

Particle Interaction Summary/Review

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From Quantum Mechanics to the String
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- Special relativity and quantum mechanics together imply the existence of anti-particles
 - special relativity treats negative and positive energies the same, implies the existence of an infinite tower of negative energy states (rather than a ground state)
 - we make sense of this by assuming all negative energy states are filled: the universe is full of negative energy particles
 - we *define* this as the zero energy, zero charge state
 - a hole in this “sea” of negative energy states has positive energy and the opposite charge: it is an anti-particle
 - a particle/anti-particle pair can be created out of energy when a particle moves from a negative energy state into a positive energy state. The pair can then annihilate by it falling back into the negative energy state.
- Forces are mediated by the exchange of virtual particles
 - the exchange of photons is responsible for the electromagnetic force
 - the photon carries momentum and energy being exchanged between the charged particles. In order to do this, it must use the quantum uncertainty in the virtual particle. It exists only for a short time and is never directly measured. The larger the momentum and energy being exchanged is, the more uncertainty there must be to account for it.
 - the larger the distance between the charged particles, the longer the virtual particle must exist, and the less uncertainty there is about it. This means the effect of the exchanged mediator particle must be smaller.
 - if the mediator particle is massive, there is a minimum necessary uncertainty corresponding to the mass energy of the mediator. This creates an effective range beyond which the associated force must drop rapidly to zero.
 - the attractive force between particles in the nucleus of an atom has an effective range like this. The pion has the correct mass and properties to be the mediator for the nuclear force.
- Conservation Laws determine what particle interactions can and can't occur
 - energy, momentum, angular momentum (spin), charge, and quark number are all conserved charges.
 - If a particle interaction is not expressly forbidden by some conservation law, it must occur. This means that a particle is only stable if it is protected by some conservation law.
 - the electron is stable because it is the lightest negatively charged particle, the proton because it is the lightest particle with non-zero quark number.
 - the neutron is unstable, it decays into a proton, an electron, and a neutrino. The existence and properties of the neutrino were deduced from this decay; without it energy, momentum, and angular momentum are not conserved.
 - the pion is unprotected by any conservation laws, therefore it is unstable.
- the vacuum is not really empty because virtual pairs of electrons and positrons are constantly popping into and out of existence (within quantum mechanical uncertainty). The net effect is to shield charges in the vacuum so that the farther away from them you are, the smaller they seem.