## *Series Circuits*

In order for two components to be in series, there must be one and only one current path that includes both components.

Current must enter the first component, flow through both components, and then exit the last component without encountering any branches in the circuit.

(A branch is a point where the current can divide into two or more paths).

Figure 5 - 1 (a) shows two resistors in series. The current entering $R_1$ must pass through $R_2$ as it leaves the circuit. There are no other paths for the current to take.
A series circuit is constructed by combining various elements in series, as shown in Figure 5-1 (b)

Current will leave the positive terminal of the voltage source, move through the resistors, and return to the negative terminal of the source.

***Current is the same everywhere in series circuit*** since all the current leaving the source passes through each resistor and then returns to the source.

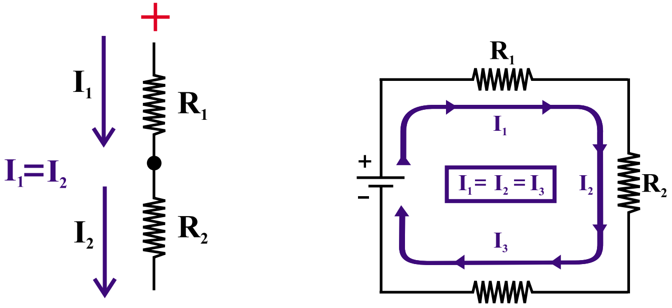


**Fig 5-1(a)** **Fig 5-1(b)**

**Current is the same everywhere in a series circuit.**

## *The Voltage Polarity Convention*

Look at Figure 5 - 3(a). The plus + and - symbols mean that you are looking at the voltage at the point marked + with respect to the point marked -.

The red (positive lead) of the meter is on point (a) and the negative (black) lead is on point (b). The meter is reading +6V. This means that you are looking at point (a) with respect to (b). Since point (A) is 6V positive with respect to point (b), the meter reads 6V.

Look at Fig. 5-3(b). The circuit is exactly the same. Now the meter leads are reversed. The negative (black) lead is on point (a) and the positive (red) lead is on point (b). Now we are looking at point (b) with respect to (a). The meter reads -6V telling us that point (b) is 6V more negative than point (a)

It is important to realize here, that the voltage across R has not changed. What has changed is how we are looking at it and how we have connected the meter to measure it. Since the actual voltage is the same in both cases.

Figure 5 -3 (a) and (b) are equivalent representations.

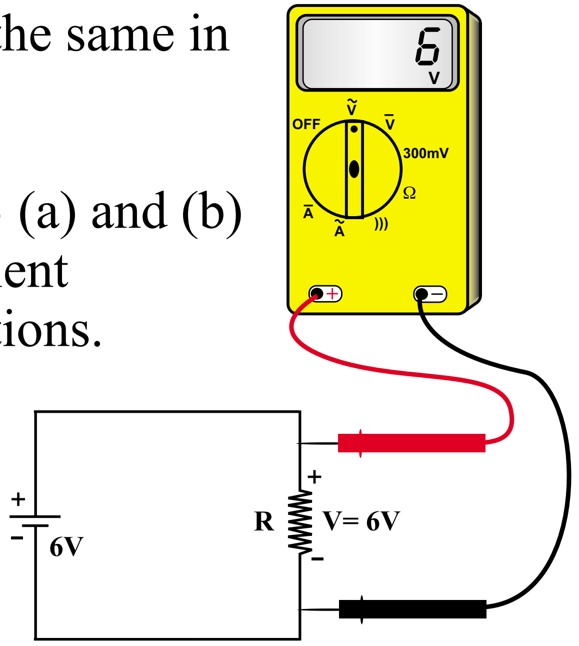


Fig 5-3(a)

Voltage at (a) with respect to (b) is 6V

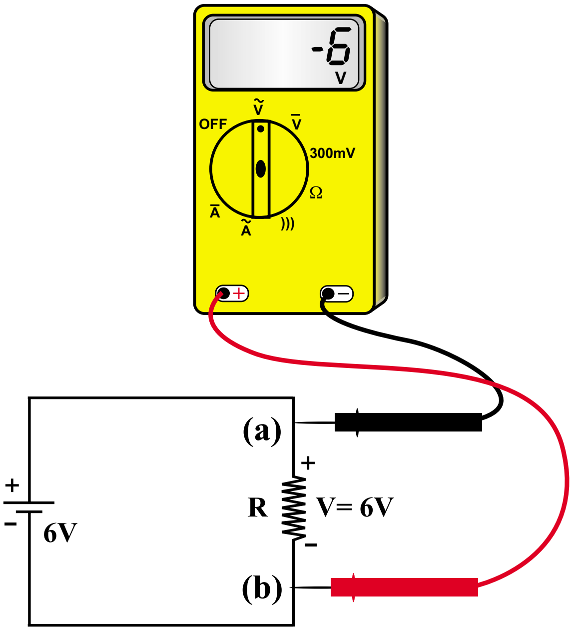


Fig 5-3(b)

Voltage at (b) with respect to (a) is -6V

Two representations of the same voltage

## Kirchhoff's Voltage Law

Kirchhoff's Voltage Law is as follows: ***the summation of voltage rises is equal to the summation of voltage drops around closed loop.***

$$\boxed{\sum E_{\text{rises}} = \sum V_{\text{drops}} \quad \text{for a closed loop}}$$

The following sequential procedure can be used to produce a closed loop equation to describe the circuit:

1. Label the polarity of all voltage sources and all voltage drops.

2. Start at any point in the circuit and write the voltages (including polarity) as you progress around the loop in either direction. Stop when you have completed the loop.

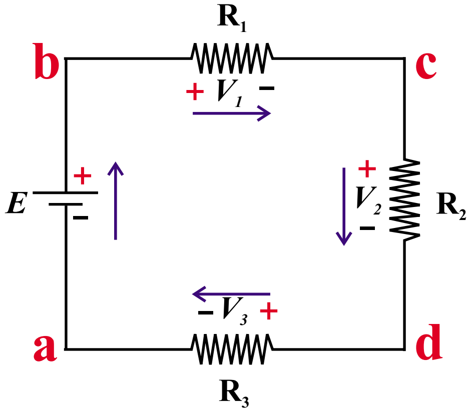


**Fig 5-4 Kirchhoff's Voltage Law**

Look at figure 5-4

1. Label the polarity of the voltage sources and voltage drops.
   - for a source, plus and minus are marked as shown
   - for all resistances, the plus sign is at the tail of the current arrow.

2. Start at point (a) in the circuit and write the voltages (including polarity) as you progress around the loop in either direction. Stop when you have completed the loop.

# Kirchhoff's Voltage Law

## Kirchhoff's Voltage Law     The Process

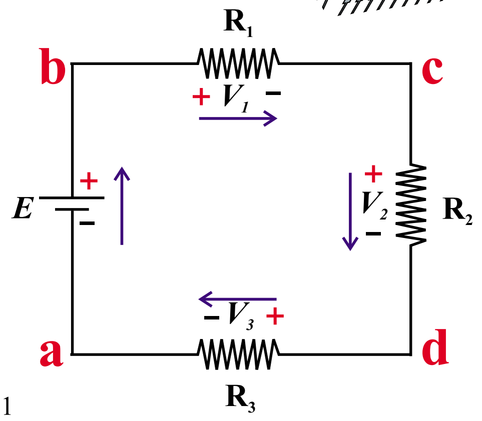


Fig 5-4 Kirchhoff's Voltage Law

***a to b*** we move through the voltage source, which represents a rise in potential.

***b to c*** we move through the resistor $R_1$ which represents the voltage drop $V_1$

***c to d*** we move through the resistor $R_2$ which represents the voltage drop $V_2$

***d to a*** we move through the resistor $R_3$ which represents the voltage drop $V_3$

**This gives us the equation**

$$E - V_1 - V_2 - V_3 = 0$$

**If we went around the circuit in the opposite direction the equation would be**

$$V_3 + V_2 + V_1 - E = 0$$

### Examples 5-1 & 5-2 page 132, 133

## Resistors in Series

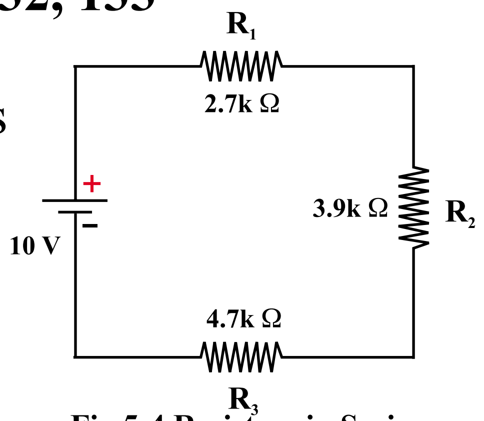


**Fig 5-4 Resistors in Series**
**Calculate the total resistance**

Each resistor in the series circuit contributes to the total resistance.

This gives us the formula:

$$R_T = R_1 + R_2 + R_3 \text{ ...... } R_N$$

For Figure 5-4 the total resistance is:

$$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 2.7\ \text{k}\Omega + 3.9\ \text{k}\Omega + 4.7\ \text{k}\Omega \\ &= 11.3\ \text{k}\Omega \end{aligned}$$

## *Power Dissipated by Each Resistor*

The power dissipated by each resistor in a series network is determined by the following formulas:

$$\boxed{\begin{array}{ll} P_1 = V_1 I = \dfrac{V^2}{R_1} = I^2 R_1 & [\text{watts,W}] \\ P_2 = V_2 I = \dfrac{V_2^{\;2}}{R_2} = I^2 R_2 & [\text{watts,W}] \\ P_n = V_n I = \dfrac{V_n^{\;2}}{R_n} = I^2 R_n & [\text{watts,W}] \end{array}}$$

The power delivered by a voltage source of the circuit is given as:

$$\boxed{P_T = EI \quad [\text{watts,W}]}$$

The power delivered by the voltage source, must be completely dissipated by all the resistors in the network.

Each resistor in a network dissipates some of the power. The total power used by the network is the addition of the power used by each resistor.

$$\boxed{P_T = P_1 + P_2 + \cdots\cdots + P_n \quad [\text{watts,W}]}$$

**Example 5-4 page 135-136**

## *Series Aided Voltage Sources*

Figure 5-5 shows two voltage sources that are connected in the same polarity.

They are said to be series-aiding, since both voltage sources cause current flow in the same direction.

The effective voltage in the circuit is the sum of the series aiding voltages.

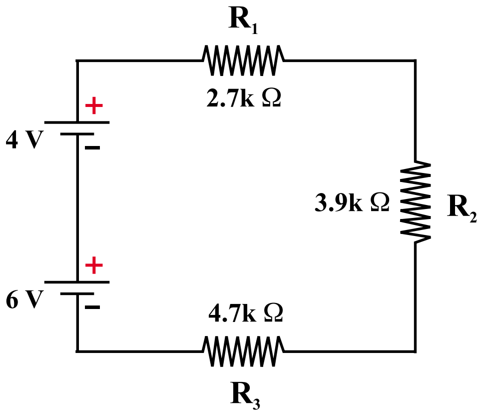


**Fig 5-5 Series Aided Voltage Sources**

## *Series Opposing Voltage Sources*

Figure 5-6 shows two voltage sources that are connected in the opposite polarity.

They are said to be series-opposing, since both voltage sources try to cause current flow in opposite directions.

The effective voltage in the circuit is the difference between the two individual sources.

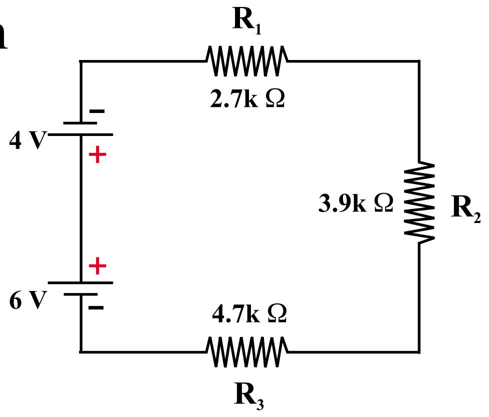


**Fig 5-6 Series Opposed Voltage Sources**

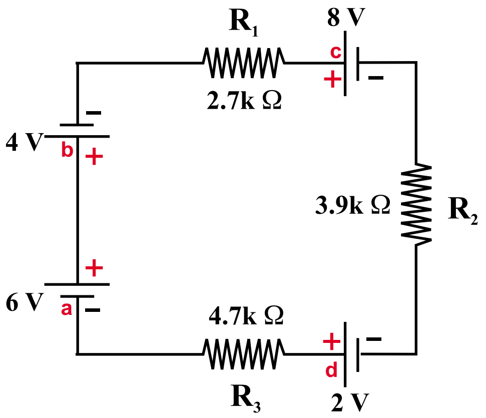


**Fig 5-7 Multiple Voltage Sources**

## *Voltage Sources In Series*

Figure 5-7 shows the same circuit with 4 voltage sources.

In order to determine which way current flowing in this circuit, do the following:

## *Voltage Sources In Series*

1) Add the voltages of the sources that would push current in one direction.(counter-clockwise)
   ***Sources (b) + (c)= 12 V***

2) Add the voltages of the sources that would push current in the opposite direction.(clockwise)
   ***Sources (a) + (d)= 8 V***

3) Find the difference between the two directions.
   ***12V - 8V = 4V***

***Therefore, conventional current is flowing in the first direction (counter-clockwise) and the magnitude of the pressure is 4V.***

An equivalent circuit is shown in Figure 5-8

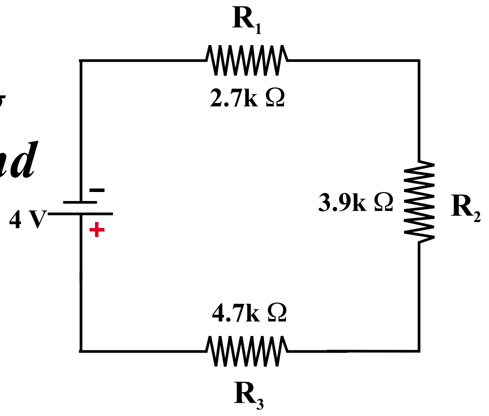


**Fig 5-8 Equivalent Circuit for Figure 5-6**

## *Interchanging Series Components*

The order of serious components may be changed without affecting the operation of the circuit. The two circuits below are equivalent.

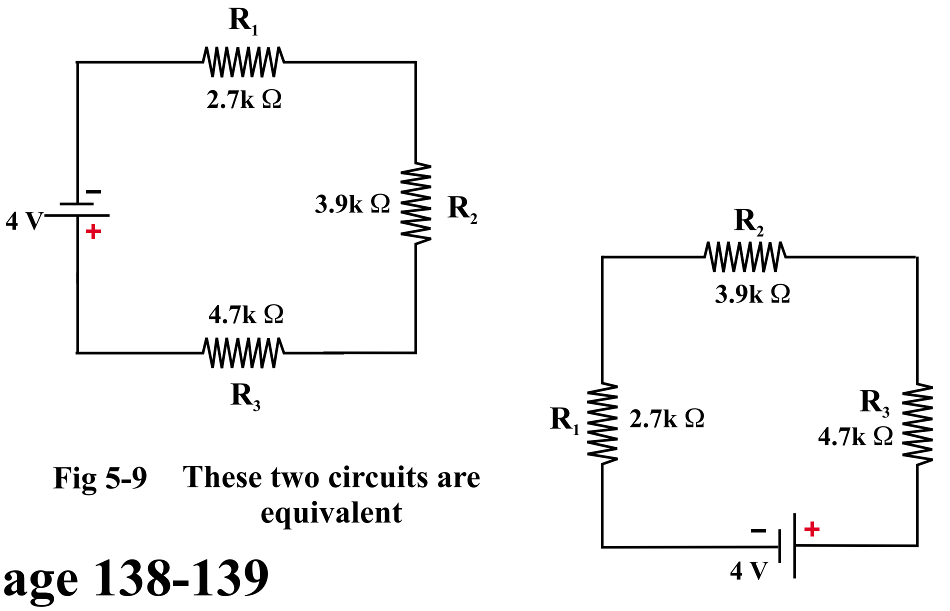


**Fig 5-9 These two circuits are equivalent**

**Example 5-5 page 138-139**

## *The Voltage Divider Rule*

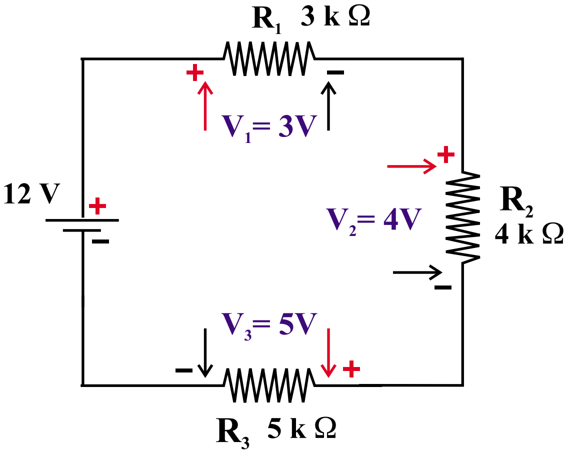


**Fig 5-10 The Voltage Divider Rule**

In Figure 5 -10 we can easily find the voltage drop across each resistor in the circuit.

1) Find the total current

$$I = \frac{E}{R_T} = \frac{12\text{V}}{12\ \text{k}\Omega} = 1\ \text{mA}$$

2) Find the IR drop across each resistor

$$V_1 = IR_1\ (1\text{mA})(3\ \text{k}\Omega) = 3\text{V}$$
$$V_2 = IR_2\ (1\text{mA})(4\ \text{k}\Omega) = 4\text{V}$$
$$V_3 = IR_3\ (1\text{mA})(5\ \text{k}\Omega) = 5\text{V}$$

We can also see that Kirchhoff's Law is satisfied also since the sum of the voltage drops (3V+4V+5V=12V) equals the supply voltage of 12V.

You can also see that there is a direct relationship between the value of the resistor and the voltage that appears across it.

We can use this relationship to come up with the voltage divider rule.

In general, for any number of resistors, the voltage drop across any resistor may be found as:

$$\boxed{V_X = \frac{R_X}{R_T} E}$$

**Example 5-6, 5-7 page 140 - 141**

## Circuit Ground ⏚

In most electronic circuits, there is a point from which all circuit voltages are measured. This common point is called the ***circuit ground***.

Most often, but certainly not always, ground is considered to be one side of the circuit's power source. Ground is considered to be 0 V.

Figure 5-11(a) shows a series circuit where the negative side of the voltage source is considered to be the circuit ground. Note the symbol used to represent ground. ⏚

Figure 5-11(b) shows exactly the same circuit. Two ground symbols are used. Both ground symbols represent the same electrical point in the circuit.

The interconnecting wire is assumed but not shown. The omission of the interconnecting ground wires on circuit diagrams is a normal practice since it removes unnecessary clutter from otherwise complex diagrams.

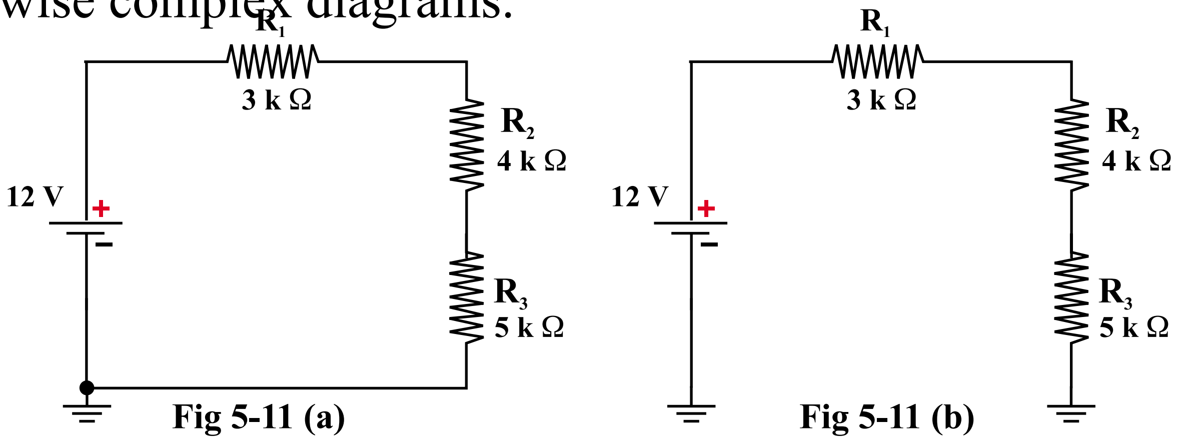


**Fig 5-11 (a)** **Fig 5-11 (b)**

**Ground is a reference point from which other voltages are measured.**

# Circuit Ground

## Chassis Ground ⏚

Very often, the metal chassis of an appliance is connected to the circuit ground. Such a connection is referred to as a ***chassis ground.***

The symbol for chassis ground is ⏚

## Earth Ground ⏚

In order to help prevent electrocution, the chassis ground is usually further connected to the ***earth ground*** through a connection provided at the electrical outlet box.

In the event of a failure within the circuit, the chassis would redirect current to ground (tripping a circuit breaker or fuse), rather than presenting a hazard to an unsuspecting operator.

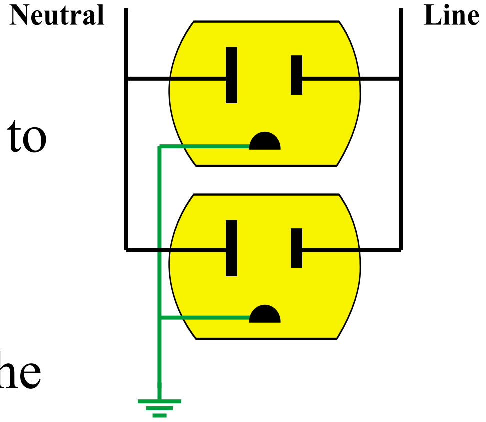


**Figure 5- 12 Ground connection in a typical 120 Vac outlet**

Earth ground is a connection which is bonded to the earth, either through water pipes or by connection to ground rods.

Figure 5-12 shows a standard wall receptacle. The rounded terminal is always the ground terminal. It is not only by the ac circuits but may also be used to provide a common point for dc circuits.
When a circuit is bonded to the earth through the ground terminal, then the ground symbol no longer represents an arbitrary connection, but rather represents a very specific type of connection.

## Voltage Subscripts

We already know that voltages are expressed as the potential difference between two points.

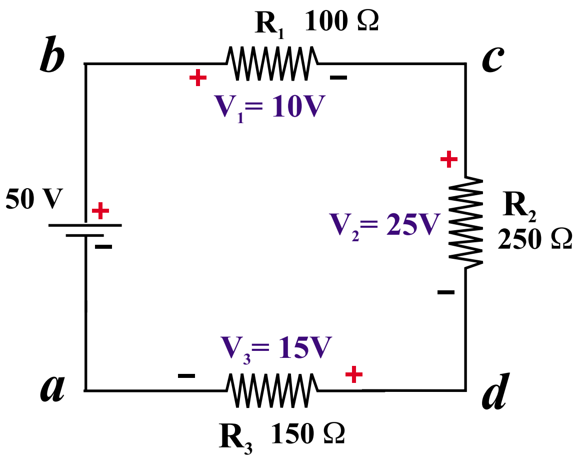
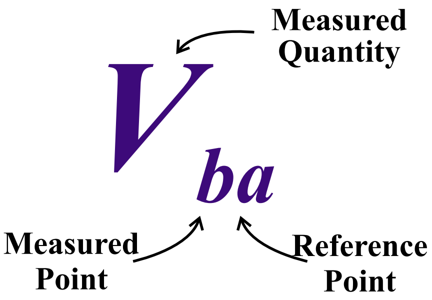


Fig 5-13

## Double Subscripts

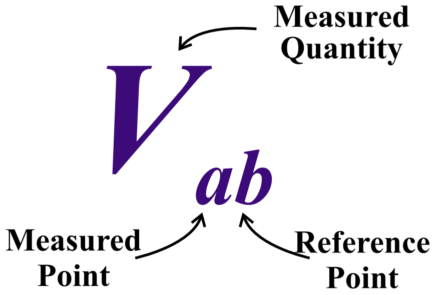
With double subscripts, we can examine the voltage between two points. In Figure 5-13,we have labeled the points ***a,b,c,d.***

If we wanted to measure the supply voltage with a voltmeter, we would place the leads across the supply with the red lead to ***point b*** and a black lead to ***point a.*** The voltmeter would read +50 volts. This voltage can be written as $V_{ba}$



$V_{ba}$ - what this means is that the voltage at ***point b*** is 50 volts more positive than at ***point a***. We examined the voltage at ***point b*** with respect to ***point a.***

If we turned the leads of the voltmeter around; the red lead on ***point a.*** and the black lead on ***point b.*** The meter would read -50 V. This voltage can be written as $V_{ab}$



$V_{ab}$ - what this means is that the voltage at ***point a*** is 50 volts more negative than at ***point b***. We examined the voltage at ***point a*** with respect to ***point b.***

# Voltage Subscripts

Looking at Figure 5-13 further,
we will find: $V_{bc} = +10\text{ V}$  $V_{cb} = -10\text{ V}$

$V_{cd} = +25\text{ V}$  $V_{dc} = -25\text{ V}$

$V_{da} = +15\text{ V}$  $V_{ad} = -15\text{V}$

$V_{bd} = V_{bc} + V_{cd} = +35\text{ V}$

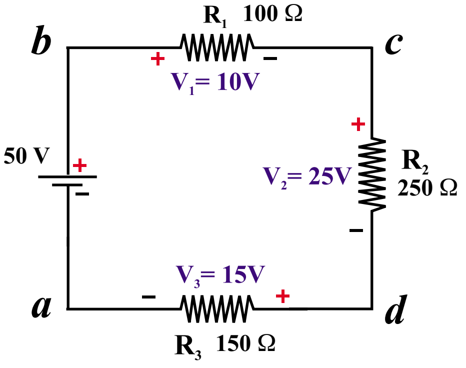


Fig 5-13

**Example 5-8 and Practical Note Page 144 - 146**

## *Single Subscripts*

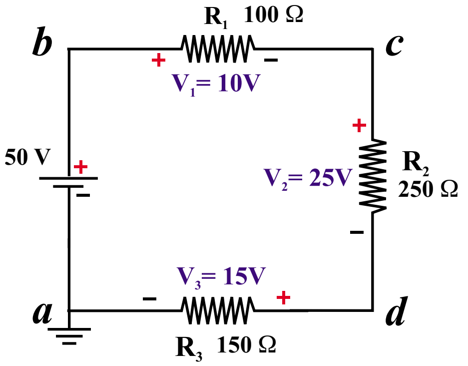


Fig 5-14 Point (*a*) is now grounded at 0 volts

In a circuit which has a ground, most voltages will be expressed with respect to ground.
Single subscript voltages are always referenced to ground. In Figure 5-14, we have added a ground.

$V_b$ is the voltage from ***point b***. to ground and is + 50 volts.
$V_d$ is the voltage from ***point d***. to ground and is + 15 volts.
$V_c$ is the voltage from ***point c***. to ground and is + 35 volts.

Ground is considered to be at 0 volts. In this circuit, all other points are at a positive voltage above ground as shown above.

**Example 5-9, 5-10 Page 147**

## *Point Sources*

When a voltage source is given with respect to ground, it may be simplified in the circuit as a ***point source.***

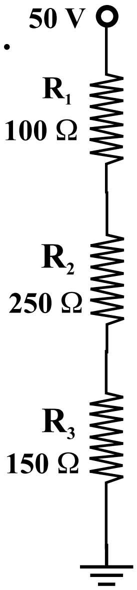
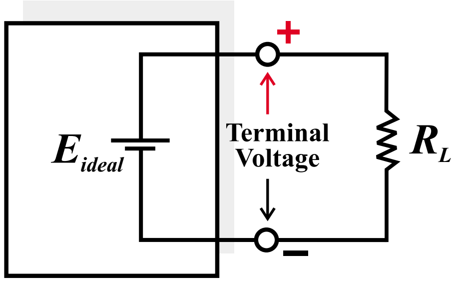


Fig. 5-15 is really 5-14 simplified using a point source. Keep in mind that point sources always represent ***voltages with respect to ground*** even if the ground is not shown.

**Example 5-11 Page 148**

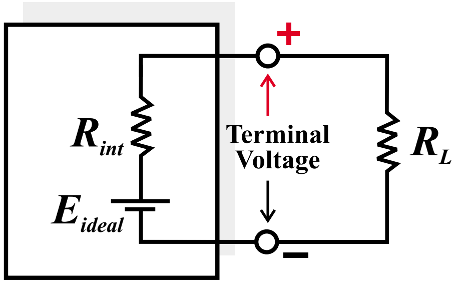
**Fig 5-15** **Simplified equivalent circuit for Fig 5-14**

## Internal Resistance



5-16 (a) Ideal Voltage Source

So far we have worked only with ideal voltage sources, which maintain constant voltages regardless of the loads connected across the terminals. Fig 5-16 (a)



5-16 (b) Actual Voltage Source

In actuality, all batteries have an internal resistance that is in series with the voltage source. This internal resistance is actually inside the battery. Fig. 5-16 (b).

The voltage which appears between the positive and negative terminals is called the ***terminal voltage***. In an ideal voltage source, the terminal voltage will remain constant regardless of the load connected. An ideal voltage source will be able to provide as much current as the circuit demands.

A standard car battery normally has a very low internal resistance If you turn the headlights on and then try to start the car, you'll notice the headlights dim as the engine turns over. The car engine's starter is drawing a very heavy current and the terminal voltage of the battery drops. This voltage drop at the terminals of the battery is caused by the batteries own internal resistance.

We said above, that a car battery has a very low internal resistance. Because of this, we can draw a very large current with only a small drop in terminal voltage

If we connected eight C cells together in series, the terminal voltage would be 12 V.

# Voltage Sources - Internal Resistance

If we were to replace our car battery with series connected C cells, and then tried to start the car, the terminal voltage on the C cells would dropped to near 0.

This is because the C cells have a much higher internal resistance than the automobile battery. As soon as we attempt to draw a heavy current in order to start the car, the IR drop across the internal resistance will be very high. This causes the battery terminal voltage to drop to close to 0.

**Example 5-12 page 149**