What is Voltage?

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First, What is Charge?

One of the greatest discoveries in physics, by William Watson (in 1746) and Benjamin Franklin (in 1747), was that there is something that Franklin called “electrical fluid,” and which we now refer to as charge.

Famously, in 1752, Benjamin Franklin flew a kite carrying a metal key beneath it into a storm cloud and then brought the kite and the key back down. The key was holding some of the electrical fluid! So he deduced that lightning is electrical fluid.

How do we (or Ben Franklin) know we have charge (or “electrical fluid”)? We catch it in a jar invented to hold charge. It was invented independently by two people, Ewald Georg von Kleist, and Pieter van Musschenbroek. Van Musschenbroek lived in Leiden, and the jar is known as the Leyden jar. It is a glass jar coated with metal.

Nowadays, and emerging at the time, was the observation that the “electrical fluid” barely moved through glass or not at all, and that it easily moved through metal.

I only need you to accept that there is something called charge, and that it easily moves through metal. You don’t yet have to have a mental picture of what charge is.

An extremely important property of charge is that it cannot be created or destroyed. It can move from place to place. It can divide and recombine, but it cannot simply disappear. More on this when we discuss negative charge. *We say, “charge is conserved.”*

Second, What is Energy?

That there is something called energy and that it is also conserved was postulated and on its way to being established in the 1840s.

We both say “there is conservation of energy,” and “energy is conserved,” and they mean the same thing.

You can think of energy as a quantification of how much work can be done. Or how much damage can be done. Or how much work it takes to do something.

The Units of Charge and Energy

In SI (System Internationale) units, charge is measured in Coulombs (abbreviated C), and energy is measured in Joules (abbreviated J). The Joule is directly related to the meter, the kilogram, and the second, but at this moment, it doesn't matter how. We'll get to that later. The meter (abbreviated m), the kilogram (kg), and the second (s) are also part of the SI system, and SI units are sometimes called mks units.

You are probably familiar with other units for energy, such as the chemist's calorie (abbreviated c), and the dietician's calorie (also abbreviated C or kcal). The dietician's calorie is just 1000 times the chemist's and it exists so that you don't have so many zeros on the nutrition labels on the sides of cans. Imagine writing that a serving of tuna contains 203000c instead of 203 kcal. The kcal is so much more convenient for dieticians, they generally have forgotten that it is 1000 of the chemist's calories, and dieticians and dieters just say “calorie” not “kcal” or “kilocalorie.”

Now what is the chemist's calorie!? The chemist's calorie is by definition how much energy it takes to heat 1 gram of water from 14.5°C to 15.5°C.

By the way °C is the abbreviation for a degree of Centigrade. Centigrade is also called Celsius to honor the Swedish polymath who decided to divide the temperature scale between the freezing of water and the boiling of water into 100 equal parts. I'm kind of fond of Fahrenheit, abbreviated °F. In Fahrenheit, the same range is divided into 180 equal parts, and body temperature is very nearly the nice round number of 100°F. As measurement precision increased, it came to be seen that normal body temperature is actually about 98.6°F.

Since the chemist's calorie depends on the specific properties of water, which is just a common compound that we have handy, whereas *the Joule is deeply related to the meter, the kilogram, and the second,* the Joule is way more convenient for most scientific work.

You will hear no more from me about the calorie or the kilocalorie. I only brought them up so that you would have some tangible, everyday example of energy. It's good that we are done with the calorie and the kilocalorie, because we already had too many things that start with “c.”

From here on the only things that start with “c” are the Coulomb and the degree of Centigrade. Again, these are abbreviated C, and °C.

(Well, actually, we'll get to capacitance at some point, and unfortunately capacitance also starts with the letter “c,” but thankfully the unit of capacitance is the Farad, abbreviated F. Capacitance will come later. Don't think about it yet.)

Finally, What is Voltage!

It is observed that it sometimes requires energy to move charge from place to place (and that it sometimes releases energy when charge moves from place to place).

It is observed that if you have two such places then there is a proportionality between the amount of charge moved and the energy required (or the energy released).

We write:

$\Delta E \propto \Delta q$

The funny symbol, $\propto$, is the proportionality symbol.

If two things are proportional to each other, they are in a constant ratio, which we call the proportionality constant. Let’s call this ratio V. *Note that V like the E and the q are italicized!!*

So we write:

$\Delta E = V \Delta q$

The ratio V is the amount of energy per amount of charge that is required (or released) when a charge moves between two places.

The Units of Voltage

Since

$V = \frac{\Delta E}{\Delta q}$

and snce the numerator has units of Joules, and the denominator has units of Coulombs (in the mks system), clearly V has the units of Joules/Coulomb.

Joules per Coulomb comes up so much in science, we get sick of writing Joules/Coulomb, or even just J/C, and so we define a new unit, the Volt, which has abbreviation V.

$1\,\mathrm{V} = \frac{1\,\mathrm{J}}{1\,\mathrm{C}}$

Italics

Now you see why I was a stickler about using the italics for the V in

$$V = \frac{\Delta E}{\Delta q}$$

It is because the quantity voltage is usually denoted V, whereas the unit Volt, is usually denoted V.

Sorry about that. Just get it right and get over it. The re-use of the letter V is going to be the least of our difficulties in understanding circuitry.

More generally, abstract quantities, like length, charge, energy, etc., are written in italics, and units are written without italics.

To give a mundane example, we can state as an equation that the length, d, is 3 feet, by writing:

$$d = 3\ \mathrm{ft}$$

The d is italicized. The abbreviation for feet is not. You'd read that as "the distance, d, is three feet."

This is of course extremely hard to tell in hand-written documents, but textbooks almost always make the typographical effort, as I have in this handout.

A less mundane example of the kind that we are talking about and that will actually show up soon is:

$$V = 3\ \mathrm{V}$$

You'd read that as "the voltage, V, is three volts."

Conclusion

The units that have so far appeared are the Coulomb, the Joule, and the Volt, and the corresponding concepts are charge, energy, and voltage.

The rest of this course will be meaningless if you fail to deeply internalize these three units and concepts. They are foundational to all of electronics.