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NEW JERSEY CENTER
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Algebra Based Physics

Electric Current & DC Circuits

2016-02-02

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Electric Current & DC Circuits

Click on the topic to go to that section

- Circuits
- Conductors
- Resistivity and Resistance
- Circuit Diagrams
- Measurement

https://www.njctl.org/video/?v=cYF-V8ms-yA

Circuits

https://www.njctl.org/video/?v=qEjbT-EWS2E

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Electric Current

Electric Current is the rate of flow of electric charges (charge carriers) through space. More specifically, it is defined as the amount of charge that flows past a location in a material per unit time. The letter "I" is the symbol for current.

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

ΔQ is the amount of charge, and Δt is the time it flowed past the location.

The current depends on the type of material and the Electric Potential difference (voltage) across it.

Electric Current

A good analogy to help understand Electric Current is to consider water flow. The flow of water molecules is similar to the flow of electrons (the charge carriers) in a wire.

Water flow depends on the pressure exerted on the molecules either by a pump or by a height difference, such as water falling off a cliff.

Electric current depends on the "pressure" exerted by the Electric Potential difference - the greater the Electric Potential difference, the greater the Electric Current.

Electric Current

The current, $I = \frac{\Delta Q}{\Delta t}$ has the units Coulombs per second.

The units can be rewritten as Amperes (A).

$$1\ A = 1\ C/s$$

Amperes are often called "amps".

Electric Current

We know that if an Electric Potential difference is applied to a wire, charges will flow from high to low potential - a current.

However, due to a convention set by Benjamin Franklin, current in a wire is defined as the movement of positive charges (not the electrons which are really moving) and is called "conventional current."

Ben didn't do this to confuse future generations of electrical engineers and students. It was already known that electrical phenomena came in two flavors - attractive and repulsive - Ben was the person who explained them as distinct positive and negative charges.

Electric Current

He arbitrarily assigned a positive charge to a glass rod that had been rubbed with silk. He could just as easily called it negative - 50/50 chance.

The glass rod was later found to have a shortage of electrons (they were transferred to the silk). So if the glass rod is grounded, the electrons will flow from the ground to the rod.

The problem comes in how Electric Potential is defined - charge carriers will be driven from high to low potential - from positive to negative. For this to occur in the glass rod - ground system, the conventional current will flow from the rod to the ground - opposite the direction of the movement of electrons.

Electric Current

To summarize - conventional Electric Current is defined as the movement of positive charge. In wires, it is opposite to the direction of the electron movement.

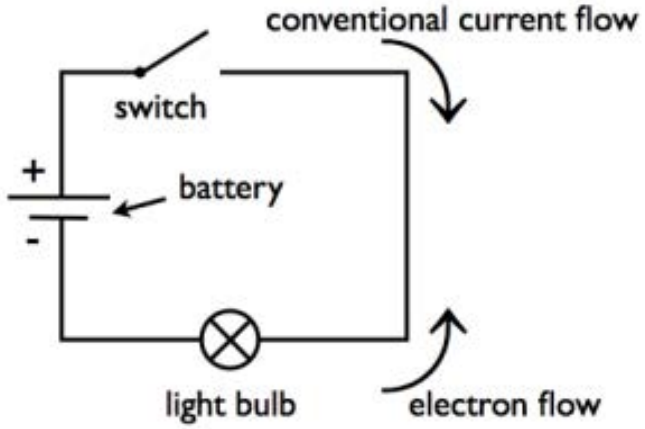
However - in the case of a particle accelerator, where electrons are stripped off of an atom, resulting in a positively charged ion, which is then accelerated to strike a target - the direction of the conventional current is the same as the direction of the positive ions!

Circuits

An electric circuit is an external path that charges can follow between two terminals using a conducting material.

For charge to flow, the path must be complete and unbroken.

An example of a conductor used to form a circuit is copper wire. Continuing the water analogy, one can think of a wire as a pipe for charge to move through.



1 12 C of charge passes a location in a circuit in 10 seconds. What is the current flowing past the point?

Answer

https://www.njctl.org/video/?v=qcBtq9MEORA

2 20 C of charge passes a location in a circuit in 30 seconds. What is the current flowing past the point?

Answer

https://www.njctl.org/video/?v=tHjr1l5b1xQ

3 A circuit has 3 A of current.How long does it take 45 C of charge to travel through the circuit?

Answer

https://www.njctl.org/video/?v=AFkDCiivDSc

4 A circuit has 10 A of current.How long does it take 20 C of charge to travel through the circuit?

Answer

https://www.njctl.org/video/?v=0vvFnqHeU2w

5 A circuit has 10 A of current.How much charge travels through the circuit after 20s?

Answer

https://www.njctl.org/video/?v=HGhJ1Z-aMkI

6 A circuit has 2.5 A of current. How much charge travels through the circuit after 4 s?

Answer

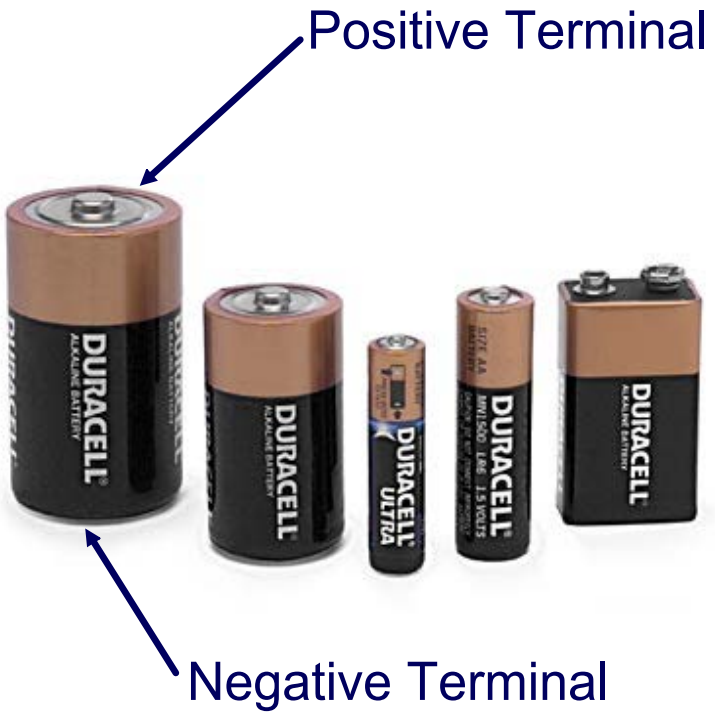
https://www.njctl.org/video/?v=0Wg7hU47gRk

Batteries

Each battery has two terminals which are conductors. The terminals are used to connect an external circuit allowing the movement of charge.

Batteries convert chemical energy to electrical energy which maintains the potential difference.

The chemical reaction acts like an escalator, carrying charge up to a higher voltage.



Click here for a Battery Voltage Simulation from PhET

https://www.njctl.org/video/?v=MD9JALuhU8g

Reviewing Basic Circuits

The circuit cannot have gaps.

The bulb had to be between the wire and the terminal.

A voltage difference is needed to make the bulb light.

The bulb still lights regardless of which side of the battery you place it on.

As you watch the video,observations and

the answers to the questions below.

What is going on in the circuit?

Click here for video using the circuit simulator from PhET

What is the role of the battery?

How are the circuits similar? different?

Batteries and Current

The battery pushes current through the circuit. A battery acts like a pump, pushing charge through the circuit. It is the circuit's energy source.

Charges do not experience an electrical force unless there is a difference in electrical potential (voltage).Therefore, batteries have a potential difference between their terminals. The positive terminal is at a higher voltage than the negative terminal.

click here for a video from Veritasium's Derek on current

How will voltage affect current?

Conductors

https://www.njctl.org/video/?v=mr3r1Bz2hVY

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Conductors

Some conductors "conduct" better or worse than others. Reminder: conducting means a material allows for the free flow of electrons.

The flow of electrons is just another name for current. Another way to look at it is that some conductors resist current to a greater or lesser extent.

We call this resistance, R. Resistance is measured in ohms which is noted by the Greek symbol omega (Ω)

How will resistance affect current?

Click here to run another PhET simulation

Current vs Resistance & Voltage

Raising resistance reduces current.
Raising voltage increases current.

We can combine these relationships in what we call "Ohm's Law".

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

Another way to write this is that:

$$R = \frac{V}{I} \quad \text{OR} \quad V = IR$$

You can see that one $\Omega = \frac{V}{A}$

click here for a Veritasium music video on electricity

7 A flashlight has a resistance of 25 Ω and is connected by a wire to a 120 V source of voltage. What is the current in the flashlight?

Answer

https://www.njctl.org/video/?v=muLnlVJt7d8

8 A flashlight has a resistance of 30 Ω and is connected by a wire to a 90 V source of voltage. What is the current in the flashlight?

Answer

https://www.njctl.org/video/?v=TcnjPsD59Es

9 What is the current in a wire whose resistance is 3 Ω if 1.5 V is applied to it?

Answer

https://www.njctl.org/video/?v=n2z73ToNdrQ

10 How much voltage is needed in order to produce a 0.70 A current through a 490 Ω resistor?

Answer

https://www.njctl.org/video/?v=WXSW7nHi2XY

11 How much voltage is needed in order to produce a 0.5 A current through a 150 Ω resistor?

Answer

https://www.njctl.org/video/?v=uhg76Swygls

12 What is the resistance of arheostat coil, if 0.05 A of current flows through it when 6 V is applied across it?

Answer

https://www.njctl.org/video/?v=rqsfe8lEoTk

13 What is the resistance of arheostat coil, if 20 A of current flows through it when 1000 V is applied across it?

Answer

https://www.njctl.org/video/?v=YQCfqYSBs0k

Electrical Power

Power is defined as work per unit time

$$P = \frac{W}{t}$$

if W = QV then substitute:

$$P = \frac{QV}{t}$$

if $I = \frac{Q}{t}$ then substitute:

$$P = IV$$

What happens if the current is increased?

What happens if the voltage is decreased?

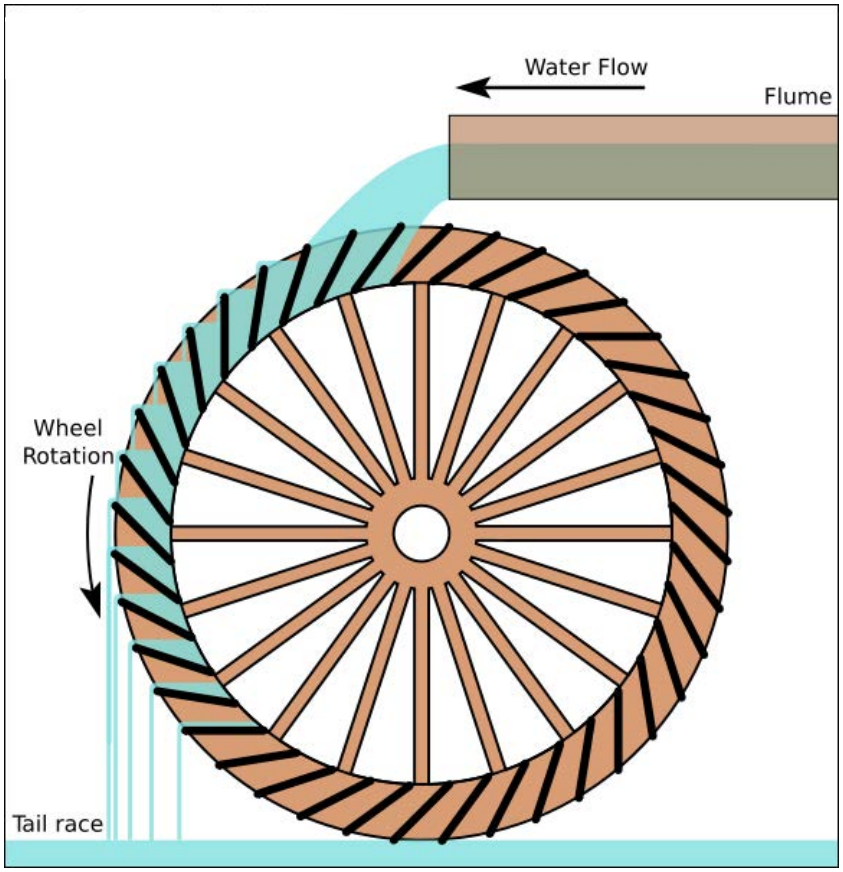
https://www.njctl.org/video/?v=Cm8VmJSk5iY

Electrical Power

Let's think about this another way...

The water at the top has GPE & KE.

As the water falls, it loses GPE and the wheel gets turned, doing work.When the water falls to the bottom it is now slower, having done work.

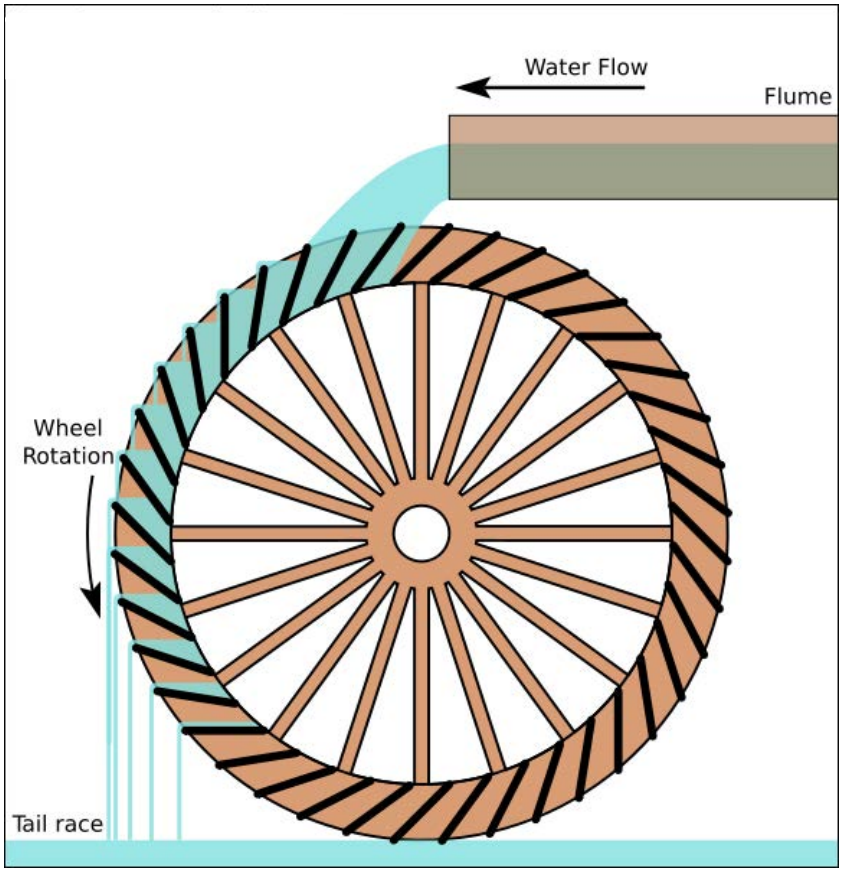


Electrical Power

Electric circuits are similar.

A charge falls from high voltage to low voltage.

In the process of falling energy may be used (light bulb, run a motor, etc).



What is the unit of Power?

Electrical Power

How can we re-write electrical power by using Ohm's Law?

(electrical power) $P = IV$

(Ohm's Law) $I = \frac{V}{R}$

$$P = \frac{VV}{R}$$

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

Electrical Power

Is there yet another way to rewrite this?

$I = \frac{V}{R}$ *can be rewritten as* $V = IR$.

(electrical power) $P = IV$

(Ohm's Law) $V = IR$

We can substitute this into Power

$P = I(IR)$

$$\boxed{P = I^2R}$$

Batteries

D, C, AA, & AAA have the same voltage, however they differ in the amount of power they deliver.

For instance, D batteries can deliver more current and therefore more power.

14 A toy car's electric motor has a resistance of 17 Ω; find the power delivered to it by a 6-V battery.

Answer

https://www.njctl.org/video/?v=zGPEnMSjQH0

15 A toy car's electric motor has a resistance of 6 Ω; find the power delivered to it by a 7-V battery.

Answer

https://www.njctl.org/video/?v=7HCqGr-Kr4Q

16 What is the power consumption of a flash light bulb that draws a current of 0.28 A when connected to a 6 V battery?

Answer

https://www.njctl.org/video/?v=H3gFobVzbU8

17 What is the power consumption of a flash light bulb that draws a current of 0.33 A when connected to a 100 V battery?

Answer

https://www.njctl.org/video/?v=cFhbxaJnBMc

18 A 30Ω toaster consumes 560 W of power: how much current is flowing through the toaster?

Answer

https://www.njctl.org/video/?v=aYfmw00jqXk

19 A 50 Ω toaster consumes 200 W of power: how much current is flowing through the toaster?

Answer

https://www.njctl.org/video/?v=JK0j3faqvjc

20 When 30 V is applied across a resistor it generates 600 W of heat: what is the magnitude of its resistance?

Answer

https://www.njctl.org/video/?v=qss0lmcOMcM

21 When 100 V is applied across a resistor it generates 200 W of heat: what is the magnitude of its resistance?

Answer

https://www.njctl.org/video/?v=F5wMdXpRseM

"Pipe" size

How could the wire in the circuit affect the current?

If wire is like a pipe, and current is like water that flows through the pipe...

if there were pipes with water in them, what could we do to the pipes to change the speed of the water (the current)?

Answer

** Resistivity and Resistance

https://www.njctl.org/video/?v=22iIFMgCbRk

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**

Resistivity & Resisitance

Every conductor "conducts" electric charge to a greater or lesser extent.

The last example also applies to conductors like copper wire. Decreasing the length (L) or increasing the cross-sectional area (A) would increase conductivity.

Also, the measure of a conductor's resistance to conduct is called its resistivity. Each material has a different resistivity.

Resistivity is abbreviated using the Greek letter rho (ρ).

Combining what we know about A, L, and ρ, we can find a conductor's total resistance.

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

**

Resistivity & Resisitance

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

Resistance, R, is measured in Ohms (Ω). Ω is the Greek letter Omega.

Cross-sectional area, A, is measured in m^2

Length, L, is measured in m

Resistivity, ρ, is measured in Ωm

How can we define A for a wire?

**

Resisitance

$$\rho = \frac{RA}{L}$$

What is the resistance of a good conductor?

Low; low resistance means that electric charges are free to move in a conductor.

Click here for a PhET simulation about Resistance

**Resistivities of Common Conductors

Material	Resistivity ($10^{-8}\ \Omega m$)
Silver	1.59
Copper	1.68
Gold	2.44
Aluminum	2.65
Tungsten	5.60
Iron	9.71
Platinum	10.6
Mercury	98
Nichrome	100

**

22 Rank the following materials in order of best conductor to worst conductor.

A Iron, Copper, Platinum

B Platinum, Iron, Copper

C Copper, Iron, Platinum

Material	Resistivity (10^{-8} Ωm)
Silver	1.59
Copper	1.68
Gold	2.44
Aluminum	2.65
Tungsten	5.60
Iron	9.71
Platinum	10.6
Mercury	98
Nichrome	100

Answer

https://www.njctl.org/video/?v=22iIFMgCbRk

**

23 What is the resistance of a 2 m long copper wire whose cross-sectional area of 0.2 mm^2?

Answer

https://www.njctl.org/video/?v=JzMdYb5U1a4

**

24 An aluminum wire with a length of 900 m and a cross-sectional area of 10 mm^2 has a resistance of 2.5 Ω. What is the resistivity of the wire?

Answer

https://www.njctl.org/video/?v=D6vB1-nTi-k

** 25 What diameter of 100 m long copper wire would have a resistance of 0.10 Ω?

Answer

https://www.njctl.org/video/?v=O7fFFa3pQg4

** 26 What is the cross-sectional area of a 10 Ω copper wire 10000 meters long?

Answer

https://www.njctl.org/video/?v=xHiCi7u2RUI

**

27 What is the length of a 10 Ω copper wire whose diameter is 3.2 mm?

Answer

https://www.njctl.org/video/?v=vpqKKgbpP-w

Circuit Diagrams

https://www.njctl.org/video/?v=pW1a4hahYbE

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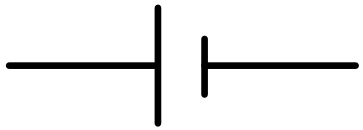
Circuit Diagrams

Drawing realistic pictures of circuits can be very difficult.
For this reason, we have common
symbols to represent each piece.

Resistor



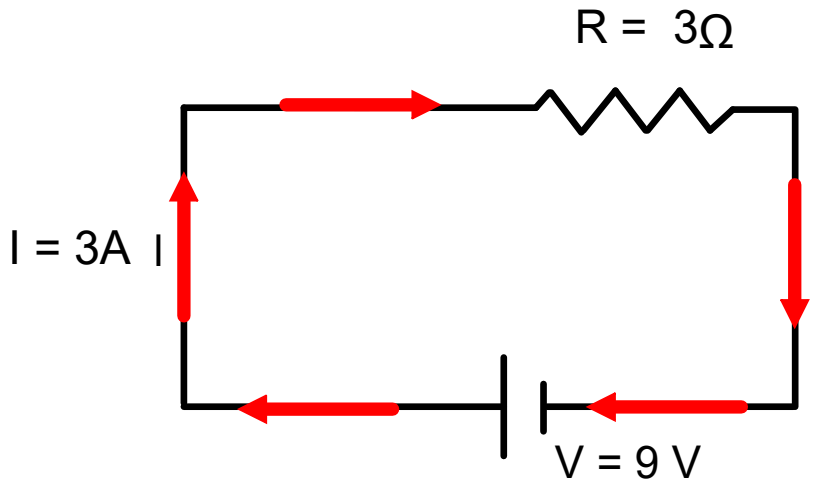
Battery

Wire

**Note: Circuit diagrams do not show where each part is physically located.*

Circuit Diagrams

Draw a simple circuit that has a 9 V battery with a 3 Ω resistor across its terminals. What is the magnitude and direction of the current?



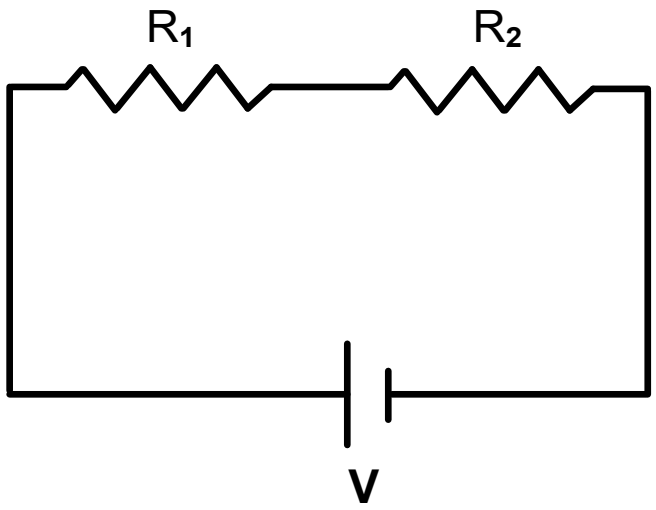
Answer

Conventional current flows from the positive terminal to the negative terminal.

Circuit Diagrams

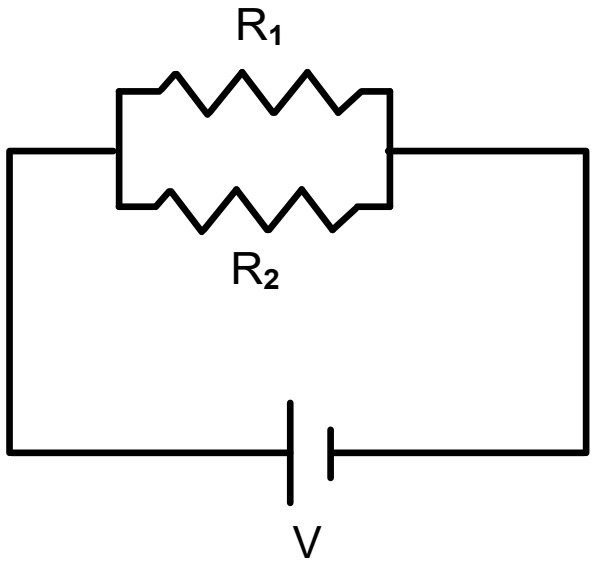
There are two ways to add a second resistor to the circuit.

Series



All charges must move through both resistors to get to the negative terminal.

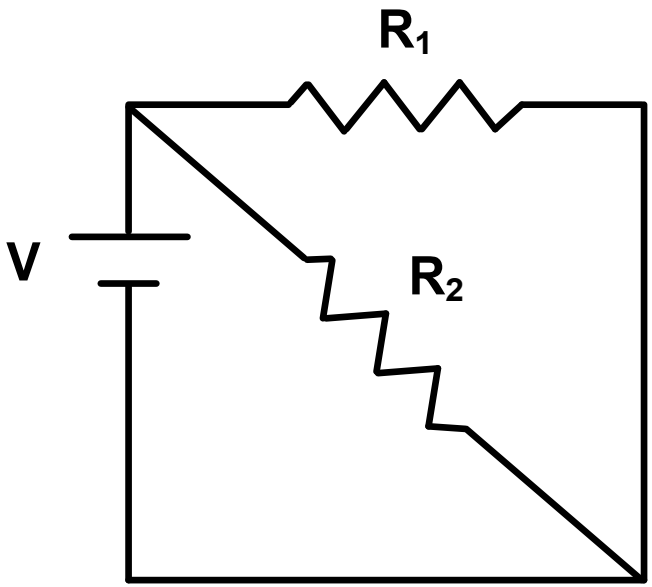
Parallel

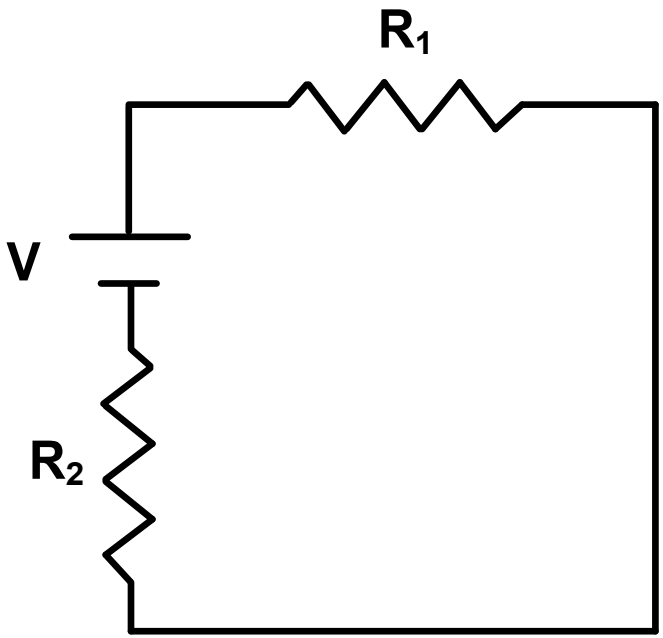


Charges pass through either R_1 or R_2 but not both.

Circuit Diagrams

Are the following sets of resistors in series or parallel?





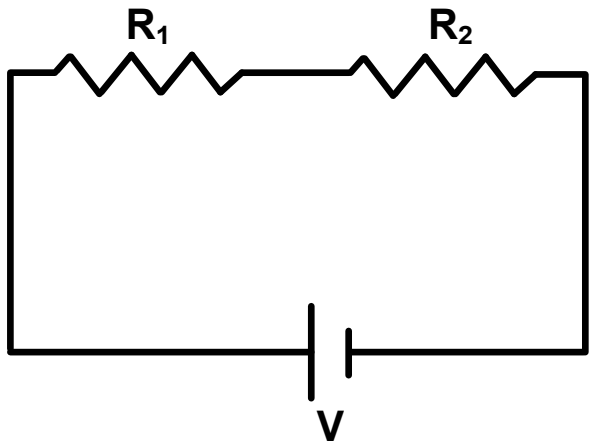
Answer

Equivalent Resistance

Resistors and voltage from batteries determine the current.

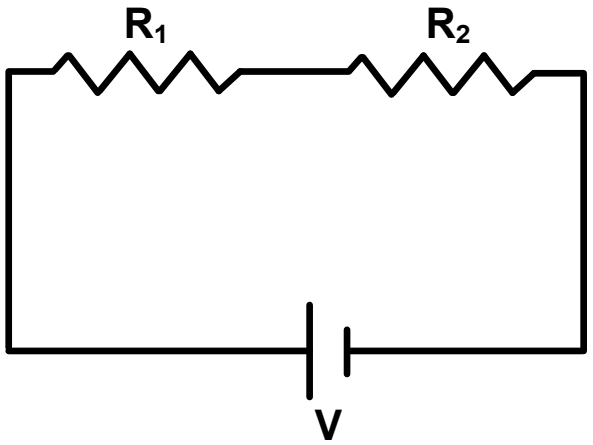
Circuits can be redrawn as if there were only a single resistor and battery.By reducing the circuit this way, the circuit becomes easier to study.

The process of reducing the resistors in a circuit is called finding the equivalent resistance (R_{eq}).



Series Circuits: Equivalent Resistance

What happens to the current in the circuit to the right?



Answer

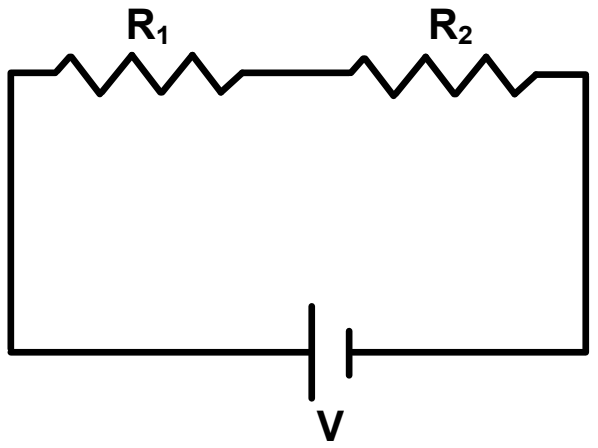
The current passing through all parts of a series circuit is the same. For example: $I = I_1 = I_2$

Series Circuits: Equivalent Resistance

What happens to the voltage as it moves around the circuit?

The sum of the voltage drops across each of the resistors in a series circuit equals the voltage of the battery.

For example: $V = V_1 + V_2$



Answer

Series Circuits: Equivalent Resistance

If $V = V_1 + V_2 + V_3 + ...$

substitute Ohm's Law solved for V is: V = IR

$IR = I_1R_1 + I_2R_2 + I_3R_3$

but since current (I) is the same everywhere in a series circuit,

$IR = IR_1 + IR_2 + IR_3$

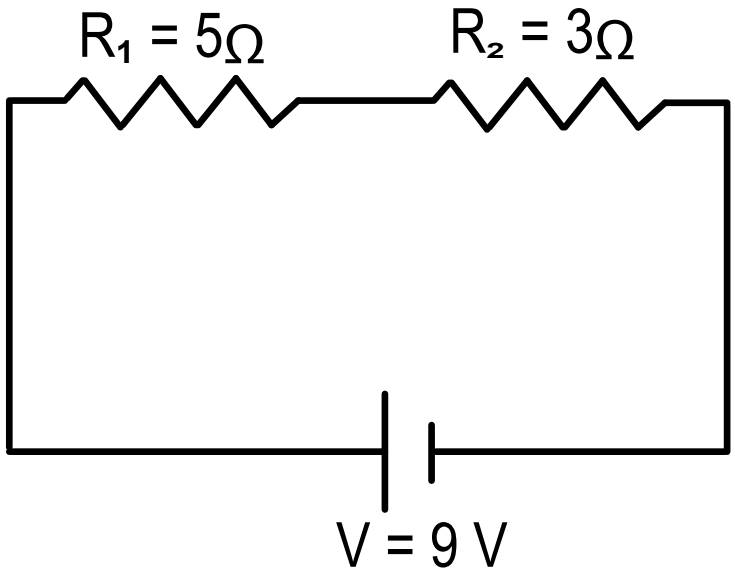
$I = I_1 = I_2 = I_3$

Now divide by I

$R_{eq} = R_1 + R_2 + R_3 + ...$

To find the equivalent resistance (R_{eq}) of a series circuit, add the resistance of all the resistors.If you add more resistors to a series circuit, what happens to the resistance?

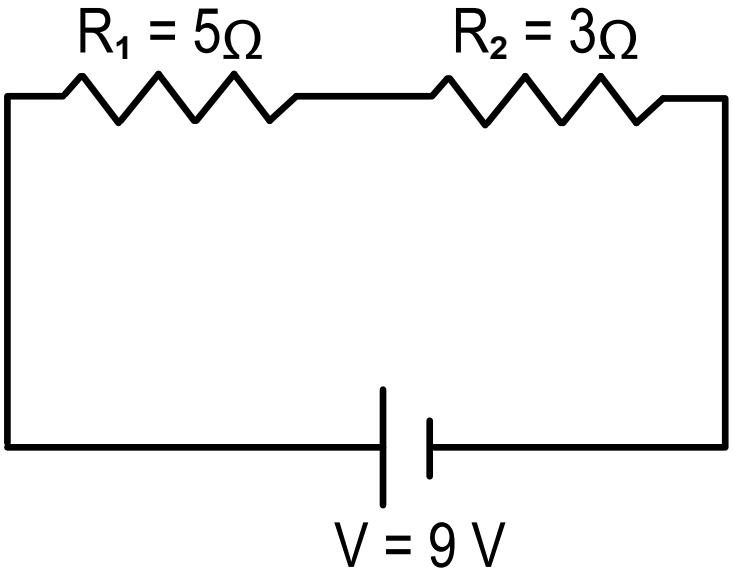
28 What is the equivalent resistance in this circuit?



Answer

https://www.njctl.org/video/?v=t_KHxvQme3E

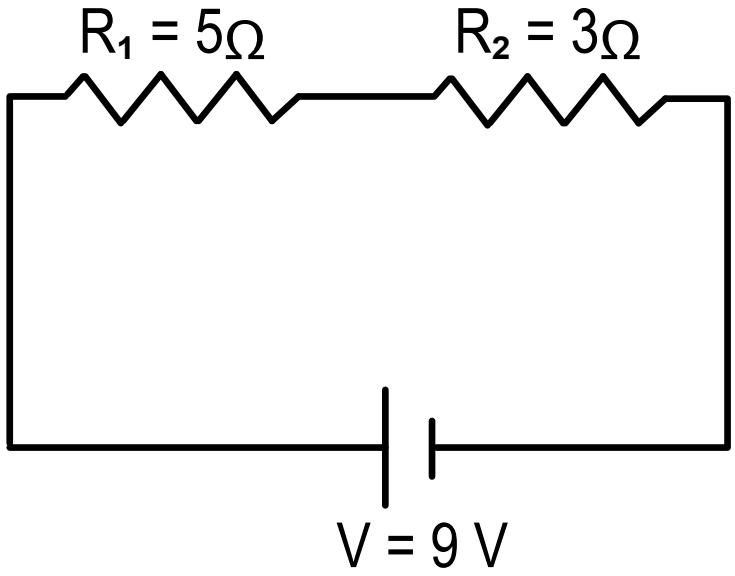
29 What is the total current at any spot in the circuit?



Answer

https://www.njctl.org/video/?v=E6vsTDb5_cw

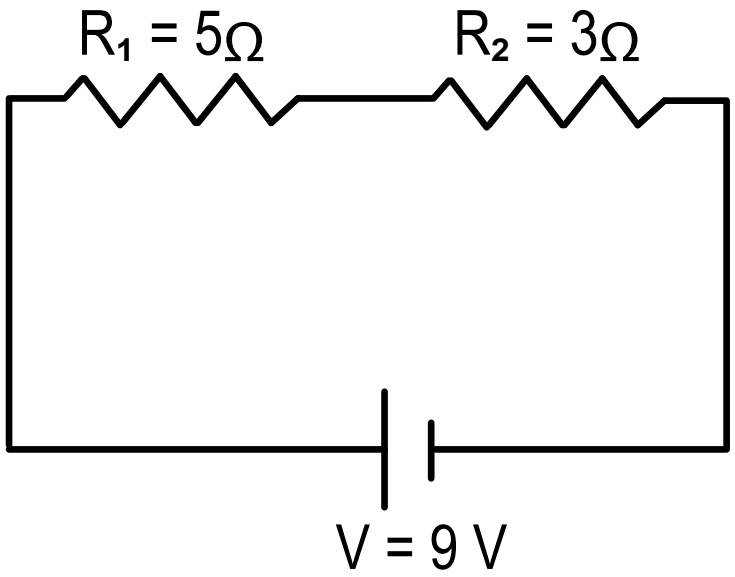
30 What is the voltage drop across R_1?



Answer

https://www.njctl.org/video/?v=ghXHOqlNB44

31 What is the voltage drop across R_2?

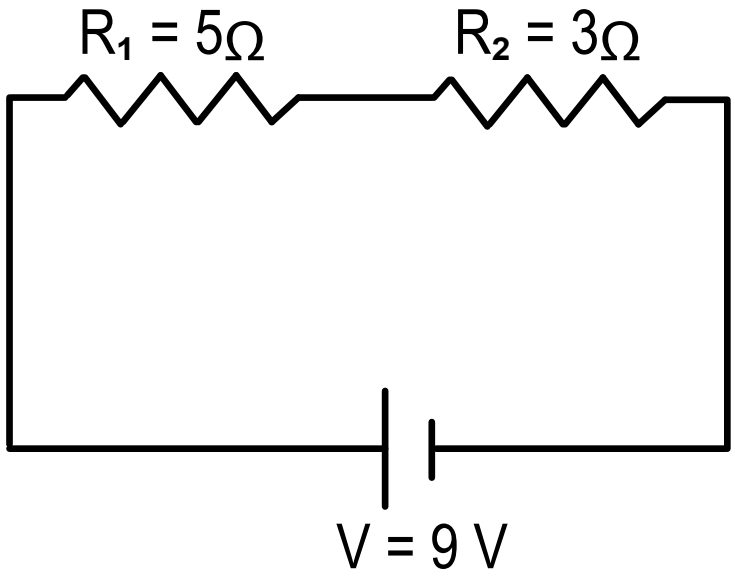


Answer

hint: A good way to check your work is to see if the voltage drop across all resistors equals the total voltage in the circuit.

https://www.njctl.org/video/?v=0d3GoKbFEOE

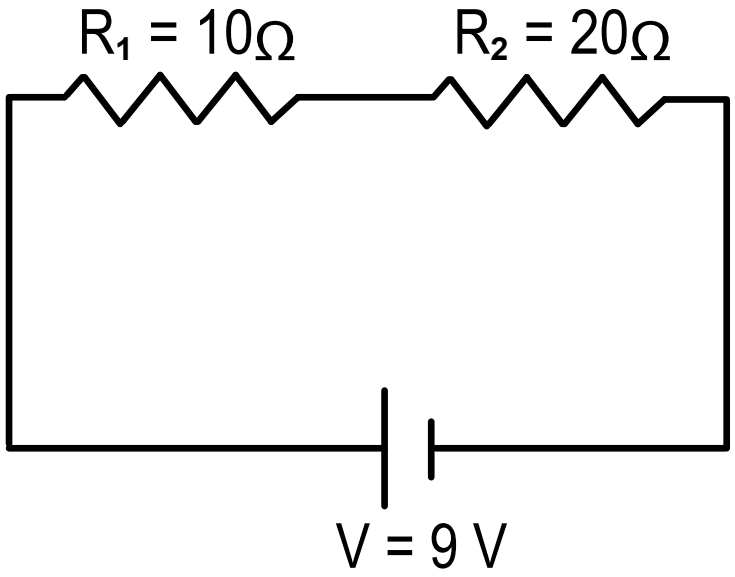
32 How much power is used by R_1?



Answer

https://www.njctl.org/video/?v=72Hax_NoIHs

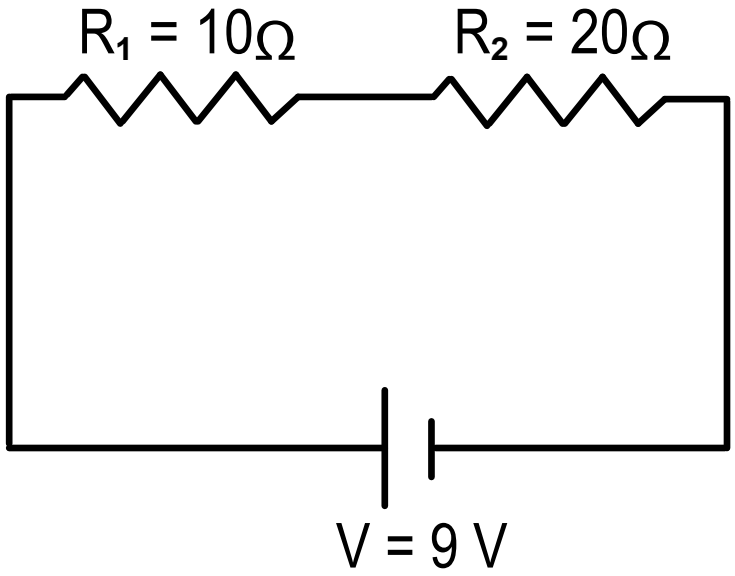
33 What is the equivalent resistance in this circuit?



Answer

https://www.njctl.org/video/?v=5EJ7PUPx7j8

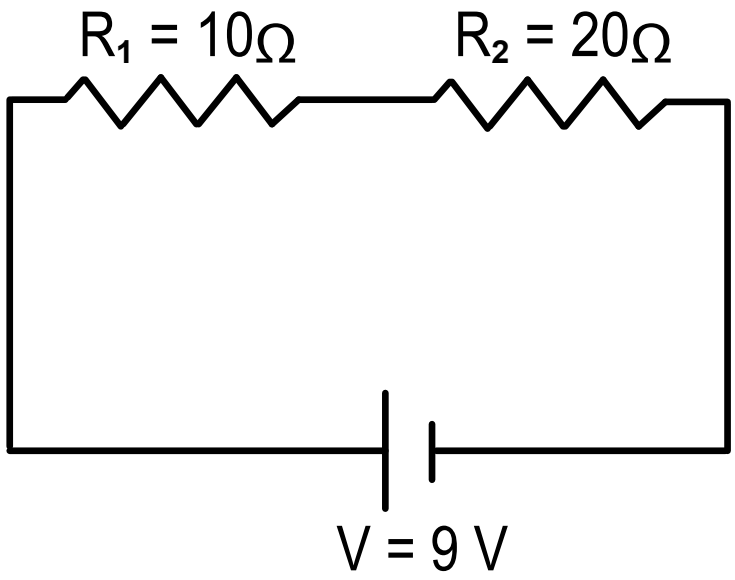
34 What is the total current at any spot in the circuit?



Answer

https://www.njctl.org/video/?v=qutX6Q378Co

35 What is the voltage drop across R_1?



Answer

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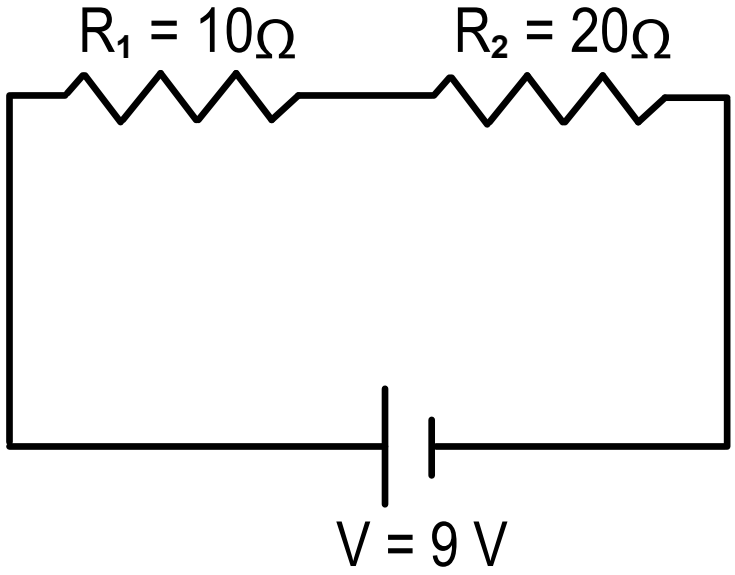
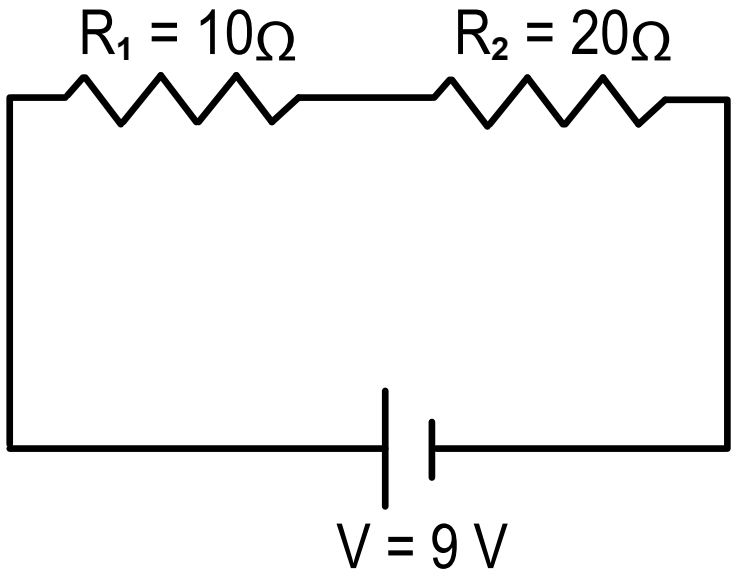
36 What is the voltage drop across R_2?



Answer

https://www.njctl.org/video/?v=chK_TQSlivo

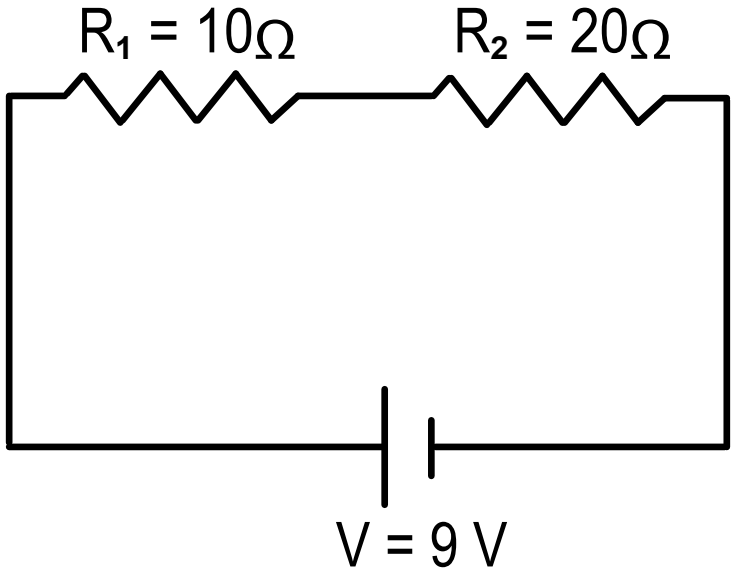
37 How much power is used by R_1?



Answer

https://www.njctl.org/video/?v=8DXNhuYHXKU

38 How much power is used by R_2?

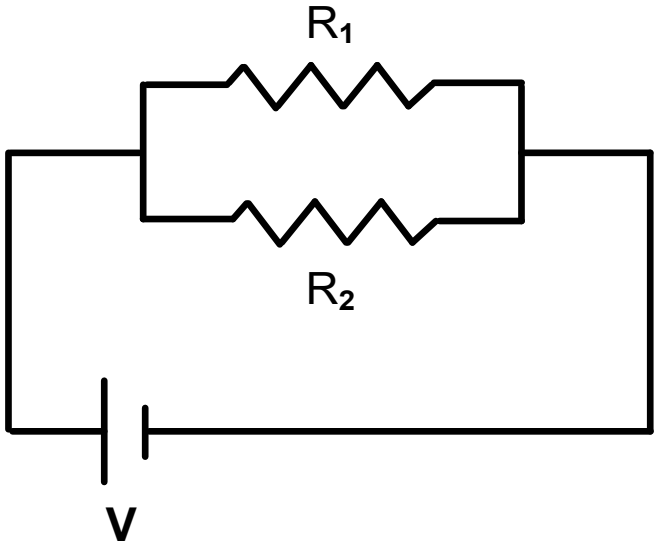


Answer

https://www.njctl.org/video/?v=tmAAUHz9jW4

Parallel Circuits: Equivalent Resistance

What happens to the current in the circuit to the right?

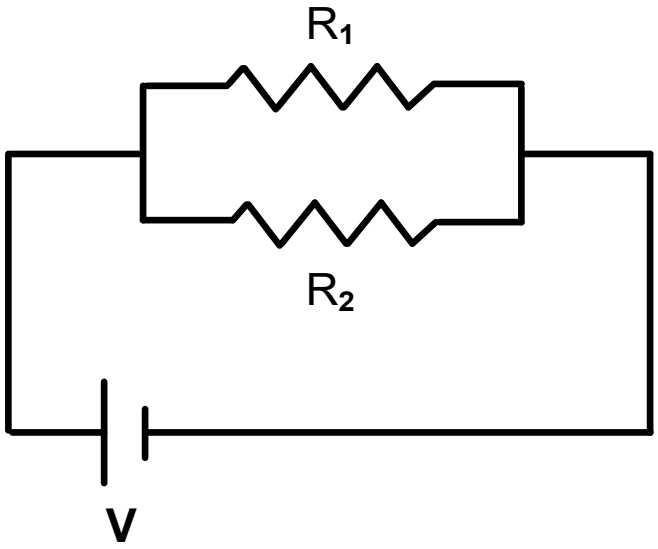


Answer

https://www.njctl.org/video/?v=4XRbjy2SQXY

Parallel Circuits: Equivalent Resistance

What happens to the voltage as it moves around the circuit?



Answer

Parallel Circuits: Equivalent Resistance

If $I = I_1 + I_2 + I_3$

$$\frac{V}{R} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

Rewrite Ohm's Law for I and substitute for each resistor

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

Also, since $V = V_1 = V_2 = V_3$ we can substitute V for any other voltage

$$\frac{V}{R} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

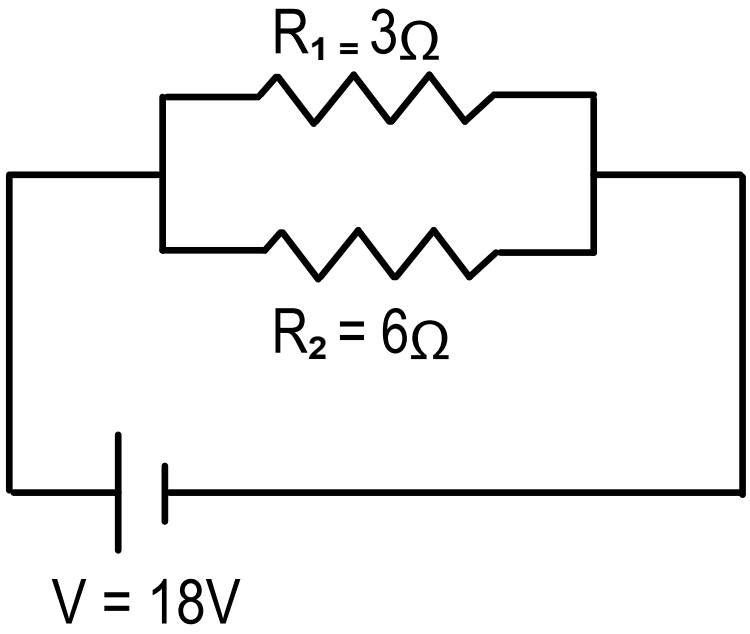
Voltage is a common factor, so factor it out!

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Divide by V to eliminate voltage from the equation.

If you add more resistors in parallel, what will happen to the resistance of the circuit?

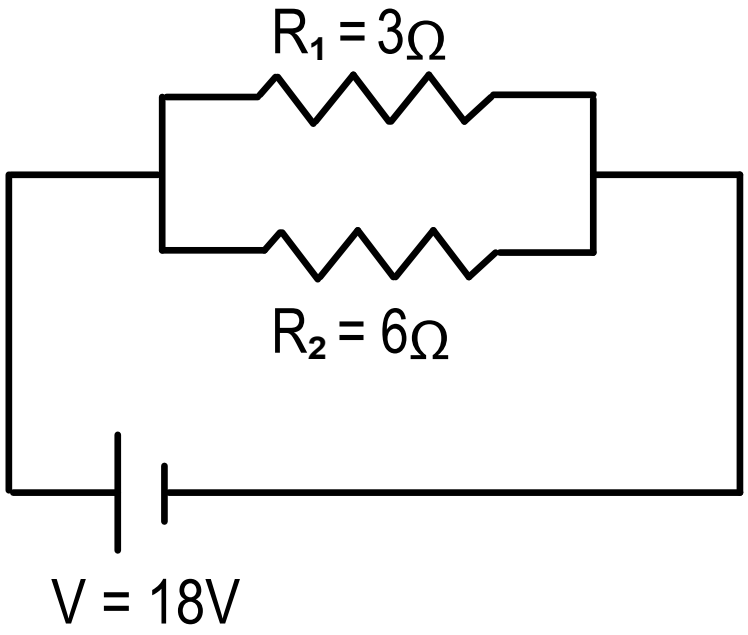
39 What is the equivalent resistance in the circuit?



Answer

https://www.njctl.org/video/?v=Pxsv5gppHh0

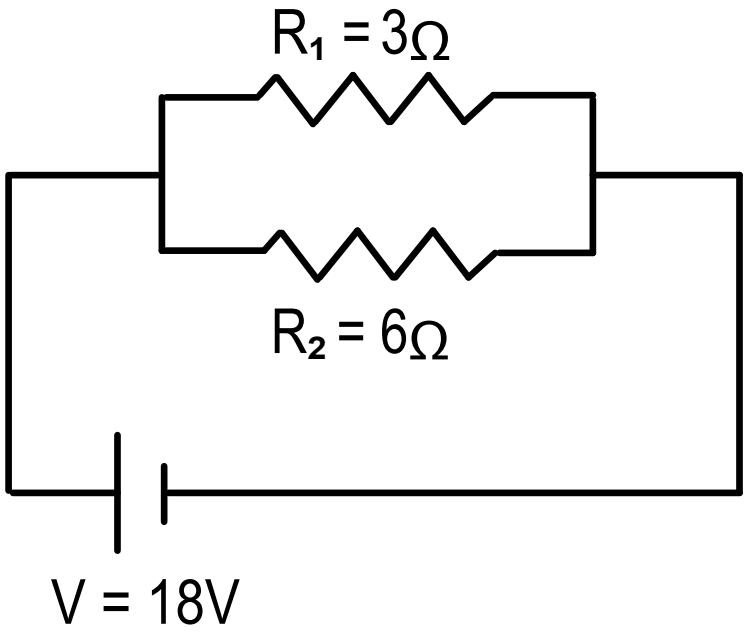
40 What is the voltage at any spot in the circuit?



Answer

https://www.njctl.org/video/?v=OPTa6nhoy8g

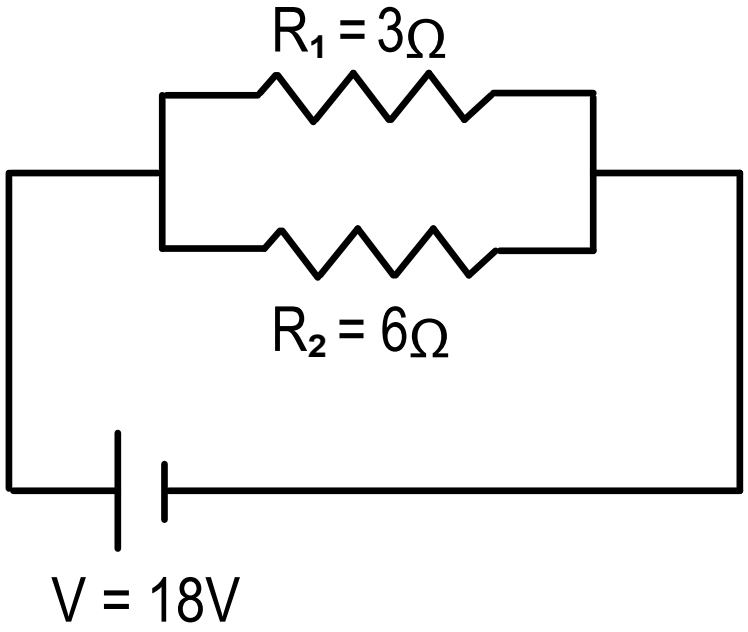
41 What is the current through R_1?



Answer

https://www.njctl.org/video/?v=uLLtkIHilYI

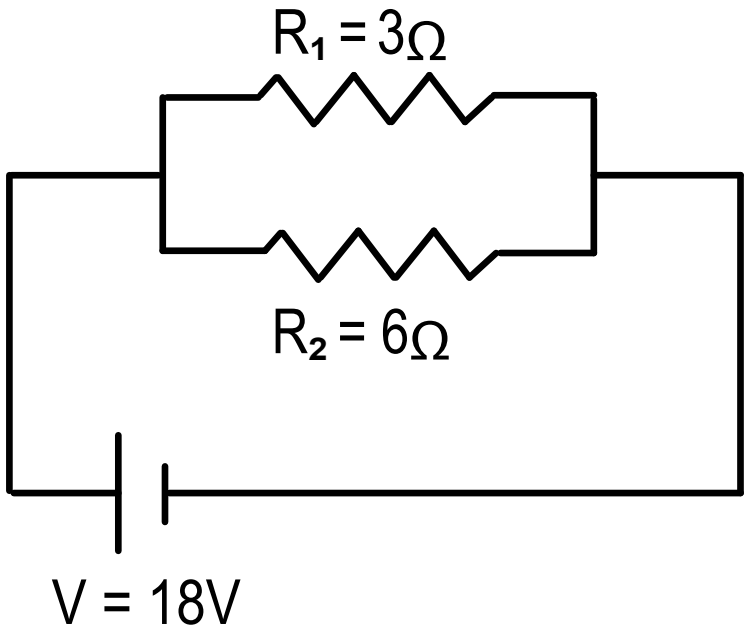
42 What is the power used by R_1?



Answer

https://www.njctl.org/video/?v=4nSd7G3zNXI

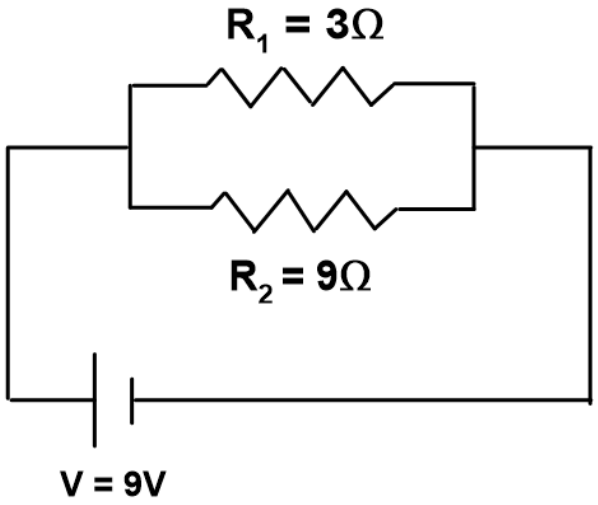
43 What is the power used by R_2?



Answer

https://www.njctl.org/video/?v=TPfEgteUKdM

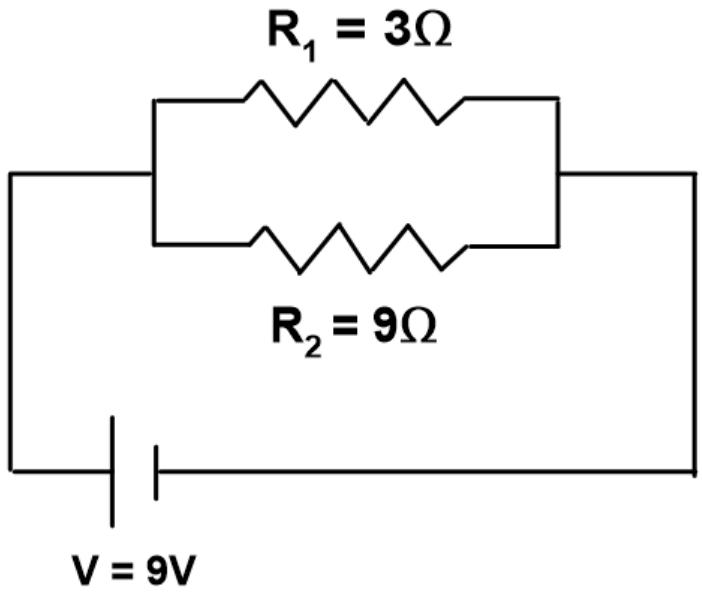
44 What is the equivalent resistance in the circuit?



Answer

https://www.njctl.org/video/?v=ILgggIS1MUk

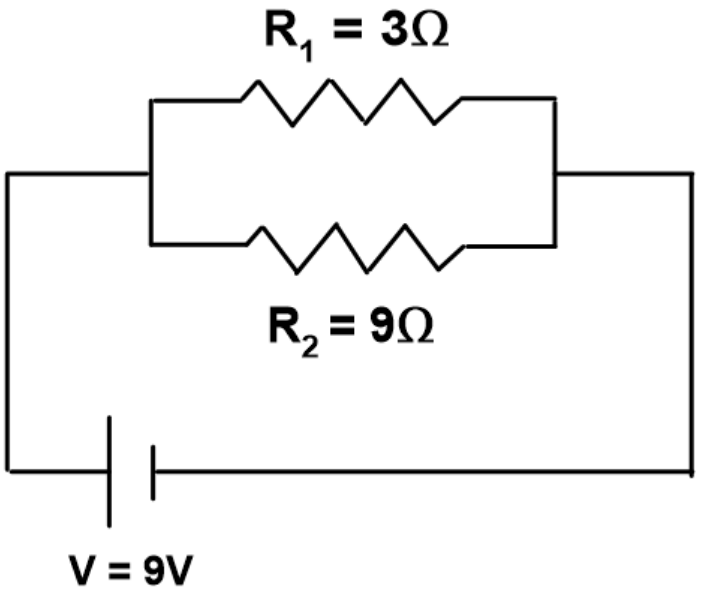
45 What is the voltage at any spot in the circuit?



Answer

https://www.njctl.org/video/?v=S3xtdJjC6ws

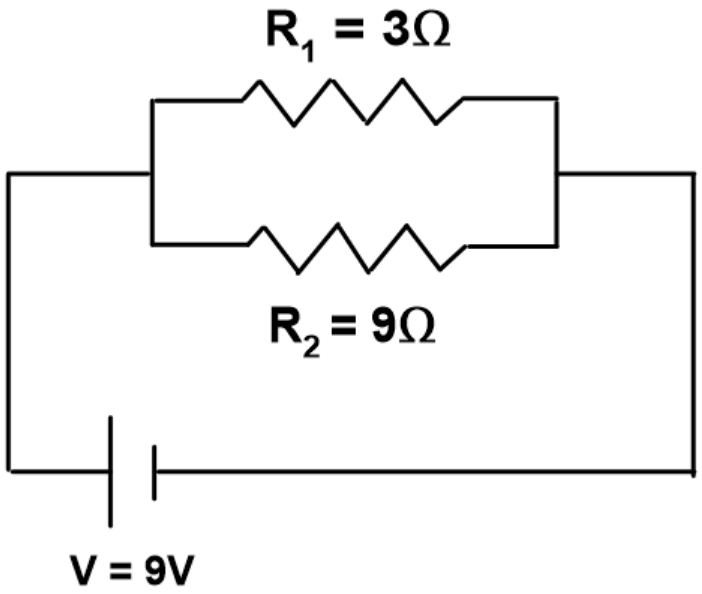
46 What is the current through R_1?



Answer

https://www.njctl.org/video/?v=17LVntdZ9JQ

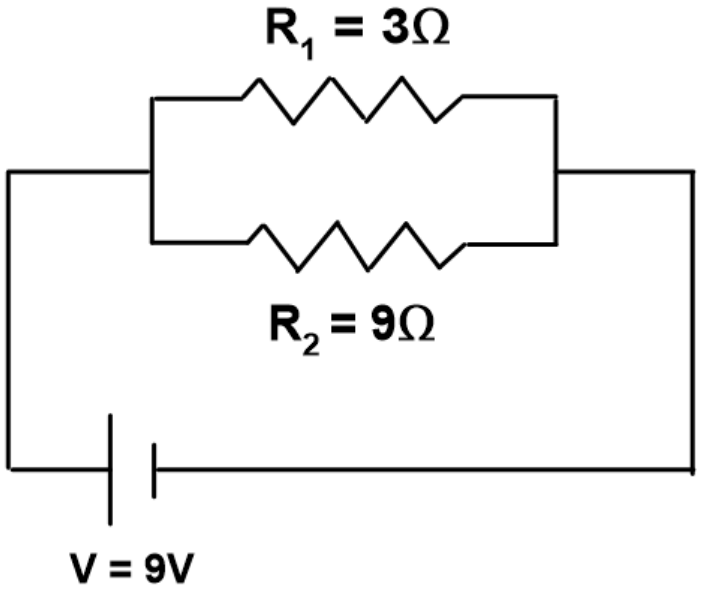
47 What is the current through R_2?



Answer

https://www.njctl.org/video/?v=B63uhzj5yx0

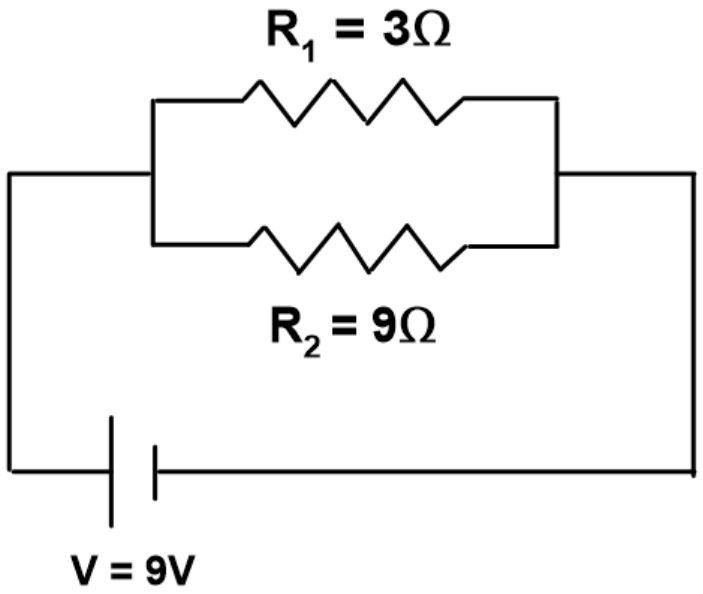
48 What is the power used by R_1?



Answer

https://www.njctl.org/video/?v=E_FDcqxpIWI

49 What is the power used by R_2?



Answer

https://www.njctl.org/video/?v=e-mfMEjR1bo

Measurement

https://www.njctl.org/video/?v=CoQQcP163lk

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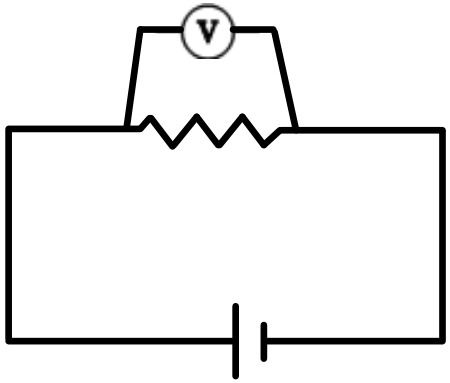
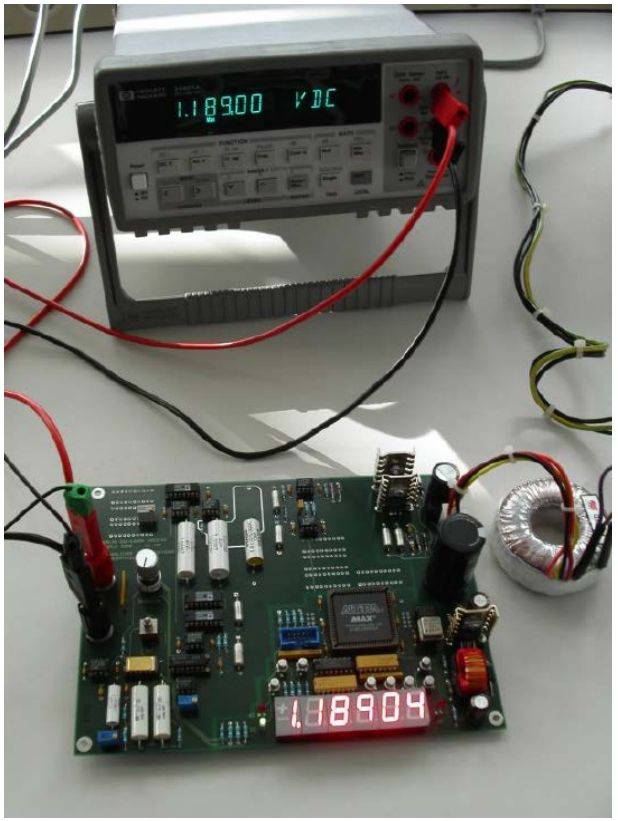
Voltmeter



Voltage is measured with a voltmeter. Voltmeters are connected in parallel and measure the difference in potential between two points.



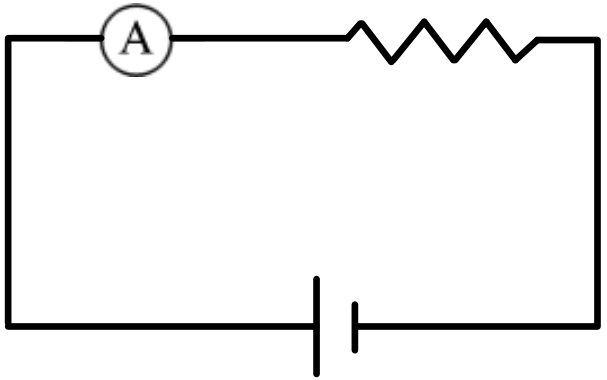
Since circuits in parallel have the same voltage, and a voltmeter has very high resistance, very little current passes through it.

This means that it has little effect on the circuit.

Ammeter

Current is measured using an ammeter.

Ammeters are placed in series with a circuit. In order to not interfere with the current, the ammeter has a very low resistance.



Multimeter

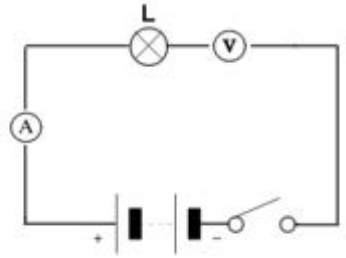
Although there are separate items to measure current and voltage, there are devices that can measure both (one at a time).

These devices are called multimeters.Multimeters can also measure resistance.

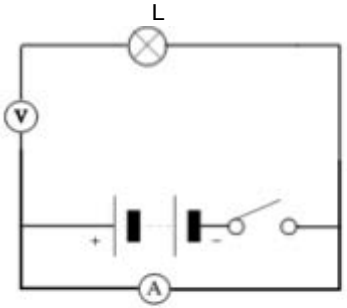
Click here for a PhET simulation on circuits

50 A group of students prepare an experiment with electric circuits. Which of the following diagrams can be used to measure both current and voltage?

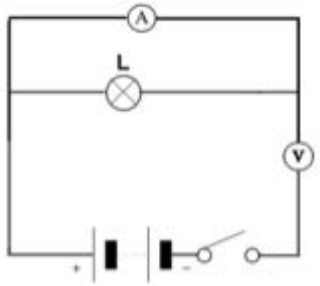
A



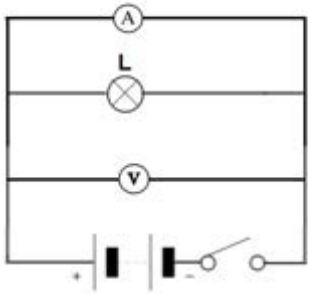
B



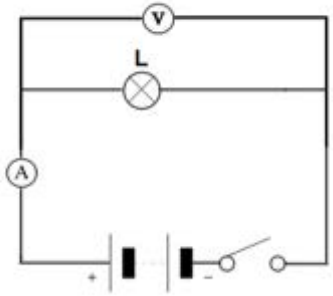
C



D



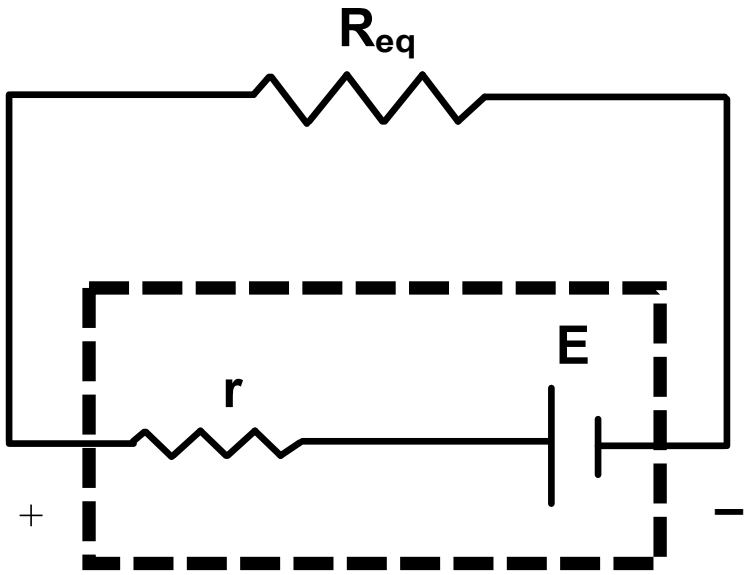
E



https://www.njctl.org/video/?v=JCIfxk2ctlw

Answer

* Electromotive Force



A battery is a source of voltage AND a resistor.

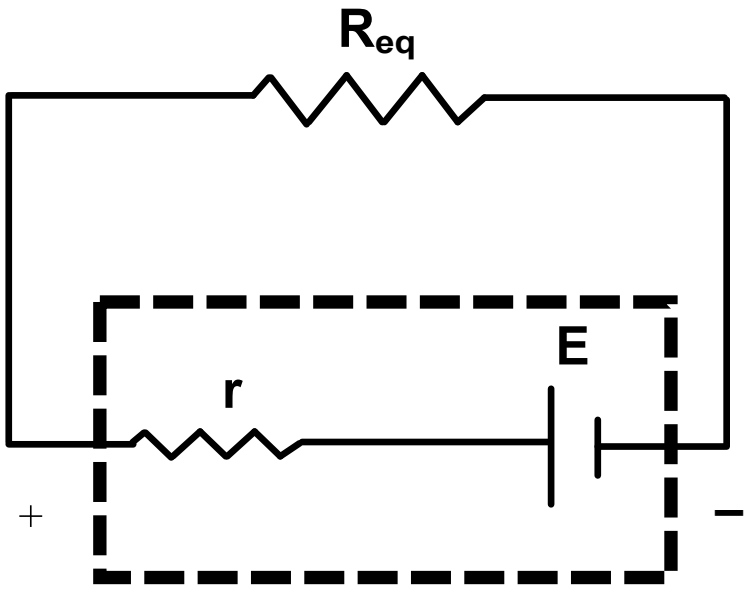
Each battery has a source of electromotive force and internal resistance.

Electromotive force (EMF) is the process that carries charge from low to high voltage.

Another way to think about it is that EMF is the voltage you measure when no resistance is connected to the circuit.

https://www.njctl.org/video/?v=zmgky4gpAvE

* Electromotive Force

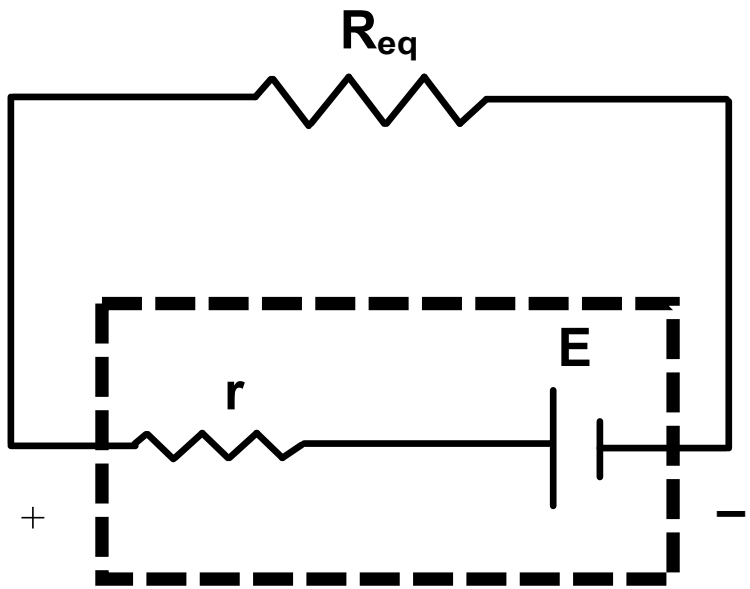


Terminal voltage (V_T) is the voltage measured when a voltmeter is across its terminals.

If there is no circuit attached, no current flows, and the measurement will equal the EMF.

If however a circuit is attached, the internal resistance will result in a voltage drop, and a smaller terminal voltage. (E - Ir)

* Terminal Voltage



We say that the terminal voltage is:

$V_T = E - Ir$

Maximum current will occur when there is zero external current.

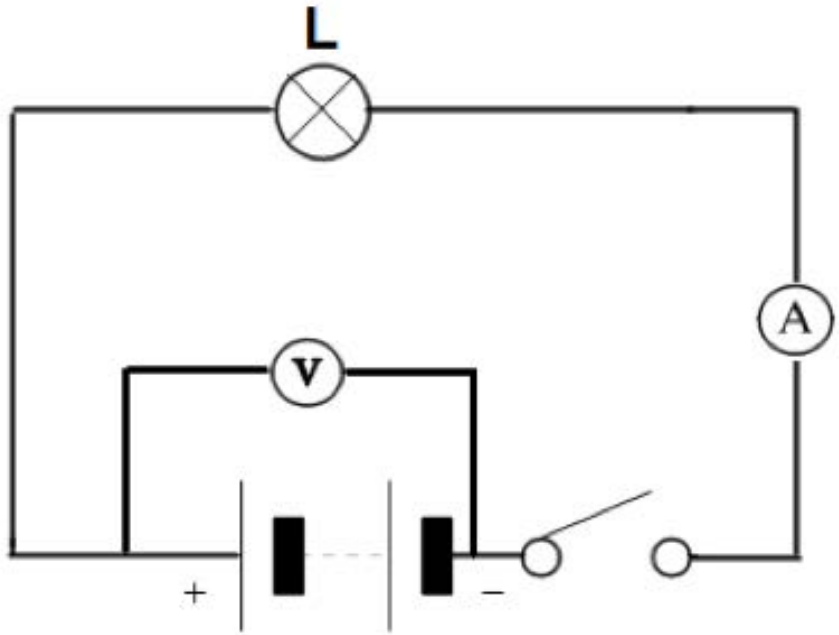
When solving for equivalent resistance in a circuit, the internal resistance of the battery is considered a series resistor.

$R_{EQ} = R_{int} + R_{ext}$

*

51 When the switch in the circuit below is open, the voltmeter reading is referred to as:

A EMF
B Current
C Power
D Terminal Voltage
E Restivity



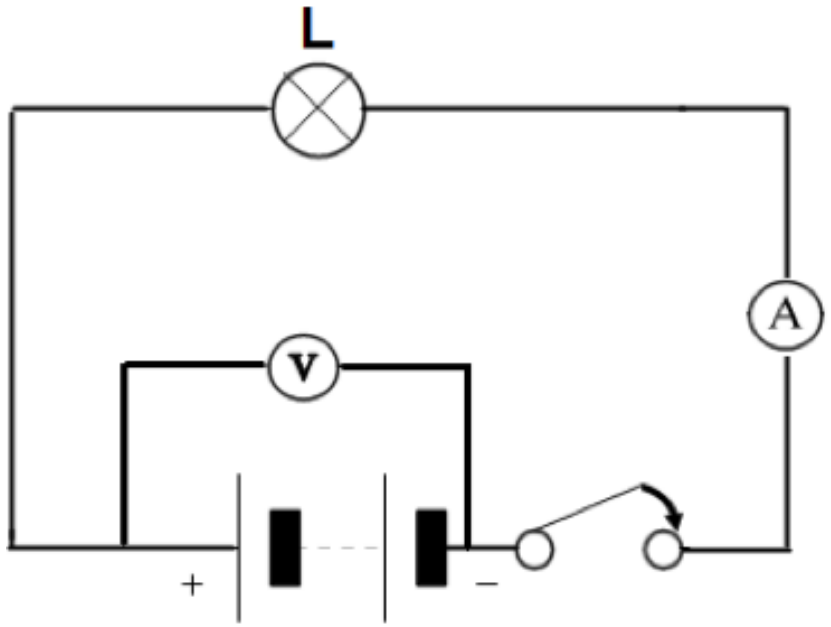
Answer

https://www.njctl.org/video/?v=Y8v3q-pWrbY

*

52 When the switch in the circuit below is closed, the voltmeter reading is referred to as:

A Terminal Voltage
B EMF
C Current
D Resistance
E Power



Answer

https://www.njctl.org/video/?v=_ONlJs3ii78

*

53 A 6V battery, whose internal resistance 1.5 Ω is connected in series to a light bulb with a resistance of 6.8 Ω. What is the current in the circuit?

Answer

https://www.njctl.org/video/?v=5qEtrI_gOJ8

*

54 A 6 V battery, whose internal resistance 1.5 Ω is connected in series to a light bulb with a resistance of 6.8 Ω. What is the terminal voltage of the battery?

Answer

https://www.njctl.org/video/?v=fhChTI3F5IY

*

55 A 25 Ω resistor is connected across the terminals of a battery whose internal resistance is 0.6 Ω. What is the EMF of the battery if the current in the circuit is 0.75 A?

Answer

https://www.njctl.org/video/?v=YPSXNX8fpFQ

Attachments

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