8.6: Photon Used to Create Mass

proton hits proton, creates proton-antiproton pair

Particles other than the photon can also create particles. A particle of any type can carry enough energy to create particles similar to or different from itself. Each such creation must not only follow momenergy conservation laws of special relativity, but is also subject to the law of conservation of total electric charge and other conservation laws, as described in elementary particle physics.

Any energetic particle can create other particles

Box 8.1 BACKYARD ZOO OF PARTICLES

This is not a textbook of particle physics, but our examples include interactions between common particles. Here are brief descriptions of some of them.

Electron

Electrons form the outer structure of every atom and rattle around in approximately 99.99999999999percent of its volume. The mass of the electrons of an atom, however, accounts for only about one two-thousandth of its mass or less. The electron carries a negative "elementary" electrical charge. Every accepted theory of particle physics treats the electron itself as an elementary particle - it is not made up of anything more fundamental. The positron is the antiparticle of the electron, with the same mass but a positive elementary charge. When positron and electron meet, sooner or later they mutually annihilate, yielding two or more high-energy photons (gamma rays). This will be the fate of the positron and one of the electrons in the polyelectron discussed in Section 8.5 soon after they begin to orbit one another.

Proton

The proton (Greek for "the first one’") is, with the neutron, the most massive constituent of atomic nuclei. The sirnplest atom, hydrogen, in its most abundant form has a single proton as nucleus. The proton has a positive charge equal in magnitude to that of the electron, but a mass almost two thousand times as great as that of the electron. As far as we know the proton is stable; experiments have shown its lifetime to be greater than 10^{31} years - very much longer than the current age of the universe (about 10^{10} years). Particle physicists postulate that protons (and neutrons) are composed of still-moreelementary particles called quarks. The antiproton, antiparticle of the proton, has mass equal to that of the proton but negative unit charge. When it encounters a proton, the two particles annihilate, sometimes creating gamma rays but more often other particles not listed in this box.

Neutron

The neutron (from Latin neuter - "neither’" ; neither positively nor negatively charged) is similar to the proton but has no charge and has slightly greater mass. It is a constituent of all nuclei except for the most abundant form of elementary hydrogen. When not in a nucleus, the neutron decays into a proton, electron, and neutrino with half-life of about 10 minutes.

Photon

The photon, the quantum of light, has zero mass. Its properties are described in Section 8.4.

Neutrino

There are several kinds of neutrinos, all of which appear to have zero mass and to move at light speed. The neutrino (ltalian for "little neutral one"’) has no charge and interacts only weakly with ordinary matter: Neutrinos of certain energies can pass through a block of lead one light-year thick with only a $50-50$ chance of being absorbed! An immense flux of neutrinos passes continually through our bodies without injuring us. "Ten million trillion $\left[10^{19}\right]$ neutrinos will speed harmlessly through your brain and body in the time it takes to read this sentence. By the time you have read this sentence, they will be farther away than the moon."

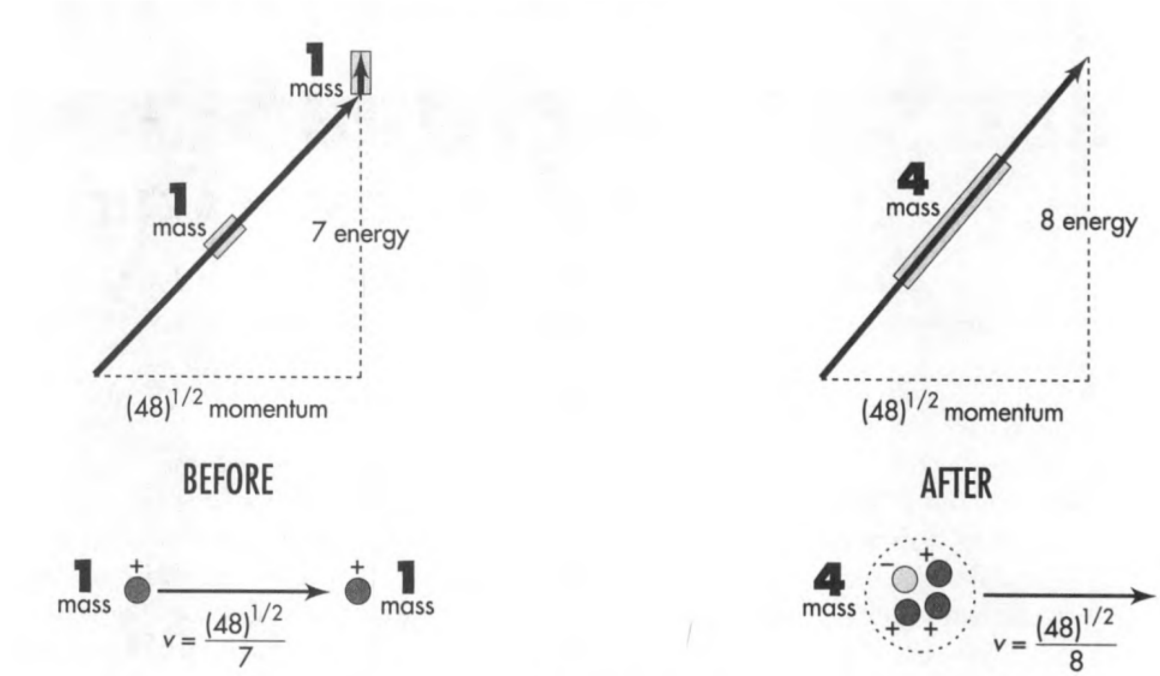

Figure 8.6.1: Conservation of energy and momentum in the process of creation of a protonantiproton pair by the impact of a proton on another proton. Before: The incoming proton (sloping arrow) moves with a speed $(48)^{1/2}/7 = 99$ percent that of light. The target proton initially stands at rest (vertical arrow). After: The resulting three protons and one antiproton are kicked to the right at $(48)^{1/2}/8 = 87$ percent of light speed.

Threshold energy defined

Figure $8.6.1$ shows "the creation of a proton-antiproton pair by a proton in the presence of another proton." "The antiproton has mass equal to that of the proton but carries a negative unit charge (Box 8-1). The interaction shown leaves all four resulting particles moving along together. The resulting particles stay together when the incoming particle has the lowest energy that can create the additional pair. This minimum energy is called the threshold energy. We don't want the four particles to move apart after the creation. If they did, we would have to supply the incoming particle with additional kinetic energy. It would have to carry an energy greater than the threshold energy. We discuss here the threshold energy of the incoming proton.

Magnitudes of the momenergy vectors displayed in Figure $8-9$ are expressed in " "natural units" for the proton, namely the mass of the proton itself, 1.67×10^{-27} kilograms or $938.27 \mathrm{MeV}$. This time the numbers are not all integers: the momentum of the system has a value equal to the square root of 48, or 6.928 proton masses.

"Efficiency" of particle production

The creation of a proton - antiproton pair by a PROTON requires a total of eight proton units of energy to create two proton units of mass. In contrast the creation of an electron-antielectron pair by a PHOTON requires a total of only four electron units of energy to create two electron units of mass. Why is the photon process so much more efficient (in units of mass of the struck particle) than the proton process? Answer: The photon is annihilated in the creation process. In contrast, the incoming proton is not annihilated; the bookkeeper must keep the incoming proton on the payroll, providing momenergy after the collision to keep the proton in step with the other three particles. This after-collision momenergy of the proton is not available to be applied to other products of the collision. Therefore a proton of given total energy can create less mass than a photon of the same energy when each strikes a stationary target.

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