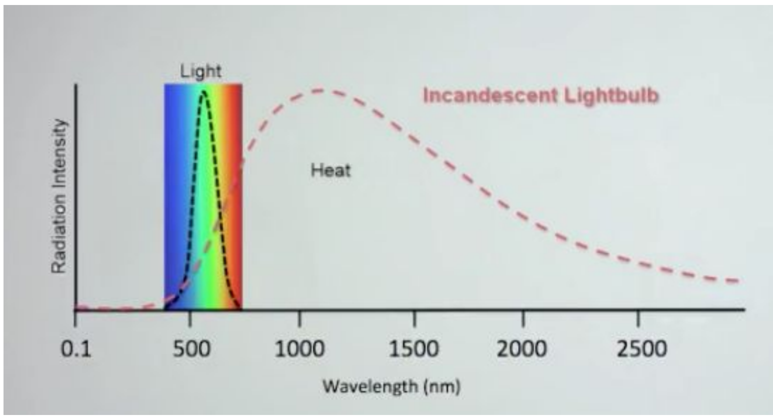
Power

Current flow results from the application of force — electromotive force. The process is never 100% efficient ... meaning that not all the energy applied is used to provide the desired effect.

A very good example is the incandescent light bulb. When voltage is applied, it results in a current through the bulb's filament, making it hot enough to glow white-hot, thereby emitting the desired result — *light*.

Thus, we are able to convert electrical energy to light. However, the bulb also gets very hot, so to the extent that it was not *heat* that we wished to produce, a part of the electrical energy is also wasted. In this case, about 95% of it!



To express *the rate of energy conversion with respect to time*, the unit is the *watt*.

Yes, that name comes from the home-schooled Scottish engineer James Watt, sometimes called “the father of the industrial revolution” because of his development of the first practical steam engines.

The watt is equal to a current of one ampere passing through a resistance of one ohm for one second. $1A|1\Omega|1sec \rightarrow 1W$

Back to algebra!

As used in electronics, the term generally refers to power consumption or *power dissipation*, and there are three formulas that you will occasionally find useful ...

$P = IE \quad E2 \quad P = I2R \quad P=R$

Where:

• P = power in watts

• E = volts (as in electromotive force) • I = current in amps

Suppose, for example, that we connect a 100Ω resistor across a 6V battery. By ohm's law, the current in the circuit would be ...

E6

I = R = 100 = 0.06 amps

So, all three formulas should give the same result ...

$P = IE = 0.06 \times 6 = 0.36$ watts

$$P = \frac{E^2}{R} = \frac{6^2}{100} = 0.36 \text{ watts}$$

$P = I^2R = 0.06^2 \times 100 = 0.36$ watts

As with Ohms law, the power formulas can be manipulated to find any one parameter when the other two are known.

For example, if wondering how much current ten 100-watt light bulbs draw, in order to select a proper size fuse for the circuit, use the simple $P = IE$ equation. Standard 120-volt residential power is assumed.

First, divide both sides of the equation by *P*...

$PIE\ IE\ P = P\ \therefore 1 = P$

... then divide both sides by *I* and invert the result ...

$1 IE\ P$

$I = IP\ \therefore\ I = E$

$$I = \frac{10\times100}{120} = 8.33 \text{ amps}$$

It’s not always a concern in electronics, but if wondering how much the electric company will charge you to run these ten light bulbs, you need to know that they charge you by the hour on the basis of watts being used.

The average rate in the U.S. is about 13¢ per *kilowatt-hour*, or *KWH*, which means 1,000 watts used for one hour. Since your ten 100- watt light bulbs amount to 1,000-watts total, they would cost about $1.56 if operated for an average 12-hours per day.

How much would it cost to run your vacuum cleaner for 30-minutes? Assuming that it draws 12-amps on 120-volts ...

$P = IE$ = 12×120 = 1440 watts

If operated for one hour at 13¢ per KWH, the cost would be 1.44 x .13 = 18.7¢, so half of that would be just a little over 9-cents.

So, go sweep your carpet!

Numerical Prefixes

What’s all this “kilo” business about anyway?

This is a good time to talk about numerical prefixes — nothing more than a sort of shorthand used to express big or little quantities in easier ways. In electronics, there are generally eight ...

tera - 1,000,000,000,000 *giga* - 1,000,000,000 *mega* - 1,000,000 *kilo* - 1,000

milli - .001 *micro* - .000001 *nano* - .000000001 *pico* - .000000000001

As an example, 1,000 Watts could also be called 1-kilowatt, or 1KW.

The “*a*” and “*o*” are sometimes omitted from mega and kilo when the pronunciation would be unwieldy, such that 1,000 ohms becomes 1- kilohm (instead of 1-kiloohm) or more simply 1KΩ. 1,000,000 ohms becomes 1- megohm (instead of 1-megaohm) or 1MΩ, or sometimes just “one meg”.

Going the other way, 0.06 amps would usually be called 60-milliamps, written as “60mA”.

Scientific Notation

For calculation purposes, these prefixes can also be seen as representing *powers of ten*, which is also called *scientific notation* ...

tera - ×1,000,000,000,000 - *(T)*
giga - ×1,000,000,000 - *(G)*
mega - ×1,000,000 – *(M)*
kilo - ×1,000 – *(K)*
mili - ×.001 – *(m)*
micro - ×.000001 – *(μ)*
nano - ×.000000001 – *(η)*
pico - ×.000000000001 – *(ρ)*

tera = *giga* = *mega*= *kilo* = *milli* = micro = *nano* = *pico* =

10^{12} *(T)* 10^{9} *(G)* 10^{6} *(M)* 10^{3} *(K)* 10^{-3} *(m)* 10^{-6} *(µ)* 10^{-9} *(n)* 10^{-12} *(p)*

tera =	1,000,000,000,000 =	10^{12}
giga =	1,000,000,000 =	10^{9}
mega =	1,000,000 =	10^{6}
kilo =	1,000 =	10^{3}
mili =	.001 =	10^{-3}
micro =	.000001 =	10^{-6}
nano =	.000000001 =	10^{-9}
pico =	.000000000001 =	10^{-12}

Here’s an example of how powers of ten work ... let’s calculate the voltage drop across a 1KΩ resistor with a current of

1.0mA. We could do it the hard way, like this ...

$E = IR = .001A \times 1{,}000 = 1.0V$ ... or the easy way, like this ...

$E = IR = 1 10^{-3} A \times 1 10^{3} = 1.0V$

To multiply numbers expressed in powers of ten, simply multiply the whole numbers, and add the exponents algebraically.

In this example, the algebraic sum of the exponents is zero, and 10^0 is equal to 1.

The “10” is called the *base.* Values are expressed as a whole number raised to some power of *base 10*, as indicated by an exponent. This is therefore sometimes called *exponential notation*, and a shorthand method of writing such numbers is available...

$E = IR = 1_{e-3}A \times 1_{e3} = 1.0V$

The *“e”* is simply a symbol which flags the exponent as a power of ten, making sure that it won’t be mistaken as an exponent of the whole number itself. For example, 10_{e3} means 10,000, whereas 10_{3} equals 1,000.

When I first encountered this *“e”* sort of notation, I got nervous about it right off the bat, and it seemed very confusing. Please don't go there ... there's no need for that because it's actually almost kindergarten stuff.

Think of it as a simple system for sliding the decimal point one way or the other, with *"e"* as the index. If *"e"* is positive, the

decimal point slides to the right by that number of places.

1×10^6

$\equiv 1e6$

$\equiv 1{,}000{,}000$

If it’s negative, the decimal point slides to the left by that number of places.

$1 \times 10^{-6} \equiv 1e{-6}$

$\equiv .000001$

When dividing numbers expressed in powers of ten or exponential notation, divide the whole numbers in the usual way, then subtract the exponent of the divisor from the exponent of the dividend, and assign the result to the quotient.

$2e3\ e{-3}\ 1e6 = 2$

To add or subtract these sorts of values, the exponents must match. To make them match, you can simply slide the decimal

point one way or the other. If you need to reduce the exponent, slide the decimal point to the right by that much.

$2e3 + 1e6 =? \equiv 2e3 + 1000e3$

$= 1002e3$

or ...

$\equiv .002e6 + 1e6 = 1.002e6$

If you want to increase the exponent, slide the decimal point to the left by that many places.

Then do the addition or subtraction in the usual way, the sum or difference having the same exponential value. By convention, the correct procedure is usually considered to be the one that provides the smallest value for the whole number in the result ... as in the second case shown here.

At first glance, scientific notation might look like an unnecessary complication. But if, in the future, you find yourself involved in lengthy circuit design calculations, you’ll soon discover that it’s actually a handy convenience ... much easier than writing or keying in numbers the long-hand way. It’s not complicated; it’s just a matter of what you’re used to.

Incidentally, you can use this sort of notation with most *engineering* or *scientific* calculators ... including my very most favorite, *Judy’s Ten Key*!

Before going on, let's talk a little bit more about the number-one enemy of electronic systems — HEAT!