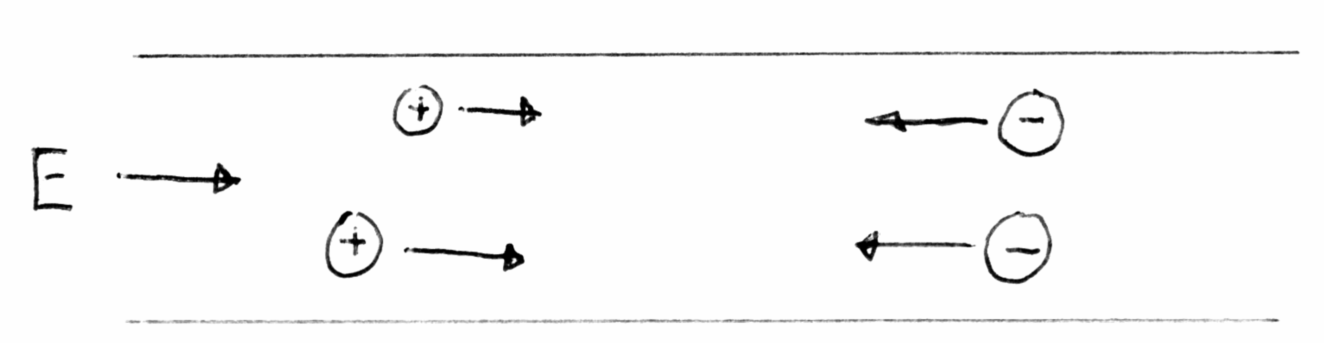
Where

n_e = electron density (cm^{-3})
n_p = positive charge density (cm^{-3})
v_e = electron velocity (cm/s)
v_p = positive charge velocity (cm/s)
A = area of conductor (cm^2)

- NOTE: negative electron charge is cancelled by negative direction of current.

- The differential form is:

$$\frac{dI}{dx} = e\left(\frac{dn_e}{dt} + \frac{dn_p}{dt}\right)A$$



Voltage

- Voltage: potential of an electric system to do work
- Voltage: is a "scalar" measured between two points
- Voltage: Work done moving a unit charge between 2 points

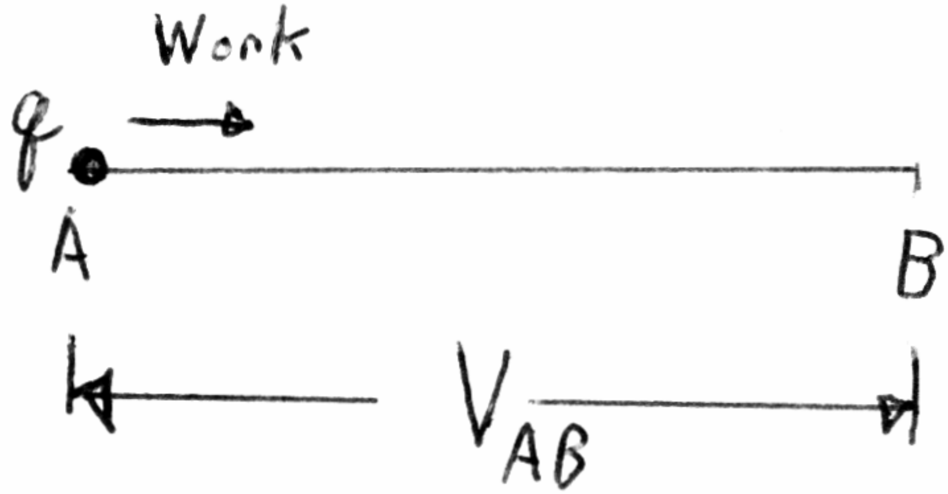
$$V_{AB} = \frac{Work\ moving\ e\ from\ A\ to\ B}{q} = \frac{dW}{dq}$$

where

W = Work moving q from A to B in Joules
q = charge in coulombs

- Work done on charge q accelerated through voltage V:

$$W = qV$$



Voltage and Electric Fields

- Electric fields are often given in Volts per metre (V/m)
- Derived from:

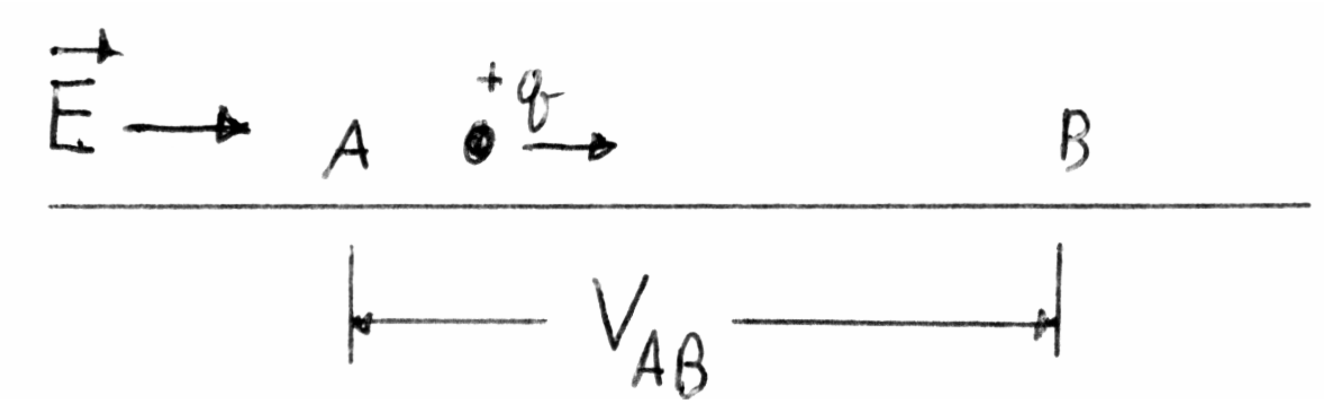
$$W = Fd = qEd = Vq$$

where

F = force in Newtons
d = distance in metres
E = Electric field (V/m)

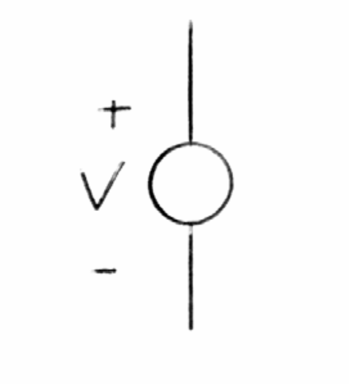
Thus:

$$\vec{E} = \frac{V}{\vec{d}}$$

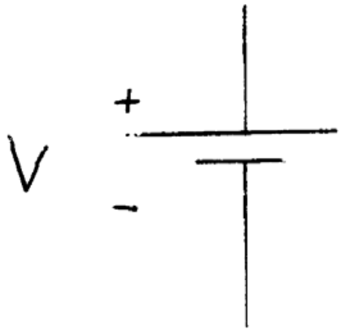


Voltage Sources

- Voltage source has a positive & negative terminal
- Creates Electric Field in material between terminals
- Ideal Voltage source creates a specific, pure voltage
- Ideal source creates that voltage at all times



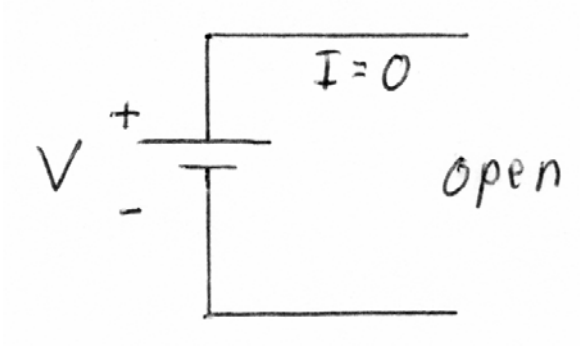
- Battery is a nearly a pure source (but not quite)
- Has finite internal resistance
- Hence batteries get hot when shorted



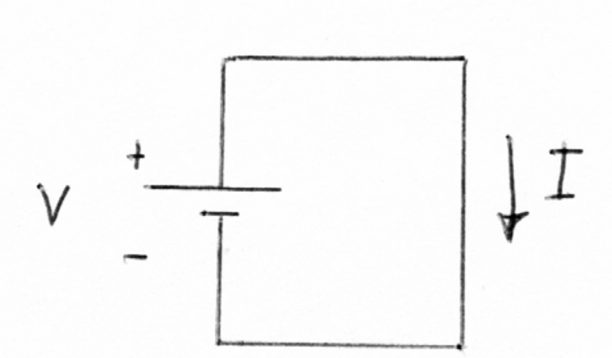
- Polarity: identification of which terminal is positive
- Long bar is positive terminal

Circuits & Current Directions

- Circuit: when the terminals of a voltage source are connected through some conducting element.
- Open circuit: when no current flows
  Infinite resistance path



- Short circuit: terminals directly connected to each other
- Perfect short circuit sets voltage to zero across it
  Zero resistance between paths
- Cannot have a perfect short on an ideal voltage source!



- Current $\vec{I}$ is a vector quantity: has magnitude & direction
- Current shown coming out of positive terminal
- Original error (from 1700's):
  assumed current flow was positive charges
- Thus actual electron (neg charge) flow is into positive terminals

Power

- Power loss: energy dissipated in a device per unit time

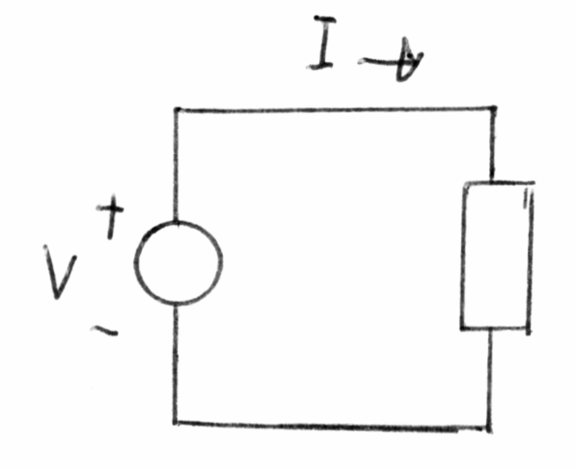
$$P = \frac{dW}{dt} = \frac{dW}{dq}\frac{dq}{dt} = VI$$

Since:

$$V = \frac{dW}{dq} \quad and \quad I = \frac{dq}{dt}$$

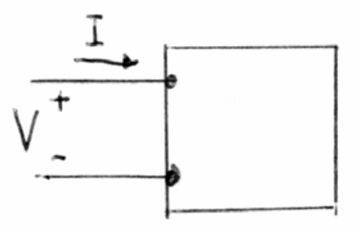
- Units of power = Watts (W) = Joules/sec
- Total work done is

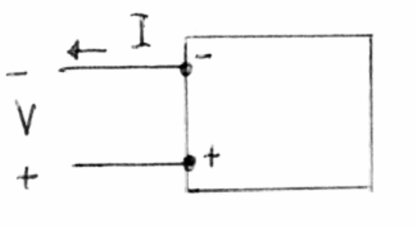
$$W = \int P(t)dt = \int V(t)\, I(t)dt$$



Basic Circuit Elements

- Basic Circuit Element: has two lines entering it
- Terminals: places were circuit current/voltage applied
- Simple elements 2 terminal devices
- Complicated elements have 3 or more terminals: eg. Transistor
- Devices may be either: a load element or source element



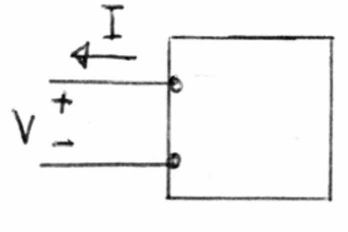


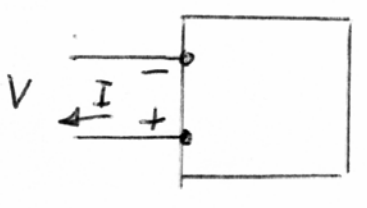
- **Load element**: consumes power
- When voltage applied, get current flow
- When current applied, get voltage across it
- Current flows into positive terminal or out negative

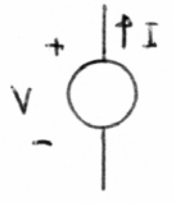
Active (source) element: Power source: supplies energy

$$P = -VI$$

- Power is negative: ie supplied
- Current flows out of the positive terminal
- or current flows into the negative terminal







Unit Prefixes

- Standard Systems International (SI) prefixes
- Note: while SI units are meters usually use cm in electronics

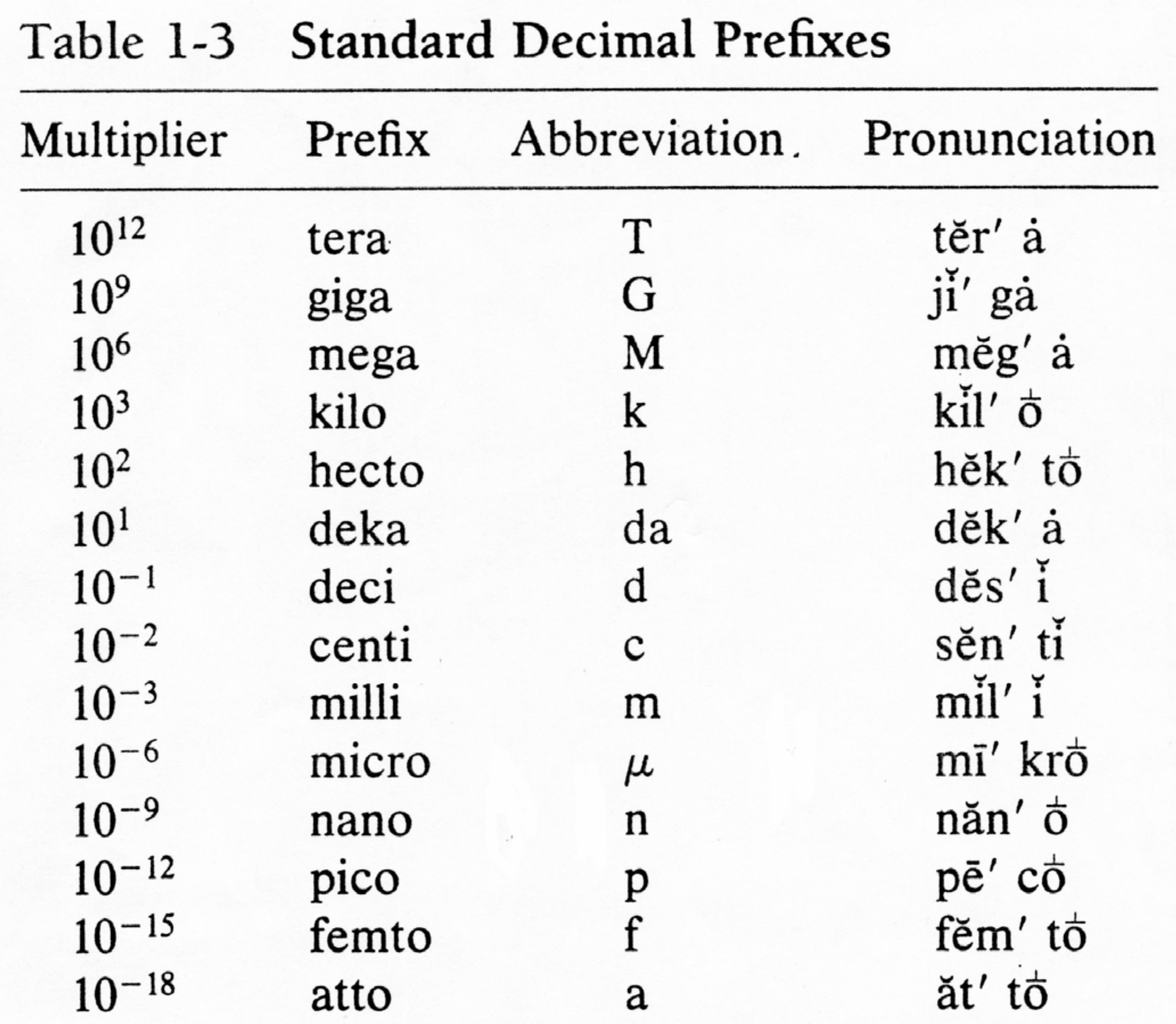


Table 1-3 Standard Decimal Prefixes

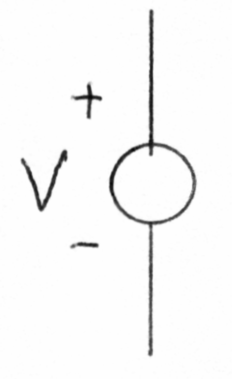
Multiplier	Prefix	Abbreviation	Pronunciation
10^{12}	tera	T	tĕr′ ȧ
10^{9}	giga	G	jĭ′ gȧ
10^{6}	mega	M	mĕg′ ȧ
10^{3}	kilo	k	kĭl′ ō
10^{2}	hecto	h	hĕk′ tō
10^{1}	deka	da	dĕk′ ȧ
10^{-1}	deci	d	dĕs′ ĭ
10^{-2}	centi	c	sĕn′ tĭ
10^{-3}	milli	m	mĭl′ ĭ
10^{-6}	micro	μ	mī′ krō
10^{-9}	nano	n	năn′ ō
10^{-12}	pico	p	pē′ cō
10^{-15}	femto	f	fĕm′ tō
10^{-18}	atto	a	ăt′ tō

Constant Voltage and Current Sources & Nodes (EC2)

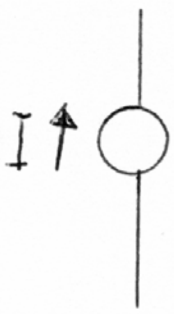
- There are two types of Ideal power source:
- Constant Current & Constant Voltage

- **Constant Voltage** always produces that voltage output

When off acts like a short circuit

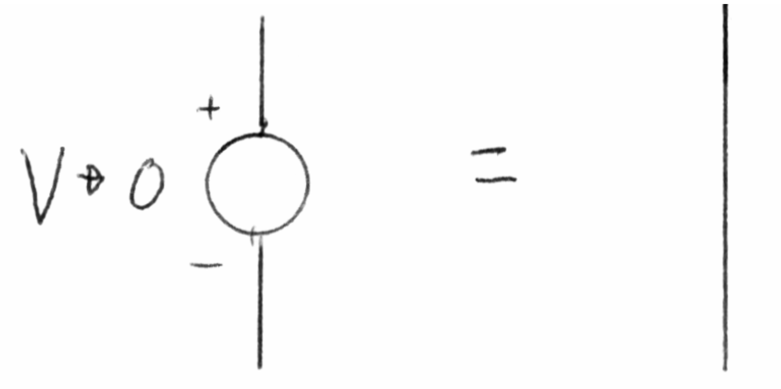


- **Constant Curre**nt always produces that current output
- When off acts like an open circuit $R \to \infty$

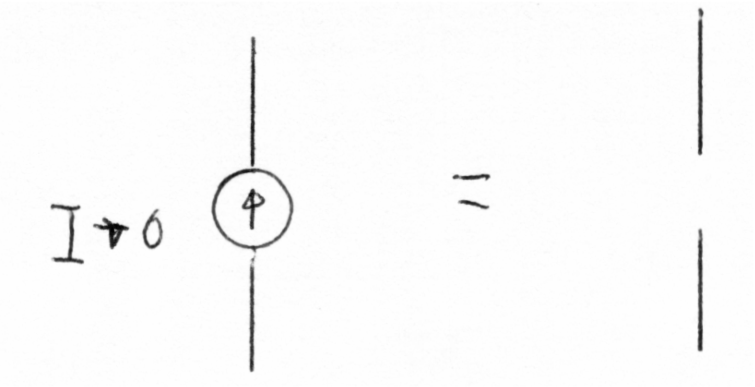


Turning off Current & Voltage Sources

- Voltage source is turned off when output is 0 V
- This means it acts like a perfect short circuit
- Hence turn off voltage source: replaced by a short



- Current source is turned off when output = 0 A
- This means it acts like a perfect open circuit
- Hence turn off current: replaced by an open



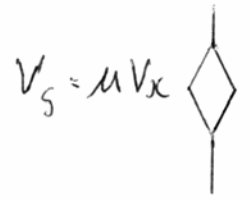
Ideal Dependent Current & Voltage Sources

- **Dependent Sources**:
  V or I is a function of values across others devices
- Dependent voltage source follows a relationship
- Voltage dependent voltage source

$$v_s = \mu v_x$$

where: μ = dimensionless multiplier

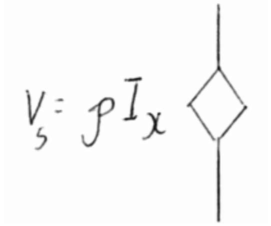
- MOS transistor behaves like this



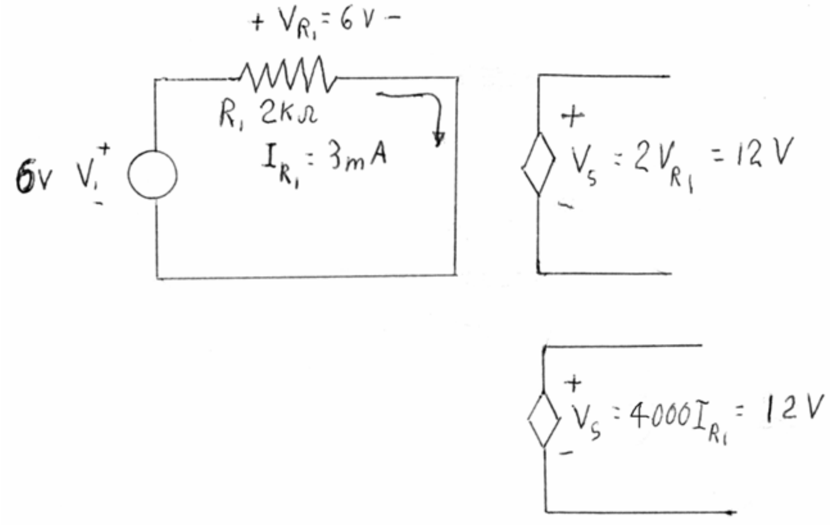
- Current dependent voltage source

$$v_s = \rho i_x$$

where: ρ = multiplier: units Volt/Amp



- Eg. Dependent voltage source with V = 2 times R_1 voltage

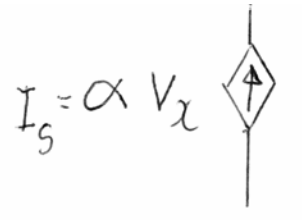


Ideal Dependent Current Sources

- Dependent current source follows the relationships
- Voltage dependent current source

$$i_s = \alpha v_x$$

where: α = multiplier: units Amp/Volt

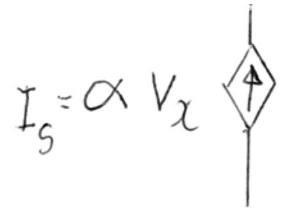


- Current dependent current source

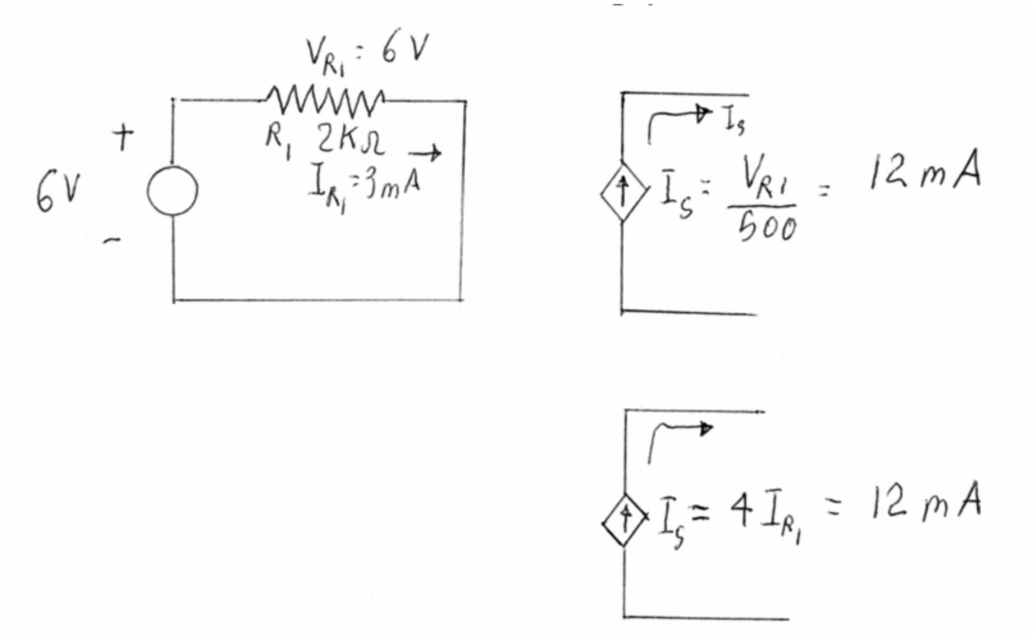
$$i_s = \beta i_x$$

where: β = dimensionless multiplier

- Bipolar transistor acts like this

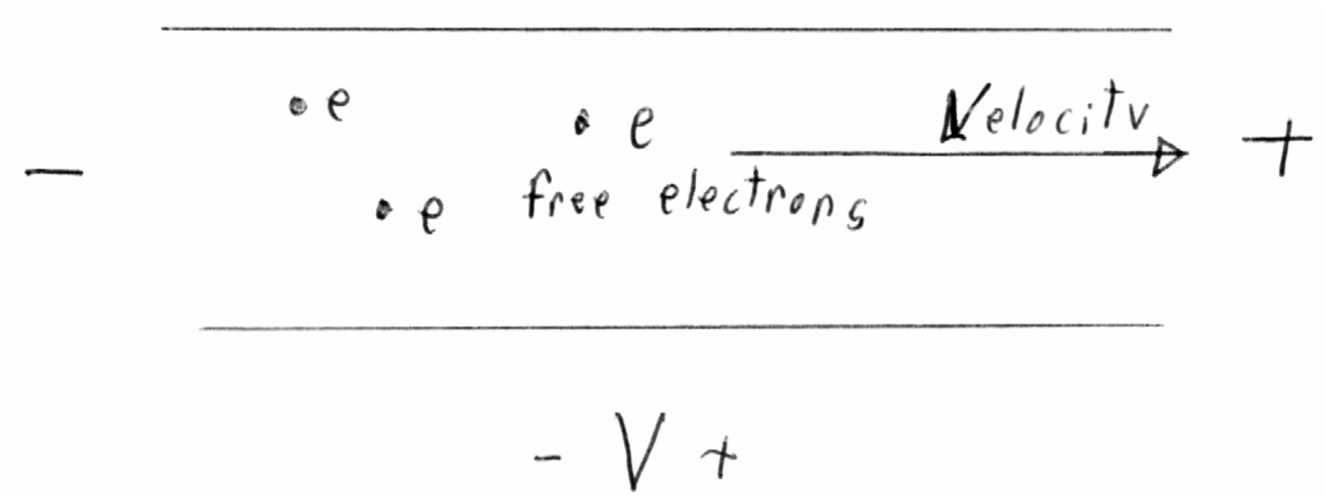


- Eg. Dependent current source with I = 4 times R_1 current



Conductors, Insulators & Resistors (EC 2)

- Conductor has surplus of free charges, usually electrons
- Current flows:
  when an Electric field applied across a conductors
- Insulators have few free charges
- Typically 10^{10}-10^{20} higher resistance than conductors
- Almost no current flows when voltage applied
- But hard to get no current at all



Insulators & Resistors

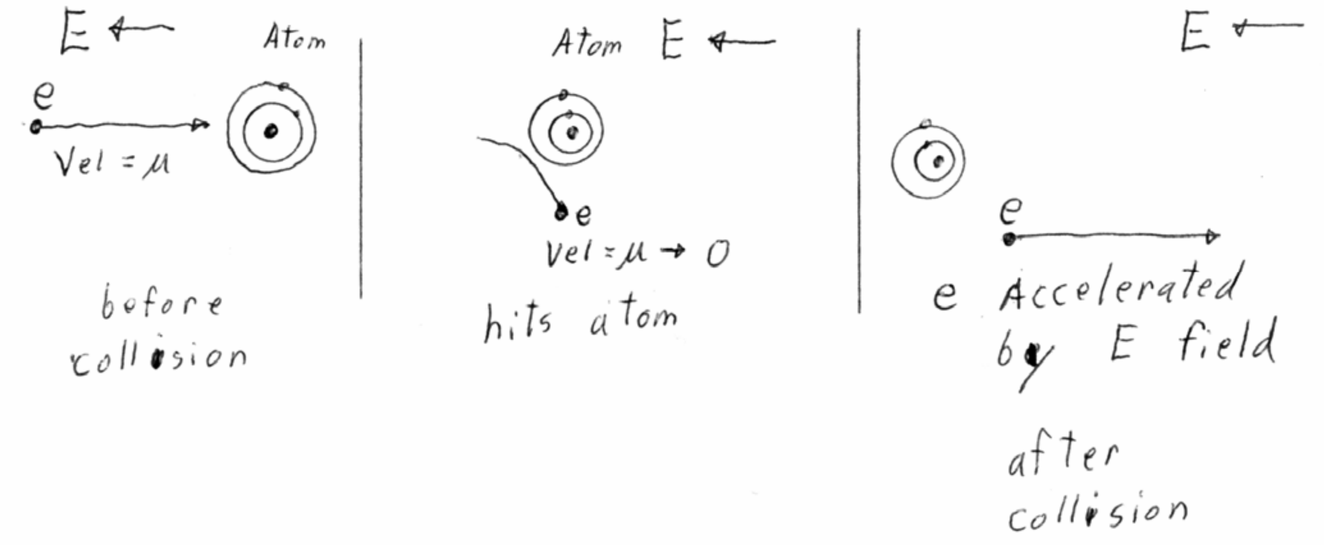
- Recall that the current is given by

$$I = nqA\mu$$

Where

n = number of charges
q = charge on the particle (electron)
A = area of the conductor
μ = velocity of the charges

- Materials vary widely in the number of free charges
- Free charges are those not tied to atoms
- Metals have many free electrons ~10^{22} cm^{-3}
- Velocity of the charges is limited by the atoms
- Electrons "hit" an atom and are slowed down.
- Then reaccelerated by the electric field
- Collision with the atom cause a loss of energy
- Appears as heating of conductor
- Loss of energy creates a Resistance to current flow



Resistors (EC2)

- Resistors: cause energy loss from resistance to current flow
- Resistors are made up of materials that are poor conductors

- **Ohm's law**

$$R = \frac{dV}{dI}$$

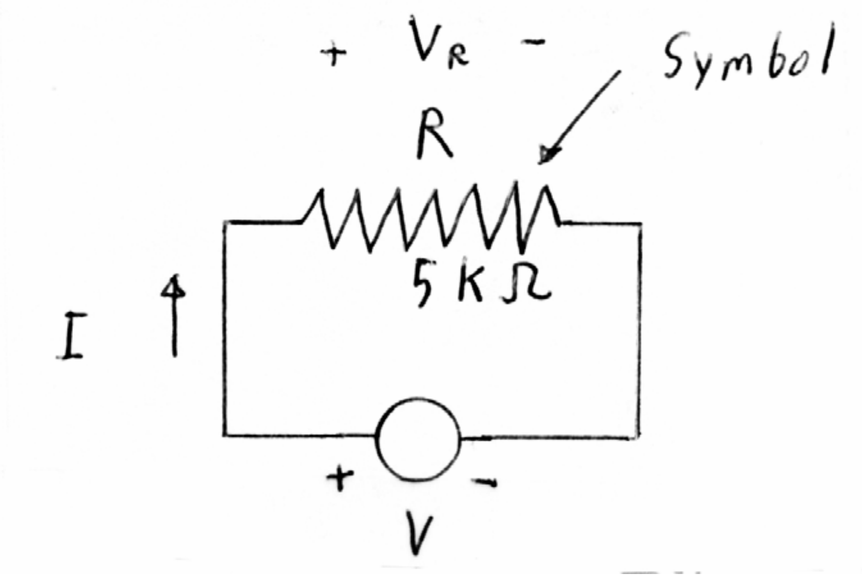
where:

R = resistance in ohms Ω
I = current in Amperes A
V = voltage in volts V

or for simple resistors:

$$V = IR \quad or \quad R = \frac{V}{I} \quad or \quad I = \frac{V}{R}$$

- Thus resistors give a voltage drop across the device from current



Power and Resistors

- Recall Power loss: energy dissipated in a device per unit time

$$P = \frac{dW}{dt} = \frac{dW}{dq}\frac{dq}{dt} = VI$$

- Recall Ohm's law

$$V = IR \quad or \quad R = \frac{V}{I} \quad or \quad I = \frac{V}{R}$$

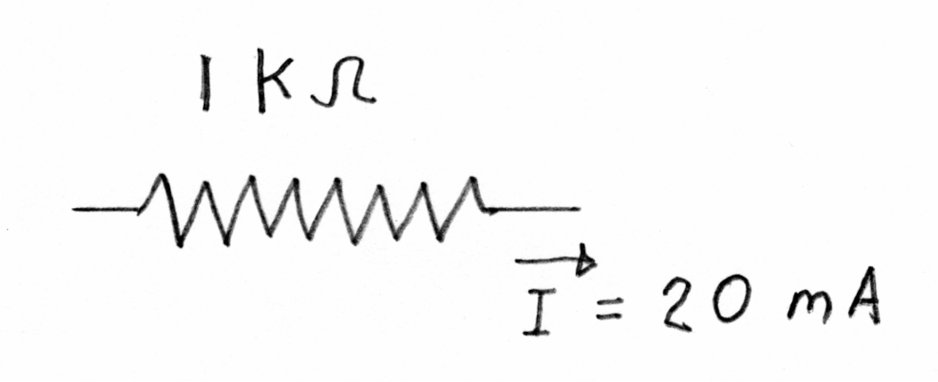
- Thus power in loss in resistors is

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

- NOTE: power alters as V, I or R changes instantaneously

- Example: a 1 Kohm resistor carries 20 mA of current.
  What is the power loss:

$$P = I^2 R = (0.02)^2 (1000) = 0.4W = 400mW$$



Resistors and Resistivity

- Basic unit for resistive materials is their resistivity
- Resistivity rho = ρ is related to resistance by

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

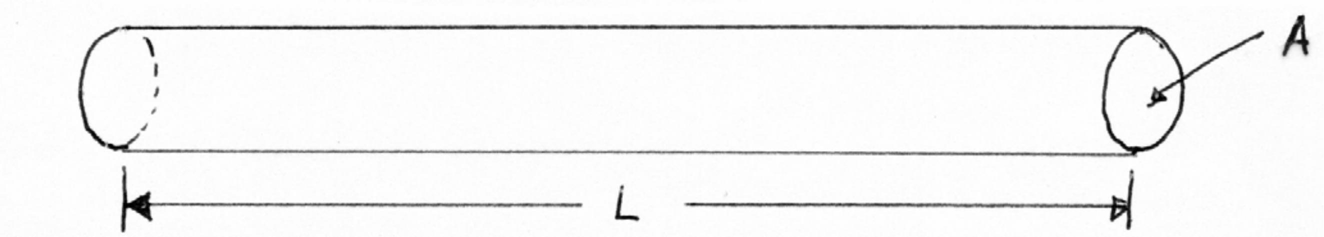
where

ρ = resistivity in ohm-cm = Ωcm
L = length of wire (cm)
A = cross-sectional area in cm^2

- Typical values for copper is 2 x 10^{-6} ohm-cm = 2 µΩcm
- Typical insulators 10^{7} to 10^{22} ohm-cm

- Example a copper wire is 40 cm long by 1 sq mm cross section: what is the resistance?

$$R = \frac{\rho L}{A} = \frac{2\times10^{-6}(40)}{\left(0.1\right)^2} = 0.008\Omega$$



Conductivity & Conductance

- For conductors often use the conductivity
- symbol sigma = σ

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

- Units are (ohm-cm)$^{-1}$

- Conductance (G) is the inverse of resistance

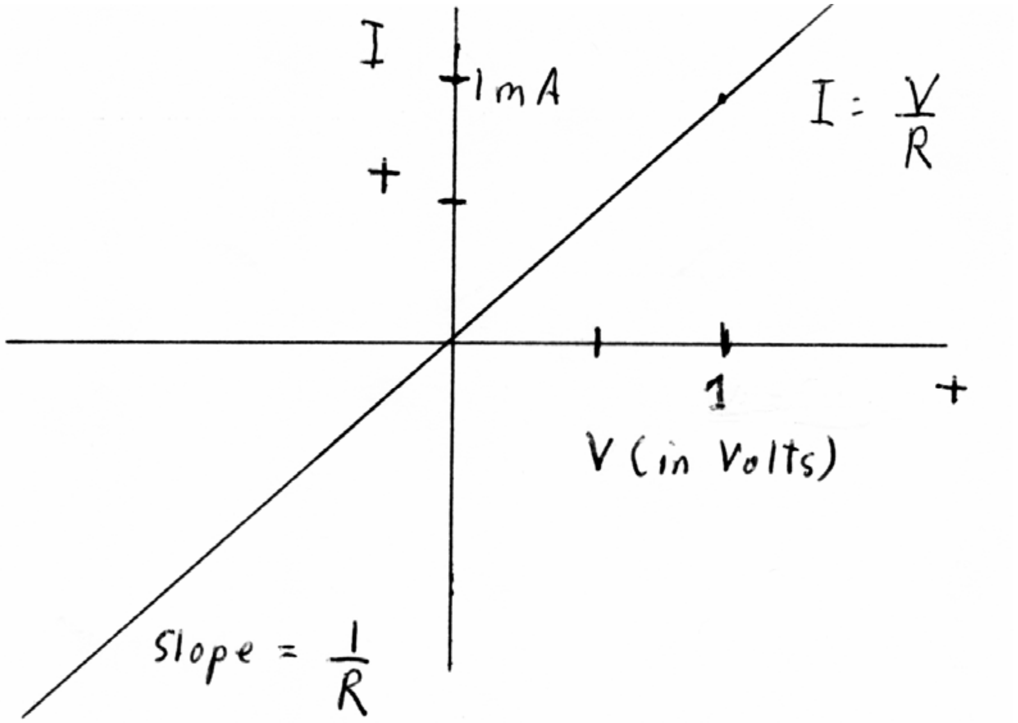
$$G = \frac{1}{R}$$

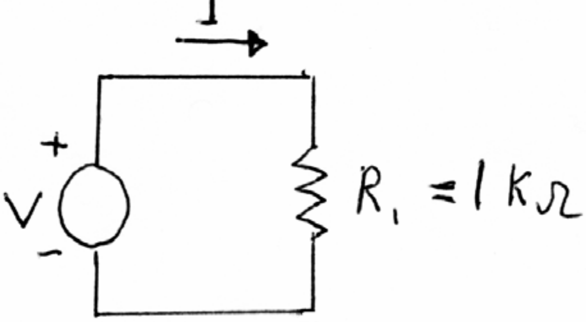
- units are mhos (ohms spelled backwards) or Siemens

I-V Characteristics of Resistors

- I-V curves characterize the operation of any electrical device.
- Also called V-I curves.
- Obtained by plotting current in device against the applied voltage between two terminals on the device

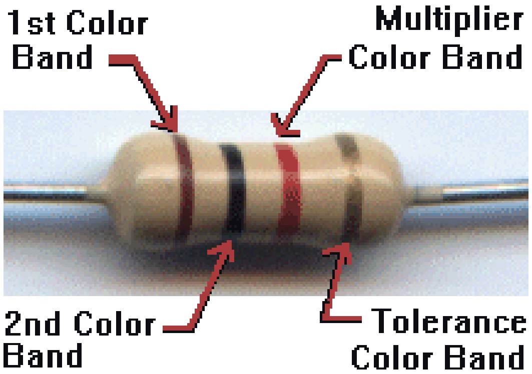
- In practice obtained using "curve tracers" or parametric analyzers

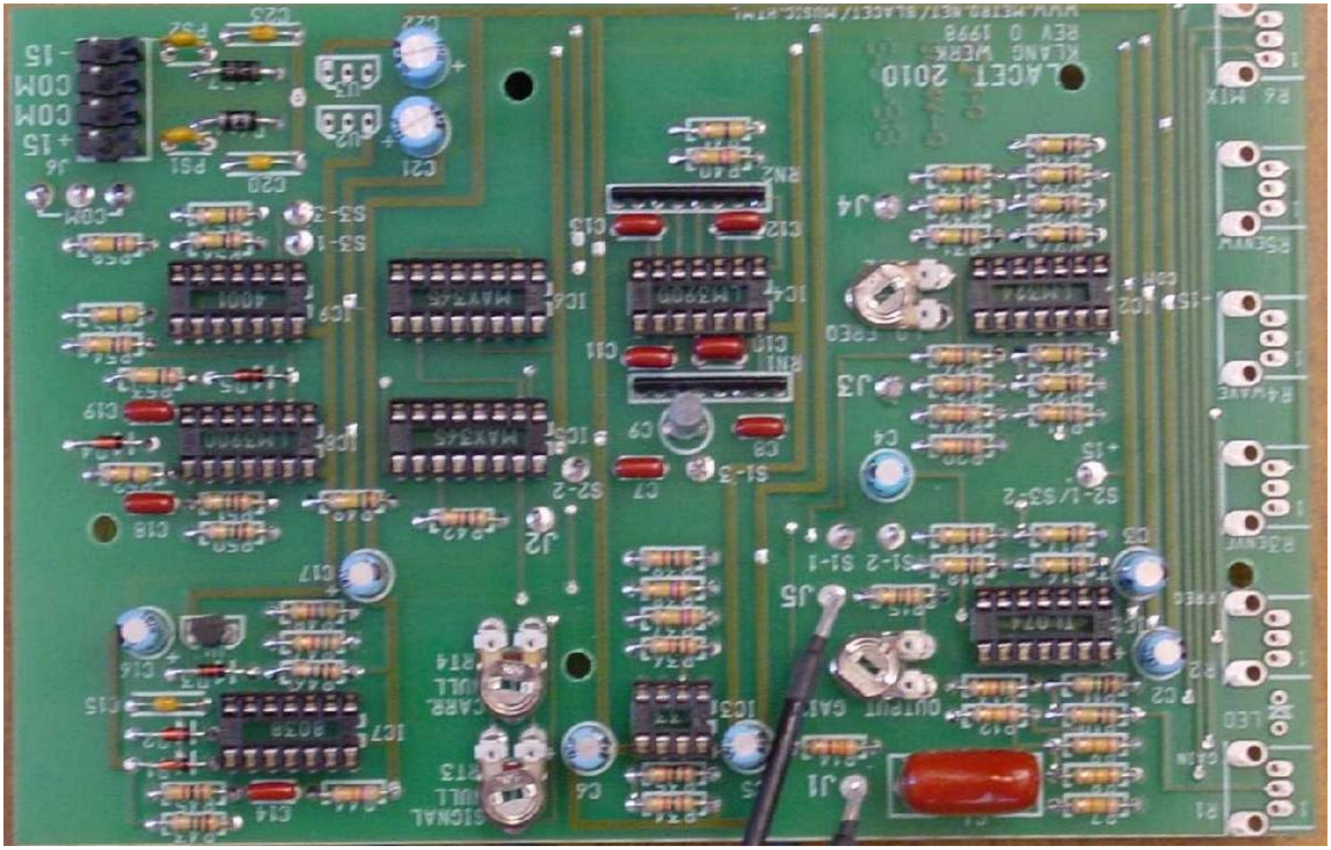




Practical Resistors

- Resistor is the most widely used component
- Cost >$0.01 to >$1
- Provides way to control V or I values
  Feedback values in op-amp
- Low power resistors use a carbon film, plastic case
- High power are wire resistors
- Note hard to make high value resistors in microchips
- Often use external resistors
- Resistors are used created desired voltages or remove power





Resistors and Power ratings

- Resistors are rated in terms of maximum power capability
- 1/4 W (most common), 1/2 W, 1 W, 2W, 5W are usual
- The larger surface area, the higher the power
- More surface area, faster heat loss
- Low power resistors have plastic surface
- High power resistors are ceramic
- Typically use a resistor rated for 2 times max power expected
- Thus less than 1/8 W power use 1/4 W resistors

- Example: a 1 Kohm resistor carries 20 mA of current.
- What is the size needed?

- As previously

$$P = I^2 R = 0.4W = 400mW$$

- Since max for 1/2 W resistor is 250 mW
- Thus want to use a 1 Watt resistor
- 1/2 W would work, but with very small safety range