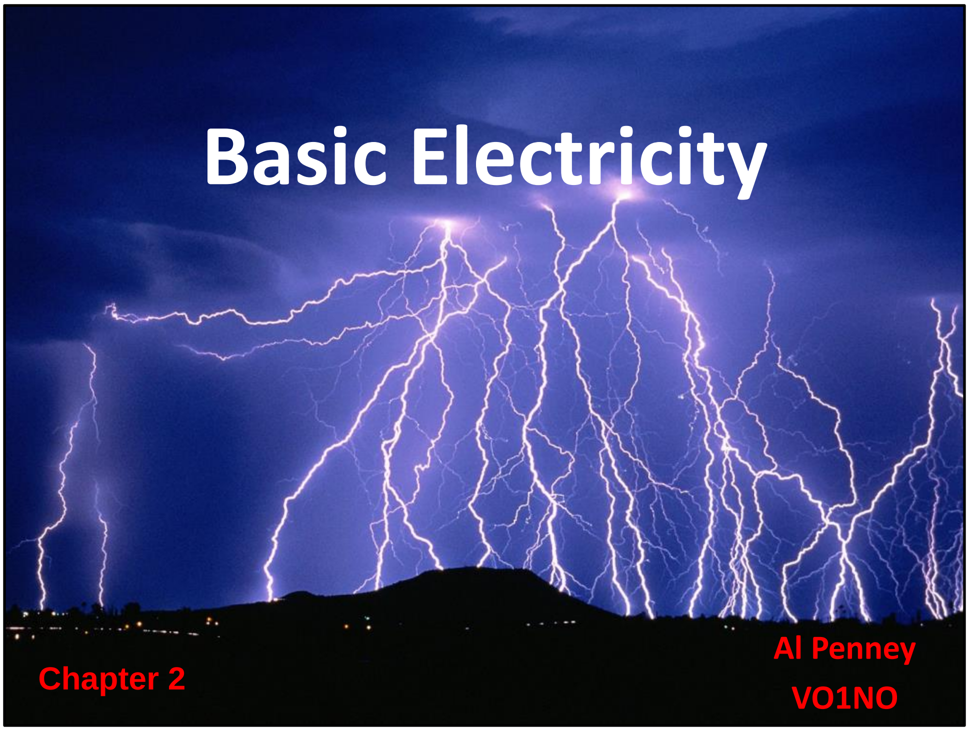


Basic Electricity

Chapter 2

Al Penney
VO1NO

Code of Ethics

for Canadian Amateur Radio Operators
Bill Wilson, VE3NR (SK)

The thoughtful Radio Amateur is:

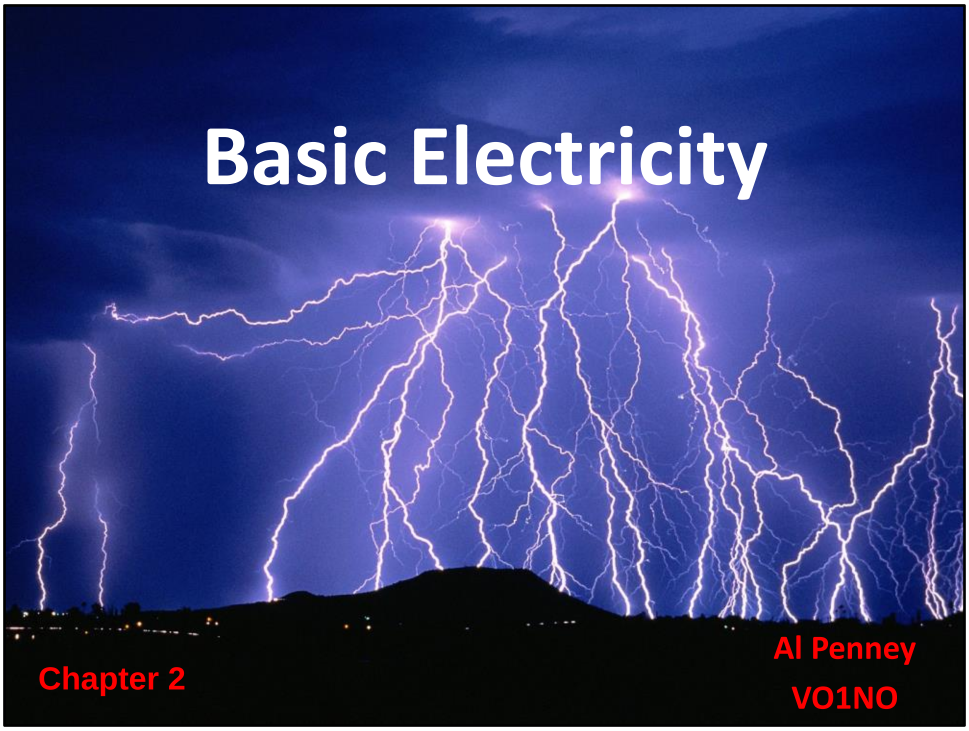
- **Responsible** – using courteous operating practice, complying with regulations and accepted technical standards;
- **Progressive** – striving to develop and improve operating and technical skills;
- **Helpful** – offering assistance, support and encouragement to other Amateurs, especially beginners; and
- **Public Spirited** – offering use of station, knowledge and skills as a public service whenever possible.

The Radio Amateur's Code

Paul M. Segal, W9EEA, in 1928

The Radio Amateur is

- **CONSIDERATE**...He/[She] never knowingly operates in such a way as to lessen the pleasure of others.
- **LOYAL**...He/[She] offers loyalty, encouragement and support to other amateurs, local clubs, the IARU Radio Society in his/[her] country, through which Amateur Radio in his/[her] country is represented nationally and internationally.
- **PROGRESSIVE**...He/[She] keeps his/[her] station up to date. It is well-built and efficient. His/[Her] operating practice is above reproach.
- **FRIENDLY**...He/[She] operates slowly and patiently when requested; offers friendly advice and counsel to beginners; kind assistance, cooperation and consideration for the interests of others. These are the marks of the amateur spirit.
- **BALANCED**...Radio is a hobby, never interfering with duties owed to family, job, school or community.
- **PATRIOTIC**...His/[Her] station and skills are always ready for service to country and community.



Basic Electricity

Chapter 2

Al Penney
VO1NO

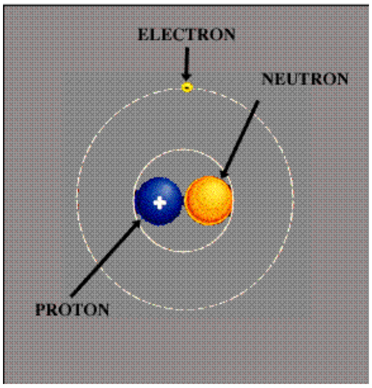
Objectives

- On completion of this chapter you will have an introductory knowledge of:
  - Elementary atomic theory; and
  - Basic electrical concepts such as conductors, insulators, resistance, direct and alternating current, electromotive force, magnets, cells, batteries and schematics.

Al Penney
VO1NO

The Structure of Matter

- All matter is composed of Atoms.
- Atoms consist of:
  - **Neutrons**;
  - **Protons**; and
  - **Electrons**
- Over 100 different atoms.
- These are called Elements.



Al Penney
VO1NO

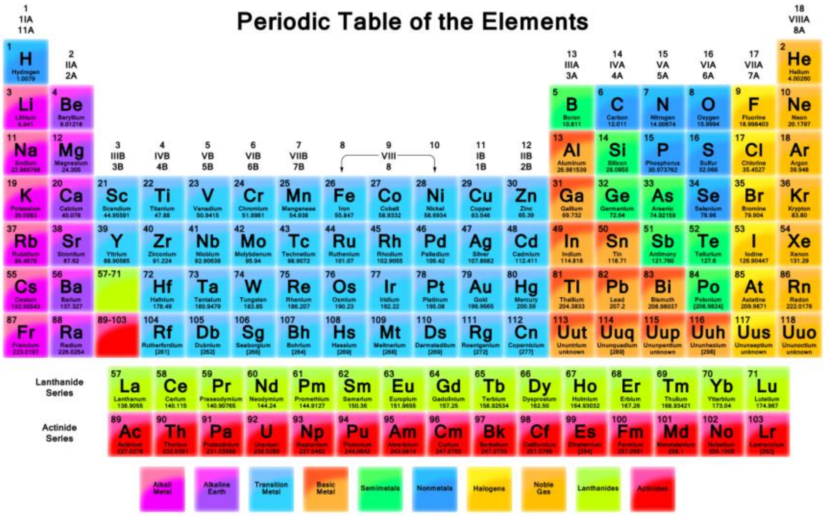
The **atom** is a basic unit of matter that consists of a dense central nucleus surrounded by a cloud of negatively charged electrons. The atomic nucleus contains a mix of positively charged protons and electrically neutral neutrons (except in the case of hydrogen-1, which is the only stable nuclide with no neutrons). The electrons of an atom are bound to the nucleus by the electromagnetic force. Likewise, a group of atoms can remain bound to each other by chemical bonds based on the same force, forming a molecule. An atom containing an equal number of protons and electrons is electrically neutral, otherwise it is positively or negatively charged and is known as an ion. An atom is classified according to the number of protons and neutrons in its nucleus: the number of protons determines the chemical element, and the number of neutrons determines the isotope of the element. Chemical atoms, which in science now carry the simple name of "atom," are minuscule objects with diameters of a few tenths of a nanometer and tiny masses proportional to the volume implied by these dimensions. Atoms can only be observed individually using special instruments such as the scanning tunneling microscope. Over 99.94% of an atom's mass is concentrated in the nucleus,[] with protons and neutrons having roughly equal mass. Each element has at least one isotope with an unstable nucleus that can undergo radioactive decay. This can result in a transmutation that changes the number of protons or neutrons in a nucleus. Electrons that are bound to atoms possess a set of stable energy levels, or orbitals, and can undergo transitions between them by absorbing or emitting photons that match the energy differences between the levels. The electrons determine the chemical properties of an element, and strongly influence an atom's magnetic properties. The principles of quantum mechanics have been successfully used to model the observed properties of the atom.

Electron is the lightest subatomic particle. It is negatively charged particle. Its mass is 9.109×10^{-31} kg which is only 1/1,840 the mass of a proton. An electron is therefore considered to be mass less in comparison with proton and neutron and is not included in calculating atomic mass of an atom. The electron was discovered in 1897 by British Physicist J.J. Thomson during his investigations of cathode rays.

Proton is a subatomic particle with a positive charge. It has a mass of 1.67262×10^{-27} kg which is 1,836 times of the mass of an electron. When the number of proton is equal to the number of electrons orbiting in nucleus we say that the atom is electrically neutral.

Neutron is subatomic particle. Neutron does not have any charge, that is, it is neutral. Its mass is 1.67493×10^{-27} kg, greater than that of a proton and electron. Neutrons and protons are commonly called nucleons. The neutron was discovered in 1932 by the English physicist James Chadwick.

Deuterium is a **hydrogen isotope** consisting of one proton, one neutron and one electron. It has major applications in nuclear magnetic resonance studies. Tritium is a **hydrogen isotope** consisting of one proton, two neutrons and one electron.



Periodic Table of the Elements

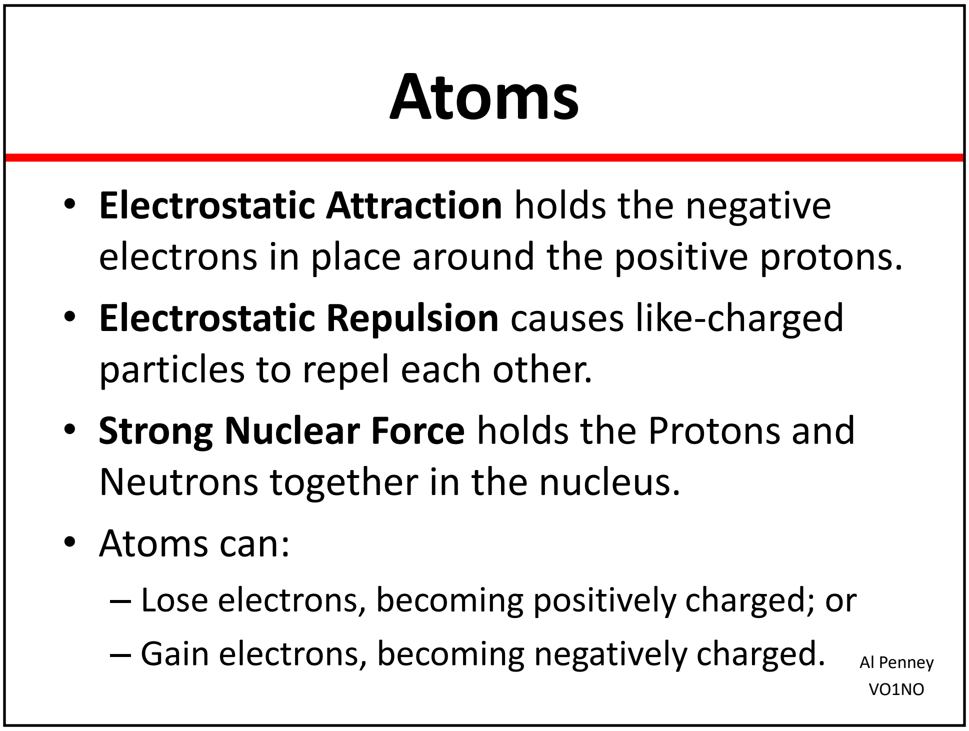
1 1IA 11A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 VIII 8	10	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
	Lanthanide Series	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
	Actinide Series	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Al Penney
VO1NO

The **periodic table** is a tabular arrangement of the chemical elements, organized on the basis of their atomic numbers, electron configurations (electron shell model), and recurring chemical properties. Elements are presented in order of increasing atomic number (the number of protons in the nucleus). The standard form of the table consists of a grid of elements laid out in 18 columns and 7 rows, with a double row of elements below that. The table can also be deconstructed into four rectangular blocks: the s-block to the left, the p-block to the right, the d-block in the middle, and the f-block below that.

The rows of the table are called periods; the columns are called groups, with some of these having names such as halogens or noble gases. Since, by definition, a periodic table incorporates recurring trends, any such table can be used to derive relationships between the properties of the elements and predict the properties of new, yet to be discovered or synthesized, elements. As a result, a periodic table—whether in the standard form or some other variant—provides a useful framework for analyzing chemical behavior, and such tables are widely used in chemistry and other sciences.

All elements from atomic numbers 1 (hydrogen) to 118 (ununoctium) have been discovered or reportedly synthesized, with elements 113, 115, 117 and 118 having yet to be confirmed. The first 98 elements exist naturally although some are found only in trace amounts and were initially discovered by synthesis in laboratories. Elements with atomic numbers from 99 to 118 have only been synthesized, or claimed to be so, in laboratories. Production of elements having higher atomic numbers is being pursued, with the question of how the periodic table may need to be modified to accommodate any such additions being a matter of ongoing debate. Numerous synthetic radionuclides of naturally occurring elements have also been produced in laboratories.



Atoms

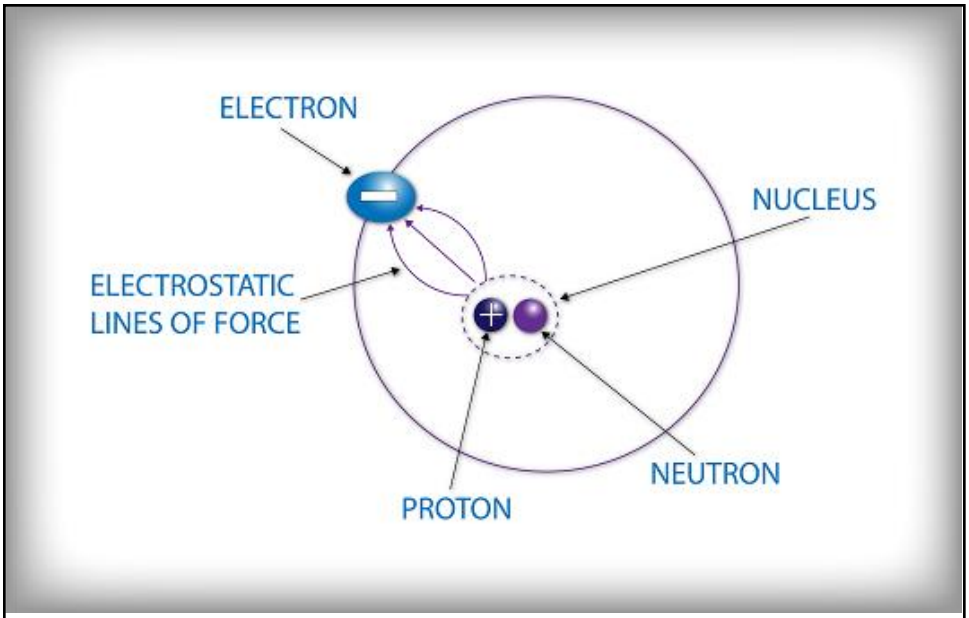
- **Electrostatic Attraction** holds the negative electrons in place around the positive protons.
- **Electrostatic Repulsion** causes like-charged particles to repel each other.
- **Strong Nuclear Force** holds the Protons and Neutrons together in the nucleus.
- Atoms can:
  - Lose electrons, becoming positively charged; or
  - Gain electrons, becoming negatively charged.

Al Penney
VO1NO

In particle physics, the **strong interaction** (also called the **strong force**, **strong nuclear force**, **nuclear strong force** or **color force**) is one of the four fundamental interactions of nature, the others being electromagnetism, the weak interaction and gravitation. At atomic scale, it is about 100 times stronger than electromagnetism, which in turn is orders of magnitude stronger than the weak force interaction and gravitation. During the electroweak epoch, the electroweak force separated from the strong force.

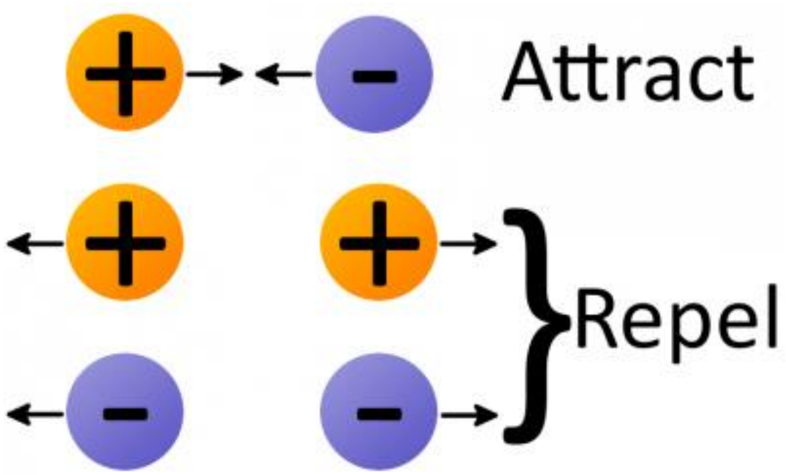
The strong interaction is observable in two areas: on a larger scale (about 1 to 3 femtometers (fm)), it is the force that binds protons and neutrons (nucleons) together to form the nucleus of an atom. On the smaller scale (less than about 0.8 fm, the radius of a nucleon), it is the force (carried by gluons) that holds quarks together to form protons, neutrons, and other hadron particles.

In the context of binding protons and neutrons together to form atoms, the strong interaction is called the nuclear force (or *residual strong force*). In this case, it is the residuum of the strong interaction between the quarks that make up the protons and neutrons. As such, the residual strong interaction obeys a quite different distance-dependent behavior between nucleons, from when it is acting to bind quarks within nucleons. The binding energy related to the residual strong force is used in nuclear power and nuclear weapons.

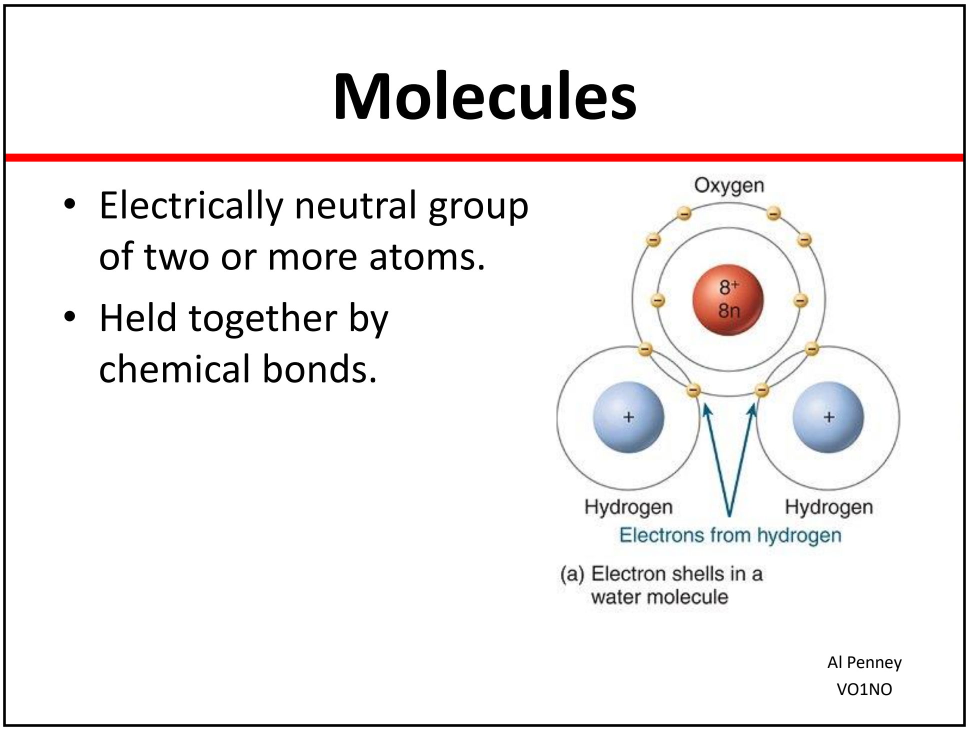


Al Penney
VO1NO

Deuterium, an isotope of Hydrogen.



Al Penney
VO1NO



Molecules

- Electrically neutral group of two or more atoms.
- Held together by chemical bonds.

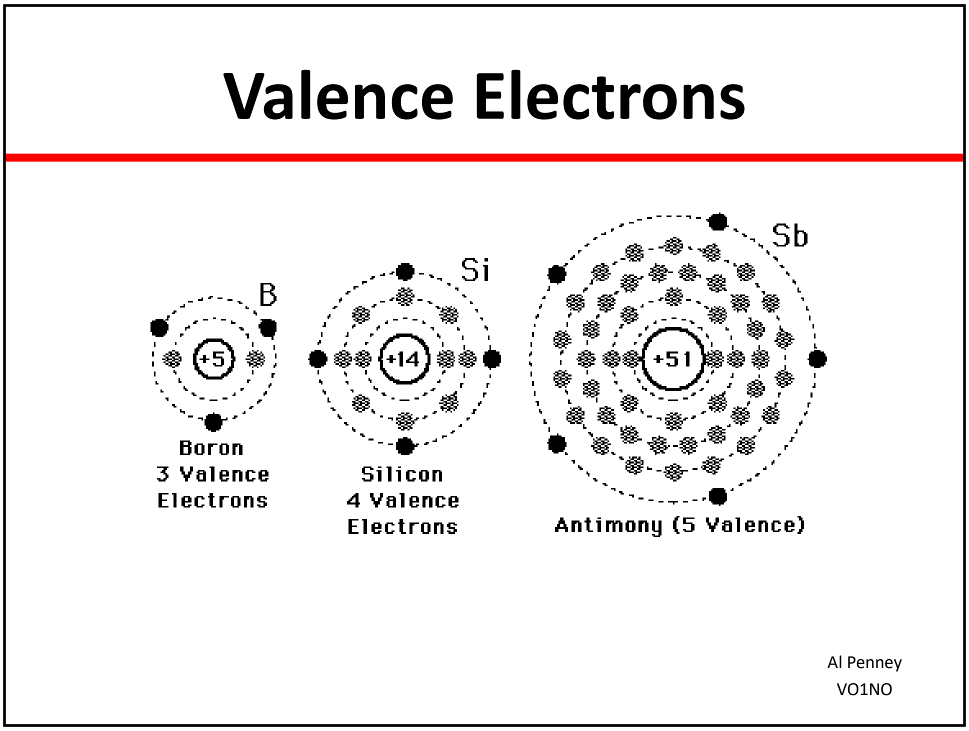
(a) Electron shells in a water molecule

Al Penney
VO1NO

A **molecule** is an electrically neutral group of two or more atoms held together by chemical bonds. Molecules are distinguished from ions by their lack of electrical charge. However, in quantum physics, organic chemistry, and biochemistry, the term *molecule* is often used less strictly, also being applied to polyatomic ions.

An **ion** is a charged atom or molecule. It is charged because the number of electrons do not equal the number of protons in the atom or molecule. An atom can acquire a positive charge or a negative charge depending on whether the number of electrons in an atom is greater or less then the number of protons in the atom.

Isotopes are **members of a family of an element that all have the same number of protons but different numbers of neutrons**. The number of protons in a nucleus determines the element's atomic number on the Periodic Table. For example, carbon has six protons and is atomic number 6.



Valence Electrons

Al Penney
VO1NO

2 – 8 – 18 – 32 – 50 – 72

In chemistry, a **valence electron** is an electron that is associated with an atom, and that can participate in the formation of a chemical bond; in a single covalent bond, both atoms in the bond contribute one valence electron in order to form a shared pair. The presence of valence electrons can determine the element's chemical properties and whether it may bond with other elements: For a main group element, a valence electron can only be in the outermost electron shell. In a transition metal, a valence electron can also be in an inner shell.

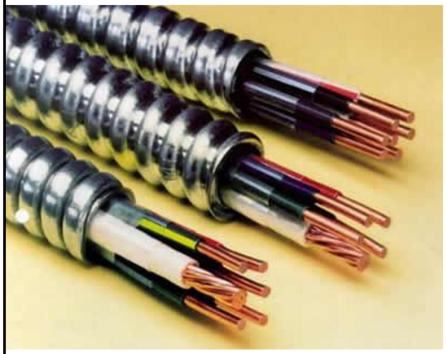
An atom with a closed shell of valence electrons (corresponding to an electron configuration s^2p^6) tends to be chemically inert. An atom with one or two valence electrons more than a closed shell is highly reactive, because the extra valence electrons are easily removed to form a positive ion. An atom with one or two valence electrons fewer than a closed shell is also highly reactive, because of a tendency either to gain the missing valence electrons (thereby forming a negative ion), or to share valence electrons (thereby forming a covalent bond).

Like an electron in an inner shell, a valence electron has the ability to absorb or release energy in the form of a photon. This gain or loss of energy can trigger an electron to move (jump) to a more outer shell or even break free from its associated atom's valence shell; this is known as atomic excitation. When an electron loses energy (thereby causing a photon to be emitted), then it moves to a more inner shell.

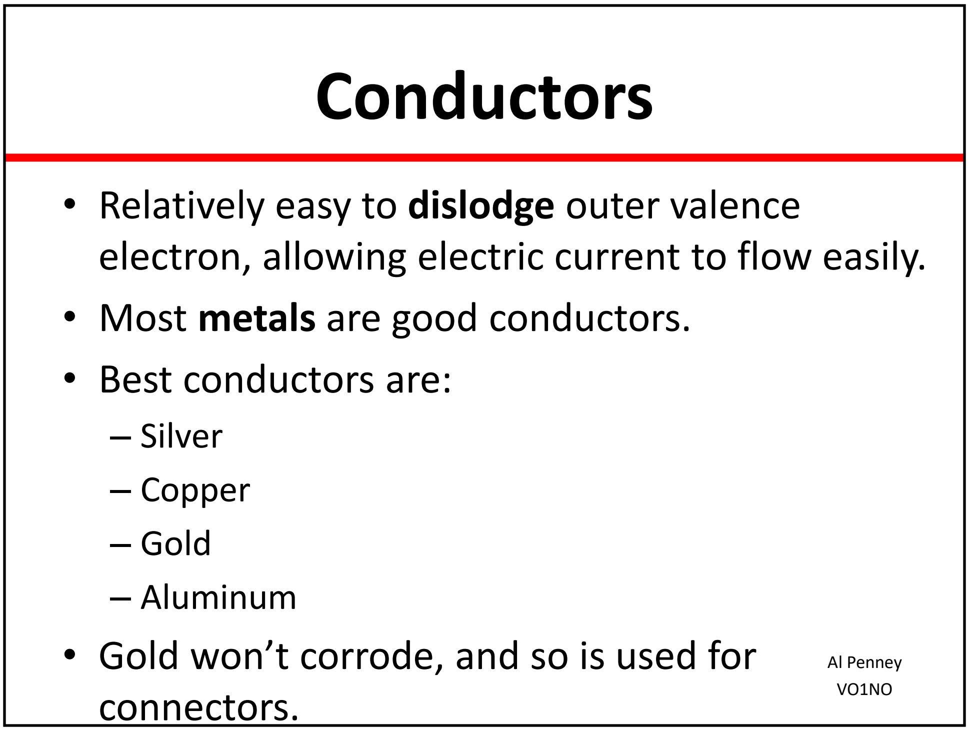
Each shell can contain only a fixed number of electrons: The first shell can hold up to **two electrons**, the second shell can hold up to eight (2 + 6) electrons, the third shell can hold up to **18** (2 + 6 + 10) and so on. The general formula is that the nth shell can in principle hold up to $2(n^2)$ electrons.

2 – 8 – 18 – 32 – 50 – 72

Conductors vs Insulators!



Al Penney
VO1NO



Conductors

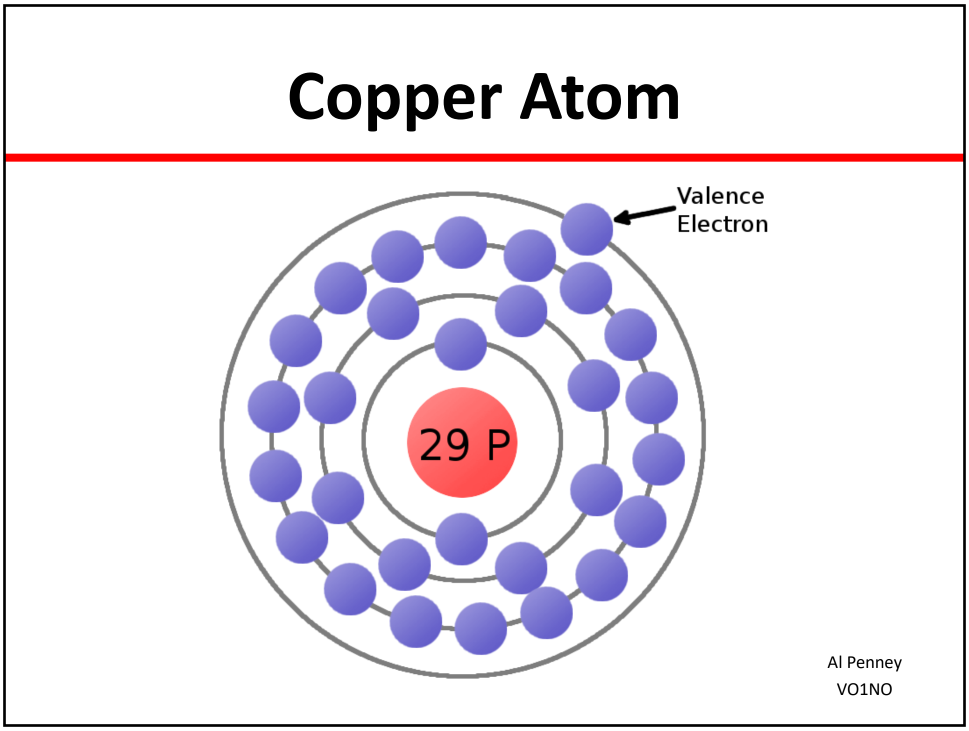
- Relatively easy to **dislodge** outer valence electron, allowing electric current to flow easily.
- Most **metals** are good conductors.
- Best conductors are:
  - Silver
  - Copper
  - Gold
  - Aluminum
- Gold won’t corrode, and so is used for connectors.

Al Penney
VO1NO

In a conductor, electric current can flow freely, in an insulator it cannot. Metals such as copper typify conductors, while most non-metallic solids are said to be good insulators, having extremely high resistance to the flow of charge through them. "Conductor" implies that the outer electrons of the atoms are loosely bound and free to move through the material. Most atoms hold on to their electrons tightly and are insulators. In copper, the valence electrons are essentially free and strongly repel each other. Any external influence which moves one of them will cause a repulsion of other electrons which propagates, "domino fashion" through the conductor.

Simply stated, most metals are good electrical conductors, most nonmetals are not. Metals are also generally good heat conductors while nonmetals are not.

Gold is between copper and aluminum in terms of conductivity



Copper Atom

Al Penney
VO1NO

Valence electrons are also responsible for the electrical conductivity of an element; as a result, an element may be classified as a metal, a nonmetals, or semiconductors (or metalloid).

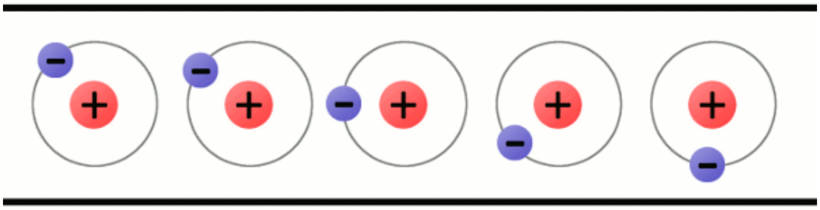
A metal is an element with high electrical conductivity or malleability when in the solid state. In each row of the periodic table, the metals occur to the left of the nonmetals, and thus a metal has fewer possible valence electrons than a nonmetal. However, a valence electron of a metal atom has a small ionization energy, and in the solid state this valence electron is relatively free to leave one atom in order to associate with another nearby. Such a "free" electron can be moved under the influence of an electric field, and its motion constitutes an electric current; it is responsible for the electrical conductivity of the metal. Copper, aluminium, silver, and gold are examples of good conductors.

A nonmetallic element has low electrical conductivity; it acts as an insulator. Such an element is found toward the right of the periodic table, and it has a valence shell that is at least half full (the exception is boron). Its ionization energy is large; an electron cannot leave an atom easily when an electric field is applied, and thus such an element can conduct only very small electric currents. Examples of solid elemental insulators are diamond (an allotrope of carbon) and sulfur.

A solid compound containing metals can also be an insulator if the valence electrons of the metal atoms are used to form ionic bonds. For example, although elemental sodium is a metal, solid sodium chloride is an insulator, because the valence electron of sodium is transferred to chlorine to form an ionic bond, and thus that electron cannot be moved easily.

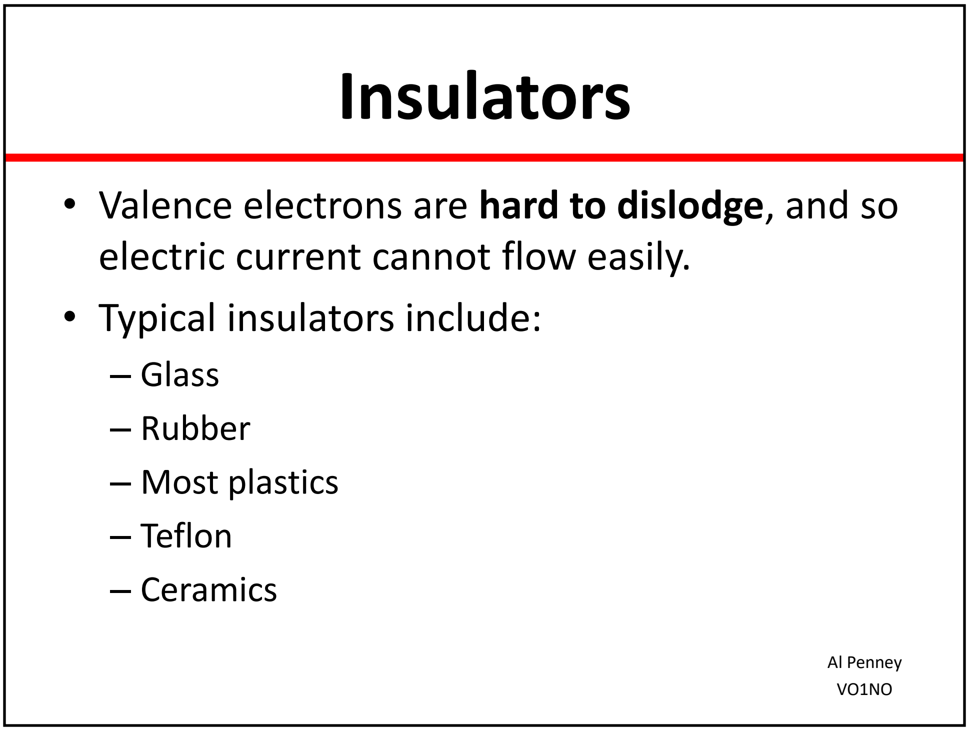
A semiconductor has an electrical conductivity that is intermediate between that of a metal and that of a nonmetal; a semiconductor also differs from a metal in that a semiconductor's conductivity increases with temperature. The typical elemental semiconductors are silicon and germanium, each atom of which has four valence electrons. The properties of semiconductors are best explained using band theory, as a consequence of a small energy gap between a valence band (which contains the valence electrons at absolute zero) and a conduction band (to which valence electrons are excited by thermal energy).

Electric Current



Electric current is the flow of electrons through a conductor.

Al Penney
VO1NO



Insulators

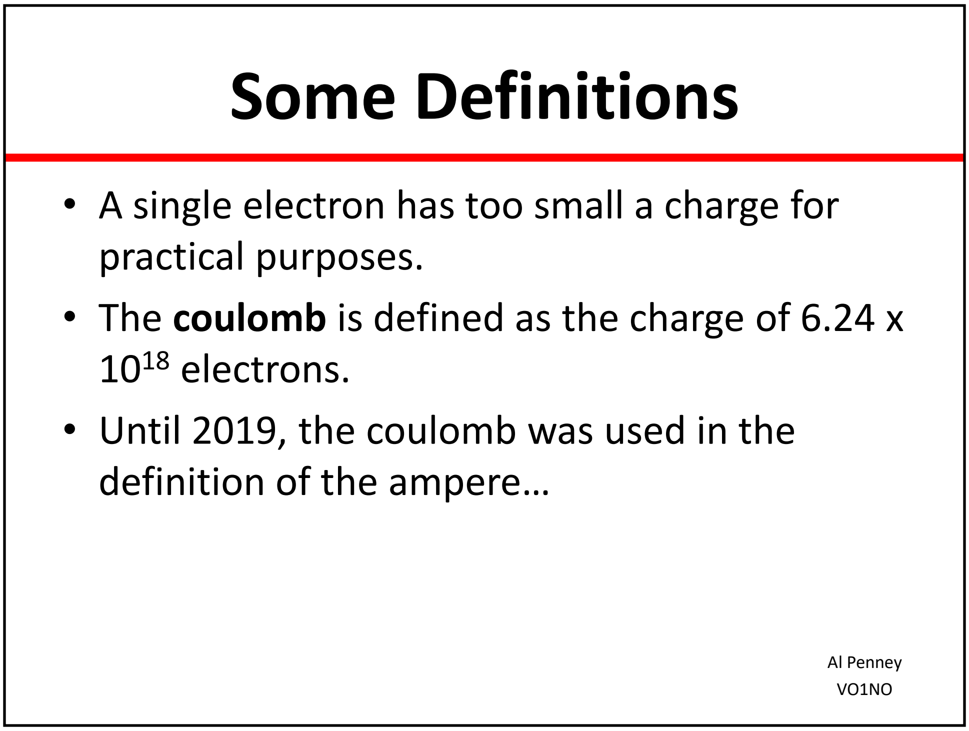
- Valence electrons are **hard to dislodge**, and so electric current cannot flow easily.
- Typical insulators include:
  - Glass
  - Rubber
  - Most plastics
  - Teflon
  - Ceramics

Al Penney
VO1NO

An **electrical insulator** is a material whose internal electric charges do not flow freely; very little electric current will flow through it under the influence of an electric field. This contrasts with other materials, semiconductors and conductors, which conduct electric current more easily. The property that distinguishes an insulator is its resistivity; insulators have higher resistivity than semiconductors or conductors. The most common examples are non-metals.

A perfect insulator does not exist because even insulators contain small numbers of mobile charges (charge carriers) which can carry current. In addition, all insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms. This is known as the breakdown voltage of an insulator. Some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators. A much larger class of materials, even though they may have lower bulk resistivity, are still good enough to prevent significant current from flowing at normally used voltages, and thus are employed as insulation for electrical wiring and cables. Examples include rubber-like polymers and most plastics which can be thermoset or thermoplastic in nature.

Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves. An insulating material used in bulk to wrap electrical cables or other equipment is called *insulation*. The term *insulator* is also used more specifically to refer to insulating supports used to attach electric power distribution or transmission lines to utility poles and transmission towers. They support the weight of the suspended wires without allowing the current to flow through the tower to ground.



Some Definitions

- A single electron has too small a charge for practical purposes.
- The **coulomb** is defined as the charge of 6.24 x 10^{18} electrons.
- Until 2019, the coulomb was used in the definition of the ampere…

Al Penney
VO1NO

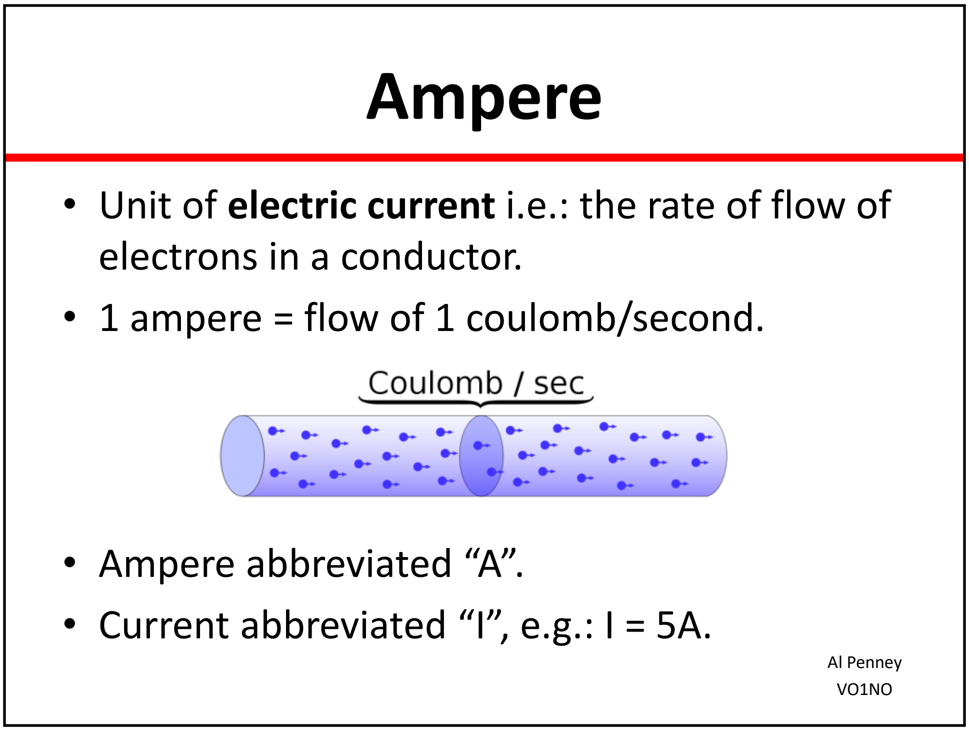
The coulomb (symbolized C) is the standard unit of electric charge in the International System of Units (SI). It is a dimensionless quantity, sharing this aspect with the mole. A quantity of 1 C is equal to approximately 6.24 x 10^{18}, or 6.24 quintillion.
In terms of SI base units, the coulomb is the equivalent of one ampere-second. Conversely, an electric current of A represents 1 C of unit electric charge carriers flowing past a specific point in 1 s. The unit electric charge is the amount of charge contained in a single electron. Thus, 6.24 x 10^{18} electrons have 1 C of charge. This is also true of 6.24 x 10^{18} positrons or 6.24 x 10^{18} protons, although these two types of particle carry charge of opposite polarity to that of the electron.

The **coulomb** (symbol: **C**) is the International System of Units (SI) unit of electric charge. Under the 2019 redefinition of the SI base units, which took effect on 20 May 2019, the coulomb is exactly $1/(1.602176634\times10^{-19})$ elementary charges. The same number of electrons has the same magnitude but opposite sign of charge, that is, a charge of −1 C.

In SI, the unit of charge, the coulomb, is defined as the charge carried by one ampere during one second.
New definitions, in terms of **invariant constants of nature**, specifically the elementary charge, took effect on 20 May 2019.

The charges in static electricity from rubbing materials together are typically a few microcoulombs. The amount of charge that travels through a lightning bolt is typically around 15 C, although large bolts can be up to 350 C

Positive **lightning** strikes tend to be **much** more intense than their negative counterparts. An average **bolt** of negative **lightning** carries an electric current of 30,000 amperes (30 kA), and transfers 15 coulombs of electric **charge** and 1 gigajoule of energy.



Ampere

- Unit of **electric current** i.e.: the rate of flow of electrons in a conductor.
- 1 ampere = flow of 1 coulomb/second.

Coulomb / sec

- Ampere abbreviated “A”.
- Current abbreviated “I”, e.g.: I = 5A.

Al Penney
VO1NO

The **ampere** (symbol: **A**), often shortened to "amp", is the base unit of electric current in the International System of Units (SI). It is named after André-Marie Ampère (1775–1836), French mathematician and physicist, considered the father of electrodynamics.

The International System of Units defines the ampere in terms of other base units by measuring the electromagnetic force between electrical conductors carrying electric current. The earlier CGS measurement system had two different definitions of current, one essentially the same as the SI's and the other using electric charge as the base unit, with the unit of charge defined by measuring the force between two charged metal plates. The ampere was then defined as one coulomb of charge per second. In SI, the unit of charge, the coulomb, is defined as the charge carried by one ampere during one second.

New definitions, in terms of invariant constants of nature, specifically the elementary charge, took effect on 20 May 2019.

Ampere

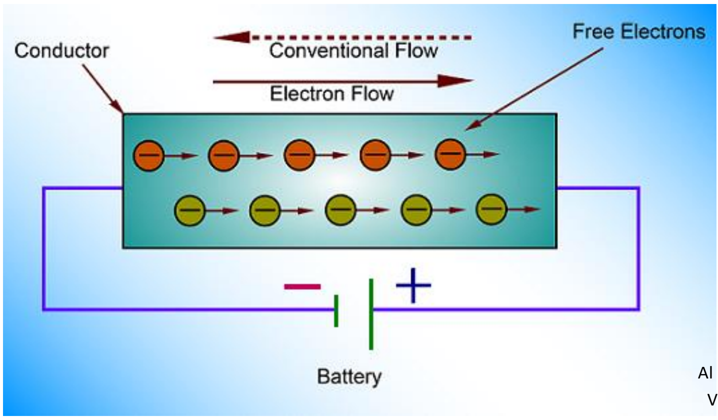
- Current measured using **Ammeters**.

- Milliamperes (mA) = 1/1,000 amperes.
- Microamperes (µA) = 1/1,000,000 amperes.

Al Penney
VO1NO

Conventional Current

- Electron flow is negative to positive.
- Conventional Current is positive to negative.



Al Penney
VO1NO

Early experimenters believed that electric current was the flow of positive charges, so they described electric current as the flow of a positive charge from a positive terminal to a negative terminal. Much later, experimenters discovered electrons and determined that they flow from a negative terminal to a positive terminal. That original convention is still around today — so the standard is to depict the direction of electric current in diagrams with an arrow that points **opposite** the direction of actual electron flow.

Conventional Current assumes that current flows out of the positive terminal, through the circuit and into the negative terminal of the source. This was the convention chosen during the discovery of electricity. They were wrong!

Electron Flow is what actually happens and electrons flow out of the negative terminal, through the circuit and into the positive terminal of the source.

Both Conventional Current and Electron Flow are used. Many textbooks are available in both formats.

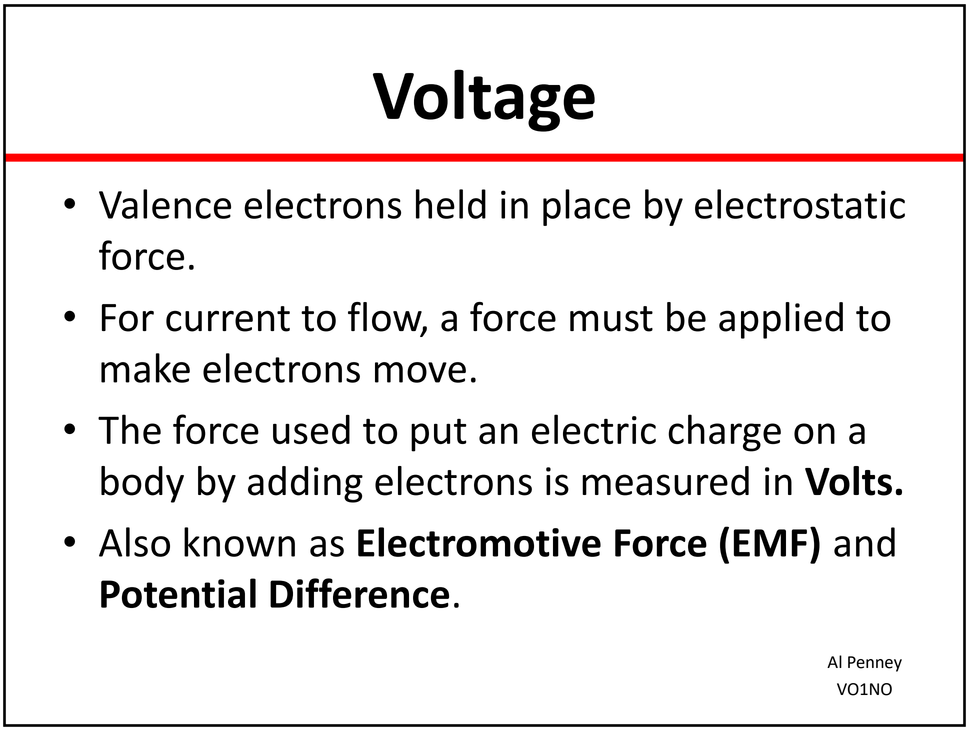
In fact, it makes no difference which way current is flowing as long as it is used **consistently**. The direction of current flow does not affect what the current does.

In general, high school Physics and two year technician programs use Electron Flow.

But three year technologist and university engineering programs use Conventional Current. Certain symbols (ex. diodes and transistors) and rules (ex. Right-hand rules) were created using Conventional Current. Changing from Conventional Current to Electron Flow would cause a degree of confusion for old and new students and errors would occur, so Conventional Current was kept to ensure there was no confusion with those already trained with Conventional Current. Two systems may seem confusing, but as long as usage is consistent, it really is not!

You must realize what convention is being used because the rules change. Ex. Right-Hand rules in Conventional Current become Left-Hand rules in Electron Flow.

Irish physicist George Johnstone Stoney named this charge 'electron' in 1891, and J. J. Thomson and his team of British physicists identified it as a particle in 1897 during the cathode-ray tube experiment



Voltage

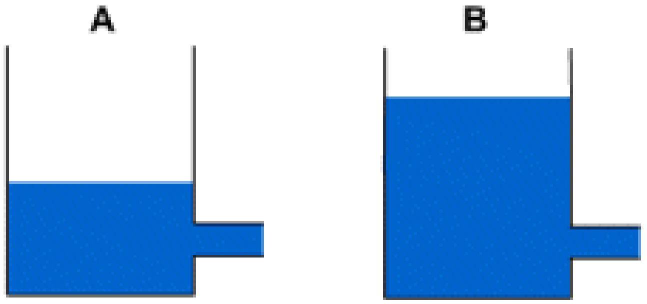
- Valence electrons held in place by electrostatic force.
- For current to flow, a force must be applied to make electrons move.
- The force used to put an electric charge on a body by adding electrons is measured in **Volts.**
- Also known as **Electromotive Force (EMF)** and **Potential Difference**.

Al Penney
VO1NO

Voltage, **electrical potential difference**, **electric tension** or **electric pressure** (denoted Δ*V* and measured in units of electric potential: volts, or joules per coulomb) is the electric potential difference between two points, or the difference in electric potential energy of a unit charge transported between two points. Voltage is equal to the work done per unit charge against a static electric field to move the charge between two points. A voltage may represent either a source of energy (electromotive force), or lost, used, or stored energy (potential drop). A voltmeter can be used to measure the voltage (or potential difference) between two points in a system; usually a common reference potential such as the ground of the system is used as one of the points. Voltage can be caused by static electric fields, by electric current through a magnetic field, by time-varying magnetic fields, or some combination of these three.

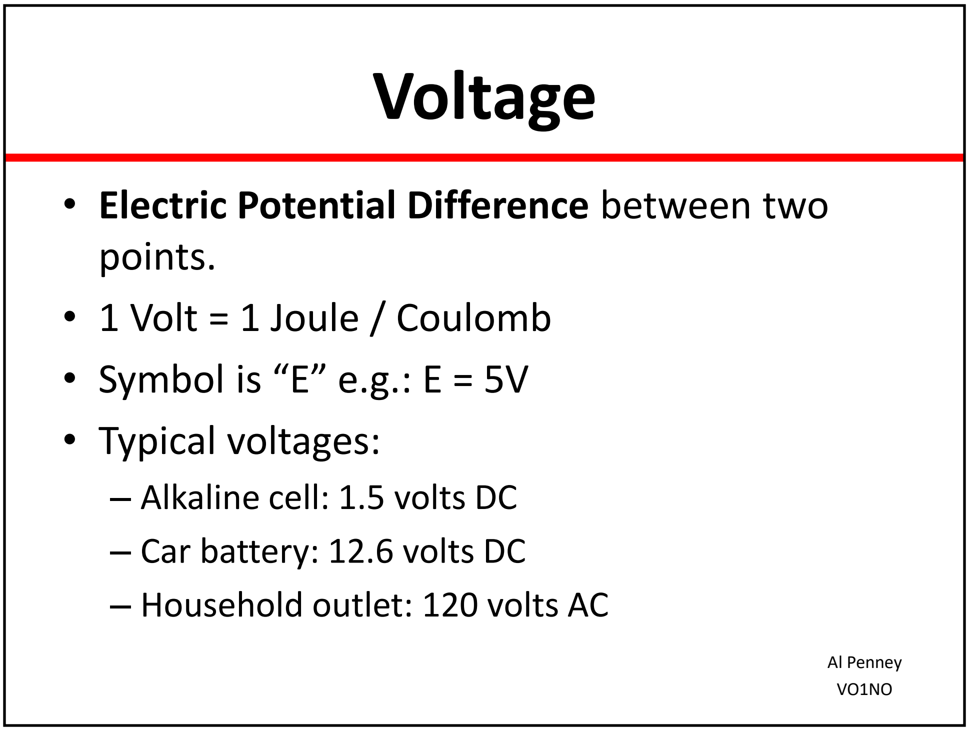
Voltage

- Think of voltage as the "pressure" that pushes electrons through a conductor.



Lower pressure = lower voltage **Higher pressure = higher voltage**

Al Penney
VO1NO



Voltage

- **Electric Potential Difference** between two points.
- 1 Volt = 1 Joule / Coulomb
- Symbol is “E” e.g.: E = 5V
- Typical voltages:
  - – Alkaline cell: 1.5 volts DC
  - – Car battery: 12.6 volts DC
  - – Household outlet: 120 volts AC

Al Penney
VO1NO

The joule (symbol: J) is the unit of energy in the International System of Units (SI). It is equal to the amount of work done when a force of 1 newton displaces a mass through a distance of 1 metre in the direction of the force applied. It is also the energy dissipated as heat when an electric current of one ampere passes through a resistance of one ohm for one second. It is named after the English physicist James Prescott Joule (1818–1889).

The coulomb (symbol: C) is the unit of electric charge in the International System of Units (SI). In the present version of the SI it is equal to the electric charge delivered by a 1 ampere constant current in 1 second and to 5 x 10 to exponent 18 / 0.801088317 elementary charges, e, (about 6.241509×10 exponent 18 e)

Voltage

- Measured with a **Voltmeter**.

- Millivolt (mV) = 1/1,000 volts.
- Microvolt (µV) = 1/1,000,000 volts.

Resistance

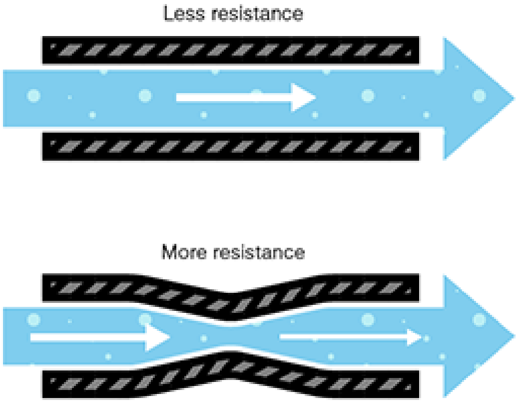
- **Opposition** to the flow of current.
- Unit of resistance is the **ohm**.
- Symbol is the Greek letter Omega: Ω
- Abbreviation for resistance is “R”: e.g.: R = 5 Ω

Al Penney
VO1NO

The **electrical resistance** of an object is a measure of its opposition to the flow of electric current. The inverse quantity is **electrical conductance**, and is the ease with which an electric current passes. Electrical resistance shares some conceptual parallels with the notion of mechanical friction. The SI unit of electrical resistance is the ohm (Ω), while electrical conductance is measured in siemens (S).

The resistance of an object depends in large part on the material it is made of—objects made of electrical insulators like rubber tend to have very high resistance and low conductivity, while objects made of electrical conductors like metals tend to have very low resistance and high conductivity. This material dependence is quantified by resistivity or conductivity. However, resistance and conductance are extensive rather than bulk properties, meaning that they also depend on the size and shape of an object. For example, a wire's resistance is higher if it is long and thin, and lower if it is short and thick. All objects show some resistance, except for superconductors, which have a resistance of zero.

Resistance



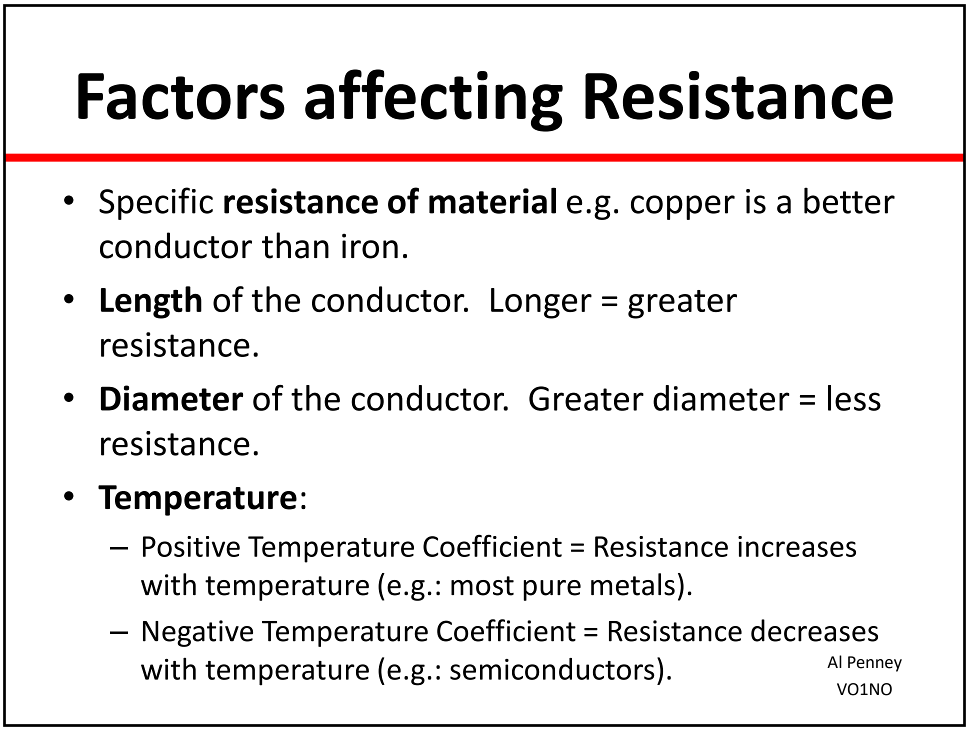
Al Penney
VO1NO

Resistance

- Measured with an **Ohmmeter**.

- Milliohm (mΩ) = 1/1,000 ohm.
- Kiloohm (kΩ) = 1,000 ohm.
- Megaohm (MΩ) = 1,000,000 ohm.

Al Penney
VO1NO

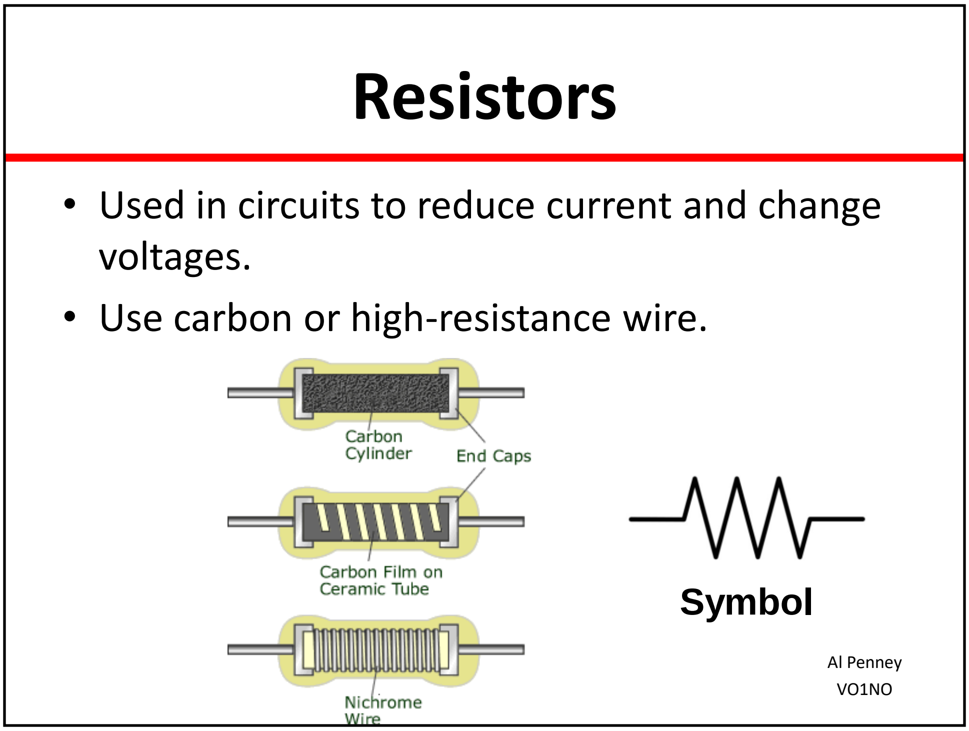


Factors affecting Resistance

- Specific **resistance of material** e.g. copper is a better conductor than iron.
- **Length** of the conductor. Longer = greater resistance.
- **Diameter** of the conductor. Greater diameter = less resistance.
- **Temperature**:
  - Positive Temperature Coefficient = Resistance increases with temperature (e.g.: most pure metals).
  - Negative Temperature Coefficient = Resistance decreases with temperature (e.g.: semiconductors).

Al Penney
VO1NO

The resistance of a given object depends primarily on two factors: What material it is made of, and its shape. For a given material, the resistance is inversely proportional to the cross-sectional area; for example, a thick copper wire has lower resistance than an otherwise-identical thin copper wire. Also, for a given material, the resistance is proportional to the length; for example, a long copper wire has higher resistance than an otherwise-identical short copper wire.



Resistors

- Used in circuits to reduce current and change voltages.
- Use carbon or high-resistance wire.

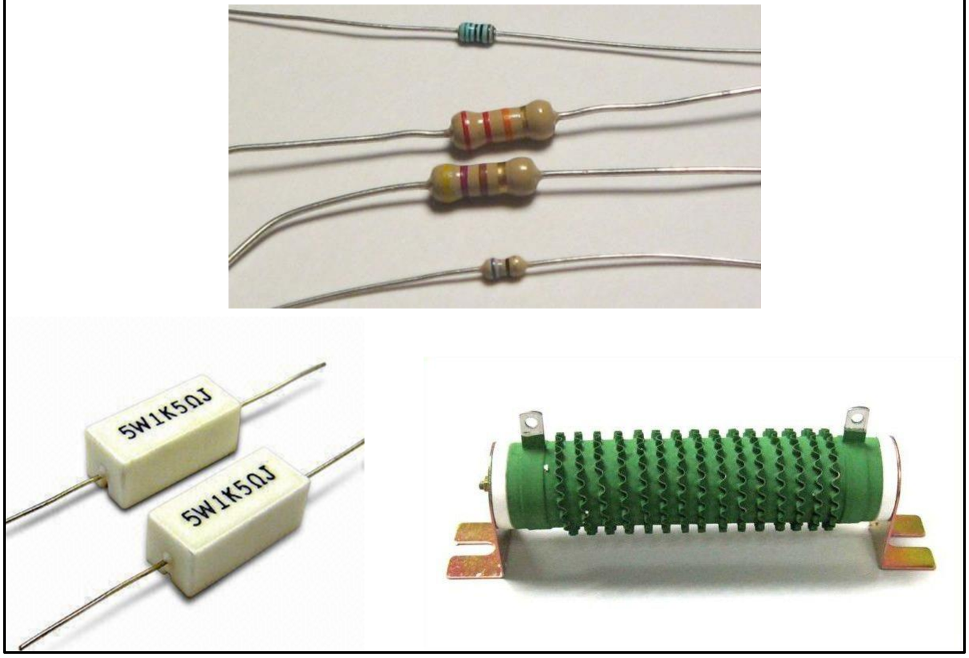
Symbol

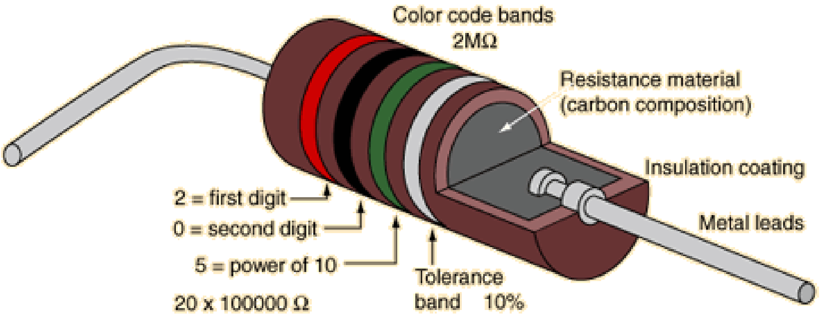
Al Penney
VO1NO

A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

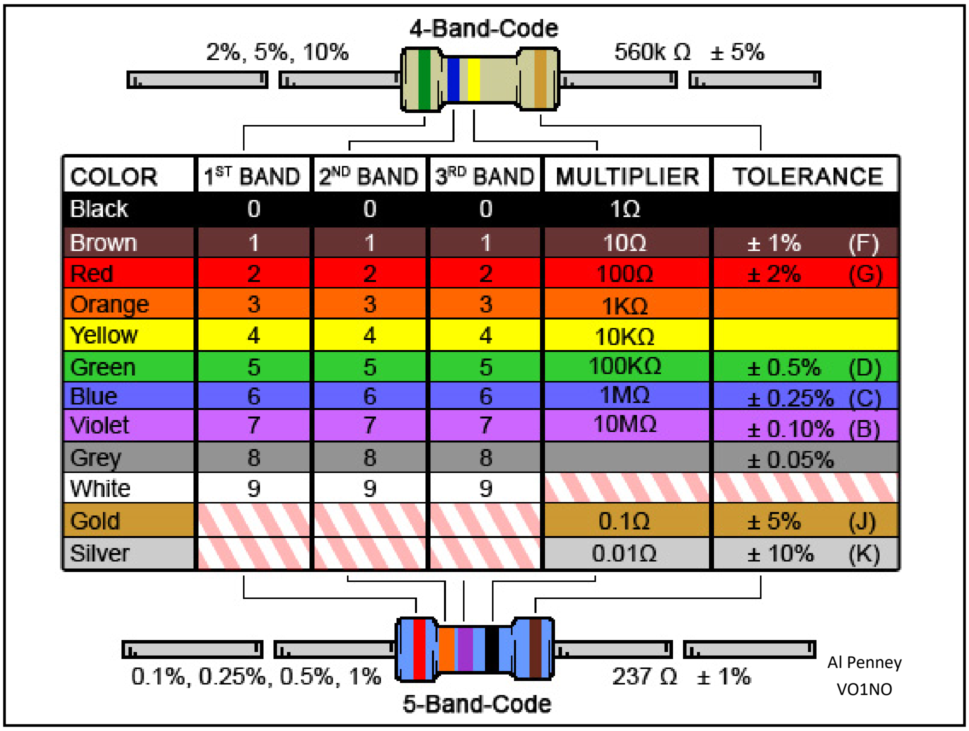
Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in electronic equipment. Practical resistors as discrete components can be composed of various compounds and forms. Resistors are also implemented within integrated circuits.

The electrical function of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than nine orders of magnitude. The nominal value of the resistance falls within the manufacturing tolerance, indicated on the component.


5W1K5ΩJ
5W1K5ΩJ



Al Penney
VO1NO



COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8		± 0.05%
White	9	9	9	▨	▨
Gold	▨	▨	▨	0.1Ω	± 5% (J)
Silver	▨	▨	▨	0.01Ω	± 10% (K)

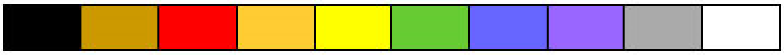
Al Penney
VO1NO

Axial resistors' cases are usually tan, brown, blue, or green (though other colors are occasionally found as well, such as dark red or dark gray), and display 3–6 colored stripes that indicate resistance (and by extension tolerance), and may be extended to indicate the temperature coefficient and reliability class. The first two stripes represent the first two digits of the resistance in ohms, the third represents a multiplier, and the fourth the tolerance (which if absent, denotes ±20%). For five- and six- striped resistors the third is the third digit, the fourth the multiplier and the fifth is the tolerance; a sixth stripe represents the temperature coefficient. The power rating of the resistor is usually not marked and is deduced from the size.

Surface-mount resistors are marked numerically.

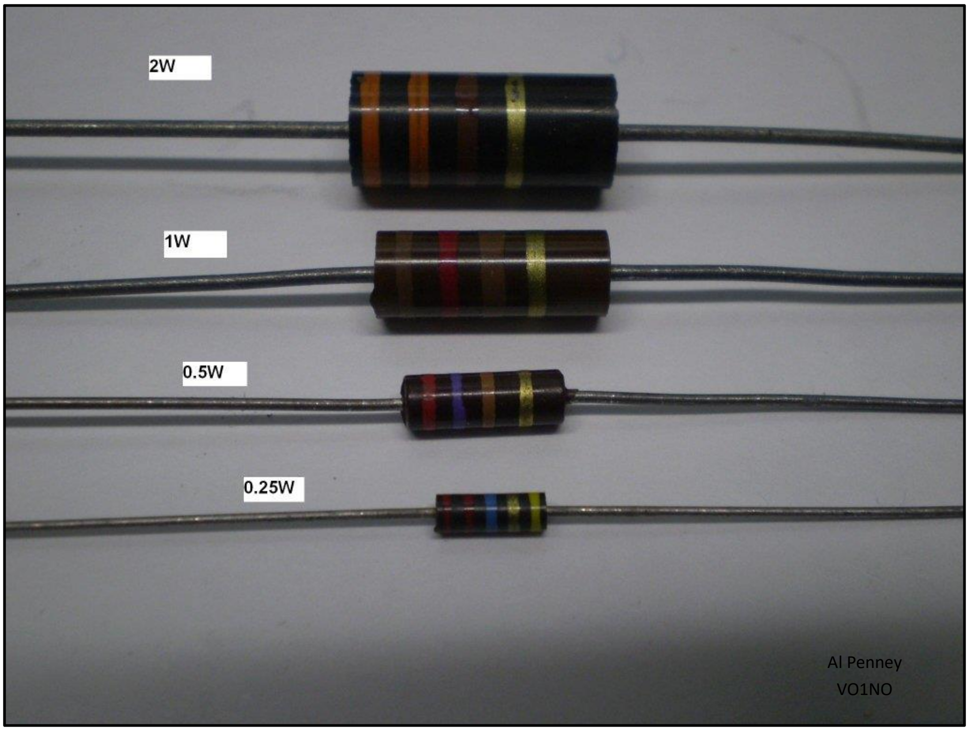
Sometimes depending upon the manufacturer, after the written resistance value there is an additional letter which represents the resistors tolerance value such as 4k7 J and these suffix letters are given in brackets in the Tolerance column.

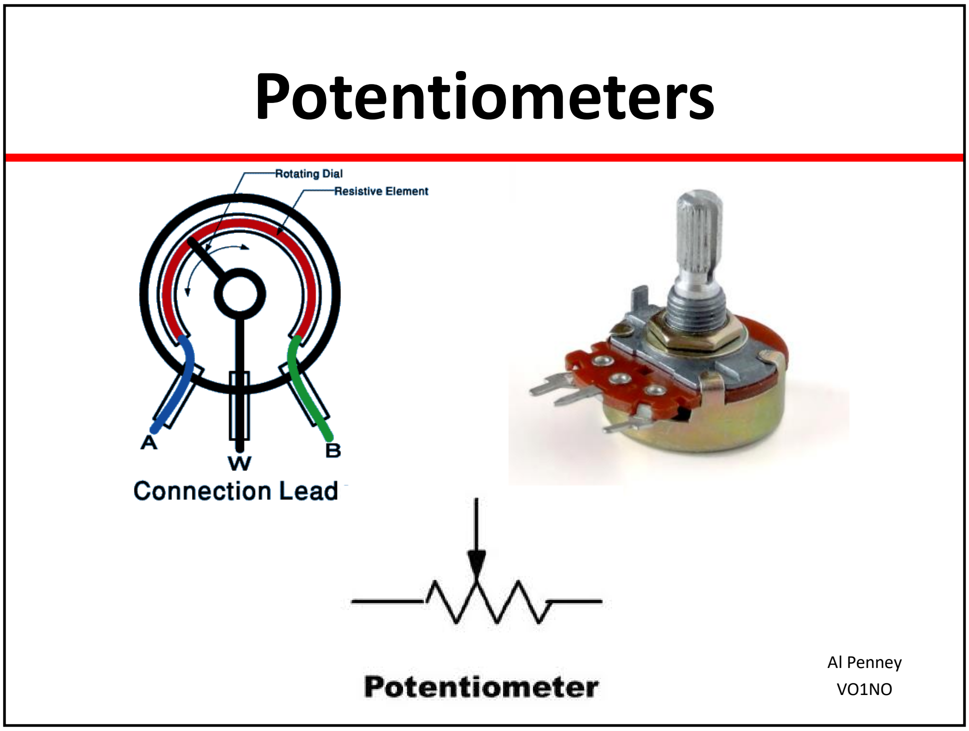
Resistor Colour Code Mnemonic



0	1	2	3	4	5	6	7	8	9
Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Gray	White
Bad	Booze	Rots	Our	Young	Guts	But	Vodka	Goes	Well

Al Penney
VO1NO


2W
1W
0.5W
0.25W
Al Penney
VO1NO



Potentiometers

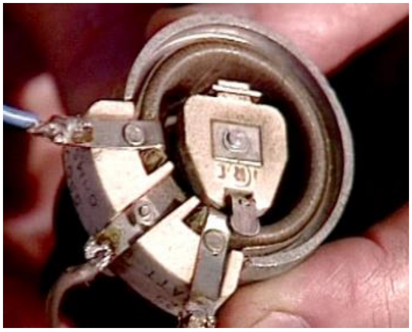
Al Penney
VO1NO

A **potentiometer** is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminals are used, one end and the wiper, it acts as a **variable resistor** or **rheostat**.

The measuring instrument called a potentiometer is essentially a voltage divider used for measuring electric potential (voltage); the component is an implementation of the same principle, hence its name.

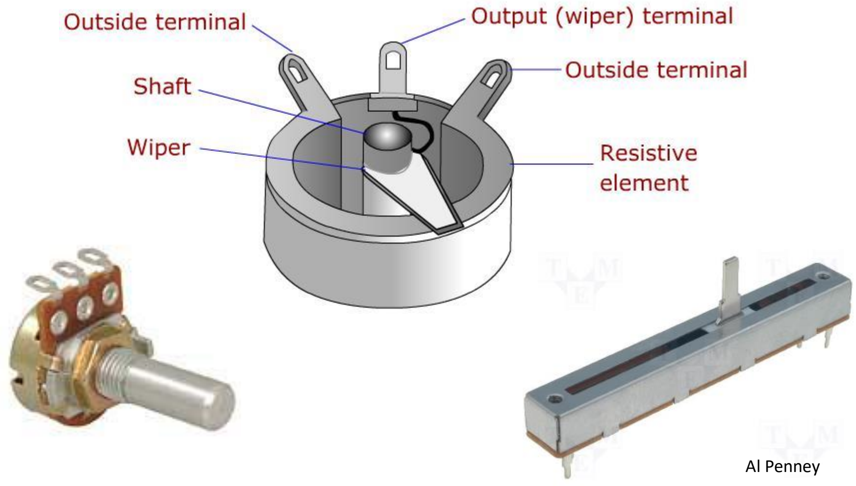
Potentiometers are commonly used to control electrical devices such as volume controls on audio equipment.

Wirewound Potentiometer



Al Penney
VO1NO

Composition Potentiometer

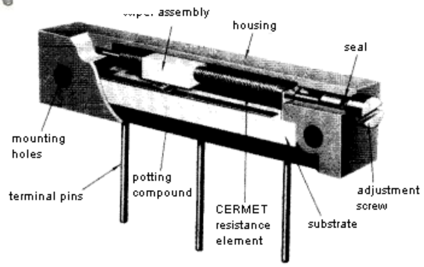


Al Penney
VO1NO

Trimmers

3266
BOURNS
CW
3
1

PIHER



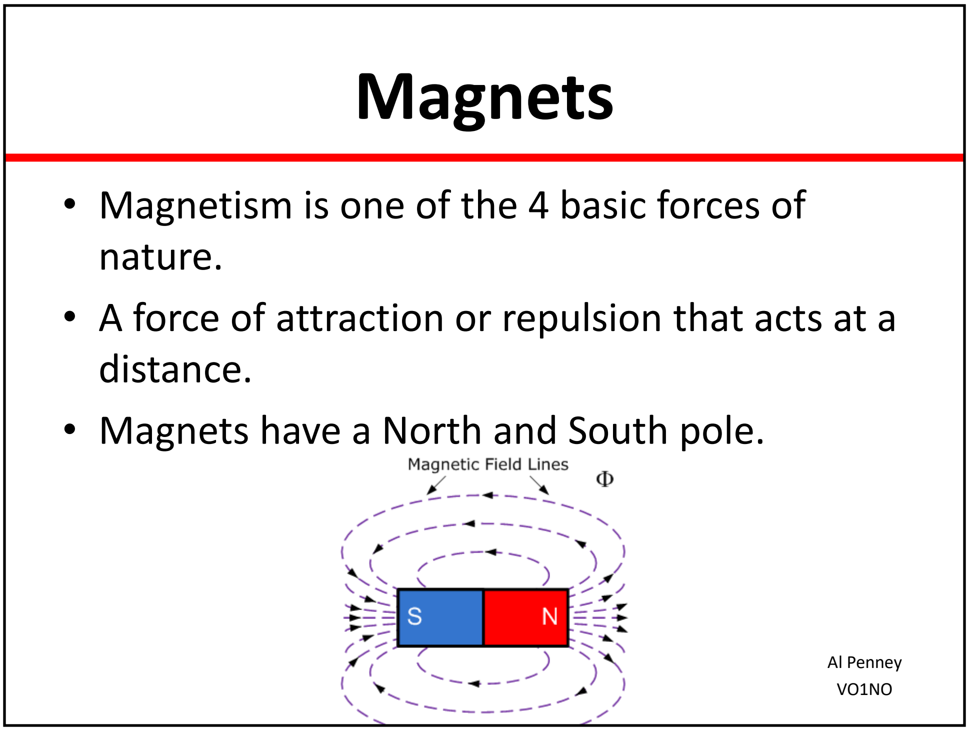
assembly
housing
seal
mounting holes
terminal pins
potting compound
CERMET resistance element
substrate
adjustment screw

Conductance

- Sometimes easier to consider how well a material conducts rather than its resistance.
- Conductance is **reciprocal** of resistance.
- Symbol for Conductance is G: G = 1/R
- Unit of measure is the **siemen**, abbreviated S (formerly the mho – ohm spelled backwards).
- Example: If R = 10 Ω, then G = 1/10 S = 0.1 S

Al Penney
VO1NO

Electrical conductivity or **specific conductance** is the reciprocal of electrical resistivity. It represents a material's ability to conduct electric current. It is commonly signified by the Greek letter σ (sigma), but κ (kappa) (especially in electrical engineering) and γ (gamma) are sometimes used. The SI unit of electrical conductivity is siemens per metre (S/m).



Magnets

- Magnetism is one of the 4 basic forces of nature.
- A force of attraction or repulsion that acts at a distance.
- Magnets have a North and South pole.

Al Penney
VO1NO

Magnetic Fields

What is a magnetic field? The space surrounding a magnet, in which magnetic force is exerted, is called a magnetic field. If a bar magnet is placed in such a field, it will experience magnetic forces. However, the field will continue to exist even if the magnet is removed. The direction of magnetic field at a point is the direction of the resultant force acting on a hypothetical North Pole placed at that point.

The **Four Fundamental Forces** of **Nature**. The **Four Fundamental Forces** of **Nature** are Gravitational **force**, Weak Nuclear **force**, Electromagnetic **force** and Strong Nuclear **force**. The weak and strong **forces** are effective only over a very short range and dominate only at the level of subatomic particles.

Gravity is the attraction between two objects that have mass or energy, whether this is seen in dropping a rock from a bridge, a planet orbiting a star or the moon causing ocean tides. Gravity is probably the most intuitive and familiar of the fundamental forces, but it's also been one of the most challenging to explain.

The weak force, also called the weak nuclear interaction, is responsible for particle decay. This is the literal change of one type of subatomic particle into another. So, for example, a neutrino that strays close to a neutron can turn the neutron into a proton while the neutrino becomes an electron.

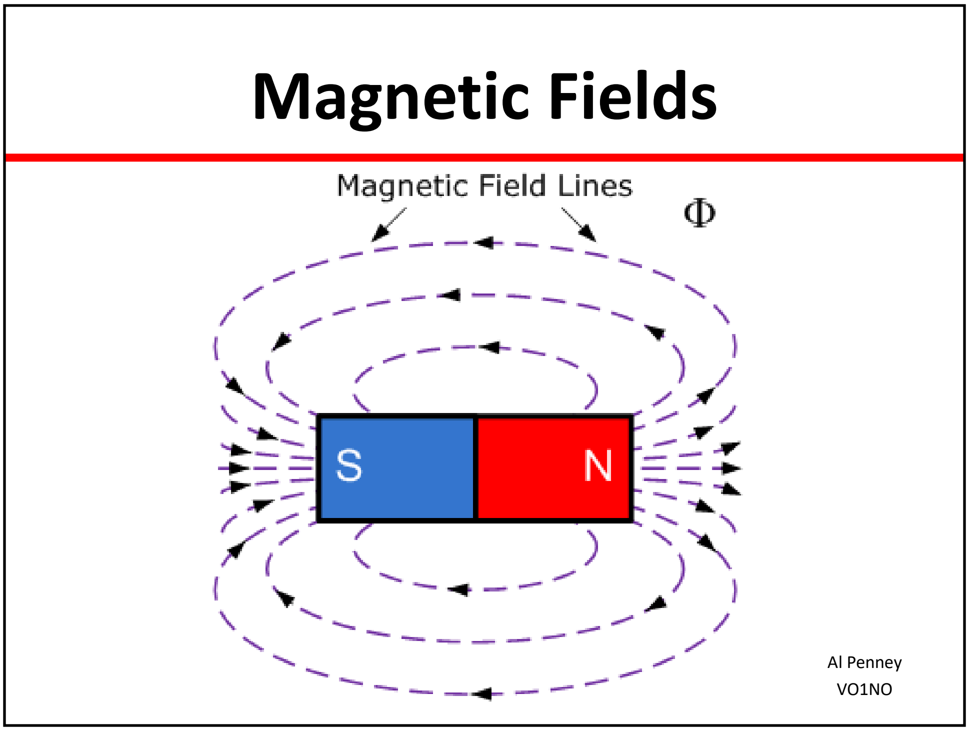
The electromagnetic force, also called the Lorentz force, acts between charged particles, like negatively charged electrons and positively charged protons. Opposite charges attract one another, while like charges repel. The greater the charge, the greater the force. And much like gravity, this force can be felt from an infinite distance (albeit the force would be very, very small at that distance).

As its name indicates, the electromagnetic force consists of two parts: the electric force and the magnetic force. At first, physicists described these forces as separate from one another, but researchers later realized that the two are components of the same force.

The strong nuclear force, also called the strong nuclear interaction, is the strongest of the four fundamental forces of nature. It's 6 thousand trillion trillion trillion (that's 39 zeroes after 6!) times stronger than the force of gravity, according to the HyperPhysics website. And that's because it binds the fundamental particles of matter together to form larger particles. It holds together the quarks that make up protons and neutrons, and part of the strong force also keeps the protons and neutrons of an atom's nucleus together.

Much like the weak force, the strong force operates only when subatomic particles are extremely close to one another. They have to be somewhere within 10^-15 meters from each other, or roughly within the diameter of a proton, according to the HyperPhysics website.

NOTE: In April 2021, a Fermilab group reported "strong evidence for the existence of an undiscovered sub-atomic particle or new force" that interacts with muons.



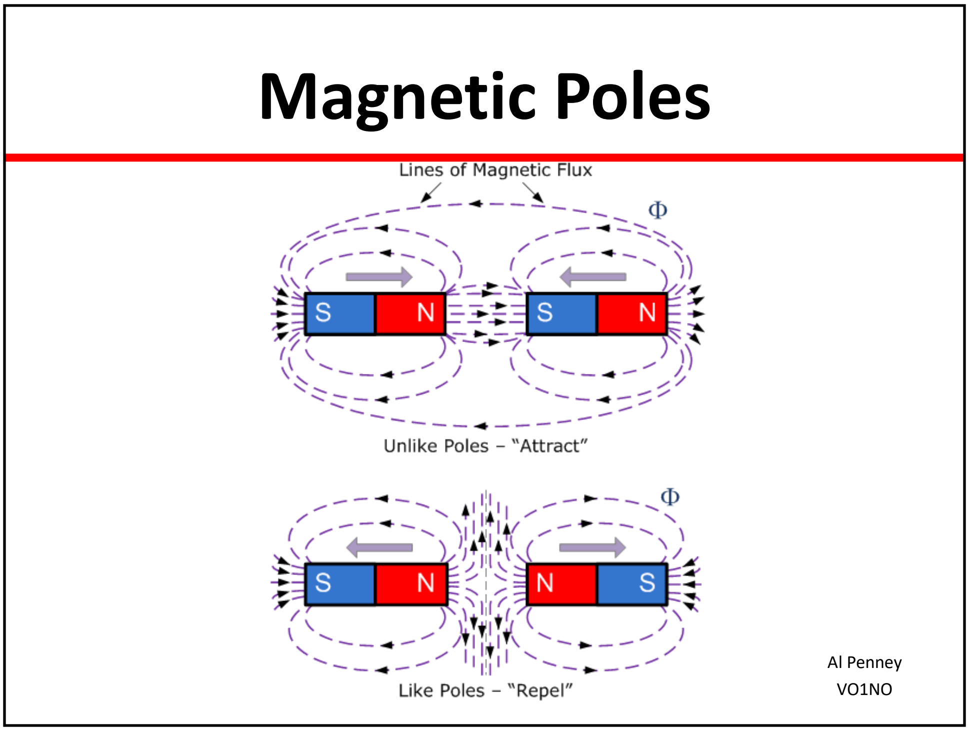
Magnetic Fields

Al Penney
VO1NO

As shown above, the magnetic field is strongest near to the poles of the magnet were the lines of flux are more closely spaced. The general direction for the magnetic flux flow is from the North (N) to the South (S) pole. In addition, these magnetic lines form closed loops that leave at the north pole of the magnet and enter at the south pole. Magnetic poles are always in pairs.

However, magnetic flux does not actually flow from the north to the south pole or flow anywhere for that matter as magnetic flux is a static region around a magnet in which the magnetic force exists. In other words magnetic flux does not flow or move it is just there and is not influenced by gravity. Some important facts emerge when plotting lines of force:

1. - Lines of force NEVER cross.
2. - Lines of force are CONTINUOUS.
3. - Lines of force always form individual CLOSED LOOPS around the magnet.
4. - Lines of force have a definite DIRECTION from North to South.
5. - Lines of force that are close together indicate a STRONG magnetic field.
6. - Lines of force that are farther apart indicate a WEAK magnetic field.



Magnetic Poles

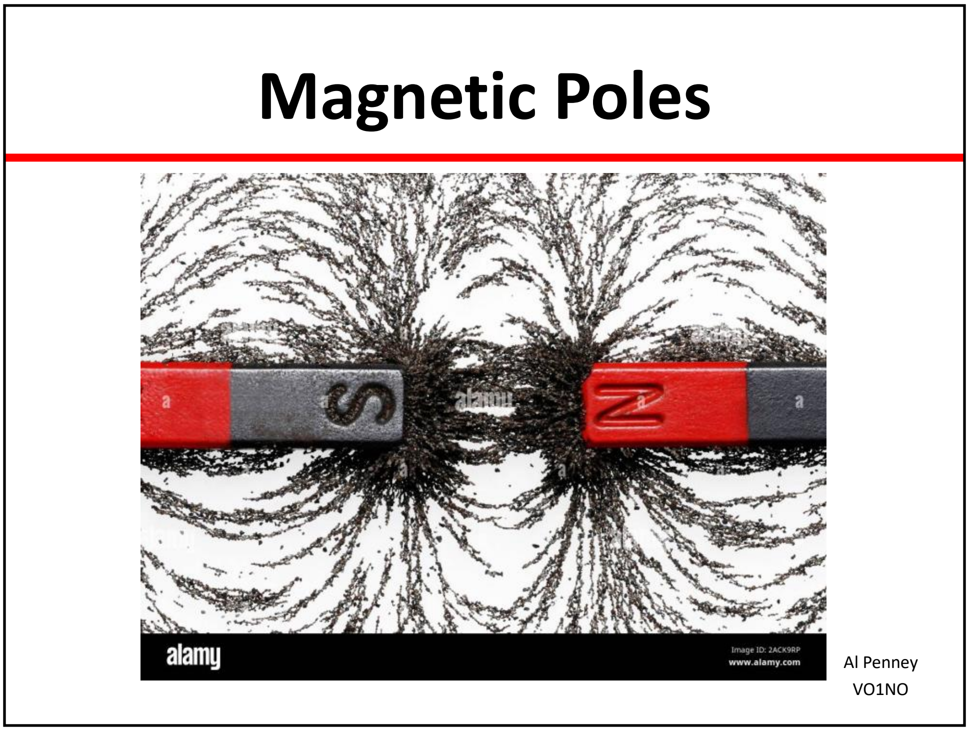
Al Penney
VO1NO

Magnetic forces attract and repel like electric forces and when two lines of force are brought close together the interaction between the two magnetic fields causes one of two things to occur:

1. - When adjacent poles are the same, (north-north or south-south) they REPEL each other.

2. - When adjacent poles are not the same, (north-south or south-north) they ATTRACT each other.

It can be remembered by the famous expression that "opposites attract" and this interaction of magnetic fields is easily demonstrated with iron fillings. The effect upon the magnetic fields of the various combinations of poles as like poles repel and unlike poles attract can be seen below.



Magnetic Poles

Al Penney
VO1NO

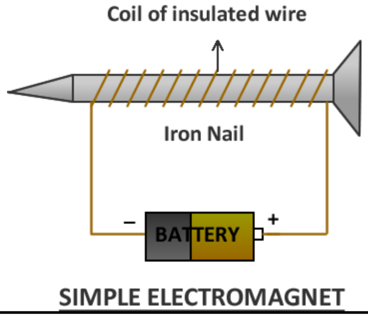
Magnetic forces attract and repel like electric forces and when two lines of force are brought close together the interaction between the two magnetic fields causes one of two things to occur:

1. - When adjacent poles are the same, (north-north or south-south) they REPEL each other.

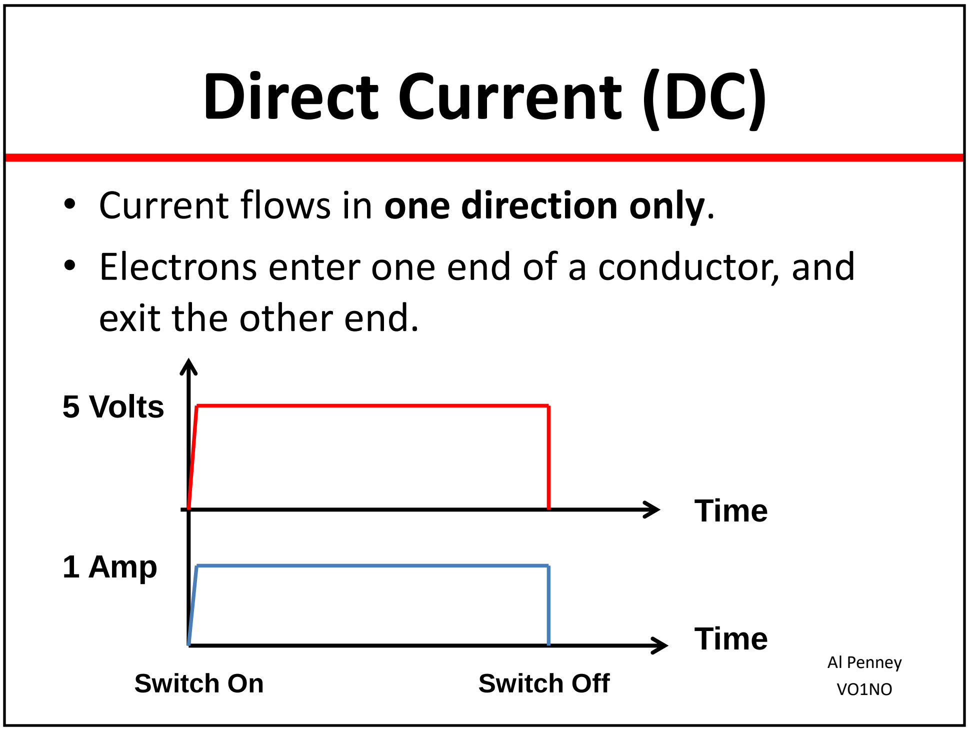
2. - When adjacent poles are not the same, (north-south or south-north) they ATTRACT each other.

It can be remembered by the famous expression that "opposites attract" and this interaction of magnetic fields is easily demonstrated with iron fillings. The effect upon the magnetic fields of the various combinations of poles as like poles repel and unlike poles attract can be seen below.

Types of Magnets



Al Penney
VO1NO



Direct Current (DC)

- Current flows in **one direction only**.
- Electrons enter one end of a conductor, and exit the other end.

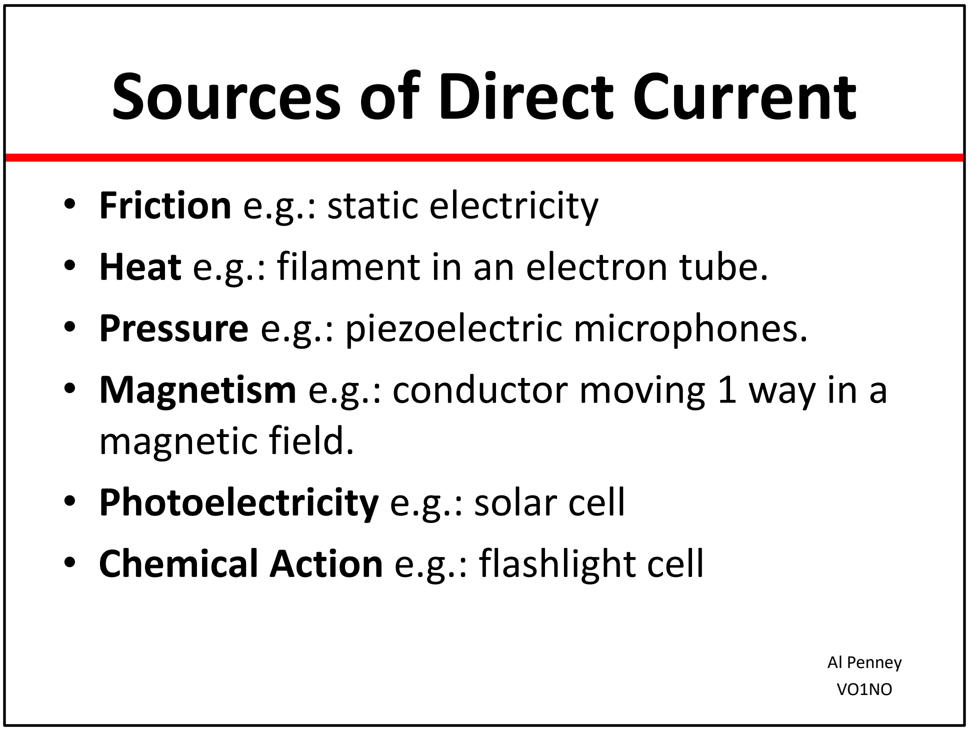
Al Penney
VO1NO

Direct current (**DC**) is the unidirectional flow of an electric charge. An electrochemical cell is a prime example of DC power. Direct current may flow through 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). A term formerly used for this type of current was **galvanic current**.

The abbreviations *AC* and *DC* are often used to mean simply *alternating* and *direct*, as when they modify *current* or *voltage*.

Direct current may be converted from an alternating current supply by use of a rectifier, which contains electronic elements (usually) or electromechanical elements (historically) that allow current to flow only in one direction. Direct current may be converted into alternating current via an inverter.

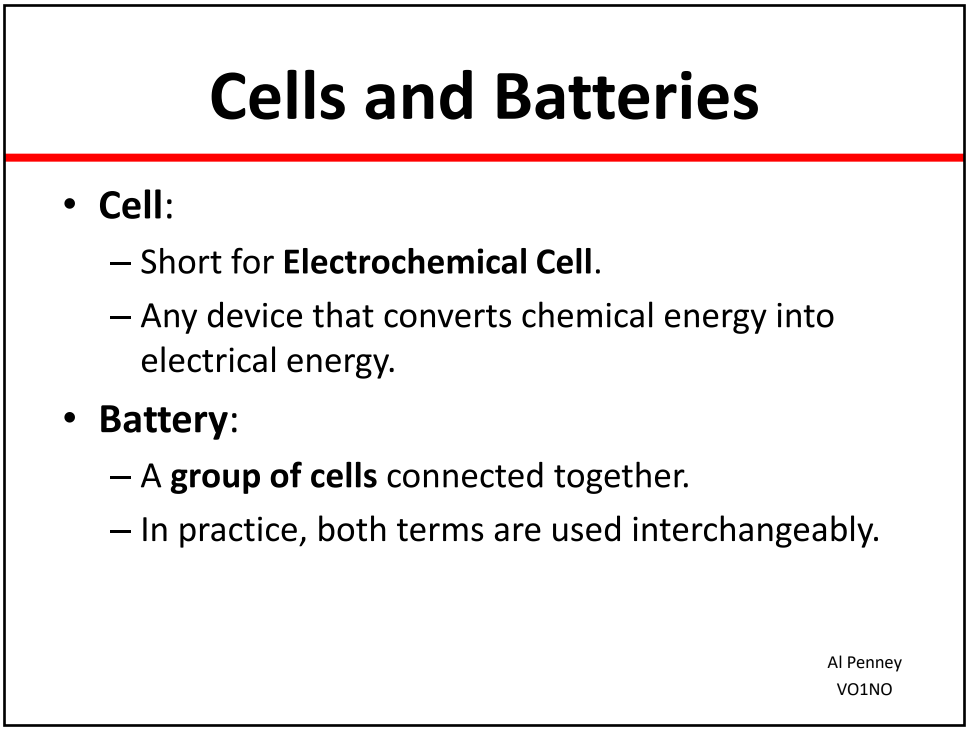
Direct current has many uses, from the charging of batteries to large power supplies for electronic systems, motors, and more. Very large quantities of electrical energy provided via direct-current are used in smelting of aluminum and other electrochemical processes. It is also used for some railways, especially in urban areas. High-voltage direct current is used to transmit large amounts of power from remote generation sites or to interconnect alternating current power grids.



Sources of Direct Current

- **Friction** e.g.: static electricity
- **Heat** e.g.: filament in an electron tube.
- **Pressure** e.g.: piezoelectric microphones.
- **Magnetism** e.g.: conductor moving 1 way in a magnetic field.
- **Photoelectricity** e.g.: solar cell
- **Chemical Action** e.g.: flashlight cell

Al Penney
VO1NO



Cells and Batteries

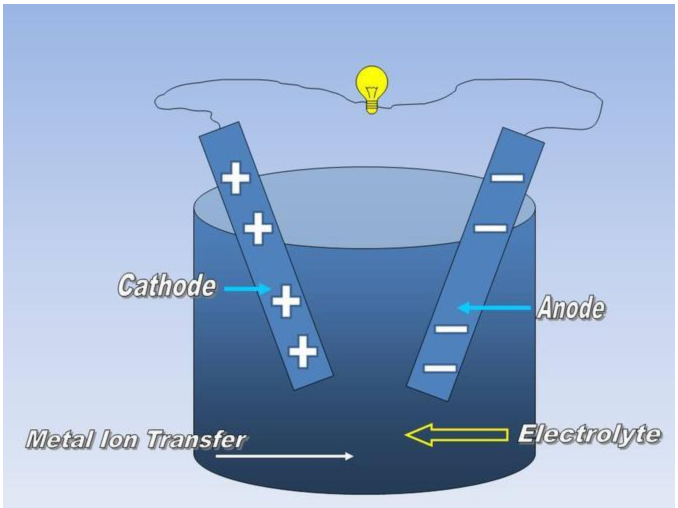
- **Cell**:
  - Short for **Electrochemical Cell**.
  - Any device that converts chemical energy into electrical energy.
- **Battery**:
  - A **group of cells** connected together.
  - In practice, both terms are used interchangeably.

Al Penney
VO1NO

An **electrochemical cell** is a device capable of generating electrical energy from chemical reactions.

A *battery* consists of one or more cells, connected in parallel, series or series-and-parallel pattern.

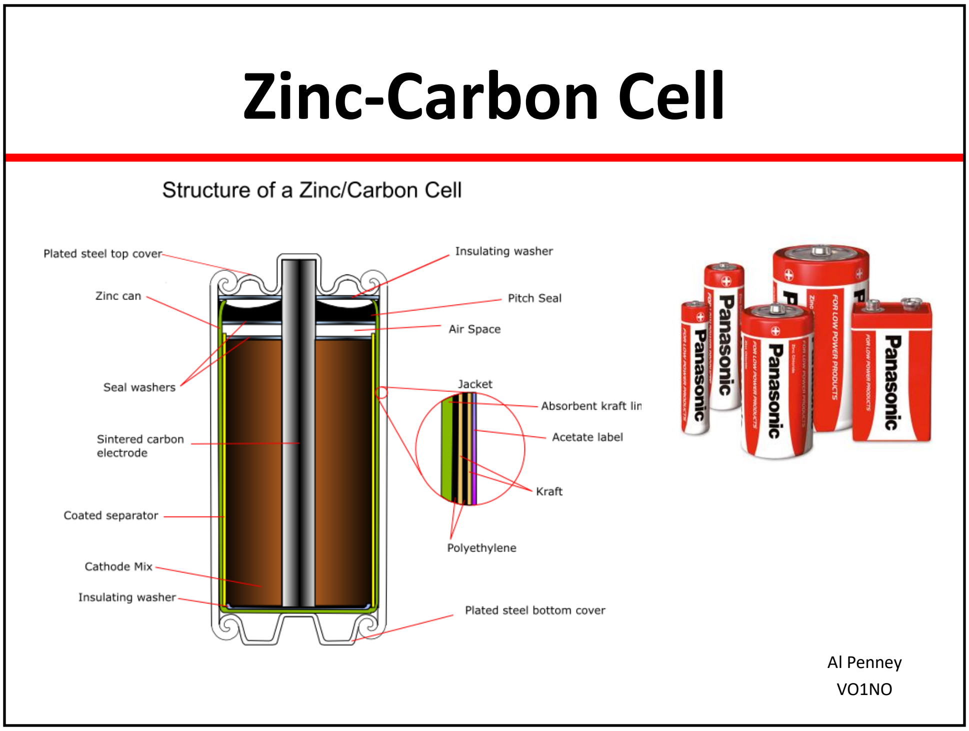
Electrochemical Cells



Al Penney
VO1NO

The CATHODE and ANODE are electrodes. The Cathode loses electrons to BECOME positive and the anode gains electrons to BECOME negative. They do not start out that way. The electrolyte allows the transfer of ions through solution so that the circuit become complete.

Voltage depends on the chemical solution of the electrolyte and the materials of the electrodes.



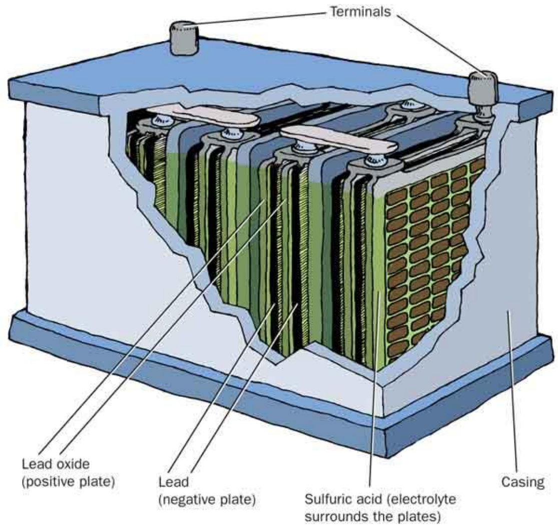
Zinc-Carbon Cell

Al Penney
VO1NO

A **zinc–carbon battery** (or "heavy duty") is a battery packaged in a zinc can that serves as both a container and negative terminal. It was developed from the wet Leclanché cell (/lɛklɑːnˈʃeɪ/). The positive terminal is a carbon rod surrounded by a mixture of manganese dioxide and carbon powder. The electrolyte used is a paste of zinc chloride and ammonium chloride dissolved in water. Zinc chloride cells are an improved version from the original ammonium chloride variety. Zinc–carbon batteries are the least expensive primary batteries and thus a popular choice by manufacturers when devices are sold with batteries included. They are commonly labeled as *general purpose* batteries, while Zinc chloride cells are often labeled "Heavy Duty". They were the first commercial dry battery and made flashlights and other portable devices possible, because the battery can function in any position. They can be used in low drain or intermittent devices such as remote controls, flashlights, clocks or transistor radios. They are replaced, in many usages, by alkaline cells, and rechargeable NiMH batteries.

Four sizes – AAA, AA, C and D. All produce 1.5 volts, but the larger the battery the more current it can deliver because the electrodes are physically larger.

12 Volt Car Battery



Al Penney
VO1NO

Automotive SLI batteries are usually lead-acid type, and are made of six galvanic cells in series to provide a 12-volt system. Each cell provides 2.1 volts for a total of 12.6 volts at full charge. Heavy vehicles, such as highway trucks or tractors, often equipped with diesel engines, may have two batteries in series for a 24-volt system or may have parallel strings of batteries.

Lead-acid batteries are made up of plates of lead and separate plates of lead dioxide, which are submerged into an electrolyte solution of about 38% sulfuric acid and 62% water. This causes a chemical reaction that releases electrons, allowing them to flow through conductors to produce electricity. As the battery discharges, the acid of the electrolyte reacts with the materials of the plates, changing their surface to lead sulfate. When the battery is recharged, the chemical reaction is reversed: the lead sulfate reforms into lead dioxide and lead. With the plates restored to their original condition, the process may now be repeated.

Types

Lead-acid batteries for automotive use are made with slightly different construction techniques, depending on the application of the battery. The "flooded cell" type, indicating liquid electrolyte, is typically inexpensive and long-lasting, but requires more maintenance and can spill or leak. Some flooded batteries have removable caps that allow for the electrolyte to be tested and maintained.

More costly alternatives to flooded batteries are valve regulated lead acid (VRLA) batteries, also called "sealed" batteries. The absorbed glass mat (AGM) type uses a glass mat separator, and a "gel cell" uses fine powder to absorb and immobilize the sulfuric acid electrolyte. These batteries are not serviceable: the cells are sealed so the degree of charge cannot be measured by hydrometer and the electrolyte cannot be replenished. They are typically termed "maintenance-free" by proponents, or "unable to be maintained" by skeptics. In particular, they are not suitable for older (pre-alternator) vehicles with unsophisticated charging control systems. Both types of sealed batteries may be used in vehicular applications where leakage or ventilation for vented gasses is a concern.

The **starting** (*cranking*) or *shallow cycle* type is designed to deliver large bursts of power for a short time, as is needed to start an engine. Once the engine is started, the battery is recharged by the engine-driven charging system. Starting batteries are intended to have a low depth of discharge on each use. They are constructed of many thin plates with thin separators between the plates, and may have a higher specific gravity electrolyte to reduce internal resistance.

The **deep cycle** (or *motive*) type is designed to continuously provide power for long periods of time (for example in a trolling motor for a small boat, auxiliary power for a recreational vehicle, or traction power for a golf cart or other battery electric vehicle). They can also be used to store energy from a photovoltaic array or a small wind turbine. Deep-cycle batteries have fewer, thicker plates and are intended to have a greater depth of discharge on each cycle, but will not provide as high a current on heavy loads. The thicker plates survive a higher number of charge/discharge cycles. The specific energy is in the range of 30-40 watt-hours per kilogram.

Some cars use more exotic starter batteries–the 2010 Porsche 911 GT3 RS offers a lithium-ion battery as an option to save weight over a conventional lead-acid battery.

Use and maintenance

Fluid level

Filling a (flooded lead-acid type) car battery with distilled water.

Car batteries using lead-antimony plates require regular watering to replace water lost due to electrolysis on each charging cycle. By changing the alloying element to calcium, more recent designs have lower water loss, unless overcharged. Modern car batteries have reduced maintenance requirements, and may not provide caps for addition of water to the cells. Such batteries include extra electrolyte above the plates to allow for losses during the battery life. If the battery has easily detachable caps then a top-up with distilled water may be required from time to time. Prolonged overcharging or charging at excessively high voltage causes some of the water in the electrolyte to be broken up into hydrogen and oxygen gases, which escape from the cells; this is called gassing. If the electrolyte liquid level drops too low, the plates are exposed to air, lose capacity, and are damaged. The sulfuric acid in the battery normally does not require replacement since it is not consumed even on overcharging. Impurities or additives in the water will reduce the life and performance of the battery. Manufacturers usually recommend use of demineralized or distilled water, since even potable tap water can contain high levels of minerals.

Charge and discharge

In normal automotive service the vehicle's charging system powers the vehicle's electrical systems and restores charge used from the battery during engine cranking. When installing a new battery or recharging a battery that has been accidentally discharged completely, one of several different methods can be used to charge it. The most gentle of these is called trickle charging. Other methods include slow-charging and quick-charging, the latter being the harshest.

The voltage regulator of the charge system does not measure the relative currents charging the battery and for powering the car's loads. The charge system essentially provides a fixed voltage of typically 13.8 to 14.4 V, adjusted to ambient temperature, unless the alternator is at its current limit. A discharged battery draws a high charge current of typically 20 to 40 A. As the battery becomes charged the charge current typically decreases to 2—5 amperes. A high load is when multiple high-power systems such as ignition, radiator fan, heater blowers, lights and entertainment system are running at the same time. In older (up to the 1980s) vehicles the battery may discharge unless the engine is running at a higher than idle rpm and the alternator/generator is delivering enough current to power the load. This is not an issue for modern vehicles where alternators provide enough current for all loads and a regulator keeps charging voltage in check. In such cars rpm has little influence on the battery voltage - tests show near normal voltage regardless of the AC / headlights / music / fan / defrosting / other electrical loads, even at idle.

Some manufacturers include a built-in hydrometer to show the state of charge of the battery, a transparent tube with a float immersed in the electrolyte visible through a window. When the battery is charged, the specific gravity of the electrolyte increases (since all the sulfate ions are in the electrolyte, not combined with the plates), and the colored top of the float is visible in the window. When the battery is discharged, or the electrolyte level is too low, the float sinks and the window appears yellow (or black). The built-in hydrometer only checks the state of charge of one cell and will not show faults in the other cells. In a non-sealed battery each of the cells can be checked with a portable or hand-held hydrometer.

A positive (red) jumper cable connected to battery post. An optional hydrometer window is visible by the single jumper clamp. (The black negative jumper clamp is not shown)

In emergencies a vehicle can be jump started by the battery of another vehicle or by a portable battery booster. It is possible to charge a battery fully using solely the alternator, either by raising the engine's RPM while parked or by regular driving. It will typically take one and a half hours of driving overall to charge the battery, plus another minute or two for every time the car is started. This process can be enhanced by using lower gears as that leads to higher RPM's and therefore higher alternator output, which can also preserve battery life when lots of electricity is being used by the air conditioner or heater, the radio, the headlights, etc., although that has the drawback of lower gas mileage. A 12 volt car battery fully charged should output around 12.6 volts.

However, it is preferable to use a battery charger whenever possible because the above method will shorten the lifespan of the alternator and gasoline is much more expensive than wall outlet electricity. Simple chargers do not regulate the charge current, and the user needs to stop the process or lower the charge current to prevent excessive gassing of the battery. More elaborate chargers, in particular those implementing the *3-step charge* profile, also referred to as IUoU, charge the battery fully and safely in a short time without requiring user intervention. Desulfating chargers are also commercially available for charging all types of lead-acid batteries.

Storage

Unlike lithium based batteries, automotive batteries last longer when stored in a charged state. Leaving an automotive battery discharged will shorten its life, or make it unusable if left for a long time (usually several years); sulfation eventually becomes irreversible with normal charging. Batteries in storage may be monitored and periodically charged, or attached to a "float" charger to retain their capacity. One practical method is to use an inexpensive 24 hour timer that turns a charger on for 30 minutes per day. Batteries are prepared for storage by charging and cleaning deposits from the posts. Batteries are stored in a cool, dry environment for best results since high temperatures increase the self discharge rate and plate corrosion.

In the past, storing lead-acid batteries on the ground, or on concrete or cement floors, was believed to cause batteries to discharge or be otherwise damaged, but this is no longer a concern.[7] In spite of this, the advice to never leave a battery on a concrete floor persists.[8][9] Modern batteries use tough polycarbonate cases that do not conduct current or allow moisture to pass, and maintenance free batteries are the norm, so large amounts of leaking acid are rarely seen, providing no route for current to flow.[10] One battery manufacturer even prefers storing new batteries on concrete in the summer to keep them cooler, decreasing the natural discharge rate.[10] Early batteries had wooden cases, and could absorb moisture from wet concrete, giving current a route to discharge.[11] Another explanation for the admonition to avoid concrete is that wooden cases in the earliest batteries encased a glass jar, which could be broken by swelling wood if the wood casing became damp.[12] Later hard rubber cases were porous and had a high carbon content, leaving another route for current leakage, but modern plastic cases are five or more times better insulators than rubber, and the terminal seals do not leak as they once did.[12]

Changing a battery

When changing a battery, battery manufacturers recommend disconnecting the negative ground connection first to prevent accidental short-circuits between the battery terminal and the vehicle frame. Conversely the positive cable is connected first. Of course, this only applies to negative-earth vehicles - a better rule is to disconnect the earth or ground terminal first, this works whatever the polarity of the system. A study by the National Highway Traffic Safety Association estimated that in 1994 more than 2000 people were injured in the United States while working with automobile batteries. Another safety factor in the operation is to remove metal bracelets including watches.

The majority of automotive lead-acid batteries are filled with the appropriate electrolyte solution at the manufacturing plant, and shipped to the retailers ready to sell. Decades ago, this was not the case. The retailer filled the battery, usually at the time of purchase, and charged the battery. This was a time-consuming and potentially dangerous process. Care had to be taken when filling the battery with acid, as acids are highly corrosive and can damage eyes, skin and mucous membranes. Fortunately, this is less of a problem these days, and the need to fill a battery with acid usually only arises when purchasing a motorcycle or ATV battery.

Freshness

Because of sulfation, lead-acid batteries stored with electrolyte slowly deteriorate. Car batteries are date coded to ensure installation within one year of manufacture. In the United States, the manufacturing date is printed on a sticker. The date can be written in plain text or using an alphanumerical code. The first character is a letter that specifies the month (A for January, B for February and so on). The letter "I" is skipped due to its potential to be mistaken for the number 1. The second character is a single digit that indicates the year of manufacturing (for example, 6 for 2006). When first installing a newly purchased battery a "top up" charge at a low rate with an external battery charger (available at auto parts stores) may maximize battery life and minimize the load on the vehicle charging system.

Failure

Common battery faults include:
Shorted cell due to failure of the separator between the positive and negative plates
Shorted cell or cells due to build up of shed plate material below the plates of the cell
Broken internal connections due to corrosion
Broken plates due to vibration and corrosion
Low electrolyte level
Cracked or broken case
Broken terminals
Sulfation after prolonged disuse in a low or zero charged state
Frequent and continuous overcharge

Corrosion at the battery terminals can prevent a car from starting due to electrical resistance. The white powder sometimes found around the battery terminals is usually lead sulfate which is toxic by inhalation, ingestion and skin contact. The corrosion is caused by an imperfect seal between the plastic battery case and lead battery post allowing sulfuric acid to react with the lead battery posts. The corrosion process is also expedited by over charging. Corrosion can also be caused by factors such as salt water, dirt, heat, humidity, cracks in the battery casing or loose battery terminals. Inspection, cleaning and protection with a light coating of dielectric grease are measures used to prevent corrosion of battery terminals.

Sulfation occurs when a battery is not fully charged. The longer it remains in a discharged state the harder it is to overcome sulfation. This may be overcome with slow, low-current (trickle) charging. Sulfation is the formation of large, non-conductive lead sulfate crystals on the plates; lead sulfate formation is part of each cycle, but in the discharged condition the crystals become large and block passage of current through the electrolyte.

The primary wear-out mechanism is the shedding of active material from the battery plates, which accumulates at the bottom of the cells and which may eventually short-circuit the plates.

Early automotive batteries could sometimes be repaired by dismantling and replacing damaged separators, plates, intercell connectors and other repairs. Modern battery cases do not facilitate such repairs; an internal fault generally requires replacement of the entire unit.

Exploding batteries

Car battery after explosion

Any lead-acid battery system when overcharged (>14.34 V) will produce hydrogen gas (*gassing voltage*) by electrolysis of water. If the rate of overcharge is small, the vents of each cell allow the dissipation of the gas. However, on severe overcharge or if ventilation is inadequate, or the battery is faulty, a flammable concentration of hydrogen may remain in the cell or in the battery enclosure. An internal spark can cause a hydrogen and oxygen explosion, which will damage the battery and its surroundings and which will disperse acid into the surroundings. Anyone close to the battery may be injured.

Sometimes the ends of a battery will be severely swollen, and when accompanied by the case being too hot to touch, this usually indicates a malfunction in the charging system of the car. Reversing the positive and negative leads will damage the battery. When severely overcharged, a lead-acid battery produces high levels of hydrogen and the venting system built into the battery cannot handle the high level of gas, so the pressure builds inside the battery, resulting in the swollen ends. An unregulated alternator can quickly ruin a battery by excessive voltage. A swollen, hot battery is dangerous.

Another potential cause of explosion is when the battery terminals are short-circuited via a very low resistance path (like a wrench or other tool dropped or lying across the terminals). Apart from the sparks which usually occur in a short circuit, heating due to the internal resistance of the battery can cause the electrolyte to boil, also leading to explosion due to buildup of water vapor pressure (unrelated to electrolysis).

Persons handling car batteries should wear protective equipment (goggles, overalls, gloves) to avoid injury by acid spills. Any open flame or electric spark including lit tobacco products like cigarettes, cigars, or pipes in the area also present a danger of igniting any hydrogen gas escaping from a battery. Also for this reason, the final connection of a jumper cable should be to the car's frame rather than the grounded terminal of the battery; doing this keeps any potential sparks further from the battery.

Terms and ratings

Ampere-hours (A·h) is a measure of electrical charge that a battery can deliver. This quantity is one indicator of the total amount of charge that a battery is able to store and deliver at its rated voltage. Its value is the product of the discharge current (in amperes), multiplied by the duration (in hours) for which this discharge current can be sustained by the battery. Generally, this value (or rating) varies widely with the duration of the discharge period (see: Peukert's Law), therefore the value is typically only meaningful when the duration is specified. This rating is rarely stated for automotive batteries, except in Europe where it is required by law. Nominal capacity(A·h) by EN 60095-1 is rated at a fixed discharge current of I/20, within 20 hours until final discharge voltage of 10.5 V at 25 °C is reached.

Cranking amperes (CA), also sometimes referred to as *marine cranking amperes* (MCA), is the amount of current a battery can provide at 32 °F (0 °C). The rating is defined as the number of amperes a lead-acid battery at that temperature can deliver for 30 seconds and maintain at least 1.2 volts per cell (7.2 volts for a 12 volt battery).

Cold cranking amperes (CCA) is the amount of current a battery can provide at 0 °F (−18 °C). The rating is defined as the current a lead-acid battery at that temperature can deliver for 30 seconds and maintain at least 1.2 volts per cell (7.2 volts for a 12-volt battery). It is a more demanding test than those at higher temperatures. This is the most widely used cranking measurement for comparison purposes.

Hot cranking amperes (HCA) is the amount of current a battery can provide at 80 °F (26.7 °C). The rating is defined as the current a lead-acid battery at that temperature can deliver for 30 seconds and maintain at least 1.2 volts per cell (7.2 volts for a 12-volt battery).

Reserve capacity minutes (RCM), also referred to as *reserve capacity* (RC), is a battery's ability to sustain a minimum stated electrical load; it is defined as the time (in minutes) that a lead-acid battery at 80 °F (27 °C) will continuously deliver 25 amperes before its voltage drops below 10.5 volts.

Battery Council International group size (BCI) specifies a battery's physical dimensions, such as length, width, and height. These groups are determined by the Battery Council International organization.

Peukert's Law states that the capacity available from a battery varies according to how rapidly it is discharged. A battery discharged at high rate will give fewer ampere-hours than one discharged more slowly.

The hydrometer measures the density, and therefore indirectly the amount of sulfuric acid in the electrolyte. A low reading means that sulfate is bound to the battery plates and that the battery is discharged. Upon recharge of the battery, the sulfate returns to the electrolyte.

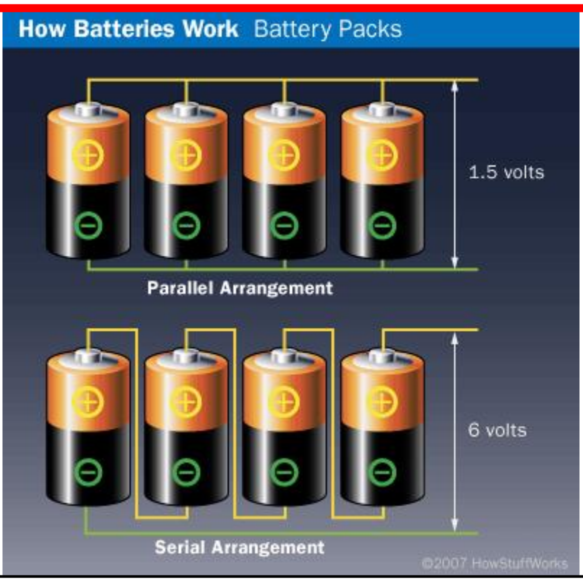
Terminal voltage

The open-circuit voltage is measured when the engine is off and no loads are connected. It can be approximately related to the charge of the battery:

Open-circuit voltage Approximate
charge Relative
acid density 12 V 6 V 12.60 V 6.32 V 100% 1.265 g/cm^3 12.35 V 6.22 V 75% 1.225 g/cm^3 12.10 V 6.12 V 50% 1.190 g/cm^3 11.95 V 6.03 V 25% 1.155 g/cm^3 11.70 V 6.00 V 0% 1.120 g/cm^3 Open-circuit voltage is also affected by temperature and the specific gravity of the electrolyte at full charge.

The following is common for a six-cell automotive lead-acid battery at room temperature:
Quiescent (open-circuit) voltage at full charge: 12.6 V
Fully discharged: 11.8 V
Charge with 13.2–14.4 V
Gassing voltage: 14.4 V
Continuous-preservation charge with max. 13.2 V
After full charge the terminal voltage will drop quickly to 13.2 V and then slowly to 12.6 V
Open-circuit voltage is measured 12 hours after charging to allow surface charge to dissipate and enable a more accurate reading.
All voltages are at 20 °C (68 °F), and must be adjusted −0.022 V/°C (−0.012 V/°F) for temperature changes (negative temperature coefficient – lower voltage at higher temperature).

Cells in Parallel and Series



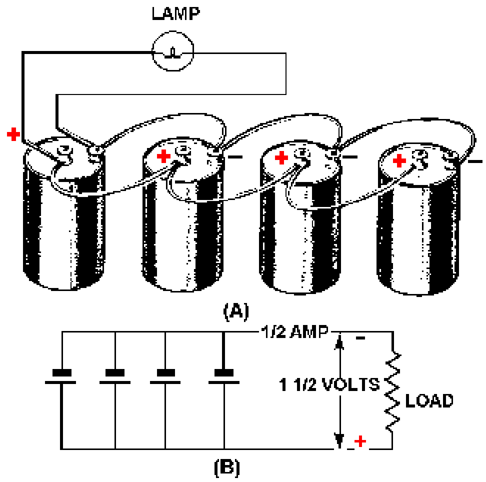
Al Penney
VO1NO

The upper diagram shows a **parallel arrangement**. The four batteries in parallel will together produce the voltage of one cell, but the current they supply will be four times that of a single cell. **Current** is the rate at which electric charge passes through a circuit, and is measured in amperes. Batteries are rated in amp-hours, or, in the case of smaller household batteries, milliamp-hours (mAH). A typical household cell rated at 500 milliamp-hours should be able to supply 500 milliamps of current to the load for one hour. You can slice and dice the milliamp-hour rating in lots of different ways. A 500 milliamp-hour battery could also produce 5 milliamps for 100 hours, 10 milliamps for 50 hours, or, theoretically, 1,000 milliamps for 30 minutes. Generally speaking, batteries with higher amp-hour ratings have greater capacities.

The lower diagram depicts a **serial arrangement**. The four batteries in series will together produce the current of one cell, but the voltage they supply will be four times that of a single cell. **Voltage** is a measure of energy per unit charge and is measured in volts. In a battery, voltage determines how strongly electrons are pushed through a circuit, much like pressure determines how strongly water is pushed through a hose. Most AAA, AA, C and D batteries are around 1.5 volts.

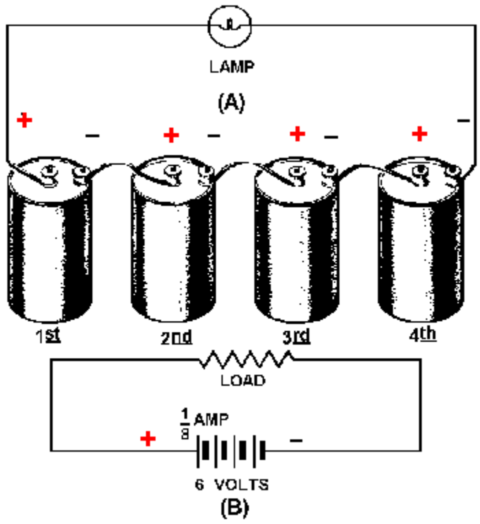
Imagine the batteries shown in the diagram are rated at 1.5 volts and 500 milliamp-hours. The four batteries in parallel arrangement will produce 1.5 volts at 2,000 milliamp-hours. The four batteries arranged in a series will produce 6 volts at 500 milliamp-hours.

Cells in Parallel

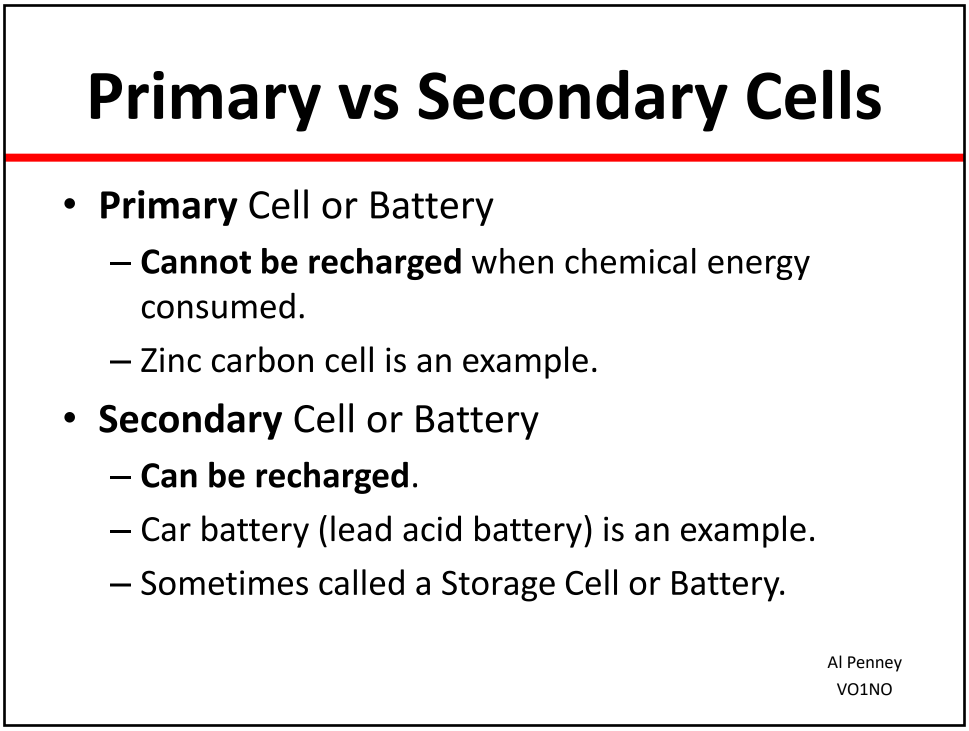


Al Penney
VO1NO

Cells in Series



Al Penney
VO1NO



Primary vs Secondary Cells

- **Primary** Cell or Battery
  - **Cannot be recharged** when chemical energy consumed.
  - Zinc carbon cell is an example.
- **Secondary** Cell or Battery
  - **Can be recharged**.
  - Car battery (lead acid battery) is an example.
  - Sometimes called a Storage Cell or Battery.

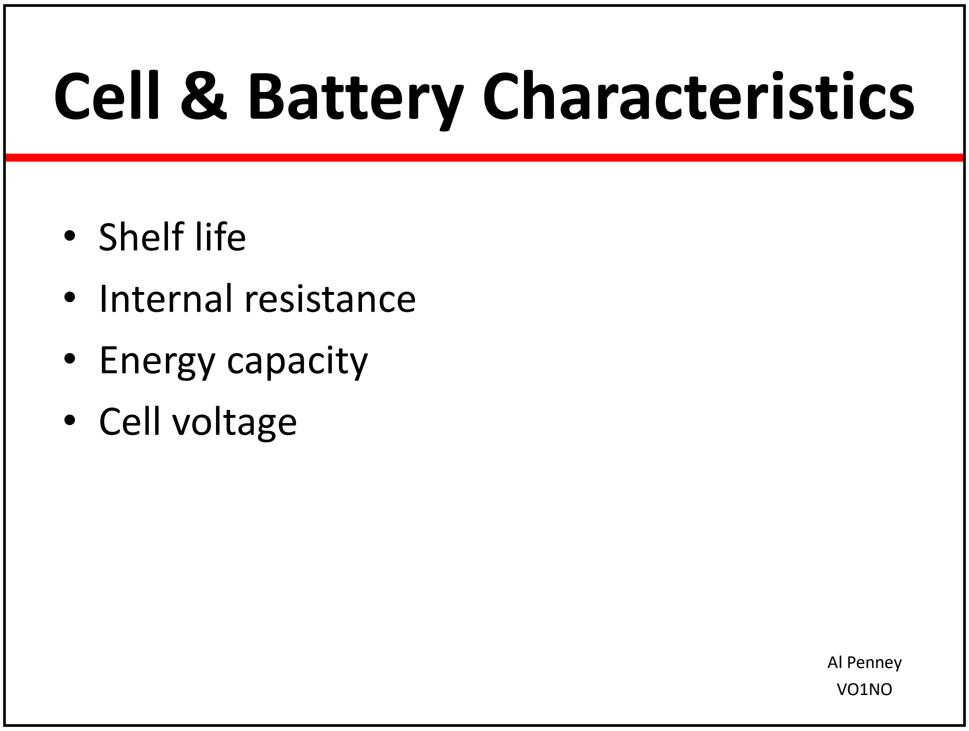
Al Penney
VO1NO

Batteries are classified into primary and secondary forms.

Primary batteries irreversibly transform chemical energy to electrical energy. When the supply of reactants is exhausted, energy cannot be readily restored to the battery.

Secondary batteries can be recharged; that is, they can have their chemical reactions reversed by supplying electrical energy to the cell, approximately restoring their original composition.

Some types of primary batteries used, for example, for telegraph circuits, were restored to operation by replacing the electrodes. Secondary batteries are not indefinitely rechargeable due to dissipation of the active materials, loss of electrolyte and internal corrosion.



Cell & Battery Characteristics

- Shelf life
- Internal resistance
- Energy capacity
- Cell voltage

Al Penney
VO1NO

Shelf Life, Self-discharge

Disposable batteries typically lose 8 to 20 percent of their original charge per year when stored at room temperature (20°–30°C).[36] This is known as the "self-discharge" rate, and is due to non-current-producing "side" chemical reactions that occur within the cell even when no load is applied. The rate of side reactions is reduced for batteries are stored at lower temperatures, although some can be damaged by freezing.

Old rechargeable batteries self-discharge more rapidly than disposable alkaline batteries, especially nickel-based batteries; a freshly charged nickel cadmium (NiCd) battery loses 10% of its charge in the first 24 hours, and thereafter discharges at a rate of about 10% a month. However, newer low self-discharge nickel metal hydride (NiMH) batteries and modern lithium designs display a lower self-discharge rate (but still higher than for primary batteries).

Internal resistance

Real batteries are made of real materials that exhibit resistance to the flow of electricity. When a load tries to draw too much current from a battery, that resistance causes the actual voltage delivered is less. Internal resistance determines the amount of current that can be delivered. Zinc carbon cells have a high internal resistance, while many rechargeable cells have a very low internal resistance. NEVER put a battery in your pocket with coins or keys – a fire can result if the battery is shorted!

Battery capacity

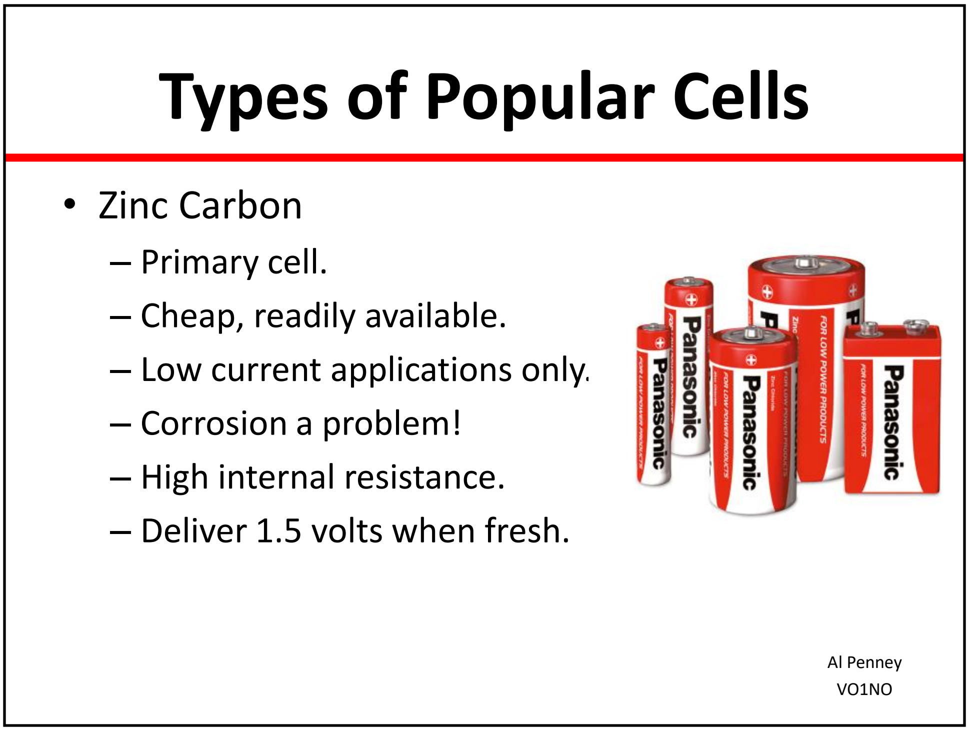
A battery's *capacity* is the amount of electric charge it can deliver at the rated voltage. The more electrode material contained in the cell the greater its capacity. A small cell has less capacity than a larger cell with the same chemistry, although they develop the same open-circuit voltage. Capacity is measured in units such as amp-hour (A·h).

The rated capacity of a battery is usually expressed as the product of 20 hours multiplied by the current that a new battery can consistently supply for 20 hours at 68 °F (20 °C), while remaining above a specified terminal voltage per cell. For example, a battery rated at 100 A·h can deliver 5 A over a 20-hour period at room temperature.

The fraction of the stored charge that a battery can deliver depends on multiple factors, including battery chemistry, the rate at which the charge is delivered (current), the required terminal voltage, the storage period, ambient temperature and other factors.

Voltage

The voltage developed across a cell's terminals depends on the energy release of the chemical reactions of its electrodes and electrolyte. Alkaline and zinc–carbon cells have different chemistries, but approximately the same emf of 1.5 volts; likewise NiCd and NiMH cells have different chemistries, but approximately the same emf of 1.2 volts. The high electrochemical potential changes in the reactions of lithium compounds give lithium cells emfs of 3 volts or more



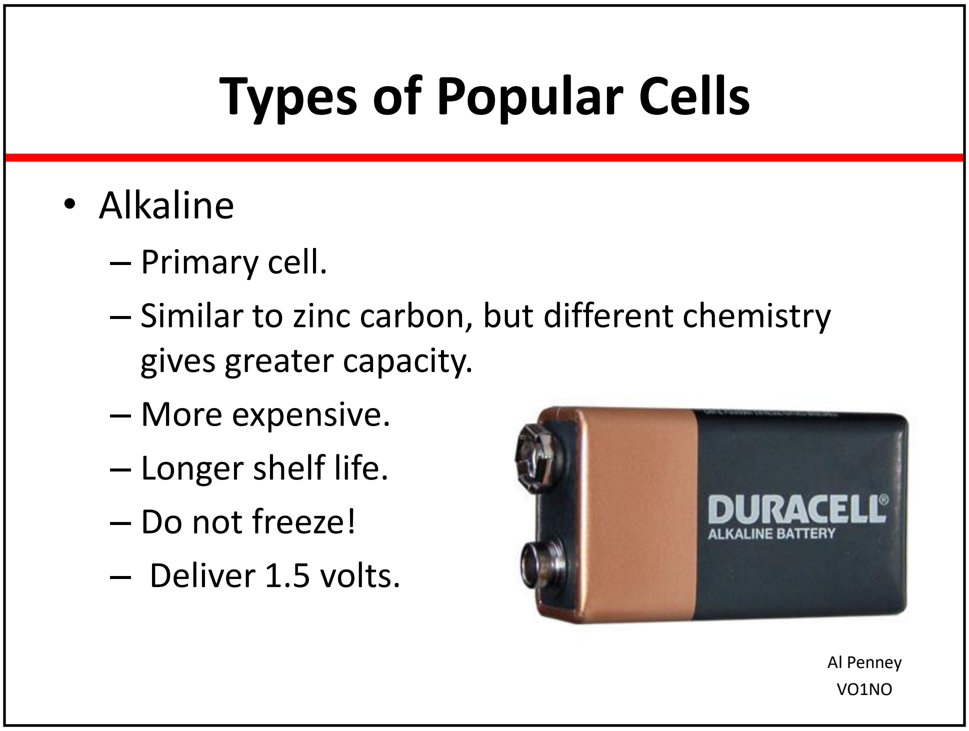
Types of Popular Cells

- Zinc Carbon
  - Primary cell.
  - Cheap, readily available.
  - Low current applications only.
  - Corrosion a problem!
  - High internal resistance.
  - Deliver 1.5 volts when fresh.

Al Penney
VO1NO

A **zinc–carbon battery** is a dry cell primary battery that delivers about 1.5 volts of direct current from the electrochemical reaction between zinc and manganese dioxide. A carbon rod collects the current from the manganese dioxide electrode, giving the name to the cell. A dry cell is usually made from zinc, which serves as the anode with a negative electrical polarity, while the inert carbon rod is the positive electrical pole cathode. General-purpose batteries may use an aqueous paste of ammonium chloride as electrolyte, possibly mixed with some zinc chloride solution. *Heavy-duty* types use a paste primarily composed of zinc chloride.

Zinc–carbon batteries were the first commercial dry batteries, developed from the technology of the wet Leclanché cell. They made flashlights and other portable devices possible, because the battery can function in any orientation. They are still useful in low drain or intermittent use devices such as remote controls, flashlights, clocks or transistor radios. Zinc–carbon dry cells are single-use primary cells.



Types of Popular Cells

- Alkaline
  - Primary cell.
  - Similar to zinc carbon, but different chemistry gives greater capacity.
  - More expensive.
  - Longer shelf life.
  - Do not freeze!
  - Deliver 1.5 volts.

Al Penney
VO1NO

An **alkaline battery** is a type of primary battery which derives its energy from the reaction between zinc metal and manganese dioxide.

Compared with zinc-carbon batteries of the Leclanché cell or zinc chloride types, alkaline batteries have a higher energy density and longer shelf life, yet provide the same voltage.

The alkaline battery gets its name because it has an alkaline electrolyte of potassium hydroxide instead of the acidic ammonium chloride or zinc chloride electrolyte of the zinc-carbon batteries. Other battery systems also use alkaline electrolytes, but they use different active materials for the electrodes.

Alkaline batteries account for 80% of manufactured batteries in the US and over 10 billion individual units produced worldwide. In Japan alkaline batteries account for 46% of all primary battery sales. In Switzerland alkaline batteries account for 68%, in the UK 60% and in the EU 47% of all battery sales including secondary types. Alkaline batteries contain zinc and manganese dioxide (Health codes 1), which can be toxic in higher concentrations. However, compared to other battery types, the toxicity of alkaline batteries is moderate.

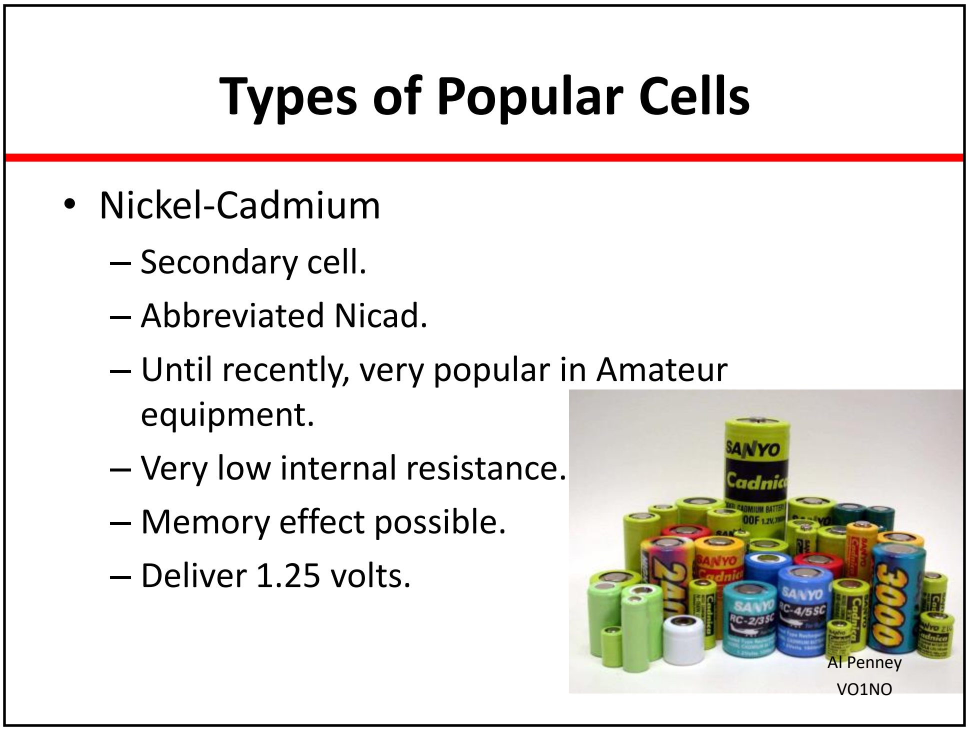
Alkaline batteries are used in many household items such as MP3 players, CD players, digital cameras, toys, lights, and radios.

Types of Popular Cells

- Mercury Cells
  - – Primary cell.
  - – Long working life.
  - – More expensive.
  - – Maintains full working voltage until end.
  - – Used as voltage references in test equipment.
  - – Deliver 1.35 volts.
  - – Now banned in some countries.

A **mercury battery** (also called **mercuric oxide battery**, **mercury cell**, **button cell**, or **Ruben-Mallory**) is a non-rechargeable electrochemical battery, a primary cell. Mercury batteries use a reaction between mercuric oxide and zinc electrodes in an alkaline electrolyte. The voltage during discharge remains practically constant at 1.35 volts, and the capacity is much greater than that of a similarly sized zinc carbon battery. Mercury batteries were used in the shape of button cells for watches, hearing aids, cameras and calculators, and in larger forms for other applications.

For a time during and after World War II, batteries made with mercury became a popular power source for portable electronic devices. Due to the content of toxic mercury and environmental concerns about its disposal, the sale of mercury batteries is now banned in many countries. Both ANSI and IEC have withdrawn their standards for mercury batteries.



Types of Popular Cells

- Nickel-Cadmium
  - Secondary cell.
  - Abbreviated Nicad.
  - Until recently, very popular in Amateur equipment.
  - Very low internal resistance.
  - Memory effect possible.
  - Deliver 1.25 volts.

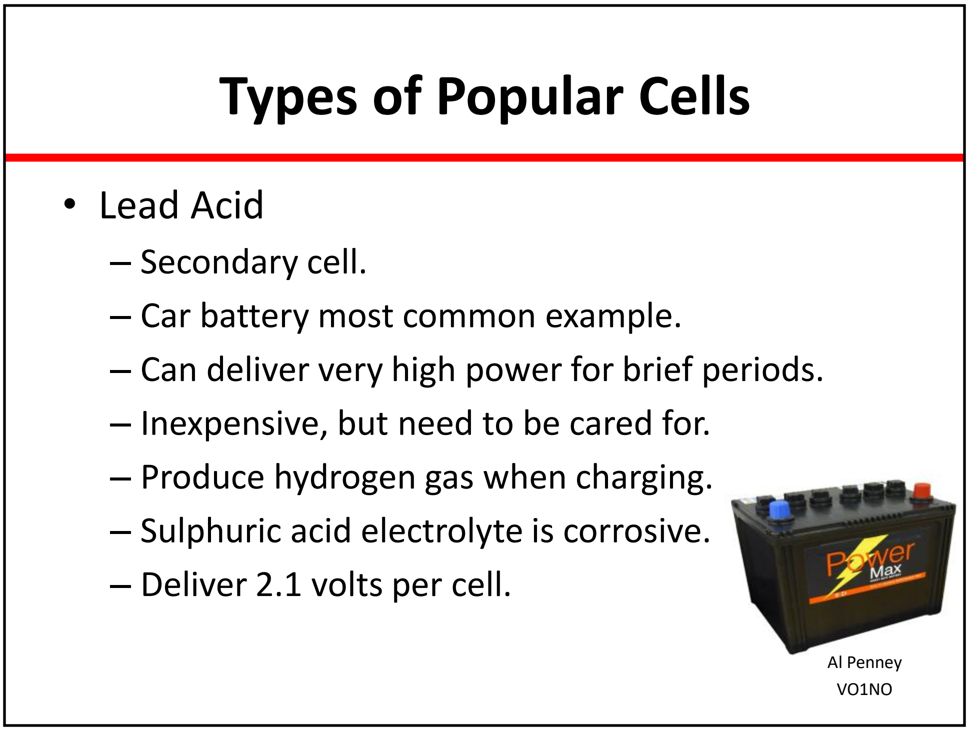
Al Penney
VO1NO

The **nickel–cadmium battery** (**NiCd battery** or **NiCad battery**) is a type of rechargeable battery using nickel oxide hydroxide and metallic cadmium as electrodes. The abbreviation *NiCd* is derived from the chemical symbols of nickel (Ni) and cadmium (Cd): the abbreviation *NiCad* is a registered trademark of SAFT Corporation, although this brand name is commonly used to describe all Ni–Cd batteries.

Wet-cell nickel-cadmium batteries were invented in 1899. Among rechargeable battery technologies, NiCd rapidly lost market share in the 1990s, to NiMH and Li-ion batteries; market share dropped by 80%. A NiCd battery has a terminal voltage during discharge of around 1.2 volts which decreases little until nearly the end of discharge. NiCd batteries are made in a wide range of sizes and capacities, from portable sealed types interchangeable with carbon-zinc dry cells, to large ventilated cells used for standby power and motive power. Compared with other types of rechargeable cells they offer good cycle life and performance at low temperatures with a fair capacity but their significant advantage is the ability to deliver practically their full rated capacity at high discharge rates (discharging in one hour or less). However, the materials are more costly than that of the lead–acid battery, and the cells have high self-discharge rates.

Sealed NiCd cells were at one time widely used in portable power tools, photography equipment, flashlights, emergency lighting, hobby R/C, and portable electronic devices. The superior capacity of the Nickel-metal hydride batteries, and more recently their lower cost, has largely supplanted their use. Further, the environmental impact of the disposal of the toxic metal cadmium has contributed considerably to the reduction in their use. Within the European Union, NiCd batteries can now only be supplied for replacement purposes or for certain types of new equipment such as medical devices.

Larger ventilated wet cell NiCd batteries are used in emergency lighting, standby power, and uninterruptible power supplies and other applications.



Types of Popular Cells

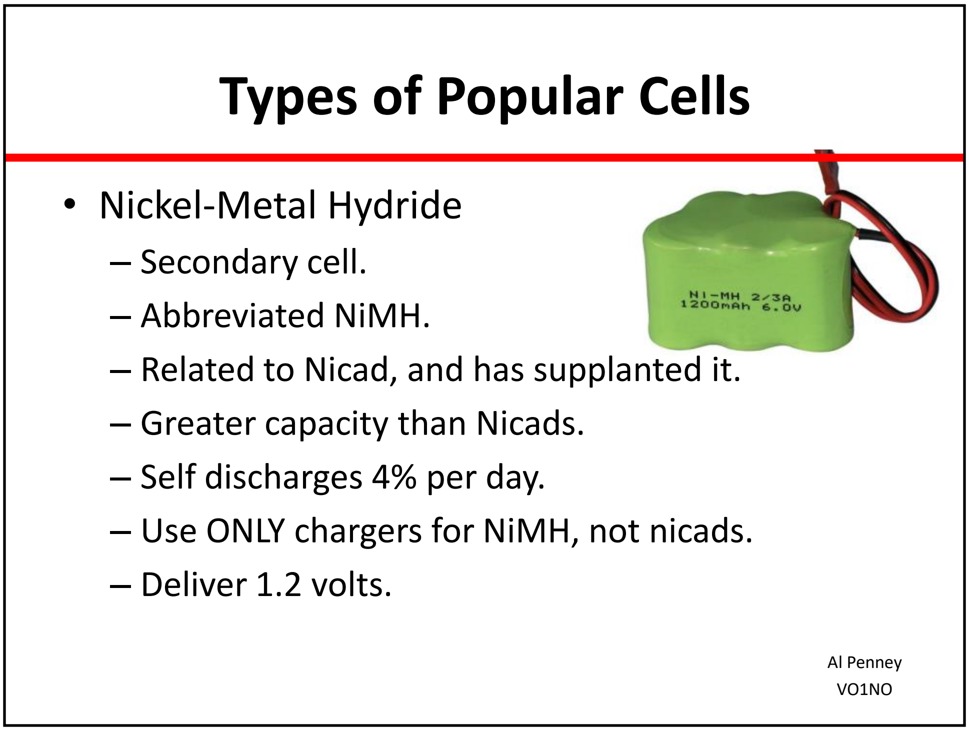
- Lead Acid
  - Secondary cell.
  - Car battery most common example.
  - Can deliver very high power for brief periods.
  - Inexpensive, but need to be cared for.
  - Produce hydrogen gas when charging.
  - Sulphuric acid electrolyte is corrosive.
  - Deliver 2.1 volts per cell.

Al Penney
VO1NO

The **lead–acid battery** was invented in 1859 by French physicist Gaston Planté and is the earliest type of rechargeable battery. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, its ability to supply high surge currents means that the cells have a relatively large power-to-weight ratio. These features, along with their low cost, make them attractive for use in motor vehicles to provide the high current required by starter motors.

As they are inexpensive compared to newer technologies, lead–acid batteries are widely used even when surge current is not important and other designs could provide higher energy densities. In 1999 lead–acid battery sales accounted for 40–45% of the value from batteries sold worldwide (excluding China and Russia), equivalent to a manufacturing market value of about $15 billion. Large-format lead–acid designs are widely used for storage in backup power supplies in cell phone towers, high-availability settings like hospitals, and stand-alone power systems. For these roles, modified versions of the standard cell may be used to improve storage times and reduce maintenance requirements. *Gel-cells* and *absorbed glass-mat* batteries are common in these roles, collectively known as VRLA (valve-regulated lead–acid) batteries.

In the charged state, the chemical energy of the battery is stored in the potential difference between the pure lead at the negative side and the PbO_2 on the positive side, plus the aqueous sulphuric acid. The electrical energy produced by a discharging lead–acid battery can be attributed to the energy released when the strong chemical bonds of water (H_2O) molecules are formed from H^+ ions of the acid and O^{2-} ions of PbO_2. Conversely, during charging the battery acts as a water–splitting device.



Types of Popular Cells

- Nickel-Metal Hydride
  - Secondary cell.
  - Abbreviated NiMH.
  - Related to Nicad, and has supplanted it.
  - Greater capacity than Nicads.
  - Self discharges 4% per day.
  - Use ONLY chargers for NiMH, not nicads.
  - Deliver 1.2 volts.

Al Penney
VO1NO

nickel metal hydride battery, abbreviated **NiMH** or **Ni–MH**, is a type of rechargeable battery. The chemical reaction at the positive electrode is similar to that of the nickel–cadmium cell (NiCd), with both using nickel oxide hydroxide (NiOOH). However, the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. A NiMH battery can have two to three times the capacity of an equivalent size NiCd, and its energy density can approach that of a lithium-ion battery.

Discharge

A fully charged cell supplies an average 1.25 V/cell during discharge, declining to about 1.0–1.1 V/cell (further discharge may cause permanent damage in the case of multi-cell packs, due to polarity reversal). Under a light load (0.5 ampere), the starting voltage of a freshly charged AA NiMH cell in good condition is about 1.4 volts.

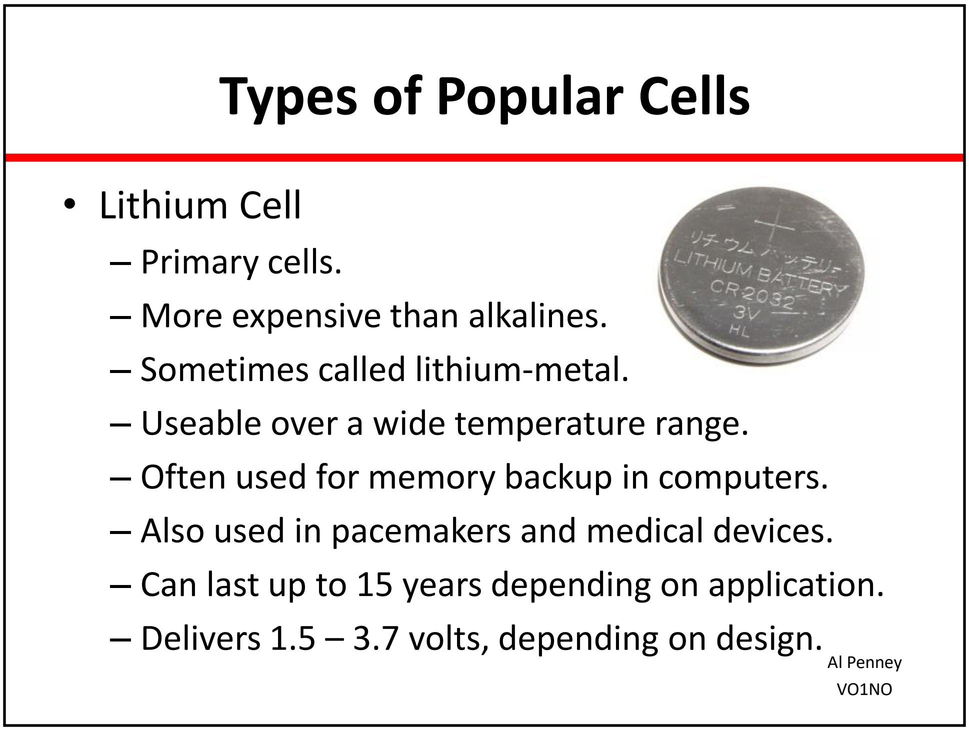
Over-discharge

Complete discharge of multi-cell packs can cause reverse polarity in one or more cells, which can permanently damage them. This situation can occur in the common arrangement of four AA cells in series in a digital camera, where one completely discharges before the others due to small differences in capacity among the cells. When this happens, the good cells start to drive the discharged cell into reverse polarity (i.e. positive anode/negative cathode). Some cameras, GPS receivers and PDAs detect the safe end-of-discharge voltage of the series cells and perform an auto-shutdown, but devices such as flashlights and some toys do not.

Irreversible damage from polarity reversal is a particular danger, even when a low voltage-threshold cutout is employed, when the cells vary in temperature. This is because capacity significantly declines as the cells are cooled. This results in a lower voltage under load of the colder cells.

Self-discharge

Historically, NiMH cells have had a somewhat higher self-discharge rate (equivalent to internal leakage) than NiCd cells. The self-discharge rate varies greatly with temperature, where lower storage temperature leads to slower discharge and longer battery life. The self-discharge is 5–20% on the first day and stabilizes around 0.5–4% per day at room temperature. But at 45 °C it is approximately three times as high.



Types of Popular Cells

- Lithium Cell
  - Primary cells.
  - More expensive than alkalines.
  - Sometimes called lithium-metal.
  - Useable over a wide temperature range.
  - Often used for memory backup in computers.
  - Also used in pacemakers and medical devices.
  - Can last up to 15 years depending on application.
  - Delivers 1.5 – 3.7 volts, depending on design.

Al Penney
VO1NO

Lithium batteries are primary batteries that have metallic lithium as an anode. These types of batteries are also referred to as lithium-metal batteries.

They stand apart from other batteries in their high charge density (long life) and high cost per unit. Depending on the design and chemical compounds used, lithium cells can produce voltages from 1.5 V (comparable to a zinc–carbon or alkaline battery) to about 3.7 V.

Disposable primary lithium batteries must be distinguished from secondary lithium-ion or a lithium-polymer, which are rechargeable batteries. Lithium is especially useful, because its ions can be arranged to move between the anode and the cathode, using an intercalated lithium compound as the cathode material but without using lithium metal as the anode material. Pure lithium will instantly react with water, or even moisture in the air; the lithium in lithium ion batteries is in a less reactive compound.

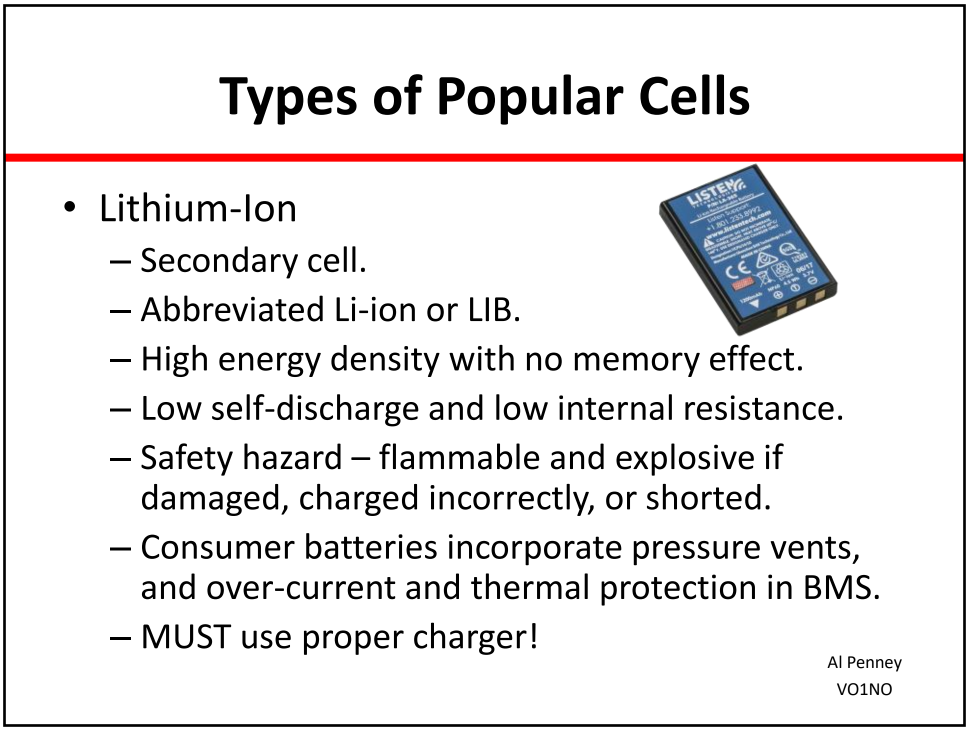
Lithium batteries are widely used in portable consumer electronic devices, and in electric vehicles ranging from full sized vehicles to radio controlled toys. The term "lithium battery" refers to a family of different lithium-metal chemistries, comprising many types of cathodes and electrolytes but all with metallic lithium as the anode. The battery requires from 0.15 to 0.3 kg of lithium per kWh. As designed these primary systems use a charged cathode, that being an electro-active material with crystallographic vacancies that are filled gradually during discharge.

The most common type of lithium cell used in consumer applications uses metallic lithium as anode and manganese dioxide as cathode, with a salt of lithium dissolved in an organic solvent.

Lithium batteries find application in many long-life, critical devices, such as pacemakers and other implantable electronic medical devices. These devices use specialized lithium-iodide batteries designed to last 15 or more years. But for other, less critical applications such as in toys, the lithium battery may actually outlast the device. In such cases, an expensive lithium battery may not be cost-effective.

Lithium batteries can be used in place of ordinary alkaline cells in many devices, such as clocks and cameras. Although they are more costly, lithium cells will provide much longer life, thereby minimizing battery replacement. However, attention must be given to the higher voltage developed by the lithium cells before using them as a drop-in replacement in devices that normally use ordinary zinc cells.

Lithium batteries also prove valuable in oceanographic applications. While lithium battery packs are considerably more expensive than standard oceanographic packs, they hold up to three times the capacity of alkaline packs. The high cost of servicing remote oceanographic instrumentation (usually by ships) often justifies this higher cost.



Types of Popular Cells

- Lithium-Ion
  - Secondary cell.
  - Abbreviated Li-ion or LIB.
  - High energy density with no memory effect.
  - Low self-discharge and low internal resistance.
  - Safety hazard – flammable and explosive if damaged, charged incorrectly, or shorted.
  - Consumer batteries incorporate pressure vents, and over-current and thermal protection in BMS.
  - MUST use proper charger!

Al Penney
VO1NO

A **lithium-ion battery** or **Li-ion battery** (abbreviated as **LIB**) is a type of rechargeable battery. Lithium-ion batteries are commonly used for portable electronics and electric vehicles and are growing in popularity for military and aerospace applications.

In the batteries, lithium ions move from the negative electrode through an electrolyte to the positive electrode during discharge, and back when charging. Li-ion batteries use an intercalated lithium compound as the material at the positive electrode and typically graphite at the negative electrode. The batteries have a high energy density, no memory effect (other than LFP cells)[1] and low self-discharge. They can however be a safety hazard since they contain a flammable electrolyte, and if damaged or incorrectly charged can lead to explosions and fires. Samsung was forced to recall Galaxy Note 7 handsets following lithium-ion fires, and there have been several incidents involving batteries on Boeing 787s.

Chemistry, performance, cost and safety characteristics vary across LIB types.

Safety issues and regulation

The computer industry's drive to increase battery capacity can test the limits of sensitive components such as the membrane separator, a polyethylene or polypropylene film that is only 20–25 µm thick. The energy density of lithium batteries has more than doubled since they were introduced in 1991. When the battery is made to contain more material, the separator can undergo stress.

Rapid-discharge problems

Lithium batteries can provide extremely high currents and can discharge very rapidly when short-circuited. Although this is useful in applications where high currents are required, a too-rapid discharge of a lithium battery - especially if cobalt is present in the cells' design - can result in overheating of the battery (that lowers the electrical resistance of any cobalt content within the cell), rupture, and even an explosion. Lithium-thionyl chloride batteries are particularly susceptible to this type of discharge. Consumer batteries usually incorporate overcurrent or thermal protection or vents to prevent an explosion as a part of battery management system.

Air travel

From January 1, 2013, much stricter regulations were introduced by IATA regarding the carriage of lithium batteries by air. They were adopted by the International Postal Union; however, some countries, e.g. the UK, have decided that they will not accept lithium batteries unless they are included with the equipment they power.

Because of the above risks, shipping and carriage of lithium batteries is restricted in some situations, particularly transport of lithium batteries by air.

Methamphetamine labs

Unused lithium batteries provide a convenient source of lithium metal for use as a reducing agent in methamphetamine labs. Some jurisdictions have passed laws to restrict lithium battery sales or asked businesses to make voluntary restrictions in an attempt to help curb the creation of illegal meth labs. In 2004 Wal-Mart stores were reported to limit the sale of disposable lithium batteries to three packages in Missouri and four packages in other states.

Health issues on ingestion

Button cell batteries are attractive to small children and often ingested. In the past 20 years, although there has not been an increase in the total number of button cell batteries ingested in a year, researchers have noted a 6.7-fold increase in the risk that an ingestion would result in a moderate or major complication and 12.5-fold increase in fatalities comparing the last decade to the previous one. The primary mechanism of injury with button battery ingestions is the generation of hydroxide ions, which cause severe chemical burns, at the anode.[42] This is an electrochemical effect of the intact battery, and does not require the casing to be breached or the contents released

Consumer-grade lithium-ion batteries should not be charged at temperatures below 0 °C (32 °F). Although a battery pack[128] may appear to be charging normally, electroplating of metallic lithium can occur at the negative electrode during a subfreezing charge, and may not be removable even by repeated cycling. Most devices equipped with Li-ion batteries do not allow charging outside of 0–45 °C for safety reasons, except for mobile phones that may allow some degree of charging when they detect an emergency call in progress.[

- Class B fire, NOT Class D.
- Class B is flammable liquid.
- Use Class ABC, BC or CO2 type fire extinguishers.

Lithium Ion Battery Fires

How to extinguish a lithium-ion battery fire

Despite their name, lithium-ion batteries used in consumer products do not contain any actual lithium metal (lithium is combined with other elements). Therefore, **a Class D fire extinguisher is not to be used** to fight a lithium-ion battery fire. Class D fire extinguishers, which contain dry powder, are intended for combustible metal fires only. Since lithium-ion batteries aren't made with metallic lithium, a Class D dry powder extinguisher would not be effective.

So, what kind of fire extinguisher *should* you use in this scenario? **Lithium-ion batteries are considered a Class B fire**, so a standard ABC or BC dry chemical fire extinguisher should be used. Class B is the classification given to flammable liquids. Lithium-ion batteries contain liquid electrolytes that provide a conductive pathway, so the batteries receive a B fire classification.

Once a fire has started, the race is on to put it out. Lithium ion battery fires are even more dangerous than fires from older batteries because they release a flammable vapor that is toxic and which essentially produces its own fuel.

Strategies for putting out a lithium ion battery fire vary depending on the fire's location and size. However, as a general rule, special fire suppressants are required for the fire to be fully and safely extinguished.

But first, here are four things you should know about lithium ion batteries:

1. Lithium ion batteries are a Class B flammable liquid and require dry chemical extinguishers to put out.
2. It is vital to implement the appropriate preventative measure to avoid a chemical reaction that could start a fire.
3. Facilities that store or transport lithium batteries should be outfitted with a fire suppression system or have protocols in place to extinguish fires quickly.
4. During shipping, especially via plane or ship, lithium batteries need protective packaging and the correct HAZMAT labels.

Basics of Lithium-Ion Battery Fires

Lithium ion battery fires usually occur after a battery has been damaged. Damage to a battery can cause a rupture in the membrane that separates the chemicals inside, causing a reaction that sparks a dangerous and self-perpetuating fire. Although these fires were poorly understood at first, analyses show a thermal runaway causes fire and explosion of the lithium ion batteries.

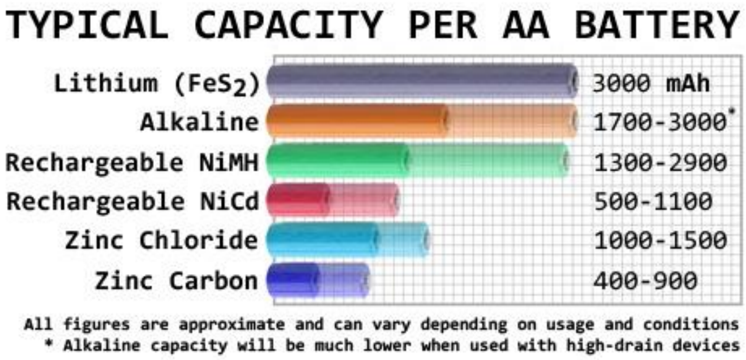
In any environment, small lithium ion fires can be put out with special fire extinguishers. Contrary to popular belief, Class D fire extinguishers are ineffective on lithium ion fires. Although they are labeled for use on metal fires, lithium ion batteries are a special case because they do not contain any actual lithium metal. The dry powder in Class D fire extinguishers will not slow a lithium ion chemical reaction.

Lithium ion battery fires are considered a Class B flammable liquid fire. A type ABC or BC fire extinguisher is effective against this type of blaze. These fire extinguishers interrupt the chemical reaction in the lithium ion battery, eventually stopping the fire.

Fire extinguishers designed to combat Class B fires are available in a few different formats. The best one is the dry chemical type because the extinguisher can launch the dry powder up to 20 feet horizontally. Carbon dioxide (CO2) and foam fire retardants are also effective, but their range is around half that of dry chemical extinguishers. Clean agent extinguishers are better for the environment and are less harmful to humans, so they are a better choice for close quarters like airplanes.

Surprisingly, water can be somewhat effective in dampening lithium ion fires, in part because it reduces the heat. However, chemical fire retardants are more effective, and any industrial or transportation setting that regularly has lithium ion batteries present should invest in more substantial fire prevention systems and protocols.

Battery Capacity Comparison


TYPICAL CAPACITY PER AA BATTERY

All figures are approximate and can vary depending on usage and conditions
* Alkaline capacity will be much lower when used with high-drain devices

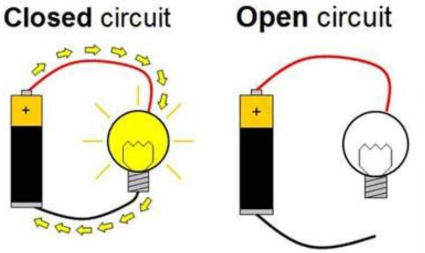
Battery Disposal

- Batteries contain toxic materials.
- Dispose of old batteries in an approved manner!

Al Penney
VO1NO

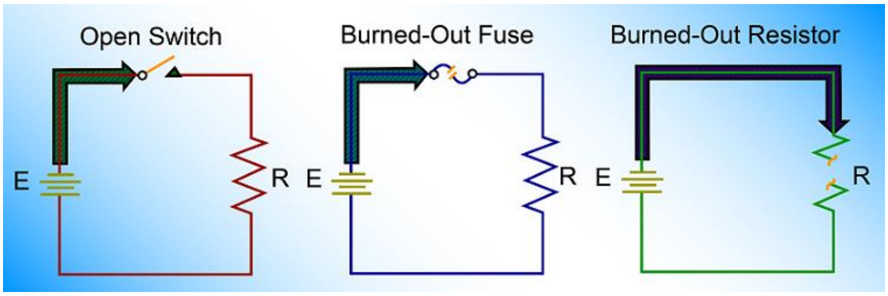
Closed and Open Circuits

- **Closed Circuit**: Circuit is complete and current will flow when voltage is applied.
- **Open Circuit**: Circuit does not provide a path for current to flow. Could be deliberate (switch) or accidental (broken wire).



Al Penney
VO1NO

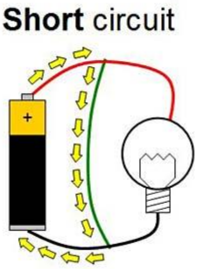
Open Circuit



Al Penney
VO1NO

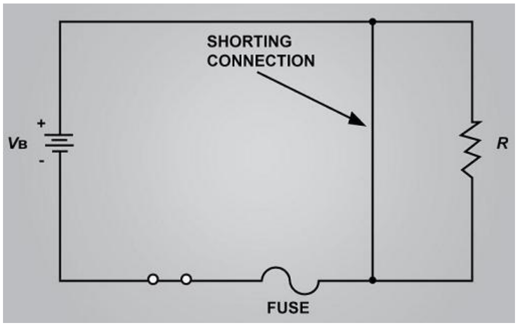
Short Circuit

- **Abnormal** connection of relatively low resistance between two points in a circuit.



Al Penney
VO1NO

Fuses



Al Penney
VO1NO

In electronics and electrical engineering, a **fuse** is an electrical safety device that operates to provide overcurrent protection of an electrical circuit. Its essential component is a metal wire or strip that melts when too much current flows through it, thereby stopping or interrupting the current. It is a sacrificial device; once a fuse has operated it is an open circuit, it must be replaced or rewired, depending on type.

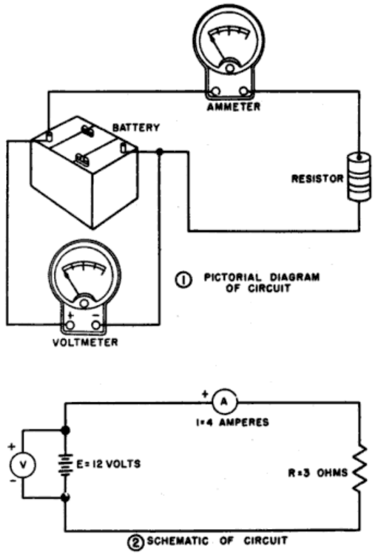
Fuses have been used as essential safety devices from the early days of electrical engineering. Today there are thousands of different fuse designs which have specific current and voltage ratings, breaking capacity and response times, depending on the application. The time and current operating characteristics of fuses are chosen to provide adequate protection without needless interruption. Wiring regulations usually define a maximum fuse current rating for particular circuits. Short circuits, overloading, mismatched loads, or device failure are the prime or some of the reasons for fuse operation.

A fuse is an automatic means of removing power from a faulty system; often abbreviated to ADS (Automatic Disconnection of Supply). Circuit breakers can be used as an alternative to fuses, but have significantly different characteristics.

A fuse consists of a metal strip or wire fuse element, of small cross-section compared to the circuit conductors, mounted between a pair of electrical terminals, and (usually) enclosed by a non-combustible housing. The fuse is arranged in series to carry all the current passing through the protected circuit. The resistance of the element generates heat due to the current flow. The size and construction of the element is (empirically) determined so that the heat produced for a normal current does not cause the element to attain a high temperature. If too high a current flows, the element rises to a higher temperature and either directly melts, or else melts a soldered joint within the fuse, opening the circuit.

Never replace a blown fuse with one rated for a higher current. Always investigate a blown fuse to determine why it blew.

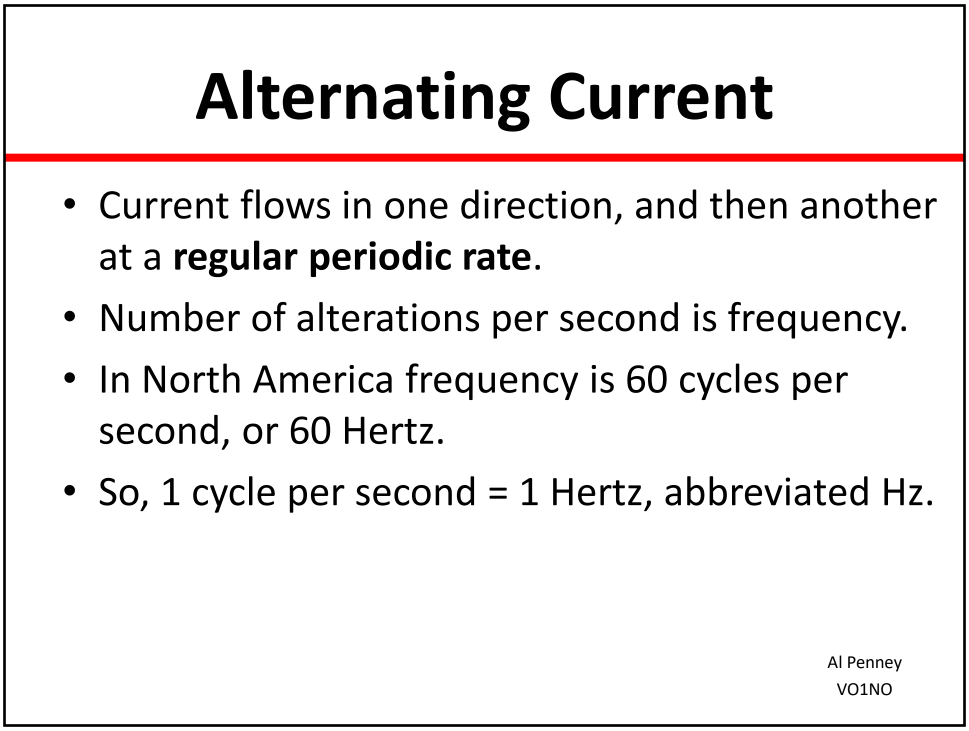
Schematic Diagrams



① PICTORIAL DIAGRAM OF CIRCUIT

② SCHEMATIC OF CIRCUIT

Al Penney
VO1NO



Alternating Current

- Current flows in one direction, and then another at a **regular periodic rate**.
- Number of alterations per second is frequency.
- In North America frequency is 60 cycles per second, or 60 Hertz.
- So, 1 cycle per second = 1 Hertz, abbreviated Hz.

Al Penney
VO1NO

Alternating current (**AC**) is an electric current which periodically reverses direction, in contrast to direct current (DC) which flows only in one direction. Alternating current is the form in which electric power is delivered to businesses and residences, and it is the form of electrical energy that consumers typically use when they plug kitchen appliances, televisions, fans and electric lamps into a wall socket. A common source of DC power is a battery cell in a flashlight. The abbreviations *AC* and *DC* are often used to mean simply *alternating* and *direct*, as when they modify *current* or *voltage.*

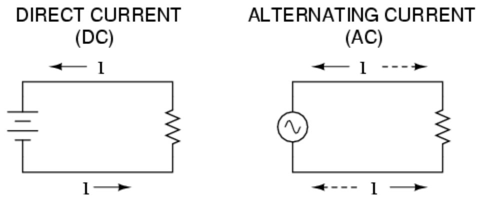
The usual waveform of alternating current in most electric power circuits is a sine wave, whose positive half-period corresponds with positive direction of the current and vice versa.

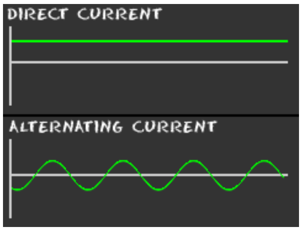
AC power supply frequencies

The frequency of the electrical system varies by country and sometimes within a country; most electric power is generated at either 50 or 60 Hertz. Some countries have a mixture of 50 Hz and 60 Hz supplies, notably electricity power transmission in Japan. A low frequency eases the design of electric motors, particularly for hoisting, crushing and rolling applications, and commutator-type traction motors for applications such as railways. However, low frequency also causes noticeable flicker in arc lamps and incandescent light bulbs. The use of lower frequencies also provided the advantage of lower impedance losses, which are proportional to frequency. The original Niagara Falls generators were built to produce 25 Hz power, as a compromise between low frequency for traction and heavy induction motors, while still allowing incandescent lighting to operate (although with noticeable flicker). Most of the 25 Hz residential and commercial customers for Niagara Falls power were converted to 60 Hz by the late 1950s, although some 25 Hz industrial customers still existed as of the start of the 21st century. 16.7 Hz power (formerly 16 2/3 Hz) is still used in some European rail systems, such as in Austria, Germany, Norway, Sweden and Switzerland. Off-shore, military, textile industry, marine, aircraft, and spacecraft applications sometimes use 400 Hz, for benefits of reduced weight of apparatus or higher motor speeds. Computer mainframe systems were often powered by 400 Hz or 415 Hz for benefits of ripple reduction while using smaller internal AC to DC conversion units. In any case, the input to the M-G set is the local customary voltage and frequency, variously 200 V (Japan), 208 V, 240 V (North America), 380 V, 400 V or 415 V (Europe), and variously 50 Hz or 60 Hz.

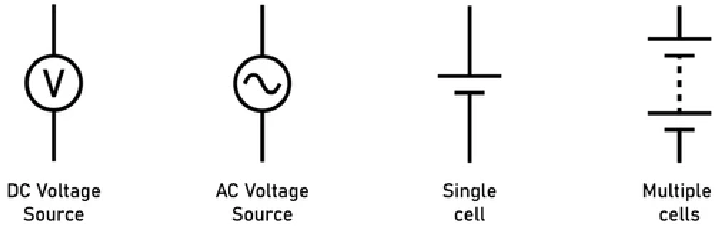
Direct vs Alternating Current

- Direct Current (DC) – flows in one direction only.
- Alternating Current (AC) – flows in one direction, then the other, in a regular sequence.



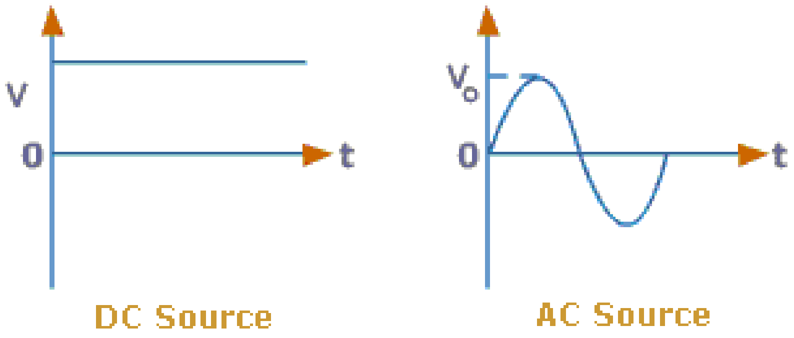


Symbology



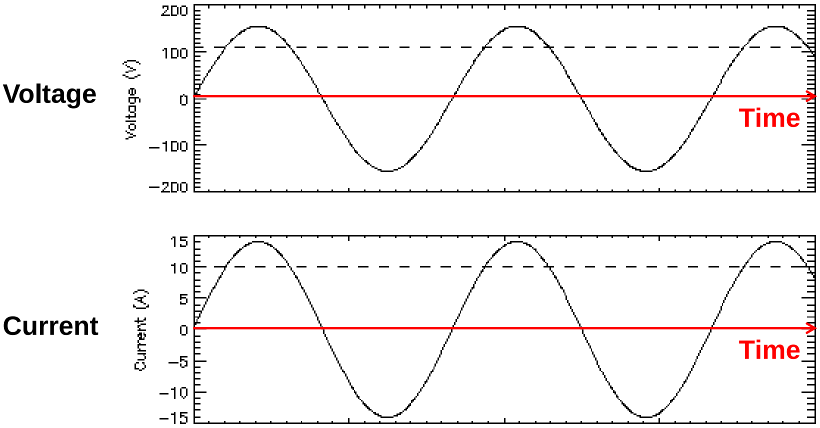
Al Penney
VO1NO

Direct vs Alternating Current



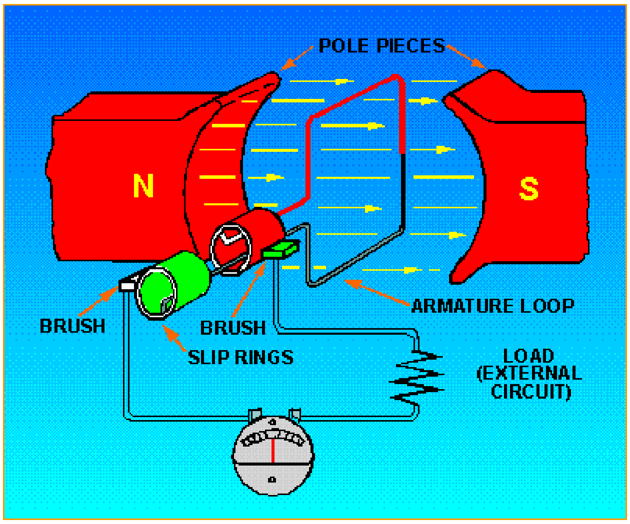
Al Penney
VO1NO

AC Voltage and Current

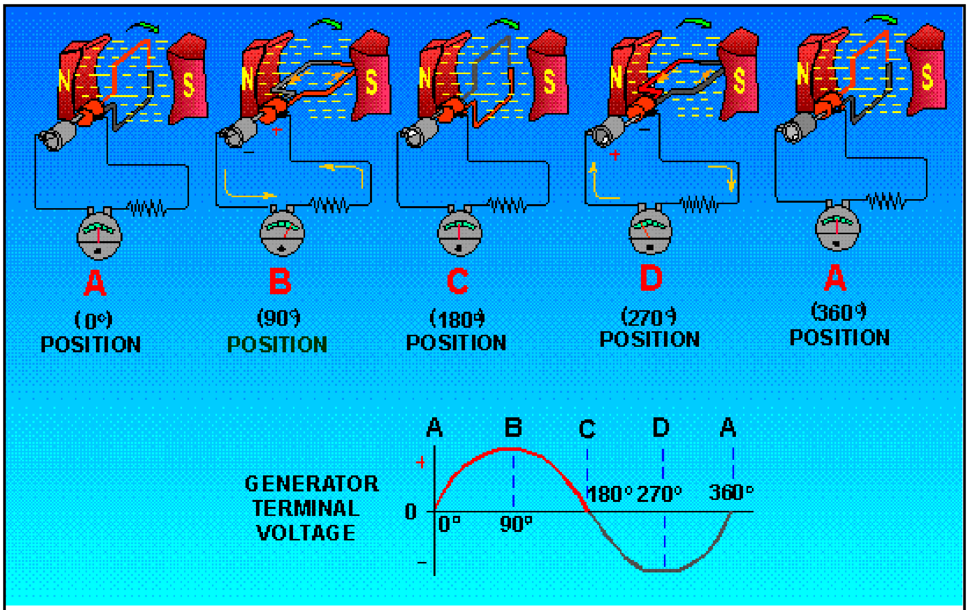


Al Penney
VO1NO

Elementary Generator



Al Penney
VO1NO



Al Penney
VO1NO

The elementary generator produces a voltage in the following manner. The armature loop is rotated in a clockwise direction. The initial or starting point is shown at position A. (This will be considered the zero-degree position.)

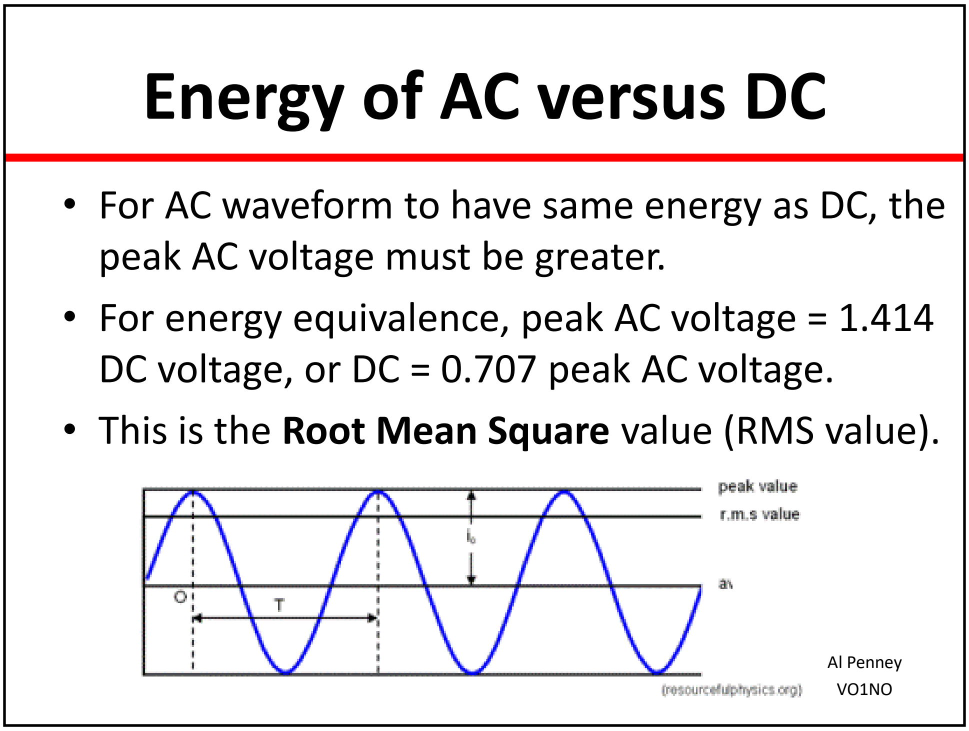
At 0º the armature loop is perpendicular to the magnetic field. The black and white conductors of the loop are moving parallel to the field. The instant the conductors are moving parallel to the magnetic field, they do not cut any lines of flux. Therefore, no emf is induced in the conductors, and the meter at position A indicates zero. This position is called the NEUTRAL PLANE.

As the armature loop rotates from position A (0º) to position B (90º), the conductors cut through more and more lines of flux, at a continually increasing angle. At 90º they are cutting through a maximum number of lines of flux and at maximum angle. The result is that between 0º and 90º , the induced emf in the conductors builds up from zero to a maximum value. Observe that from 0º to 90º , the black conductor cuts DOWN through the field. At the same time the white conductor cuts UP through the field. The induced emfs in the conductors are series-adding. This means the resultant voltage across the brushes (the terminal voltage) is the sum of the two induced voltages. The meter at position B reads maximum value.

As the armature loop continues rotating from 90º (position B) to 180º (position C), the conductors which were cutting through a maximum number of lines of flux at position B now cut through fewer lines. They are again moving parallel to the magnetic field at position C. They no longer cut through any lines of flux. As the armature rotates from 90º to 180º , the induced voltage will decrease to zero in the same manner that it increased during the rotation from 0º to 90º . The meter again reads zero.

From 0º to 180º the conductors of the armature loop have been moving in the same direction through the magnetic field. Therefore, the polarity of the induced voltage has remained the same. This is shown by points A through C on the graph. As the loop rotates beyond 180º (position C), through 270º (position D), and back to the initial or starting point (position A), the direction of the cutting action of the conductors through the magnetic field reverses. Now the black conductor cuts UP through the field while the white conductor cuts DOWN through the field. As a result, the polarity of the induced voltage reverses.

Following the sequence shown by graph points C, D, and back to A, the voltage will be in the direction opposite to that 1-4 shown from points A, B, and C. The terminal voltage will be the same as it was from A to C except that the polarity is reversed (as shown by the meter deflection at position D). The voltage output waveform for the complete revolution of the loop is shown on the graph in the figure.



Energy of AC versus DC

- For AC waveform to have same energy as DC, the peak AC voltage must be greater.
- For energy equivalence, peak AC voltage = 1.414 DC voltage, or DC = 0.707 peak AC voltage.
- This is the **Root Mean Square** value (RMS value).

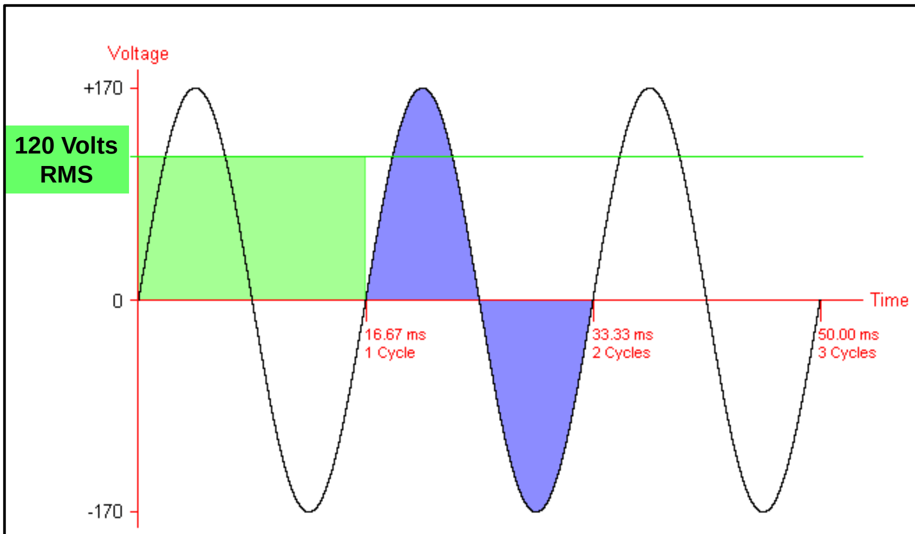
(resourcefulphysics.org)

Al Penney
VO1NO

The qualifier “RMS” stands for *Root Mean Square*, the algorithm used to obtain the DC equivalent value from points on a graph (essentially, the procedure consists of squaring all the positive and negative points on a waveform graph, averaging those squared values, then taking the square root of that average to obtain the final answer).

Sometimes the alternative terms *equivalent* or *DC equivalent* are used instead of “RMS,” but the quantity and principle are both the same.

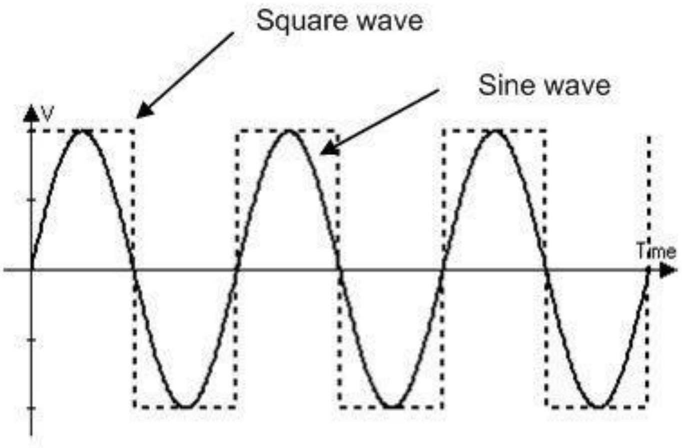
RMS amplitude measurement is the best way to relate AC quantities to DC quantities, or other AC quantities of differing waveform shapes, when dealing with measurements of electric power.



RMS Voltage = 0.707 x Peak AC voltage
= 0.707 x 170 volts
= 120 volts

Al Penney
VO1NO

Sine Wave vs Square Wave



Al Penney
VO1NO

Questions?

Al Penney
VO1NO

Review Question 1

How do you find a resistor's tolerance rating?

- By reading its Baudot code
- By using a voltmeter
- By reading the resistor's colour code
- By using Thevenin's theorem for resistors

Al Penney
VO1NO

Review Question 1

How do you find a resistor’s tolerance rating?

- By reading its Baudot code
- By using a voltmeter
- By reading the resistor’s colour code
- By using Thevenin’s theorem for resistors

< By reading the resistor’s colour code >

Al Penney
VO1NO

Review Question 2

Which colour band would differentiate a 120-ohm from a 1200-ohm resistor?

- Third band
- First band
- Second band
- Fourth band

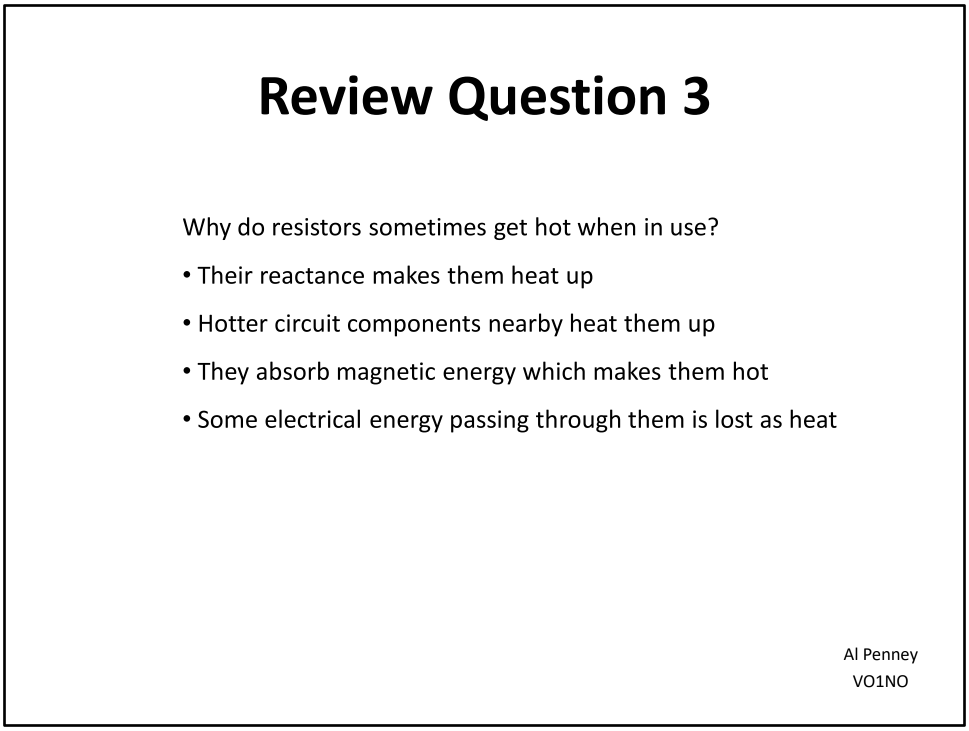
Review Question 2

Which colour band would differentiate a 120-ohm from a 1200-ohm resistor?

- Third band
- First band
- Second band
- Fourth band

< Third band >

Al Penney
VO1NO



Review Question 3

Why do resistors sometimes get hot when in use?

- Their reactance makes them heat up
- Hotter circuit components nearby heat them up
- They absorb magnetic energy which makes them hot
- Some electrical energy passing through them is lost as heat

Al Penney
VO1NO

Review Question 3

Why do resistors sometimes get hot when in use?

- Their reactance makes them heat up
- Hotter circuit components nearby heat them up
- They absorb magnetic energy which makes them hot
- Some electrical energy passing through them is lost as heat

< Some electrical energy passing through them is lost as heat >

Al Penney
VO1NO

Review Question 4

The letter “R” is the symbol for:

- reactance
- resistance
- impedance
- reluctance

Al Penney
VO1NO

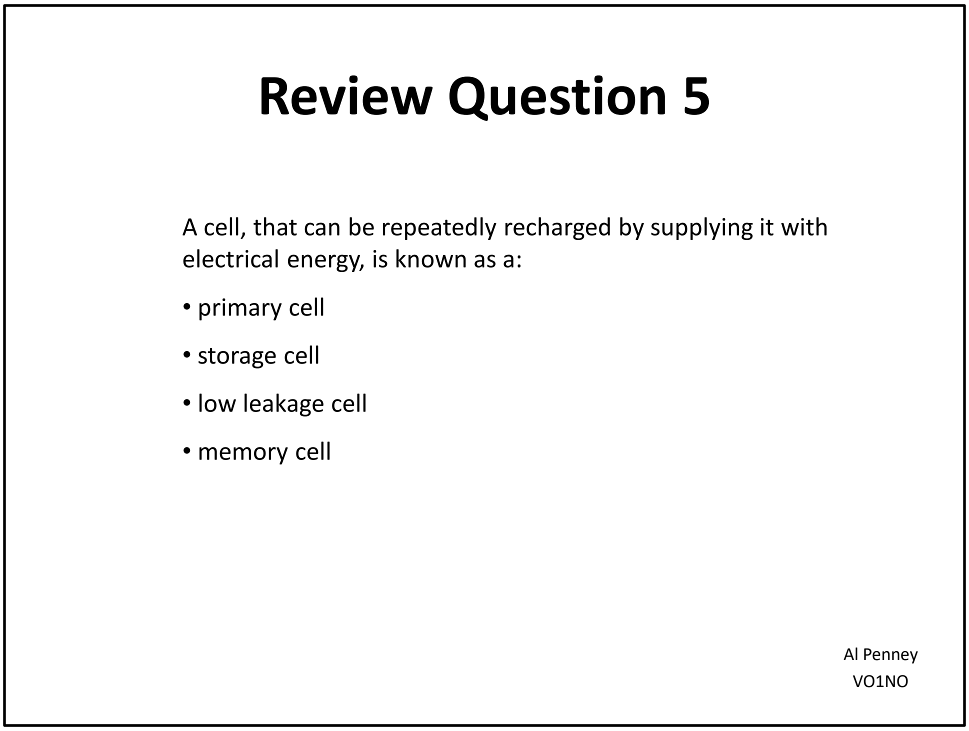
Review Question 4

The letter “R” is the symbol for:

- reactance
- resistance
- impedance
- reluctance

< resistance >

Al Penney
VO1NO



Review Question 5

A cell, that can be repeatedly recharged by supplying it with electrical energy, is known as a:

- primary cell
- storage cell
- low leakage cell
- memory cell

Al Penney
VO1NO

Review Question 5

A cell, that can be repeatedly recharged by supplying it with electrical energy, is known as a:

- primary cell
- storage cell
- low leakage cell
- memory cell

< storage cell >

Al Penney
VO1NO

Review Question 6

An alkaline cell has a nominal voltage of 1.5 volts. When supplying a great deal of current, the voltage may drop to 1.2 volts. This is due to the cell’s:

- voltage capacity
- internal resistance
- electrolyte becoming dry
- current capacity

Al Penney
VO1NO

Review Question 6

An alkaline cell has a nominal voltage of 1.5 volts. When supplying a great deal of current, the voltage may drop to 1.2 volts. This is due to the cell’s:

- voltage capacity
- internal resistance
- electrolyte becoming dry
- current capacity

< internal resistance >

Al Penney
VO1NO

Review Question 7

To increase the current capacity of a cell, several cells should be connected in:

- parallel
- series
- parallel resonant
- series resonant

Al Penney
VO1NO

Review Question 7

To increase the current capacity of a cell, several cells should be connected in:

- parallel
- series
- parallel resonant
- series resonant

< parallel >

Al Penney
VO1NO

Review Question 8

Battery capacity is commonly stated as a value of current delivered over a specified period of time. What is the effect of exceeding that specified current?

- The battery will accept the subsequent charge in a shorter time
- The voltage delivered will be higher
- A battery charge will not last as long
- The internal resistance of the cell is short-circuited

Al Penney
VO1NO

Review Question 8

Battery capacity is commonly stated as a value of current delivered over a specified period of time. What is the effect of exceeding that specified current?

- The battery will accept the subsequent charge in a shorter time
- The voltage delivered will be higher
- A battery charge will not last as long
- The internal resistance of the cell is short-circuited

< A battery charge will not last as long >

Al Penney
VO1NO

Review Question 9

Which of the following is a source of electromotive force (EMF)?

- germanium diode
- P channel FET
- carbon resistor
- lithium-ion battery

Al Penney
VO1NO

Review Question 9

Which of the following is a source of electromotive force (EMF)?

- germanium diode
- P channel FET
- carbon resistor
- lithium-ion battery

< lithium-ion battery >

Review Question 10

To increase the voltage output, several cells are connected in:

- parallel
- series-parallel
- resonance
- series

Al Penney
VO1NO

Review Question 10

To increase the voltage output, several cells are connected in:

- parallel
- series-parallel
- resonance
- series

< series >

Al Penney
VO1NO

Review Question 11

A lithium-ion battery should never be:

- short-circuited
- recharged
- left disconnected
- left overnight at room temperature

Al Penney
VO1NO

Review Question 11

A lithium-ion battery should never be:

- short-circuited
- recharged
- left disconnected
- left overnight at room temperature

< short-circuited >

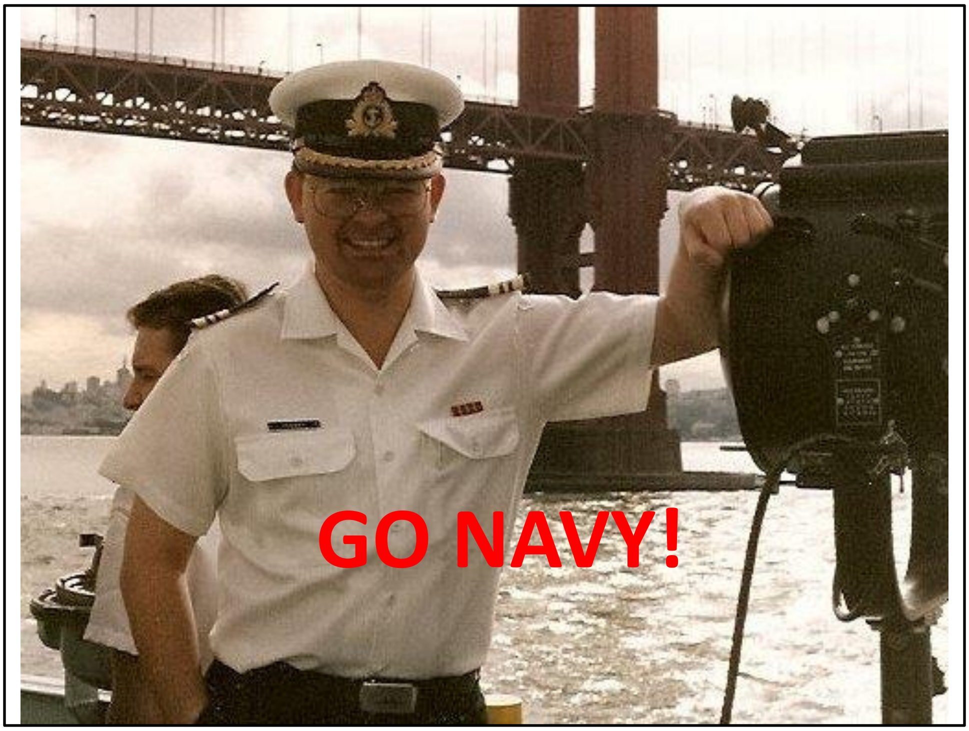
Al Penney
VO1NO

Questions?

Al Penney
VO1NO

For Next Class:

- Review Chapter 2 of Basic Study Guide;
- Read Chapter 3 of Basic Study Guide; and
- Read Radiocommunications Information Circular (RIC-3):
  - https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01008.html


GO NAVY!

Bon Portage 2019

Bon Portage 2019

Questions?

Al Penney
VO1NO