FUNDAMENTAL PARTICLES CLASSIFICATION

Fermions

Quarks

(protons, neutrons)

Leptons

(electrons, muons and neutrinos)

commonly thought of as "matter"

Gauge Bosons

(photons and gluons)

commonly thought of as "radiation"

FERMIONS

--Fermions are generally structures you associate with "matter."

--In an atom, no two fermions can occupy the same quantum state. That is, they are said to obey "the Pauli Exclusion Principle."

--This characteristic is what gives atoms their apparent rigidness.

--This characteristic also makes an electron's shell stable.

--Fermions are said to have "half-integer" spin.

QUARKS

Up and Down

What makes up everyday matter

proton

--2 UPs (+2/3 ecu each), 1 DOWN (-1/3 ecu)--net charge +1 elementary charge unit

neutron

--2 DOWNs (-1/3 ecu each), 1 UP (+2/3 ecu)--net charge neutral

Strange and Charm

(same as UP and DOWN but more massive)

Top and Bottom

(same as STRANGE and CHARM but more massive)

BOSONS

--Bosons are generally associated with radiation and are sometimes characterized as "force carrier particles."

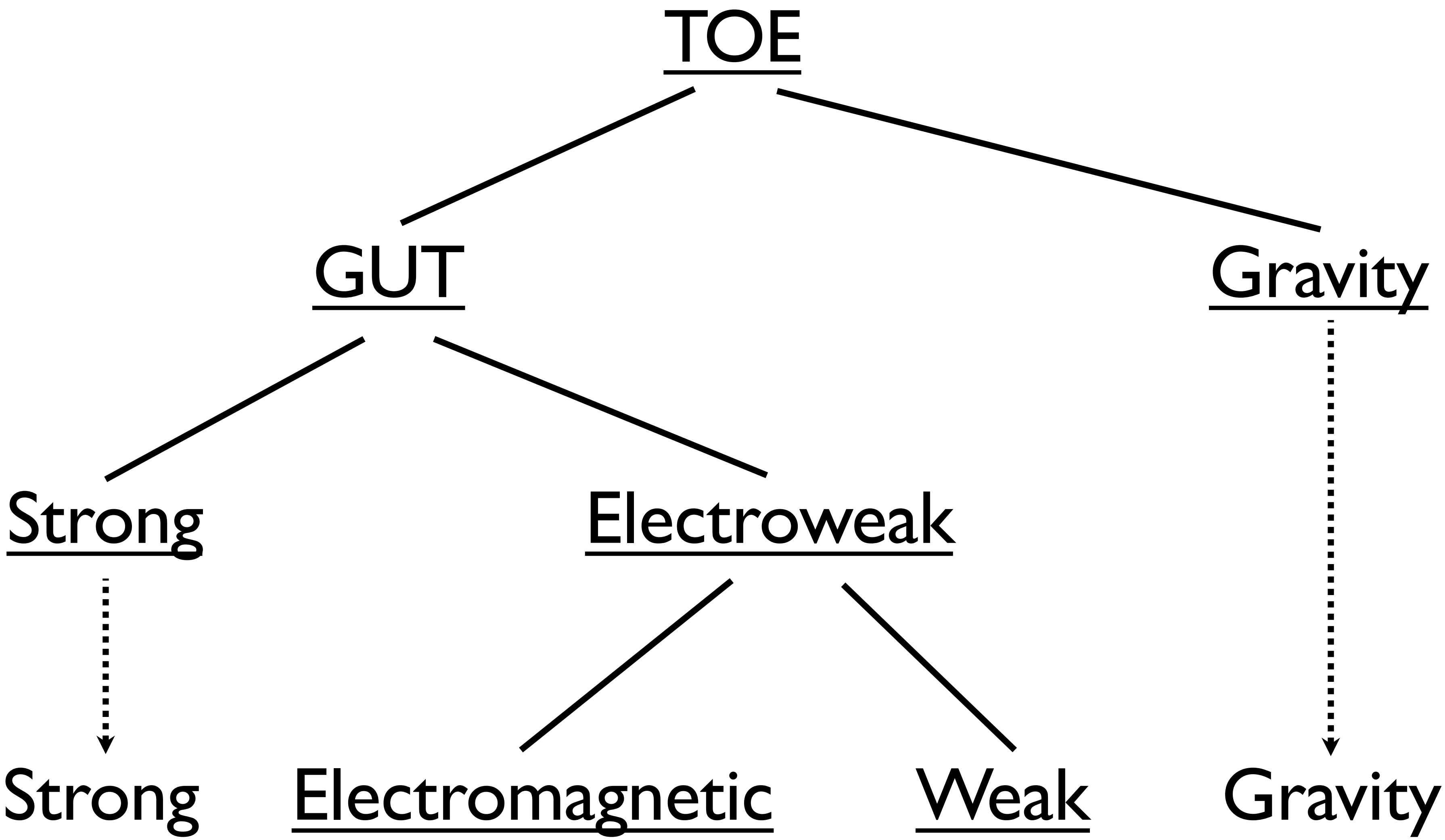
--Bosons do not obey the Pauli Exclusion Principle.

--This means many bosons can occupy the same quantum state..

--This characteristic allows LASERS to exist.

--Bosons are said to have "integer" spin.

FUNDAMENTAL FORCES



FUNDAMENTAL FORCES-- TIME LINE

--During the “Planck” era before 10^{-43} seconds after the Big Bang, all four “elementary” forces were a part of one, single force and the laws of physics as they stand today did not hold!

--Gravity became distinct at the beginning of the GUT period at around the 10^{-43} seconds mark (after the Big Bang), leaving the electroweak and strong forces as one. (Note that the GUT period may have ended with inflation.)

--At the end of the GUT period at around 10^{-40} seconds after the Big Bang, the strong force became distinct leaving the electromagnetic and weak forces as one (this was called the “electroweak forces”).

FUNDAMENTAL FORCES-- TIME LINE

--At around 10^{-10} seconds after the Big Bang, the electroweak force split into the electromagnetic force and the weak force.

--In other words, by around 10^{-10} seconds after the Big Bang, there were four distinct forces in the universe, the gravitational force, the strong force, the weak force and the electromagnetic force.

A WORD ABOUT GRAVITATION

--The gravitational force (or gravitational interaction) acts between any two massive objects.

--Gravity is the weakest of the fundamental forces being 10^{-38} times as strong as the strongest fundamental force, the *strong force*.

--On the other hand, gravity is one of the two longest ranged forces extending, at least theoretically, to infinity.

--If you want to think of the gravitational force being an exchange of particles, the gravitational intermediary is called a "graviton."

A WORD ABOUT the STRONG FORCE

--The strong force (or strong interaction) acts between quarks, anti-quarks and gluons.

--The theory that describes its action is called "quantum chromodynamics," or QCD (we're talking "cocktail heaven," here)

--The strong force is the strongest of the fundamental forces being approximately 10^{38} times strong than gravity (this is $6x10^{-39}$ going the other way)

--The strong force has an incredibly short range--no more than the diameter of a proton. Outside that range, the force drops off as $1/r^4$.

--The strong force is mediated by gluons (i.e., this is how quarks interact with one another).

MORE WORDS ABOUT the STRONG FORCE

--A residual effect of the interaction between quarks, etc., is the strong nuclear force that holds protons together in the nucleus of an atom.

--When within range, the strong nuclear force is approximately 1000 times stronger than the repulsive electromagnetic force between two side-by-side, like-charged protons in an atomic nucleus.

--Minor note: The binding energy between two protons via the strong interaction is around 25 MeV. The electromagnetic repulsion has an energy equivalent of around 24 MeV. In other words, it only takes around 1 MeV of energy to split up protons in a nucleus.

A WORD ABOUT the ELECTROMAGNETIC FORCE

--The electromagnetic force (or electromagnetic interaction) acts between charged particles.

--The electromagnetic force is the second strongest of the fundamental forces.

--The electromagnetic force is one of the two longest ranged forces extending, at least theoretically, to infinity.

--The electromagnetic force is mediated by photons.

A WORD ABOUT the WEAK FORCE

--The weak force (or weak interaction) acts between left-handed leptons and quarks. (No, this is not a joke. Remember, leptons are, like, electrons, etc.)

--NOTE: What you and I call an electron is really a massive particle that carries a charge and has the possibility of having two spin states (these are the easily observable characteristics we associate with an electron) coupled with a nearly massless neutrino that has only one spin state. This neutrino spin state is called "left-handed" spin. Anti-neutrinos have the other type of spin possible, or "right-handed" spin.

--In any case, the weak force is mediated by extremely massive W and Z bosons.

WORDS ABOUT the WEAK FORCE

--The weak interaction force-carriers are so massive, the Heisenberg Uncertainty Principle limits the average amount of time that they can exist to around 3×10^{-27} seconds.

--At the speed of light, this means they can travel, on average, only 10^{-18} meters. In other words, they can't travel more than, maybe, 1/1000 of the diameter of an atomic nucleus before decaying into something else.

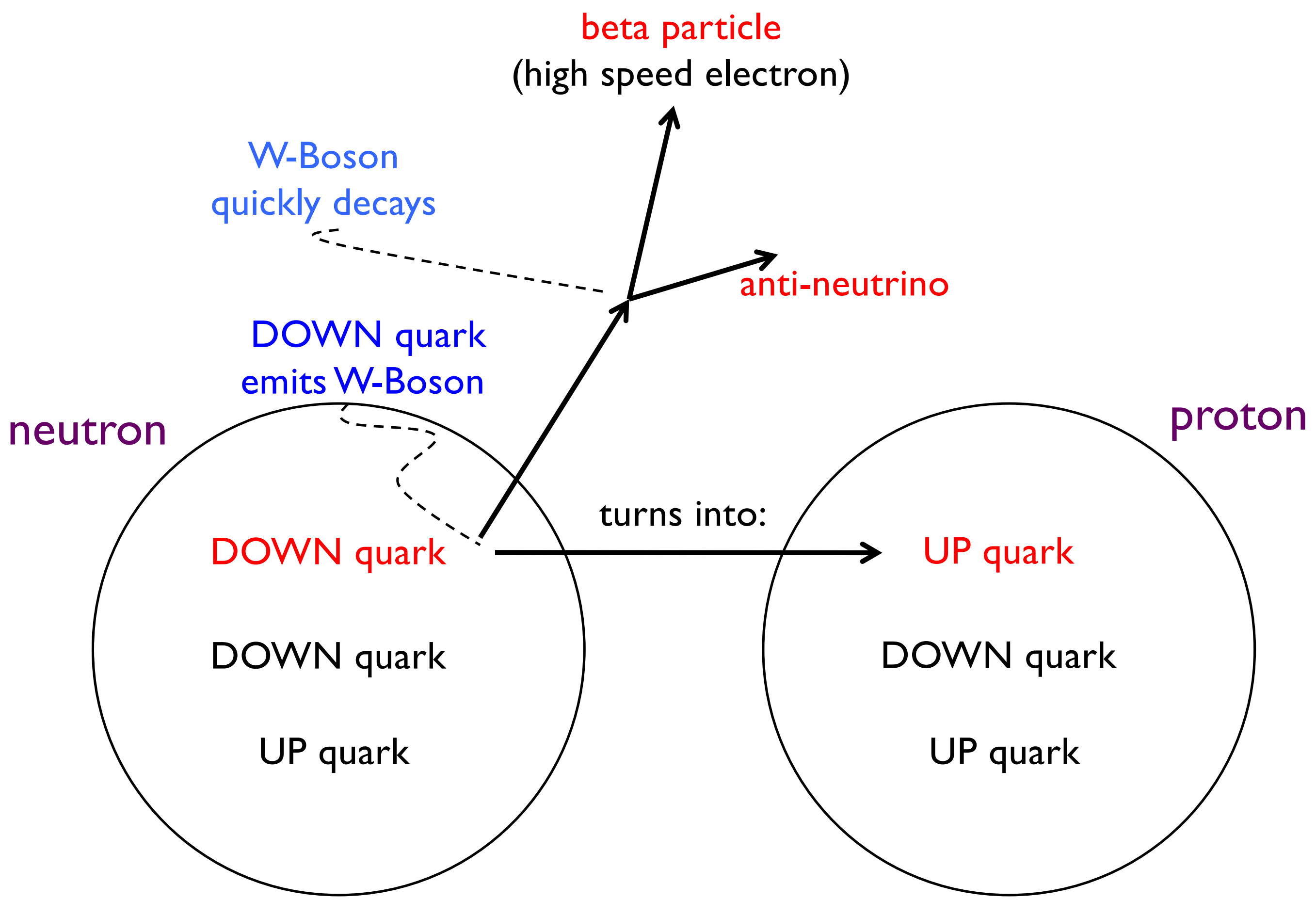
--This extremely short range (of the interaction) means that our primary observations of their existence (and the existence of this "weak interaction") comes from secondary effects the most notable being beta decay.

STILL MORE ABOUT the WEAK FORCE

In atoms that have "too many" neutrons, beta decay can occur whereupon a neutron (2 DOWN quarks and 1 UP quark) changes "flavor" when one of its DOWN quarks emits a W-boson (radiation) and turns into an UP quark in the process. This leaves the particle with 1 DOWN quarks and 2 UP quarks, which is a proton.

As a consequence, the atomic mass (number of nucleons) of the atom doesn't change but it's atomic number (number of protons) increases by 1.

Meanwhile, the W boson shortly thereafter decays into a high energy electron (the "beta" particle) and an anti-neutrino (a nearly massless particle).



Net effect: A neutron turns into a proton while emitting an electron and neutrino, the the number of nucleons doesn't change but the number of protons increases by 1.

STILL MORE INFO ABOUT the WEAK FORCE

NOTE: By knowing how this process works, it is obvious why most people think of the operation as an "interaction" instead of a "force."

Aside from the fact that the type of atom changes in the process, what is observed when the weak interaction occurs is a high energy electron leaving the site.

Force	Relative Strength Within Nucleus	Relative Strength Beyond Nucleus	Exchange Particles	Major Role
Strong	1	0	gluon	Hold nuclei together
Electromagnetic	1/137	1	photon	chemistry n biology
Weak	10^{-5}	0	weak boson	nuclear attraction
Gravity	$1.7x10^{-40}$	10^{-43}	graviton	large-scale structures

In a little easier form, the strong force is 137 times stronger than the electromagnetic force, 100,000 times stronger than the weak force and 6,000 billion billion billion billion (approximately 10^39) times stronger than gravity.