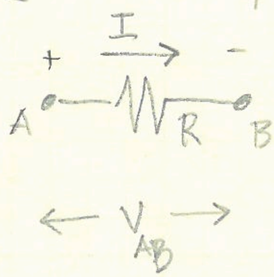
Ohm's Law Steady current flow through a resistor.



V_{AB} = the voltage difference or voltage drop across the resistor (volts) V

I = steady current flowing from ⊕ve to ⊖ve Amps (A)

R = resistance of the conductor that connects points A and B

$$\boxed{V = IR}$$

$1 \text{ Volt} = 1 \text{ amp} \times 1 \text{ ohm} \Rightarrow 1 \text{ amp} = \dfrac{1 \text{ Volt}}{1 \text{ ohm}}$ or $1 \text{ ohm} = \dfrac{1 \text{ volt}}{1 \text{ amp}}$

$1\,V = 1\,A \times 1\,\Omega$ $\quad 1\,A = \dfrac{1\,V}{1\,\Omega}$ $\quad 1\,\Omega = \dfrac{1\,V}{1\,A}$

review: express current in terms of the flow of charge

$$1\,A = \frac{1\,C}{1\,s} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

review: express voltage in terms of the work (or energy) necessary to separate opposite charges.

$$1\,V = \frac{1\,J}{1\,C} = \frac{1 \text{ Joule}}{1 \text{ Coulomb}}$$

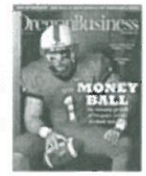
Power and Energy

Why is it important to understand power and energy requirements of electrical systems?

1. Output (external) non-electrical effects of circuits can involve significant energy exchange with the environment ~~e.g. turbines or electrical motors.~~ We may need to know how much energy an electrical device generates (e.g. a turbine) or how much energy an electrical device consumes (e.g. motor)

2. All practical circuits (more generally, all electrical devices) have limits on the power they can handle. Too much power consumption (dissipation) will cause a device to fail or "burn out". We need to work within the power limits when we design equipment

Tangent: what is design?



Google's secret thirst for power

Articles - August 2010

4 Like 0

0810_ATS09

SOURCE: NORTHERNWASCO COUNTY PUBLIC UTILITY DISTRICT

How much electricity does Google use to power its servers in The Dalles?

You'll never find out from employees of the search engine giant or from the utility officials who sell them the power, all sworn to secrecy through nondisclosure agreements. Nor will you find the answer within the frequently asked questions section of Google's web page for its Oregon data center.

For five years Google has remained mum on how much energy the data center uses, even as the facility has made headlines on the front page of *The New York Times* and raised the ire of *Harper's* magazine in a March 2008 article titled "Key Word: Evil." *Oregon Business* examined Google's power usage in June but couldn't get specifics.

But the operating reports of the Northern Wasco County PUD tell the story that Google will not. In pre-Google 2005, the PUD sold 242.4 million kilowatt-hours of electricity for $13.3 million. In post-Google 2009, the PUD sold more than twice as much energy, 592.4 million kilowatt-hours for $26.1 million.

Coincidence? 242.4×10^6 kWhr $\rightarrow$ 592.4×10^6 kWhr

Highly unlikely. One of the subcategories in the PUD's monthly and annual reports is for primary service customers. In pre-Google 2005 there were five unidentified customers. In post-Google 2006-2009, there were six. Whoever it was, that new, unnamed customer certainly improved the PUD's bottom line. Primary service sales jumped from $1.4 million for five customers in 2005 to $13.8 million for six customers in 2009. The Wasco PUD's primary service category has grown larger than total revenues were in 2005.

Using good old-fashioned arithmetic, Google spends about $12.4 million per year on about 330 million kilowatt-hours of energy in The Dalles. That's enough to power 33,000 homes, or roughly three cities the size of The Dalles.

BEN JACKLET

Email This Share on Facebook, Digg, etc.

Subscribe to this comment's feed

And?
written by John , August 03, 2010 1:29:45 pm PDT

The point is?

BROWSE NEWS BY INDUSTRY

Select

100 BEST MENU

- 100 Best Companies 2010
- 100 Best Green Companies 2010
- 100 Best 2009
- 100 Best Nonprofits 2009
- 100 Best Green Companies 2009
- 100 Best 2008
- 100 Best 2007

LATEST COMMENTS

The 2009 100 Best Companies List
It appears per the pie graph, companies, the top 100 to work for do not embrace diversity? go figure!

A big, hairy deal
Just revisited this article...this is my house that was featured and I would do it all over again, still love Gorilla Capital!!

Fruit stands crush farmers markets on price
Most of the produce at farmers markets is certified organic or produced under the same guidelines. Produce at roadside markets might be local but it's...

read more comments »

LATEST FORUM POSTS

GOP blocks bill meant to promote less outsourcing
Emma Hall 9-28-2010

Can Icahn help Blockbuster recover

Power and Energy

Energy and work are finite or discrete quantities

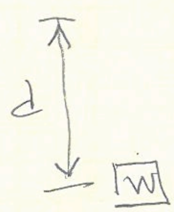
Power is a rate or continuous quantity

Work and Energy

"Work" is a thermodynamic quantity with the same units as energy.

Mechanical work is defined as the energy necessary to raise a weight

$\underset{\text{distance}}{\uparrow}$ (raise) $\qquad$ $\underset{\text{Force}}{\uparrow}$ (weight)



$w = mg = \text{weight}$

$$\text{Work or Energy} = \text{force} \times \text{distance}$$

$$1\,J = 1\,N \times 1\,m$$

$\uparrow$

Newton = unit of force

$$1\,N = 1\,kg \times 1\,\frac{m}{s^2}$$

$$F = ma \qquad \text{(a.k.a. Newton's Law)}$$

Power is the <u>rate</u> at which work is done or energy is expended

$$\boxed{1\,W = \frac{1\,J}{1\,s}}$$

"rate" ⇒ ____ per unit time

Watt = SI unit of power

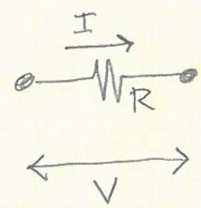
For electrical current:

$$P = VI$$

Power (W)

Voltage drop across the resistor (V)

Current through the resistor (Ω)



Use Ohm's law to obtain alternative formulas for computing power

$$\left.\begin{array}{l} P = VI \\ V = IR \end{array}\right\} \rightarrow P = (IR)I = I^2R$$

$$\left.\begin{array}{l} P = VI \\ V = IR \Rightarrow I = \frac{V}{R} \end{array}\right\} \rightarrow P = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

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

$$1\,\text{Watt} = 1\,\text{Volt} \times 1\,\text{amp} = (1\,\text{amp})^2 \times 1\,\text{ohm} = \frac{(1\,\text{Volt})^2}{1\,\text{ohm}}$$

"unit of V is volt"

[V] = volt

[I] = amp

[R] = ohm

[P] = Watt

"unit of P is Watt"

Example: How much energy is consumed when a 40W light bulb "burns" for 5 minutes? (Answer in Joule)

40W

Given: a 40W light bulb

Find: Energy consumed in 5 minutes

Solution: [Comment: No voltage or current are given. Is there enough information to solve this problem?]

Use the definition of the relationship between energy and power

Power = rate at which work is done

= rate at which energy is expended

rate $\Rightarrow \dfrac{\text{energy}}{\text{time}}$

Let E = amount of energy consumed in time Δt

$$P = \frac{E}{\Delta t} \Rightarrow E = P\Delta t$$

known: $P = 40\,W$ $\quad \Delta t = 5\,min \times \dfrac{60\,s}{min} = 300\,s$

$$\therefore E = (40\,W)(300\,s) = \left(40\,\frac{J}{s}\right)(300\,s) = 12000\,J$$

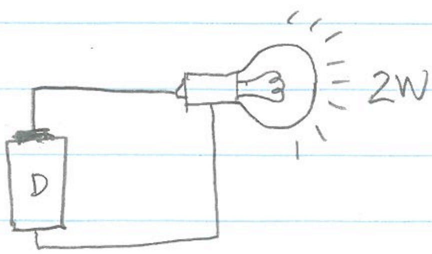
$$\boxed{E = 12000\,J = 12\,kJ}$$

Discussion: The calculation involves a straightforward application of the definition of power.

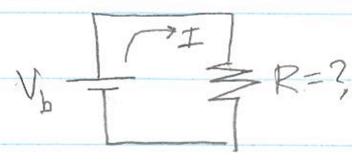
Example A D-cell battery supplies 2W of power to a small lightbulb

a.) Find the current from the battery

b.) Find the resistance of the bulb



Circuit diagram:



What do we know? Battery is a D-cell $\Rightarrow V_b = 1.5V$

Power is 2W

Does Ohm's Law apply? Answer: Yes!

$$V_b = IR$$

but both I and R are unknown

Additional information is available from the specification of 2W of power

$$P = V_b I = 2W$$

Both P and V_b are known. Solve for I

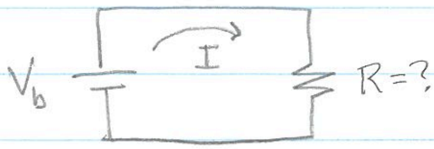
$$\Rightarrow I = \frac{P}{V_b} = \frac{2W}{1.5V} = \frac{2}{3/2} A = \boxed{\frac{4}{3} A = I}$$

Now that I is known, apply to Ohm's Law

$$V = IR \Rightarrow R = \frac{V}{I} = \frac{1.5V}{\frac{4}{3}A} = 1.125\Omega \quad \boxed{R = 1.13\Omega}$$

Comment on example

There are two paths through the solution to the preceding problem. Either path is acceptable



At the beginning, V_b and P are known. I and R are unknown

Path A:

✓ means known

○ means unknown

$$P = V_b I$$

known, known, unknown

Solve for I: $I = \frac{P}{V_b}$

with I known (freshly computed), apply Ohm's law

$$V_b = I R$$

solve for R: $R = \frac{V_b}{I}$

Path B:

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

known, known, unknown

Solve for R: $R = \frac{V_b^2}{P}$

with R known (freshly computed), apply Ohm's law

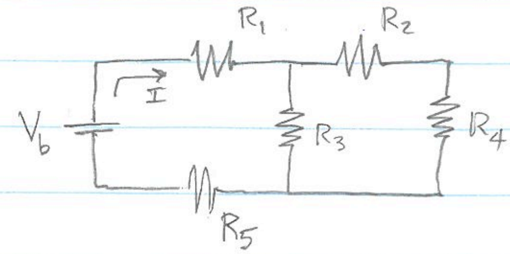
$$V_b = I R$$

solve for I: $I = \frac{V_b}{R}$

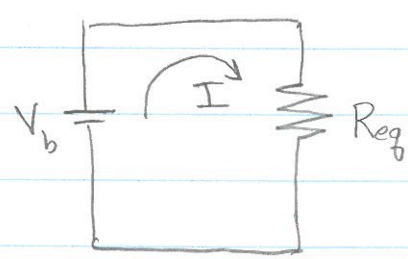
It is not uncommon to have multiple algebraic paths to the solution of a problem.

Equivalent Resistance

Consider the complicated-looking circuit to the right. Suppose that the values of R_1, R_2, R_3, R_4 and R_5 are known. If V_b is also known, how would we compute the current I supplied by the voltage source?



Using the techniques presented in this module, you will be able to analytically combine the resistors into an equivalent value R_{eq}. The voltage source V_b will supply the same current to the original network of resistors as it does to the single equivalent resistor.



Resistors in Series:

Resistors in series are equivalent to a single resistor having a resistance equal to the sum of the individual resistances

"is equivalent to"

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

EAS 199A Fall 2010 Lecture #2 9/12

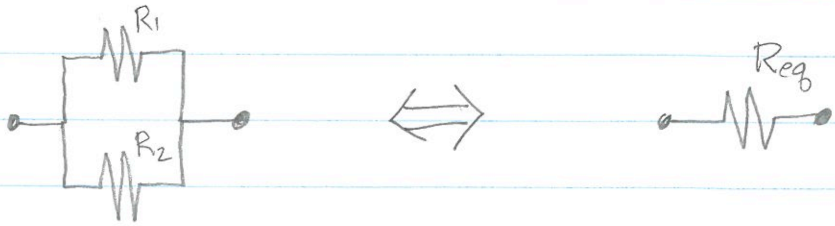
Resistors in Series (continued)

Any number of resistors in series can be combined by simply adding the values of the individual resistances

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

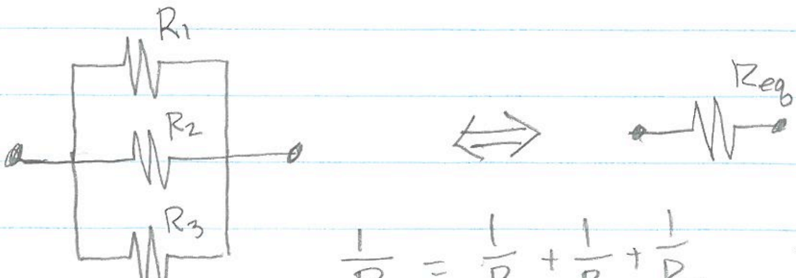
Resistors in Parallel

Resistors in parallel are equivalent to a single resistor having a value obtained by summing the inverses of the individual resistors



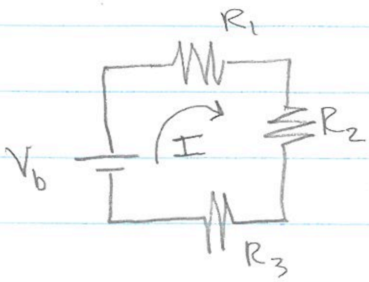
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

This generalizes to three or more resistors in parallel



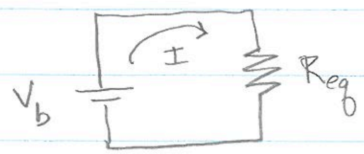
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \Rightarrow R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Example: What is the current flowing through the following circuit?



$V_b = 5V$, $R_1 = 3\Omega$, $R_2 = 2\Omega$, $R_3 = 5\Omega$

Equivalent Circuit:



$$R_{eq} = R_1 + R_2 + R_3 = 10\Omega$$

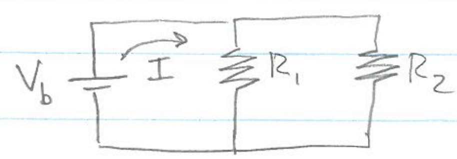
$$V_b = I R_{eq} \Rightarrow I = \frac{V_b}{R_{eq}} = \frac{5V}{10\Omega} = 0.5A$$

$$\boxed{I = 0.5A}$$

Example For the circuit to the right

a.) What is the current supplied to the resistors?

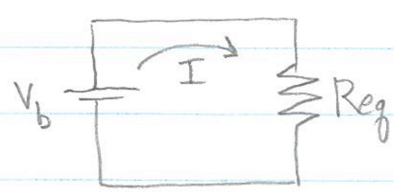
b.) What is the power consumed by the resistors?



$V_b = 3V$

$R_1 = 2\Omega$, $R_2 = 6\Omega$

The problem statement asks for power which can calculate from $P = V_b I$ but we only know V_b. Find I from the equivalent circuit (part (a))



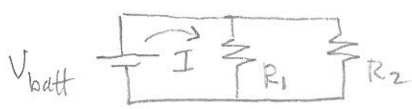
$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} = \frac{1}{\frac{1}{2\Omega} + \frac{1}{6\Omega}} = \frac{1}{\frac{3}{6\Omega} + \frac{1}{6\Omega}} = \frac{1}{\frac{4}{6\Omega}} = \frac{3}{2}\Omega$$

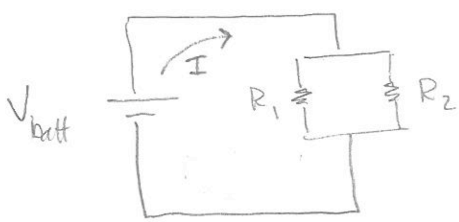
$$\therefore R_{eq} = \frac{3}{2}\Omega$$

Work the previous problem using Mathcad:

(The variable subscripts here are called literal subscripts and are used strictly for naming purposes)

	Keystrokes
$R_1 := 2 \cdot \Omega$	R.1 : 2* <pick Ω from the Greek palette > <enter>
$R_2 := 6 \cdot \Omega$	R.2 : 6* <pick Ω from the Greek palette> <enter>
$V_1 := 3 \cdot V$	V.1 : 3*V <enter>
$R_{eq} := \dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2}}$	R.eq : 1 / 1 / R.1 <space> + 1 / R.2 <enter>
$R_{eq} = 1.5\,\Omega$	R.eq =
$I := \dfrac{V_1}{R_{eq}}$	I : V.1 / R.eq <enter>
$I = 2\,A$	I =

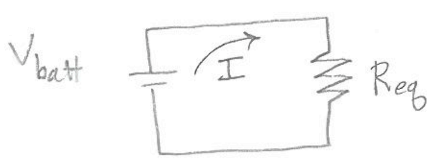




$R_1 = 2\,\Omega$

$R_2 = 6\,\Omega$

$I = ?$



Example, continued

Now that we know R_{eq} we apply Ohm's law to compute I

$$V_b = I R_{eq} \Rightarrow I = \frac{V_b}{R_{eq}} = \frac{3V}{\frac{3}{2}\Omega} = 2A$$

$$\boxed{I = 2A}$$

(b) With V_b and I known, compute the power from $P = V_b I$

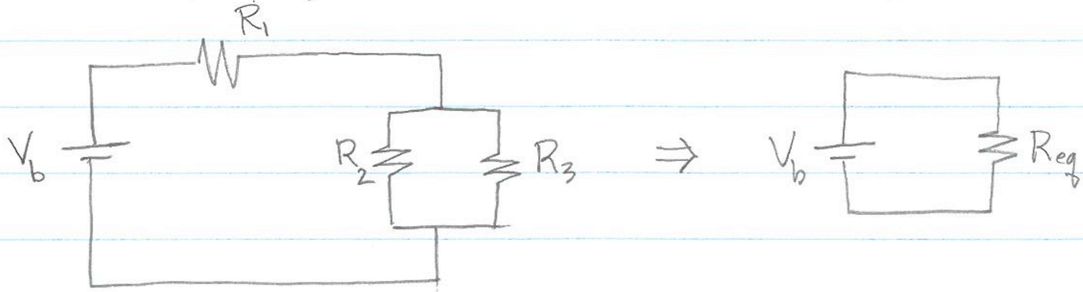
$$P = V_b I = (3V)(2A) = 6W \qquad \boxed{P = 6W}$$

Circuits with Both Series and Parallel Resistors

Be systematic: simplify the circuit in stages

1. Combine all series resistors first — they are easy
2. Combine all parallel resistors
3. Repeat steps ① and ② until R_{eq} is found

Example: Find the equivalent resistance for the following circuit



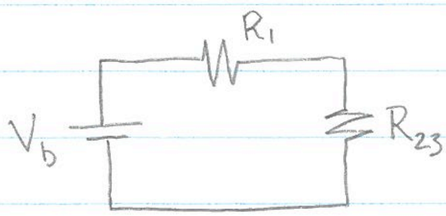
The goal is to transform the circuit on the left to the circuit on the right

Step 1: there are no series combinations of resistors to simplify at this time

step 2: combine the two parallel resistors

$$R_{23} = \frac{1}{\frac{1}{R_2} + \frac{1}{R_e}}$$

this leads to the partially simplified circuit



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

repeat step 1: combine R_1 and R_{23}

$$R_{eq} = R_1 + R_{23} = R_1 + \frac{1}{\frac{1}{R_2} + \frac{1}{R_3}}$$