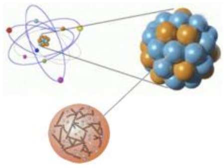
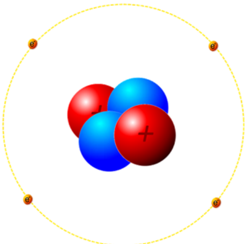


What is matter and how is it formed?

Lesson 6: Subatomic Particles

Subatomic particles refers to particles that are more "fundamental" than ……………………..



proton

neutron

electron

Are these fundamental particles or are they made up of smaller, more fundamental particles?

Are there other subatomic particles?

Cosmic Rays

In 1909, whilst investigating the level of background radiation, Physicists in France made an unusual discovery.

They measured background radiation at the top of the Eiffel Tower and found that the level of background radiation …………………………… with height.

They postulated that some radiation must be coming from space and called it …………………………. rays.

It turns out that cosmic rays are actually ………………………………………

90% of cosmic rays are protons, from the Sun but also from other objects in the

Remnants of Super Nova Explosion of 1054 AD

The most energetic cosmic protons probably come from ………………………………………. explosions.

'Cosmic' protons can have energies up to 40 million times the energy of protons produced in the Large Hadron Collider in the search for the Higgs Boson.

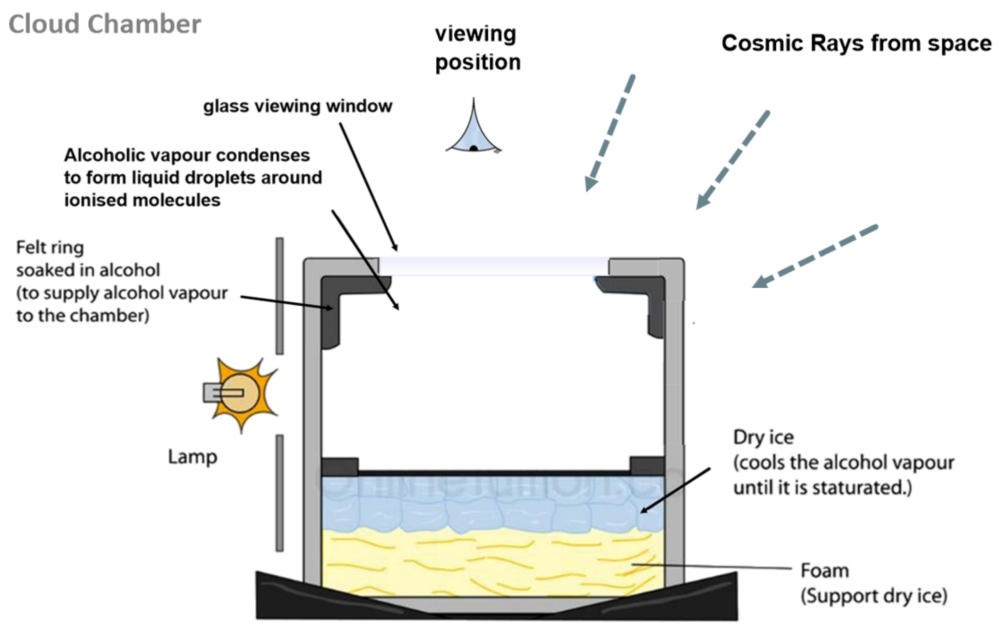
Cosmic particles collide with atoms high in our atmosphere to produce cosmic …………………. consisting of millions of particles.

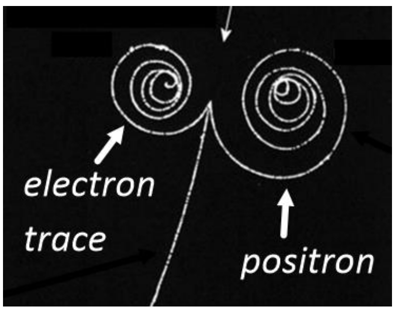
Discovery of the Positron

In 1932, Carl David Anderson, an American Physicist, studied the charged particles produced by cosmic showers using a cloud chamber.

The cloud chamber is a device which shows the paths of ………………………………….particles.

Magnetic fields are applied to the cloud chamber to discover further properties such as a particle's charge-to-mass ratio.





The magnetic field applies a force at right angles to a particle’s velocity causing a …………………….. shaped trace.

Measurements of the radius and strength of magnetic field allow the charge-to-mass ratio of the particle to be calculated.

The **positro**n had the same charge to mass ratio as the electron, but bent in the ……………………………… direction.

The trace spirals inwards as the particles lose ………………………………….. in collisions with other particles.

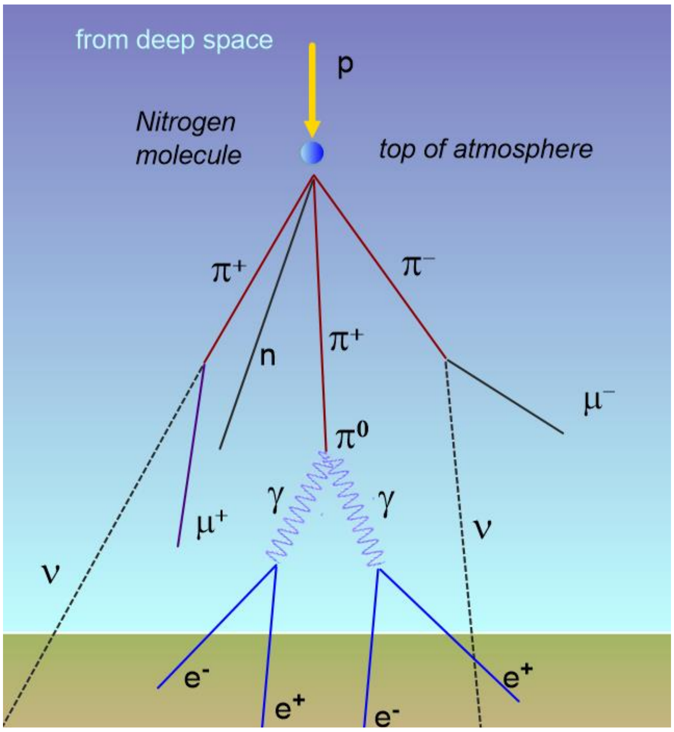
Accords with Einstein’s mass-energy equivalence equation, $E = mc^2$

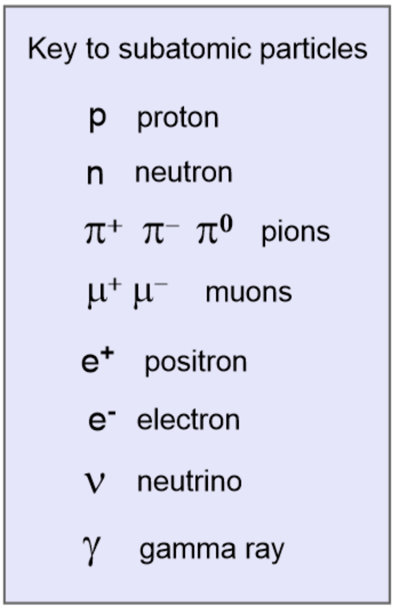
Other investigators had earlier obtained photographs of positrons in cloud chambers but had dismissed them as being protons.

Anderson won the Nobel Prize in 1936 for his discovery of the positron.

The positron was the first evidence of **…………………………………………….**

Typical Cosmic Shower





Antimatter

The modern theory of antimatter began in 1928 with a paper by English Physicist Paul Dirac, who predicted the theoretical existence of antielectrons.

Discovered in 1932 by Carl Anderson and called ……………………………….

In fact we now know that virtually all subatomic particles have antimatter equivalents.

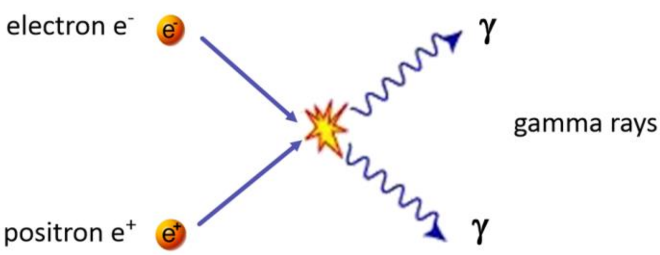
They have the same ………………………………. as ordinary matter but have opposite charge, as well as possessing opposites of other properties such as spin.

Antimatter particles are most commonly denoted by a …………………… over their symbol.

neutrino ν	antineutrino $\bar{\nu}$	proton p	antiproton $\bar{p}$

If matter and antimatter particles collide they annihilate each other and produce high energy …………………………………… ray(s).

Mass is turned into energy according to $E = mc^2$



The observed universe consist almost entirely of matter (rather than antimatter) and the reason for this is one the great unsolved problems of Physics.

Timeline of discovery of subatomic particles

By the **1920s**, only two were known, **proton** and **…………………………..**

The **……………………………** was discovered in **1932**

By **1940**, three more were discovered, the **positron**, and two **muons.**

By **1950** two more were found, two **………………………**

By **1960** several more particles were discovered.

The **…………………………………. model** was proposed which predicted the existence of many new particles.

By **1970** many of the predicted particles were discovered.

Over **200** subatomic particles have now been discovered.

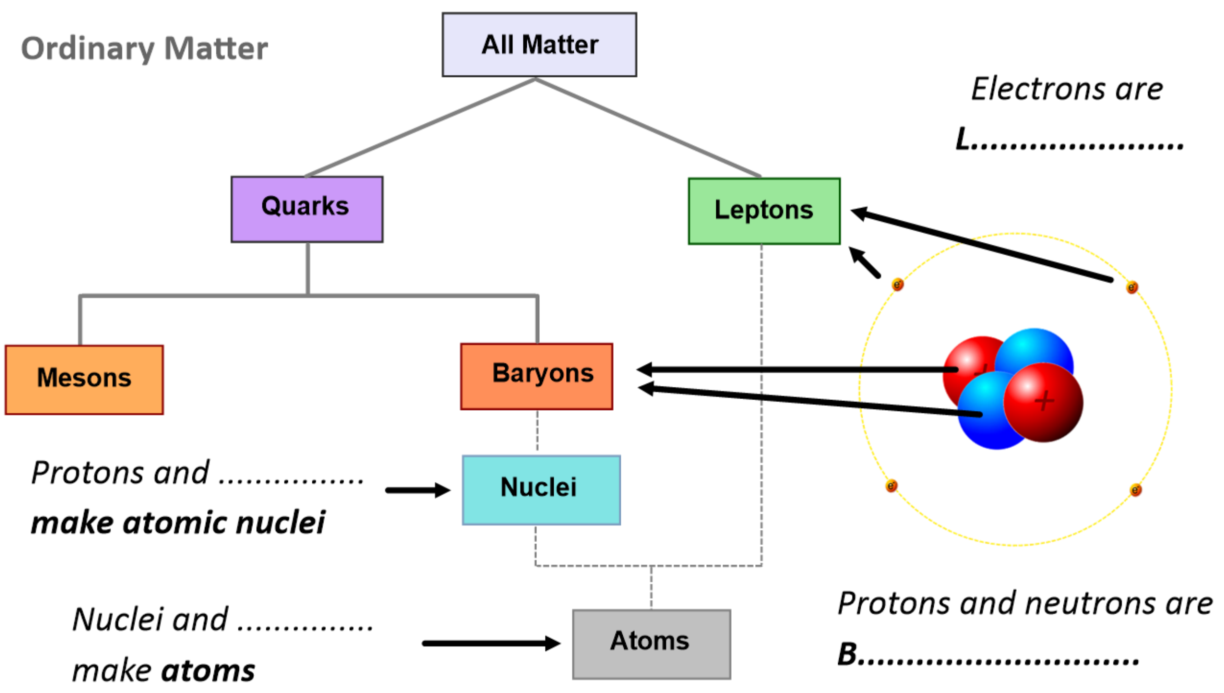
Making Sense of Particles

In the late 1900s, Physicist faced a similar problem when faced with a large number of subatomic particles.

How could they be arranged or grouped in order to make more sense of them?

Physicist arranged particles into the following groups.

Quarks, Leptons, Mesons, Baryons and Hadrons

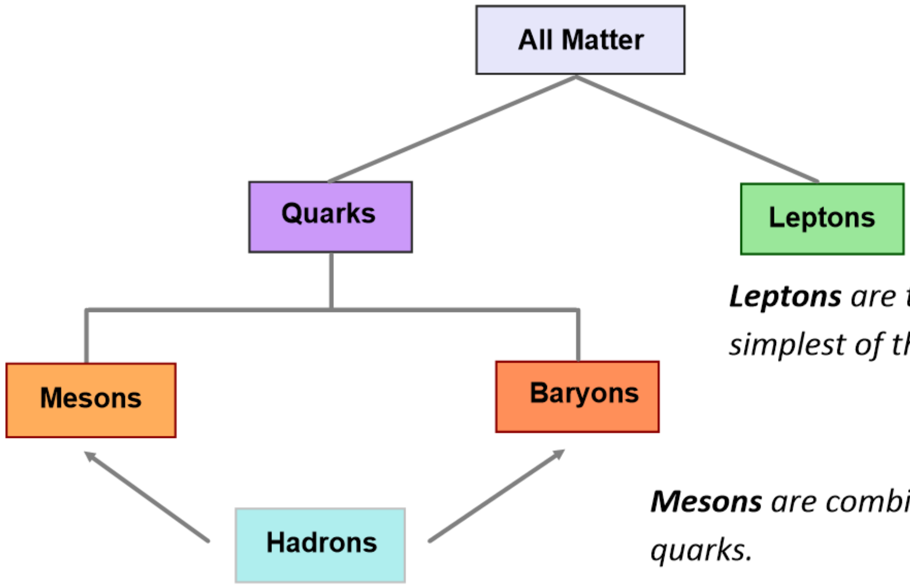


Protons and neutrons are made up of combinations

of ……………………………… **quarks**

All Matter

Made of combinations of quarks and ……………………………



***Leptons** are the lightest and simplest of the subatomic particles.*

***Mesons** are combinations of ……….. quarks.*

***Baryons** are combinations of …………… quarks.*

***Hadrons** are made up of different combinations of ……………………*

Leptons are the lightest and simplest of the subatomic particles. They are fundamental particles, having no internal structure. Each of the six leptons has a corresponding …………………………………..

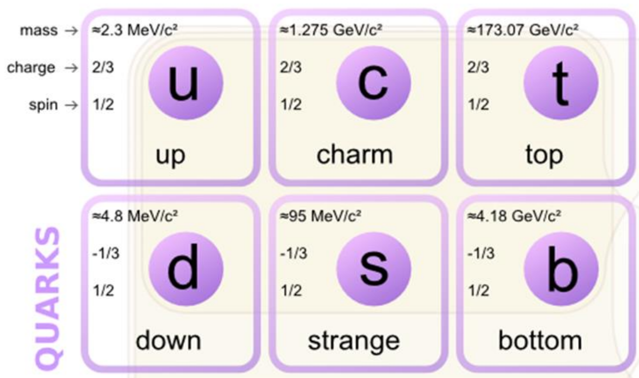
Mesons play a role in nuclear interactions but have very short half-lives, making them hard to detect. There are over **60** types of mesons, each one having its own antiparticle.

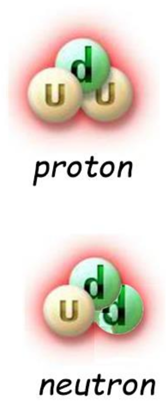
Baryons include the neutron and the proton. There are about 70 other different types of baryons. Only the neutron and the proton are stable. All other baryons are very short-lived. Each baryon has its own antiparticle.

Quarks

The **six** different quarks each have different mass, charge and spin.

Protons and **neutrons** are made different combinations of ………………. and ……………………… quarks.

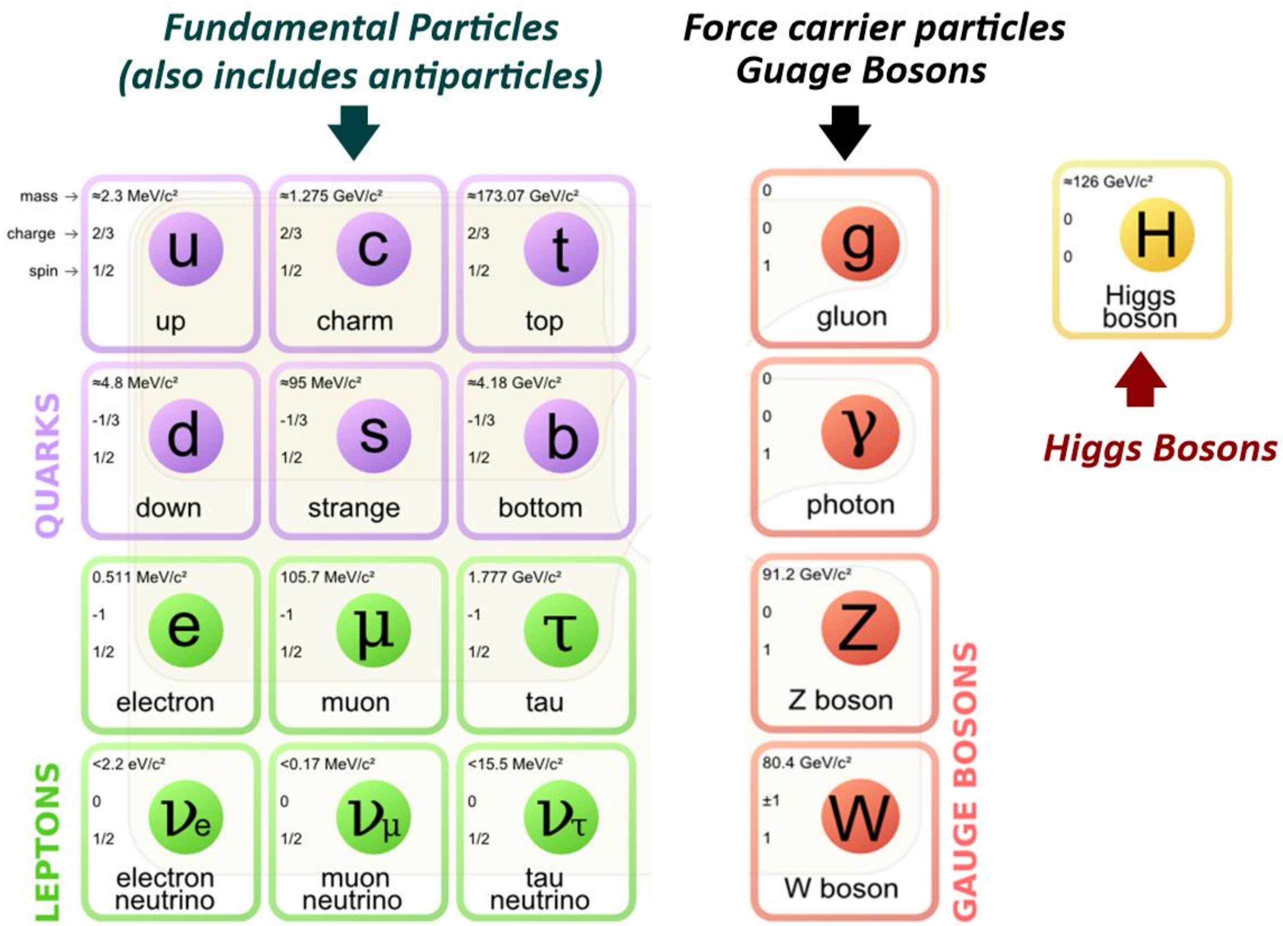




The Standard Model

The **Standard Model** is a theory that explains what makes up all ……………………..and how it is held together. The Standard Model contains 24 fundamental particles, (12 particles and their associated anti-particles), which are the constituents of all matter.

It interprets the three fundamental …………………………… between particles, the strong, **weak**, and **electromagnetic forces** as being the result of force carrier particles called gauge bosons.
All known matter particles are composites of quarks and leptons, and they interact by **exchanging** force carrier particles.



The Standard Model is not yet a complete description of matter as it does not include the force of ………………………., nor does it explain the existence of dark matter and dark energy.

Details of the Standard Model are beyond this course.

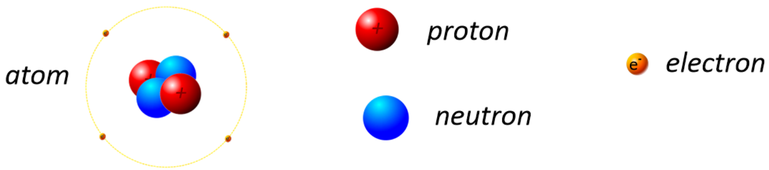
Want to know more? Take the Particle tour at http://particleadventure.org/

The Standard Model predicted the existence of a type of boson known as the …………………… boson.
Fifty years after its predicted existence, on 4 July 2012, physicists with the Large Hadron Collider at CERN announced they had found a new particle that behaves similarly to what is expected from the Higgs boson.

Summary

Subatomic Particles

Subatomic particles are particles that are more "fundamental" than atoms.



Are these fundamental particles or are they made up of smaller, more fundamental particles?

Are there other subatomic particles?

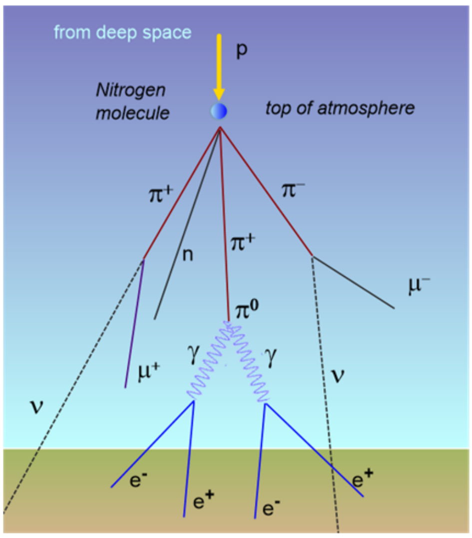
Cosmic Rays

Cosmic rays are particles, mostly protons, from the Sun but also from other objects in the Milky Way Galaxy such as supernova explosions, black holes and neutron stars.

'Cosmic' protons can have energies up to 40 million times the energy of protons produced in the Large Hadron Collider in the search for the Higgs Boson.

Cosmic particles collide with atoms high in our atmosphere to produce cosmic showers consisting of millions of particles.

Cosmic particles collide with atoms high in our atmosphere to produce **cosmic showers** consisting of millions of particles.



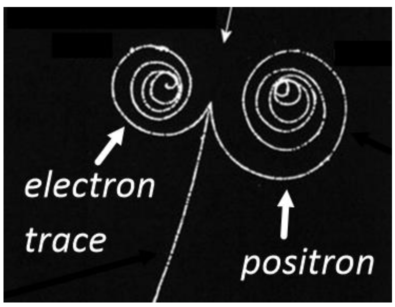
Key to subatomic particles

p	proton
n	neutron
π^+ π^- π^0	pions
μ^+ μ^-	muons
e^+	positron
e^-	electron
ν	neutrino
γ	gamma ray

In 1932, Carl David Anderson, an American Physicist, studied the charged particles produced by cosmic showers using a cloud chamber.

He discovered the positron. It had the same charge to mass ratio as the electron, but bent in the opposite direction.

The positron was the first evidence of **antimatter**.



Summary

Antimatter

Virtually all subatomic particles have antimatter equivalents.

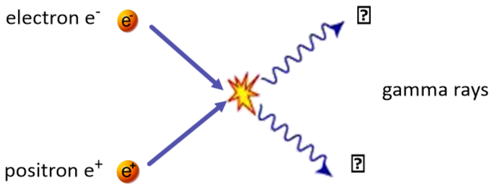
They have the same **mass** as ordinary matter but have opposite charge, as well as possessing opposites of other properties such as spin.

Antimatter particles are most commonly denoted by a bar over their symbol.

neutrino ν antineutrino $\bar{\nu}$

proton p antiproton $\bar{p}$

If matter and antimatter particles collide they annihilate each other and produce high energy gamma ray(s).

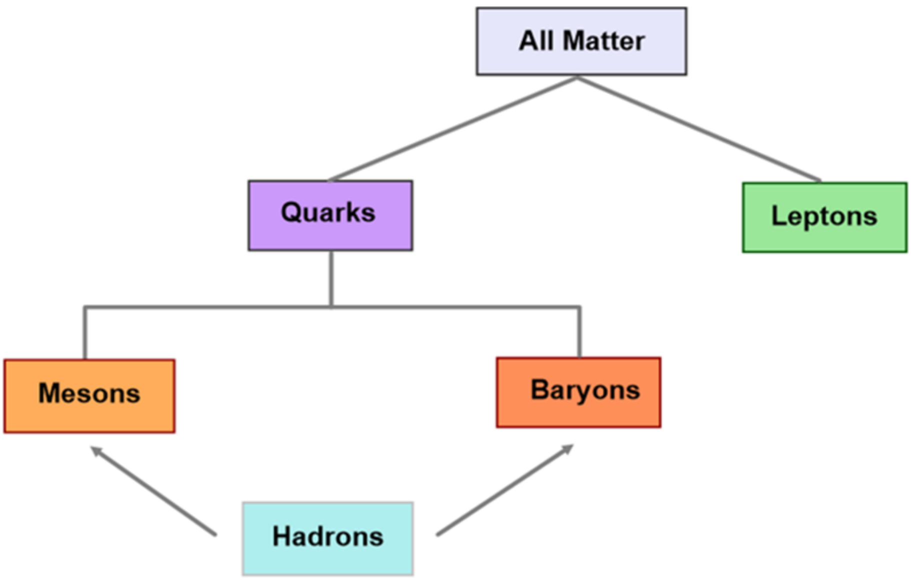


The observed universe consist almost entirely of matter (rather than antimatter) and the reason for this is one the great unsolved problems of Physics.

Making Sense of Particles

Over **200** subatomic particles have now been discovered.

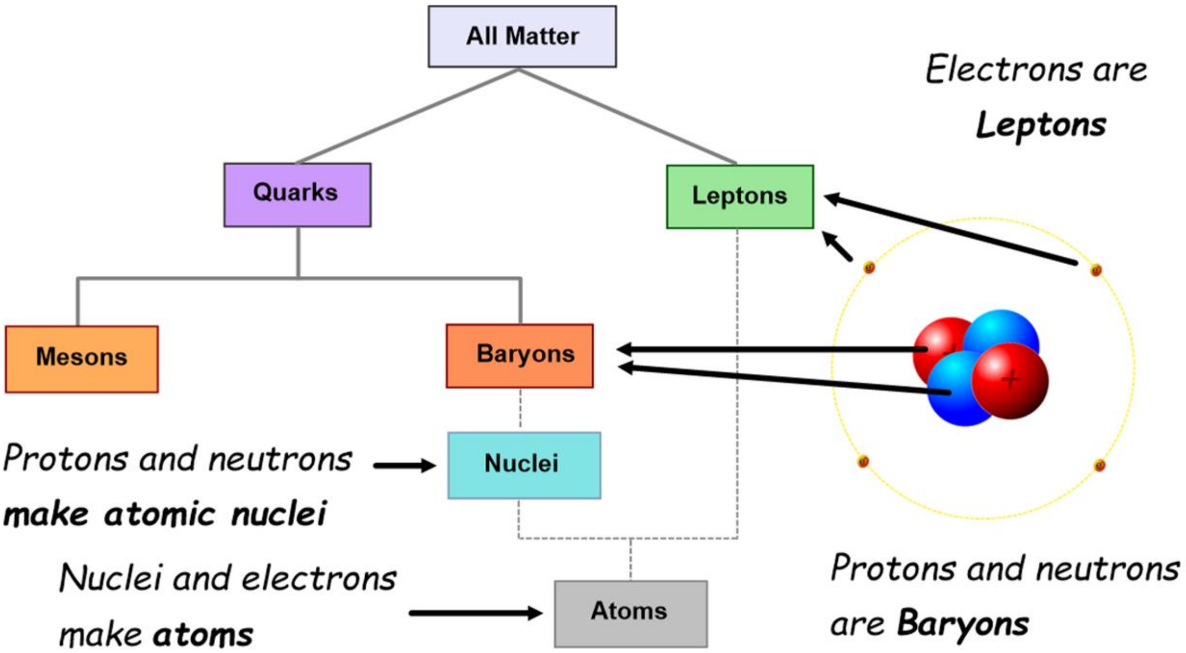
Physicist arranged particles into groups called Quarks, Leptons, Mesons, Baryons and Hadrons



Summary

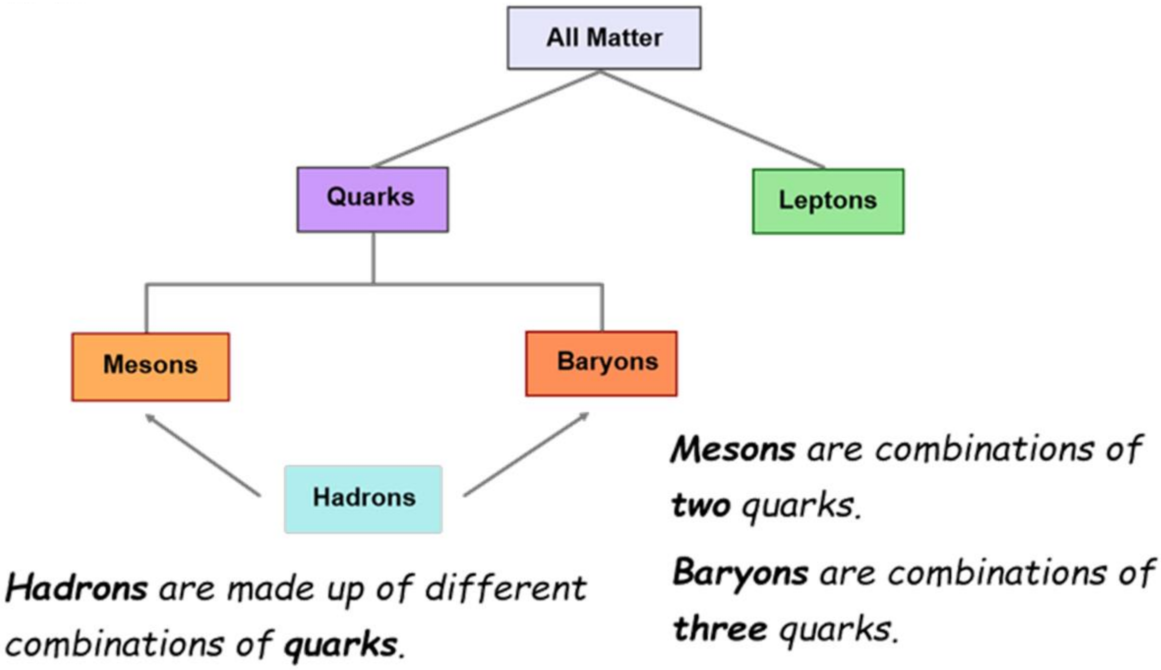
Ordinary (Stable) Matter

Made of electrons (which are leptons) and protons and neutrons (which are baryons).



All Matter

Consists of combinations of **quarks** and **leptons**.



Summary

Groups of Matter

Leptons *are the lightest and simplest of the subatomic particles.*

They are fundamental particles, having no internal structure. Each of the six leptons has a corresponding antiparticle.

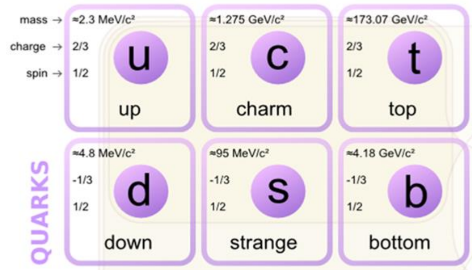
Mesons *play a role in nuclear interactions but have very short half-lives, making them hard to detect.*

Baryons *include the neutron and the proton. There are about 70 other different types of baryons. Only the neutron and the proton are stable. All other baryons are very short-lived.*

Quarks *The **six** different quarks each have different mass, charge and spin.*

*Subatomic particles can be modelled as being made up of different types of **quarks**.*

Protons *and **neutrons** are made different combinations of up and **down** quarks.*



neutron

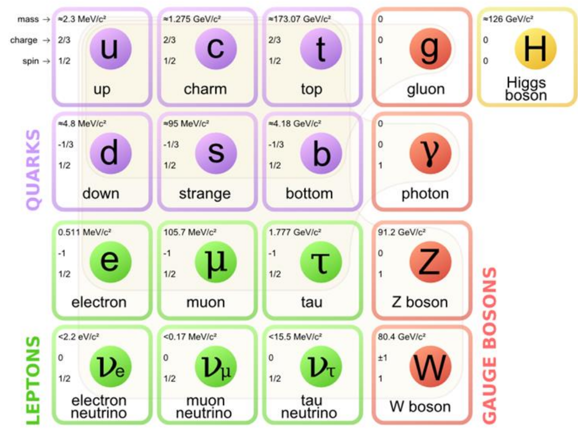
proton

The Standard Model

The Standard Model is a theory that explains what makes up all matter and how it is held together.

24 fundamental particles, (12 particles and their anti-particles).

These are the constituents of all matter.



All known matter particles are composites of quarks and leptons, and they interact by **exchanging** force carrier particles.

Fifty years after its predicted existence, on 4 July 2012, physicists found the Higgs boson.

The Standard Model is not yet a complete description of matter and there is much still to be discovered.