	Date: 7 February 2021	Classes: 6WEW8 5AL / 5BL
	Team 13: Rufina Gaydarzhi, Silvia Pallotti, Emma Cortier, Irina Van Holm and Louise Wostyn	
	Teachers: Els Merveillie, Peter Helgesson	
	BACK TO THE FUTURE OF PHYSICS *one small step towards the final frontiers*	

The Standard Model

INTRODUCTION: THE STANDARD MODEL

We start this scientific report with a brief summary of what The Standard Model is. In the following, we will go more deeply into various topics related to this.

The Standard Model of particle physics is a theory. It describes the smallest particles in our universe (also their properties), and the forces of nature that act on them. To get to the smallest particle, you have to zoom in a lot.

As an example, we will take a water drop:

Under a microscope you can see that the water drop consists of a molecule. This molecule consists of three atoms: two hydrogen atoms and one oxygen atom. If you zoom in on one of these atoms, you'll see a nucleus and electrons that rotate around the nucleus. If we examine that nucleus, we'll find particles with a positive charge (protons) and particles with no charge (neutrons). Eventually, we examine the neutrons and protons in detail. We observe that it consists of even smaller particles: quarks. Quarks and electrons are the elementary particles.

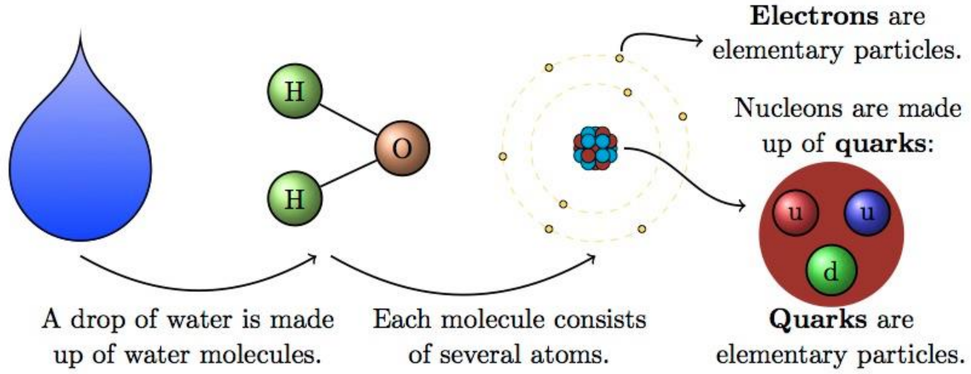


Image 1, Elementary Particles. Taken over from Ghosts in The Universe (https://ghostsintheuniverse.org/theory/)

But as mentioned before, The Standard Model doesn't only consist of elementary particles. It also includes three natural forces namely: the weak nuclear force, the strong nuclear force and the electromagnetic force. These forces determine the interactions between the particles. For example: attraction or repulsion. We will discuss the three forces of nature in more detail below.

EXPLANATION ELEMENTARY PARTICLES

Back to history

Humanity has long been interested in the fundamental building blocks of matter. Even the ancient Greeks believed that matter was made up of a finite number of indivisible particles. They did not have the means, the material and the knowledge, to prove this.

Centuries after the ancient Greeks, in the 19th century, John Dalton came up with a theory. A theory in which all elements consisted of fundamental particles: atoms. This name originates from Ancient Greek which means ‘not divisible’.

In 1897, Thomson discovered the electron. This was a breakthrough in physics. The electron was 1800 times smaller than the known atoms. Because of this Dalton’s theory was no longer correct.

In 1911, we came one step closer to the known particles of today. Rutherford concluded that the nucleus of an atom consists of two even smaller particles: protons and electrons. This model replaced the one from Thomson.

To be complete, we also mention Bohr’s atomic model (1913), he stated that the electrons around the nucleus weren’t random. According to him, they moved in orbits at specific distances from the nucleus.

And finally, in 1926, Erwin Schrödinger came up with a quantum mechanical model in which electrons were presented not as particles, but as a wave phenomenon.

Here are all the theories briefly.

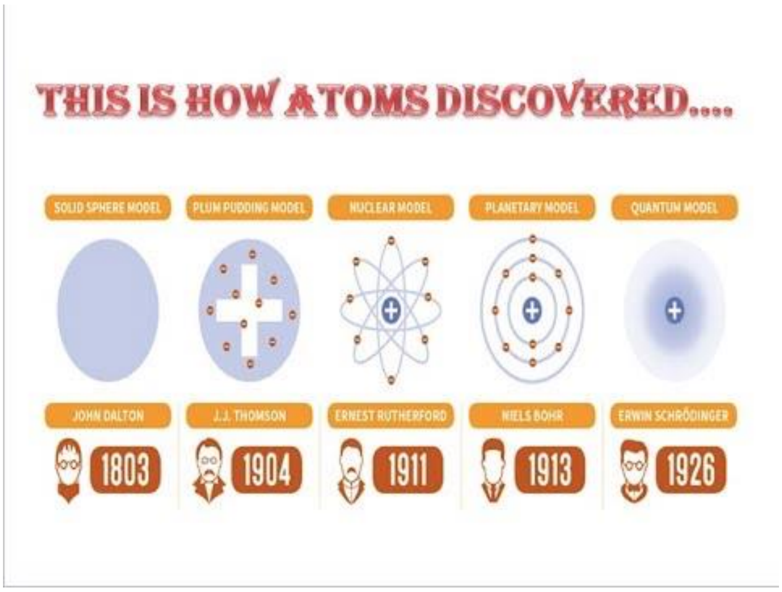


Image 2, the discovery of atoms. Taken over from CRYSTAL CLEAR CHEMISTRY CLASSES (https://www.youtube.com/watch?v=ffkCsCjYBfA)

Up until this day

An elementary particle is a particle that cannot be split into other particles. According to the current models, there are 3 examples: electrons, neutrinos and quarks. Since elementary particles have the smallest possible particles, they have no internal structure. All larger particles are composed of elementary particles. By studying their trajectories and mutual collisions, in which new particles form, their properties can be studied. We explain more about how collisions happen: if the temperature rises, the particles move faster. With more movement, the chance of collision is greater. The number of collisions per unit of time will not only increase, but the force with which particles collide will also increase. The LHC is an underground particle accelerator, located in an annular tunnel with a circumference of 27 km, at a depth of 50 to 175 meters. The LHC is used to conduct physics research on elementary particles and their properties. You will find more information about CERN in the course of this report.

We can subdivide the elementary particles into two groups: fermions and bosons. These particles differ from each other in a number of properties, including charge and mass. The spin determines the difference between fermions and bosons: the spin of fermions is 0,5 and the spin of bosons is 1.

We take a closer look at the fermions. Fermions are the building blocks of matter. We can split these fermions into two groups.

The first group: the quarks, the building blocks of protons and neutrons. Overall, we have six types of quarks: quark up and down, strange and charm, bottom and top. The up- and down quarks are the most relevant, because normal matter is made up of these. Up quarks have an electric charge of *+2/3* while down quarks possess *–1/3* of a unit of electric charge. In addition, up and down quarks can be either “left-handed” or “right-handed”, this characteristic is defined according to their spinning, which could be clockwise or counterclockwise, depending on their direction of motion. To clarify: a neutron contains 2 down quarks and 1 up quark ((-1/3) +(-1/3) +(2/3) =0) together they are neutral in charge. A similar reasoning for the proton for a proton: 2 up quarks and 1 down quark.

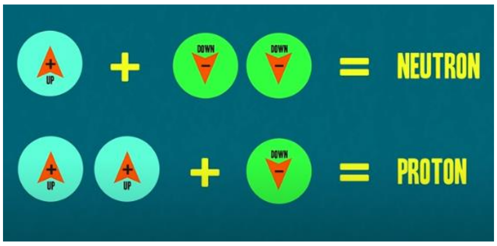


Image 3, Composition of neutrons and protons. Taken over from SCISHOW (https://www.youtube.com/watch?v=cnL_nwmCLpY%29)

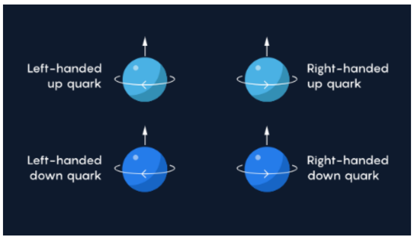


Image 4, Left/right-handed quarks, taken over from QUANTA MAGAZINE (https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

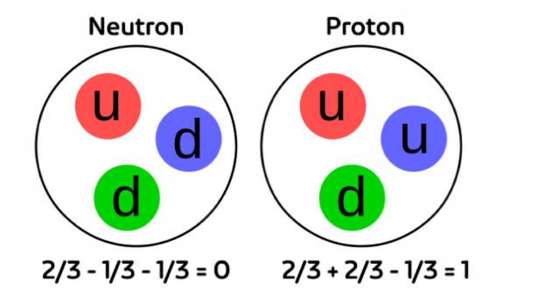


Image 5, Elementary particles. Taken over from VISSER, H. (https://npokennis.nl/longread/8029/het-standaardmodel-waar-is-alles-van-gemaakt)

The second group are the leptons. They interact with the forces of nature except for the strong nuclear force. This group includes the negatively charged electron, the neutrino, that has 0 charge, the muon, the muon neutrino, the tau and the tau neutrino. The neutrino is an electrically uncharged elementary particle. They fly right through almost everything because it interacts so little with matter. Finally, we mention that each fermion has its own anti-particle. These anti-particles have the same properties as the 'normal' particles except that their electrical charge is reversed.

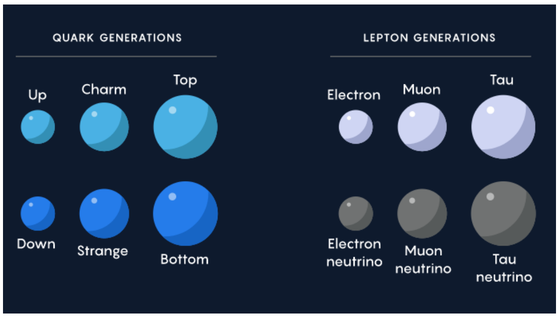


Image 6, Quark and lepton generations. Taken over from QUANTA MAGAZINE (https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

As the last part of the elementary particles, we delve into the bosons, these are force-carrier particles. They convey the three forces of nature. Within the group of fundamental bosons, we distinguish between gauge bosons and the Higgs boson. The gauge bosons are responsible for carrying the fundamental interactions. For example: the massless photon carries the electromagnetic force, the massless gluons the strong nuclear force and the Z and W bosons for the weak force. On the other hand, the Higgs boson is an outsider among fundamental bosons, as it doesn't carry a fundamental interaction. It's named after Peter Higgs. The Higgs boson is responsible for the mass of most fundamental particles. This is the most recently discovered fundamental particle: 2012. In 2013, Peter Higgs and François Englert won the Nobel Prize in Physics.

Eventually, a summary of all elementary particles.

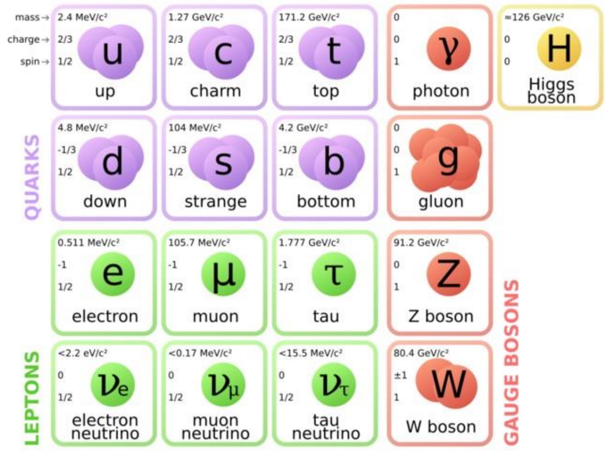


Image 7, Quantumfysica (14): Het standaardmodel. Taken over from VONK, M.(https://www.quantumuniverse.nl/quantumfysica-14-het-standaardmodel)

<u>EXPLANATION FORCES</u>

The natural forces

In nature, there are three natural forces: the strong nuclear force, the weak nuclear force and the electromagnetic force. These are fundamental interactions that underlie the exchange of energy between particles and are responsible for the structure and evolution of the Universe.

The strong nuclear force

The strong nuclear force keeps the particles in the atomic nuclei together and thus ensures stability. It is the force that holds quarks together to form protons and neutrons. Without this force, the positively charged protons in the nucleus would repel each other and the nucleus would disintegrate. This force only works on a very small distance scale.

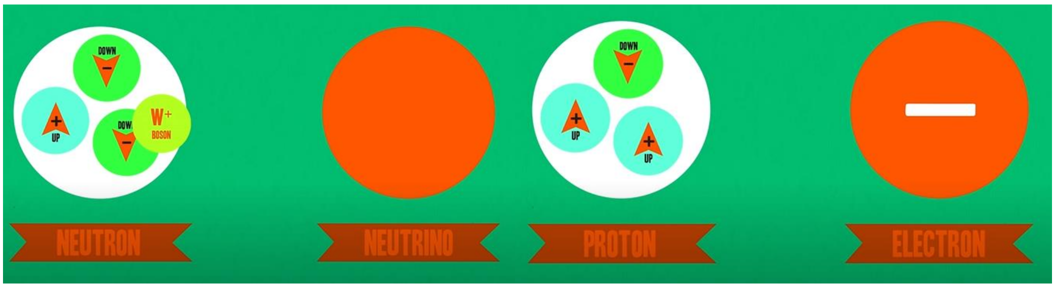
The weak force

The weak force, only effective at very short distances, govern all matter and is the mechanism of interaction between subatomic particles. It involves an exchange of force carries particles, whose aim, is to convey forces between other particles.

Some important outcomes of the weak interaction are the radioactive decay, essential in nuclear fission, as also the crucial role in powering stars and in creating elements.

The W boson, which can be either positively or negatively charged, and Z boson, which have no charge, are the force carriers of this field. Weak force only interacts with left-handed particles and right-handed antiparticles.

A practical example of this interaction could be the approach between a neutron and a neutrino that produces a proton and an electron. When these two mass-particles come close, a positively charged W boson would travel from the neutrino to that neutron on account of the weak force. That completely changes the internal structure of both. The neutrino becomes negatively charged, because of the loss of the positive boson, and consequently it turns into an electron. Meanwhile, inside the neutron, the positive W boson encounters a down quark and charges it positive, which is possible because left-handed up and down quarks can transform into each other. In doing so a down quark becomes an up quark and, since the neutron and the proton differs by only one quark, this changes the neutron into a proton.

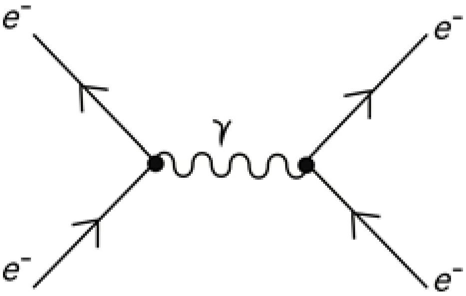


Images 8-9, Function of the W boson. Taken over from SCISHOW (https://www.youtube.com/watch?v=cnL_nwmCLpY0)

Generally speaking, this happens when an elementary particle exchanges a force-particle, Z or W boson. That causes the change of that particle itself. Widening, the changing of the particle implies that the composition of the nucleus and, subsequently, the entire atom has been modified into an entirely new element.

The electromagnetic force

Electromagnetism is the force that acts between electrically charged particles. To describe an interaction, it is important to define two quantities: the range and the intensity. The range of an interaction is the maximum distance at which it is influential while the intensity provides a measure of the force relationships between interactions of different natures.



Electromagnetic interaction is responsible for the atomic and molecular structure of matter and manifests itself in our daily lives in many ways, from visible light to microwave radiation, from electricity to the signals that bring TV into our homes and that allow us to communicate. It is responsible for the repulsion between the superficial atoms.

Image 10, Feynman diagram invented by Richard Feynman in the 1940s. As mentioned, the diagram represents the temporal and spatial evolution of the interaction: here is a simple diagram to better understand what happens during an interaction. (https://www.google.com/search?q=Feynman+diagram+for+the+electromagnetic+repulsion&sxsrf=ALeKk00nsEiA4n_-RNpDC7LYdUJRgAFTzQ:1612704933660&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjCycqF8tfuAhUO-qQKHQAjAeYQ_AUoAXoECAYQAw&biw=1280&bih=578#imgrc=LvxYVEsX2JjkJM)

A particle is both subject to but also releases the electromagnetic force if it has a charge. This charge is called electric charge which is normally expressed in electron charge units. For historical reasons the electron charge was the first to be precisely defined, therefore the electron has a negative electric charge, the positron a positive electric charge and so on.

The electromagnetic force is the only force with an infinite range of action, therefore 2 charged particles can in principle capture each other even from one end of the galaxy to the other, given the technical time required to travel from one particle to the other at the speed of light.

To illustrate:

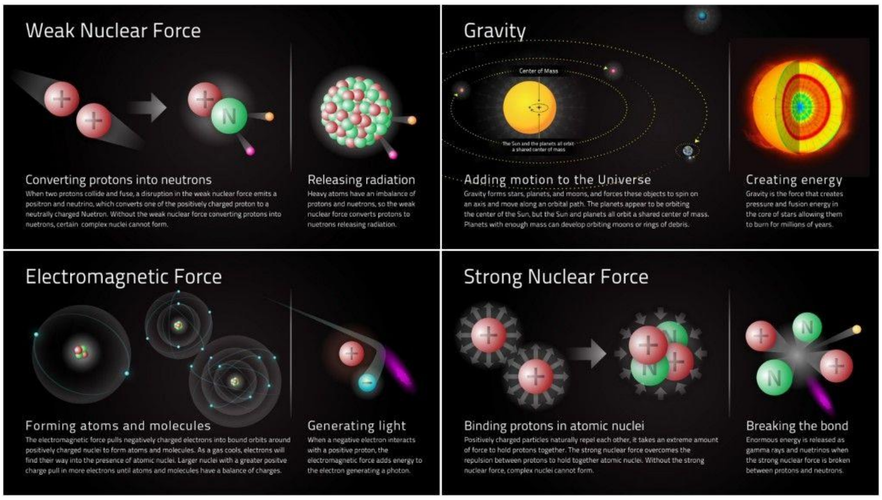


Image 11, The forces. Taken over from Derekscope (http://www.derekscope.co.uk/the-universe-20th/the-universe1/the-big-bang/)

GRAVITY

Research on elementary particles is far from complete. For example, gravity in the standard model is still unexplained. Gravity plays a role in the world of elementary particles, but it is considerably weaker than the other three forces. Presumably, there exists a particle that carries gravity: the hypothetical graviton. Physicists think we will never find the particle because the energy required to demonstrate the graviton is higher than we can generate. The role of gravity in the standard model is thus still unexplained.

CERN

Cern is a European organization that researches elementary particles. It’s located in Genève in Switzerland. There are several scientists from 80 different countries who work together. The experiments are carried out in one of the particle accelerators. The most famous and largest one: the LHC. The purpose of the experiments is to gain understanding into how matter is constructed: which particles make up matter and what are the forces that hold the particles together. The particle accelerator works as follows: it does exactly what its name says: it speeds up particles. Minute particles are fired at each other at high speed. There are about 600 million collisions every second. The particles disintegrate into elementary particles. 7 scanners measure the consequences. Fun fact: the collisions provide enough data to fill 100.000 double-sided DVDs every year.

CONCLUSION

We can therefore conclude that there is so much to learn about the Standard Model in physics. There are already many things that have been proven, but many question marks also remain. Maybe they will be resolved in the future...

Bibliography

- CERN, *The Standard Model*, internet, (1 February 2021).
  (https://home.cern/science/physics/standard-model)

- CIAFALONI, P., *Il Modello Standard delle interazioni elettrodeboli*, internet, (29 January 2021).
  (http://www.dmf.unisalento.it/~ciafalon/ModelloStandard.pdf)

- DEMICHEL, T., *The Standard Model (of Particle Physics) Explained*,3 March 2016.
  (http://factmyth.com/the-standard-model-of-particle-physics-explained/)

- FERMILAB, *The standard model*, internet, 2 October 2012.
  (https://www.youtube.com/watch?v=XYcw8nV_GTs)

- HAWKING, S., *Elementaire deeltjes en het CERN*, internet, 13 June 2020.
  (https://vvn.ugent.be/blog/introductie-tot-de-deeltjesfysica/)

- ISIDORI, G., *Introduzione al Modello Standard*, internet, 2014.
  (http://www.lnf.infn.it/edu/stagelnf/2014/masterclass/slide/11-03-14_Isidori_IIparte.pdf)

- MAYUKH, *The Standard Model Of Particle Physics*, internet, 17 June 2018.
  (https://cosmicescapes.com/the-standard-model-of-particle-physics/)

- MELODY ON TIME, *Atto 1 - Il Modello Standard delle Particelle Elementari*, internet, 6 July 2020.
  (https://www.youtube.com/watch?v=pcOGyB81dDk&list=PL45H2AzHaXEtObKAlLlzUQaghHdGak5rm)

- NOUWEN, A., *Een nieuwe manier om de deeltjes en krachten van het Standaard Model in 3D weer te geven*, internet, 25 oktober 2020.
  (https://www.astroblogs.nl/2020/10/25/een-nieuwe-manier-om-de-deeltjes-en-krachten-van-het-standaard-model-in-3d-weer-te-geven/)

- SCIENZA E PROFESSIONI BIOMEDICHE, *Interazioni fondamentali*, internet, 1 July 2013.
  (INTERAZIONI FONDAMENTALI - ASTRONOMIA - LEZIONE 4)

- SCISHOW, *Weak Interaction: The Four Fundamental Forces of Physics #2*, internet, 8 luglio 2012
  (https://www.youtube.com/watch?v=cnL_nwmCLpY)

- VISSER, H., *Het standaardmodel: waar is alles van gemaakt?*, internet, (26 January 2021).
  (https://npokennis.nl/longread/8029/het-standaardmodel-waar-is-alles-van-gemaakt)

- WIKIPEDIA, *Cern*, internet, 7 January 2021.
  (https://nl.wikipedia.org/wiki/CERN)

- WIKIPEDIA, *Standaardmodel van de deeltjesfysica*, internet, 2 October 2020.
  (https://nl.wikipedia.org/wiki/Standaardmodel_van_de_deeltjesfysica)

- WOLCHOVER, N., VELASCO, S. en READING-IKKANDA, L., *A New Map of All the Particles and Forces*, internet, 22 October 2020. (https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

Figures:

- *Image 1*, Elementary Particles. Taken over from Ghosts in The Universe (https://ghostsintheuniverse.org/theory/)

- *Image 2*, the discovery of atoms. Taken over from CRYSTAL CLEAR CHEMISTRY CLASSES (https://www.youtube.com/watch?v=ffkCsCjYBfA)

- *Image 3*, Composition of neutrons and protons. Taken over from SCISHOW

  (https://www.youtube.com/watch?v=cnL_nwmCLpY)

- *Image 4*, Left/right-handed quarks. Taken over from QUANTAMAGASINE

  (https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

- *Image 5*, Elemenary . Taken over from VISSER, H.

  (https://npokennis.nl/longread/8029/het-standaardmodel-waar-is-alles-van-gemaakt)

- *Image 6*, Quark and leptons generations. Taken over from QUANTAMAGASINE

  (https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/)

- *Image 7*, Quantumfysica (14): Het standaardmodel. Taken over from VONK, M. (https://www.quantumuniverse.nl/quantumfysica-14-het-standaardmodel)

- *Images 8-9*, Function of the W boson. Taken over from SCISHOW

  (https://www.youtube.com/watch?v=cnL_nwmCLpY0)

- *Images 10*, Feynman diagram for the electromagnetic repulsion

  (https://www.google.com/search?q=Feynman+diagram+for+the+electromagnetic+repulsion&sxsrf=ALeKk00nsEiA4n_-RNpDC7LYdUJRgAFTzQ:1612704933660&source=lnms&tbm=isch&sa=X&ved=2ahUKEwjCycqF8tfuAhUO-qQKHQAjAeYQ_AUoAXoECAYQAw&biw=1280&bih=578#imgrc=LvxYVEsX2JjkJM)

- *Image 11*, The forces. Taken over from Derekscope (http://www.derekscope.co.uk/the-universe-20th/the-universe1/the-big-bang/)