YYC Science Bowl

Physics Guide

Beyond Micro and Macro

Introduction

Since the dawn of time, humans were always scared of the unknown. Making our home in the milky way galaxy, there is so much out there that we as humans do not know. We strive to know more and more regarding the world with each year, and while we have made some progress, we are so far away from uncovering the entirety of space. Astrophysics, one of the topics of this year's physics science bowl focuses on applying physics laws to help explain and allow us to understand better about what lies in space. It helps explain the birth, life and death of stars, planets, galaxies, nebulae as well as millions of other objects that are in our galaxy. Get ready to find knowledge that is astronomical yet subatomic, and pay close attention to all the information given.

The topic of this year's Science Bowl Physics guide will focus on the location where humans make their homes, the solar system. There are many forces at work in our solar system, more than just the gravitational and electric forces. The term “Solar System” is not just due in part to the sun being present in this system of planets, moons and space junk. The term is based on the interactions that the objects in the system have on one another, and they are all interlinked together through the presence of the sun. Spanning over 18.75 trillion kilometers and having existed for approximately 4.6 billion years, the solar system may seem large but compared to the rest of space, it is smaller than comparing a grain of rice to the burj khalifa.

Fun Fact #1

The universe is always expanding, and the expansion is getting faster over time. Scientists are pointing towards dark energy and matter for being the reason for the rapid expansion.

Hot and Bright

Discovery

While the Greek astronomers had most of the planets in the solar system, the true detailed discovery of the solar system began in the year 1543. Starting initially with the ideas proposed by *Nicolas Copernicus* in 1543 , the notion that Earth was the centre of the universe was proven to be false. Copernicus believed that the earth rotates on its own axis as well as around the sun. While Copernicus wrote about these ideas in his books, he failed to gain many followers as he did not sticky refute with the ideas that were proposed by the Catholic Church.

Years later, roughly around the year 1632, *Galileo* picked up on the *Heliocentric* model that was proposed by Copernicus but he was condemned for his ideas by the Catholic Church. The book written by Copernicus, On the Revolutions of the Heavenly Spheres, was banned by the church and Galileo was considered a Heretic. Following the condemnation of Galileo, another Pope was chosen who was in favor of the ideas that were proposed by Galileo. This led the Catholic Church to acknowledge that the earth rotated around the Sun, which led to the abolishment of the Geocentric model.

Gravitational Forces

Mass and weight are not the same. Mass is dictated essentially by the amount of "stuff" the object has. It is synonymous with the amount of atoms and objects that would always be constant, regardless of the planet or the force of gravity. Mass is measured in kilograms, while weight is measured in N. Weight is dependent on the force of gravity on the planet, and is measured in Newtons. This distinction is important as it is necessary for any calculations that are involved in this field, and it is generally good knowledge to possess.

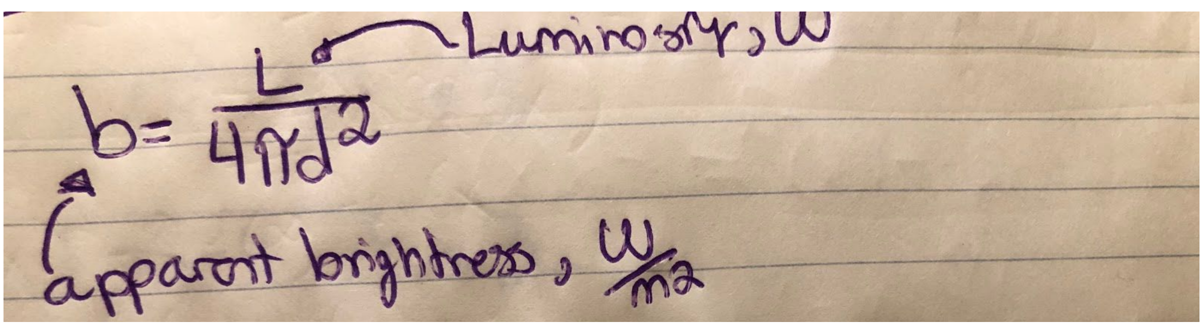
All objects in the world, however small, possess gravitational fields. These fields are areas that surround the object, and can impact other objects that are nearby. While all objects have a field around them, the field around larger objects is noticeable. The gravitational field of an object can be determined through the use of the equation $g=Fg/m$. The gravitational field will always point towards the centre of the mass of the object, meaning that the direction of the field is headed towards the object. The effect of gravity is the strongest as you move closer to the object. This idea led to the basis of Newton's theory that $F_g \propto 1/r^2$.

Another key concept that Newton used to complete his full equation was that the force of gravity is proportional to mass. When he put all the concepts together, he had formed his completed equation. Below is the equation, in various manipulated forms. Note that you will need to be able to manipulate the equation given throughout the competition, as you will be asked about multiple faucets of gravity.

Luminosity

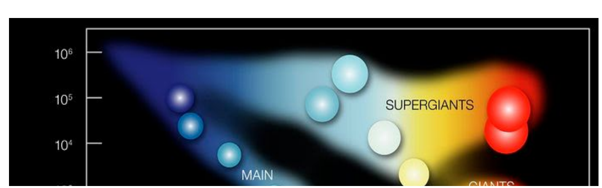
The sun is the source of light in the solar system, and the total power that is radiated by the sun is all the direction is called its luminosity. The unit that is used to calculate this is Watts, similar to the unit that is used for labelling the power of light bulbs. There is a large discrepancy between the power luminosity and the power that is received by an individual on earth. If this was not the case, humans would have been melted into a slush due to the immense power of the sun.

The power that is received per unit is called the star's brightness, and it is measured in watts per meter squared. This value is used as the original luminosity is in Watts, and the distance it travels is given in meters. The luminosity of a star will decrease as the distance increases from the earth, hence the reason why some stars appear brighter than others. The equation given below is used to calculate the apparent brightness, and can be manipulated to find luminosity.



Hertzsprung-Russell(HR) Diagram

One of the most important tools that is used by modern astronomers, physicists and scientists alike is the Hertzsprung Russell Diagram. This diagram was developed by two individuals, Ejnar Hersrpung and Henry Norris Russell. The diagram plots the temperature of the stars against their luminosity, or the color of the stars against their absolute magnitude. The HR diagram allows



physicists to have consistent information as each star goes through different stages throughout its conception to its death. All the stages are accompanied by temperature changes, changes in mass, luminity of the star and the different regions are displayed on the HR diagram.
There are different regions as indicated by the diagram, and most stars fall under the main sequence region. At this stage, the stars are burning hydrogen. Information that can also be gained from this diagram is the distance of the star from earth. In the main sequence, as you start from the upper left, the temperature is the highest and it decreases as you move to the bottom right. The supergiants have exhausted all sources of hydrogen and are now burning helium and heavy elements.
White dwarfs make up the final evolutionary stage, and they have extremely high temperatures but have low luminosity.

A Star is Born

From clouds of dust, a star if formed. These are the remains of previous stars that have fully reached the end of their evolutionary cycles and have died. These clouds consist of hydrogen, helium and an assortment of other heavier elements. When gravity is influencing this nebula, it can form a protostar and at this stage, a process called nucleosynthesis begins.

The process of nucleosynthesis utilizes fusion, where lighter nuclei fuse together and produce a heavier nucleus, along with gamma rays. This process is referred to as the proton-proton cycle, and it occurs on the sun. Stars will continue this process throughout its main-sequence. As indicated by the diagram above, the Sun is currently following this cycle.

Death of a Star

After all helium is used up by the star, the core collapses and along with additional gravitation pressure, the core of the star, made of helium, will start to undergo fusion. This causes rapid expansion in the outer layers and the other layers are cool, which causes this star to be referred to as a red giant. After all sources of fuel run out, the red giant collapses.

As the fuel gets used up, the thermal pressure of the star increases, and the star begins to get smaller. This is why the diameter of white dwarf stars dwarf in comparison to red giants. As the star becomes smaller, all the electrons in the star become to get closer to one another, and be compressed.

Due to electrons being Fermions, more on that later, they cannot be compressed into the same state. The electrons produce electron degeneracy pressure, and this causes the white dwarf from constantly getting smaller. At this stage, the dwarf would fall into a state of equilibrium, where the electron degeneracy pressure counteracts the power of gravity, and this would be the final stage of the death of a star. This was changed due to discoveries made by Subrahmayan Chandrasekhar.

Chandrasekhar Limit

A white star, the end stage for the majority of all stars, occurs after red giants have collapsed. The Chandrasekhar limit is the maximum mass of a stable white dwarf, and it is found by Subrahmayan Chandrasekhar, an Indian-American Physicists and one of the greatest Scientists of the 20th century.

He theories that the force of gravity would be stronger than the electron degeneracy pressure, as there would be only so much force that the electron degeneracy pressure could exert again the force of gravity. He believed that if a star had a mass so immense, the force of gravity of that star would be greater than the force electrons could exert. This mass was referred to as the Chandrasekhar limit.

One of the main uses of the Chandrasekhar limit is the ability to be able to know what the star is going to turn into. Following the stage where the star turns into the red giant, there are different possibilities for the next stage of the star. If the mass of the star is 1.44 times the mass of the sun, then instead of a red giant becoming a white dwarf, the red giant becomes a super red giant. When the super red giant dies, it either becomes a black hole or a neutron star. If the mass of the star is less than 1.44 times the mass of the sun, then the red giant forms a white dwarf. This white dwarf cools until it becomes invisible.

To derive or even use this limit, one needs to have an expansive understanding regarding the laws of physics and have an extensive knowledge in math. Due to this, any questions that regard this limit will provide you with the required formulas and equations.

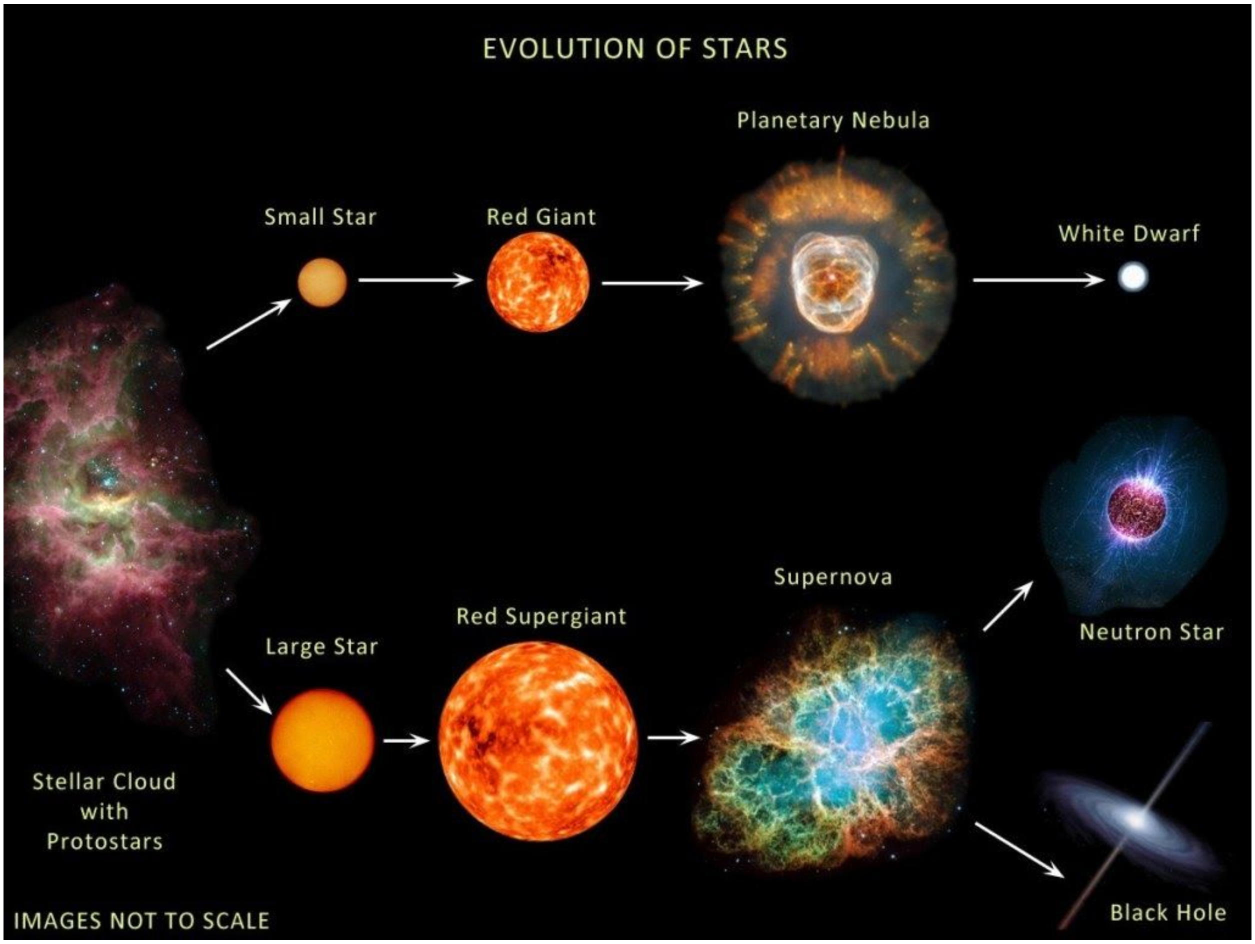


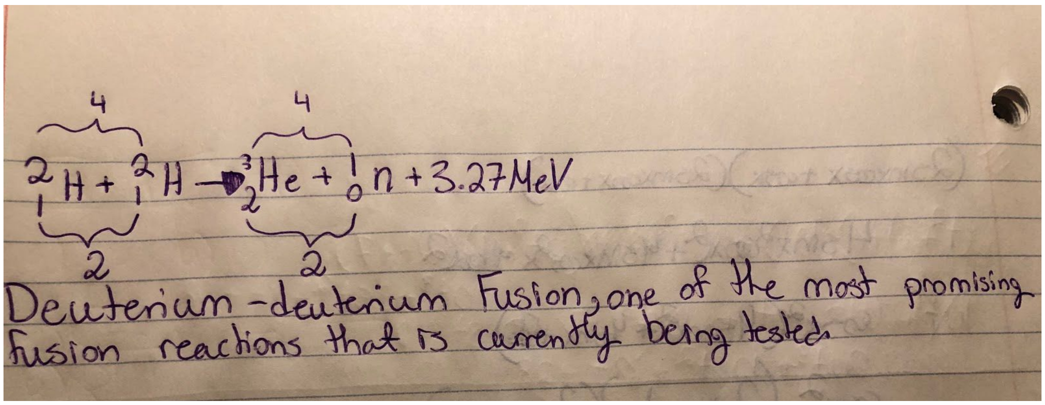
Diagram of the evolution of the star, and the different final forms of the stars.

Fusion

The Sun itself is an absolute giant. Literally. The Sun accounts for over 99.68% of the total mass of the solar system. The sun weighs 1.989 times 10^30 kg. The heaviest man on earth, John Brower Minnoch had the reported weight of 636 kg. The sun weighs approximately 3.13 times 10^27 of that man. On a more scientific note, the sun works through the means of nuclear fusion. This method of energy works on the principle. When two atoms of hydrogen come together and FUSE, it creates an atom of Helium. Fusion only occurs when the atomic mass number of the nuclei is less than 60.

As the mass of Helium is 1.01 u, this follows the rule. This causes the nucleus to be more tightly bound. The fusion reaction gives off energy that is equal to the difference between the total binding energy of the original nuclei and the binding energy of the product. The process of fusion requires high temperatures and pressure to overcome the electrostatic repulsion. While this occurs in the sun, fusion reactors and fusion energy have both been contending ideas that are presented as alternatives to fossil fuels. The waste products of the fusion reactions are stable elements and not radioactive, which would make these a safe and reliable source of energy.

Below is a written equation of what a fusion reaction can look like. Ensure that you understand all the aspects of the diagram that is shown below.



Question Set 1

The following equations and questions that are provided below are regarding the information provided in the previous page. Feel free to practice, memorize and understand the following concepts and information as they will play a key role throughout aspects of the competition. The questions listed are meant to test a basic level of understanding, and the questions during the actual competition will utilize similar structure, but will not be exactly the same. Answers for the questions are provided at the bottom of the page, but ensure that you attempt the questions first for the most experience.

1. Deuterium-helium-3 fusion

$^{2}_{1}H + ^{3}_{2}He \rightarrow ^{4}_{2}He + ^{1}_{1}H + 18.3\,MeV$

Deuterium-helium-3 fusion. Helium-3 (He3) is a gas that has the potential to be used as a fuel source, but it does not exist in abundance on earth. It is believed that there are significant supplies on Mars.

2. Who initially proposed the Heliocentric model, and in what year?
    a. Copernicus, 1632
    b. Galileo, 1543
    c. Copernicus, 1534
    d. Galileo 1632
3. If the mass of the sun is 1.989 times 10^30 kg, how much does an individual weight, if the force of gravity is 3.48 N and the distance between the sun and the individual is 19000m. (Use the

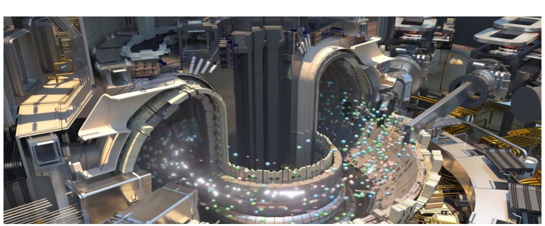
    Answer:

4. What is the effect on the force of gravity as the distance from the object increases?
    a. There is no change
    b. Inverse squared relationship
    c. Inverse relationship
    d. Squared relationship

Answer: 2C, 4B, 3()

Fusion Energy and Decay

Currently on earth, there are no fusion reactors or fusion power plants but they are proposed to be built in the United Kingdom by the year 2040. When fusion atoms together, there is approximately 4 million times the level of energy given off than fission. Based on the new developments regarding the impacts that humans are having on the planet, it is of the utmost importance to ensure that there is the creation of renewable and sustainable energy. While it is not currently available to us at this time, fusion energy can lead to new innovations and can sustain many generations to come on the earth.



Fun Fact #2

The International Thermonuclear Experimental Reactor has recently reached the halfway point. It is located south of France.

The nuclear plants that are currently working on the planet are running through the process of nuclear fission. While this process is a great alternative fossil fuels, it is much more inefficient than the nuclear fusion reactors. This process also creates a radioactive byproduct which is much harder to get rid of as it causes chemical damage and harm to animals, humans and the planet. The process of which this radioactive material causes damage is through the process of beta decay.

Beta Decay

The process of beta decay is an essential process that occurs during the process of nuclear fission. There are two different methods that can result in the production of Beta decay, which are Beta negative and Beta positive decay. The most common/well known Beta decay was the beta negative decay, as it was observed by Ernest Rutherford. An electron is released in the process of Alpha decay, and this electron is referred to as a Beta particle. The notation of the beta particle is denoted by the symbol of β^-. Along with the release of the beta particle, there is the release of an antineutrino.

The antineutrino was made as when physicists took a more detailed look at the Beta Decay process and realized that it did not follow the conservation laws. Due to electrons having such a small mass, (9.109×10^{-31} kilograms), scientists believed that they would shoot out of the nucleus at extreme speed, which would follow the already established laws of conservation of momentum and energy. This caused scientists to come up with the antineutrino. This is a neutral particle that is emitted in the process of Beta Decay along side with the beta particle. The following Beta negative decay is shown below.

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}B + \bar{v}$$ antineutrino, indicated by the line over.

Beta Negative Decay

Alternatively, Beta Positive Decay can also occur. This process is the opposite of the process of Beta negative decay, and instead of the electron being released, a positron is released. The positron is also referred to as the antielectron, as it is essentially the electron but with a positive charge. They have the exact same mass, but instead of having the charge of -1, their charge is +1. If you notice in the diagram below, the neutrino looks different than the one that was in Beta Negative decay. This is because during the beta positive decay, a neutrino is released rather than an Antineutrino.

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{1}B + v$$ neutrino

Beta positive Decay

Questions #2

1. What is the difference between Beta Positive and Negative Decay?
    a. There is no difference

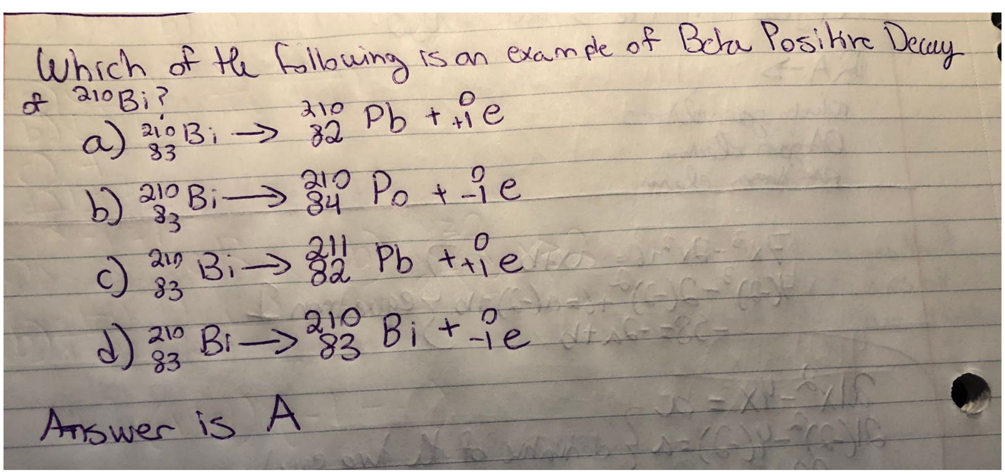
b. Anti neutrino is released during Beta negative and neutrino is released during Beta positive
c. Anti neutrino is released during Beta negative and neutrino is released during Beta positive; Positron is released by Beta negative
d. Anti neutrino is released during Beta negative and neutrino is released during Beta positive; Positron is released by Beta Positive

Answer: D

2. Write an example of a Beta Positive and Beta Negative Decay. Hint(It would be in your favour to memorize the examples you will write down). Use values from your period tables.

   a. Beta Negative Decay

   b. Beta Positive Decay

3. 

Which of the following is an example of Beta Positive Decay of ^{210}Bi?

a) $^{210}_{83}Bi \rightarrow {}^{210}_{82}Pb + {}^{0}_{+1}e$

b) $^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e$

c) $^{210}_{83}Bi \rightarrow {}^{211}_{82}Pb + {}^{0}_{+1}e$

d) $^{210}_{83}Bi \rightarrow {}^{210}_{83}Bi + {}^{0}_{-1}e$

Answer is A

The Subatomic Zoo

Fundamental

Throughout the last century and through the use of bubble and gas chambers as well as high energy accelerators, over 300 different fundamental particles have been found. The list of all the different fundamental particles are now classified as the subatomic particle zoo. Fundamental particles are separated into two sections, one that are the Quarks and one that is the Leptons. Quarks are believed to be the building block of Hadrons.

Spin

Spin is the angular momentum of the particles, and it is different between the particles. If the Spin is a half integer value (3/2, 5/2) then it is called a Fermion. If the spin is a whole integer (0,1,2), they are called bosons.

Distinction

The distinction between the Hadrons and Leptons is that Leptons do not interact using strong nuclear force. There have also been only 6 Lepton particles that have been discovered. Leptons also have half integer spin, which makes them fermions. Hadrons interact through strong nuclear force, and there have been over 100 discovered. Hadrons can be further broken down into Baryons and Mesons. Mesons have an integer spin, which makes them bosons and Baryons have half integer spin, which makes them fermions.

Quarks

Hadrons are much larger than Leptons, and due to the existence of many different Hadrons, it is believed that they are created from a smaller building block, known as Quarks. An up Quark has the charge of $+\frac{2}{3}$, and is written by the symbol of u. A down Quark has the charge of $-\frac{1}{3}$ and is written by the symbol of d. These two Quarks, up and down, are called the first generation quarks. The quarks are held together by the strong force, that is carried by particles known as Gluons.

At any given time, a proton contains 2 up quarks and 1 down quark. These quarks are known as the valence quarks. A proton may also contain an up quark and an anti up quark pair. The Quarks that make up the proton contain 1% of the total mass of the proton. A neutron contains 1 up and 2 down quarks, and an electron contains 3 down quarks. If a quark with the charge of $+\frac{2}{3}$ appears, another partner quark must have the charge of $-\frac{2}{3}$. The spin of the particles must also be opposite.

During an experiment of a proton collision with a nucleus, the product of the collison lived for longer than expected and this caused Scientists to come with the Strangeness aspect of the particle. They believed that the product was made up of an up, down and a strange quark. This led to the creation of new conservation laws, known as the conservation of strangeness. The strange quark is denoted by the letter s. The full evidence of the strange quark was found during the Stanford Linear Accelerator Center, when electrons were shot at protons. This led to the proof of the existence of the strange quark.

Higgs Boson

In 1964, Peter Higgs, came up with the idea of the Higgs field. Along with the work of others, he believed that there existed a field that was spread throughout the entire universe and pervaded it. It is believed that the Higgs field provides mass to elementary particles. Elementary particles are the most fundamental and basic building blocks of the universe, and these include Quarks. According to the current standard model, it is believed that there are fermions and bosons. The fermions make up matter, and they have a half integer spin, and the Bosons carry forces, and they also have a half integer spin.

When particles interact with the Higgs field, they gain mass. The more they interact with the field, the more mass they gain. The Higgs field is composed of Higgs boson, and the Higgs bosons are elementary particles. Some particles, such as Photons, go straight through the field without much interaction, which correlates to the Photons having no mass.

Thank you for taking the time and reading the Physics Guide. If you read through this material and understand the key concepts, you will do great during the competition. If you have any questions or concerns, feel free to email us for further clarification.

Sources:

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13. Topic 7: Atomic, nuclear and particle physics