

PHYS 1444 – Section 002

Lecture #15

Wednesday, Apr. 1, 2020

Dr. Jaehoon Yu

CH 26

- EMF and Terminal Voltage
- Resistors in Series and Parallel
- Kirchhoff's rules
- RC Circuit



Announcements

- Reading Assignments: CH25.9 and 25.10
- 2nd Non-comprehensive term exam in class Wednesday, Apr. 15
 - Covers CH25.1 through what we finish Monday, Apr. 13
 - Do NOT miss the exam!
- Quiz #4
 - Beginning of the class coming Monday, Apr. 6, from 1:07pm
 - Covers CH25.1 through what we finish today or CH26.4
 - Online quiz based on Quest but must join zoom class 12:55pm!
 - You can use your calculator but DO NOT input formula into it!
 - Cell phones or any types of computers cannot replace a calculator!
 - Turn off your phones!!
 - BYOF: You may prepare a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants
 - No derivations, word definitions or solutions of any problems!
 - Let's be fair to other students and not cheat!



Reminder: Special Project #4

- Make a list of the power consumption and the resistance of all electric and electronic devices at your home and compile them in a table. (10 points total for the first 10 items and 0.5 points each additional item.)
- Estimate the cost of electricity for each of the items on the table using your own electric cost per kWh (if you don't find your own, use \$0.12/kWh) and put them in the relevant column. (5 points total for the first 10 items and 0.2 points each additional items)
- Estimate the the total amount of energy in Joules and the total electricity cost per day, per month and per year for your home. (8 points)
- Due: Beginning of the class Monday, Apr. 13
 - Scan all pages of your special project into the pdf format
 - Save all pages into one file with the filename SP5-YourLastName-YourFirstName.pdf
 - Send me the file no later than 1pm Monday, Apr. 13
- Spreadsheet has been posted on the class web page. Download ASAP.



Item Name	Rated power (W)	Number of devices	Number of Hours per day	Daily Power Consumption (kWh)	Energy Cost per kWh (cents)	Daily Energy Consumption (J).	Daily Energy Cost (\$)	Monthly Energy Consumption (J)	Monthly Energy Cost (\$)	Yearly Energy Consumption (J)	Yearly Energy Cost (\$)
Light Bulbs	30	4									
	40	6									
	60	15									
Heaters	1000	2									
	1500	1									
	2000	1									
Fans											
Air Conditioners											
Fridgers, Freezers											
Computers (desktop, laptop, ipad)											
Game consoles											
Wednesday, Apr. 1, 2020				PHYS 1444-002, Spring 2020						4	
				Dr. Jaehoon Yu							
Total				0		0	0	0	0	0	0

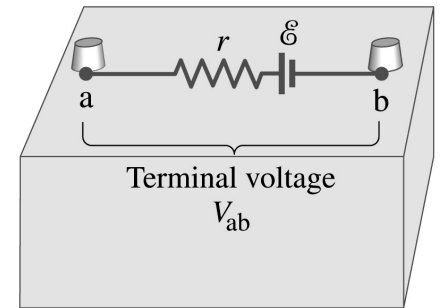
EMF and Terminal Voltage

- What do we need to have a current in an electric circuit?
 - A device that provides a potential difference, such as a battery or a generator
 - They normally convert some types of energy into the electric energy
 - These devices are called source of electromotive force (emf)
 - This is does NOT refer to a real “force”.
- Potential difference between terminals of an emf source, when no current flows to an external circuit, is called the emf (\mathcal{E}) of the source.
- The battery itself, however, has some **internal resistance** (r) due to the flow of charges in the electrolyte
 - Why does the headlight dim when you start the car?
 - The starter needs a large amount of current but the battery cannot provide charge fast enough to supply current to both the starter and the headlight



EMF and Terminal Voltage

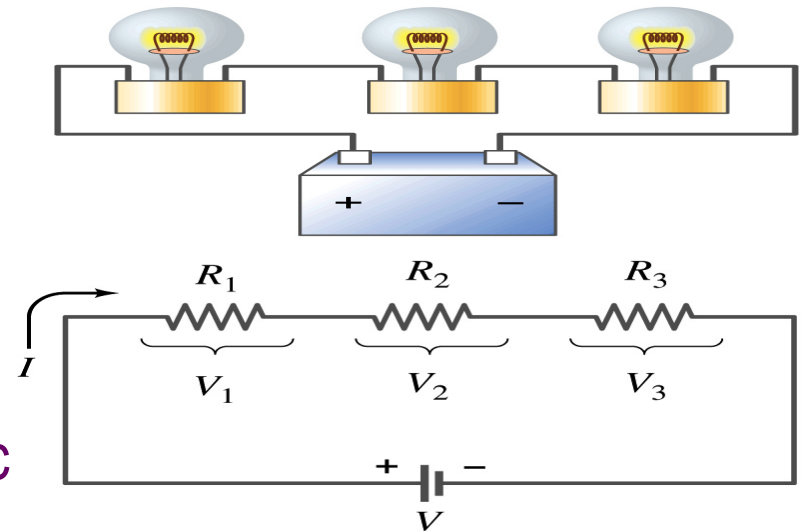
- Since the internal resistance is inside the battery, we can never separate them out.
- So the terminal voltage difference is $V_{ab} = V_a - V_b$.
- When no current is drawn from the battery, the terminal voltage equals the emf which is determined by the chemical reaction; $V_{ab} = \mathcal{E}$.
- However when the current I flows naturally from the battery, there is an internal drop in voltage which is equal to \underline{Ir} . Thus the actual **delivered** terminal voltage to the circuit is $V_{ab} = \mathcal{E} - Ir$



Resistors in Series

- Resistors are in series when two or more resistors are connected end to end

- These resistors represent simple resistors in circuit or electrical devices, such as light bulbs, heaters, dryers, etc



- What is common for the devices in a series circuit?
 - Current is the same through all the elements in series
- Potential difference (drop) across every element in the circuit is
 - $V_1=IR_1$, $V_2=IR_2$ and $V_3=IR_3$
- Since the total potential difference is V , we obtain
 - $V=IR_{eq}=V_1+V_2+V_3=I(R_1+R_2+R_3)$
 - Thus, $R_{eq}=R_1+R_2+R_3$

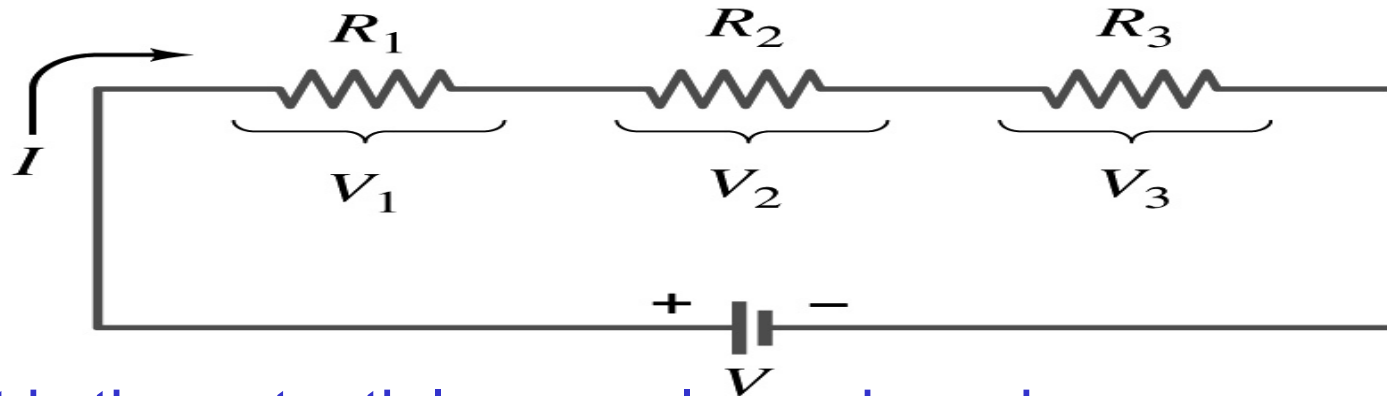
$$R_{eq} = \sum_i R_i$$

Resistors
in series

When resistors are connected in series, the total resistance increases, and the current decreases.

Energy Losses in Resistors

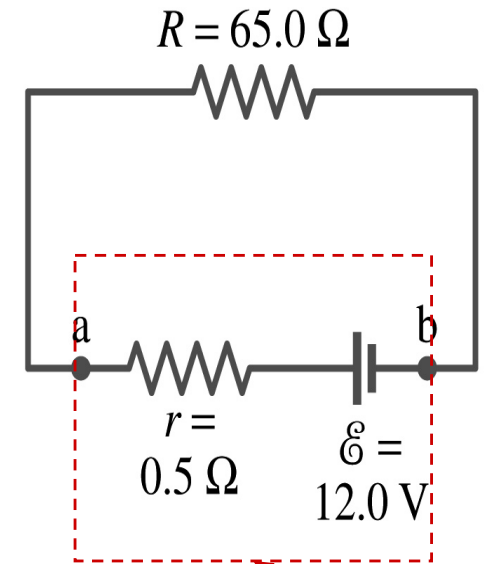
- Why is it true that $V=V_1+V_2+V_3$?



- What is the potential energy loss when charge q passes through resistors R_1 , R_2 and R_3
 - $\Delta U_1=qV_1$, $\Delta U_2=qV_2$, $\Delta U_3=qV_3$
- Since the total energy loss should be the same as the total energy provided to the system (energy conservation), we obtain
 - $\Delta U=qV=\Delta U_1+\Delta U_2+\Delta U_3=q(V_1+V_2+V_3)$
 - Thus, $V=V_1+V_2+V_3$

Example 26 – 1

Battery with internal resistance. A $65.0\text{-}\Omega$ resistor is connected to the terminals of a battery whose emf is 12.0V and internal resistance is $0.5\text{-}\Omega$. Calculate (a) the current in the circuit, (b) the terminal voltage of the battery, V_{ab} , and (c) the power dissipated in the resistor R and in the battery's internal resistor.



(a) Since $V_{ab} = \varepsilon - Ir$ We obtain $V_{ab} = IR = \varepsilon - Ir$

Solve for I
$$I = \frac{\varepsilon}{R + r} = \frac{12.0\text{V}}{65.0\Omega + 0.5\Omega} = 0.183\text{A}$$

What is this?

A battery or a source of emf.

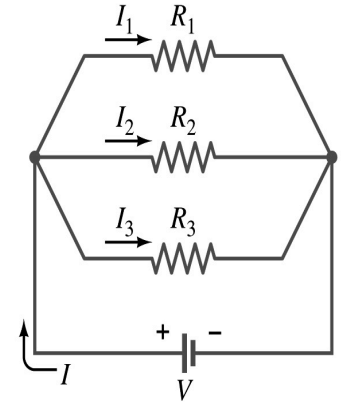
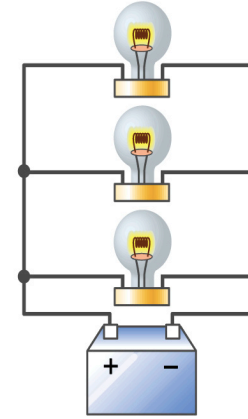
(b) The terminal voltage V_{ab} is $V_{ab} = \varepsilon - Ir = 12.0\text{V} - 0.183\text{A} \cdot 0.5\Omega = 11.9\text{V}$

(c) The power dissipated in R and r are $P = I^2 R = (0.183\text{A})^2 \cdot 65.0\Omega = 2.18\text{W}$

$$P = I^2 r = (0.183\text{A})^2 \cdot 0.5\Omega = 0.02\text{W}$$

Resistors in Parallel

- Resistors are in parallel when two or more resistors are connected in separate branches
 - Most the house and building wirings are arranged this way.
- What is common for the devices in a parallel circuit?
 - The voltage is the same across all the resistors in the same circuit
 - The total current that leaves the battery is, however, split.
- The current that passes through every element is
 - $I_1 = V/R_1$, $I_2 = V/R_2$, $I_3 = V/R_3$
- Since the total current is I , we obtain
 - $I = V/R_{eq} = I_1 + I_2 + I_3 = V(1/R_1 + 1/R_2 + 1/R_3)$
 - Thus, $1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$



$$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$

**Resistors
in parallel**

When resistors are connected in parallel, the total resistance decreases, and the current increases.

Resister and Capacitor Arrangements

- Parallel Capacitor arrangements

$$C_{eq} = \sum_i C_i$$

- Parallel Resistor arrangements

$$\frac{1}{R_{eq}} = \sum_i \frac{1}{R_i}$$

- Series Capacitor arrangements

$$\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i}$$

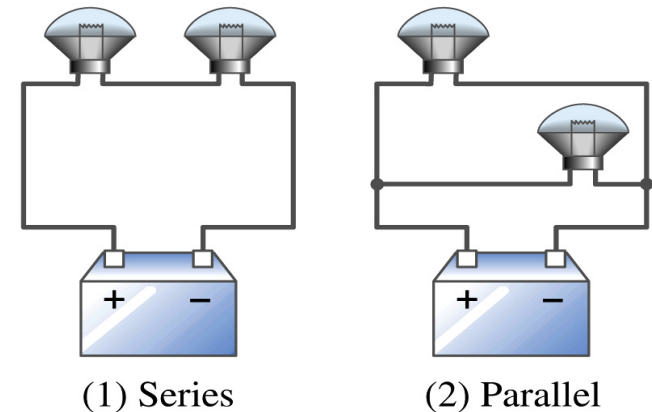
- Series Resistor arrangements

$$R_{eq} = \sum_i R_i$$



Example 26 – 2

Series or parallel? (a) The light bulbs in the figure are identical and have identical resistance R . Which configuration produces more light? (b) Which way do you think the headlights of a car are wired?



(a) What are the equivalent resistances for the two cases?

Series $\Rightarrow R_{eq} = 2R$ **Parallel** $\Rightarrow \frac{1}{R_{eq}} = \frac{2}{R}$ **So** $\Rightarrow R_{eq} = \frac{R}{2}$

The bulbs get brighter when the total power transformed is larger.

series $P_S = IV = \frac{V^2}{R_{eq}} = \frac{V^2}{2R}$ parallel $P_P = IV = \frac{V^2}{R_{eq}} = \frac{2V^2}{R} = 4P_S$

So parallel circuit provides brighter lighting.

(b) Car's headlights are in parallel to provide brighter lighting and also to prevent both lights going out at the same time when one burns out.

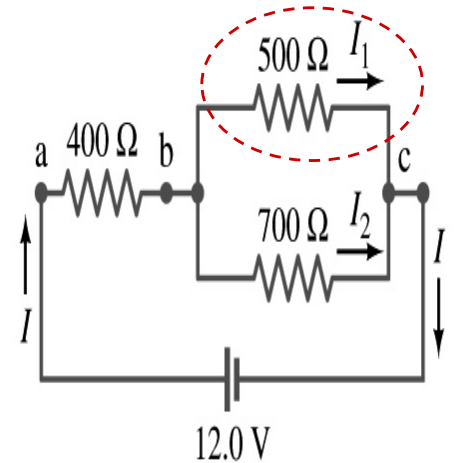
So what is bad about parallel circuits? Uses more energy in a given time.

Example 26 – 5

Current in one branch. What is the current flowing through the 500- Ω resistor in the figure?

What do we need to find first? We need to find the total current.

To do that we need to compute the equivalent resistance.



R_{eq} of the small parallel branch is: $\frac{1}{R_P} = \frac{1}{500} + \frac{1}{700} = \frac{12}{3500}$ $R_P = \frac{3500}{12}$

R_{eq} of the circuit is: $R_{eq} = 400 + \frac{3500}{12} = 400 + 292 = 692\Omega$

Thus the total current in the circuit is $I = \frac{V}{R_{eq}} = \frac{12}{692} = 17mA$

The voltage drop across the parallel branch is $V_{bc} = IR_P = 17 \times 10^{-3} \cdot 292 = 4.96V$

The current flowing across 500- Ω resistor is therefore

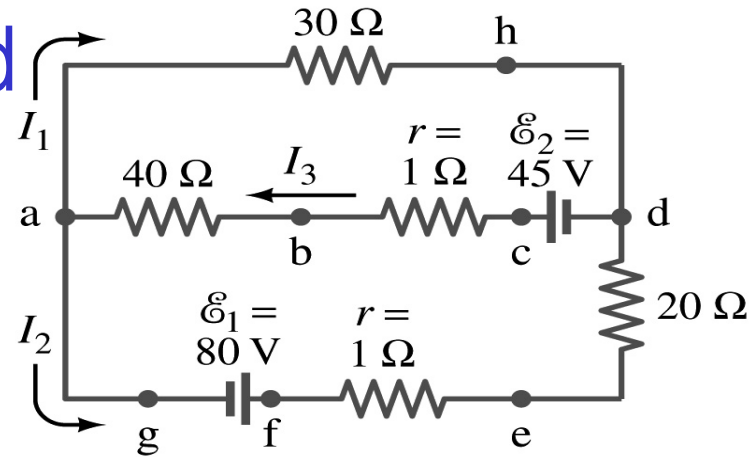
$$V_{bc} I_{500} = \frac{V_{bc}}{R} = \frac{4.96}{500} = 9.92 \times 10^{-3} = 9.92mA$$

What is the current flowing 700- Ω resistor?

$$I_{700} = I - I_{500} = 17 - 9.92 = 7.08mA$$

Kirchhoff's Rules – 1st Rule

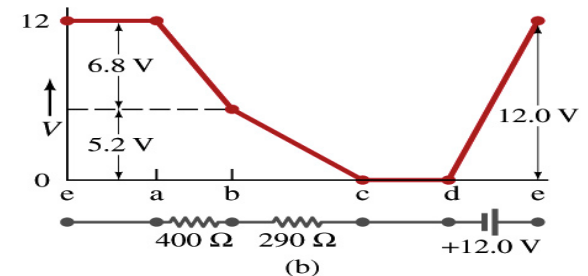
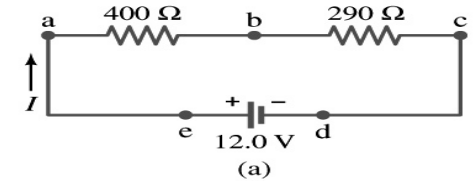
- Some circuits are very complicated to do the analysis using simple combinations of resistors
 - G. R. Kirchhoff devised two rules to deal with complicated circuits.
- Kirchhoff's rules are based on conservation of charge and conservation of energy
 - Kirchhoff's 1st rule: The junction rule, charge conservation.
 - At any junction point, the sum of all currents entering the junction must be equal to the sum of all currents leaving the junction.
 - In other words, what goes in must come out.
 - At junction a in the figure, I_3 comes into the junction while I_1 and I_2 leaves: $I_3 = I_1 + I_2$



Kirchhoff's Rules – 2nd Rule

- Kirchoff's 2nd rule: The loop rule, uses conservation of energy.

- The sum of the changes in potential in any closed path of a circuit must be zero.



- The current in the circuit in the figure is $I=12/690=0.017A$.
 - Point e is the high potential point while point d is the lowest potential.
 - When the test charge starts at e and returns to e , the total potential change is 0.
 - Between point e and a , no potential change since there is no source of potential nor any resistance.
 - Between a and b , there is a 400Ω resistance, causing $IR=0.017*400=6.8V$ drop.
 - Between b and c , there is a 290Ω resistance, causing $IR=0.017*290=5.2V$ drop.
 - Since these are voltage drops, we use negative sign for these, $-6.8V$ and $-5.2V$.
 - No change between c and d while from d to e there is $+12V$ change.
 - Thus the total change of the voltage through the loop is: $-6.8V-5.2V+12V=0V$.

Kirchhoff's Rules Summary

- Kirchhoff's 1st rule: The junction rule uses **charge conservation**
 - At any junction point, the sum of all currents entering the junction must be equal to the sum of all currents leaving the junction.
- Kirchhoff's 2nd rule: The loop rule uses **conservation of energy**.
 - The sum of the changes in potential in any closed path of a circuit must be zero.



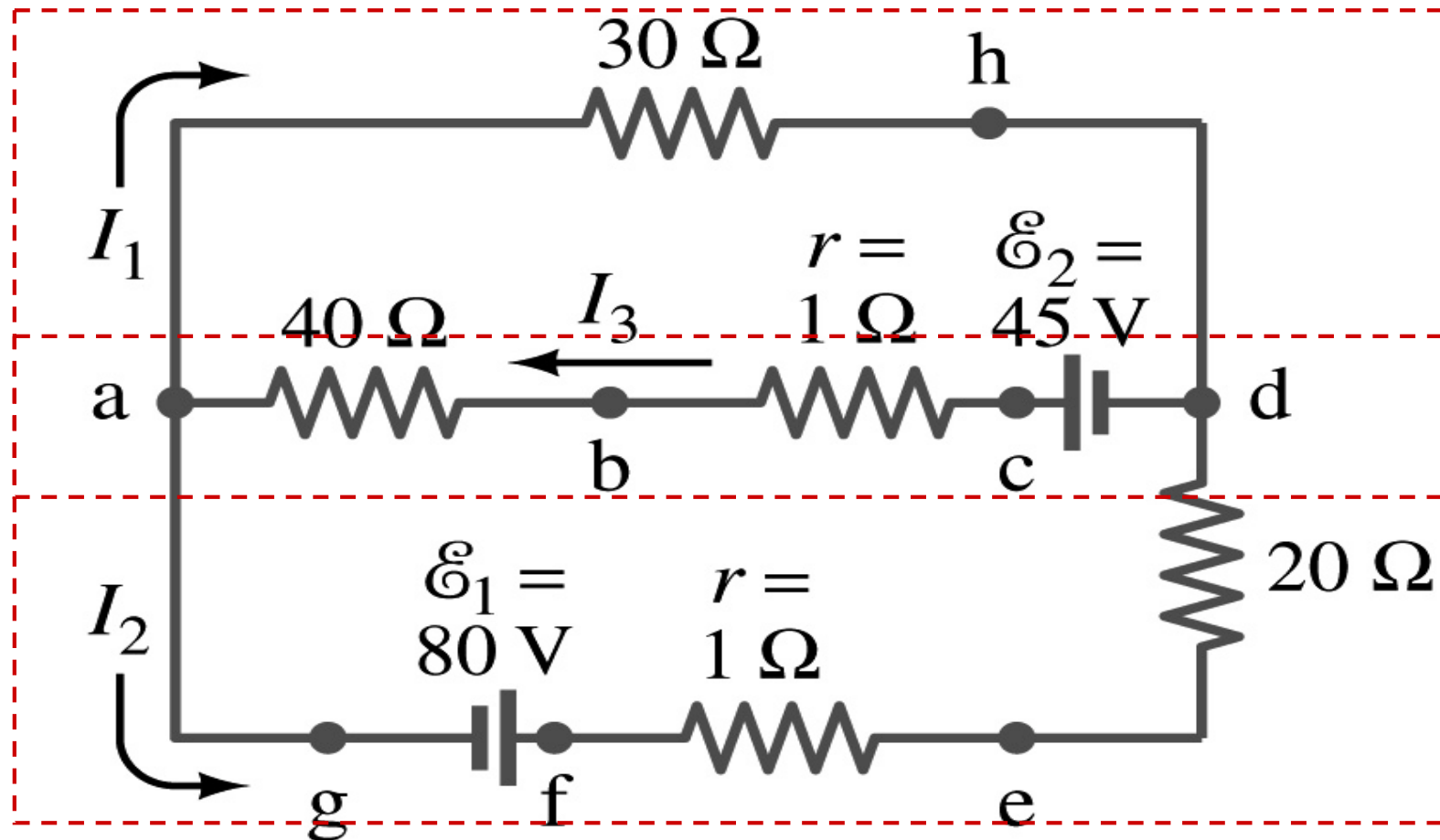
How to use Kirchhoff's Rules??

1. Determine the flow of currents at the junctions and label each and everyone of the independent currents.
 - It does not matter which direction, you decide but keep it!
 - You cannot have all current coming in or going out of a junction, though!
 - If the value of the current after completing the calculations are negative, you just need to flip the direction of the current flow.
2. Write down the current equation based on Kirchhoff's 1st rule at various junctions.
 - Be sure to see if any of them are the same.
3. Choose closed loops in the circuit
4. Write down the potential in each interval of the junctions, keeping the proper signs as you decided in step 1 above.
5. Write down the potential equations for each loop.
6. Solve the equations for unknowns.



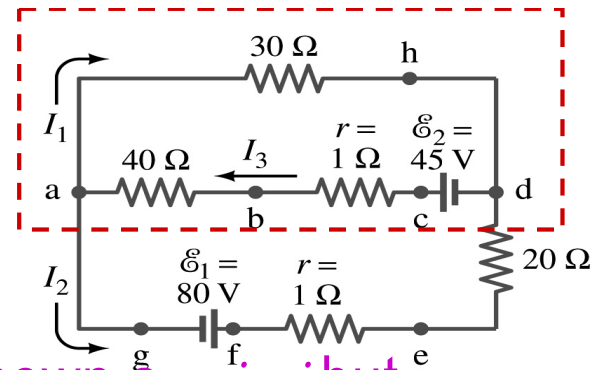
Example 26 – 9

Use Kirchhoff's rules. Calculate the currents I_1 , I_2 and I_3 in each of the branches of the circuit in the figure.



Example 26 – 9

Use Kirchhoff's rules. Calculate the currents I_1 , I_2 and I_3 in each of the branches of the circuit in the figure.



The directions of the current through the circuit is not known *a priori* but since the current tends to move away from the positive terminal of a battery, we arbitrarily choose the direction of the currents as shown.

We have three unknowns so we need three equations.

Using Kirchhoff's junction rule at point a , we obtain $I_3 = I_1 + I_2$

This is the same for junction d as well, so no additional information.

Now the second rule on the loop $ahdcba$.

$$V_{ah} = -I_1 30 \quad V_{hd} = 0 \quad V_{dc} = +45 \quad V_{cb} = -I_3 \quad V_{ba} = -40I_3$$

The total voltage change in the loop $ahdcba$ is.

$$V_{ahdcba} = -30I_1 + 45 - 1 \cdot I_3 - 40I_3 = 45 - 30I_1 - 41I_3 = 0$$

Example 26 – 9, cnt'd

Now the second rule on the other loop *agfedcba*.

$$V_{ag} = 0 \quad V_{gf} = +80 \quad V_{fe} = -I_2 \cdot 1 \quad V_{ed} = -I_2 \cdot 20$$

$$V_{dc} = +45 \quad V_{cb} = -I_3 \cdot 1 \quad V_{ba} = -40 \cdot I_3$$

The total voltage change in loop *agfedcba* is. $V_{agfedcba} = -21I_2 + 125 - 41I_3 = 0$

So the three equations become $I_3 = I_1 + I_2$

$$45 - 30I_1 - 41I_3 = 0$$

$$125 - 21I_2 - 41I_3 = 0$$

We can obtain the three current by solving these equations for I_1 , I_2 and I_3 .

Do this yourselves!!

