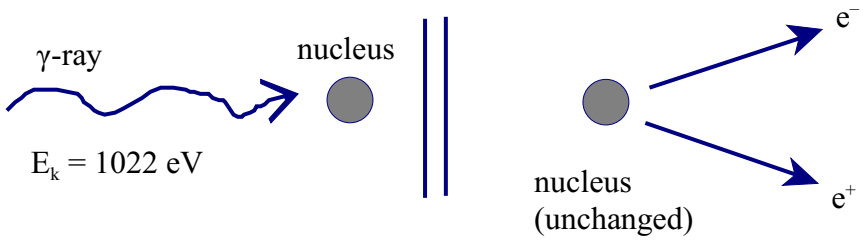
SPH4U **Quantum Oddities: Antimatter & Force Carrier Particles**

$E^2 = m^2c^4$ → $E = mc^2$ matter, e.g. electron e^-

$E^2 = m^2c^4$ → $E = -(mc^2)$ antimatter, e.g. anti-electron (positron e^+)

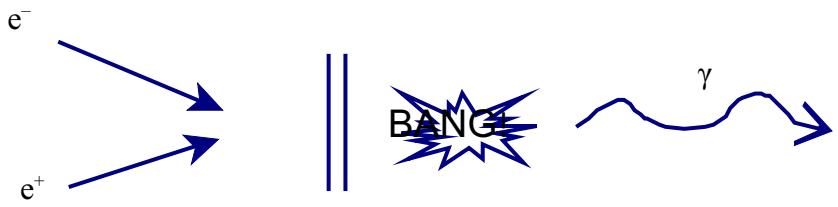
Every particle of matter has a complementary antimatter evil twin.

Pair production:

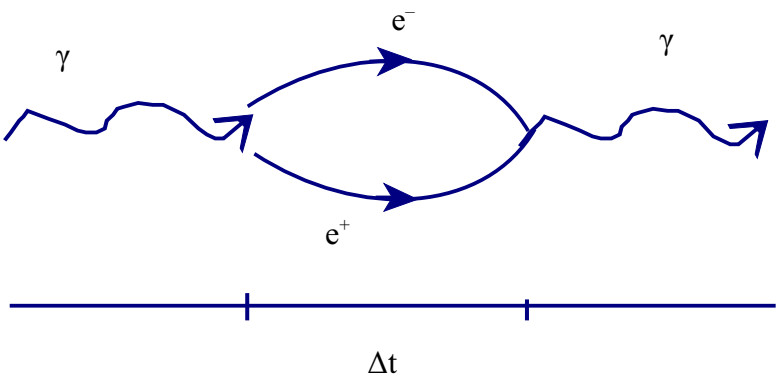


$E = mc^2$

Pair annihilation



Allowable under Heisenberg:



$$(\Delta x)(\Delta p) \geq \frac{h}{2\pi}$$

$$\downarrow$$

$$(\Delta E)(\Delta t) \geq \frac{h}{2\pi}$$

$$\downarrow$$

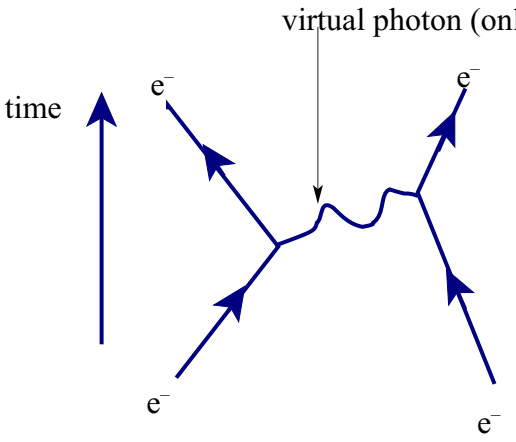
$$\Delta t \geq \frac{\hbar}{\Delta E}, \quad \hbar = \frac{h}{2\pi} \quad \text{"}h-bar\text{"}$$

∴ you can have matter ↔ energy anytime, so long as it happens very quickly.

Quantum Electrodynamics (Feynmann & Schwinger, 1950s)

- the four fundamental forces (EM, gravity, strong nuclear, weak nuclear) are "mediated" by particles

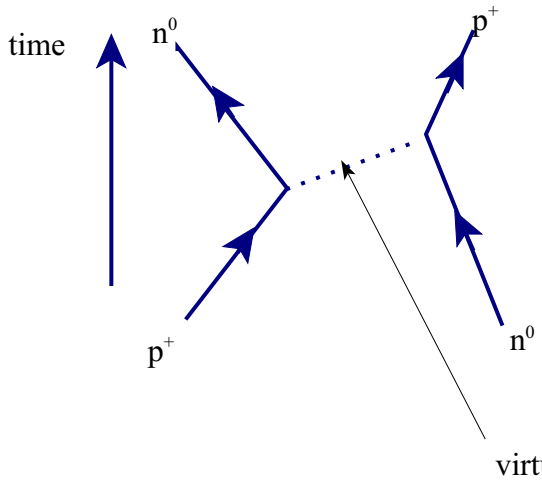
e.g. 2 electrons interacting (EM force)



momentum is carried from one e^- to another (Compton effect) + conservation of momentum

$\therefore$ EM interactions are mediated by photons.

Strong nuclear



p^+/n^0 interaction → π^+
n^0/p^+ interaction → π^-
p^+/p^+ interaction → π^0

Weak nuclear (involved in β-decay): mediated by... W^+ bosons
W^- bosons
Z bosons

$$n^0 \rightarrow p^+ + W$$

later...

$$W \rightarrow e^- + \bar{\nu}$$

Gravity is mediated by.....?

SPH4U **Quantum Oddites: The Particle Zoo**

Chadwick, 1932 - discovered the neutron

By 1932... 3 elementary particles: p^+, n^0, e^-

But after QED, new particles started to appear, so...

<u>3 Categories of Particles</u>

1. Gauge Bosons — mediate forces
   e.g. γ, W, Z, etc.

2. Leptons — affected by weak nuclear force
   e.g. e^-, $\bar{\nu}$

3. Hadrons — affected by strong nuclear force

mesons	baryons
e.g. π, κ	e.g. p^+, n^o, Λ, etc.

All hadrons are composed of 3 “quarks”

6 types of quark

up (u)	charm (c)
down (d)	top (t)
strange (s)	bottom (b)

e.g. proton: uud (2 “up” quarks, one “down”)
neutron udd

Quantities that must match up to reality:

charge	baryon #
spin	strangeness

So... by the late 20th century, “fundamental building blocks of matter” are leptons and quarks.

Problem with Quantum Theory and General Relativity... they don’t agree with each other. The search is on for a Grand Unified Theory (GUT) and Theory of Everything (TOE).