AQA AS Physics Revision Guide

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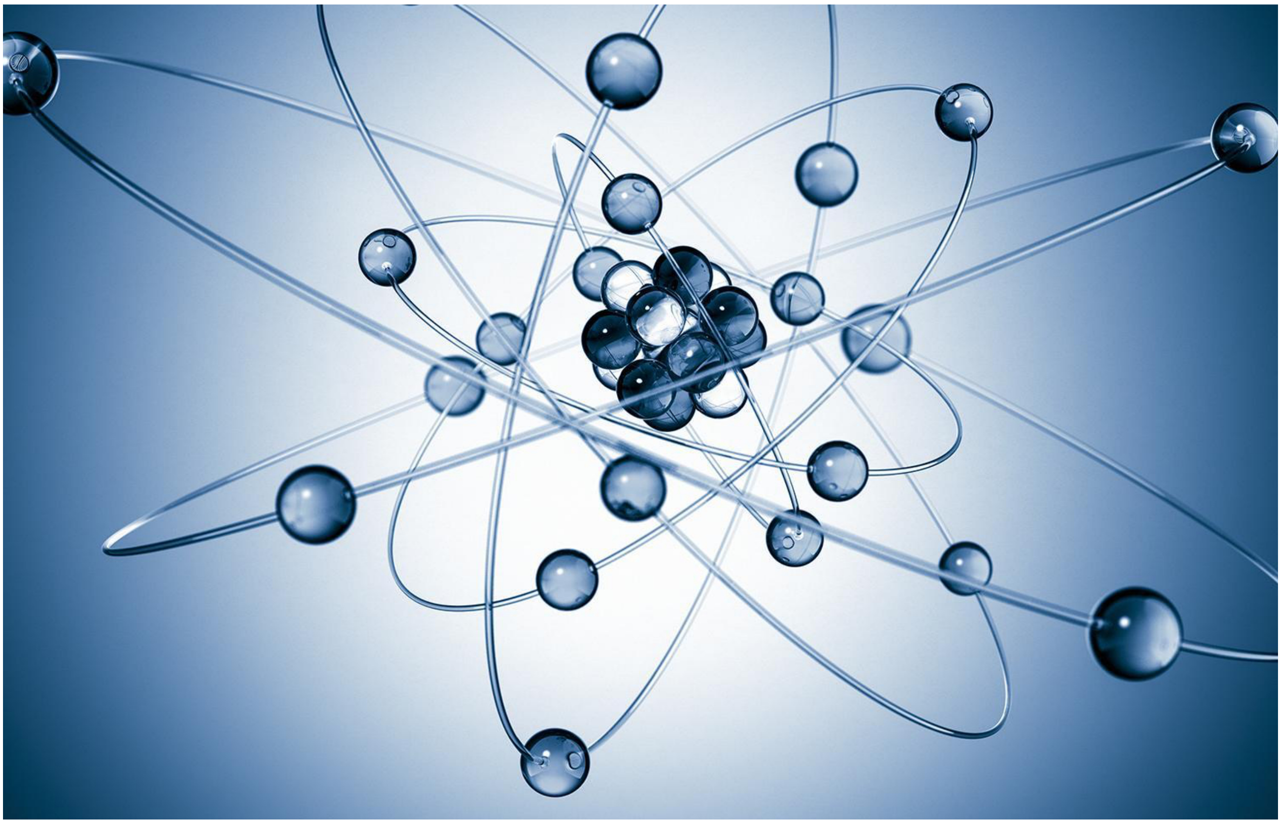

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Chapter 1

Matter and Radiation

1.1

Inside the Atom

The Structure of the Atom

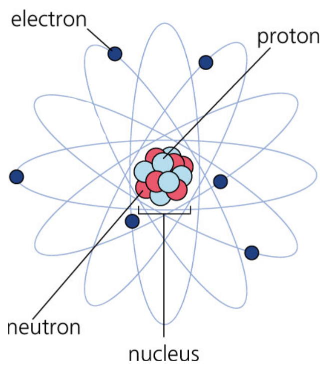
We know that every atom contains:

- A **positively charged nucleus**, which is comprised of **protons** and **neutrons**,
- **Electrons**, which surround the nucleus.

Nucleon - a proton or a neutron in the nucleus.

Electrons have a negative charge, and the nucleus of a atom has a positive charge. This means that the **electrostatic force of attraction** between the electrons and the nucleus holds them together.

The nucleus contains most of the mass of the atom. This was shown by one of Rutherford's investigations.



oldeloohuis.com/atom.jpg

The diameter of the nucleus is about 0.00001 times the diameter of a typical atom.

The electron's mass is much smaller than that of the proton or the neutron.

The mass of a proton and a neutron are almost equal (they are not exactly equal, but they appear to be so to 3sf).

Protons and electrons have **equal and opposite** charges. Neutron are **uncharged.**

	Charge		Mass	
	/Coulombs	relative to charge of proton	/kg	relative to mass of proton
Proton	$+1.6\times10^{-19}$	1	$+1.67\times10^{-27}$	1
Neutron	0	0	$+1.67\times10^{-27}$	1
Electron	-1.6×10^{-19}	-1	$+9.11\times10^{-31}$	0.0005

What is inside the atom?

Isotopes

Atomic Number - The number of protons in the nucleus of an atom. (Symbol Z). It is also known as the **Proton Number**.

Every atom of an element has the same number of protons as any other atom of the same element. This means that, for example, every atom with atomic number 6 will be Carbon, as they will all have 6 protons in their nucleus.

Atoms of and element must have the **same** number of **protons**, but can have **different** numbers of **neutrons**. Atoms of the same element which have a different number of neutrons are called **isotopes**.

One example of an isotope is Uranium-146, which contains 146 neutrons. There is also Uranium-143, which, as you probably guessed, contains 143 neutrons.

Isotopes - atoms with the same number of proton but a different number of neutrons.

Nucleon Number - the total number of protons and neutrons (nucleons) in an atom (Symbol A). It is also known as the **Mass Number**, because it is almost equal to the mass of the atom relative to a proton of mass 1.

Nuclide - a type of nucleus with a particular number of protons and neutrons.

Specific Charge

Specific Charge = Charge/Mass

If we know the **actual** charge and mass of particle, then we can calcite the specific charge.

The electron has the largest specific charge of any particle, at $1.76 \times 10^{11} Ckg^{-1}$.

1.2

Stable and Unstable Nuclei

The Strong Nuclear Force

A stable isotope has a nuclei that does not disintegrate, and so there must be a force holding it together. This is what we call the **Strong Nuclear Force**.

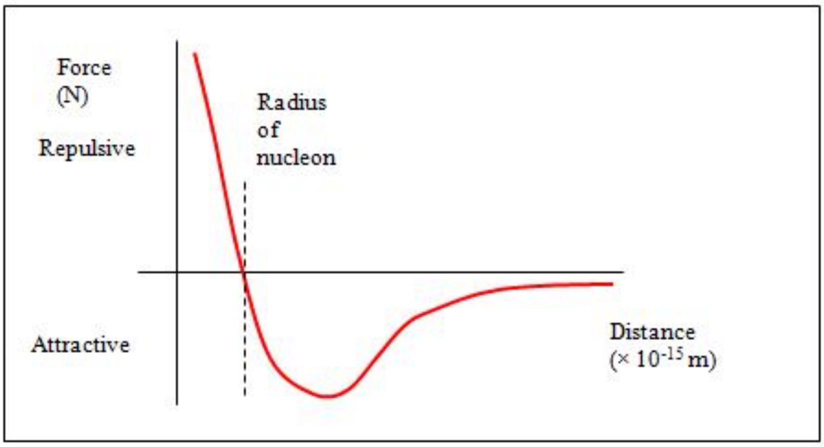
It is called the **strong** nuclear force because it overcomes the electrostatic forces of repulsion between the protons in the nucleus (as they are all positively charged, and so would repel each other), and so it keeps the nucleons together. This is only the case in **stable** nuclei.

The **range** of the strong nuclear force is about 3-4 femtometres, where 1fm = 0.000 000 000 000 001m. This is about the same as the diameter of a small nucleus. The **electrostatic** force has an infinite range in comparison, but it decreases in strength as the range increases.

The force has the same effect between 2 protons as it does 2 neutrons, or a proton and a neutron.

It is an **attractive** force from 0.5fm to 3-4fm, however, below 0.5fm, it is a **repulsive** force. This is so that nucleons are not pushed into each other.

The graph below shows the attractiveness of the strong nuclear force over a distance of about 1fm.



http://www.antonine-education.co.uk/Image_library/Physics_1/Particles/force_graph_2.JPG

Radioactive Decay

There are 3 types of radiation what are naturally occurring, and are released from radioactive isotopes. These are:

- **Alpha Radiation -** this consists of alpha particles, which are two protons and two neutrons, or, in other words, a helium nucleus. When an unstable nucleus emits an alpha particle, it's nucleon number decreases by 4, and its atomic number decreases by 2, making the product a different element.
- **Beta Radiation -** this consists of a fast-moving electron being emitted, also known as a beta particle. A neutron in the unstable nucleus changes into a proton, emitting an electron (the beta particle), which means that the atomic number increases by 1, as there is one more proton in the nucleus, and so the product is a different element. The nucleon number stays the same as the neutron is replaced by the proton. An antineutrino, which has no charge, is also emitted (you will find out why in topic 1.4). Beta decay happens in nuclei with too many neutrons.
- **Gamma Radiation -** this is electromagnetic radiation which is emitted by unable nuclei. It is a wave, and therefore has no charge or mass, and can pass through thick objects. It is emitted following alpha or beta emission, in a nucleus with too much energy.

1.3

Photons

Electromagnetic Waves

Visible light is the only part of the electromagnetic spectrum we can see, but it is definitely not the only part of the spectrum that we use! The table below shows some of the other parts of the electromagnetic spectrum, most of which are used all of the time:

Type	radio	microwave	infrared	visible	ultraviolet (UV)	x-rays	gamma rays
Wavelength Range	>0.1m	0.1m - 1mm	1mm - 700nm	700nm - 40nm	400nm - 1nm	<1nm	<1nm

The Electromagnetic Spectrum

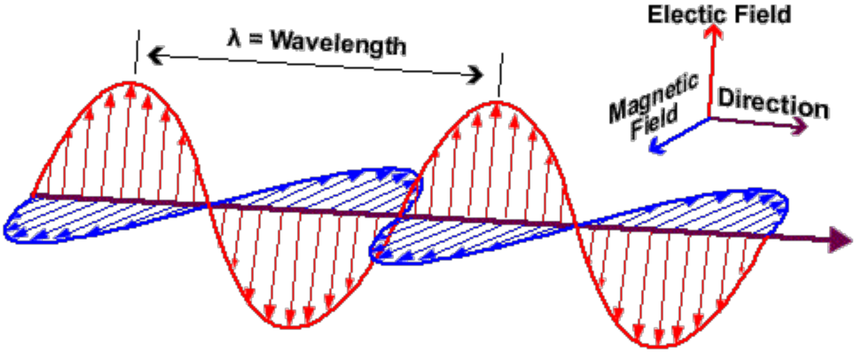
The speed of every electromagnetic wave in a vacuum is **3.0×10^8 ms^{-1}**. This is known as the **speed of light** , *c*.

The wavelength, λ, and frequency, *f*, of an electromagnetic wave are linked by the equation $\lambda = c/f$.

Wavelength is usually expressed in nanometers, or nm, where 1nm = 10^{-9}m.

The image below shows that an electromagnetic wave consists of; an **electric wave** and a **magnetic wave**. These two waves travel together, and they vibrate:

- at right angles to each other, and also to the direction at which they are travelling.
- ‘**in phase**’ with each other. This means that they reach peaks and troughs together, and so they are in sync.



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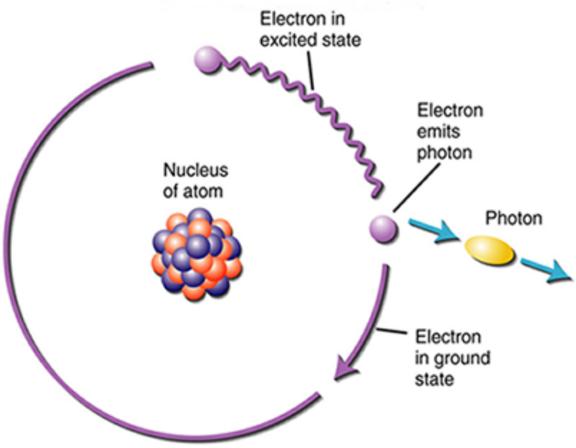
Photons

Electromagnetic waves are emitted by charged particles the they lose energy. Two ways this can happen are when:

- a fast-moving electron is stopped, slows down or changes direction,
- an electron is excited/de-excited (more of this in chapter 3).

Electromagnetic waves are emitted in small bursts, which leave the source in a random direction. These bursts are knows as **photons**.



http://2.bp.blogspot.com/-RBTOqqeavnY/VTPhlkov4ql/AAAAAAAAJDg/skRwRUOluk8/s1600/photonEmit.png

Einstein came up with the photon theory in 1905, and he used these ideas to explain photoelectricity, which is the emission of electron from the surface of a metal when light is directed on to it. Einstein assumed that the energy, E, of a photon, depends on frequency. This is shown by the equation:

$$E=hf$$

where h is referred to as Plank's constant, with the value 6.63×10^{-34} Js.

Laser Power

A laser beam is made of photons all of the same frequency. A beam's power is the energy per second transferred by the photons. This is shown by the equation:

$$power\ of\ the\ beam = nhf$$

where n is the number of photons in the beam that pass through a fixed point per second. Each photon has energy hf, and so if n photons pass a fixed point each second, the energy per second, also known as power, is nhf.

1.4

Particles and Antiparticles

Antimatter

Everything in our universe it made from matter particles. This is because there is more matter than antimatter, and when matter and antimatter meet, they annihilate each other, releasing radiation.

PET (Positron Emission Tomography) hospital scanners are examples of how antiparticles are used in real life. A positron is the antiparticle of the electron, which means that when they meet they annihilate each other and produce 2 gamma photons. For a PET scanner to work, a positron-emitting isotope must be administered to the patient, where some of it travels to the brain via the blood system. Each positron that is emitted from the isotope can only travel a few millimetres before it is annihilated by an electron, producing 2 gamma photons. This is good because the gamma photons can be be detected by the machine, and an image will be built up of the blood flow in the brain.

For positron emission to happen, a proton has to change in to a neutron in an unstable nucleus that has too many protons. This also produces a neutrino. a positron is emitted as it carries the positive charge.

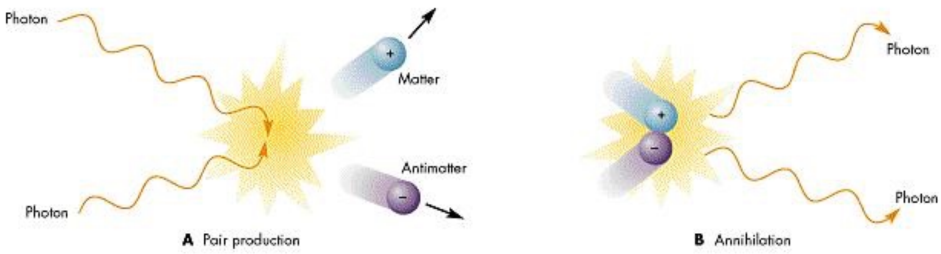
To make a positron-emitting isotope, you need to get a stable isotope, and place in front of a beam of protons. Some of the nuclei in the isotope absorb extra protons, and so become unstable positron-emitters.

The idea of antimatter first came about in 1928, about 20 years after Einstein showed that the mass of a particle increases the faster it travels, and that $E=mc^2$, which relates the energy supplied to the particle to its increase in mass. He also said that the mass of a particle when it is stationary, its rest mass, m_0, corresponds to rest energy m_0c^2, which is locked up in mass. Einstein showed that rest energy must be included in the conservation of energy, and then it the existence of antiparticles was predicted, and these would unlock rest energy whenever a particle and its corresponding antiparticle meet and annihilate each other.

The theory of antiparticles predicted that every particle had a corresponding antiparticle that:

- annihilates itself and its particle counterpart when they meet, converting their total mass into photons,
- has the same rest mass as the particle,
- has an equal but opposite charge to the particle (if the particle has a charge).

Pair Production was also predicted, which is the process where a photon that has sufficient energy will change into a particle-antiparticle pair, which would then separate from each other. However, usually this pair will annihilate soon after being created



https://www.mhhe.com/physsci/astronomy/fix/student/images/26f14.jpg

Particles and Antiparticles

A common unit for the energy of a particle is the Electron Volt, eV (or the MeV = 1,000,000 eV).

$$\mathbf{1eV = 1.6x10^{-19}\ J}$$

One electron volt is defined at: *'the energy transferred when an electron is passed through a potential difference of 1 volt'*. If you're given the rest mass of a particle, then its rest energy (in MeV) can be calculated using $E=mc^2$, but you are given these in the formula book anyway!

Annihilation - it occurs when a particle and its corresponding antiparticle meet and their mass is converted into radiation energy, in the form of 2 photons. The reason two photons is produces is to conserve momentum, as if one was produced then momentum would be created, and, well, this just can't happen, as no outside forces are acting! This means that the minimum energy of each photon, hf_{min}, can be given by equating the energy of the two photons, 2 x hf_{min}, to the positron and electron's rest energies, so $2hf_{min} = 2E_O$.

The equation is therefore:

$$\textit{minimum energy of each photon produced, } hf_{min} = E_O$$

Pair production - a photon creates a particle-antiparticle pair, and it's energy is used up in the process, so it vanishes. The minimum energy, hf_{min}, that the particle must have to produce the particle-antiparticle pair can be calculated using:

$$\textit{minimum energy of photon needed, } hf_{min} = 2E_O$$

This is because a photon that does not have as much energy as the particle-antiparticle pair would could not create it, as energy would not be conserved, as it can not just be created from nowhere!

1.5

How Particles Interact

The Electromagnetic Force

When two objects interact, they exert equal and opposite forces on each other. These objects transfer momentum between each other if no other forces act on them. For example, two protons will repel each other if they get too close, and so will move away from one another. The electromagnetic force between the two charged objects is due to the exchange of **virtual photons**. We cannot directly see virtual photons, and if we tried to intercept them, then the force would stop acting, which is why they are virtual.

The Weak Nuclear Force

The Weak Nuclear Force causes a neutron to change into a proton in β^- decay, and a proton to change into a neutron in β^+ decay. a new particle and antiparticle are created in both decays, however, they are not a corresponding particle-anti-particle pair, as one is an electron or a positron, and the other is a neutrino or an antineutrino.

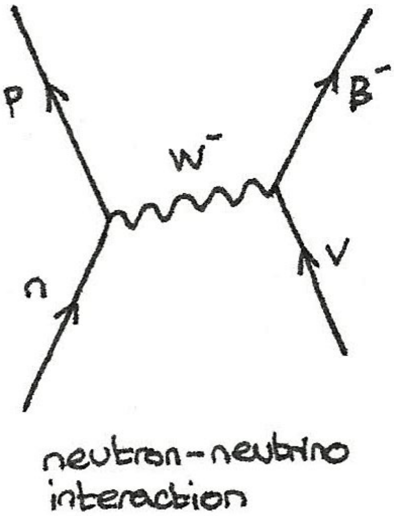
Due to the fact that neutrinos are so small, they rarely interact, however, it is possible for them to. For example:

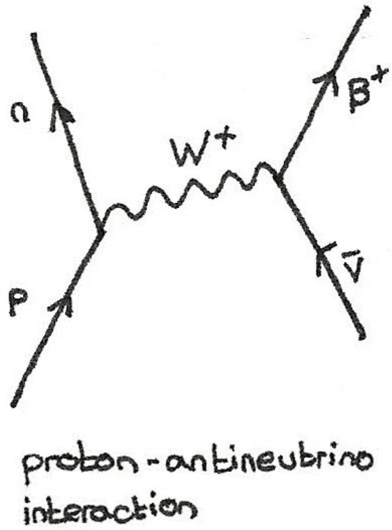
- A neutrino can interact with a neutron, changing it into a proton and an electron.
- An antineutrino can interact with a proton, changing it into a neutron and a positron.

These interactions have an exchange particle of a **W boson**, which:

- have a non-zero rest mass,
- have a very short range, which is no more than about 0.001fm,
- are charged, either positively (W^+), or negatively (W^-).

The Feynman diagrams for these interactions are on the following page.

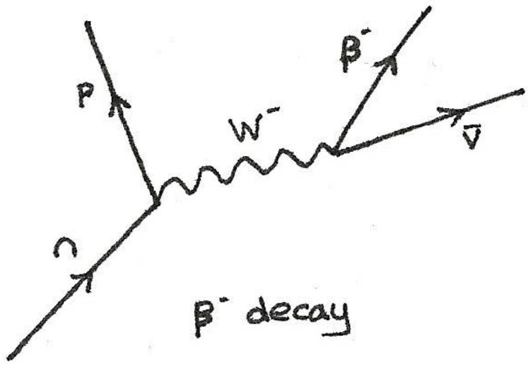


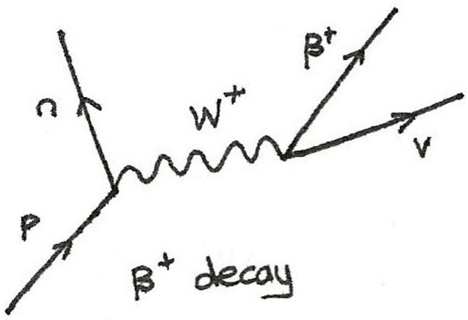


Beta Decay

W bosons also play a role in beta decay. If there is no neutrino or antineutrino present, then:

- the W^- boson decays into an electron and an antineutrino,
- the W^+ boson decays into positron and a neutrino.

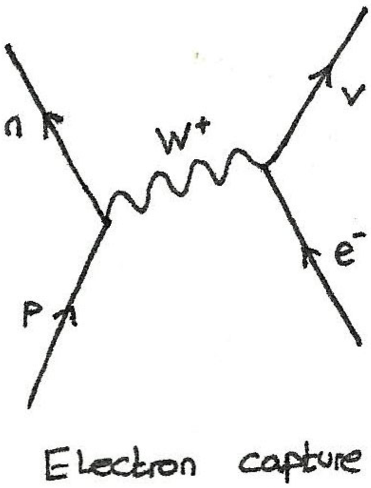




Electron Capture

In a proton-rich nucleus, sometimes a proton from the outside of the nucleus decays into a neutron as a result of interacting through the weak interaction with an inner energy level electron. The W^+ boson changes the electron into a neutrino.

This can also happen if a proton and electron collide at high speed, or if an electron has sufficient energy, the change could occur as a W^- exchange from the electron to the proton.



Interaction	Exchange Particle	Particles Affected
Strong	Gluon	Hadrons
Weak	W^+, W^-, Z^0	All
Electromagnetic	Virtual Photon	Charged Particles

Interactions and their Exchange Particles

Chapter 17

Equations

17.1

Photons and Energy Levels

Photon Energy

$E = hf = hc/\lambda$

Where:

E = Photon Energy
h = Planck's Constant
f = Photon Frequency
c = Speed of Light in a Vacuum
λ = Photon Wavelength

Photoelectricity

$hf = \varphi + E_{Kmax}$

Where:

h = Planck's Constant
f = Photon Frequency
φ = Work Function
E_{Kmax} = Maximum Kinetic Energy of the Photon

Energy Levels

$hf = E_1 - E_2$

Where:

h = Planck's Constant
f = Photon Frequency
E_1 = Photon Energy in Energy Level 1
E_2 = Photon Energy in Energy Level 2

de Broglie Wavelength

$\lambda = h/p = h/mv$

Where:

λ = de Broglie Wavelength
h = Planck's Constant
p = Momentum
m = Mass
v = Velocity

17.2

Electricity

Current and Potential Difference

$I = \Delta Q/\Delta t$

Where:

I = Current
ΔQ = Change in Charge
Δt = Change in time

$V = W/Q$

Where:

V = Potential Difference
W = Work
Q = Charge

$R = V/I$

Where:

R = Resistance
V = Potential Difference
I = Current

emf

$$\varepsilon = E/Q$$

Where:

ε = emf
E = Energy
Q = Charge

$$\varepsilon = IR + Ir$$

Where:

ε = emf
I = Current
R = Resistance
r = Internal Resistance

Resistors in Series

$$R = R_1+R_2+R_3+\ldots$$

Where:

R = Total Resistance in Circuit
R_n = Resistance of Resistor n

Resistors in Parallel

$$1/R = 1/R_1+1/R_2+1/R_3+\ldots$$

Where:

R = Total Resistance in Circuit
R_n = Resistance of Resistor n

Resistivity

$$\rho = RA/L$$

Where:

ρ = Resistivity

R = Resistance

A = Cross-sectional Area of Wire

L = Length of Wire

Power

$$P = VI = I^2R = V^2/R$$

Where:

P = Power

V = Potential Difference

I = Current

R = Resistance