Física de Partículas

- Sitios web:
  - particlesadventure.~~com~~org ← app
  - quarknet.org

- Bibliografía: links por whatsapp
- 2-3 clases de teoría; parcialito (cuestionario)
- Preparar una clase de unos 30 minutos.
  Será evaluada por los ~~compa~~ integrantes del curso

- ¿De qué está hecho el mundo?
  Respuesta de los antiguos: tierra, agua, aire y fuego
- Ppios del siglo XX: consenso mayoritario sobre la existencia de átomos
- Todos los elementos químicos conocidos se ordenan en la tabla periódica

- "Átomo" significa indivisible. ¿Es así?
- No. Núcleo formado por p^+ y n rodeados de una nube de e^-
- ¿ p^+, n, e^- son fundamentales?
- No. En la década del '60 experimentos mostraron que p^+ y n tienen una estructura interna
- Hoy se ~~piensa~~ sabe que p^+ y n están formado por quarks.
- ¿ Son los quarks los ladrillos fundamentales?

.....

- Tamaños:

1 átomo $\sim 10^{-10}$ m

núcleo $\sim 10^{-14}$ m

protón
neutrón $\sim 10^{-15}$ m

q. y e^- $< 10^{-18}$ m

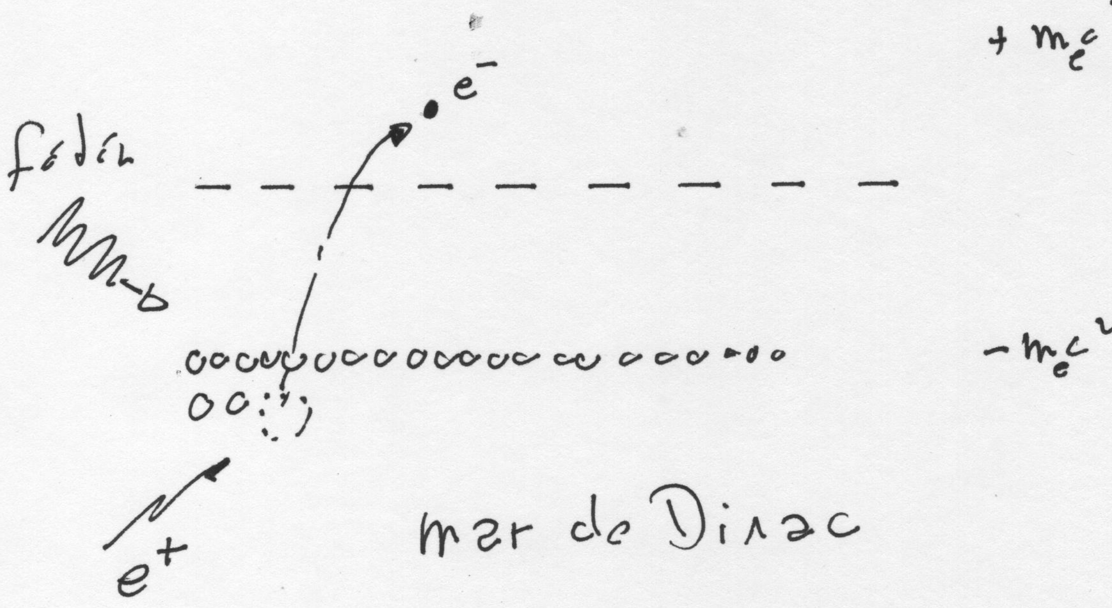
- Además de p^+, n, e^- existen cientos de partículas que se observan en los experimentos con grandes aceleradores.

- El modelo estándar permite explicar esos cientos de partículas en base a unas pocas partículas fundamentales:

  + 6 quarks
  + 6 leptones
  + portadores de fuerzas $\begin{cases} \gamma \text{ fotones} \\ g \text{ gluones} \\ W^{\pm}, Z^0 \end{cases}$
  + bosón Higgs

Materia y antimateria

- Dirac predijo la existencia del anti-electrón (positrón) en la década del '30



- ¿Por qué el universo está hecho de materia?

  No se sabe

- Cada partícula tiene su antipartícula:

  $$e^- \to e^+$$

  $$u \to \bar{u} \quad \text{(quark up)}$$

- Building blocks:

Quarks			Leptones		
u	c	t	e^-	μ^-	τ^-
d	s	b	ν_e^0	ν_μ^0	ν_τ^0

- Faltan los portadores de fuerzas.
- Cada partícula tiene su antipartícula (carga opuesta)

Familias

	1	2	3
2/3	u	c	t
-1/3	d	s	b
0	ν_e	ν_μ	ν_τ
-1	e^-	μ^-	τ^-

$\longrightarrow$ masa

¿Por qué tres familias?

.....

- Sólo la 1 es estable

Spin

- Momento angular intrínseco de las partículas
- Las partículas se clasifican en

  fermiones: spin fraccionario e^-, quarks, leptones

  bosones: spin entero: fotones, $W^{\pm}$, Z^0

Quarks

- Son fermiones
- Tienen carga fraccionaria 2/3, -1/3
- Tienen carga de "color" (interacción fuerte)
- Tienen distintos "sabores" (los distintos tipos de quarks

  u (up) s (strange) t (top)

  d (down) c (charm) b (bottom)

- Murray Gell-Mann y George Zweig ordenaron todas las partículas conocidas usando estos quarks

- Bariones: 3 quarks
- Mesones: 2 quarks
- Recién descubiertas (2020): partículas con 4 quarks
- Protón: u u d

$$\frac{2}{3}\ \frac{2}{3}\ \left(-\frac{1}{3}\right) = 1$$

bariones

- Neutrón: u d d

$$\frac{2}{3}\ \left(-\frac{1}{3}\right)\left(-\frac{1}{3}\right) = 0$$

- Pión: $\bar{d}$ u

$$\left(\frac{1}{3}\right)\left(\frac{2}{3}\right) = 1$$

mesón

- Además de carga eléctrica, los quarks tienen carga de color, aunque las partículas que se observan son "incoloras"

- Esas cargas de color se llaman "rojo", "verde" y "azul"

- Sólo existen en forma observable partículas de color neutro: 3 quarks (R, B, G)

  2 quarks $(R, \bar{R})$

Fuerzas

- Existen 4 fuerzas fundamentales
  - + gravitatoria
  - + electromagnética
  - + fuerza fuerte: (núcleos)
  - + fuerza débil: (decaimientos radioactivos)

- Partículas mediadoras de las fuerzas
  - + electromagnética: fotones γ QED
  - + ~~in~~ fuerte: gluones g QCD
  - + débil: $W^{\pm}$, Z^{0}
  - + gravedad: ¿?

- El origen de las fuerzas está en el intercambio de partículas (bosones)

	Débil	Fuerte	EM
quarks	+	+	+
Leptones cargados	+		+
Leptones neutros	+		

Leptones cargados: e^-, μ^-, τ^-

Leptones neutros. ν_e, ν_μ, ν_τ

Interacción electromagnética (QED)

- Mediada por fotones

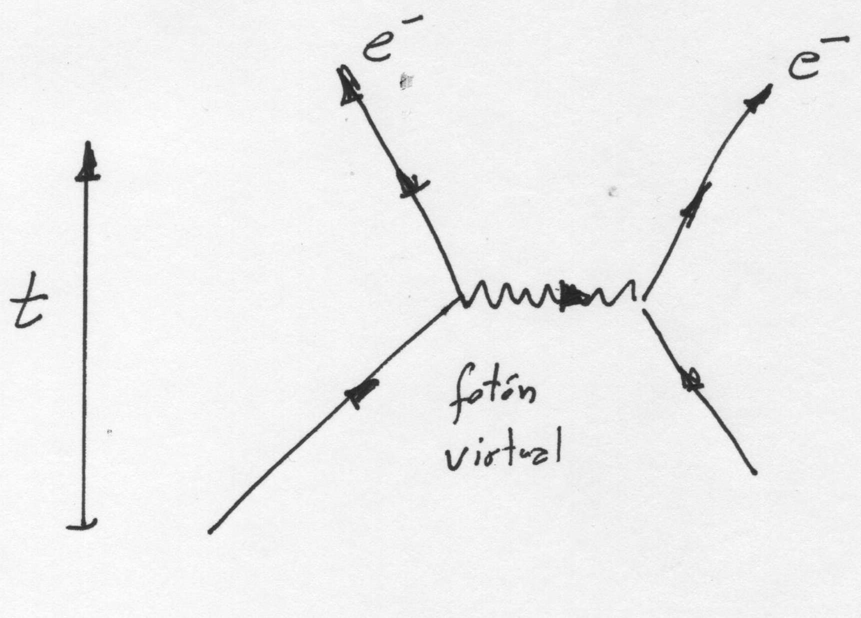
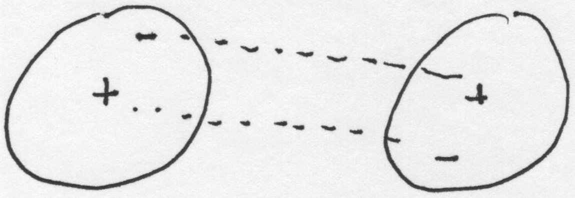


Diagrama de Feynman

- Fuerza e.m. residual

Los átomos son neutros pero como las cargas no son homogéneas en el espacio ⇒ hay interacción residual

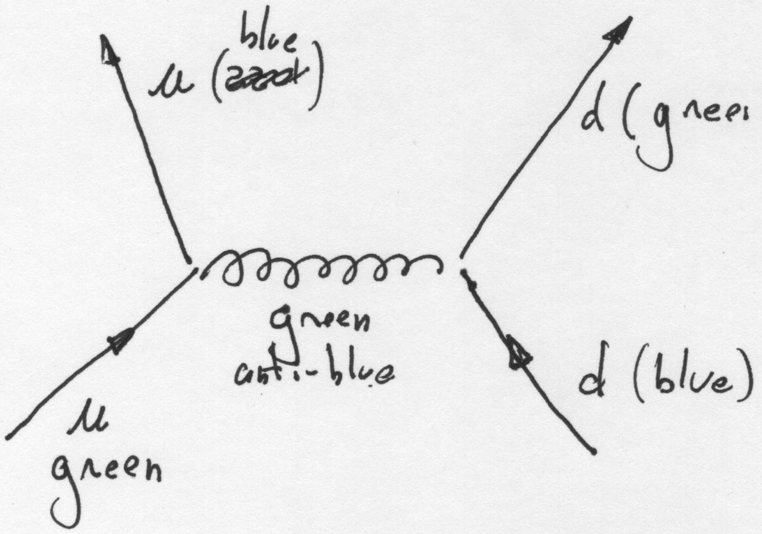


En términos formales: en un desarrollo multipolar, los átomos tienen momento dipolar, cuadrupolar, etc, $\neq 0$

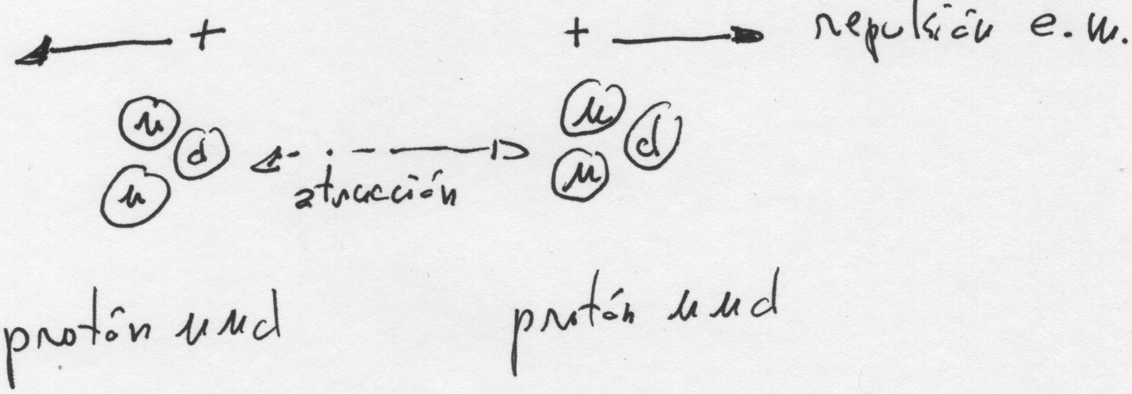
Interacción fuerte

- ¿Qué mantiene unido a los p^+ y n^0 en un núcleo? La repulsión entre protones es enorme.

- Interacción fuerte mediada por gluones
- Actúa sobre la carga de color
- Los gluones transportan color-anticolor
- Hay 8 tipos diferentes de gluones



- Existe una interacción fuerte "residual" que es la responsable de las fuerzas nucleares

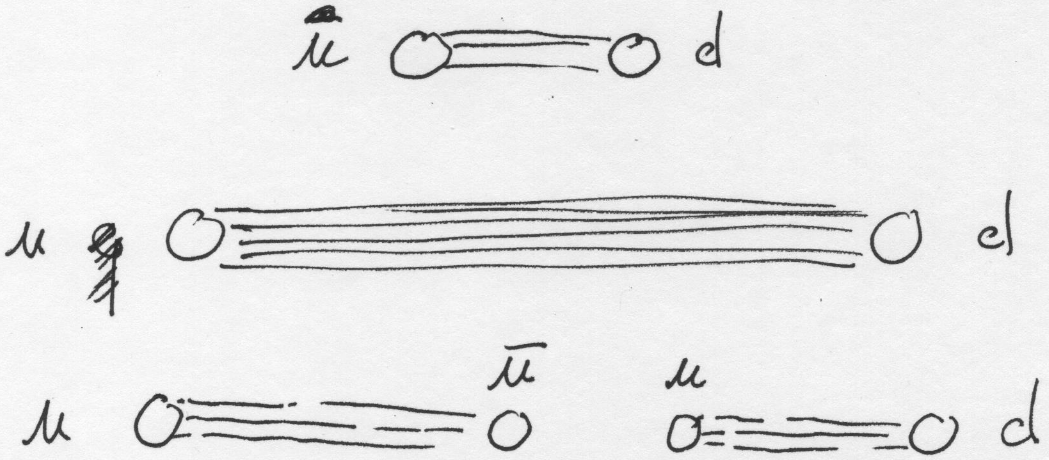


- Esta interacción fuerte residual es la que mantiene unidos a los núcleos

- Confinamiento de los quarks

  La fuerza de atracción entre quarks <u>aumenta</u> con la distancia

- Aparece un par $q\bar{q}$ ya que energéticamente es más favorable



- El par $(\bar{u}, u)$ se crea desde el vacío cuántico
- Resultado experimental: no se puede observar un quark aislado.

Interacción débil

- Es la única capaz de cambiar el "sabor" (~~la familia o lo que parece la partícula~~)

- Está mediada por los bosones $W^{\pm}$ y Z^0 que son partículas muy masivas masa e^- ~ 0.5 MeV

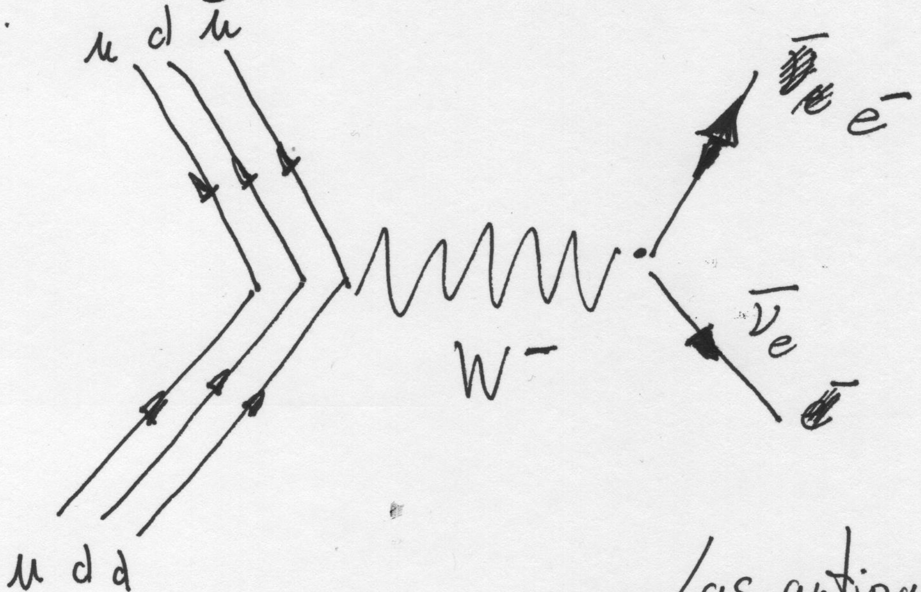
masa p^+ ~ 938 MeV

masa $W^\pm, Z^0$ ~ 95 GeV ~ 100 masa p^+

- Es la única fuerza que actúa sobre los neutrinos
- Responsable del decaimiento del neutrón

$$n \rightarrow p^+ + e^- + \bar{\nu}_e$$

- Diagrama de Feynman:



Los antipartículas "viajan hacia atrás" en el tiempo

p: (u u d) $\bar{\nu}_e$: antineutrino

n : (u d d)

THE STANDARD MODEL OF

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a quantum theory that summarizes our current knowledge of the physics of fundamental particles and fundamental interactions (interactions are manifested by forces and by decay rates of unstable particles).

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin =1/2

Flavor	Mass GeV/c^2	Electric charge
ν_L lightest neutrino*	$(0-2)\times10^{-9}$	0
e electron	0.000511	–1
ν_M middle neutrino*	$(0.009-2)\times10^{-9}$	0
μ muon	0.106	–1
ν_H heaviest neutrino*	$(0.05-2)\times10^{-9}$	0
τ tau	1.777	–1

Quarks spin =1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.002	2/3
d down	0.005	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	173	2/3
b bottom	4.2	–1/3

*See the neutrino paragraph below.

Spin is the intrinsic angular momentum of particles. Spin is given in units of ħ, which is the quantum unit of angular momentum where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $=1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The energy unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$) where 1 GeV = 10^9 eV $=1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 = 1.67×10^{-27} kg.

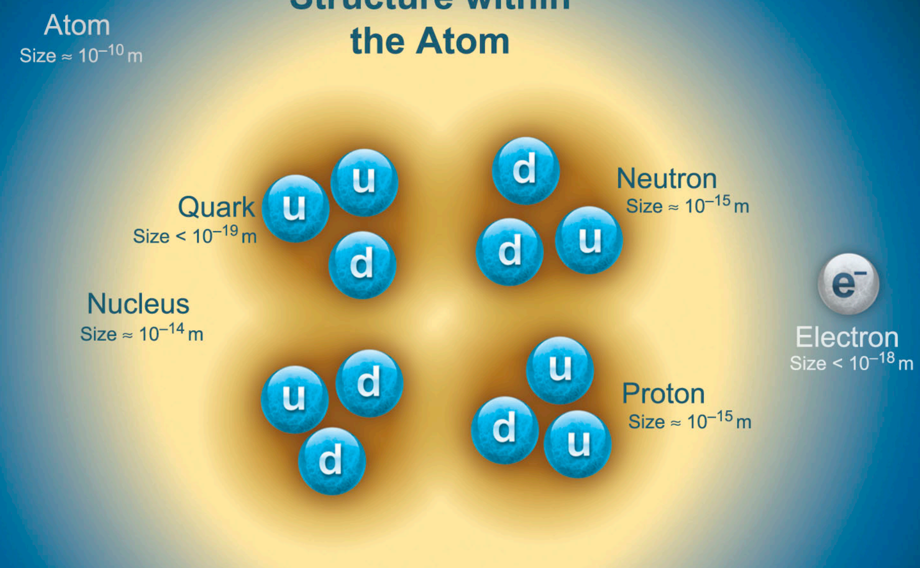
Neutrinos

Neutrinos are produced in the sun, supernovae, reactors, accelerator collisions, and many other processes. Any produced neutrino can be described as one of three neutrino flavor states ν_e, ν_μ, or ν_τ, labelled by the type of charged lepton associated with its production. Each is a defined quantum mixture of the three definite-mass neutrinos ν_L, ν_M, and ν_H for which currently allowed mass ranges are shown in the table. Further exploration of the properties of neutrinos may yield powerful clues to puzzles about matter and antimatter and the evolution of stars and galaxy structures.

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$ but not $K^0 = d\bar{s}$) are their own antiparticles.

Structure within the Atom



If the proton and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.39	–1
W^+ W bosons	80.39	+1
Z^0 Z boson	91.188	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Higgs Boson spin = 0

Name	Mass GeV/c^2	Electric charge
H Higgs	126	0

Higgs Boson

The Higgs boson is a critical component of the Standard Model. Its discovery helps confirm the mechanism by which fundamental particles get mass.

Color Charge

Only quarks and gluons carry "strong charge" (also called "color charge") and can have strong interactions. Each quark carries three types of color charge. These charges have nothing to do with the colors of visible light. Just as electrically-charged particles interact by exchanging photons, in strong interactions, color-charged particles interact by exchanging gluons.

Quarks Confined in Mesons and Baryons

Quarks and gluons cannot be isolated – they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs. The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge.

Two types of hadrons have been observed in nature **mesons** $q\bar{q}$ and **baryons** qqq. Among the many types of baryons observed are the proton (uud), antiproton ($\bar{u}\bar{u}\bar{d}$), and neutron (udd). Quark charges add in such a way as to make the proton have charge 1 and the neutron charge 0. Among the many types of mesons are the pion π^+ ($u\bar{d}$), kaon K^- ($s\bar{u}$), and B^0 ($d\bar{b}$).

Learn more at ParticleAdventure.org

Properties of the Interactions

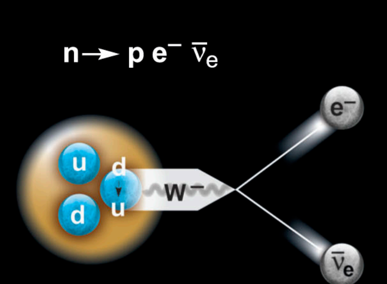
The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at 10^{-18} m	10^{-41}	0.8	1	25
Strength at 3×10^{-17} m	10^{-41}	10^{-4}	1	60

Particle Processes

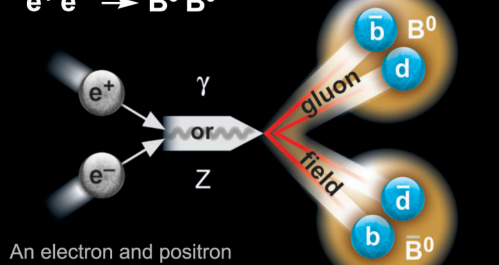
These diagrams are an artist's conception. Orange shaded areas represent the cloud of gluons.

$n \rightarrow p\, e^-\, \bar{\nu}_e$



A free neutron (udd) decays to a proton (uud), an electron, and an antineutrino via a virtual (mediating) W boson. This is neutron β (beta) decay.

$e^+ e^- \rightarrow B^0 \bar{B}^0$

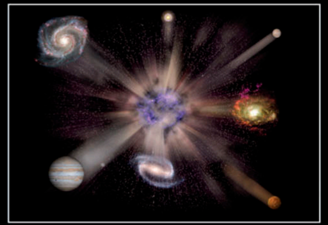


An electron and positron (antielectron) colliding at high energy can annihilate to produce $\bar{B}^0$ and B^0 mesons via a virtual Z boson or a virtual photon.

Unsolved Mysteries

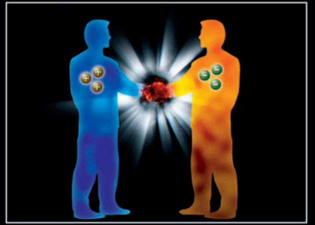
Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Experiments may even find extra dimensions of space, microscopic black holes, and/or evidence of string theory.

Why is the Universe Accelerating?



The expansion of the universe appears to be accelerating. Is this due to Einstein's Cosmological Constant? If not, will experiments reveal a new force of nature or even extra (hidden) dimensions of space?

Why No Antimatter?



Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter that we make in the lab and observe in cosmic rays?

What is Dark Matter?

Invisible forms of matter make up much of the mass observed in galaxies and clusters of galaxies. Does this dark matter consist of new types of particles that interact very weakly with ordinary matter?

Are there Extra Dimensions?

An indication for extra dimensions may be the extreme weakness of gravity compared with the other three fundamental forces (gravity is so weak that a small magnet can pick up a paper clip overwhelming Earth's gravity).

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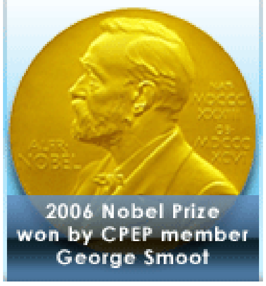
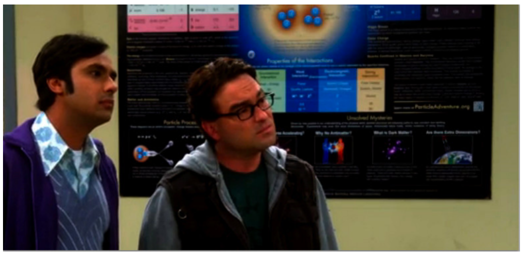


Scenes from The Big Bang Theory



qqq	Q	S	Bar.
uuu	2	0	Δ^{++}
uud	1	0	Δ^{+}
udd	0	0	Δ^{0}
ddd	-1	0	Δ^{-}
uus	1	-1	Σ^{*+}
uds	0	-1	Σ^{*0}
dds	-1	-1	Σ^{*-}
uss	0	-2	Ξ^{*0}
dss	-1	-2	Ξ^{*0}

qqbar	Q	S	Mes.
uubar	0	0	π^{0}
udbar	1	0	π^{+}
ubar d	-1	0	π^{-}
ddbar	0	0	η