Electroweak Interaction

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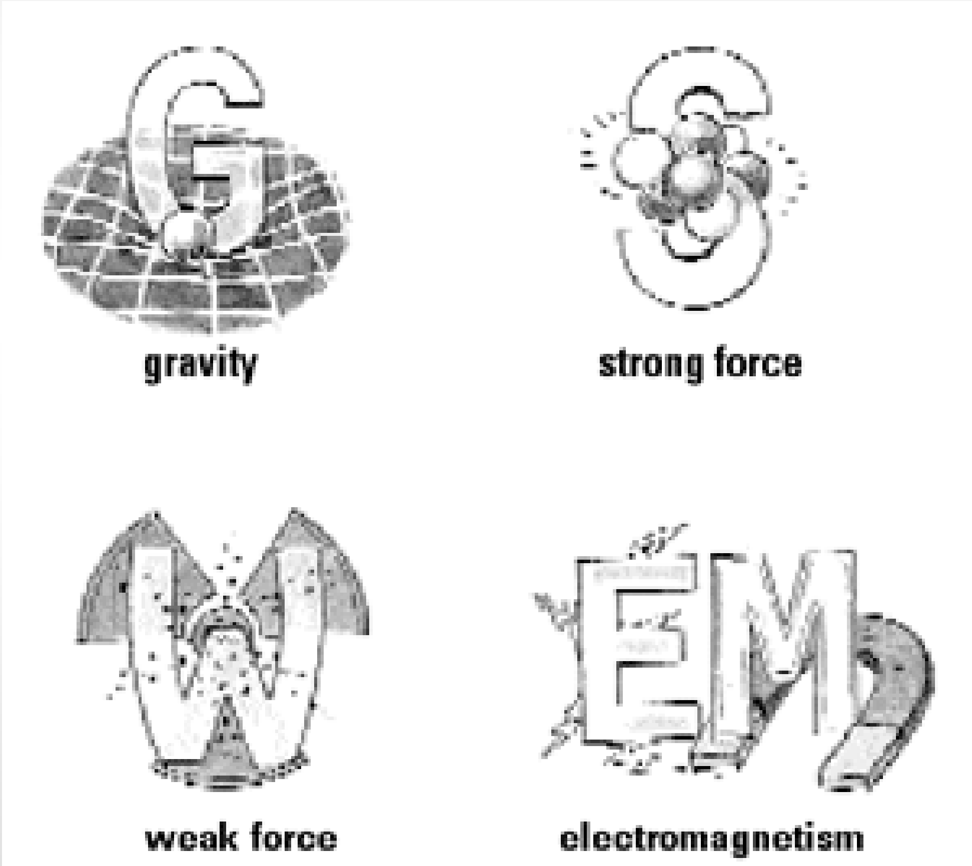
2011. 6. 7

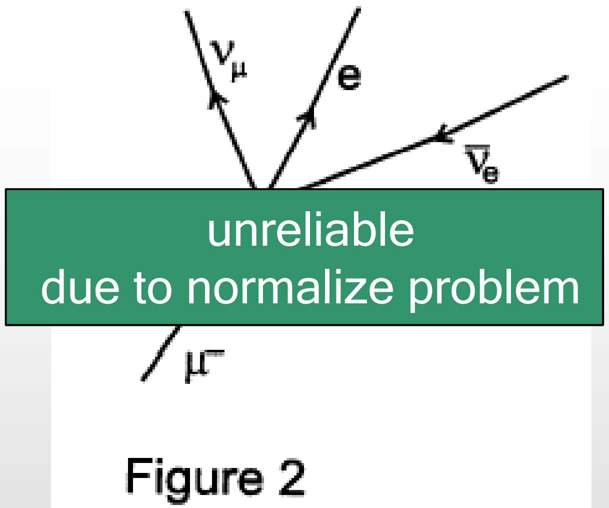
Four Forces in Nature



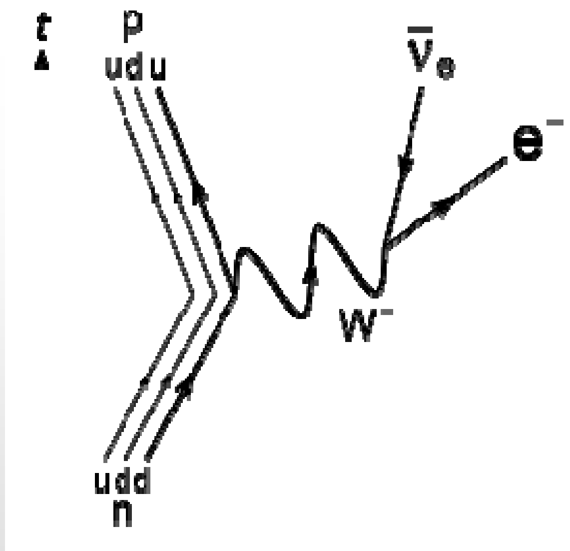
Emergence of Weak Interaction

- nuclear decay: α-decay, β-decay, and γ-decay

- for β-decay: $n \rightarrow p + e + \overline{\mu_e}$

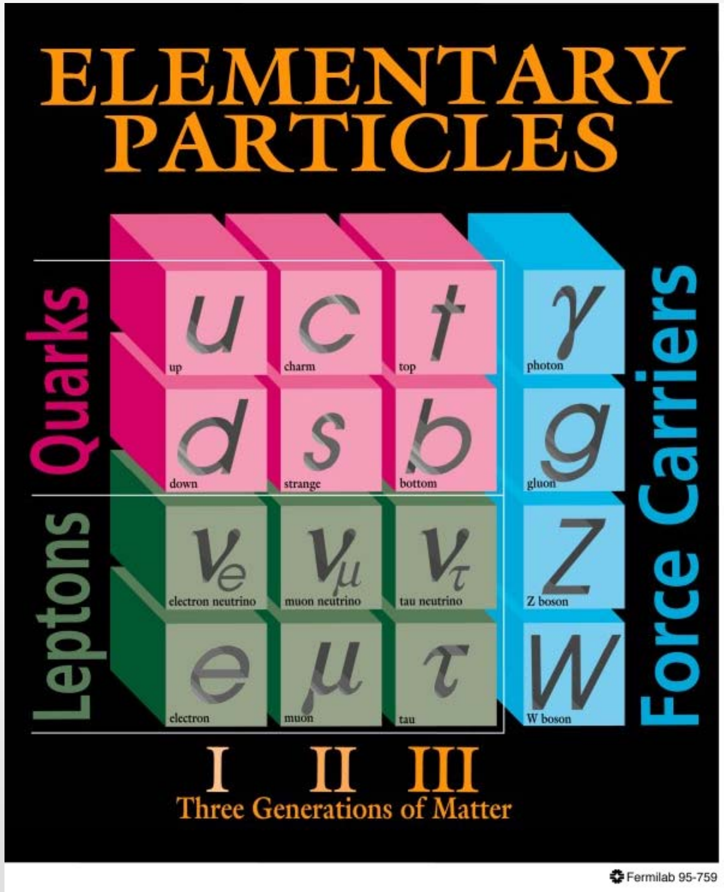


four-point interaction
(Fermi interaction)



three-point interaction

Weak Interaction in Standard Model



- all quarks and leptons conducted

- Z^0 and $W^\pm$ intermediate bosons

- contribution to decays between particles only in the same family

Weak Charge

- gravity ↔ mass
- electromagnetic interaction ↔ electric charge
- strong interaction ↔ color charge
- weak interaction ↔ weak hypercharge

$$Y_W = 2(Q - I_3)$$

Left-handed fermions in the Standard Model.[11]

Generation 1			Generation 2			Generation 3		
Fermion	Symbol	Weak isospin	Fermion	Symbol	Weak isospin	Fermion	Symbol	Weak isospin
Electron	e^-	$-1/2$	Muon	μ^-	$-1/2$	Tau	τ^-	$-1/2$
Electron neutrino	ν_e	$+1/2$	Muon neutrino	ν_μ	$+1/2$	Tau neutrino	ν_τ	$+1/2$
Up quark	u	$+1/2$	Charm quark	c	$+1/2$	Top quark	t	$+1/2$
Down quark	d	$-1/2$	Strange quark	s	$-1/2$	Bottom quark	b	$-1/2$
All left-handed antiparticles have weak isospin of 0. Right-handed antiparticles have the opposite weak isospin.								

Parity Violation

- interaction rate in electromatnetic interaction

$$\int_{all\ space} \Psi_f^*(r) H_{int.}(r) \Psi_i(r) dV \neq 0$$

$$P H_{int.}(r) = +H_{int.}(r)$$ for general case in physics

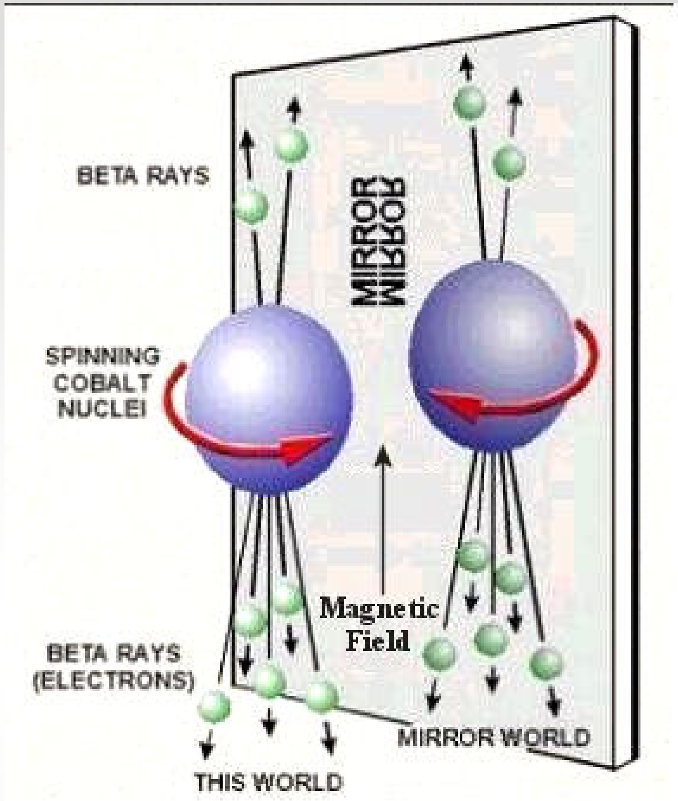
thus, in order to have non-vanished interaction

$$P\Psi_f^* = +\Psi_f^* \qquad P\Psi_i = +\Psi_i$$

or

$$P\Psi_f^* = -\Psi_f^* \qquad P\Psi_i = -\Psi_i$$

HOW ABOUT WEAK INTERACTION?



The ellipsoid on the left represents a large number of cobalt-60 nuclei, all with their spins in the same direction, and all emitting beta rays. (In reality, any one cobalt nucleus emits only one beta ray - transforming itself thereby into a nickel nucleus). On the right this process is seen in a mirror. The direction of spin is reversed, while the direction in which most beta rays are emitted remains unchanged. The mirror world is thus distinguishable from the real world.

The parity transformation of (x,y,z) to (-x,-y,-z) is completed by turning the mirror image upside down. The spins of the cobalt nuclei are thus returned to their original direction, but most beta rays are now emitted upward - contrary to experimental fact. The parity-transformed world is not identical with the real world; parity is not conserved.

Note that the asymmetry would be perfect with the beta rays emitting in one direction only (and none in the other direction), if all the cobalt nuclei are aligned perfectly with the magnetic field. In the actual experiment, the requirements of high vacuum and low temperature (~ 1/100 ^{o}K) is very difficult to achieve.

Parity Violation in Weak Interaction

- implication of parity violation in weak interaction

$$PH_{\text{int.}}(r) = -H_{\text{int.}}(r)$$

Hamiltonian (i. e potential):
no longer a function of only position

Unification of Two of Four

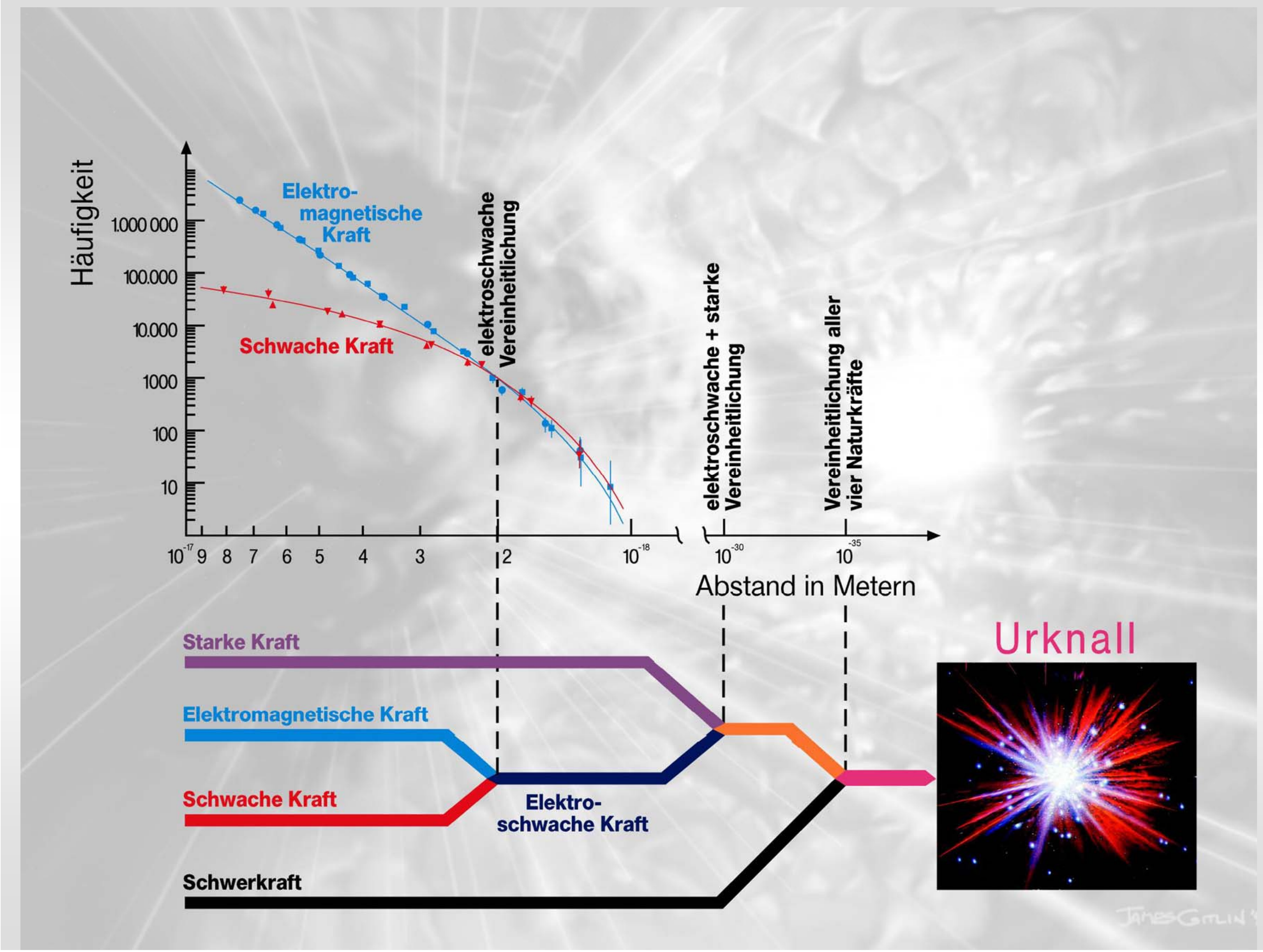
- $SU_L(2)$ X $U_Y(1)$ gauge group

$$\begin{pmatrix} \gamma \\ Z^0 \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} B^0 \\ W^0 \end{pmatrix} \qquad \cos\theta_W = \frac{m_W}{m_Z}$$

Z^0-boson: a result from mixing of W^0-boson and B^0-boson

- significant question: why are B^0 and W^0 mixed?

spontaneous symmetry breaking from HIGGS MECHANISM



Häufigkeit
1.000 000
100.000
10.000
1000
100
10
Elektro-
magnetische
Kraft
Schwache Kraft
elektroschwache
Vereinheitlichung
elektroschwache + starke
Vereinheitlichung
Vereinheitlichung aller
vier Naturkräfte
10^{-17} 9 8 7 6 5 4 3 2 10^{-18} 10^{-30} 10^{-35}
Abstand in Metern
Starke Kraft
Elektromagnetische Kraft
Schwache Kraft
Elektro-
schwache Kraft
Schwerkraft
Urknall