Physics 30 – Lesson 38
Quarks

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1) In the early 1900's electrons, protons and neutrons were thought to be fundamental. Since that time, protons and neutrons are now thought to be made of quarks. The electron remains as a fundamental particle.

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2) The quark theory was first proposed to account for the multitude of hadrons that were being discovered as particles were accelerated to greater and greater energies. Gell-Mann and Zweig proposed that hadrons and mesons were composed of fundamental particles which were called quarks. At the time, particle accelerators could only produce energies that resulted in the formation of particles that could be explained using three quarks. As particle accelerators improved, new particles were observed that required the addition of three more flavors of quark for a total of six quark flavors.

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The experimental evidence that supports the theory are electron and neutrino scattering experiments that indicate that hadrons like protons and neutrons are each composed of three smaller particles.

3) (see lesson 37, page 8)

(a) leptons are small, hadrons are large
hadrons interact via the strong force, leptons do not

(3)

(b) mesons are bosons and baryons are fermions
all mesons are composed of quark/antiquark pairs, while all baryons are composed of three quarks

(c) fermions are particles that make up matter (i.e. hadrons and leptons), while bosons are particles that mediate forces (i.e. mesons and gluons)

4) The scattering of high energy electrons off of protons and neutrons suggested that there were three internal point-like structures within them. The scattering pattern also indicated that the point-like structures had fractional (i.e. ±1/3, ±2/3) charges.

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5) Physicists used high energy electrons to probe the structure of nucleons. Their energies had to be very high so that they did not have time to interact with the proton (i.e. all three quarks within a proton), rather they had to interact with individual quarks within the proton.

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6) An individual quark will probably not be observed due to the principle of **quark confinement**. In order to pull a quark out of a particle work must be done on the quark, but as the quark is pulled away the work energy is transformed into a quark/anti-quark pair (i.e. a meson). Therefore, only pairs of quarks can be produced and never singular quarks.

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7) proton quarks are uud (up up down) and neutron quarks are udd (up down down).

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8) Mesons contain two quarks (a quark/anti-quark pair), while baryons contain three quarks.

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$$\text{udd} \longrightarrow \text{uud} + {}^{0}_{-1}\text{e} + \bar{\nu}$$
$$0 \longrightarrow (+1) + (-1) + 0$$

10)

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$$\mu^{+} \longrightarrow {}^{0}_{-1}\text{e} + \nu_{e} + \bar{\nu}_{\mu}$$
$$+1 \longrightarrow (-1) + 0 + 0$$

It is not possible since electric charge is not conserved.

11) Mass and energy are equivalent. Therefore the advantage of using the units MeV/c^2 is that it gives an instant value for what kinetic energies are required for particle collisions to produce or create particles with that mass.

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12) In 1967 by Friedman, Kendal and Taylor used a beam of high energy electrons to probe the inner structures of protons and neutrons. The resulting scatter pattern suggested three point-like centres of mass/charge within the nucleons.

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13) Since there were six leptons, physicists reasoned on the basis of symmetry that there should be six quarks. The 6th quark is called the top or truth quark. Since the top quark is so heavy a tremendous amount of energy was required to produce particles that contained top quarks.

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14)

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$$\begin{array}{ccccc} \text{u} & & \text{u} & & \text{s} \\ (+\tfrac{2}{3}) & + & (+\tfrac{2}{3}) & + & (-\tfrac{1}{3}) = +1 \end{array}$$