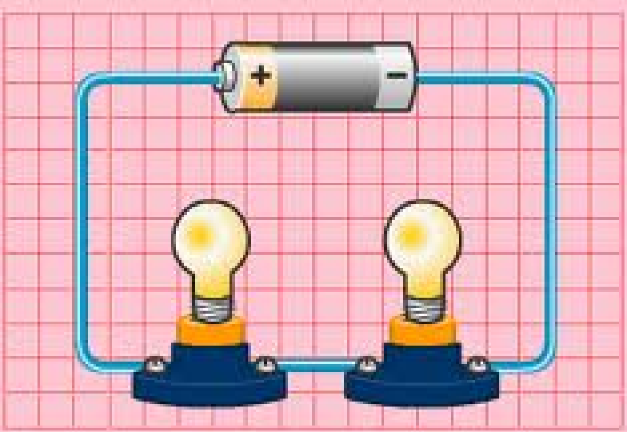
ELECTRIC CIRCUITS



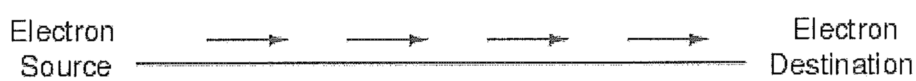
Lesson 1

Physics 12 – **Electric Circuits Pre-Reading Assignment** Name:

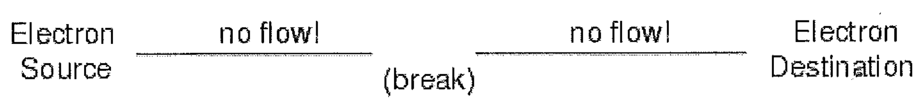
If we want electrons to flow in a certain direction to a certain place, we must provide the proper path for them to move, just as a plumber must install piping to get water to flow where he or she wants it to flow. To facilitate this, *wires* are made of highly conductive metals such as copper or aluminum in a wide variety of sizes.

Remember that electrons can flow only when they have the opportunity to move in the space between the atoms of a material. This means that there can be electric current *only* where there exists a continuous path of conductive material providing a conduit for electrons to travel through. In the marble analogy, marbles can flow into the left-hand side of the tube (and, consequently, through the tube) if and only if the tube is open on the right-hand side for marbles to flow out. If the tube is blocked on the right-hand side, the marbles will just "pile up" inside the tube, and marble "flow" will not occur. The same holds true for electric current: the continuous flow of electrons requires there be an unbroken path to permit that flow.

A thin, solid line is the conventional symbol for a continuous piece of wire. Since the wire is made of a conductive material, such as copper, its constituent atoms have many free electrons which can easily move through the wire. However, there will never be a continuous or uniform flow of electrons within this wire unless they have a place to come from and a place to go. Let's add a hypothetical electron "Source" and "Destination:"

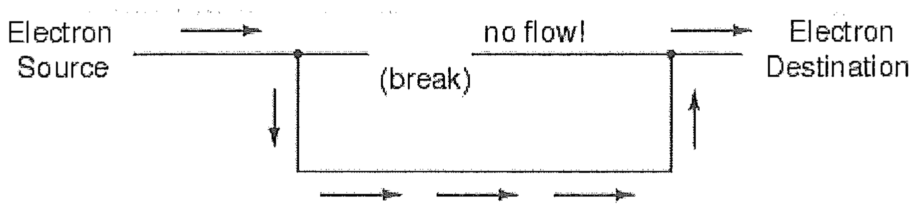


Now, with the Electron Source pushing new electrons into the wire on the left-hand side, electron flow through the wire can occur (as indicated by the arrows pointing from left to right). However, the flow will be interrupted if the conductive path formed by the wire is broken:



Since air is an insulating material, and an air gap separates the two pieces of wire, the once-continuous path has now been broken, and electrons cannot flow from Source to Destination. This is like cutting a water pipe in two and capping off the broken ends of the pipe: water can't flow if there's no exit out of the pipe. In electrical terms, we had a condition of electrical *continuity* when the wire was in one piece, and now that continuity is broken with the wire cut and separated.

If we were to take another piece of wire leading to the Destination and simply make physical contact with the wire leading to the Source, we would once again have a continuous path for electrons to flow. The two dots in the diagram indicate physical (metal-to-metal) contact between the wire pieces:



Now, we have continuity from the Source, to the newly-made connection, down, to the right, and up to the Destination. This is analogous to putting a "tee" fitting in one of the capped-off pipes and directing water through a new segment of pipe to its destination. Please take note that the broken segment of wire on the right hand side has no electrons flowing through it, because it is no longer part of a complete path from Source to Destination.

It is interesting to note that no "wear" occurs within wires due to this electric current, unlike water-carrying pipes which are eventually corroded and worn by prolonged flows. Electrons do encounter some degree of friction as they move, however, and this friction can generate heat in a conductor.

Questions:

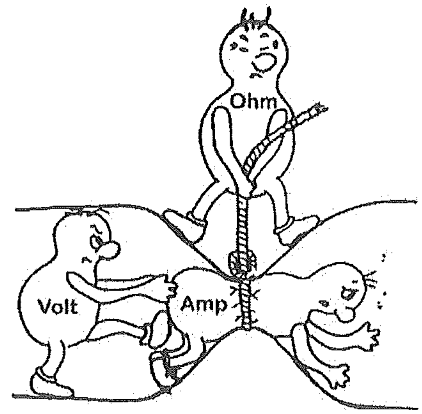
1. What are the requirements for an “electric current”?

2. What happens to the electrons when there is a break in the wire? Why does this happen?

3. How can we still have electron flow if part of the wire is broken? Draw a diagram and explain.

Lesson 1

Physics 12 – **Electric Current – Ohm's Law**



The discovery of the battery began the investigation of electric currents (the flow of charge through conductors).

Electric Current -

How do electrons "flow"?

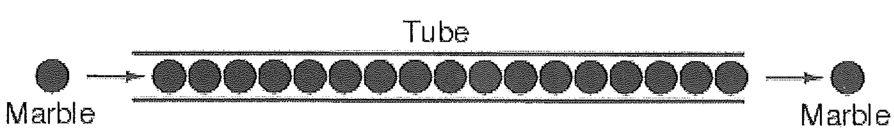
The electrons of different types of atoms have different degrees of freedom to move around. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they chaotically move in the space between the atoms of that material by nothing more than the influence of room-temperature heat energy. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called ***free electrons.***

In other types of materials such as glass, the atoms' electrons have very little freedom to move around. While external forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

This relative mobility of electrons within a material is known as electric *conductivity*. Conductivity is determined by the types of atoms in a material (the number of protons in each atom's nucleus, determining its chemical identity) and how the atoms are linked together with one another. Materials with high electron mobility (many free electrons) are called *conductors*, while materials with low electron mobility (few or no free electrons) are called *insulators*.

While the normal motion of "free" electrons in a conductor is random, with no particular direction or speed, electrons can be influenced to move in a coordinated fashion through a conductive material. This uniform motion of electrons is what we call *electricity*, or *electric current*. This is in contrast to *static* electricity, which is an unmoving accumulation of electric charge.

As each electron moves uniformly through a conductor, it pushes on the one ahead of it, such that all the electrons move together as a group. The starting and stopping of electron flow through the length of a conductive path is virtually instantaneous from one end of a conductor to the other, even though the motion of each electron may be very slow. An approximate analogy is that of a tube filled end-to-end with marbles:



The tube is full of marbles, just as a conductor is full of free electrons ready to be moved by an outside influence. If a single marble is suddenly inserted into this full tube on the left-hand side, another marble will immediately try to exit the tube on the right. Even though each marble only traveled a short distance, the transfer of motion through the tube is virtually instantaneous from the left end to the right end, no matter how long the tube is. With electricity, the overall effect from one end of a conductor to the other happens at the speed of light!!! Each individual electron, though, travels through the conductor at a *much* slower pace. (Information from http://openbookproject.net/electricCircuits/DC/DC_1.html)

Charges will not move through a conductor unless there is a potential difference (voltage). This voltage is provided by sources such as batteries and generators.

In an electric circuit, there must be a:

- Voltage source
- A complete pathway for the charge to flow through

If we have both of the requirements for a circuit, what will the rate of flow actually depend on?

A. POTENTIAL DIFFERENCE (VOLTAGE)

As we saw in previous lessons, a **potential difference will cause the charge to move as potential energy is converted into kinetic energy** $\left(\Delta V = \frac{\Delta E}{q}\right)$.

It follows then that the greater the potential difference, the greater the change in energy. The greater the change in energy, the greater the kinetic energy of the charge flow will be. This means that it will flow "faster" or it will move the same distance in less time this is what we measure for electric current.

Therefore: Electric Current is directly related to Voltage (potential difference).

B. RESISTANCE

There is always resistance to the flow of charged particles through a conductor. This is why conductors get warm or hot while a current is flowing through them. This is due to friction from the electrons passing over the material and transforming kinetic energy into thermal energy.

Because resistance causes friction, the current is slowed down.

Therefore: **Electric Current is inversely related to Resistance.**

The relationship between current, voltage and resistance was discovered by Ohm in 1826 and became known as **Ohm's Law**.

The formula for this relationship is usually written as

The unit for resistance is the ohm. - Ω

Electron Flow vs. Conventional Current

Two ways of thinking about electric current have developed:

1. **Electron Flow** –

Electron flow is always from negative (-) to positive (+).

2. **Conventional Current** –

Positive charges flow from positive (+) to negative (-).

This is now known to be incorrect, but it likely comes from the defining of electric potential and electric fields in terms of a moving positive charge.

Because of this history, electric current continues to refer to conventional current in college and university textbooks. Therefore, **unless it is indicated otherwise, electric current will refer to conventional current.**

Electric Power

Power is the rate of doing work or using energy.

When we combine this with Ohm's Law, we can derive other relationships for power using electrical terms.

Example One: What is the electric current through a conductor if a charge of 2.00 C flows through a point in the conductor in 10.0 s?

Example Two: Calculate the resistance in a conductor if the potential difference is 6.0 V and the current is 10.0 A.

Example Three: An electrical appliance uses 1.00×10^2 W when connected to a 1.20×10^2 V power line. What is the resistance in the appliance?

Example Four: A potential difference of 24 V is applied to a 75 Ω resistor for 20 s.

a) How much current flows through the resistor?

b) How much charge passes through the resistor?

c) How many electrons pass through the resistor?

Example Five: A 3.0 V battery is used to operate a 1.2 W flashlight bulb for 5.0 minutes.

a) What is the current supplied by the battery?

b) What is the resistance of the bulb?

c) How much energy does the flashbulb use during this time?

d) What total charge passes through the bulb in this time?

e) What is the total number of electrons that pass through the bulb during this time?

Lesson 1 homework

Electric Current (Ohm's Law) and Electric Power Problems:

1. A current of 3.60 A flows for 15.3 s through a conductor. Calculate the number of electrons that pass through a point in a conductor during this time. (3.44×10^{20} electrons)

2. How long would it take 2.0×10^{20} electrons to pass through a point in a conductor if the current was 10.0 A? (3.2 s)

3. Calculate the current through a conductor if a charge of 5.60 C passes through a point in the conductor in 15.4 s. (0.364 A)

4. What potential difference is required across a conductor to produce a current of 8.00 A is there is a resistance in the conductor of 12.0 Ω? (96 V)

5. What is the heat produced in a conductor in 25.0 s if there is a current of 11.0 A and a resistance in the conductor of 7.20 Ω? (2.18×10^4 J)

6. A particular conductor produces 1.50×10^2 J of heat in 5.50 s. If the current through the conductor is 10.0 A, what is the resistance in the conductor? (0.273 Ω)

7. What is the current through a 4.00×10^2 W electric appliance when it is connected to a 1.20×10^2 V power line? (3.33 A)

8. What potential difference is required across an electrical appliance to produce a current of 20.0 A when there is a resistance in the appliance of 6.00 Ω? How many electrons pass through the electrical appliance every minute? (120 V, 7.5×10^{21} electrons)

9. An electric clock is operated with a voltage of 1.5 V and a current of 3.3 A. A radio with a resistance of 2.0 Ω is operated with a voltage of 3.0 V. A light bulb with a resistance of 1.5 Ω is operated with a current of 2.0 A. Which of the household electrical appliances has the greatest rate of energy consumption? (light bulb)

10. An electric furnace of resistance 6.0 Ω is connected to a 240 V power supply. Find the resistance of another furnace if it produces the same power output when it is connected to a 120 V power supply. (1.5 Ω)

11. A clock uses a 6.0 W motor and 1.5 V battery and runs all day, every day. If the 1.5 V battery has 8.5×10^4 C of stored charge, how long does it take for the battery to lose its charge?

12. A handheld electric fan operates on a 6.0 V battery. The potential difference causes an electric charge of 0.13 C to pass through the resistor of the fan in 0.26 s.

a) Find the power dissipated by the resistor. (3.0 W)

b) If the fan is connected to a 9.0 V battery, find the current and power for this fan. (0.75A, 6.75 W)

13. An electric crane operated with a voltage of 120 V and a current of 4.2 A lifts a 300 kg piano 2.8 m vertically in 32 s. Find the efficiency of the crane. (51 %)

14. Electricity is transmitted at high potential from power plants to homes. Explain the reason for the transmission of electricity at high potential.

Lesson 2

Physics 12 – **Electric Circuits – (Kirchoff's Laws)**

An **electric circuit is a pathway that allows charges to flow**.

Within an electric circuit, there must be:

A.

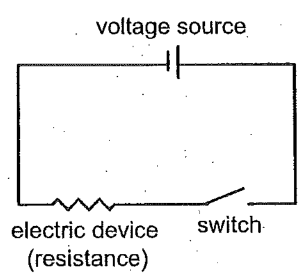
B.

When we place an electric device like a toaster or light bulb in the circuit, this device becomes part of the circuit.

As the charge flows through the device, the electrical energy is converted into other forms of energy like mechanical and heat energy.

The reason heat energy is produced is due to the friction produced by resistance to the charge flow. In order to avoid overheating and fire, circuits in our homes and cars have **circuit breakers or fuses**. They are heat sensitive and their purpose is to create a break in the circuit, shutting it down when the current is too great.

Also included in most circuits are **switches** which are a means of breaking the path for the charge to stop the flow and "turn off" the circuit.

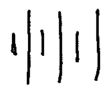


Electric current can be either direct (DC) or alternating (AC).

Batteries produce **direct current**. This means that the **charge always flows in the same direction** through the circuit. With conventional current this means the charge always flows from the positive terminal to the negative terminal.

Electrical generators can produce either direct or alternating current. With **alternating current,** the **charge in the circuit flows in one direction and then the other**. The circuits in our homes use alternating current.

Symbols for drawing circuits –

Direct Current:  or  Negative terminal →  ← Positive terminal

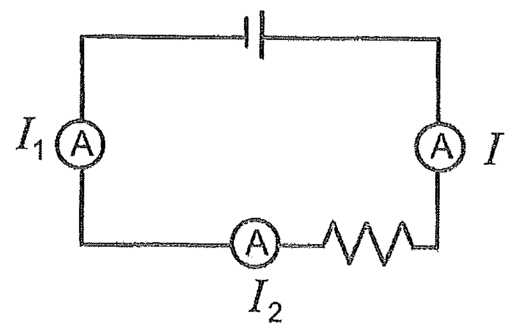
Alternating Current:  Resistor: 

Resistors in Series and Parallel Circuits

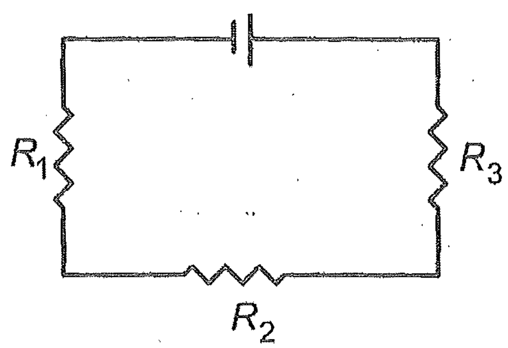
A. Series Circuit:

- **Resistors are connected end-to-end.**

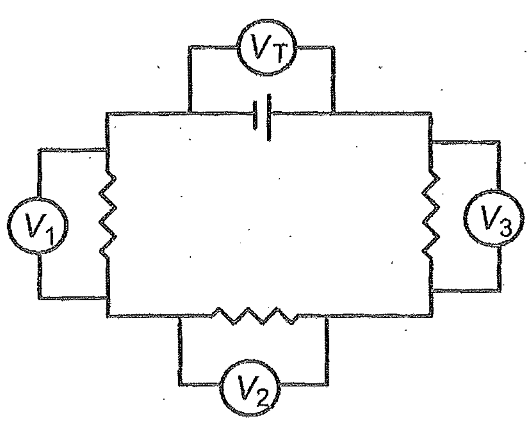
Current: The SAME current flows through each resistor when connected in series.



Equivalent Resistance: The equivalent resistance (can also be thought of as total) in series is equal to the sum of the individual resistances.

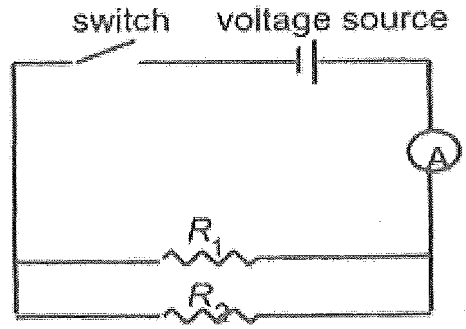


Voltage: The total voltage is equal to the sum of the voltage across each resistor.



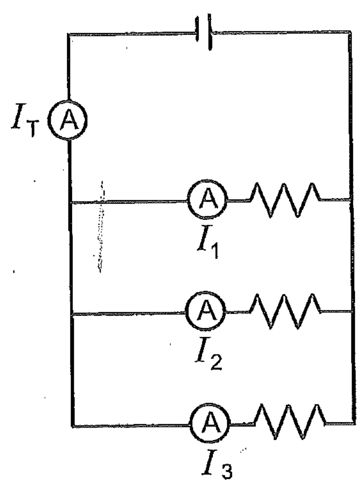
B. Parallel Circuits:

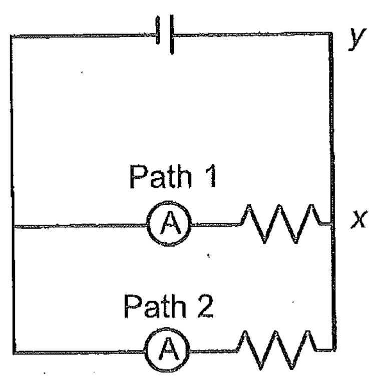
- **<u>The charge has more than one path.</u> The charge can travel through R_1 or R_2. If R_1 burns out (creates a break), the charge can still travel through R_2.**



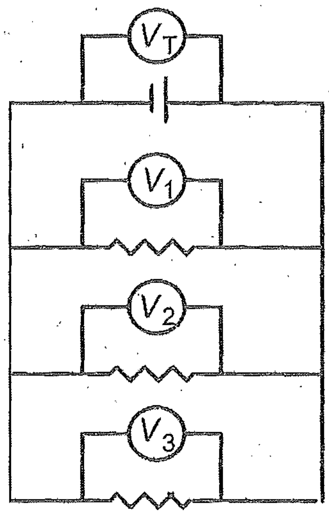
Current: The amount of charge at any point can be different.

Kirchoff's Current Law states – the sum of the currents entering a junction equals the sum of the currents leaving a junction.

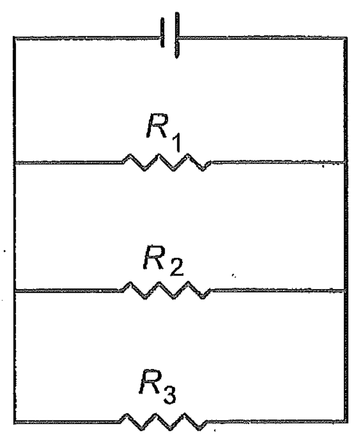




Voltage: The same voltage is applied across each device/resistor.



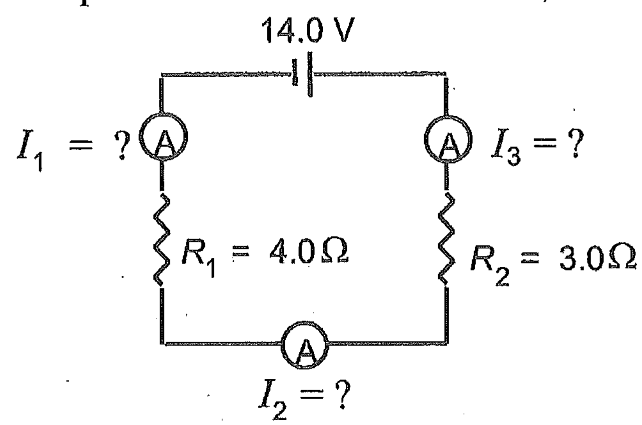
Resistance: The total resistance in a parallel circuit is the sum of the reciprocals of the individual resistances.



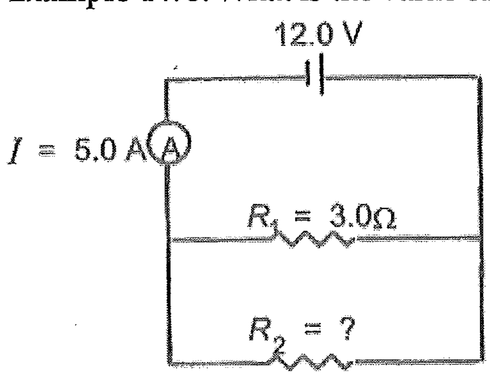
SUMMARY:

	SERIES CIRCUIT	PARALLEL CIRCUIT
CURRENT	$I_T = I_1 = I_2 = I_3 = \ldots$	$I_T = I_1 + I_2 + I_3 + \ldots$
VOLTAGE	$V_T = V_1 + V_2 + V_3 + \ldots$	$V_T = V_1 = V_2 = V_3 = \ldots$
RESISTANCE	$R_T = R_1 + R_2 + R_3 + \ldots$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

Example One: What are the values of I_1, I_2 and I_3 in this circuit?



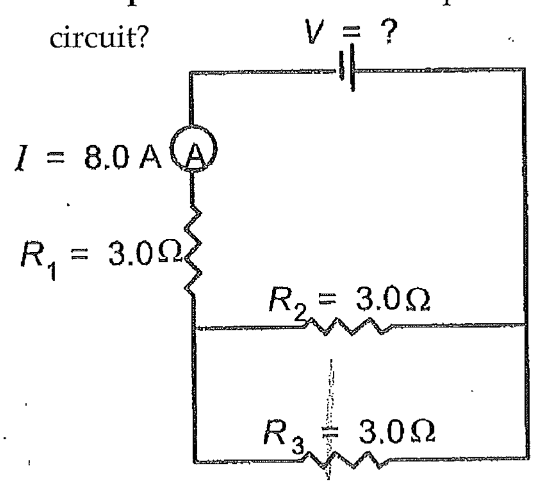
Example Two: What is the value of R_2 in this circuit?



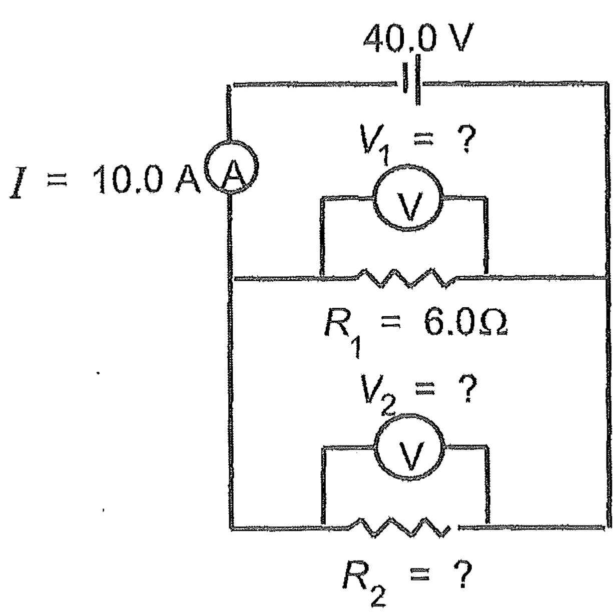
<u>Combination Circuits – Series and Parallel in the Same Circuit:</u>

If one section of a circuit is in series and another is in parallel, the circuit can be analyzed in parts, according to the respective series and parallel total resistances of the various sections.

Example Three: What is the potential difference supplied by the power source in this circuit?



Example Four: What are the values of V_1, V_2, and R_2 in this circuit?



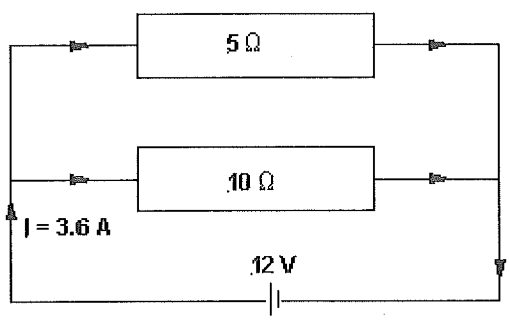
Lesson 2 homework

Electric Circuit Problems:

1. A circuit consists of a 12 V battery connected across a single resistor. If the current in the circuit is 3.0 A, calculate the size of the resistor. (4.0 Ω)

2. Two 5.0 Ω resistors are connected in series with a 12 V battery. Determine: (a) the potential difference across each resistor; and (b) the current flowing in the circuit. (6.0 V, 1.2 A)

3. Two resistors of size 10 Ω and 5.0 Ω are connected in parallel as shown below.

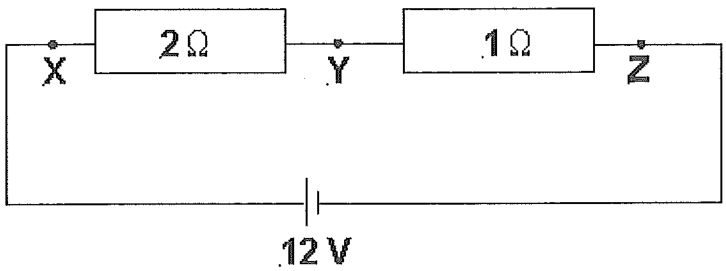


a. If 3.6 A of current flows into the parallel branch, determine the current flowing in each of the resistors. (2.4 A in the top resistor & 1.2 A in the bottom resistor)

b. What is the potential difference across each of the resistors? (12V)

c. How much current will flow out of the parallel branch? Why? (3.6 A)

4. Consider the following circuit and then answer the questions below.



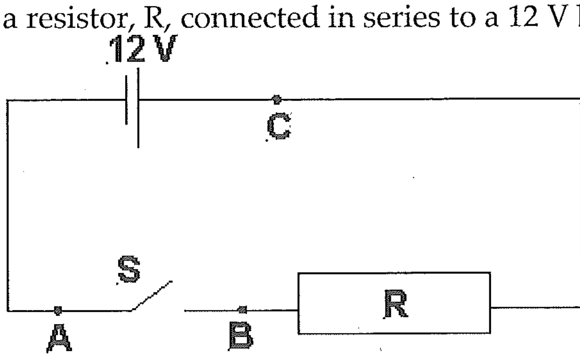
a. State the potential difference between X and Z.

b. State the potential difference between X and Y.

c. How much potential is left at Y?

(a) 12V, (b) 8V, (c) 4V)

5. The circuit below shows a resistor, R, connected in series to a 12 V battery across an open switch, S.



a. If R = 6.0 Ω, how much current flows in the circuit with the switch open?

b. When the switch is closed and R = 6Ω, determine:

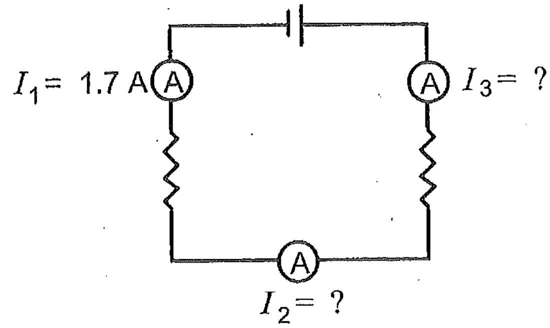
i. the current in the circuit;

ii. the potential difference between A and B; and

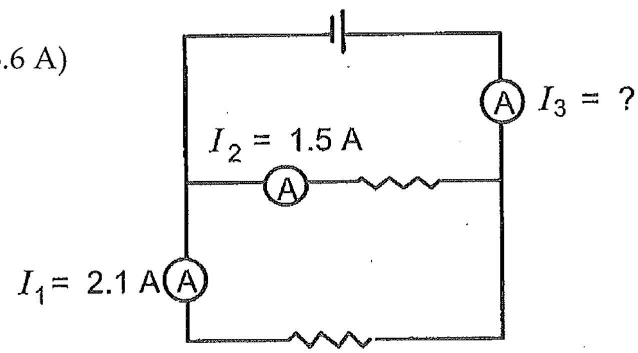
iii. the potential difference between B and C.

(a) 0A (b) (i) 2A, (ii) 0V, (iii) 12V

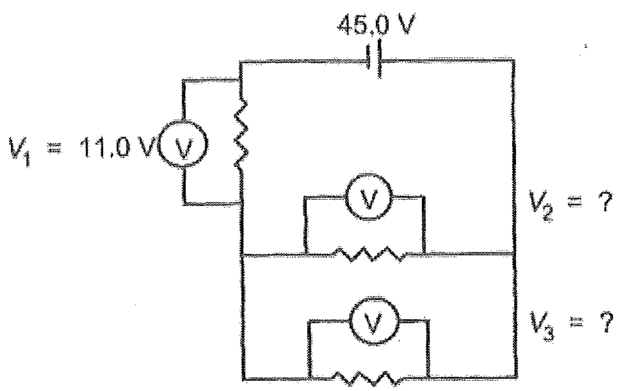
6. What are the values for I_2 and I_3 in this circuit? (1.7 A)



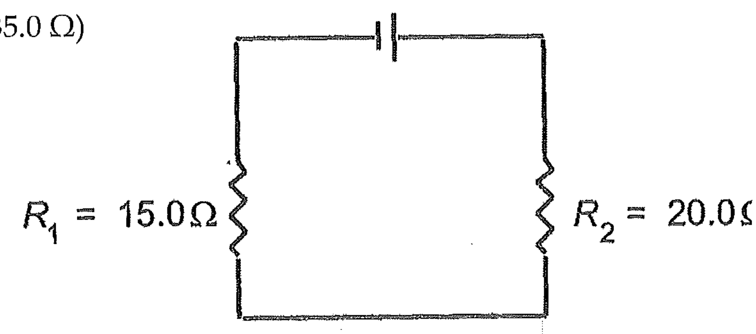
7. What is the value of I_3 in this circuit? (3.6 A)



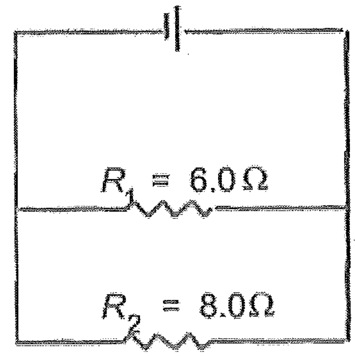
8. What are the values of V_2 and V_3 in this circuit? (34.0 V)



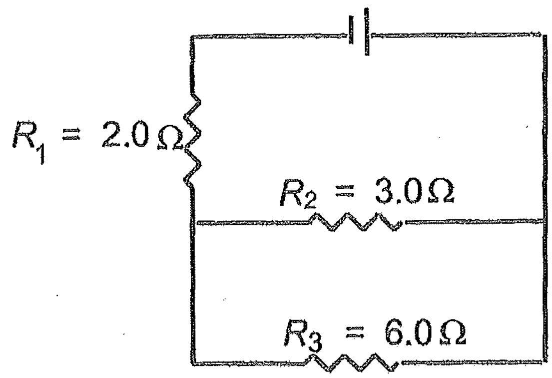
9. What is the total resistance in this circuit? (35.0 Ω)



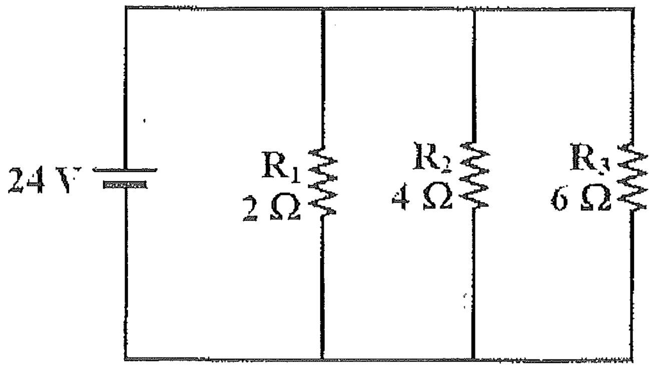
10. What is the total resistance in this circuit? (3.4 Ω)



11. What is the total resistance in this circuit? (4.0 Ω)



12. Three resistors are connected in parallel with a 24 V battery as shown in the diagram.



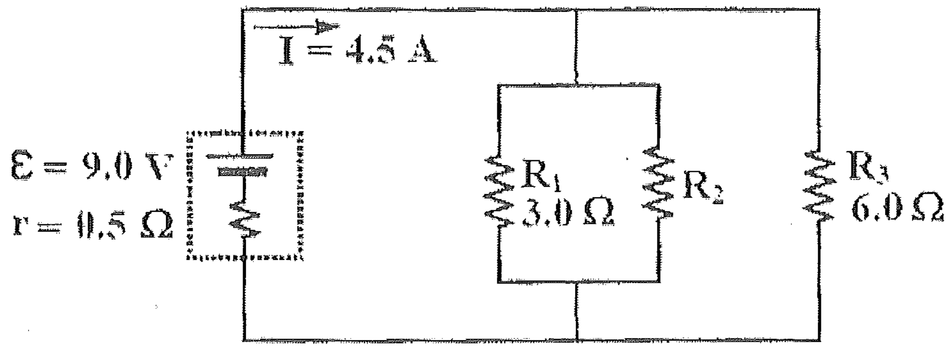
a) Find the total resistance of the three resistors. (1.1 Ω)

b) Find the total current supplied by the battery and the current through each resistor. (I_T = 22A, I_1 = 12 A, I_2 = 6.0 A, I_3 = 4.0 A)

c) Find the potential difference across each resistor.

d) Find the power dissipated by each resistor and the total power dissipated by the circuit.

13. The diagram shows a circuit composed of a battery and three resistors.



Find the resistance of R_2. (6.0 Ω)

Find the current through each resistor. (2.3 A, 1.1 A, 1.1 A)

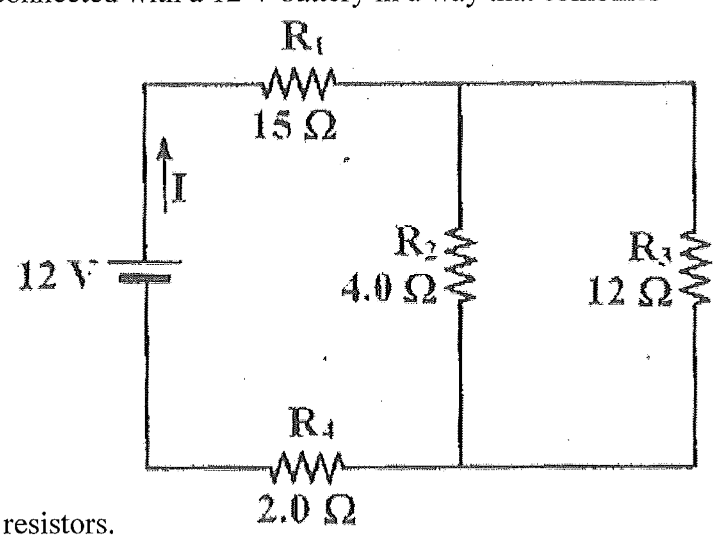
14. Two identical bulbs are connected to a battery, one set in series, the other set in parallel.

a) Which connection produces more light?

b) If one bulbs in parallel burns out, what happens to the other bulb?

c) Which way are the headlights of a car connected? Explain your answer.

15. In the circuit shown, four resistors are connected with a 12 V battery in a way that combines series and parallel features.

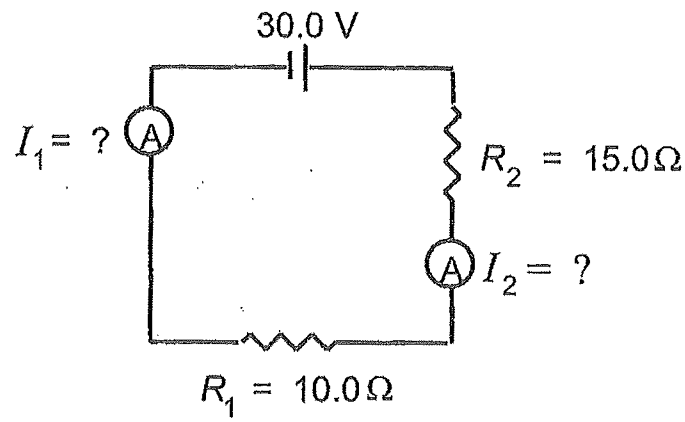


a) Find the total resistance of the four resistors.

b) Find the total current supplied by the battery and the current through each resistor. (I_T=0.60A, $I_1 = I_4 = 0.60$ A, $I_2 = 0.45$ A, $I_3 = 0.15$ A)

c) Find the potential difference across each resistor. (V_1 =9.0V, $V_2 = 1.8$V, $V_3 = 1.8$V, V_4=1.2V)

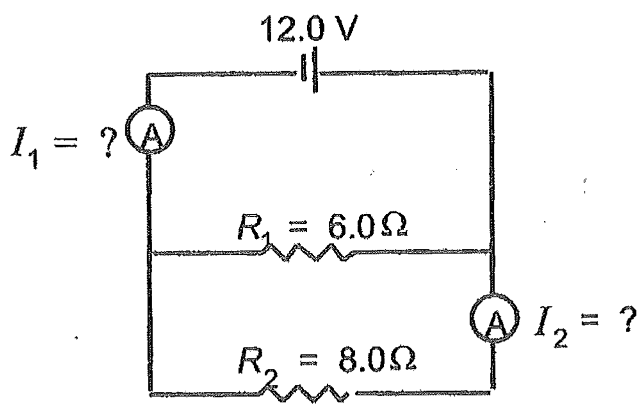
16.



a) What are the values of I_1 and I_2 in the circuit above? (1.2 A)

b) What is the power dissipated in R_1? (14.4 W)

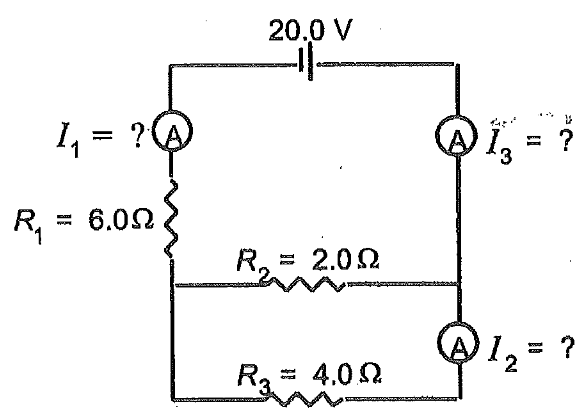
17.



a) What are the values of I_1 and I_2 in the circuit above? (I_1 = 3.5 A, I_2 = 1.5 A)

b) What is the power dissipated in the circuit? (42 W)

18.



a) What are the values of I_1, I_2 and I_3 in the circuit above? (I_1= 2.73 A, I_2 = 0.91 A, I_3 = 2.73 A)

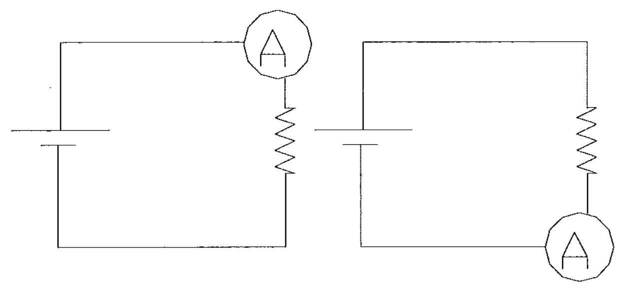
b) What is the power dissipated in the circuit? (55 W)

Lesson 3

Physics 12 - **The *Voltmeter* and the *Ammeter***

So far in our study of circuits we have been calculating the *voltage* and the *current* at various locations in a given circuit. *But how do you '**check**' the answers in the **real world?*** As with anything, there are instruments made to measure these quantities. *Voltage* is measured with a *Voltmeter,* and *Current* is measured with an *Ammeter...*

Today we are going to study the characteristics of these instruments and how they are wired into the circuit.



The Ammeter

The ammeter is the instrument we will use to measure the current. **Current is the number of electrons that flow through a given point in the circuit.**

If we want to count the number of electrons that flow through a resistor (and hence the current that flows through the resistor), we need to **connect a machine in SERIES that measures the current entering OR leaving a resistor.**

As we can see in the diagram, either set-up would display the current flowing through the resistor. The left diagram would measure the current entering the resistor, while the one on the right will measure the current leaving the resistor.

If an ammeter was wired in parallel, it would not be measuring the current flowing through the resistor.

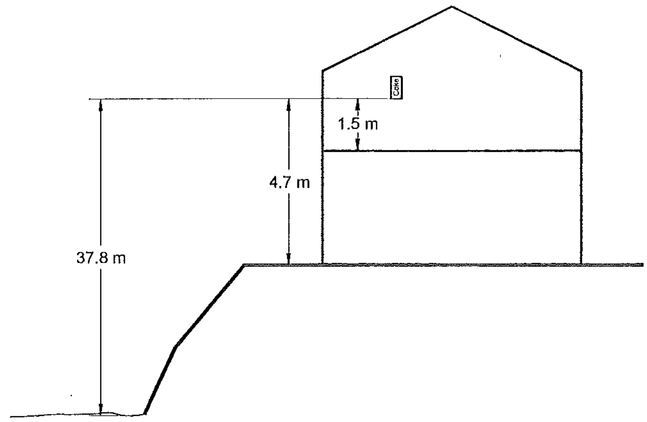
Ammeters, which are connected in series in a circuit when used, work by using a **very small amount of resistance** with **a *known value*,** and then measuring the voltage drop across that to determine current flow. In order for an ammeter to be used without significantly affecting circuit operation, it must present as little resistance as possible to the circuit in which it is being used.

Ammeters are connected in series with the circuit where they are being used in the measurement of current. **Thus, ideally there should be zero voltage drop across the ammeter.** The only way this is possible is if they have a zero internal resistance. They can't have an internal resistance of zero, but we need to keep it as low as possible.

It is known that a voltage drop across a given resistance is directly proportional to its resistance. **By measuring the voltage drop across a known resistance, we can find current flow, and this is what an ammeter does.**

The Voltmeter

In the diagram to the right, we could ask, how 'high' is the can of Coke? You would then need to ask "how high compared to what?" **Height is a relative thing.** The Coke is 1.5 m above the floor, 4.7 m above the ground, 37.8 m above sea level, 6400 km above the center of the earth.



You can see that the answer depends on what we call 'zero' height, and when we say how high, we really mean the ***difference*** in height between two points.

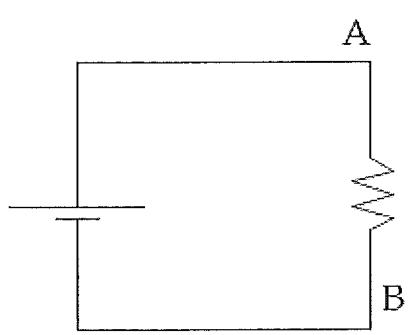
Since most physics labs stay inside the classroom, calling the floor 'zero' would be a good choice as in any demonstration done with the Coke can it will not break through the floor and go into 'negative' height. But mathematically speaking, we could even choose the ceiling as 'zero' and all of our calculations would just be using negative numbers.

Since voltage is analogous to pressure, and **voltage must be 'relative' to some arbitrary zero point that we pick**, and since **the lowest voltage in the circuit will always be at the negative terminal of the battery, we normally call this the point of 'zero' voltage**.

(*Note: We could label the positive terminal 'zero' voltage and mathematically everything would be the same, except all our numbers would be negative!*)

A voltmeter works in exactly the same way. **A voltmeter does not measure *absolute* voltage, but it does measure the voltage difference between two points in the circuit (hence the name *potential difference!*)**

So logically, it we want to check how much the *potential changes* in between points A and B, we must connect one wire from the voltmeter to point A, and the other wire from the voltmeter to point B. The reading on the voltmeter will then be the difference between point A and B!



Name: ____________________

Physics 12 Circuit Lab

Purpose: to study voltage, amps and resistance in series and parallel circuits

Procedure:

Go to the following internet address: www.article19.com. Then click on: "shockwave gallery" then "educational activities" then "Ohm zone".

1 a. Make a simple circuit with the battery and blue resistor. Measure the voltage across the resistor. Measure the current (using the ammeter) going in (or out) of the resistor. Calculate the resistance.

b. Repeat with the purple, yellow and orange resistors.

Use 3 sig digs

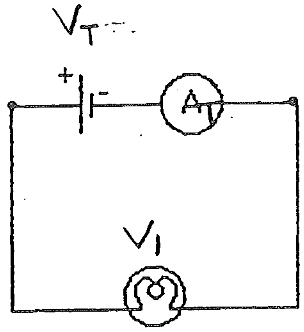
resistor	Potential Difference (in V)	Current (in A)	Resistance (in Ω)
blue			
purple			
yellow			
orange			

c. Click on the "glasses" icon that is called "visualize" to see the current flow.

2. Click on the "hand" icon. Choose each of the 14 "exhibits". Click "OK" after each selection and watch/read the information presented. Write the title of each of "exhibit" and a one or two sentence summary of the key point(s).

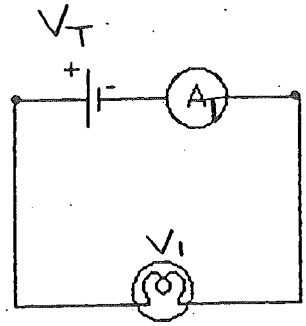
3. Build each of the following circuits
Record the potential difference across each light and the battery (→ V_T)
Record the current as indicated.
USE 3 SIG DIGS AND Include units!

(a)



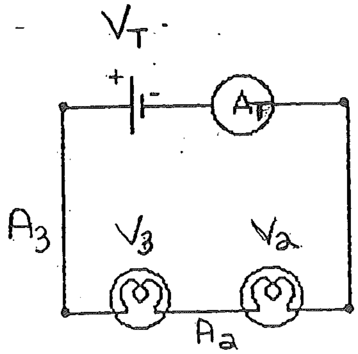
A_T = ____ V_T = ____
V_1 = ____

(d)



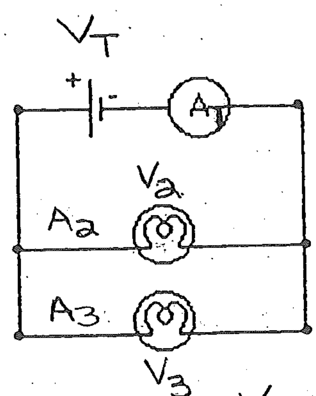
A_T = ____ V_T = ____
V_1 = ____

(b)



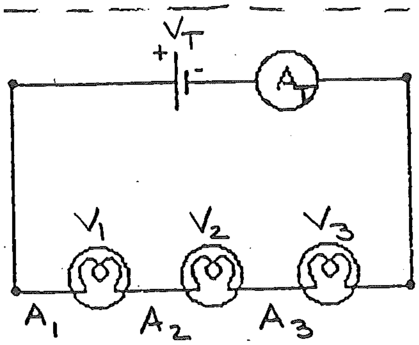
A_T = ____ V_T = ____
A_2 = ____ V_2 = ____
A_3 = ____ V_3 = ____

(e)



A_T = ____ V_T = ____
A_2 = ____ V_2 = ____
A_3 = ____ V_3 = ____

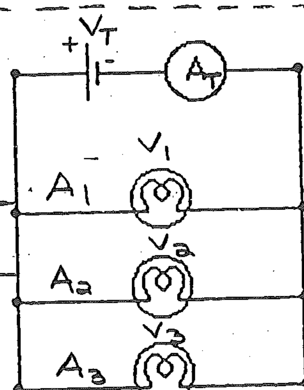
(c)



A_T = ____ V_T = ____
A_1 = ____ V_1 = ____
A_2 = ____ V_2 = ____
A_3 = ____ V_3 = ____

(f)

V_T = ____
A_T = ____



A_1 = ____ V_1 = ____
A_2 = ____ V_2 = ____
A_3 = ____ V_3 = ____

Electric current is a measure of how many charged particles (usually electrons) pass a point in a conductor in one second. In a household appliance the current might be

$$1\ A = 1\ \frac{C}{s} = 6.24 \times 10^{18}\ \frac{electrons}{s}.$$

An ampere is quite a large current. Here are some typical currents in household appliances.

kettle	12.5 A
100 W lamp	0.8 A
toaster	8.3 A
clock	0.033 A

If a battery is connected in a circuit, and a complete path is provided in which the charged particles (electrons) can flow, then the charged particles will *lose* energy as they pass through the circuit. *Energy is a conserved quantity. It is neither created nor destroyed. The energy LOST in the circuit should equal the energy GAINED in the battery.* This can be checked out using a voltmeter.

RESISTANCE

How much current exists in a conducting path depends on two factors:

(1) the voltage of the battery (or other source), and

(2) how much resistance is provided by the conducting path.

The resistance of the conducting path in turn depends on four other factors:

(a) how thick the conductor is;
(b) how long the conductor is;
(c) the material used to make the conductor; and
(d) the temperature of the conductor.

current increased
I↑
or I↓ current decreased.
↓

Concluding Questions

1. In circuits 3(a) to 3(c), all the lightbulbs were connected in one continuous path. These were *series circuits*. How did the current change when you added more and more lightbulbs "in series"?

I ____________

2. In circuits 3(d) to 3(f), the lightbulbs were connected in parallel paths. These were *parallel circuits*. What happened to the current when you added more and more lightbulbs in parallel?

I ____________

3. Which type of circuit, *series* or *parallel*, would make more sense for a set of decorative lights of the type used for Christmas trees? Explain your answer.

____________ ____________

I ______ 4. What happens to the amount of current, *I*, when the number of identical resistors *in series* is doubled, tripled then quadrupled?

V ______ 5. What happens to the voltage across an individual resistor when you connect more identical resistors in series with the same battery?

V_{total} ___ $V_{battery}$ 6. If you add up all the voltages ($V_1 + V_2 + V_3 + ...$) across all the resistors in a series circuit, how does the *total voltage* compare with the *battery voltage?*

I ______ 7. What result did you get when you measured the current in different parts of the series circuit?

R_{series} ______ 8. When you add more resistors in a series circuit, what effect does this have on the total resistance of the series circuit? Upon what evidence do you base your answer?

I ______ 9. What happens to the amount of current, *I*, from the battery when the number of identical resistors *in parallel* is doubled, tripled, then quadrupled?

10. How does the voltage, *V*, across each branch of a parallel circuit compare with

V ______ (a) the voltage across other branches?

V ______ (b) the battery voltage?

11. How does the current in the branches compare with the current from the battery when

a) I is ______ (a) there is only one resistor?

b) Branch I is ______ (b) there are two resistors in parallel?

c) Branch I is ______ (c) there are three resistors in parallel?

d) Branch I is ______ (d) there are four resistors in parallel?

12. If you had a circuit with four resistors in parallel, and one of the resistors "burned out" or broke, would the current from the battery increase, decrease or stay the same? Explain your answer. ______

R_{total} ______ 13. When you add more identical resistors in a parallel circuit, what effect does this have on the total resistance of the parallel circuit? Upon what evidence do you base your answer?

a) V ______ 14. (a) What happens to the voltage when you add more cells in series in a battery?

b) ______ (b) What happens to the voltage when you add more cells in parallel in a battery?

c) ______ (c) What advantage is there to connecting cells in parallel?

V ______ 15. In a *series* circuit, how does the battery voltage compare with the sum of the voltages across parts of the external circuit?

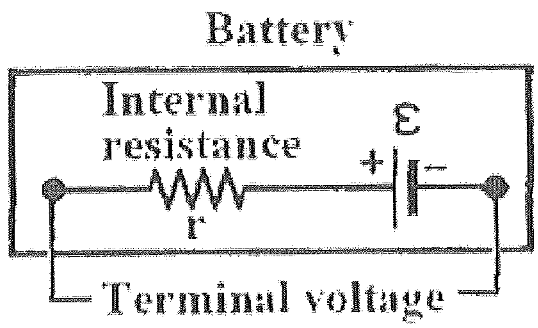
V ______ 16. In a *parallel* circuit, how does the battery voltage compare with the voltage of the external parts of the circuit?

V ______ 17. In a *parallel* circuit, what special feature did you notice about the voltages of the branches of the circuit?

Lesson 4

Physics 12 – **EMF, Terminal Voltage and Internal Resistance**

A battery and a generator are sources of potential difference (voltage). When these devices are **not connected to a working circuit** (when the electrons are flowing), **the potential difference across the terminals is called the electromotive force, or EMF (ε).**

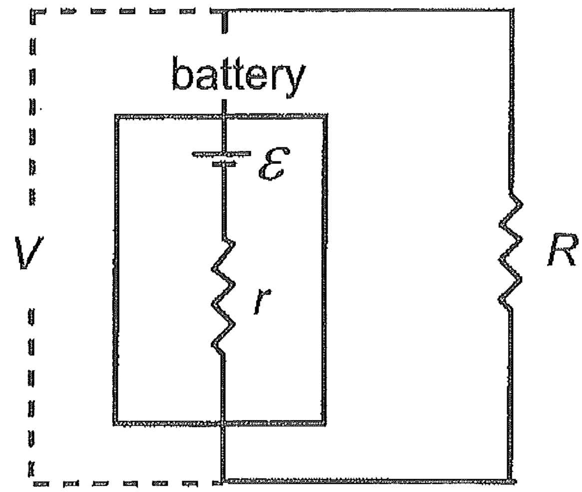


If a car battery has an EMF of 12 V, this is the voltage that can be produced based on the chemicals inside. Therefore, this is the maximum voltage capability.

Once the battery is connected to an electric circuit, the potential difference is less than the EMF due to the internal resistance of the battery. This always occurs because every battery has some internal resistance.

Because of internal resistance, the terminal voltage is always less than the EMF of the battery.

When the battery is not connected and/or no current flows, then $V = \varepsilon$. This applies to an electric generator as well as a battery.



"Dead" Batteries and Rechargeable Batteries

Voltage (V) across the battery terminals is given by: $V = \varepsilon - Ir$

When a battery goes "dead", the internal resistance becomes greater until Ir equals ε, and then current will no longer flow.

When a rechargeable battery is being charged, an external voltage is applied to the battery. The voltage of this external battery must be greater than the EMF of the battery.

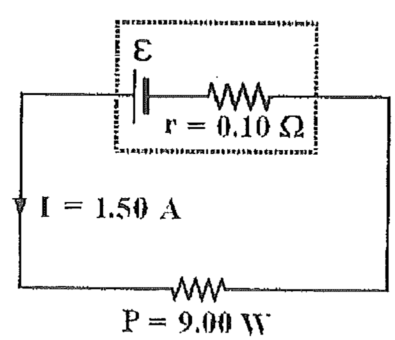
$$V \text{ (external voltage)} = \varepsilon + Ir$$

Example One: If a 12.0 V battery has an internal resistance of 0.200 Ω, what is the terminal voltage of the battery when a current of 3.00 A flows through the battery?

Example Two: In a particular battery, the EMF is 9.0 V and when a current of 2.0 A flows through the battery, the terminal voltage is 7.0 V. What is the internal resistance of the battery?

Example Three: A 12.0 V car battery is being charged using a battery charger that is supplying 15.0 V. If the internal resistance of the battery is 1.3 Ω, what is the current through the battery?

Example Four: The diagram shows a circuit composed of a battery with an internal resistance of 0.10 Ω and a 9.00 W stereo speaker. The battery delivers 1.50 A to the speaker. Find the terminal voltage and EMF of the battery.

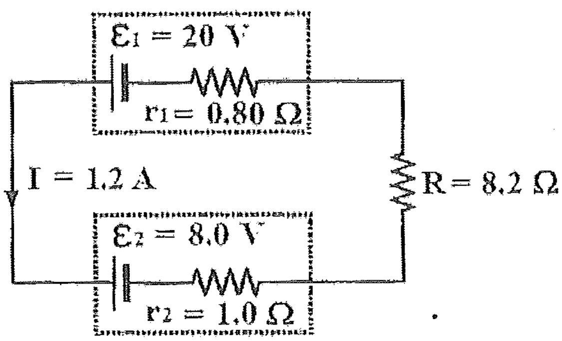


Lesson 4 homework

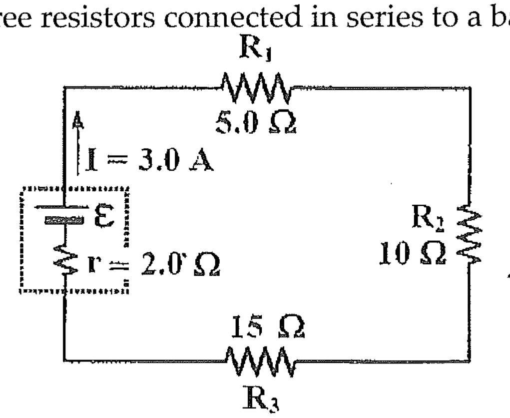
EMF, Terminal Voltage and Internal Resistance Problems:

1. When a 12 V battery with a 1.0 Ω internal resistance is connected to a motor, it delivers a current of 2.4 A. The battery is now replaced with a new battery with the same EMF but a different internal resistance and the resistor of the motor dissipates 16 W. What is the internal resistance of the new battery? (2.0 Ω)

2. A 20 V source battery is charging an 8.0 V battery as shown in the diagram. Find the terminal voltage of each battery. (19 V, 9.2 V)



3. A circuit consists of three resistors connected in series to a battery. The current in the circuit is 3.0 A.



a) Find the terminal voltage and the EMF of the battery. (90 V, 96 V)

b) Find the potential difference across each resistor. Compare the sum of each potential difference and the terminal velocity.

4. A flashlight battery of EMF 1.5 V has an internal resistance of 0.50 Ω. If there is a current of 1.0 A through the battery, what is the terminal voltage of the battery? (1.0 V)

5. What is the EMF of a battery that has a terminal velocity of 5.0 V when a current of 1.2 A flows through the battery? The battery has an internal resistance of 0.72 Ω. (5.9 V)

6. A battery that has an EMF of 24 V and an internal resistance of 0.25 Ω is being charged at a rate of 24 A. What is the voltage required to do this? (30 V)

7. A battery of 12 V EMF has an internal resistance of 1.0 Ω, and is connected to an external circuit that has a resistance of 4.0 Ω. What is the current through the circuit? (2.4 A)

8. What is the internal resistance of an electric generator that has an EMF of 120 V and a terminal voltage of 115 V when there is a current of 12 A through the generator? (0.42 Ω)

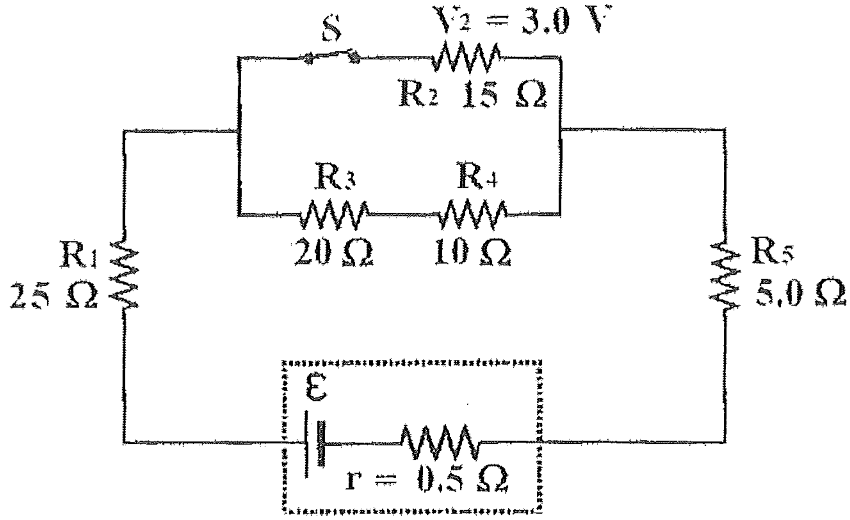
9. When a 2.0 Ω resistor is connected across a battery with an internal resistance of 0.50 Ω, the terminal voltage is observed to be 4.8 V. If the 2.0 Ω resistor is replaced with a 4.5 Ω resistor, what is the terminal voltage of the battery? (5.4 V)

(Lesson 4 extra practice)

Physics 12 – Electric Circuits Assignment Name:

SHOW ALL WORK and clearly indicate your answers.

1. The diagram shows a circuit of five resistors, a battery and a switch. The potential difference across resistor R_2 is 3.0 V.



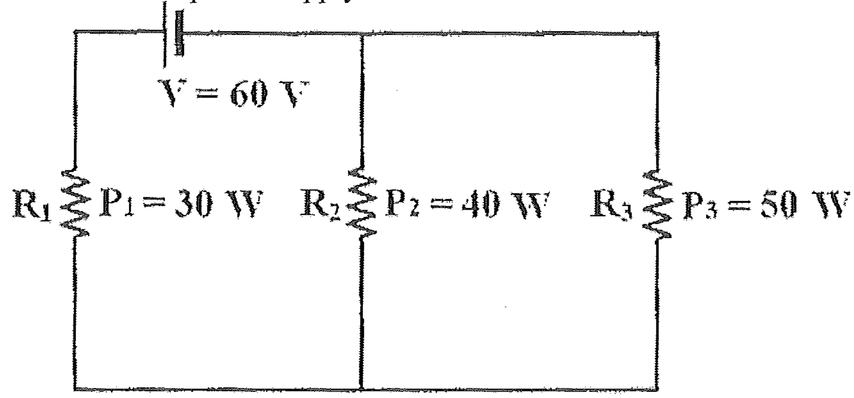
a) Find the EMF and terminal voltage of the battery.

b) Find the total power dissipated by the five resistors.

c) Find the power dissipated by resistor R_4.

d) What happens to the EMF of the battery if the switch is opened?

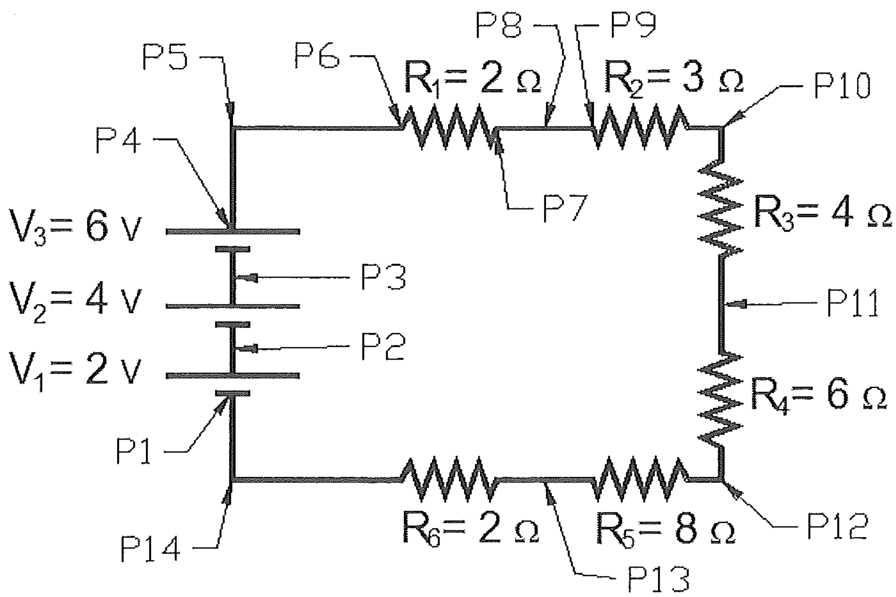
2. The circuit below consists of a power supply and three resistors.



a) Find the current from the power supply.

b) Find the current through R_2.

c) Find the resistance of R_3.



3. What is the **TOTAL VOLTAGE** of the battery in the circuit shown above?

What is the **TOTAL RESISTANCE** of the circuit shown above?

What is the **TOTAL CURRENT** of the circuit shown above?

If the voltage at point **P1 = 0 V**:

a) What is the voltage at P2?

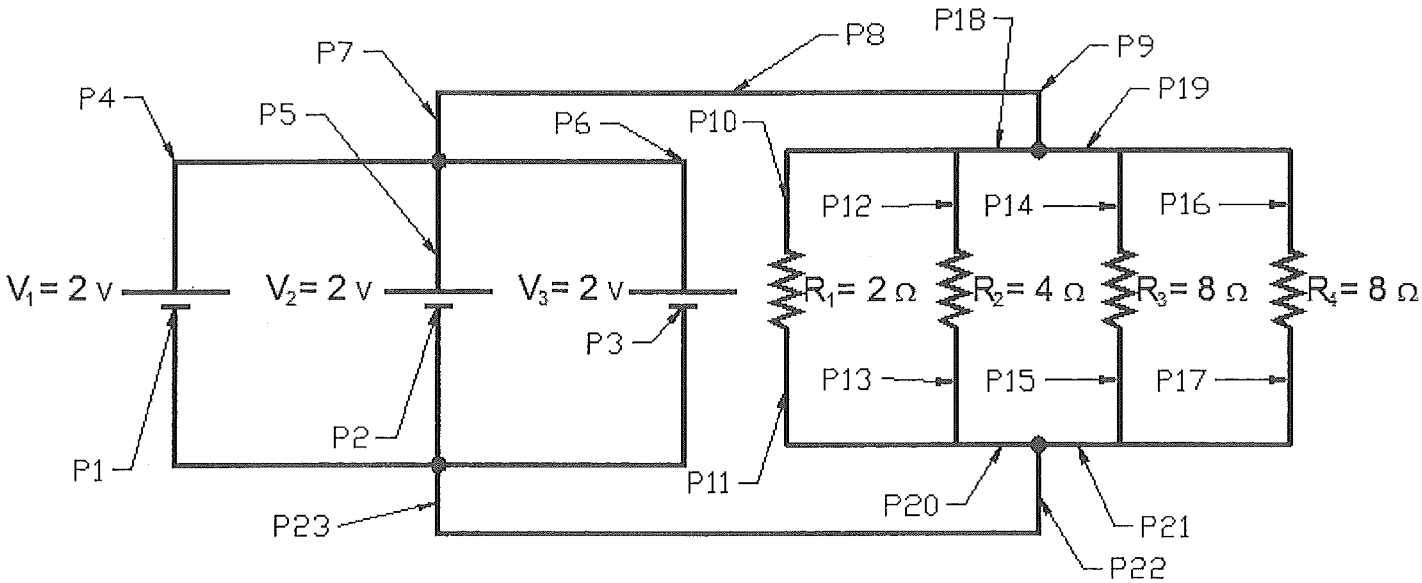
b) What is the voltage at P3?

c) What is the voltage at P6?

How many amps of current are flowing through $\mathbf{R_1}$?

What is the resistance of $\mathbf{R_1}$?

What is the *voltage **drop*** as the current goes through $\mathbf{R_1}$?



4. What is the **TOTAL VOLTAGE** of the battery in the circuit shown above?

What is the **TOTAL RESISTANCE** of the circuit shown above?

What is the **TOTAL CURRENT** of the circuit shown above?

If the voltage at point **P1 = 0 V**:

a) What is the voltage at P2?

b) What is the voltage at P3?

c) What is the voltage at P7?

What is the voltage at **P10**?

What is the voltage at **P11**?

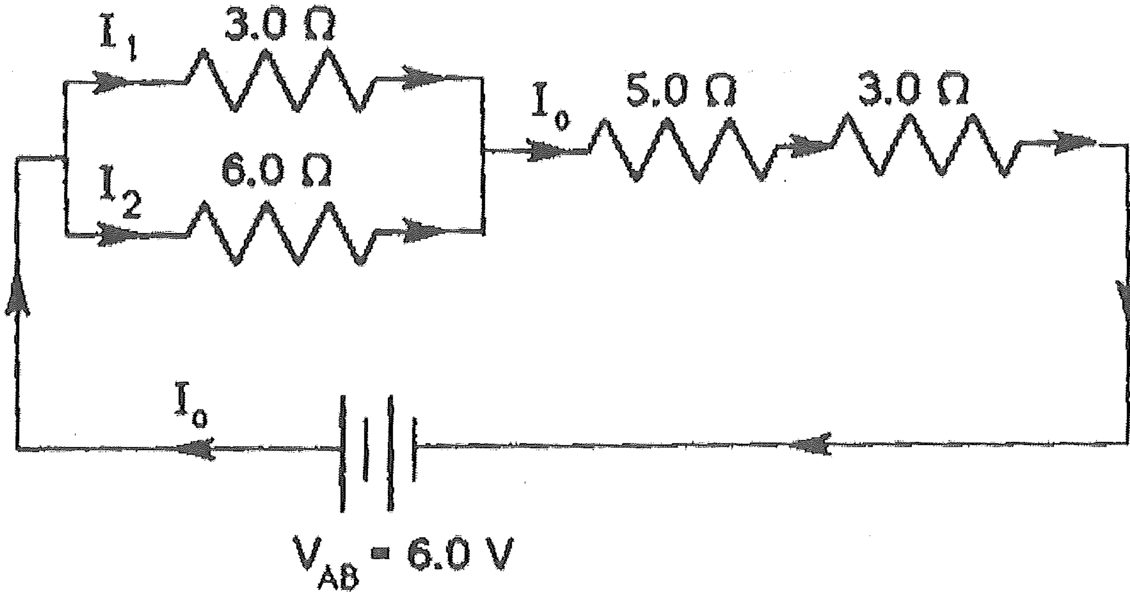
What is the current flowing through $\mathbf{R_1}$?

What is the current flowing through $\mathbf{R_2}$?

What is the current flowing through $\mathbf{R_3}$

What is the current flowing through $\mathbf{R_4}$?

What is the current flowing through **P22**?



5.

(a) What is the equivalent resistance of the circuit?

(b) What is the voltage across the 6.0 Ω resistor?

6. Draw a simple series circuit with a 1.5 V cell connected to a 12 Ω resistor, a 15 Ω resistor and a 33 Ω resistor. Calculate (a) the equivalent resistance and (b) the current in the circuit.

7. Draw a simple parallel circuit with a 3.0 V battery connected to a 3.0 Ω resistor, a 5.0 Ω resistor and a 7.5 Ω resistor.

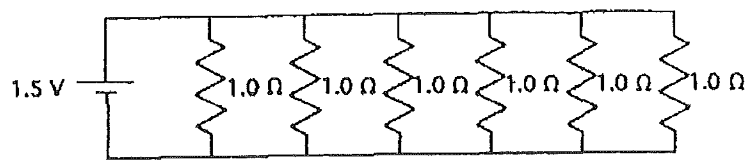
Calculate:

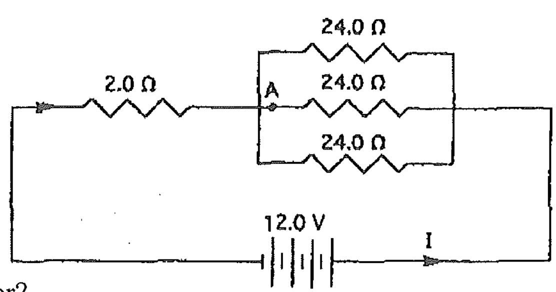
(a) the equivalent resistance,

(b) the total current,

(c) the current in the 5.0 Ω resistor.

8. What is the current in the battery?





9. (a) What is the equivalent resistance of the circuit?

(b) What is the current in the battery?

(c) What is the current at point A?

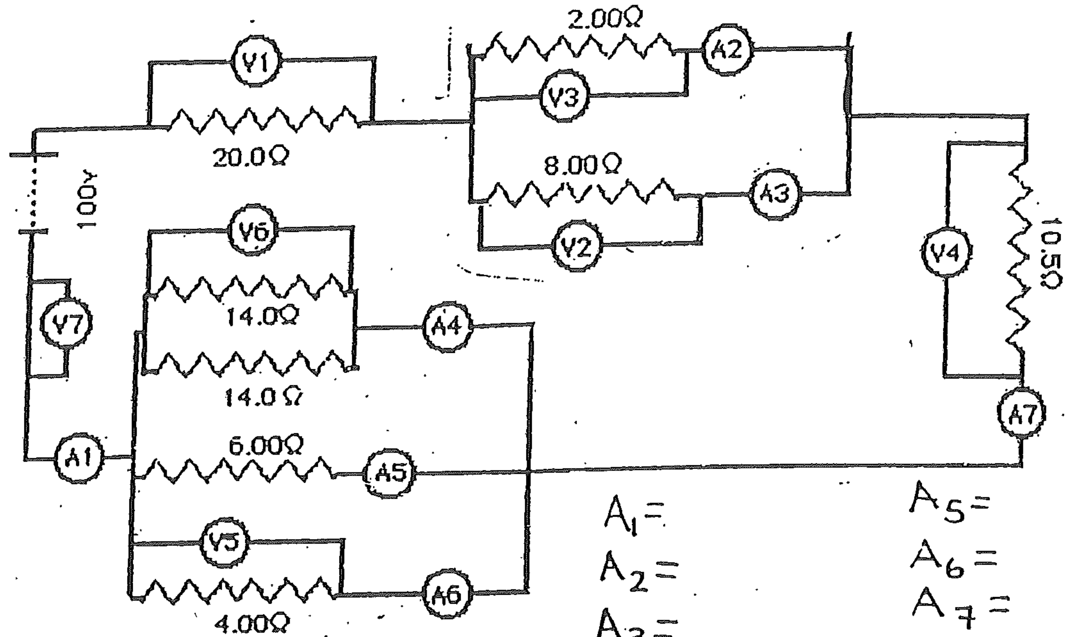
(d) What is the potential difference across the 2.0 Ω, resistor?

(e) The wire at A is cut. When this happens, predict whether the current in the battery will (i) stay the same, (ii) increase, or (iii) decrease. Check your prediction by calculating the new current in the battery.

Physics 12 Extra Big Circuit Practice Lesson 5

Determine the required meter readings

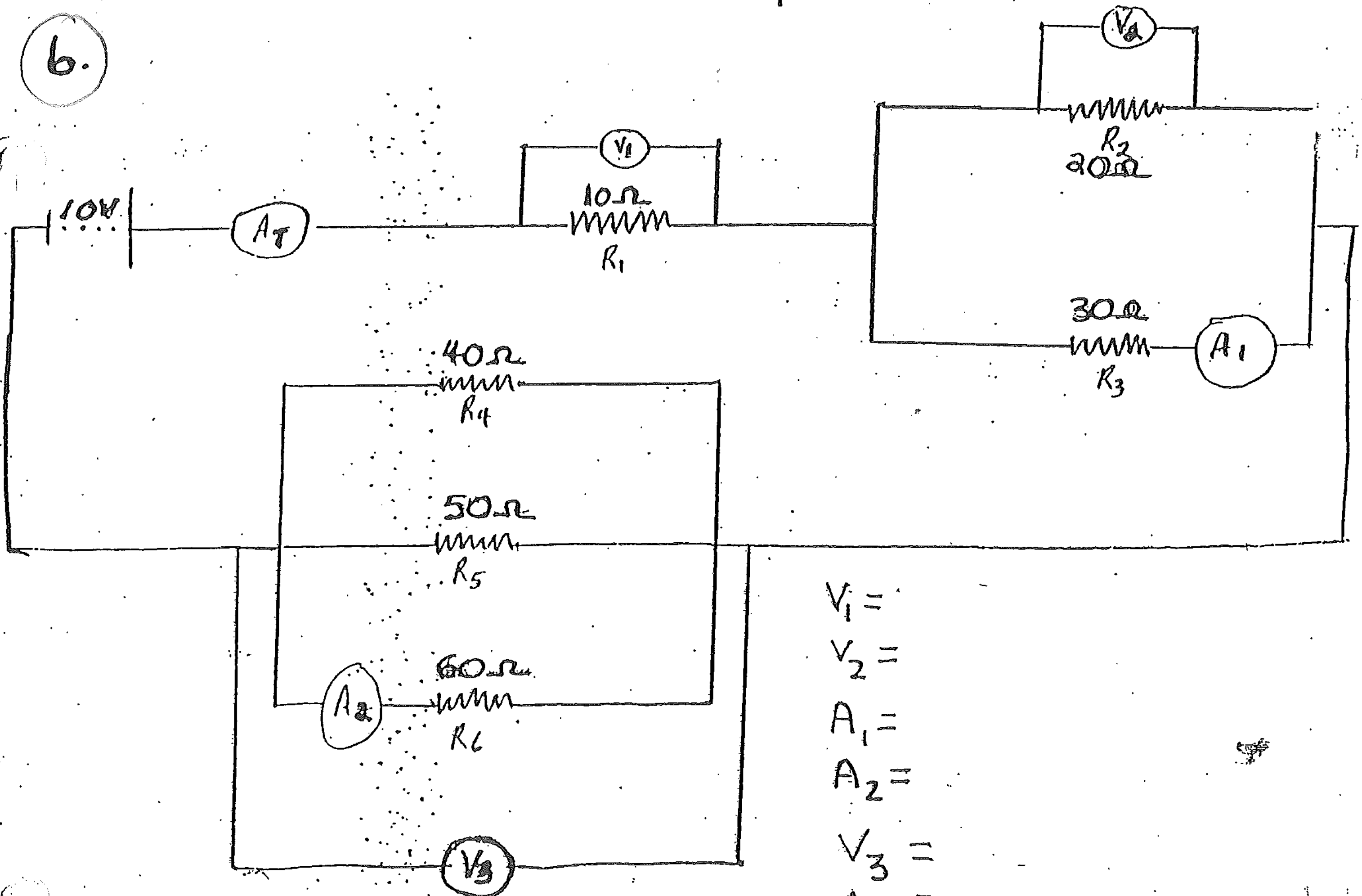
7.



V_1 =
V_2 =
V_3 =
V_4 =
V_5 =
V_6 =
V_7 =

A_1 =
A_2 =
A_3 =
A_4 =
A_5 =
A_6 =
A_7 =

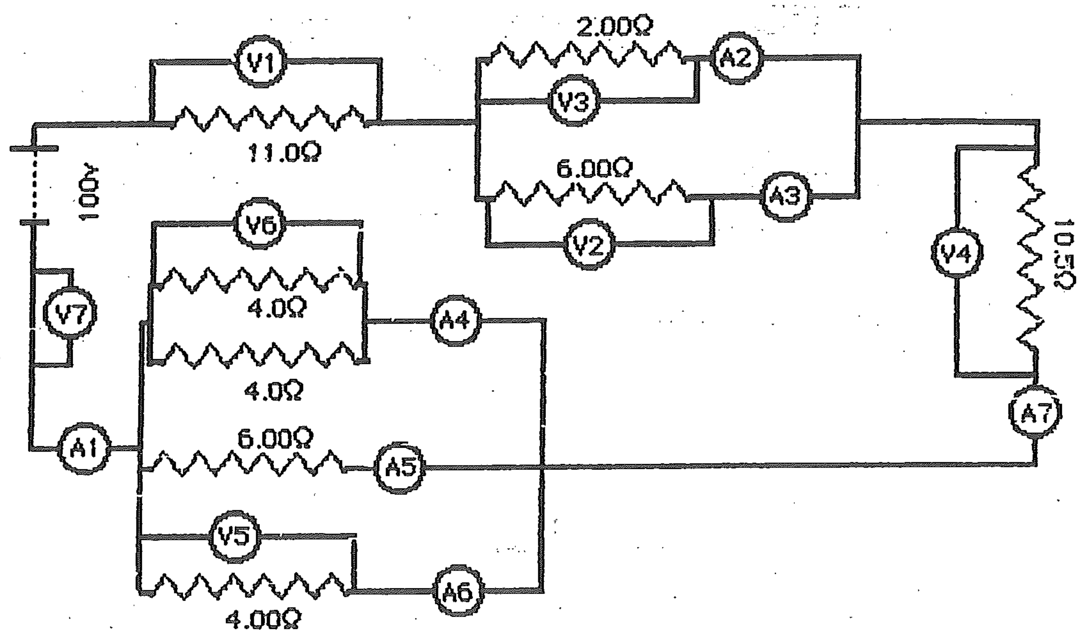
6.



V_1 =
V_2 =
A_1 =
A_2 =
V_3 =
A_T =

3610-1a

Determine the readings on the required meters



V_1 = ______ A_1 = ______

V_2 = ______ A_2 = ______

V_3 = ______ A_3 = ______

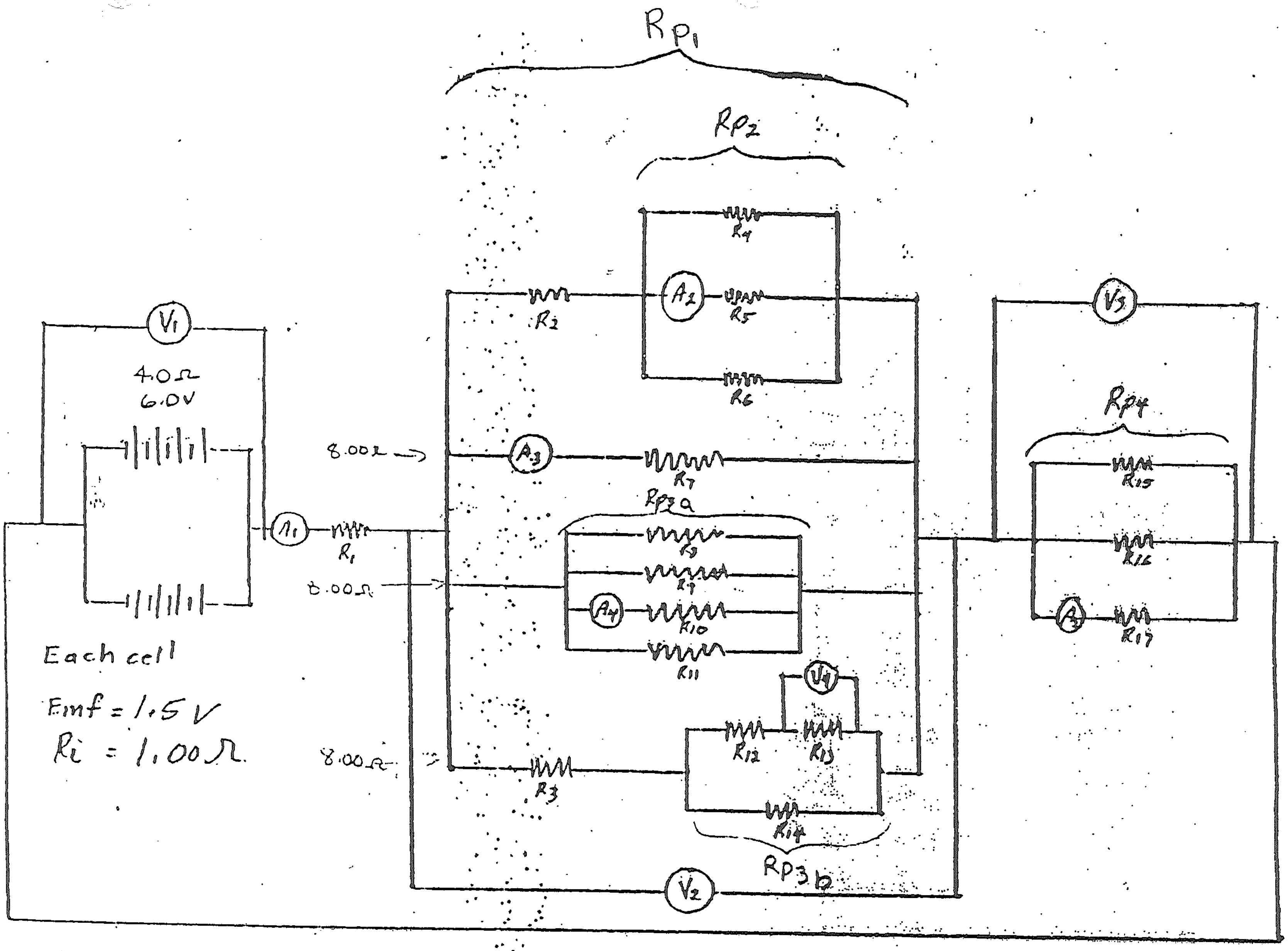
V_4 = ______ A_4 = ______

V_5 = ______ A_5 = ______

V_6 = ______ A_6 = ______

V_7 = ______ A_7 = ______

Physics 12 Electricity



R1 = 3.00
R2 = 4.00
R3 = 2.00
R4 = 12.0
R5 = 12.0
R6 = 12.0
R7 = 8.00
R8 = 32.0
R9 = 32.0
R10 = 32.0
R11 = 32.0
R12 = 8.01
R13 = 4.01
R14 = 12.0
R15 = 18.0
R16 = 18.0
R17 = 18.0

Rp1 ______
Rp2 ______
Rp3a ______
Rp4 ______

A1 ______
A2 ______
A3 ______
A4 ______
A5

V1 ______
V2 ______
V3 ______
V4 ______

(D4121)

Physics 12

ADDITIONAL PROBLEMS – ELECTRIC CIRCUITS

1. An electric appliance that is rated at 7.50×10^2 W is connected to a 1.10×10^2 V power line. What is the current through the appliance?

(6.82 A)

2. What current flows through an appliance if the resistance of the appliance is 20.0 Ω and it is connected to a 1.10×10^2 V power line.

(5.50 A)

3. What is the energy used by an electric appliance if a current of 2.40 A flows for 12.0 h through the appliance from a 1.10×10^2 V power line?

(1.14×10^7 J)

4. What is the maximum number of 60.0 W light bulbs that can be put in a household circuit ($V = 1.10 \times 10^2$ V) without tripping the circuit breaker if the maximum current through the circuit is 20.0 A?

(36)

5. If a beam of 9.39×10^{20} alpha particles passes a given point in 1.50 s, what is the current?

(2.00×10^2 A)

6. A student investigating the relationship between the current and the resistance in an electric circuit varied the resistance while keeping the potential difference constant. The following data was obtained:

I ($\times 10^{-1}$ A)	R ($\times 10^{-1}\ \Omega$)	R^2	$\sqrt{R}$	$\frac{1}{R}$
9.38	1.00			
4.68	2.00			
3.13	3.00			
2.35	4.00			
1.88	5.00			

a) Draw a graph showing the relationship between the current and resistance.

b) Complete the necessary column in the data table so that you can draw a straight line graph when you plot current vs. the column you completed. Draw this graph.

c) Using your graph, find the potential difference in the circuit.

([9.30 ±0.1] x 10^{-2} V)

7. Three electrical devices (appliances) ($R_1 = 5\ \Omega$, $R_2 = 75\ \Omega$, $R_3 = 125\ \Omega$) are connected in parallel across a 1.2 x 10^2 V line in an electric circuit. If all electrical devices are operating

a) calculate the total electric current in the line.

(3×10^1 A)

b) calculate the current through R_3.

(0.96 A)

c) calculate the power dissipated in R_2.

(1.9 x 10^2 W)

d) calculate the total power dissipated in the circuit.

(3×10^3 W)

e) calculate the voltage drop across R_1.

(1.2×10^2 V)

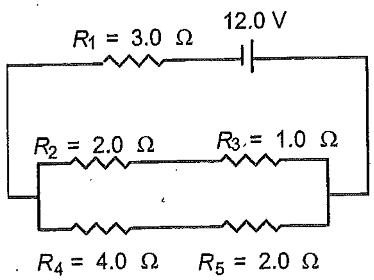
8. A 45 kg object is lifted vertically at a constant speed to a height of 9.0 m by a 7.5×10^2 W electric motor. If this motor is 25% efficient in converting electric energy to mechanical energy, how long does the motor take to lift the object?

(21 s)

9. The power rating of an electric appliance is 1.5×10^3 W. How much current does this appliance draw when it is used in a home electric circuit ($V = 1.20 \times 10^2$ V)?

(13 A)

10.



a) What is the current through R_1?

(2.4 A)

b) What is the current through R_4?

(0.80 A)

c) What is the power dissipated in R_2?

(5.1 W)

d) What is the total power dissipated in the circuit?

(29 W)

11. A 12.0 V battery has a terminal voltage of 11.0 V. If the current through the battery is 3.00 A, what is the internal resistance of the battery?

(0.33 Ω)

12. What is the voltage needed to charge a battery that has an emf of 12.0 V and an internal resistance of 0.82 Ω at a rate of 10.0 A?

(20.2 V)

A)

A)

W)

:e

13. A 2.50 Ω resistor draws a current of 2.50 A when it is connected to a 12.0 V battery.

a) What would be the terminal voltage of the battery when connected to the resistor?

(6.25 V)

b) What is the internal resistance of the battery?

(2.3 Ω)

l resistance of 0.43 Ω and a termina

Lesson 7

Electricity and Circuits
Provincial Exam Questions

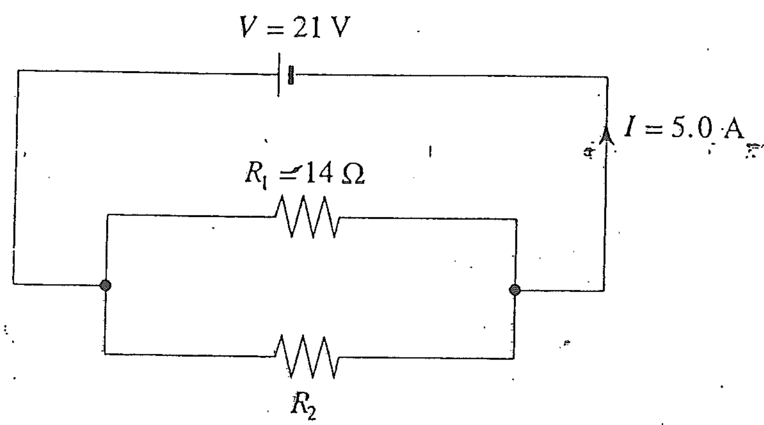
1. Which pair of values will cause the greatest deflection of an electron beam in a cathode ray tube?

	ACCELERATING VOLTAGE	DEFLECTION (PLATE) VOLTAGE
A.	400 V	20 V
B.	400 V	40 V
C.	800 V	20 V
D.	800 V	40 V

2. Electricity is transmitted at high potential to

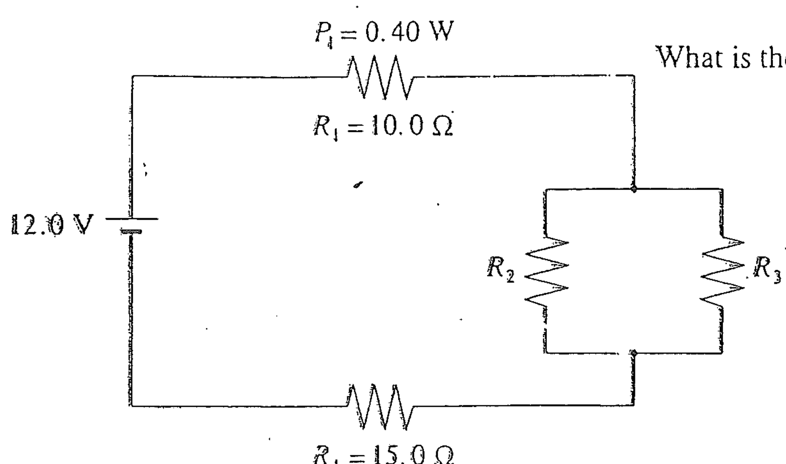
A. operate heavy equipment.
B. maximize current in the transmission lines.
C. minimize the energy lost as heat in the transmission lines.
D. produce alternating currents because they always require high voltages.

3. Find the current flowing through resistor R_2 in the circuit shown below.



4. A cell has an internal resistance of $0.50\ \Omega$. It has a terminal voltage of $1.4\ \text{V}$ when connected to a $5.0\ \Omega$ external resistance. What will its terminal voltage be if the $5.0\ \Omega$ resistor is replaced by a $10.0\ \Omega$ resistor?

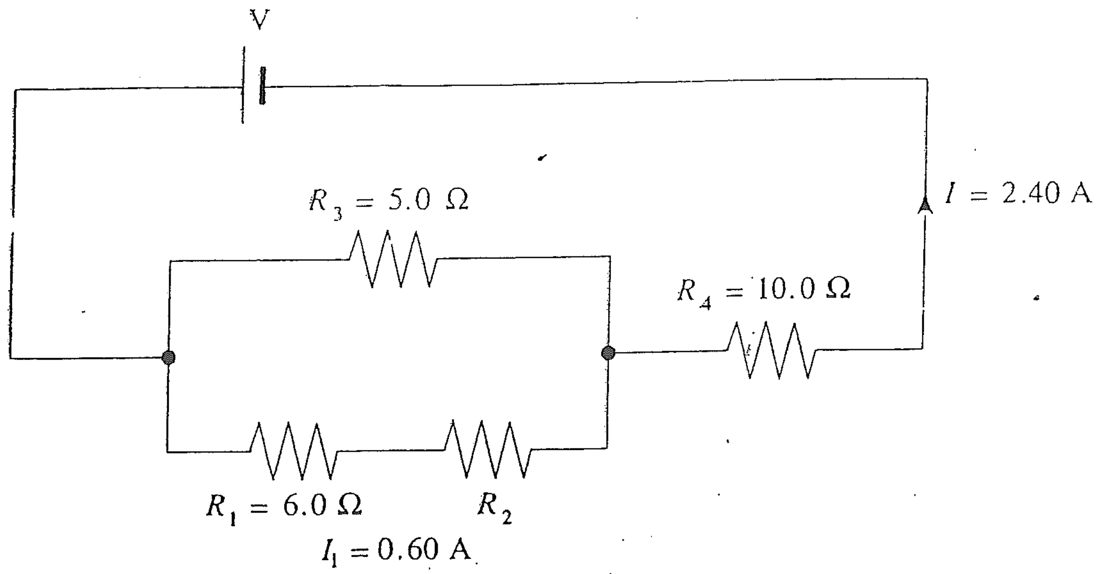
5. In the circuit below, resistor R_1 dissipates $0.40\ \text{W}$. Resistors R_2 and R_3 are identical.



What is the resistance of R_2?

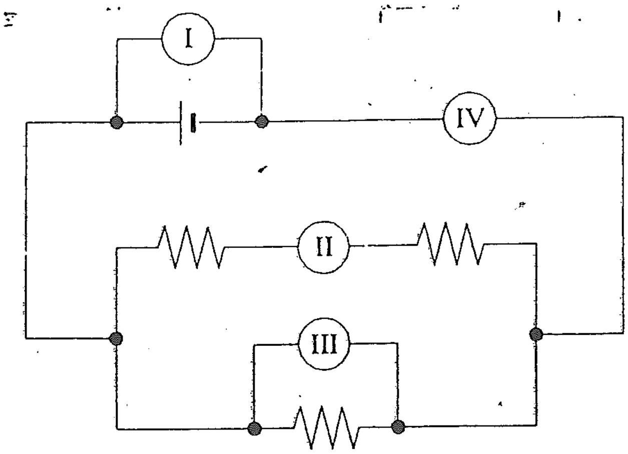
(7 marks)

6. a) Find the value of resistor R_2. (5 marks)



b) Find the potential difference of the power supply V. (2 marks)

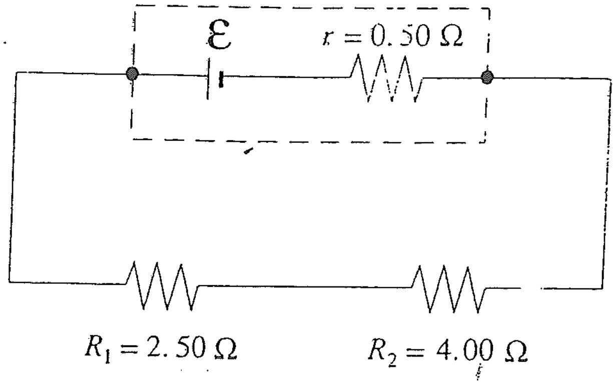
7. The circuit shown below includes two ammeters and two voltmeters. Identify the correct placement of these meters.



	AMMETERS	VOLTMETERS
A.	I, II	III, IV
B.	I, III	II, IV
C.	II, IV	I, III
D.	III, IV	I, II

8. A 120 V supply is connected to a heater of resistance 15 Ω. What must the resistance of another heater be in order to produce the same power output when connected to a 240 V

9. The cell shown in the diagram supplies a 1.80 A current to the resistors R_1 and R_2.

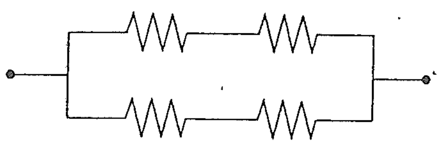


a) What is the terminal voltage of the cell? **(3 marks)**

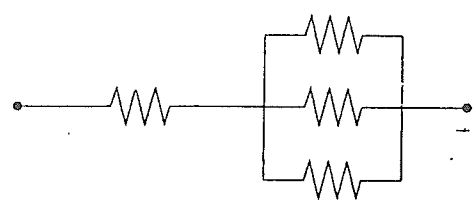
b) What is the emf of the cell? **(4 marks)**

10. Which of the following arrangements would draw the largest current when connected to the same potential difference? All resistors have the same value.

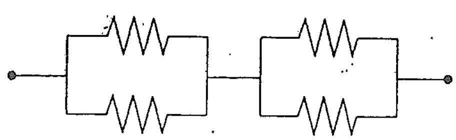
A.



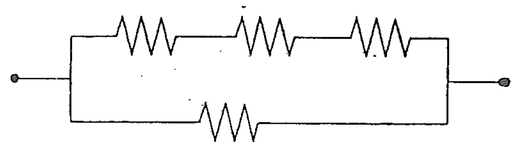
B.



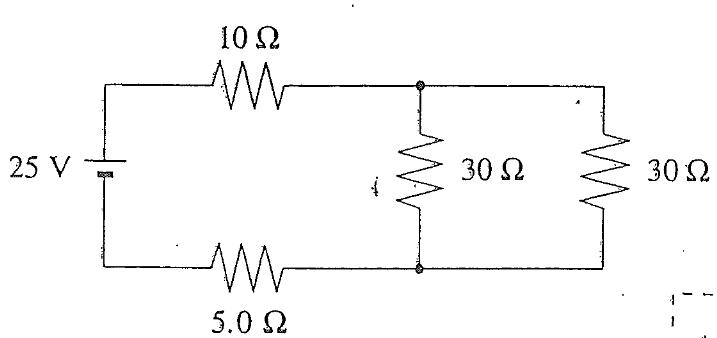
C.



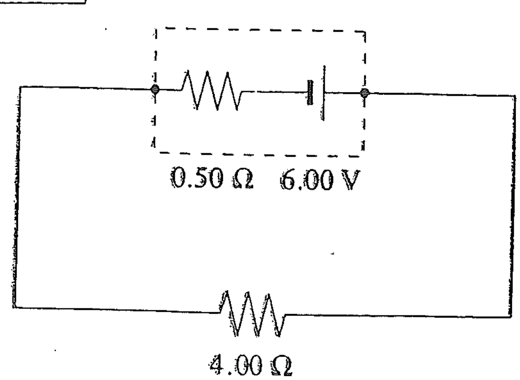
D.



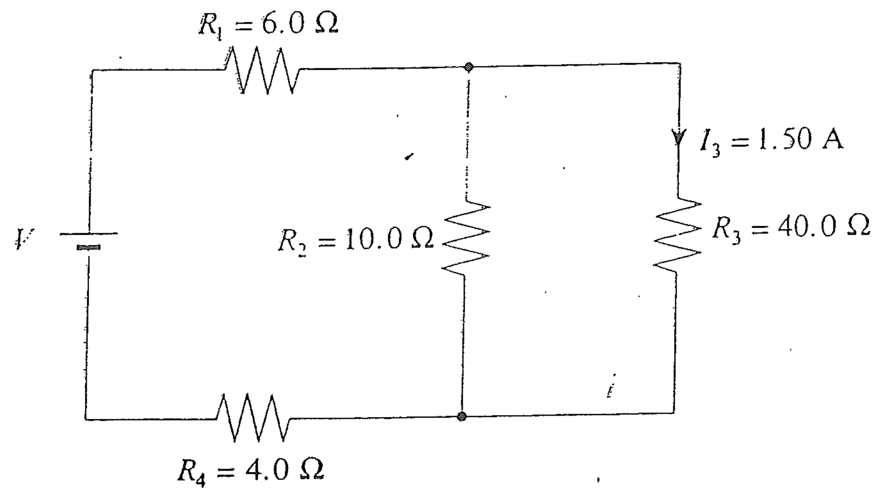
11. What is the power dissipated by the 5.0 Ω resistor in the following circuit?



12. What is the terminal voltage of the battery in the circuit shown

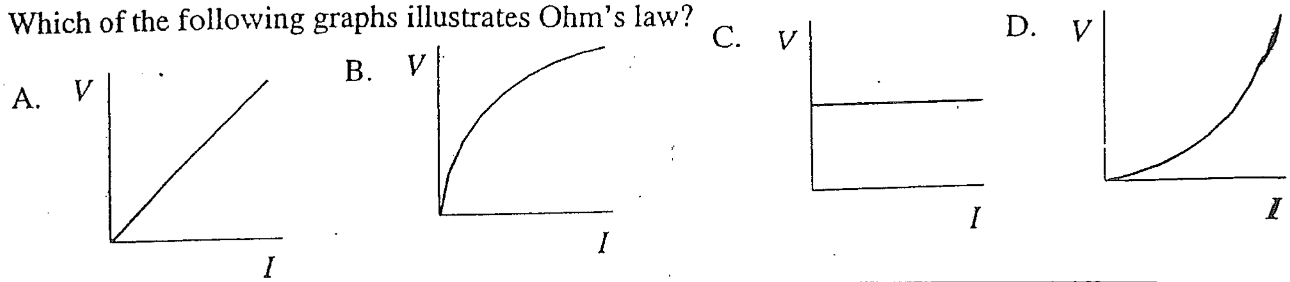


13. A current of 1.50 A flows through the 40.0 Ω resistor.

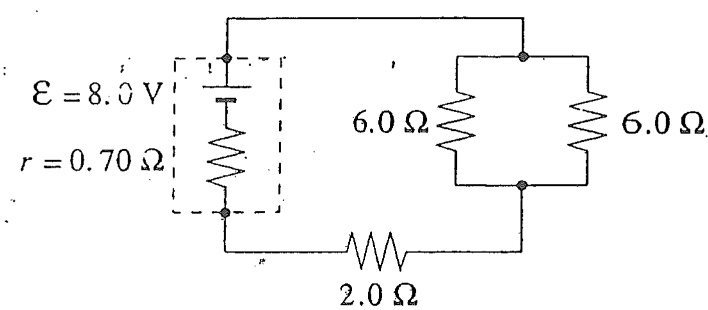


What is the potential difference of the power supply? **(7 marks)**

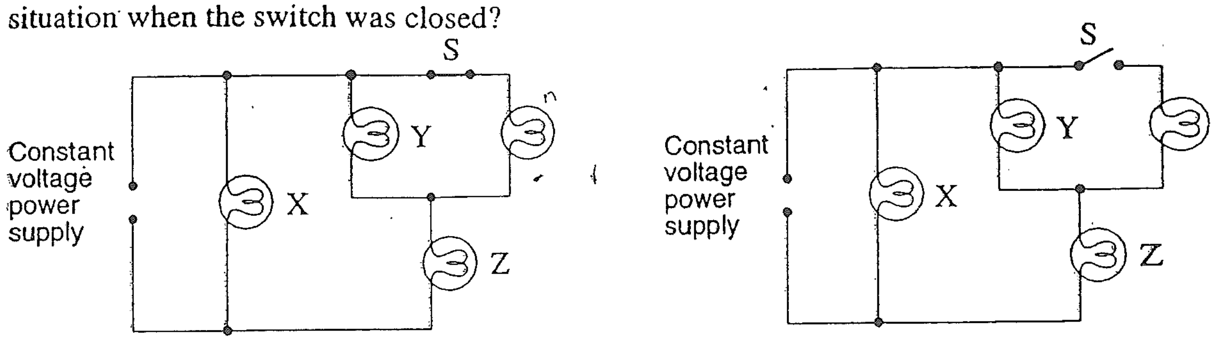
14. Which of the following graphs illustrates Ohm's law?



15. In the following circuit, what is the terminal voltage of the battery?



16. If switch S is opened, how does the brightness of each bulb (X, Y, and Z) compare to the situation when the switch was closed?

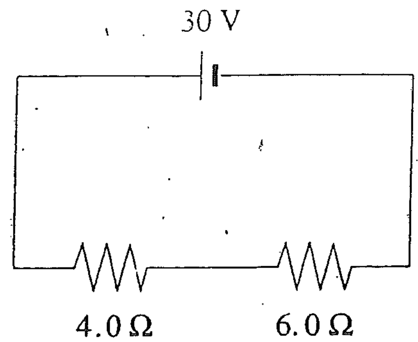


	BULB X	BULB Y	BULB Z
A.	same	same	same
B.	same	dimmer	brighter
C.	same	brighter	dimmer
D.	dimmer	dimmer	dimmer

17. Which household electrical appliance consumes the least energy in a typical month?

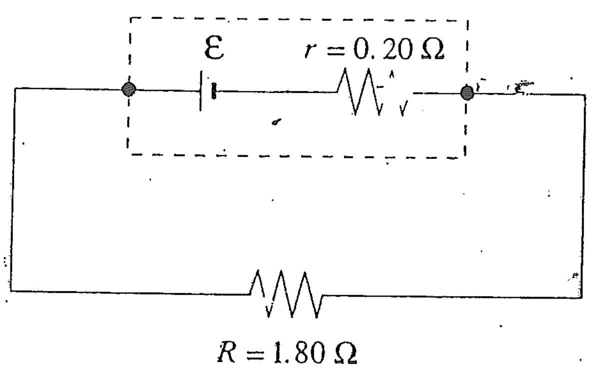
A. Stove
B. Dryer
C. Clock
D. Refrigerator

18. What is the power output of the 6.0 Ω resistor in the diagram?



19. A 12 V power supply is connected to an 8.0 Ω resistor for 50 s. How much charge passes through the resistor?

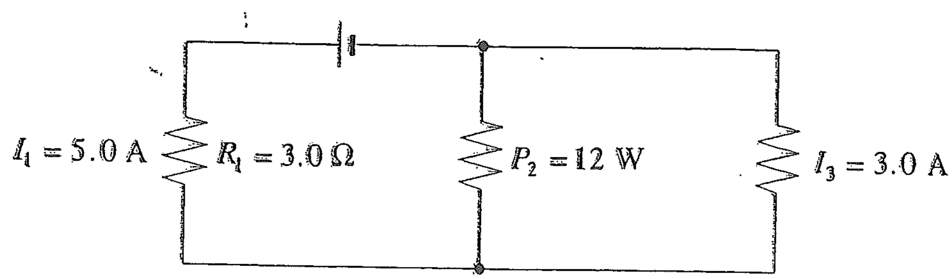
20. The cell shown delivers a 1.50 A current to the external circuit and has a terminal voltage of 2.70 V.



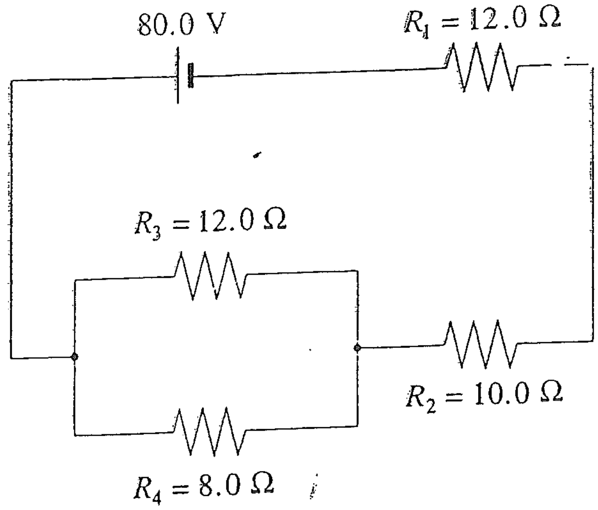
a) What is the emf of the cell? **(4 marks)**

b) The 1.80 Ω external resistance is replaced by other resistors and the current and terminal voltage are measured in each case. Using principles of physics, explain the relationship between terminal voltage V_T and current I as these resistors are changed?

21. What is the voltage of the power supply shown in the diagram?



22. What is the power dissipated in the 8.0 Ω resistor in the circuit as shown?

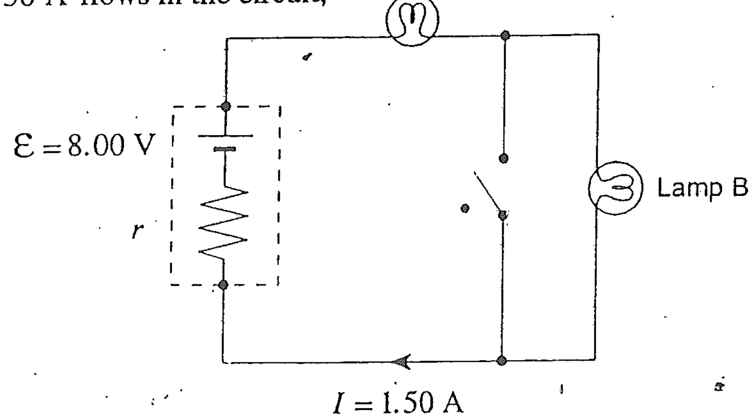


(7 marks)

23. The circuit shown consists of an 8.00 V battery and two light bulbs. Each light bulb dissipates 5.0 W. Assume that the light bulbs have a constant resistance. Switch S is open.

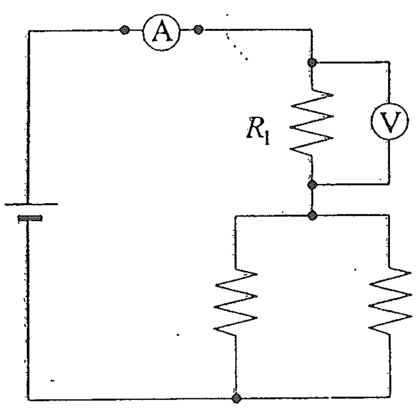
If a current of 1.50 A flows in the circuit, what is the internal resistance r of the battery?

(4 marks)

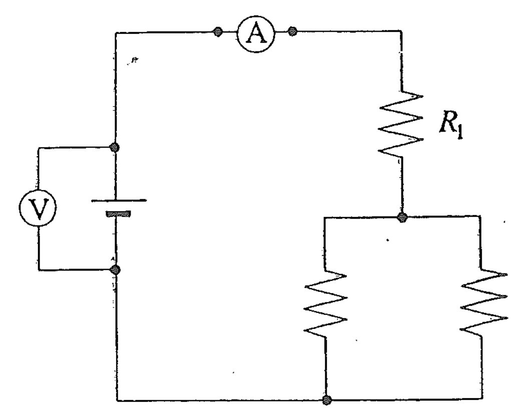


24. Which one of the following shows the correct placement of an ammeter and a voltmeter to determine the power output of resistor R_1?

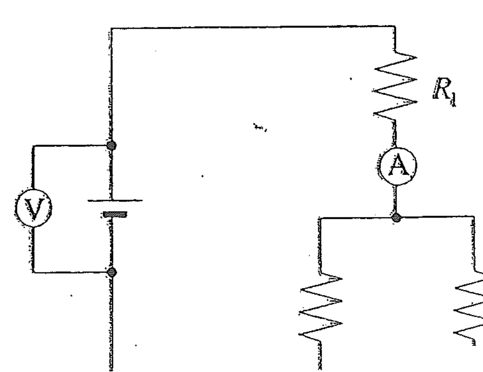
A.



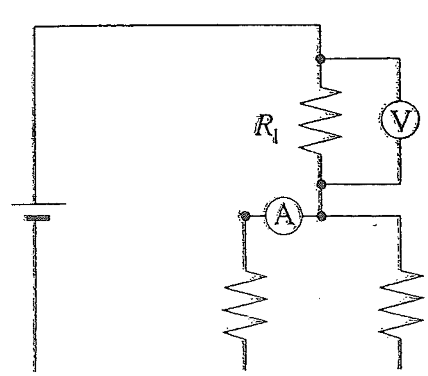
B.



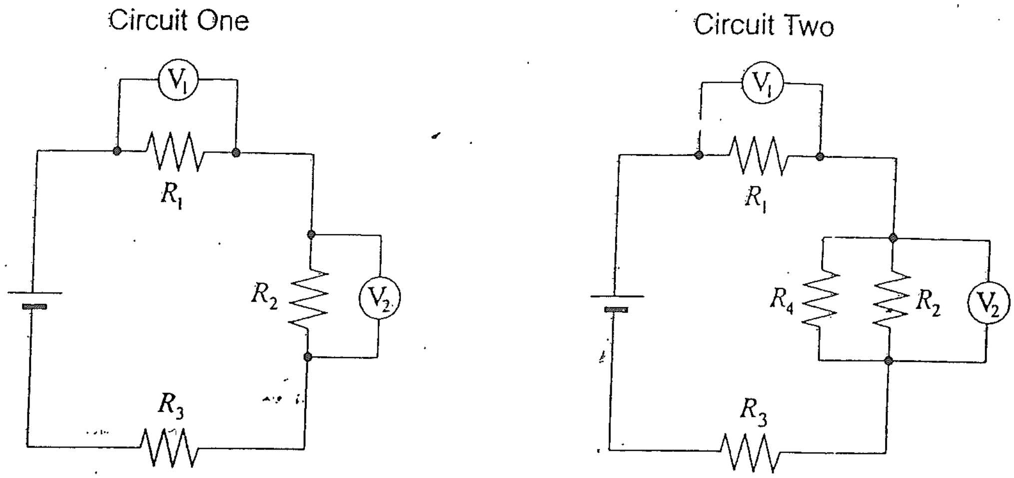
C.



D.



25. In circuit one, resistors and voltmeters are connected as shown. In circuit two, an additional resistor R_4 is placed in parallel with resistor R_2.



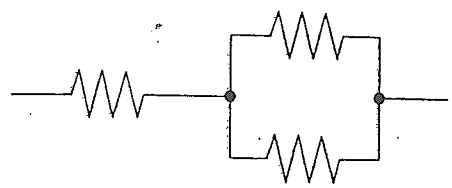
How have the values of V_1 and V_2 in circuit two changed compared to those in circuit one?

	V_1	V_2
A.	no change	decreased
B.	decreased	increased
C.	increased	decreased
D.	increased	no change

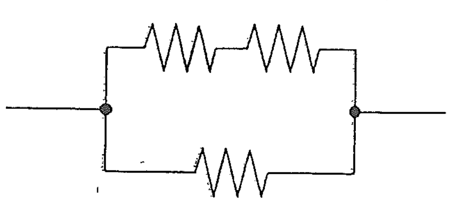
26. Which of the following combinations of three identical resistors has the least equivalent resistance?

A.

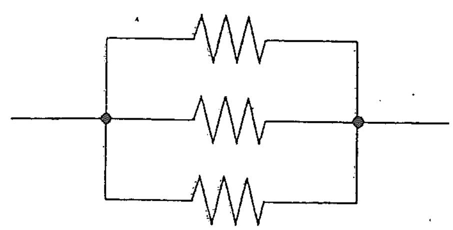
B.



C.



D.



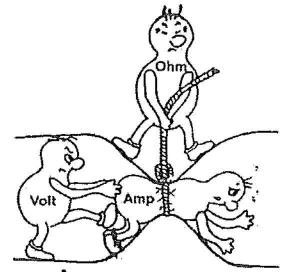
27. An electrical device with a constant resistance draws 0.75 A when connected to a 4.8 V source. What are the current and power for this device when it is connected to a 6.0 V source?

Electricity + Circuits Answers

1. E
2. C
3. 3.5 A
4. 1.5V
5. $P_1 = I^2R$, $I = \sqrt{P/R} = \sqrt{0.4/10} = 0.20\text{A}$ } 2 marks
   $V_1 = IR = 0.2(10) = 2\text{V}$ } 1 mark and $V_4 = IR = 0.2(15) = 3\text{V}$ } 1 mark
   $V_2 = V_3 = 12 - V_1 - V_4 = 7\text{V}$ } 1 mark
   $I_2 = I_3$ } 1 mark and $V_2 = I_2R_2$, $7\text{V} = 0.1\text{A} \times R_2$
   $V_2 = I_2R_2$, $7\text{V} = 0.1\text{A} \times R_2$ so $R_2 = 70\Omega$ } 1 mark
6. a) $I_3 = I - I_1 = 2.40 - 0.60 = 1.80\text{ A}$ ← 1 mark
   $V_3 = I_3R_3 = 1.80(5.0) = 9.0\text{ V}$ ← 1 mark
   $V_1 = I_1R_1 = 0.60(6.0) = 3.6\text{ V}$ ← 1 mark
   $V_2 = 9.0 - 3.6 = 5.4\text{ V}$ ← 1 mark
   $R_2 = \frac{V_2}{I_1} = \frac{5.4}{0.60} = 9.0\,\Omega$ ← 1 mark (Aug '99, 6LA)
   b) 33V
7. C
8. 60 Ω
9. a) 11.7V b) 13V
10. D
11. 3.5W
12. 5.3V
13. $V_3 = I_3R$ (1 mark) $= 1.50(40.0)$
   $V_3 = 60.0\text{ V}$ (1 mark)
   $V_2 = V_3 = 60.0\text{ V}$
   $I_2 = \frac{V_2}{R_2} = \frac{60.0}{10.0} = 6.00\text{ A}$ } 1 mark
   $I_t = I_3 + I_2 = 1.50 + 6.00 = 7.50\text{ A}$ (1 mark)
   $V_1 = I_1R_1$ (1 mark)
   $V_1 = 7.50(6.0) = 45\text{V}$
   $V_4 = I_4R_4 = 7.50(4.0) = 30\text{V}$ (1 mark)
   $V_t = V_b = V_1 + V_{11} + V_4 = 45 + 60 + 30$
   $V_b = 135\text{ V}$ } 1 mark
14. A
15. 7.0V
16. C
17. C
18. 54W
19. 75C
20. a) 3.00V b) from V=IR, as R increases, I decreases resulting in a lower "Ir" value. Thus from $V_{term} = \mathcal{E} - Ir$, as Ir decreases, the V_{term} increases.
21. 21V
22. 26W
23. 0.89Ω
24. A (Jun 00)
25. C
26. D
27. I = 0.94A, P = 5.6W

Electric Circuits Key

Physics 12 – **Electric Current – Ohm's Law**



The discovery of the battery began the investigation of electric currents (the flow of charge through conductors).

Electric Current - the rate of flow of electrical charge

- in metal conductors, it is the electrons that flow.

$$I = \frac{q}{t}$$

I (electric current), q (charge flow), t (time)

unit = C/s = A (ampere)

How do electrons "flow"?

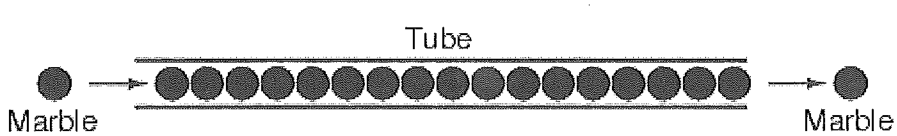
The electrons of different types of atoms have different degrees of freedom to move around. With some types of materials, such as metals, the outermost electrons in the atoms are so loosely bound that they chaotically move in the space between the atoms of that material by nothing more than the influence of room-temperature heat energy. Because these virtually unbound electrons are free to leave their respective atoms and float around in the space between adjacent atoms, they are often called ***free electrons.***

In other types of materials such as glass, the atoms' electrons have very little freedom to move around. While external forces such as physical rubbing can force some of these electrons to leave their respective atoms and transfer to the atoms of another material, they do not move between atoms within that material very easily.

This relative mobility of electrons within a material is known as electric *conductivity*. Conductivity is determined by the types of atoms in a material (the number of protons in each atom's nucleus, determining its chemical identity) and how the atoms are linked together with one another. Materials with high electron mobility (many free electrons) are called *conductors*, while materials with low electron mobility (few or no free electrons) are called *insulators*.

While the normal motion of "free" electrons in a conductor is random, with no particular direction or speed, electrons can be influenced to move in a coordinated fashion through a conductive material. This uniform motion of electrons is what we call *electricity*, or *electric current*. This is in contrast to *static* electricity, which is an unmoving accumulation of electric charge.

As each electron moves uniformly through a conductor, it pushes on the one ahead of it, such that all the electrons move together as a group. The starting and stopping of electron flow through the length of a conductive path is virtually instantaneous from one end of a conductor to the other, even though the motion of each electron may be very slow. An approximate analogy is that of a tube filled end-to-end with marbles:



The tube is full of marbles, just as a conductor is full of free electrons ready to be moved by an outside influence. If a single marble is suddenly inserted into this full tube on the left-hand side, another marble will immediately try to exit the tube on the right. Even though each marble only traveled a short distance, the transfer of motion through the tube is virtually instantaneous from the left end to the right end, no matter how long the tube is. With electricity, the overall effect from one end of a conductor to the other happens at the speed of light!!! Each individual electron, though, travels through the conductor at a *much* slower pace. (Information from http://openbookproject.net/electricCircuits/DC/DC_1.html)

Charges will not move through a conductor unless there is a potential difference (voltage). This voltage is provided by sources such as batteries and generators.

In an electric circuit, there must be a:

- Voltage source
- A complete pathway for the charge to flow through

If we have both of the requirements for a circuit, what will the rate of flow actually depend on?

A. POTENTIAL DIFFERENCE (VOLTAGE)

As we saw in previous lessons, a **potential difference will cause the charge to move as potential energy is converted into kinetic energy** $\left(\Delta V = \frac{\Delta E}{q}\right)$.

It follows then that the greater the potential difference, the greater the change in energy. The greater the change in energy, the greater the kinetic energy of the charge flow will be. This means that it will flow "faster" or it will move the same distance in less time this is what we measure for electric current.

Therefore: Electric Current is directly related to Voltage (potential difference). $I \propto V$

*if we increase the voltage, we increase current

B. RESISTANCE

There is always resistance to the flow of charged particles through a conductor. This is why conductors get warm or hot while a current is flowing through them. This is due to friction from the electrons passing over the material and transforming kinetic energy into thermal energy.

Because resistance causes friction, the current is slowed down.

Therefore: **Electric Current is inversely related to Resistance.** $I \propto \frac{1}{r}$

*increased resistance slows electrons so current decreases

The relationship between current, voltage and resistance was discovered by Ohm in 1826 and became known as **Ohm's Law**.

$$I = \frac{V}{R}$$

The formula for this relationship is usually written as → $V = IR$

The unit for resistance is the ohm. - Ω

Electron Flow vs. Conventional Current

Two ways of thinking about electric current have developed:

1. **Electron Flow** – it is the electrons that flow through the conductor when there is an electric current

Electron flow is always from negative (-) to positive (+).

*actual

2. **Conventional Current** – a positive charge flow.

Positive charges flow from positive (+) to negative (-).

*what we will use

This is now known to be incorrect, but it likely comes from the defining of electric potential and electric fields in terms of a moving positive charge.

Because of this history, electric current continues to refer to conventional current in college and university textbooks. Therefore, **unless it is indicated otherwise, electric current will refer to conventional current.**

Electric Power

Power is the rate of doing work or using energy. $P = \frac{W}{t} = \frac{\Delta E}{t}$

When we combine this with Ohm's Law, we can derive other relationships for power using electrical terms.

$P = I^2R$ ← power loss or dissapated

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

$P = IV$

Example One: What is the electric current through a conductor if a charge of 2.00 C flows through a point in the conductor in 10.0 s?

$I = \frac{q}{t} = \frac{2.00}{10.0} = 2.0 \times 10^{-1}$ A

Example Two: Calculate the resistance in a conductor if the potential difference is 6.0 V and the current is 10.0 A.

$V = IR \quad 6.0 = 10.0R \quad R = 0.60\,\Omega$

Example Three: An electrical appliance uses 1.00 x 10^2 W when connected to a 1.20 x 10^2 V power line. What is the resistance in the appliance?

$P = \frac{V^2}{R} \quad 100 = \frac{120^2}{R} \quad R = 144\,\Omega$

Example Four: A potential difference of 24 V is applied to a 75 Ω resistor for 20 s.

a) How much current flows through the resistor?
b) How much charge passes through the resistor?
c) How many electrons pass through the resistor?

a) $V = IR \quad 24 = I(75) \quad I = 0.32$ A

b) $I = \frac{q}{t} \quad 0.32 = \frac{q}{20} \quad q = 6.4$ C

c) $q = N \cdot e$ (q: total charge; N: #; e: charge of one e^-)

$6.4 = N \cdot (1.6 \times 10^{-19})$

$N = 4.0 \times 10^{19}$ electrons

Example Five: A 3.0 V battery is used to operate a 1.2 W flashlight bulb for 5.0 minutes.

a) What is the current supplied by the battery?
b) What is the resistance of the bulb?
c) How much energy does the flashbulb use during this time?
d) What total charge passes through the bulb in this time?
e) What is the total number of electrons that pass through the bulb during this time?

a) $P = IV \quad 1.2 = I(3.0) \quad I = 0.40$ A

b) $V = IR \quad 3.0 = 0.40R \quad R = 7.5\,\Omega$

c) $P = \frac{\Delta E}{t} \quad 1.2 = \frac{\Delta E}{(5.0)(60)}$

$\Delta E = 360$ J

d) $I = \frac{q}{t} \quad 0.4 = \frac{q}{300}$

$q = 120$ C

e) $q = N \cdot e^-$

$120 = N \cdot (1.6 \times 10^{-19})$

$N = 7.5 \times 10^{20}$ electrons

Electric Current (Ohm's Law) and Electric Power Problems:

1. A current of 3.60 A flows for 15.3 s through a conductor. Calculate the number of electrons that pass through a point in a conductor during this time. (3.44×10^{20} electrons)

$I = \frac{q}{t}$ $3.60 = \frac{q}{15.3}$ $q = 55.1\ C$ $55.1 = N \cdot (1.6 \times 10^{-19})$

$N = 3.44 \times 10^{20}$ electrons

2. How long would it take 2.0×10^{20} electrons to pass through a point in a conductor if the current was 10.0 A? (3.2 s)

$q = (2.0 \times 10^{20})(1.6 \times 10^{-19})$ $10.0 = \frac{32}{t}$ $t = 3.2\ s$

$= 32\ C$

3. Calculate the current through a conductor if a charge of 5.60 C passes through a point in the conductor in 15.4 s. (0.364 A)

$I = \frac{5.60}{15.4} = 0.364\ A$

4. What potential difference is required across a conductor to produce a current of 8.00 A is there is a resistance in the conductor of 12.0 Ω? (96 V)

$V = IR = (8.00)(12.0) = 96\ V$

5. What is the heat produced in a conductor in 25.0 s if there is a current of 11.0 A and a resistance in the conductor of 7.20 Ω? (2.18×10^4 J)

$P = I^2 R = (11.0)^2(7.20) = 871.2\ W$

$P = \frac{\Delta E}{t}$ $871.2 = \frac{\Delta E}{25.0}$ $\Delta E = 2.18 \times 10^4\ J$

6. A particular conductor produces 1.50×10^2 J of heat in 5.50 s. If the current through the conductor is 10.0 A, what is the resistance in the conductor? (0.273 Ω)

$P = \frac{150}{5.50} = 27.3\ W$ $P = I^2 R$ $27.3 = (10.0)^2 R$

$R = 0.273\ \Omega$

7. What is the current through a 4.00×10^2 W electric appliance when it is connected to a 1.20×10^2 V power line? (3.33 A)

$P = IV$ $400 = I(120)$ $I = 3.33\ A$

8. What potential difference is required across an electrical appliance to produce a current of 20.0 A when there is a resistance in the appliance of 6.00 Ω? How many electrons pass through the electrical appliance every minute? (120 V, 7.5 x 10^{21} electrons)

$V = IR = (20.0)(6.00) = \underline{120V}$

$I = \frac{q}{t}$ $\quad 20.0 = \frac{q}{60}$ $\quad q = 1200\ C$ $\quad 1200 = N \cdot (1.6 \times 10^{-19})$

$N = \underline{7.5 \times 10^{21}}$ electrons

9. An electric clock is operated with a voltage of 1.5 V and a current of 3.3 A. A radio with a resistance of 2.0 Ω is operated with a voltage of 3.0 V. A light bulb with a resistance of 1.5 Ω is operated with a current of 2.0 A. Which of the household electrical appliances has the greatest rate of energy consumption? (light bulb)

$P = IV$ $\quad$ clock → $P = (3.3)(1.5) = 4.95\ W$

$P = \frac{V^2}{R}$ $\quad$ radio → $P = \frac{3.0^2}{2.0} = 4.50\ W$

$P = I^2R$ $\quad$ light bulb → $P = (2.0)^2(1.5) = 6.0\ W$

*the light bulb with $\underline{6.0\ W}$

10. An electric furnace of resistance 6.0 Ω is connected to a 240 V power supply. Find the resistance of another furnace if it produces the same power output when it is connected to a 120 V power supply. (1.5 Ω)

$P = \frac{V^2}{R} = \frac{240^2}{6.0} = 9600\ W$

$9600 = \frac{120^2}{R}$ $\quad R = 1.5\ \Omega$

11. A clock uses a 6.0 W motor and 1.5 V battery and runs all day, every day. If the 1.5 V battery has 8.5 x 10^4 C of stored charge, how long does it take for the battery to lose its charge?

$P = IV$ $\quad 6.0 = I(1.5)$ $\quad I = 4.0\ A$

$I = \frac{q}{t}$ $\quad 4.0 = \frac{8.5 \times 10^4}{t}$ $\quad t = 21250\ s$

$= \underline{5.9\ hours}$

12. A handheld electric fan operates on a 6.0 V battery. The potential difference causes an electric charge of 0.13 C to pass through the resistor of the fan in 0.26 s.

a) Find the power dissipated by the resistor. (3.0 W)

b) If the fan is connected to a 9.0 V battery, find the current and power for this fan. (0.75A, 6.75 W)

a) $P = IV$ $\quad I = \frac{q}{t} = \frac{0.13}{0.26} = 0.50\ A$

$P = (0.50)(6.0)$

$P = \underline{3.0 W}$

b) before switch: $V = IR$ $\quad 6.0 = 0.50\ R$ $\quad R = 12\ \Omega$

after: $9.0 = I(12)$ $\quad I = \underline{0.75 A}$ $\quad P = IV = (0.75)(9.0) = \underline{6.75 W}$

13. An electric crane operated with a voltage of 120 V and a current of 4.2 A lifts a 300 kg piano 2.8 m vertically in 32 s. Find the efficiency of the crane. (51 %)

$P_{out} = \frac{mgh}{t} = \frac{(300)(9.8)(2.8)}{32} = 257.25\ W$

$P_{in} \rightarrow P = IV = (4.2)(120) = 504\ W$

$\frac{257.25}{504} \times 100 = \underline{51\%}$

14. Electricity is transmitted at high potential from power plants to homes. Explain the reason for the transmission of electricity at high potential.

P_{loss} is based on resistance in wires

$P_{loss} = I^2R$

&

$P = IV$

higher V means lower I into

so... the greater the voltage is, the lower the current and therefore less power is lost in the transmission lines.

Physics 12 – **Electric Circuits – (Kirchoff's Laws)**

An **electric circuit is a pathway that allows charges to flow.**

Within an electric circuit, there must be:

A. voltage source (ie. battery)

B. complete path for electrons to flow through a conductor

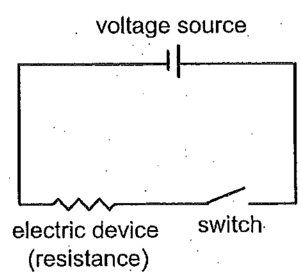
When we place an electric device like a toaster or light bulb in the circuit, this device becomes part of the circuit. * device becomes part of the complete path

As the charge flows through the device, the electrical energy is converted into other forms of energy like mechanical and heat energy.

The reason heat energy is produced is due to the friction produced by resistance to the charge flow. In order to avoid overheating and fire, circuits in our homes and cars have **circuit breakers or fuses**. They are heat sensitive and their purpose is to create a break in the circuit, shutting it down when the current is too great.

* a certain level of heat will melt the fuse or "trip" the breaker = creates break in path / circuit

Also included in most circuits are **switches** which are a means of breaking the path for the charge to stop the flow and "turn off" the circuit.

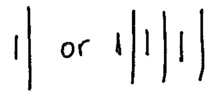


Electric current can be either direct (DC) or alternating (AC).

Batteries produce direct current. This means that the charge always flows in the same direction through the circuit. With conventional current this means the charge always flows from the positive terminal to the negative terminal.

Electrical generators can produce either direct or alternating current. With alternating current, the charge in the circuit flows in one direction and then the other. The circuits in our homes use alternating current.

Symbols for drawing circuits –

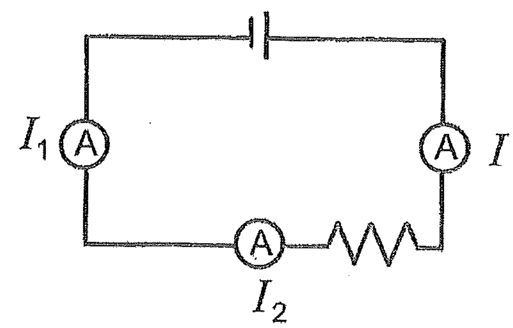
Direct Current:  Negative terminal →  ← Positive terminal

Alternating Current:  Resistor: 

Resistors in Series and Parallel Circuits

A. Series Circuit:

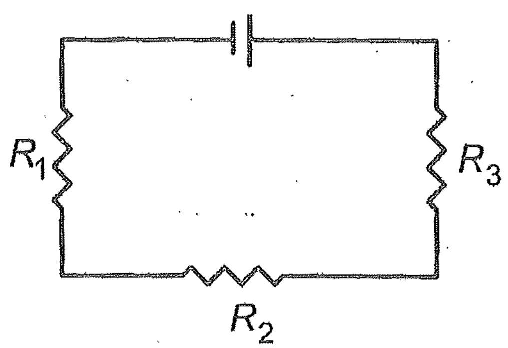
- Resistors are connected end-to-end.



Current: The SAME current flows through each resistor when connected in series.

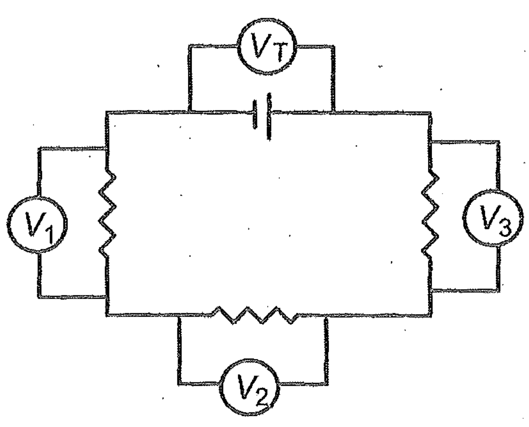
$$I_1 = I_2 = I_3 \ldots$$

Equivalent Resistance: The equivalent resistance (can also be thought of as total) in series is equal to the sum of the individual resistances.



$$R_{eq} = R_1 + R_2 + R_3 + \ldots$$
$$(R_T)$$

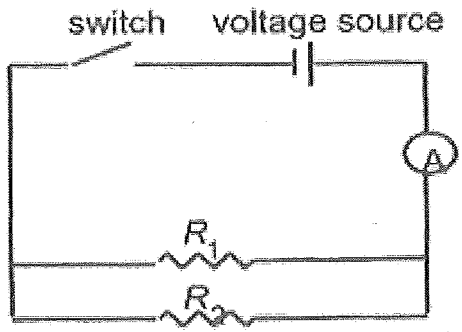
Voltage: The total voltage is equal to the sum of the voltage across each resistor.



$$V_T = V_1 + V_2 + V_3 + \ldots$$

B. Parallel Circuits: (this what we have in our homes)

- The charge has more than one path. **The charge can travel through R_1 or R_2. If R_1 burns out (creates a break), the charge can still travel through R_2.**

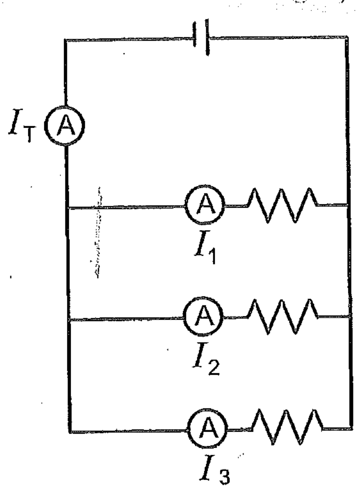


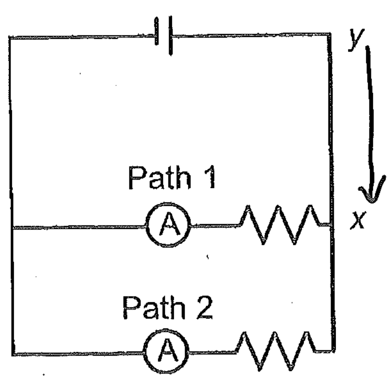
Current: The amount of charge at any point can be different.

* soldiers marching → can take different paths so the number of soldiers at any point can be different

Kirchoff's Current Law states – the sum of the currents entering a junction equals the sum of the currents leaving a junction.

→ the current is the movement of electrons, and if electrons move into a path, they must come out.

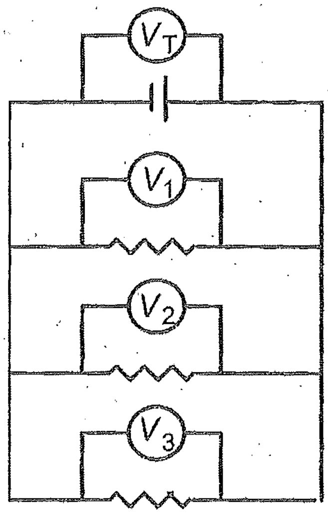




e^- travelling from y to x will be equal to the total # of e^- taking path 1 and 2

So... $I_T = I_1 + I_2 + I_3 + \ldots$

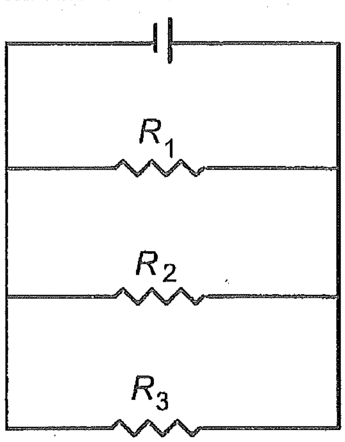
Voltage: The same voltage is applied across each device/resistor.



- since each resistor is connected across the <u>same</u> potential difference
  = the same voltage is applied to each R

$$V_T = V_1 = V_2 = V_3 = \ldots$$

Resistance: The total resistance in a parallel circuit is the sum of the reciprocals of the individual resistances.



* in a parallel circuit, the <u>more</u> <u>paths</u> there are, the <u>less</u> <u>total</u> <u>resistance</u> there will be.

Why?

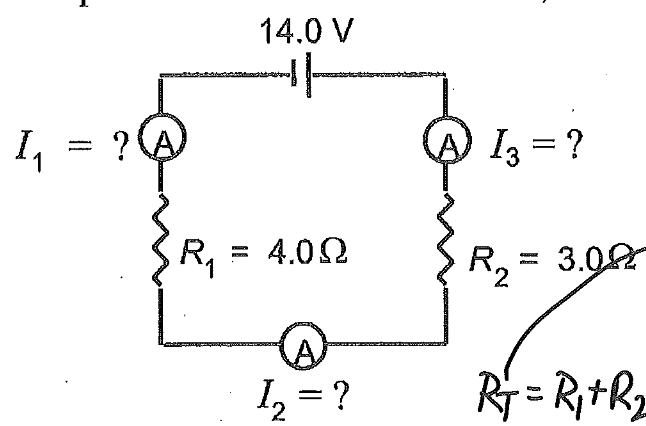
- If <u>all</u> the electrons have to pass through <u>one</u> resistor, there will be a lot of friction (resistance)
- However, if there is <u>more</u> <u>than</u> <u>one</u> <u>path</u>, there will be less electrons creating friction in each resistor = <u>less resistance</u>.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

SUMMARY:

	SERIES CIRCUIT	PARALLEL CIRCUIT
CURRENT	$I_T = I_1 = I_2 = I_3 = \ldots$	$I_T = I_1 + I_2 + I_3 + \ldots$
VOLTAGE	$V_T = V_1 + V_2 + V_3 + \ldots$	$V_T = V_1 = V_2 = V_3 = \ldots$
RESISTANCE	$R_T = R_1 + R_2 + R_3 + \ldots$	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$

Example One: What are the values of I_1, I_2 and I_3 in this circuit?



*use Ohm's & Kirchoff's Laws:

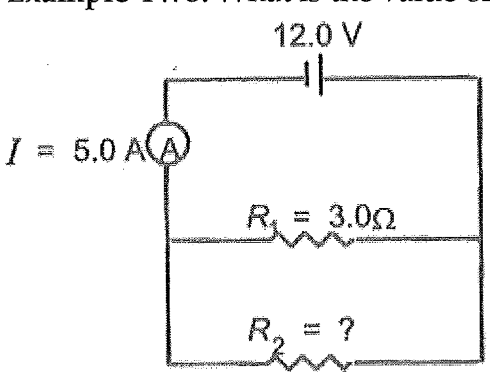
$V_T = I_T R_T$

$14.0 = I_T (7.0)$ $I_T = 2.0$ A

$R_T = R_1 + R_2 = 7.0\Omega$

$I_T = I_1 = I_2 = I_3 = \underline{2.0\text{A}}$

Example Two: What is the value of R_2 in this circuit?



Find R_T → $V_T = I_T R_T$

$12.0 = 5.0 R_T$

$R_T = 2.4\Omega$

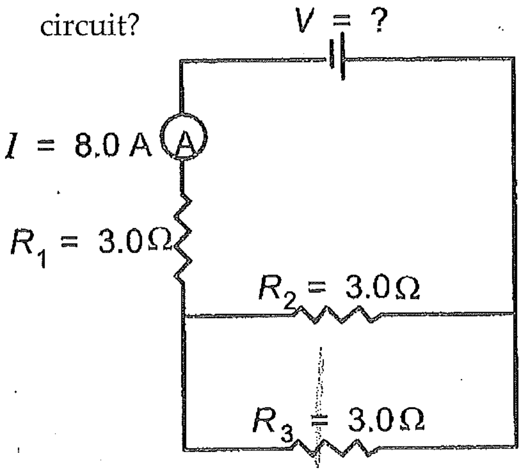
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

$2.4^{-1} = 3.0^{-1} + R_2^{-1}$ $R_2 = \underline{12\Omega}$

Combination Circuits – Series and Parallel in the Same Circuit:

If one section of a circuit is in series and another is in parallel, the circuit can be analyzed in parts, according to the respective series and parallel total resistances of the various sections.

Example Three: What is the potential difference supplied by the power source in this circuit?



① Find R_T for parallel and add to R_T for series

$R_{Tp}^{-1} = 3.0^{-1} + 3.0^{-1}$

$R_{Tp} = 1.5\,\Omega$ $\quad R_T = 4.5\,\Omega$

$R_{Ts} = 3.0\,\Omega$

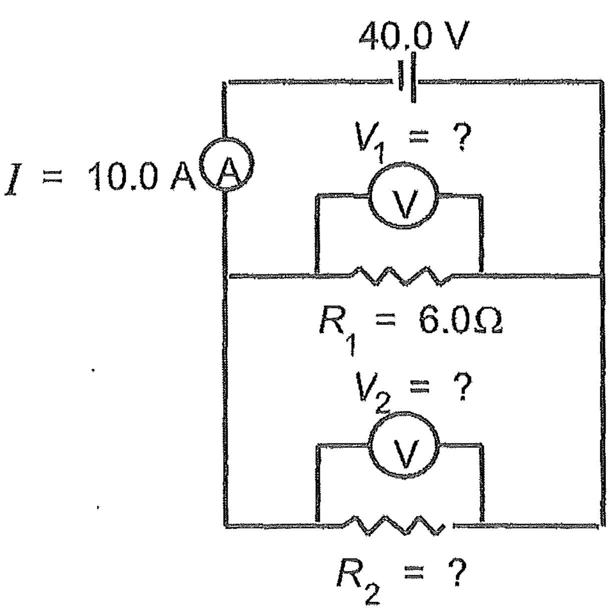
↙ to R encountered throughout circuit

② $V = IR = (8.0)(4.5)$

in series with power source

$V = \underline{36\text{ V}}$

Example Four: What are the values of V_1, V_2, and R_2 in this circuit?



Find R_T for circuit:

$V_T = I_T R_T$

$40 = (10.0)R_T \quad R_T = 4.0\,\Omega$

parallel:

$R_T^{-1} = R_1^{-1} + R_2^{-1}$

$4.0^{-1} = 6.0^{-1} + R_2^{-1} \quad R_2 = \underline{12\,\Omega}$

parallel:

$V_1 = V_2 = V_T = \underline{40\text{V}}$

Electric Circuit Problems:

1. A circuit consists of a 12 V battery connected across a single resistor. If the current in the circuit is 3.0 A, calculate the size of the resistor. (4.0 Ω)

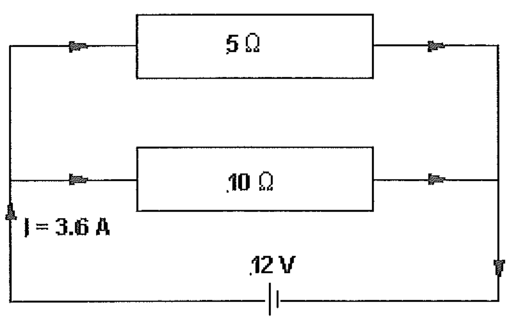
   $V = IR \quad 12 = 3.0(R) \quad R = 4.0\,\Omega$

2. Two 5.0 Ω resistors are connected in series with a 12 V battery. Determine: (a) the potential difference across each resistor; and (b) the current flowing in the circuit. (6.0 V, 1.2 A) ↖ V

   $V_1 = I_1 R_1 = (1.2)(5.0) = 6.0\,V$

   $V = IR \quad 12 = I(10) \quad I = 1.2\,A$

3. Two resistors of size 10 Ω and 5.0 Ω are connected in parallel as shown below.



a. If 3.6 A of current flows into the parallel branch, determine the current flowing in each of the resistors. (2.4 A in the top resistor & 1.2 A in the bottom resistor)

   $V = IR \quad 12 = I(5.0) \quad I_{top} = 2.4\,A$

   $12 = I(10) \quad I_{bottom} = 1.2\,A$

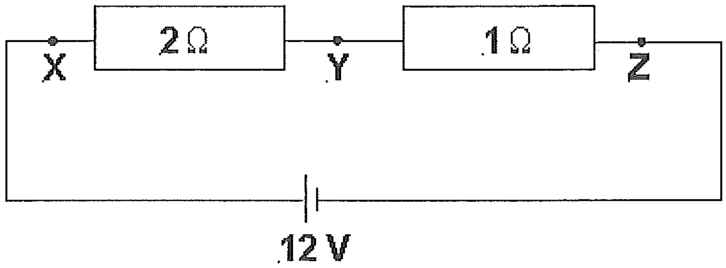
b. What is the potential difference across each of the resistors? (12V)

   $V_T = V_1 = V_2 = 12\,V$

c. How much current will flow out of the parallel branch? Why? (3.6 A)

   3.6 A = all in same branch again (series)

4. Consider the following circuit and then answer the questions below.



$12 = I(3)$

$I = 4.0A$

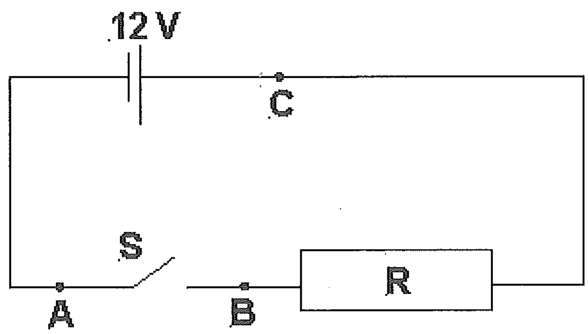
a. State the potential difference between X and Z. 12 V

b. State the potential difference between X and Y. $V = IR = (4.0)(2) = 8$ V

c. How much potential is left at Y? 4 V $(12 - 8 = 4)$

(a) 12V, (b) 8V, (c) 4V)

5. The circuit below shows a resistor, R, connected in series to a 12 V battery across an open switch, S.



a. If R = 6.0 Ω, how much current flows in the circuit with the switch open? None

b. When the switch is closed and R = 6Ω, determine:

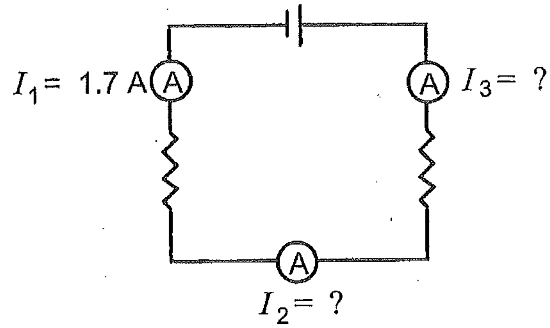
i. the current in the circuit; $V = IR \quad 12 = I(6\Omega) = 2$ A

ii. the potential difference between A and B; and 0 V (no resistance)

iii. the potential difference between B and C. 12V

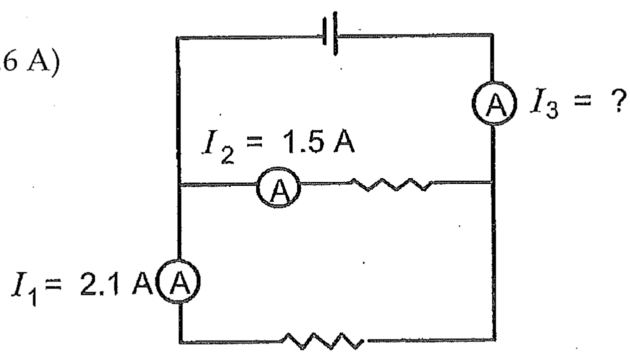
(a) 0A (b) (i) 2A, (ii) 0V, (iii) 12V

6. What are the values for I_2 and I_3 in this circuit? (1.7 A)



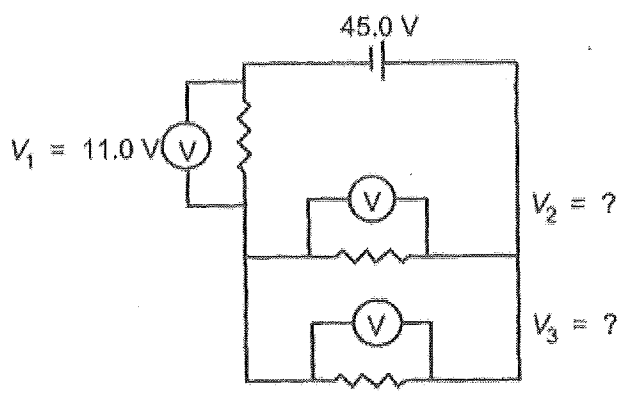
$I_1 = I_2 = I_3 = 1.7\ A$

7. What is the value of I_3 in this circuit? (3.6 A)



$I_3 = I_1 + I_2 = 3.6\ A$

8. What are the values of V_2 and V_3 in this circuit? (34.0 V)



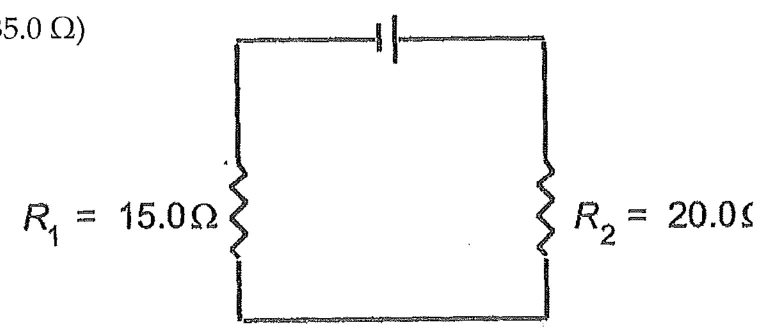
$V_2 = V_3 = 34.0\ V$

$(45.0 - 11.0 = 34.0\ V)$

9. What is the total resistance in this circuit? (35.0 Ω)

$R_T = R_1 + R_2$

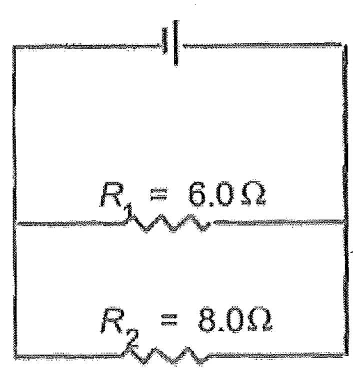
$= 15 + 20 = 35.0\ \Omega$



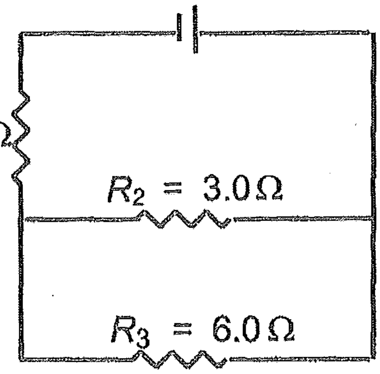
10. What is the total resistance in this circuit? (3.4 Ω)

$R_T^{-1} = R_1^{-1} + R_2^{-1}$

$= 6.0^{-1} + 8.0^{-1} = 3.4\ \Omega$



11. What is the total resistance in this circuit? (4.0 Ω)



$R_{Tp}^{-1} = 3.0^{-1} + 6.0^{-1}$

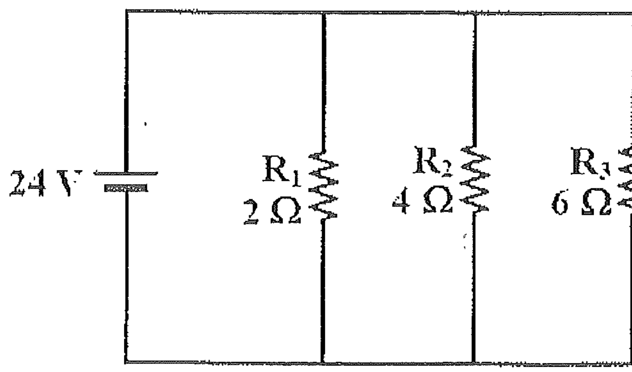
$= 2.0\,\Omega$

$+$

$R_{Ts} = 2.0\,\Omega$

$= 4.0\,\Omega$

12. Three resistors are connected in parallel with a 24 V battery as shown in the diagram.



a) Find the total resistance of the three resistors. (1.1 Ω)

$R_T^{-1} = 2^{-1} + 4^{-1} + 6^{-1}$ $R_T = 1.1\,\Omega$

b) Find the total current supplied by the battery and the current through each resistor. (I_T = 22A, I_1 = 12 A, I_2 = 6.0 A, I_3 = 4.0 A)

$24 = I_T(1.1)$ $I_T = 22\,A$

$24 = I_1(2)$ $I_1 = 12\,A$

$24 = I_2(4)$ $I_2 = 6.0\,A$

$24 = I(6)$ $I_3 = 4.0\,A$

c) Find the potential difference across each resistor.

same in parallel = 24 V

d) Find the power dissipated by each resistor and the total power dissipated by the circuit.

$P = I^2R$ $P_1 = (12)^2(2) = 288\,W$

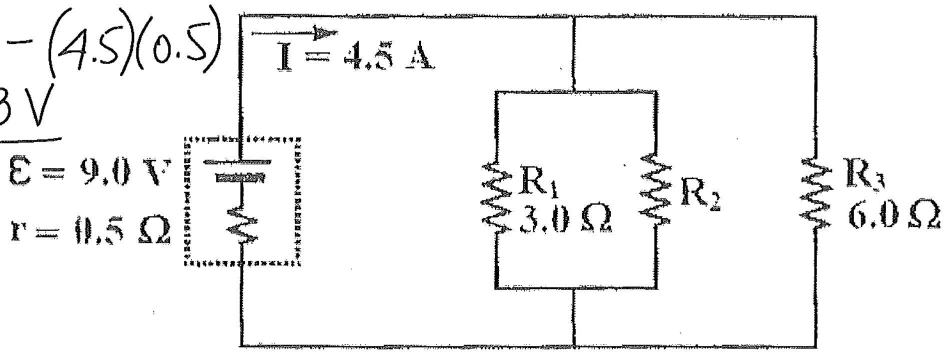
$P_2 = (6)^2(4) = 144\,W$

$P_3 = (4)^2(6) = 96\,W$

13. The diagram shows a circuit composed of a battery and three resistors.

$V = 9.0 - (4.5)(0.5)$

$V = 6.8\,V$



Find the resistance of R_2. (6.0 Ω)

$V = IR$

$6.8 = 4.5 R_T$

$R_T = 1.5\,\Omega$

$R_{T_1}^{-1} = R_{1+2}^{-1} + R_3^{-1}$

$1.5^{-1} = R_{1+2}^{-1} + 6.0^{-1}$

$R_{1+2} = 2\,\Omega$

$R_T^{-1} = R_1^{-1} + R_2^{-1}$

$2.0^{-1} = 3.0^{-1} + R_2^{-1}$

$R_2 = 6.0\,\Omega$

Find the current through each resistor. (2.3 A, 1.1 A, 1.1 A)

$6.8 = I_1(3.0)$ $I_1 = 2.3A$

$6.8 = I_2(6.0)$ $I_2 = 1.1\,A$

$6.8 = I_3(6.0)$

$I_3 = 1.1\,A$

14. Two identical bulbs are connected to a battery, one set in series, the other set in parallel.

a) Which connection produces more light?

b) If one bulbs in parallel burns out, what happens to the other bulb?

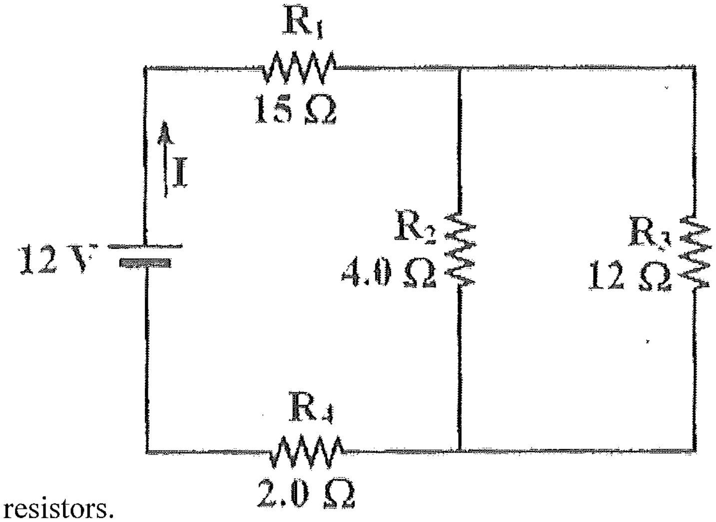
c) Which way are the headlights of a car connected? Explain your answer.

a) parallel bulbs = brighter
- R_T is less in parallel so more power is converted to light

b) the other bulbs burn brighter
- when one bulb burns out, the R_T ↑ & total current ↓
- but, the current through the working bulb will be higher than it previously was = brighter

c) parallel → if one burns out, there is still a complete circuit to the other (stays lit)

15. In the circuit shown, four resistors are connected with a 12 V battery in a way that combines series and parallel features.



a) Find the total resistance of the four resistors.

a) $R_{Tp}^{-1} = 4.0^{-1} + 12^{-1}$ $R_{Tp} = 3.0\,\Omega$

$3.0 + 2.0 + 15 = \underline{20\,\Omega}$

b) Find the total current supplied by the battery and the current through each resistor. (I_T=0.60A, $I_1 = I_4$ = 0.60 A, I_2 = 0.45 A, I_3 = 0.15 A)

$V = IR$

$12 = I(20)$

$I_T = \underline{0.60A}$

$I_1 = I_4 = \underline{0.60A}$

$I_T = I_2 + I_3$ $I_2 = (I_T - I_3)$

$V_2 = V_3$

so... $I_2 R_2 = I_3 R_3$

$(I_T - I_3)R_2 = I_3(12)$

$(0.6 - I_3)(4.0) = 12 I_3$ $I_3 = \underline{0.15A}$

$I_2 = I_T - I_3$

$= 0.60 - 0.15$

$I_2 = \underline{0.45A}$

c) Find the potential difference across each resistor. (V_1 =9.0V, V_2 = 1.8V, V_3 = 1.8V, V_4=1.2V)

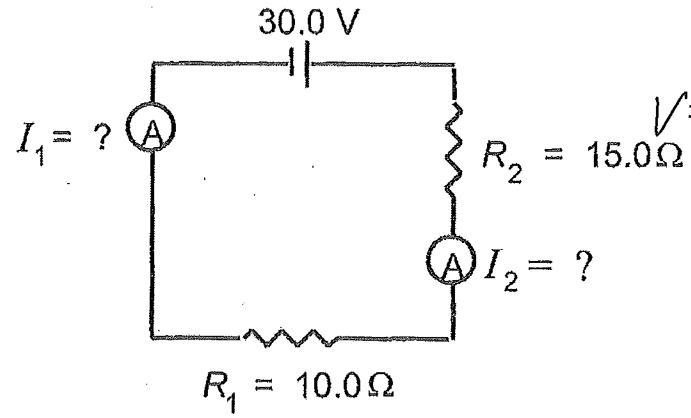
$V_1 = (0.60)(15) = 9.0V$

$V_2 = (0.45)(4.0) = 1.8V$

$V_3 = (0.15)(12) = 1.8V$

$V_4 = (0.60)(2.0) = 1.2V$

16.



$V = IR$ $30 = I(25.0)$

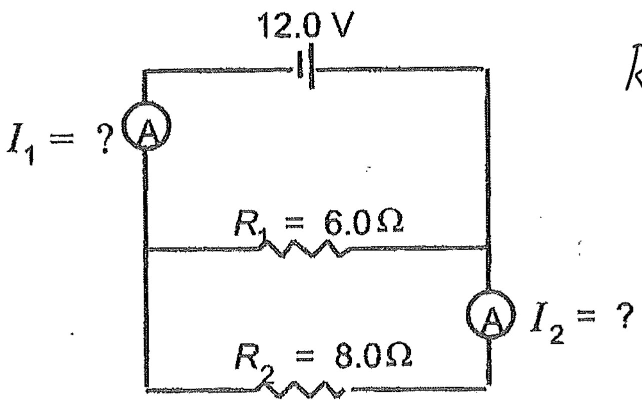
a) $I = 1.2A$

b) $P = I^2R = (1.2)^2(15.0)$
$= 14.4W$

a) What are the values of I_1 and I_2 in the circuit above? (1.2 A)

b) What is the power dissipated in R_1? (14.4 W)

17.



$R_T^{-1} = 6.0^{-1} + 8.0^{-1}$
$= 3.43\,\Omega$

$12 = I(3.43)$

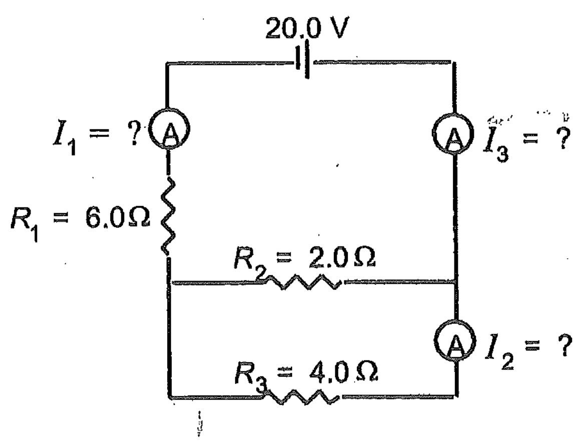
$I_T = 3.5A = I_1$

$12 = I_2(8.0) = 1.5A = I_2$

a) What are the values of I_1 and I_2 in the circuit above? (I_1 = 3.5 A, I_2 = 1.5 A)

b) What is the power dissipated in the circuit? (42 W) $P = IV = (3.5)(12) = 42W$

18.



$R_{T_P}^{-1} = 2.0^{-1} + 4.0^{-1} = 1.33\,\Omega$
$+$
6.0

$R_T = 7.33\,\Omega$

$20 = I(7.33)$ $I_T = I_1 = I_3 = 2.73A$

$\frac{R_3}{R_2} = \frac{4.0}{2.0} = 2.0\times$ larger than

a) What are the values of I_1, I_2 and I_3 in the circuit above? (I_1= 2.73 A, I_2 = 0.91 A, I_3 = 2.73 A)

$I_T = 2I_2 + I_2$ $2.73 = 3I_2$ $I_2 = 0.91A$

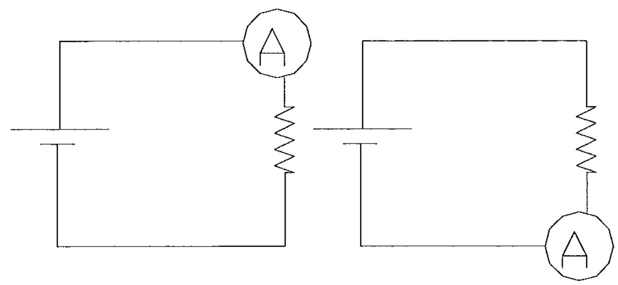
b) What is the power dissipated in the circuit? (55 W)

$P = IV = (2.73)(20) = 55W$

Physics 12 - **The *Voltmeter* and the *Ammeter***

So far in our study of circuits we have been calculating the *voltage* and the *current* at various locations in a given circuit. *But how do you '**check**' the answers in the **real world?*** As with anything, there are instruments made to measure these quantities. *Voltage* is measured with a *Voltmeter,* and *Current* is measured with an *Ammeter...*

Today we are going to study the characteristics of these instruments and how they are wired into the circuit.



The Ammeter

The ammeter is the instrument we will use to measure the current. **Current is the number of electrons that flow through a given point in the circuit.**

If we want to count the number of electrons that flow through a resistor (and hence the current that flows through the resistor), we need to **connect a machine in SERIES that measures the current entering OR leaving a resistor.**

As we can see in the diagram, either set-up would display the current flowing through the resistor. The left diagram would measure the current entering the resistor, while the one on the right will measure the current leaving the resistor.

If an ammeter was wired in parallel, it would not be measuring the current flowing through the resistor.

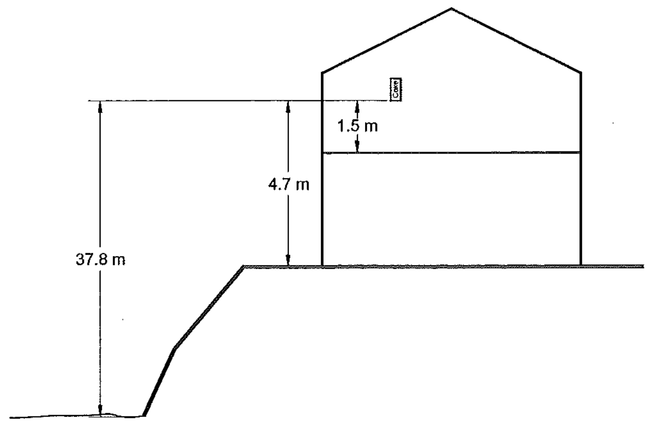
Ammeters, which are connected in series in a circuit when used, work by using a **very small amount of resistance** with **a *known value,*** and then measuring the voltage drop across that to determine current flow. In order for an ammeter to be used without significantly affecting circuit operation, it must present as little resistance as possible to the circuit in which it is being used.

Ammeters are connected in series with the circuit where they are being used in the measurement of current. **Thus, ideally there should be zero voltage drop across the ammeter.** The only way this is possible is if they have a zero internal resistance. They can't have an internal resistance of zero, but we need to keep it as low as possible.

It is known that a voltage drop across a given resistance is directly proportional to its resistance. **By measuring the voltage drop across a known resistance, we can find current flow, and this is what an ammeter does.**

The Voltmeter

In the diagram to the right, we could ask, how 'high' is the can of Coke? You would then need to ask "how high compared to what?" **Height is a relative thing.** The Coke is 1.5 m above the floor, 4.7 m above the ground, 37.8 m above sea level, 6400 km above the center of the earth.



You can see that the answer depends on what we call 'zero' height, and when we say how high, we really mean the ***difference*** in height between two points.

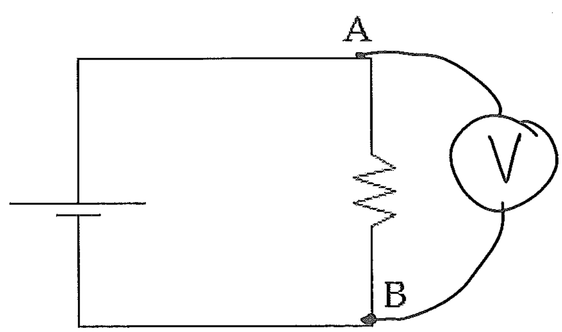
Since most physics labs stay inside the classroom, calling the floor 'zero' would be a good choice as in any demonstration done with the Coke can it will not break through the floor and go into 'negative' height. But mathematically speaking, we could even choose the ceiling as 'zero' and all of our calculations would just be using negative numbers.

Since voltage is analogous to pressure, and **voltage must be 'relative' to some arbitrary zero point that we pick**, and since **the lowest voltage in the circuit will always be at the negative terminal of the battery**, we normally call this the point of 'zero' voltage.

(*Note: We could label the positive terminal 'zero' voltage and mathematically everything would be the same, except all our numbers would be negative!*)

A voltmeter works in exactly the same way. **A voltmeter does not measure *absolute* voltage, but it does measure the voltage difference between two points in the circuit (hence the name *potential difference!*)** → also called a 'voltage drop'

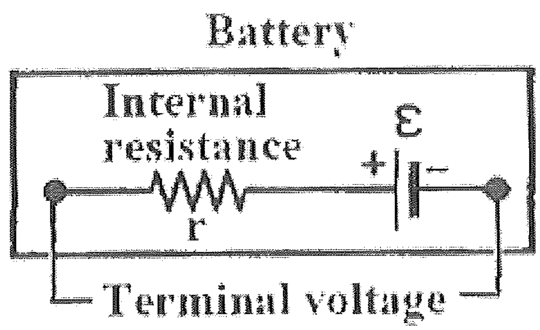
So logically, it we want to check how much the *potential changes* in between points A and B, we must connect one wire from the voltmeter to point A, and the other wire from the voltmeter to point B. The reading on the voltmeter will then be the difference between point A and B!



Physics 12 – **EMF, Terminal Voltage and Internal Resistance**

A battery and a generator are sources of potential difference (voltage). When these devices are **not connected to a working circuit** (when the electrons are flowing), **the potential difference across the terminals is called the electromotive force, or EMF (ε).**

Battery:
EMF is the potential difference determined by the chemical reactions in the battery.



EMF symbol → ε

If a car battery has an EMF of 12 V, this is the voltage that can be produced based on the chemicals inside. Therefore, this is the maximum voltage capability.

Once the battery is connected to an electric circuit, the potential difference is less than the EMF due to the internal resistance of the battery. This always occurs because every battery has some internal resistance.

Because of internal resistance, the terminal voltage is always less than the EMF of the battery.

$$V = \varepsilon - Ir$$

V: terminal voltage (what we measure as V_T in a working circuit)

ε: EMF of the battery (max. voltage capacity)

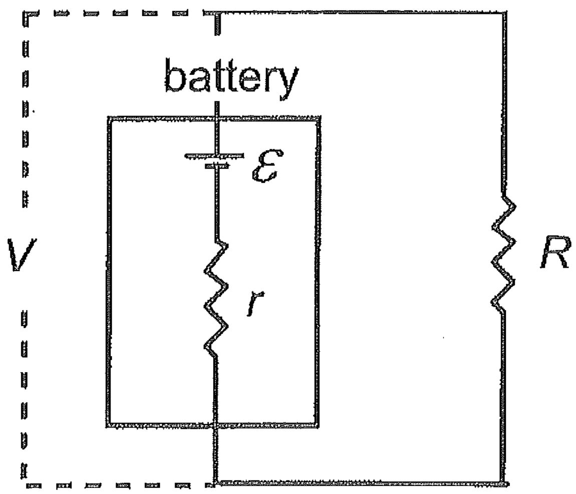
Ir: is the voltage drop due to internal resistance

I = current
r = internal resistance

*often helpful to combine Ohm's Law &

$$IR = \varepsilon - Ir$$

When the battery is not connected and/or no current flows, then $V = \varepsilon$. This applies to an electric generator as well as a battery.



"Dead" Batteries and Rechargeable Batteries

Voltage (V) across the battery terminals is given by: $V = \varepsilon - Ir$ *terminal voltage*

When a battery goes "dead", the internal resistance becomes greater until Ir equals ε, and then current will no longer flow.

When a rechargeable battery is being charged, an external voltage is applied to the battery. The voltage of this external battery must be greater than the EMF of the battery.

$$V \text{ (external voltage)} = \varepsilon + Ir$$

charging a battery:

Example One: If a 12.0 V battery has an internal resistance of 0.200 Ω, what is the terminal voltage of the battery when a current of 3.00 A flows through the battery?

$V = \mathcal{E} - Ir = (12) - (3.00)(0.200)$ $V = \underline{11.4\ V}$

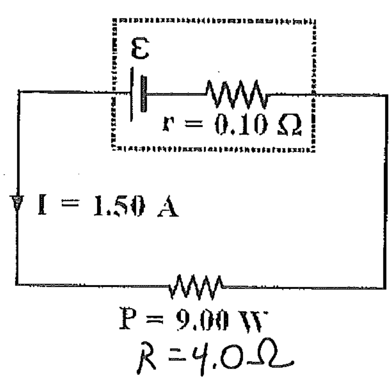
Example Two: In a particular battery, the EMF is 9.0 V and when a current of 2.0 A flows through the battery, the terminal voltage is 7.0 V. What is the internal resistance of the battery?

$7.0 = 9.0 - (2.0)r$ $r = \underline{1.0\ \Omega}$

Example Three: A 12.0 V car battery is being charged using a battery charger that is supplying 15.0 V. If the internal resistance of the battery is 1.3 Ω, what is the current through the battery? $V = \mathcal{E} + Ir$

$15.0 = 12.0 + I(1.3)$ $I = \underline{2.3\ A}$

Example Four: The diagram shows a circuit composed of a battery with an internal resistance of 0.10 Ω and a 9.00 W stereo speaker. The battery delivers 1.50 A to the speaker. Find the terminal voltage and EMF of the battery.



$P = IV$

$9.00 = 1.5(V)$

$V = 6.0\ V$ (terminal V)

$V = \mathcal{E} - Ir$

$6.0 = \mathcal{E} - (1.5)(0.10)$

$\mathcal{E} = \underline{6.15\ V}$

EMF, Terminal Voltage and Internal Resistance Problems:

1. When a 12 V battery with a 1.0 Ω internal resistance is connected to a motor, it delivers a current of 2.4 A. The battery is now replaced with a new battery with the same EMF but a different internal resistance and the resistor of the motor dissipates 16 W. What is the internal resistance of the new battery? (2.0 Ω)

motor will produce an R as well

$V = \mathcal{E} - Ir$

$IR = \mathcal{E} - Ir$

$IR + Ir = \mathcal{E}$

$I(R + r) = \mathcal{E}$

$2.4(R + 1.0) = 12$

$2.4R + 2.4 = 12$

$R = 4.0\,\Omega$

New:

$P = I^2R$

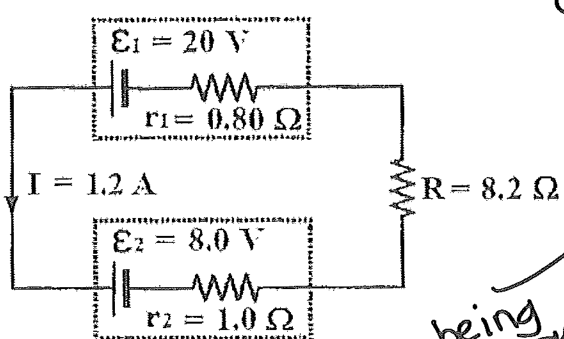
$16 = I^2(4.0)$ $\quad I = 2.0\text{ A}$

$IR = \mathcal{E} - Ir$

$(2.0)(4.0) = 12 - (2.0)r$

$r = 2.0\,\Omega$

2. A 20 V source battery is charging an 8.0 V battery as shown in the diagram. Find the terminal voltage of each battery. (19 V, 9.2 V)



① $V = \mathcal{E} - Ir$

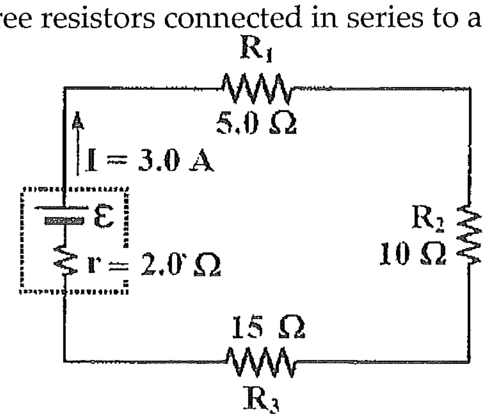
$= 20 - (1.2)(0.80)$ $\quad V = 19\text{ V}$

② $V = \mathcal{E} + Ir$

$= 8.0 + (1.2)(1.0)$ $\quad V = 9.2\text{ V}$

being charged

3. A circuit consists of three resistors connected in series to a battery. The current in the circuit is 3.0 A.



a) $V = IR$

$= (3.0)(30)$

$= 90\text{ V}$ (terminal)

$V = \mathcal{E} - Ir$

$90 = \mathcal{E} - (3.0)(2.0)$

$\mathcal{E} = 96\text{ V}$

a) Find the terminal voltage and the EMF of the battery. (90 V, 96 V)

b) Find the potential difference across each resistor. Compare the sum of each potential difference and the terminal velocity.

b) $V_1 = (3.0)(5.0) = 15\text{ V}$

$V_2 = (3.0)(10) = 30\text{ V}$

$V_3 = (3.0)(15) = 45\text{ V}$

$= 90\text{ V}$

4. A flashlight battery of EMF 1.5 V has an internal resistance of 0.50 Ω. If there is a current of 1.0 A through the battery, what is the terminal voltage of the battery? (1.0 V)

$V = 1.5 - (1.0)(0.5) \qquad V = \underline{1.0\,V}$

5. What is the EMF of a battery that has a terminal velocity of 5.0 V when a current of 1.2 A flows through the battery? The battery has an internal resistance of 0.72 Ω. (5.9 V)

$5.0 = \mathcal{E} - (1.2)(0.72) \qquad \mathcal{E} = \underline{5.9\,V}$

6. A battery that has an EMF of 24 V and an internal resistance of 0.25 Ω is being charged at a rate of 24 A. What is the voltage required to do this? (30 V)

$V = 24 + (24)(0.25) \qquad V = \underline{30\,V}$

7. A battery of 12 V EMF has an internal resistance of 1.0 Ω, and is connected to an external circuit that has a resistance of 4.0 Ω. What is the current through the circuit? (2.4 A)

$IR = \mathcal{E} - Ir$

$I(4.0) = 12 - I(1.0)$

$5.0I = 12$

$I = \underline{2.4\,A}$

8. What is the internal resistance of an electric generator that has an EMF of 120 V and a terminal voltage of 115 V when there is a current of 12 A through the generator? (0.42 Ω)

$115 = 120 - (12)r \qquad r = \underline{0.42\,\Omega}$

9. When a 2.0 Ω resistor is connected across a battery with an internal resistance of 0.50 Ω, the terminal voltage is observed to be 4.8 V. If the 2.0 Ω resistor is replaced with a 4.5 Ω resistor, what is the terminal voltage of the battery? (5.4 V)

① $V = IR$

$4.8 = I(2.0)$

$I = \underline{2.4\,A}$

$IR = \mathcal{E} - Ir$

$(2.4)(2.0) = \mathcal{E} - (2.4)(0.5)$

$\mathcal{E} = 6.0\,V$

② $I(4.5) = 6 - I(0.5)$

$5I = 6 \qquad I = 1.2\,A$

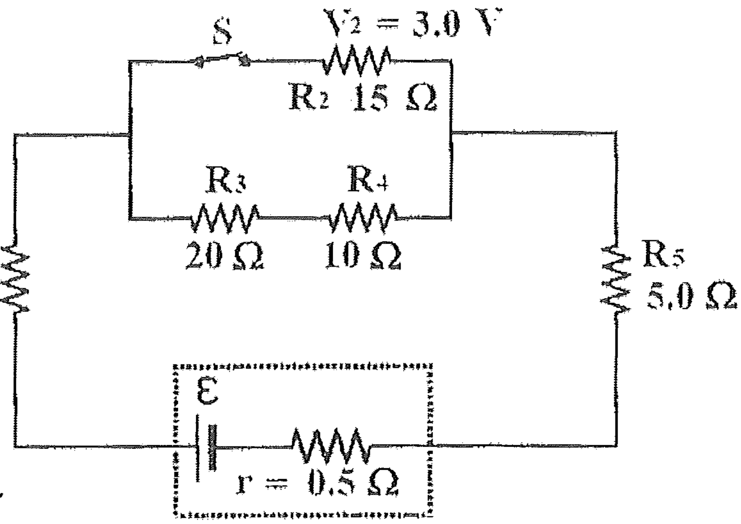
$V = IR$

$= (1.2)(4.5) = \underline{5.4\,V}$

Physics 12 – Electric Circuits Assignment Name:

SHOW ALL WORK and clearly indicate your answers.

1. The diagram shows a circuit of five resistors, a battery and a switch. The potential difference across resistor R_2 is 3.0 V.



$V_2 = I_2 R_2 \quad 3.0 = I_2(15)$

$I_2 = 0.20\,A$

$V_{3+4} = I_{3+4} R_{3+4}$

$3.0 = I_{3+4}(30) \quad I_{3+4} = 0.10\,A$

$I_T = 0.20 + 0.10 = \underline{0.30\,A}$

$R_{T_p}^{-1} = 15^{-1} + 30^{-1} \quad R_{T_p} = 10\,\Omega$

$R_T = 10 + 5.0 + 25 = 40\,\Omega$

$V_T = I_T R_T \quad V_T = (0.30)(40)$

$V_T = 12\,V$

a) $V = \mathcal{E} - Ir$

$12 = \mathcal{E} - (0.30)(0.5)$

$\boxed{\mathcal{E} = 12.15\,V \quad V = 12\,V}$

b) $P = IV = (0.30)(12)$

$\boxed{P = 3.6\,W}$

c) $P = I^2R = (0.10)^2(10) = \boxed{0.10\,W}$

d) The EMF does not change.

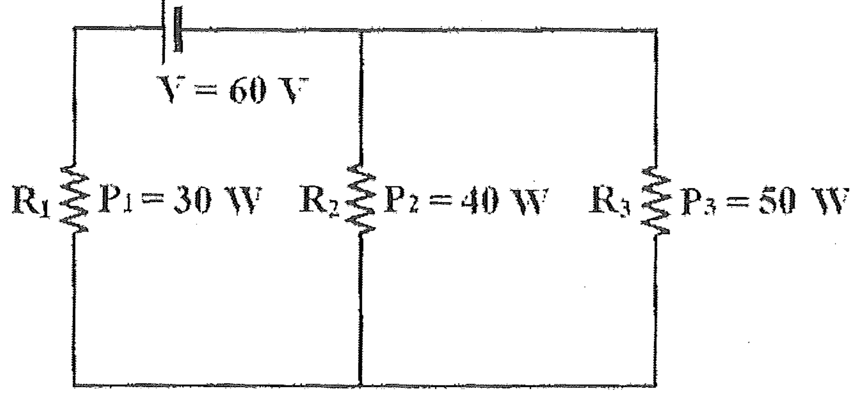
a) Find the EMF and terminal voltage of the battery.

b) Find the total power dissipated by the five resistors.

c) Find the power dissipated by resistor R_4.

d) What happens to the EMF of the battery if the switch is opened?

2. The circuit below consists of a power supply and three resistors.



a) $P = IV$ $\quad 120 = I(60)$ $\quad \boxed{I_T = 2.0A}$

b) $P_1 = I_1 V_1$ $\quad 30 = 2.0 V_1$ $\quad V_1 = 15 V$

$V_2 = V_3 = (V_T - V_1) = (60 - 15) = 45V$

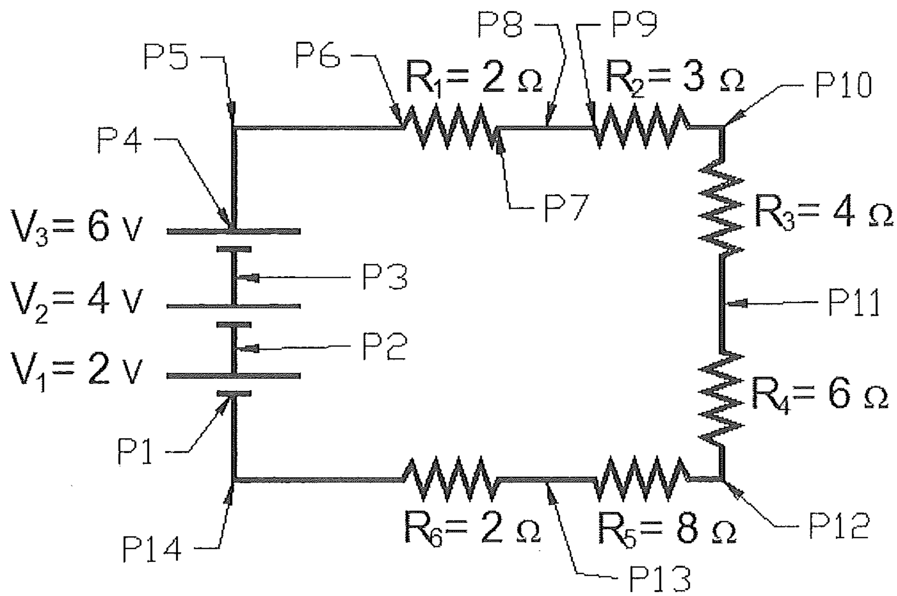
$P_2 = I_2 V_2$ $\quad 40 = I_2(45)$ $\quad \boxed{I_2 = 0.89A}$

c) $P = \frac{V^2}{R}$ $\quad 50 = \frac{45^2}{R}$ $\quad \boxed{R = 41 \Omega}$

a) Find the current from the power supply.

b) Find the current through R_2.

c) Find the resistance of R_3.



3. What is the **TOTAL VOLTAGE** of the battery in the circuit shown above?

series → 12 V

What is the **TOTAL RESISTANCE** of the circuit shown above?

series → 25 Ω

What is the **TOTAL CURRENT** of the circuit shown above?

$V = IR \quad 12 = I(25) \quad I = 0.48\ A$

If the voltage at point **P1 = 0 V**:

a) What is the voltage at P2? 2 V

b) What is the voltage at P3? 6 V

c) What is the voltage at P6? 12 V

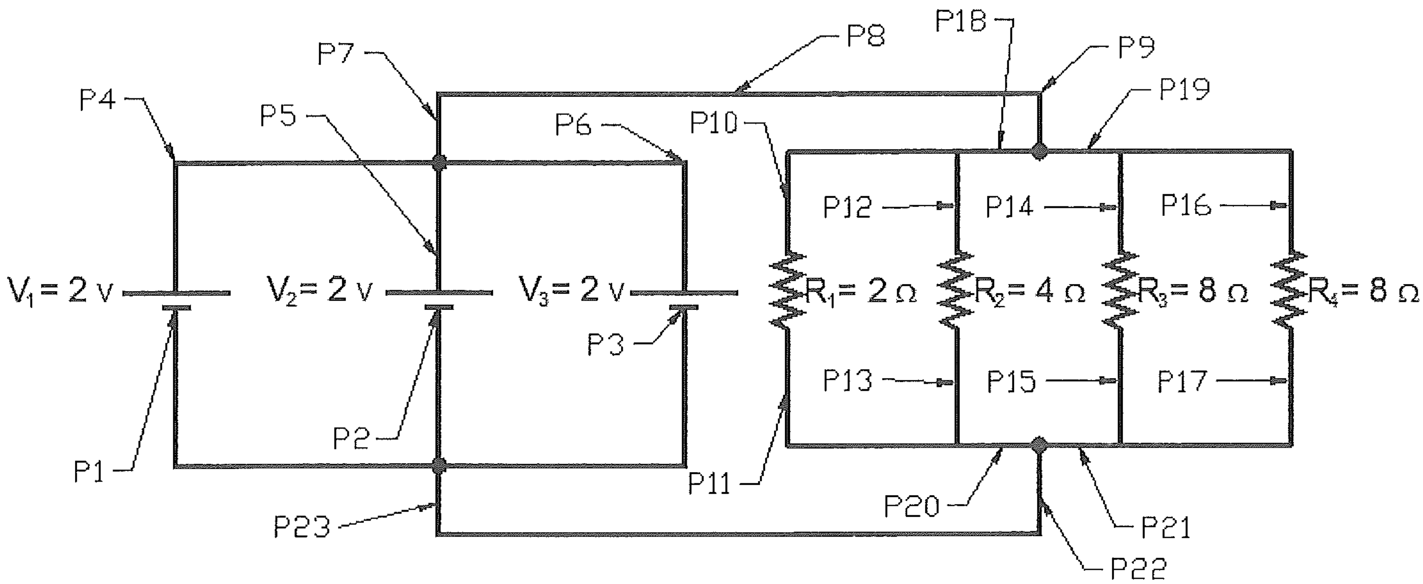
How many amps of current are flowing through $\mathbf{R_1}$?

0.48 A

What is the resistance of $\mathbf{R_1}$? 2.0 Ω

What is the *voltage* ***drop*** as the current goes through $\mathbf{R_1}$?

$V = (0.48)(2.0) = \underline{0.96\ V}$



4. What is the **TOTAL VOLTAGE** of the battery in the circuit shown above?

parallel → 2 V

What is the **TOTAL RESISTANCE** of the circuit shown above?

$R_T^{-1} = 2^{-1} + 4^{-1} + 8^{-1} + 8^{-1} = 1.0\ \Omega$

What is the **TOTAL CURRENT** of the circuit shown above?

$2.0 = I(1.0)$ $I = 2.0\ A$

If the voltage at point **P1 = 0 V**:

a) What is the voltage at P2? 0 V

b) What is the voltage at P3? 0 V

c) What is the voltage at P7? 2.0 V

What is the voltage at **P10**? 2.0 V

What is the voltage at **P11**? 2.0 V

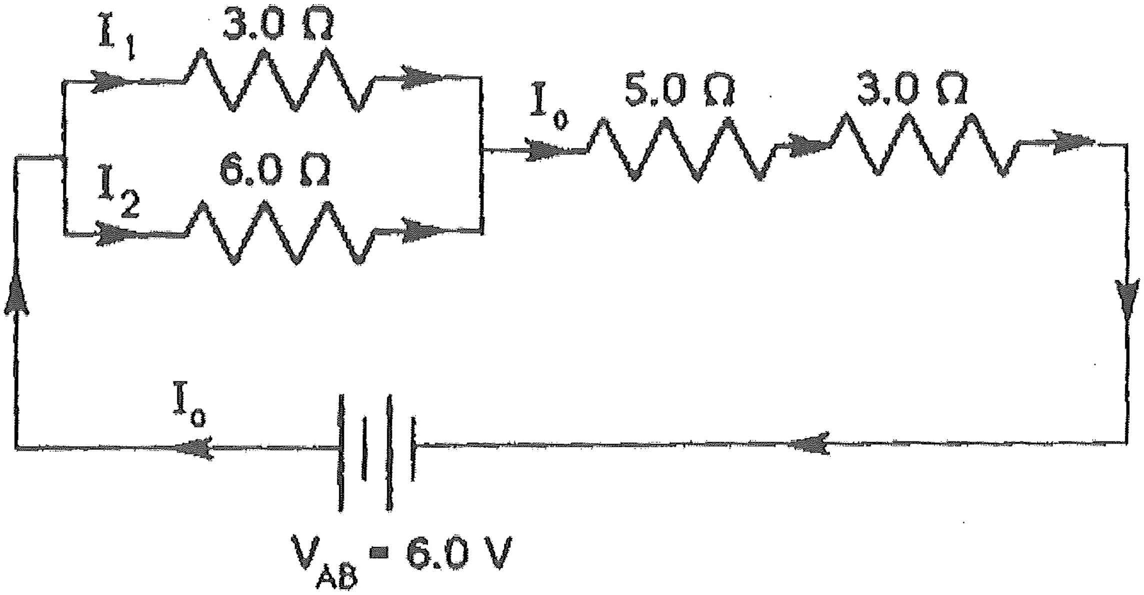
What is the current flowing through R_1? $2.0 = I(2.0)$ $I = 1.0\ A$

What is the current flowing through R_2? $2.0 = I(4.0)$ $I = 0.50\ A$

What is the current flowing through R_3 $2.0 = I(8.0)$ $I = 0.25\ A$

What is the current flowing through R_4? 0.25 A

What is the current flowing through **P22**? 2.0 A



5.

(a) What is the equivalent resistance of the circuit?

$R_{Tp}^{-1} = 3.0^{-1} + 6.0^{-1} = 2.0\,\Omega + 8.0\,\Omega$

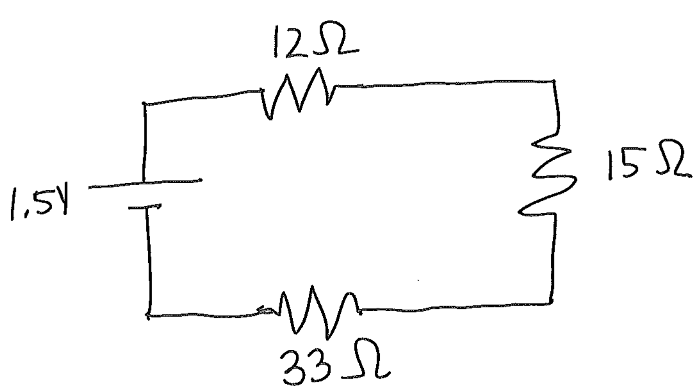
$R_T = 10\,\Omega$

(b) What is the voltage across the 6.0 Ω resistor?

$6.0 = I_T(10) \quad I_T = 0.60\,A$

$V_2 = I_T(R_{Tp}) \quad V_2 = (0.60)(2.0) \quad V_2 = 1.2\,V$

6. Draw a simple series circuit with a 1.5 V cell connected to a 12 Ω resistor, a 15 Ω resistor and a 33 Ω resistor. Calculate (a) the equivalent resistance and (b) the current in the circuit.



a) $R_T = 12 + 15 + 33 = 60\,\Omega$

b) $V_T = I_T R_T$

$1.5 = I_T(60) \quad I_T = 0.025\,A$

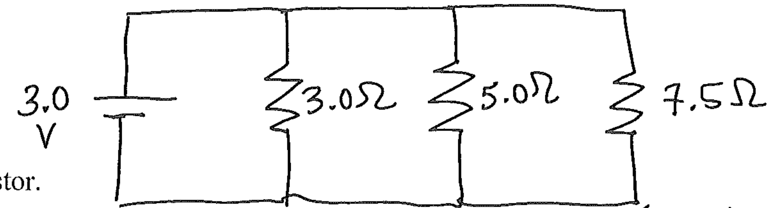
7. Draw a simple parallel circuit with a 3.0 V battery connected to a 3.0 Ω resistor, a 5.0 Ω resistor and a 7.5 Ω resistor.

Calculate:

(a) the equivalent resistance,

(b) the total current,

(c) the current in the 5.0 Ω resistor.

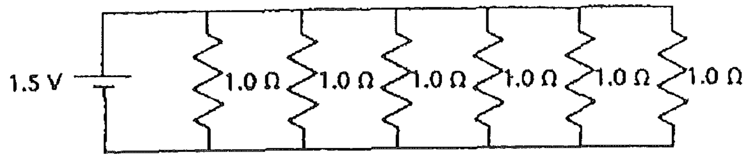


a) $R_T^{-1} = 3.0^{-1} + 5.0^{-1} + 7.5^{-1}$
$R_T = 1.5\Omega$

b) $3.0 = I_T(1.5)$
$I_T = 2.0\,A$

c) $3.0 = I(5.0)$ $I = 0.60\,A$

8. What is the current in the battery?



$R_T^{-1} = 6(1.0^{-1})$ $R_T = 0.17\Omega$

$1.5 = I_T(0.17)$ $I_T = 9.0\,A$

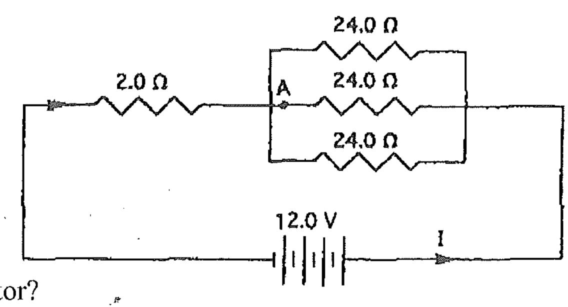
9. (a) What is the equivalent resistance of the circuit?

(b) What is the current in the battery?

(c) What is the current at point A?

(d) What is the potential difference across the 2.0 Ω, resistor?

(e) The wire at A is cut. When this happens, predict whether the current in the battery will (i) stay the same, (ii) increase, or (iii) decrease. Check your prediction by calculating the new current in the battery.



a) $R_{T_p}^{-1} = (24.0^{-1})3 = 8\Omega + 2.0\Omega = 10\Omega$

b) $12.0 = I_T(10)$ $I_T = 1.2\,A$

c) $9.6 = I(24)$ $I = 0.40\,A$

$V = (1.2)(2.0) = 2.4\,V$
$12 - 2.4 = 9.6\,V$

d) $2.4\,V$

e) decrease: R_T will ↑ so I_T must ↓

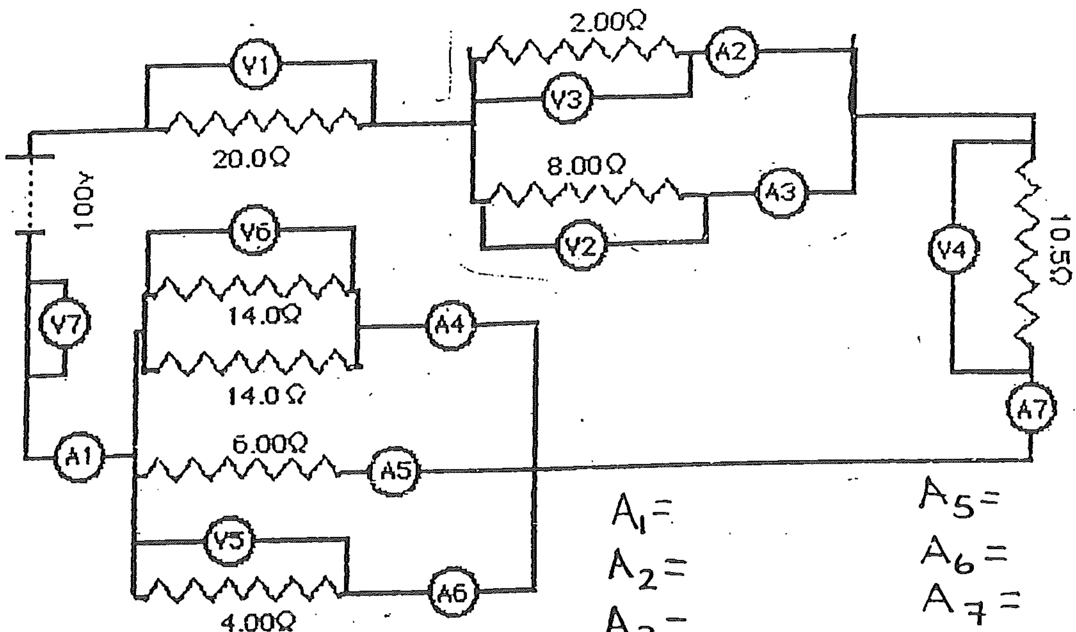
$R_T = \left((24.0^{-1})2\right)^{-1} + 2.0$
$R_T = 14\Omega$

$V_T = I_T R_T$ $12.0 = I_T(14)$
$I_T = 0.86\,A$

Physics 12 - Extra Big Circuit Practice

Determine the required meter readings

7.



$V_1 =$

$V_2 =$

$V_3 =$

$V_4 =$

$V_5 =$

$V_6 =$

$V_7 =$

$A_1 =$

$A_2 =$

$A_3 =$

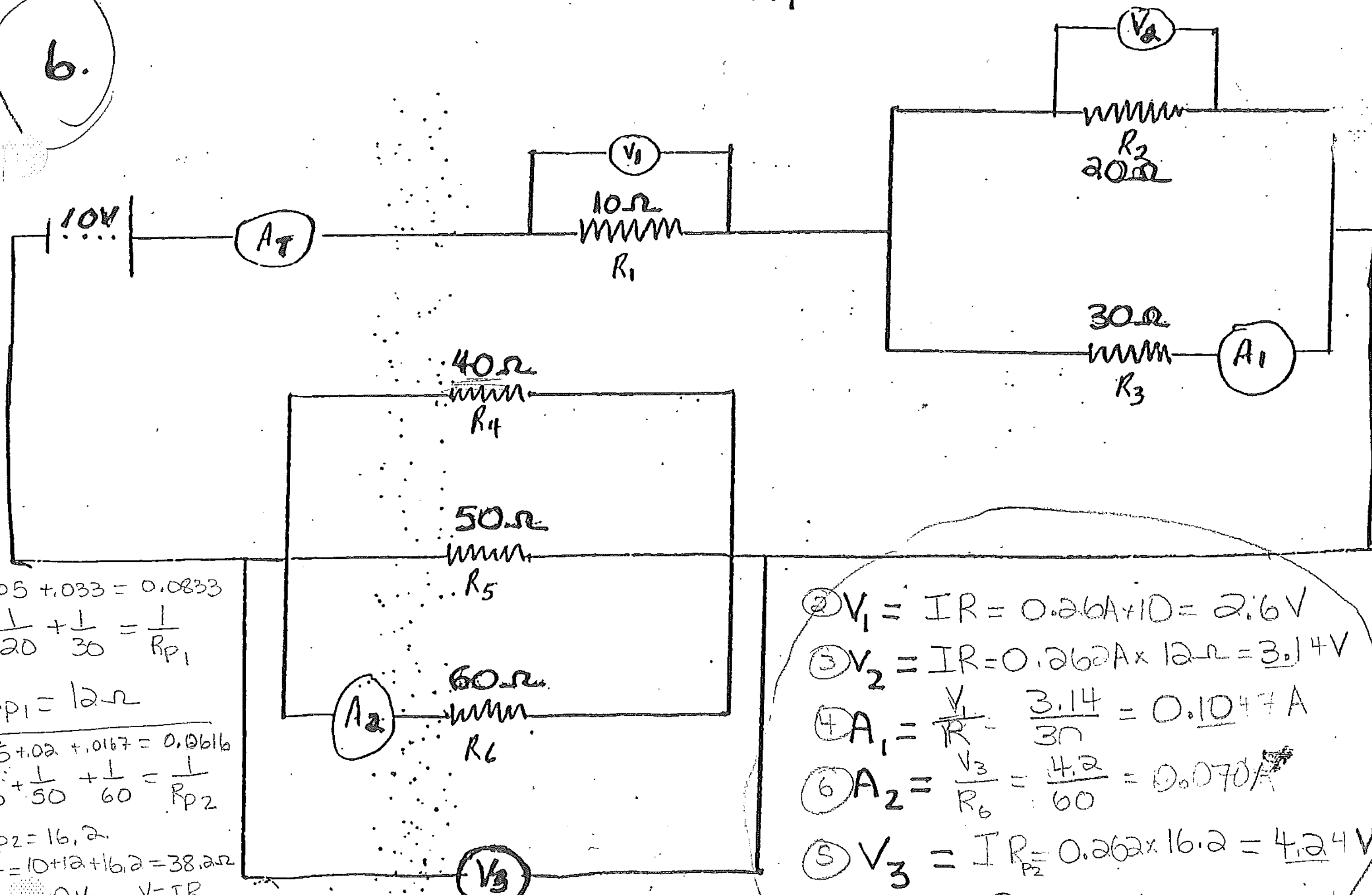
$A_4 =$

$A_5 =$

$A_6 =$

$A_7 =$

6.



.05 + .033 = 0.0833

$\frac{1}{20} + \frac{1}{30} = \frac{1}{R_{P_1}}$

$R_{P_1} = 12\Omega$

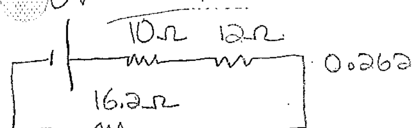
.025 + .02 + .0167 = 0.0616

$\frac{1}{40} + \frac{1}{50} + \frac{1}{60} = \frac{1}{R_{P2}}$

$R_{P2} = 16.2$

$R_T = 10 + 12 + 16.2 = 38.2\Omega$

10V V=IR



$I_T = \frac{10V}{38.2} = 0.262A$

② $V_1 = IR = 0.26A \times 10 = 2.6V$

③ $V_2 = IR = 0.262A \times 12\Omega = 3.14V$

④ $A_1 = \frac{V_2}{R} = \frac{3.14}{30} = 0.1047A$

⑥ $A_2 = \frac{V_3}{R_6} = \frac{4.2}{60} = 0.070A$

⑤ $V_3 = IR_{P2} = 0.262 \times 16.2 = 4.24V$

① $A_T = 0.262A$

3610-1b

KEY ⑦

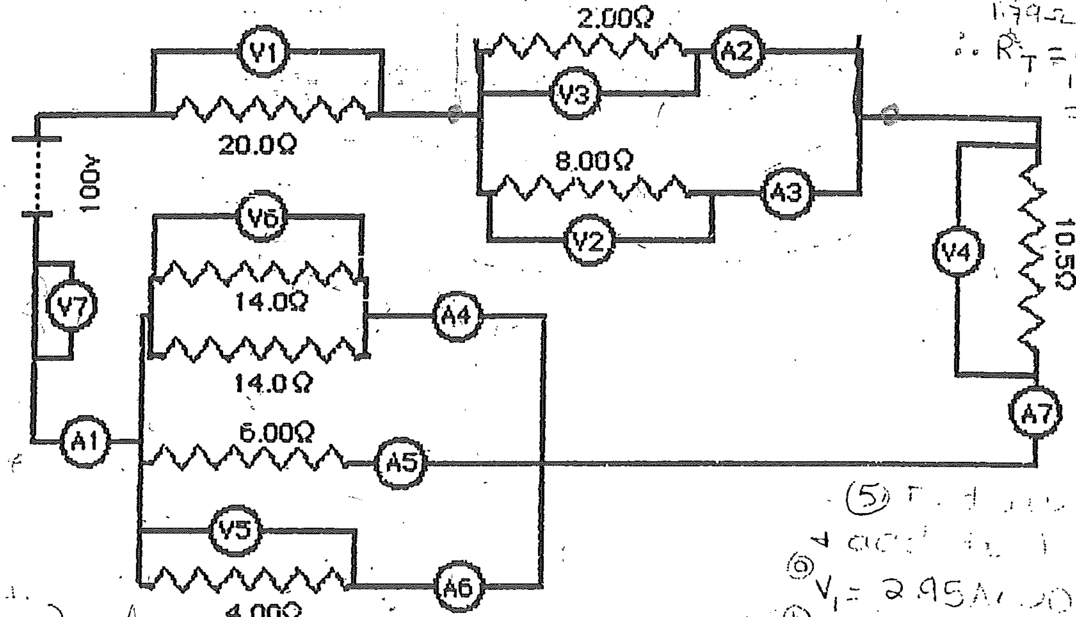
NAME________________________

#7

Determine the readings on the required meters

① $\frac{1}{R_{P1}} = \frac{1}{2} + \frac{1}{8}$

$R_{P1} = 1.60\,\Omega$



$\therefore R_T = 20.0\,\Omega + 1.60 + 10.5\,\Omega + 1.79 = 33.9\,\Omega$

$I_T = \frac{100\,V}{33.9\,\Omega} = 2.95\,A$

6.99 Ω (7.00 Ω)

③ $\frac{1}{R_{P3}} = \frac{1}{7} + \frac{1}{6} + \frac{1}{4}$ $\therefore R_{P3} = 1.79\,\Omega$

$V_2 = V_3 = 2.95\,A / 1.60\,\Omega = 4.7$

ⓒ $I_{A_2} = \frac{4.72\,V}{2.00\,\Omega}$

ⓔ $V_4 = \ldots$ 1.0 V

Check

V_1 = 59.0 V	A_1 = 2.95 A
V_2 = 4.72 V	A_2 = 2.36 A
V_3 = 4.72 V	A_3 = 0.59 A
V_4 = 31.0 V	A_4 = 0.75 A
V_5 = 5.28 V	A_5 = 0.88 A
V_6 = 5.28 V	A_6 = 1.32 A
V_7 = 0.00 V	A_7 = 2.95 A

1.32 A

Physics 30 Name ____

1) $\frac{1}{R_{P3}} = \frac{1}{4} + \frac{1}{4}$ (.25 + .25 = .5)

$R_{P3} = 2.00\,\Omega$

2) $\frac{1}{R_{P2}} = \frac{1}{12} + \frac{1}{12} + \frac{1}{12}$

$R_{P2} = 4.00\,\Omega$

3) $R_{P3a} = \frac{32.0}{4} = 8.00\,\Omega$

4) $R_{P3b} = \frac{12}{2} = 6.00\,\Omega$

5) $R_{P4} = \frac{18}{3} = 6.00\,\Omega$

7) $R_{P1} = \frac{8}{4} = 2.00\,\Omega$

8) Sim. Diag

6.00 V — 2.00 Ω, 3.00 Ω, 2.00 Ω, 6.00 Ω

9. $R_T = 13.0\,\Omega$

10) $I_T = \frac{V}{R} = \frac{6.00\,V}{13.0\,\Omega} = 0.462\,A$

a) $V_2 = 2.00\,\Omega \times 0.462\,A = 0.924\,V$

b) $I_{A3} = \frac{0.924\,V}{8.00\,\Omega} = 0.116\,A$ or $\frac{0.462}{4}$

c) $I_{A2} = \frac{0.116\,A}{3} = 0.0387\,A$

d) $I_{A4} = \frac{0.116\,A}{4} = 0.0290\,A$

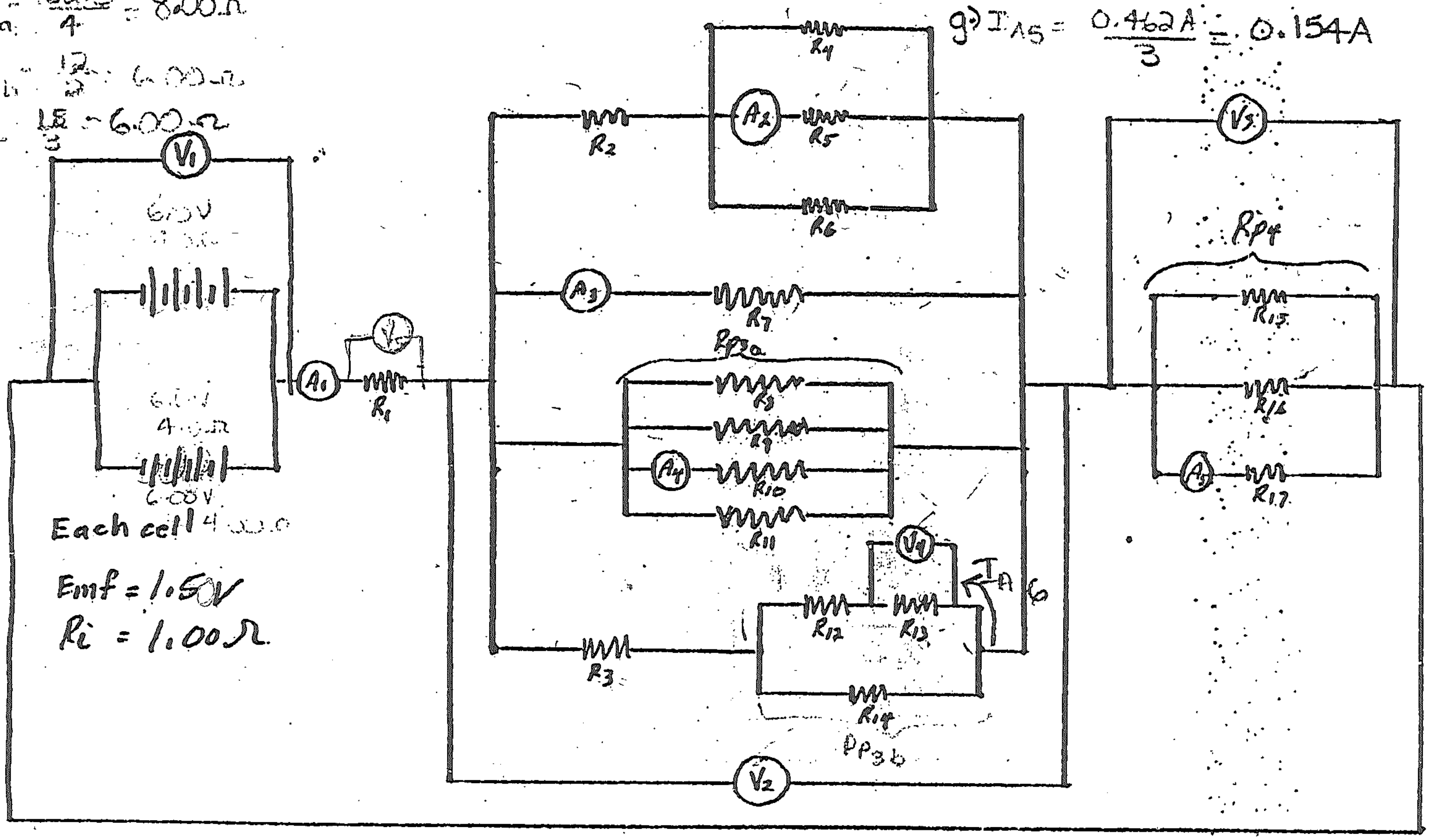
e) $I_{A6} = \frac{0.116\,A}{2} = 0.0580\,A$ ∴

$V_4 = 0.0580\,A \times 4.00\,\Omega = 0.232\,V$

f) $V_3 = 0.462\,A \times 6.00\,\Omega = 2.77\,V$

g) $I_{A5} = \frac{0.462\,A}{3} = 0.154\,A$

$R_1 = 3.00\,\Omega$
$R_2 = 4.0\,\Omega$
$R_3 = 2.0\,\Omega$
$R_4 = 12.0\,\Omega$
$R_5 = 12.0\,\Omega$
$R_6 = 12.0\,\Omega$
$R_7 = 8.00\,\Omega$
$R_8 = 32.0\,\Omega$
$R_9 = 32.0\,\Omega$
$R_{10} = 32.0\,\Omega$
$R_{11} = 32.0\,\Omega$
$R_{12} = 8.00\,\Omega$
$R_{13} = 4.00\,\Omega$
$R_{14} = 12.0\,\Omega$
$R_{15} = 18.0\,\Omega$
$R_{16} = 18.0\,\Omega$
$R_{17} = 18.0\,\Omega$



Each cell 4.00 Ω

Emf = 1.50 V

Ri = 1.00 Ω

h) $V_i = 0.462\,A \times 2.00\,\Omega = 0.924\,V$

∴ $V_1 = 6.00\,V - 0.924\,V = 5.08\,V$

Check:

$6.00\,V \stackrel{?}{=} .924\,V + 1.39\,V + .924\,V + 2.7$

$V_i + V_5 + V_2 + V_3$

YAY ✓

$V_5 = 0.462\,A \times 3.00\,\Omega$ = 1.39 V

Rp1 2.00 Ω	A1 0.462 A	V1 5.08 V
Rp2 4.00 Ω	A2 0.0387 A	V2 0.924 V
Rp3 8.00 Ω, Rp3b = 6.00	A3 0.116 A	V3 2.77 V
Rp4 6.00 Ω	A4 0.0290 A	V4 0.232 V
	A5 0.154 A	

4 (5)