18-13
The neutrino is difficult to detect because it has a very small probability of interacting with matter. Neutrinos can only interact via the weak nuclear interaction. This force has an extraordinarily small range due to the large mass of the weak interaction quanta → the $W$ and $Z^0$ particles.

18-15

- photon - exchange particle for the electric force

- photon, $W^+$, $W^-$, $Z^0$ - exchange particles for the electroweak force

Exchange particle = exchange quanta = force carrier = gauge boson. All mean the same thing.
The fundamental particles of the strong force are known as "gluons".

Protons are not fundamental particles. Protons are composed of 3 quarks: 2 up quarks and 1 down quark.

Electrons are fundamental particles in the Standard Model. We have no evidence to indicate that they are not fundamental.
Quarks feel the gravitational force (have mass), the electromagnetic force (have electric charge), the strong force (have color charge), and the weak force (have weak charge).

There are six known quarks:
- up, down, charm, strange, top, bottom

Of these, only up and down quarks are found in normal matter. The others are seen in matter formed at high energies (in accelerators and astrophysical processes).

Bare quarks can never be observed due to the phenomenon of "confinement".

\[ q \bar{q} \rightarrow q \bar{q} \rightarrow \{ qq \} \]
as two quarks are separated. The strong attraction between them is so great that it becomes energetically favorable for a $q \bar{q}$ pair to pop out of the vacuum quantum mechanically and join the separating quarks forming colorless bound states that no longer feel the strong force.

\[ 18-25 \quad \text{Review questions} \]

The gravitational and electromagnetic forces can be felt over macroscopic distances.

\[ 18-10 \quad \text{conc. ex.} \]

According to the standard model, the neutrino ($\nu$), quark, muon, photon ($\gamma$) are fundamental, elementary particles.

The neutron and anti-proton are not elementary because they are made of quarks.
1000 MW electricity generated

50% efficiency → 2000 MW energy

created by Matter-Antimatter
Anihilation

one MW = one million Joules per second

Total Joules produced =

\[
\frac{2000,000,000 \text{ Joules} \times \# \text{seconds in 1 year}}{2 \times 10^9}
\]

Seconds in 1 yr

\[
\frac{365 \text{ days}}{\text{yr}} \times 24 \frac{\text{hrs}}{\text{day}} \times 60 \frac{\text{min}}{\text{hr}} \times 60 \frac{\text{sec}}{\text{min}} = 3,153,600
\]

Total Joules produced = \((2 \times 10^9) \times (3 \times 10^7) = 6 \times 10^{16} \text{ Joules}

\[
E = mc^2
\]

\[
\frac{6 \times 10^{16}}{(3 \times 10^8)^2} = \frac{6 \times 10^{16}}{9 \times 10^{16}} = \frac{2}{3} \text{ kg of mass}
\]