Study Guide: The Four Fundamental Forces

Einstein

- Full name: Hans Albert Einstein.
- Born: 14 March 1879, in Ulm, Germany
- Died: 18 April 1955, in Princeton, US
- Very imaginative and dreamy as a child.
- Was considered a poor and disobedient student in school because he asked too many questions.
- Loved learning math.
- Studied in Milan, Italy, where his curiosity and questions were welcome.
- Wrote several scientific papers at an early age, but they were ignored due to his youth.
- In 1905, a year sometimes described as his *annus mirabilis* ('miracle year'), Einstein published four groundbreaking papers.
- Moved to Switzerland, where he was very happy and met his first wife.
- Always enjoyed spending time alone, hiking in the woods, and thinking.
- Enjoyed playing the violin.
- Had an odd appearance because he did not care what others thought of appearances. Did not comb his hair; often forgot his keys; often forgot to eat.
- Moved to Germany where he met his second wife, Ilse.
- Developed the Theory of Relativity, $E = mc^2$, which unified our understanding of energy, matter and light.
- Moved to the US due to threats on his life by the Nazis.
- Helped develop the atomic bomb because although he opposed militarism, he felt it would be even worse if the Nazis developed it first.
- Supported the creation of Israel as a homeland for Jews, but came to oppose Zionism due to the treatment of Palestinians.
- Was happily married for many years to Ilse, and until her death.
- In later years, lived quietly alone in Princeton, and continued to play his violin.
- Died quietly while working on an equation.

The Four Fundamental Forces

The familiar force of gravity pulls us down toward the Earth's center. We feel it as weight. Why don't we fall through the Earth—through matter? Another force, **electromagnetism**, holds all atoms together, preventing one atom from intruding into the space of another atom.

The remaining two forces exist at the subatomic level which—despite our being made of atoms—we can not directly sense. The **strong force** holds the **nucleus** together. The **weak force** is responsible for **radioactive decay**, specifically, $beta$-decay (beta decay), in which a neutron within the nucleus changes into a proton and an electron, and the electron is then ejected from the nucleus.

Strong Force

The strong nuclear force is the strongest of the four fundamental forces of nature. It is so strong that it can be thought of as glue (the universal glue). It's 6 thousand trillion trillion trillion (39 zeroes after 6) times stronger than the force of gravity. It binds fundamental particles of matter together to form larger particles. The strong force works 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.

Reality is stranger than fiction, and the strong force is one of the strangest phenomenon. Unlike the other fundamental forces, it gets weaker as subatomic particles move closer together. It actually reaches maximum strength when the particles are farthest away from each other. You may have heard the many strange names scientists give subatomic particles. This is their attempt to describe this strange behavior. Once within range, massless charged **bosons** called **gluons** transmit the strong force between **quarks** and keep them "glued" together. A tiny fraction of the strong force called the **residual strong force** acts between **protons** and **neutrons**. Protons in the nucleus repel one another because of their similar charge, but the residual strong force can overcome this repulsion, so the particles stay bound in an atom's nucleus.

Weak Force

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

The weak force is critical for **nuclear fusion reactions** that power the sun and produce the energy used by most life forms on Earth. It's also why archaeologists can use **carbon-14** to date ancient bone, wood and other formerly living artifacts. Carbon-14 has six protons and eight neutrons; one of those neutrons decays into a proton to make **nitrogen-14**, which has seven protons and seven neutrons. This decay happens at a **predictable rate**, allowing scientists to determine how old such artifacts are.

Electromagnetic Force

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, but would be very small at great distances.

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 aspects of a single force.

The **electromagnetic force** is responsible for some of the most commonly experienced phenomena: **friction**, **elasticity**, the **normal force** and the force holding **solids** together. It's even responsible for the drag that birds, planes and Superman experience while flying. These actions occur because of charged particles interacting with one another.

The **normal force** that keeps a book on top of a table (instead of gravity pulling the book through the table toward the center of the earth), is a consequence of electrons in the table's atoms repelling electrons in the book's atoms. Luckily for us, the same force allows us to stand on the earth.

Unified Field Theory

One of the biggest questions in science is about the four fundamental forces. Is it possible that they are actually different manifestations of a single great force of the universe? For example, can they be combined in the same way that the electric and magnetic forces have been theoretically unified? If so, each force should be able to merge with the others. Einstein believed there was such a force. He spent most of his life unsuccessfully trying to find it. There is already some evidence that such a force exists, but no one has yet been able to demonstrate it.

Physicists Sheldon Glashow and Steven Weinberg from Harvard University with Abdus Salam from Imperial College London won the Nobel Prize in Physics in 1979 for unifying the electromagnetic force with the weak force to form the concept of the **electroweak force**.

Physicists working to find a so-called grand unified theory aim to unite the **electroweak force** with the **strong force** to define an **electronuclear force**, which scientific models have predicted, but researchers have not yet been able to observe.

The final piece of the puzzle would then require unifying gravity with the electronuclear force to develop the so-called **theory of everything**, a theoretical framework that could explain the entire universe.

The Large and Small Of It

Physicists have found it especially difficult to merge what is known of the **microscopic world** (very small phenomenon) with what is known of the **macroscopic world** (very large phenomenon).

At **astronomical scales**, the force of gravity dominates and is best described by Einstein's **theory of general relativity**. But at the **molecular scale** (atomic or subatomic), **quantum mechanics** best describes the **natural world**. So far, no one has found a theory that can accurately describe both of these aspects of reality, although it seems obvious that they must be part of one universe.

Where are all the gravitons?

Physicists studying **quantum gravity** aim to describe the force in terms of the quantum world. Fundamental to that approach would be the discovery of **gravitons**, the theoretical **force-carrying boson** of the gravitational force. Gravity is the only fundamental force that physicists can currently describe without using force-carrying particles, but because descriptions of all the other fundamental forces require force-carrying particles, scientists expect that **gravitons** must exist at the subatomic level—they just haven't found them yet.

Dark Matter

Further complicating the story is the invisible realm of **dark matter** and **dark energy**, which seem to make up roughly 95% of the universe. It's unclear whether dark matter and energy consist of a single particle or a whole set of particles that have their own forces and **messenger bosons**. Dark matter can also be thought of as **Antimatter** because (Normal) Matter and Antimatter have complimentary properties:

- All particles have antiparticles!
- Antimatter has the same properties as matter, including the same mass, spin, and interactions, except that...
  - Matter and Antimatter have opposite electric charges.
  - Matter and antimatter can annihilate each other to create pure energy, or conversely, energy can create pairs of matter and antimatter. $E = mc^2$

The Fifth Fundamental Force

One messenger particle that currently interests scientists is the theoretical **dark photon**, which would mediate interactions between the visible and invisible universe. If dark photons exist, they'd be the key to detecting the invisible world of dark matter, and could lead to the discovery of a fifth fundamental force. So far, though, there's no evidence that dark photons exist, and some research provides strong evidence that they can not exist.