Voltage, Current, and Resistance

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Question 1

Describe what "electricity" is, in your own words.
file 00114

Question 2

Explain what the electrical terms *voltage*, *current*, and *resistance* mean, using your own words.
file 00008

Question 3

What units of measurement are used to express quantities of *voltage*, *current*, and *resistance*?
file 00181

Question 4

Voltage is also known by another name: *electromotive force*, or *EMF*. Explain what this other name for voltage means.
file 00148

Question 5

How many physical points must be referenced when speaking of the following electrical quantities?

- Voltage
- Current
- Resistance

In other words, does it make sense to speak of voltage at a single point, or between two points, or between three points, etc.? Does it make sense to speak of current at a single point, between two points, between three points, etc.?
file 00147

Question 6

Lightning is a natural, electrical phenomenon. It is caused by the accumulation of a large electrical charge over time resulting from air, dust, and water droplets transporting small electrical charges.

Explain how the terms *voltage*, *current*, and *resistance* relate to the process of lightning. In other words, use these three terms to explain the cycle of charge accumulation and lightning discharge.
file 00146

Question 7

What is the difference between DC and AC electricity?
file 00149

Question 8

Voltage is commonly defined as "electrical pressure." The unit of the *volt*, however, may be defined in terms of more fundamental physical units. What are these units, and how do they relate to the unit of the volt?
file 00108

Question 9

Electric current is measured in the unit of the *ampere*, or *amp*. What is the physical definition for this unit? What fundamental quantities constitute 1 ampere of electric current?
file 00109

Question 10

Suppose a battery outputs a voltage of 9 volts. Using algebra, calculate how many joules of energy are imparted to every individual electron moving through this battery.

file 00150

Question 11

Is it possible to have a condition where an electrical voltage exists, but no electric current exists? Conversely, is it possible to have a condition where an electric current exists without an accompanying voltage? Explain your answers, and give practical examples where the stated conditions are indeed possible.

file 00151

Answers

Answer 1

If you're having difficulty formulating a definition for "electricity," a simple definition of "electric current" will suffice. What I'm looking for here is a description of how an electric current may exist within a solid material such as a metal wire.

Answer 2

Voltage: electrical "pressure" between two different points or locations.
Current: the flow of electrons.
Resistance: opposition, or "friction," to the flow of electrons.

Answer 3

- Voltage is measured in the unit of the *volt* (V).
- Current is measured in the unit of the *ampere*, or *amp* (A).
- Resistance is measured in the unit of the *ohm* (Ω).

Answer 4

Electromotive force literally means, "a force that motivates electrons."

Answer 5

- Voltage is always measured *between two points*.
- Current may be measured at a single point (at a cross-section of a conductive path).
- Resistance is always measured *between two points*.

Follow-up question: explain, if you can, the relevance of these facts to electrical safety. For example, why is it important to know that voltage is always a quantity existing *between* two points (rather than existing *at* a single point) when considering your personal safety?

Answer 6

As electric charges accumulate between clouds and earth, the **voltage** between these points increase. Air under normal conditions is a good insulator of electricity: that is, it possesses very high electrical **resistance**. So, at first there is no **current** resulting from the rise in voltage between clouds and earth. However, when the **voltage** exceeds the air's "ionization" potential, the air becomes a good conductor of electricity (its electrical **resistance** decreases dramatically), resulting in a transient **current** as the accumulated electric charge dissipates in the form of a lightning bolt.

Answer 7

DC is an acronym meaning *Direct Current*: that is, electrical current that moves in one direction only. *AC* is an acronym meaning *Alternating Current*: that is, electrical current that periodically reverses direction ("alternates").

It is important to realize that "DC" and "AC" may also be used to represent *voltage* as well as current. That is, it is possible to have a voltage that alternates back and forth in polarity ("AC" voltage) just as it is possible to have a current that alternates back and forth in direction of motion.

Answer 8

1 volt is equal to 1 joule of energy imparted to 1 coulomb of charge (6.25×10^{18} electrons):

$$V = \frac{W}{Q}$$

Where,

V = Voltage (volts)
W = Work, or potential energy (joules)
Q = Charge (coulombs)

Answer 9

1 ampere of electric current is the rate of electron motion equal to 1 coulomb per second:

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

Where,

I = Electric current (amperes)
Q = Charge in motion (coulombs)
t = Time (seconds)

Answer 10

For a 9 volt battery, there will be 1.44×10^{-18} joules of energy imparted to each electron moving through it.

Answer 11

It is not only possible, but quite common in fact, to have a condition of voltage with no current. However, the existence of an electric current must normally be accompanied by a voltage. Only in very unique conditions (in "superconducting" circuits) may an electric current exist in the absence of a voltage.

Notes 1

This question is not as easy to answer as it may first appear. Certainly, electric current is defined as the "flow" of electrons, but how do electrons "flow" through a solid material such as copper? How does *anything* flow through a solid material, for that matter?

Many scientific disciplines challenge our "common sense" ideas of reality, including the seemingly solid nature of certain substances. One of the liberating aspects of scientific investigation is that it frees us from the limitations of direct sense perception. Through structured experimentation and rigorous thinking, we are able to "see" things that might otherwise be impossible to see. We certainly cannot see electrons with our eyes, but we can detect their presence with special equipment, measure their motion by inference from other effects, and prove empirically that they do in fact exist.

In this regard, scientific method is a tool for the expansion of human ability. Your students will begin to experience the thrill of "working with the invisible" as they explore electricity and electric circuits. It is your task as an instructor to foster and encourage this sense of wonder in your students' work.

Notes 2

While it is easy enough for students to look up definitions for these words from any number of references, it is important that they be able to cast them into their own words. Remembering a definition is not the same as really understanding it, and if a student is unable to describe the meaning of a term using their own words then they definitely do not understand it! It is also helpful to encourage students to give real-life examples of these terms.

Notes 3

Like all other physical quantities, there are units of measurement appropriate for specifying electrical quantities. In this sense, the "volt," "amp," or "ohm" are no different from "gram," "yard," or "bushel."

Notes 4

This sheds some light on why the letter "E" is often used to symbolize voltage in mathematical equations. Some of your students may wonder later why the letter "I" is used to represent current. Let them research this on their own!

Notes 5

One of the more confusing aspects of electrical theory is that both voltage and resistance are quantities relative between two points. It is meaningless to speak of the amount of voltage "at this point" in a circuit, at least without implying a reference point such as ground. The same goes for resistance: it makes no sense to speak of how much electrical resistance there is "at this point" in a circuit either.

Conversely, it makes perfect sense to speak of either voltage or resistance lying "between *this* point and *that* point," because both these quantities are relative between exactly two points.

Current, on the other hand, is the coordinated motion of electric charge through a conductor. As such, it may be measured at any single point in a circuit, like measuring the flow of water in a river at any one particular cross-sectional sample.

Notes 6

I usually avoid spending a lot of time on technical definitions, because undue emphasis on the definitions of words tends to reinforce rote memorization rather than true comprehension. If students must master certain definitions, though, it is best to develop that mastery in the context of application: ask the students to *use* their new vocabulary, not just recite it.

Notes 7

Though it may seem oxymoronic to refer to either "DC" or "AC" voltage (Direct Current voltage, or Alternating Current voltage – "current voltage"?), the usage of these acronyms as such is commonplace.

Notes 8

Note that I use the letter "V" to denote voltage rather than "E" as I usually do. This is because in general physics work, "E" usually stands for either "Energy" or "Electric field". Some electronics reference books use the letter "E" for voltage, while others use the letter "V", or even use the two letters interchangeably.

Notes 9

It may be helpful at this point to review the number of electrons constituting one coulomb of charge: 6.25×10^{18} electrons.

Technically, current's mathematical definition involves calculus:

$$I = \frac{dQ}{dt}$$

However, students at this stage may not be ready to explore derivatives yet, and so the equation give in the answer for (average) current will suffice.

Notes 10

This problem is another exercise in using scientific notation, and requires that students put concepts together that were learned previously.

Notes 11

This question challenges students' comprehension of voltage and current by asking them to explain the relationship between the two quantities in practical contexts. Do not allow students to simply give a "yes" or a "no" answer to either of the stated conditions. Encourage them to think of examples illustrating a possible condition.

The term "superconducting" may spur some additional questions. As usual, do not simply tell students what superconductivity is, but let them research this on their own. Your more inquisitive students will probably have already researched this topic in response to the answer!