Direct Current Fundamentals for Non-Electrical Engineers

An Online Continuing Education Course for Engineers

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Credit: 2 Hours / 2 PDH / 2 CPD

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Introduction

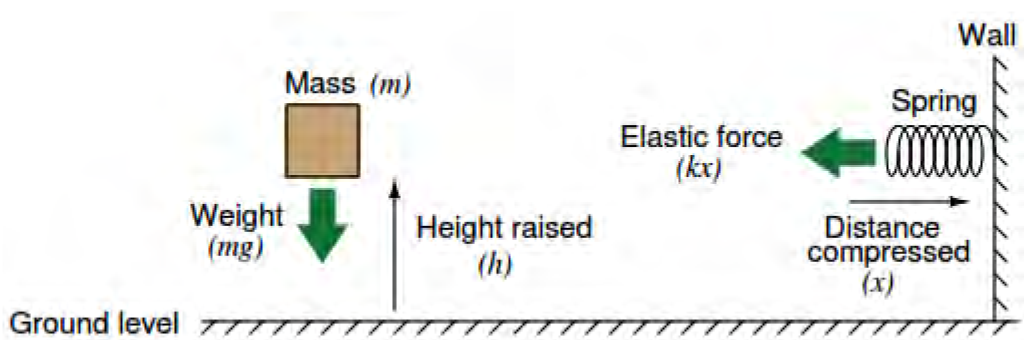
Direct current (DC) is the unidirectional flow of electric charge. Direct current is produced by sources such as batteries, thermocouples, solar cells, and commutator-type electric machines of the dynamo type. Direct current may flow in a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams. The electric current flows in a constant direction, distinguishing it from alternating current (AC).

The first commercial electric power transmission (developed by Thomas Edison in the late nineteenth century) used direct current. However, because of the significant advantages of alternating current over direct current in transforming and transmission, electric power distribution is nearly all alternating current today.

DC is commonly found in many extra-low voltage applications and some low-voltage applications, especially where these are powered by batteries or solar power systems, which can produce only DC. Most automotive applications use DC, although the alternator is an AC device which uses a rectifier to produce DC. Most electronic circuits require a DC power supply. Applications using fuel cells (mixing hydrogen and oxygen together with a catalyst to produce electricity and water as byproducts) also produce only DC.

Electrical voltage

Voltage is the amount of specific potential energy available between two points in an electric circuit. Potential energy is energy that is potentially available to do work. Looking at this from a classical physics perspective, potential energy is what we accumulate when we lift a weight above ground level, or when we compress a spring:



In either case, potential energy is calculated by the work done in exerting a force over a parallel distance. In the case of the weight, potential energy (Ep) is the simple product of weight (gravity g acting on the mass m) and height (h):

$$E_p = mgh$$

For the spring, things are a bit more complex. The force exerted by the spring against the compressing motion increases with compression (F = kx, where k is the elastic constant of the spring). It does not remain steady as the force of weight does for the lifted mass. Therefore, the potential energy equation is nonlinear:

$$E_p = \frac{1}{2}kx^2$$

Releasing the potential energy stored in these mechanical systems is as simple as dropping the mass, or letting go of the spring. The potential energy will return to the original condition (zero) when the objects are at rest in their original positions. If either the mass or the spring were attached to a machine to harness the return-motion, that stored potential energy could be used to do useful tasks.

Potential energy may be similarly defined and quantified for any situation where we exert a force over a parallel distance, regardless of where that force or the motivating distance comes from. For instance, the static cling you experience when you pull a cotton sock out of a dryer is an example of a force. By pulling that sock away from another article of clothing, you are doing work, and storing potential energy in the tension between that sock and the rest of the clothing. In a similar manner, that stored energy could be released to do useful tasks if we placed the sock in some kind of machine that harnessed the return motion as the sock went back to its original place on the pile of laundry inside the dryer.

If we make use of non-mechanical means to move electric charge from one location to another, the result is no different. Moving attracting charges apart from one another means doing work (a force exerted over a parallel distance) and storing potential energy in that physical tension. When we use chemical reactions to move electrons from one metal plate to another in a solution, or when we spin a generator and electro-magnetically motivate electrons to seek other locations, we impart potential energy to those electrons. We could express this potential energy in the same unit as we do for mechanical systems (the Joule). However, it is actually more useful to express the potential energy in an electric system in terms of how many joules are available per a specific quantity of electric charge (a certain number of electrons). This measure of specific potential energy is simply called electric potential or voltage, and we measure it in units of Volts, in honor of the Italian physicist Alessandro Volta, inventor of the first electrochemical battery.

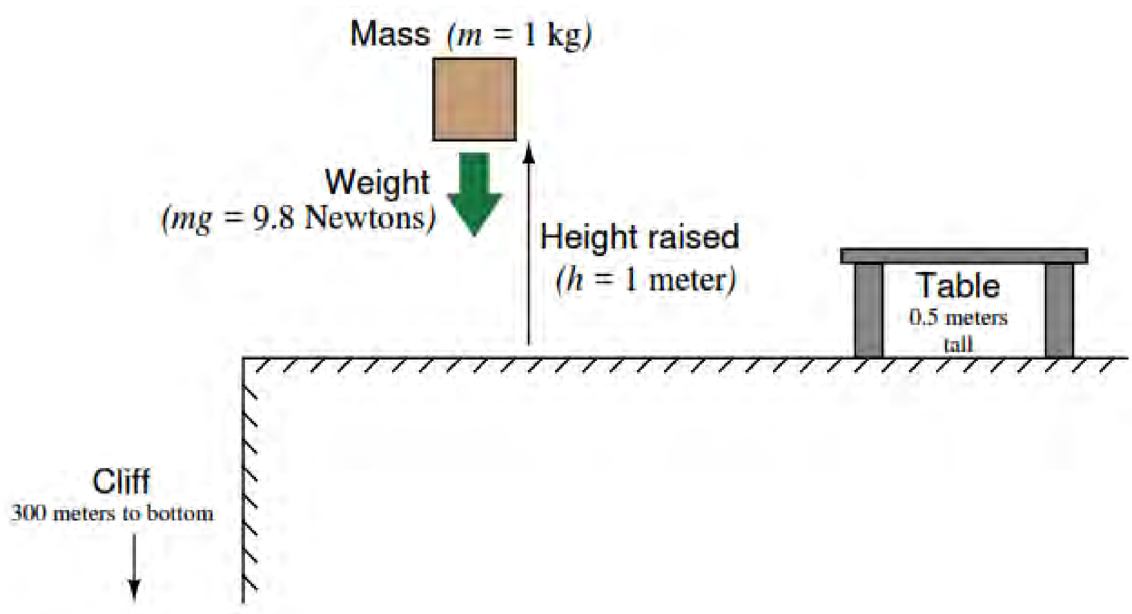
$$1 \text{ Volt} = \frac{1 \text{ Joule of potential energy}}{1 \text{ Coulomb of electric charge}}$$

In other words, if we forced 1 Coulomb's worth of electrons (6.24 x 1018 of them, to be exact) away from a positively-charged place, and did one Joule's worth of work in the process, we would have generated one Volt of electric potential.

Electric potential (voltage) and potential energy share a common, yet confusing property: both quantities are fundamentally relative between two physical locations. There is really no such thing as specifying a quantity of potential energy at a single location. The amount of potential energy in any system is always relative between two different points.

If I lift a mass off the ground, I can specify its potential energy, but only in relation to its former position on the ground. The amount of energy that mass is potentially capable of releasing by free-fall depends on how far it could possibly fall. To illustrate, imagine lifting a 1 kilogram mass 1 meter off the ground. Is it correct that 1-kilo mass weighs 9.8 Newtons on Earth, and the distance lifted was 1 meter, so the potential energy stored in the mass is 9.8 joules?

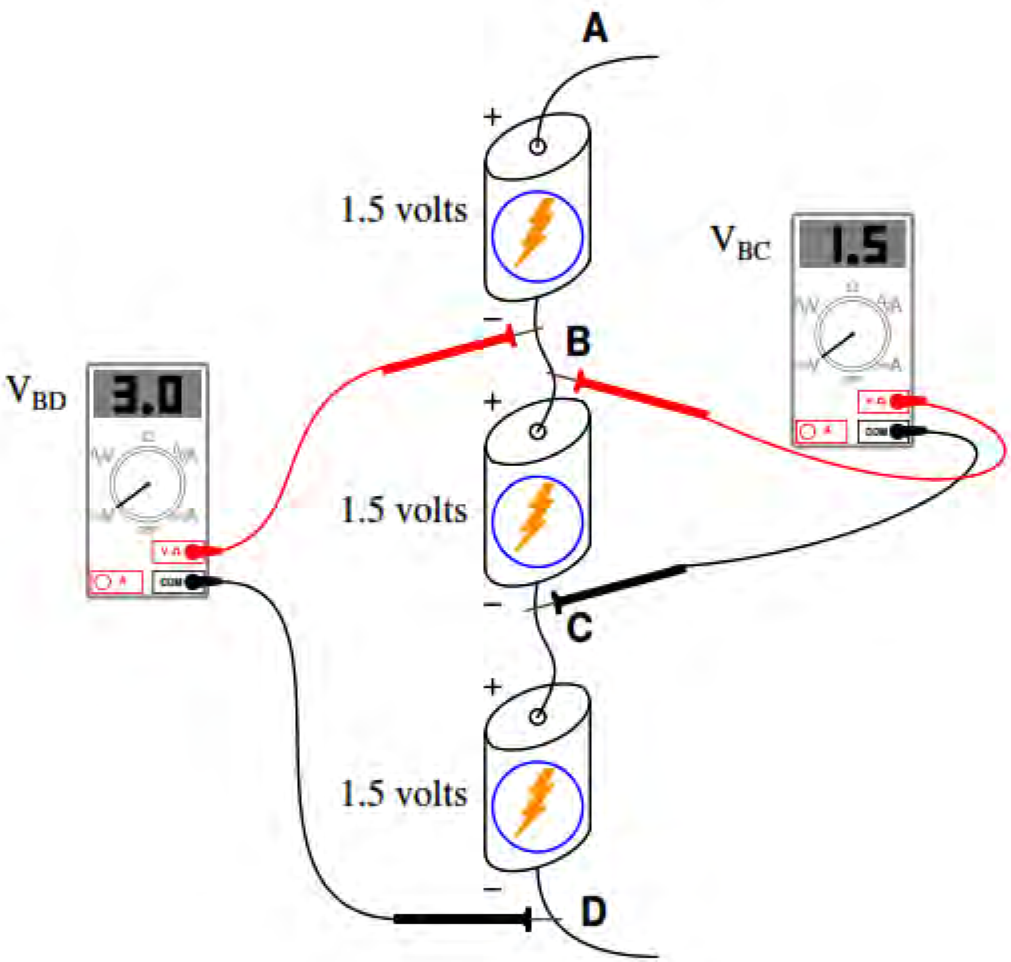
Consider the following scenario:



If we drop the mass over the spot we first lifted it from, it will release all the potential energy we invested in it: 9.8 joules. But what if we carry it over to the table and release it there? Since now it can only fall half a meter, it will only release 4.9 joules in the process. How much potential energy did the mass have while suspended above that table? What if we carry it over to the edge of the cliff and release it there? Falling 301 meters, it will release 2.95 kilojoules (kJ) of energy. How much potential energy did the mass have while suspended over the cliff ?

As you can see, potential energy is a relative quantity. We must know the mass's position relative to its falling point before we can quantify its potential energy. Likewise, we must know an electric charge's position relative to its return point before we can quantify the voltage it has.

Consider a series of batteries connected as shown:



The voltage as measured between any two points directly across a single battery will be 1.5 volts:

V_{AB} = 1.5 volts
V_{BC} = 1.5 volts
V_{CD} = 1.5 volts

If, however, we span more than one battery with our voltmeter connections, our voltmeter will register more than 1.5 volts:

V_{AC} = 3.0 volts
V_{BD} = 3.0 volts
V_{AD} = 4.5 volts

There is no such thing as 'voltage" at a single point in a circuit. The concept of voltage has meaning only between pairs of points in a circuit, just as th... ...pt of potential energy for a mass has meaning only between two ph... ...mass is, and where it could potentially fall.

Things get interest... ...configurations. Consider the following example... ...iddle battery has been reversed: