

# COMPOSANTS ÉLÉMENTAIRES

David Calvet



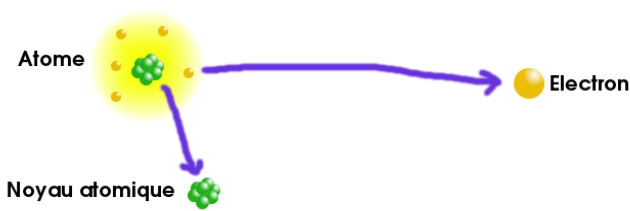
MasterClass@Clermont 2019

Que trouvons-nous dans cette pièce ?

1 H																	2 He	
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	89 Ac																
			58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu		
			90 Th	91 Pa	92 U	93 Np	94 Pu											

Atome





**Noyau atomique**



**Electron**



Noyau atomique



Electron



Inktober #6



Do ya think Darth  
Vader ever used his  
force powers to take  
care of those pesky  
space gnats?

Darth  
Vader



[www.gggghhkk.blogspot.com](http://www.gggghhkk.blogspot.com)

D. Calvert

**Noyau atomique**



**Electron**





Noyau atomique



Electron



Noyau atomique



Electron



Photon

Noyau atomique



Electron



Noyau atomique



Electron



**Noyau atomique**



**Electron**



**Noyau atomique**



**Electron**



**Noyau atomique**



**Electron**



Noyau atomique



Electron





**Noyau atomique**



**Electron**



Noyau atomique



Electron



Noyau atomique



Electron



Noyau atomique

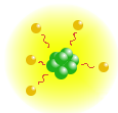


Electron





Atome



Photon 

 Electron

Noyau atomique



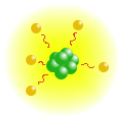
Proton



Neutron



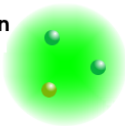
Atome



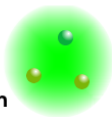
Photon 

 Electron

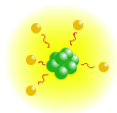
Proton



Neutron



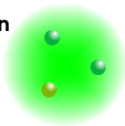
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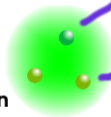
Photon 

 Electron

Proton



Neutron

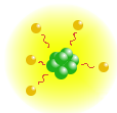


 Quark up

 Quark down



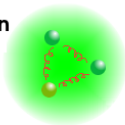
Atome



Photon 

 Electron

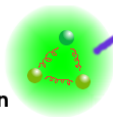
Proton



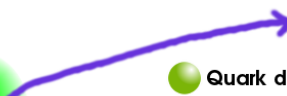
 Quark up

Gluon 

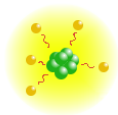
Neutron



 Quark down



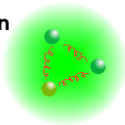
Atome



Photon 

 Electron

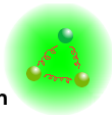
Proton



 Quark up

Gluon 

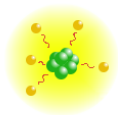
Neutron



 Quark down



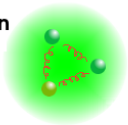
Atome



Photon 

 Electron

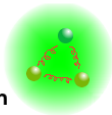
Proton



 Quark up

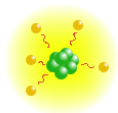
Gluon 

Neutron



 Quark down

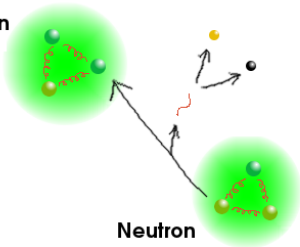
Atome



Photon 

 Electron

Proton

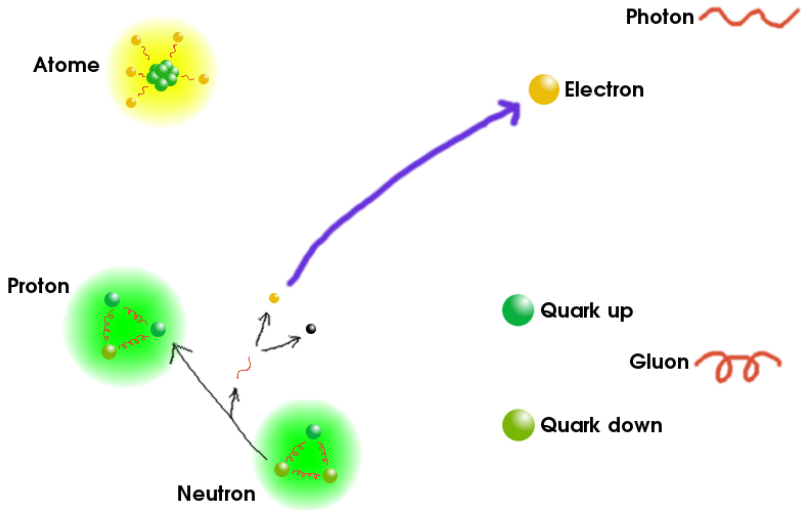


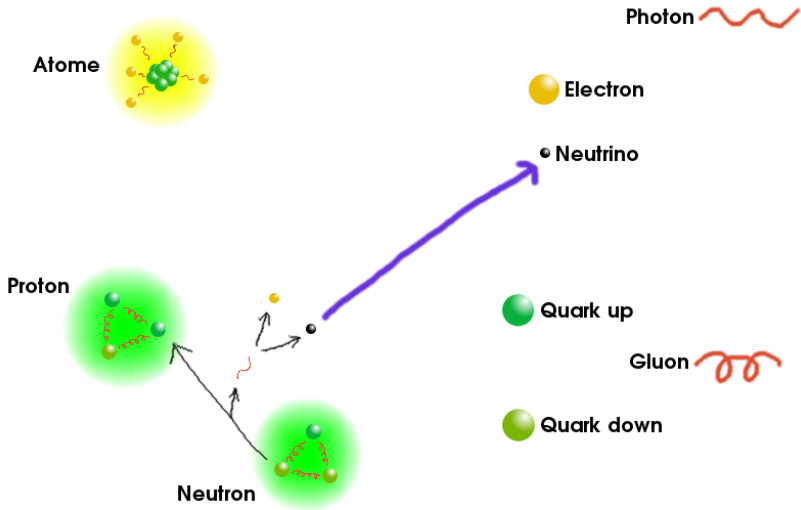
Neutron

 Quark up

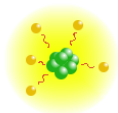
Gluon 

 Quark down





Atome

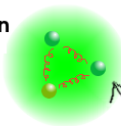


Photon 

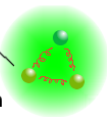
 Electron

• Neutrino

Proton



Neutron

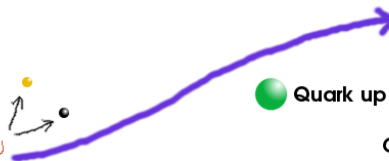


W 

 Quark up

Gluon 

 Quark down





Photon 

 Electron

• Neutrino

W 

 Quark up

Gluon 

 Quark down

## Fermions

## Bosons

Photon 

 Electron

• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

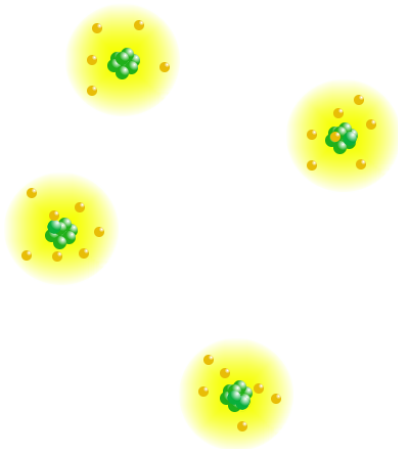
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

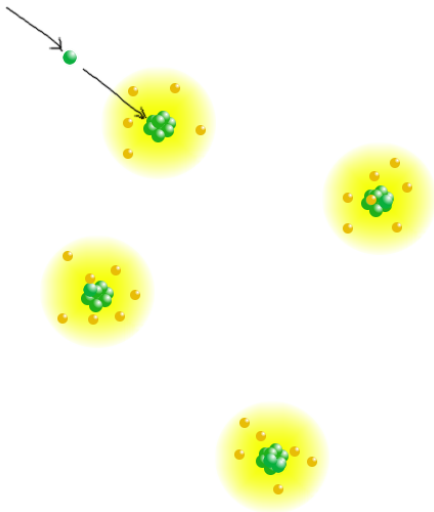
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

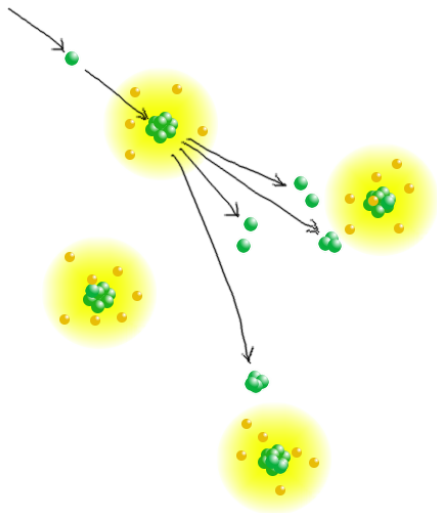
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

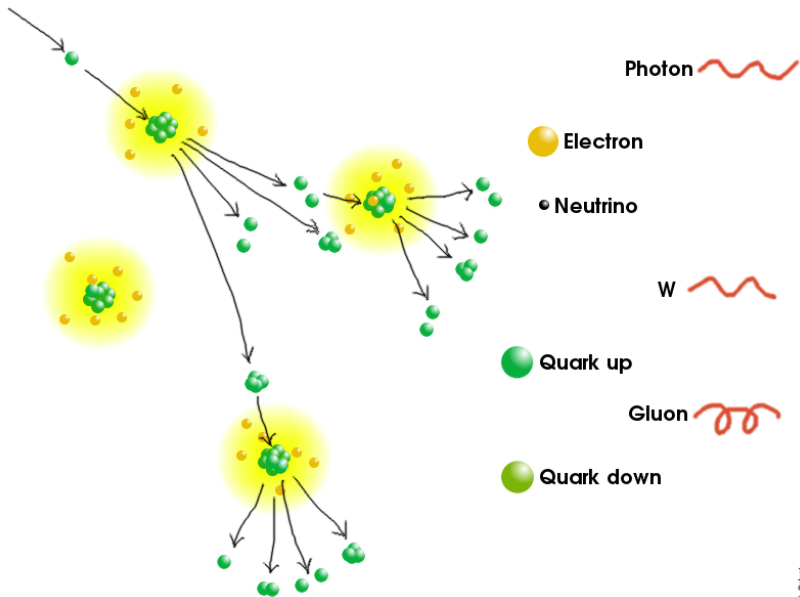
 Neutrino

W 

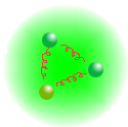
 Quark up

Gluon 

 Quark down







Photon 

 Electron

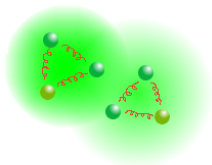
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

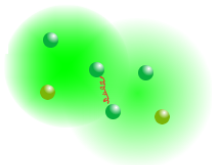
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

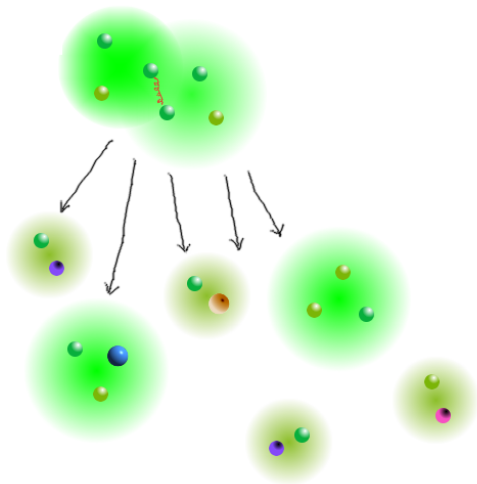
• Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

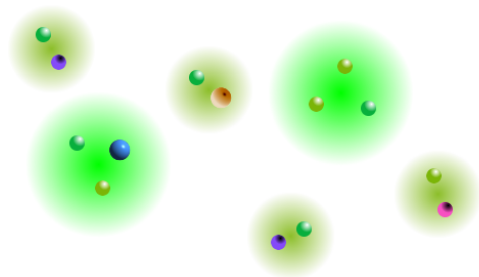
 Neutrino

W 

 Quark up

Gluon 

 Quark down



Photon 

 Electron

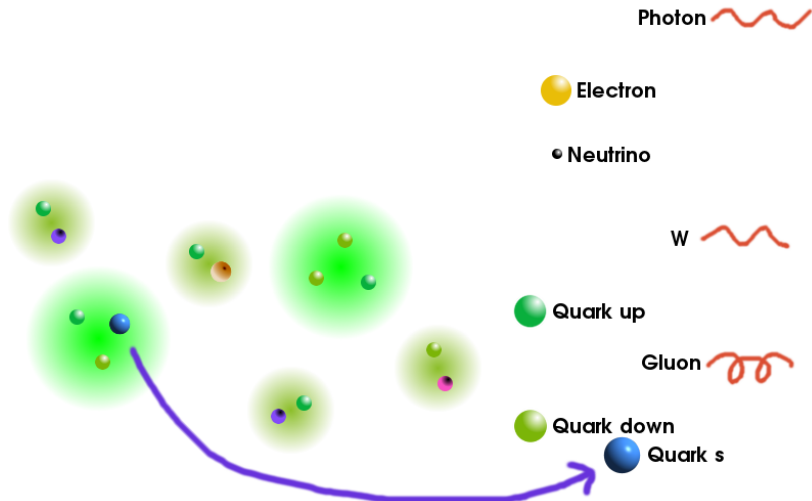
• Neutrino

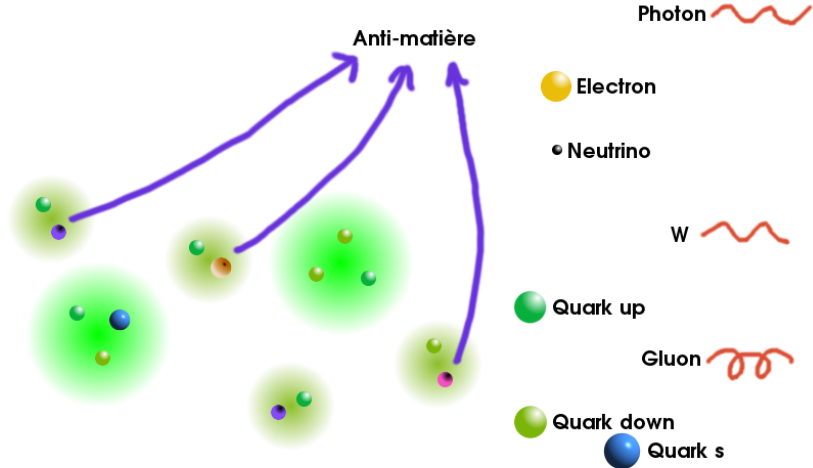
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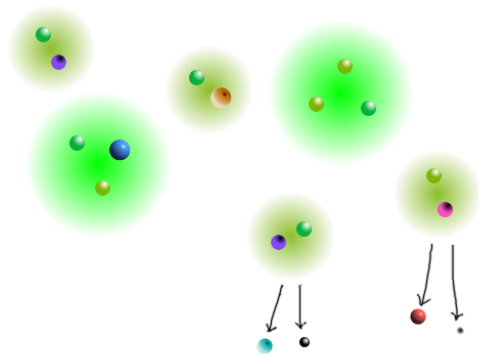
 Quark up

Gluon 

 Quark down







Photon 

 Electron


• Neutrino

W 

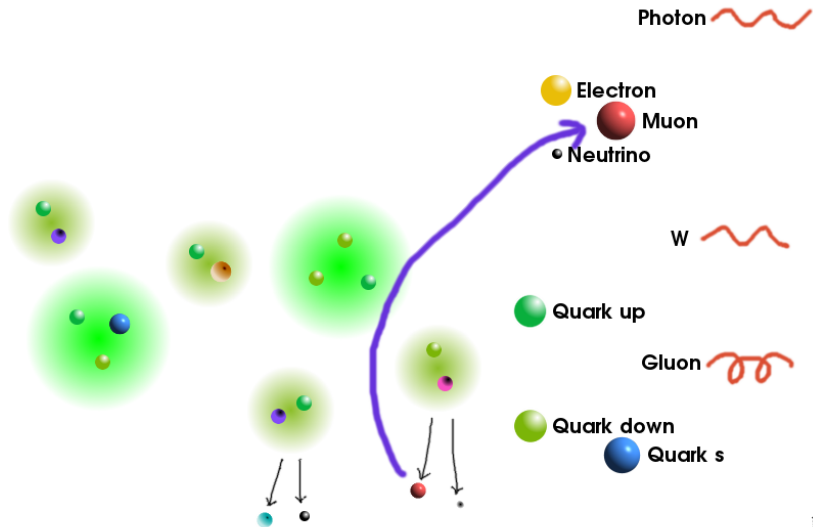
 Quark up

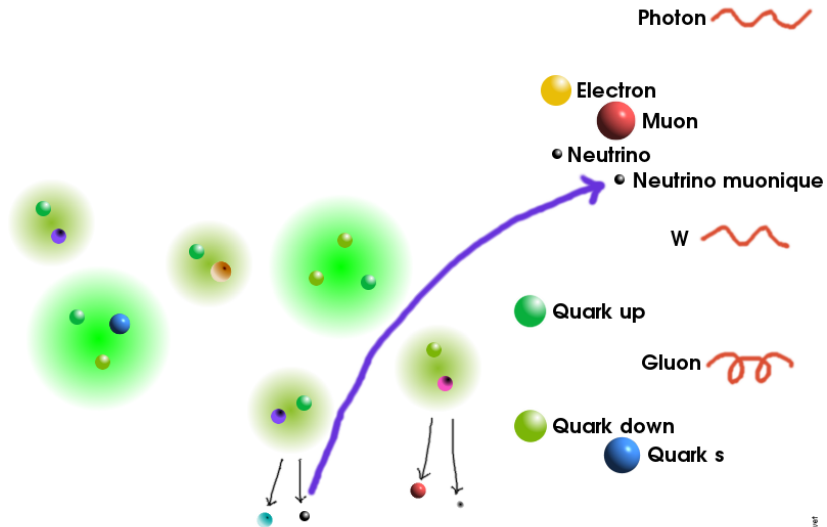
Gluon 

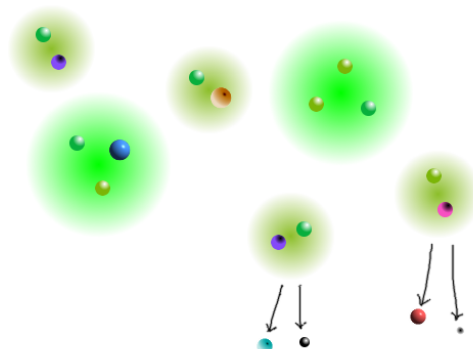
 Quark down

 Quark s









Photon 

 Electron

 Muon

• Neutrino électronique


• Neutrino muonique

W 

 Quark up

Gluon 

 Quark down

 Quark s

Photon 

 Electron

 Muon

• Neutrino électronique


• Neutrino muonique

W 

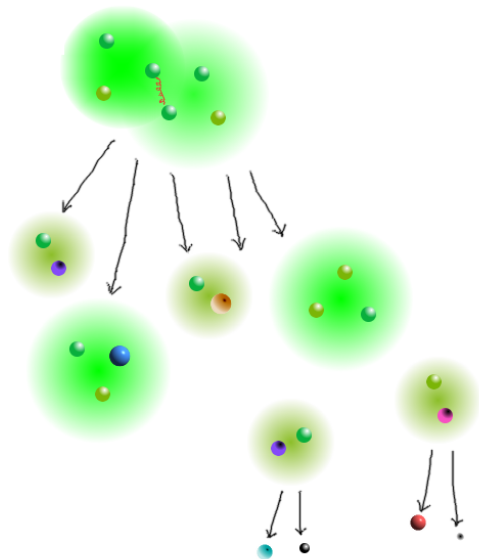
 Quark up

Gluon 

 Quark down

 Quark s





Photon 

 Electron

 Muon

• Neutrino électronique


• Neutrino muonique

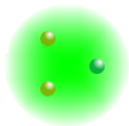
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique


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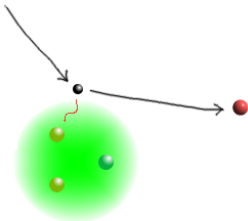
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique


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W 

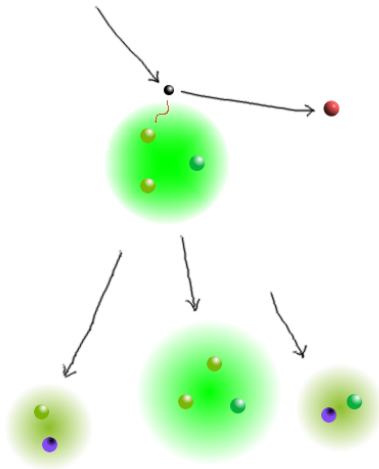
 Quark up

Gluon 

 Quark down

 Quark s





Photon 

 Electron

 Muon

• Neutrino électronique

• Neutrino muonique

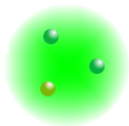
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique


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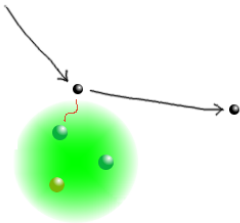
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique


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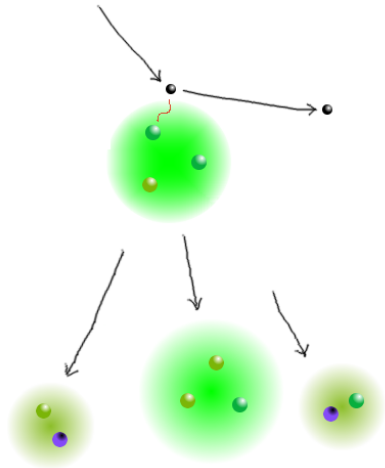
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique


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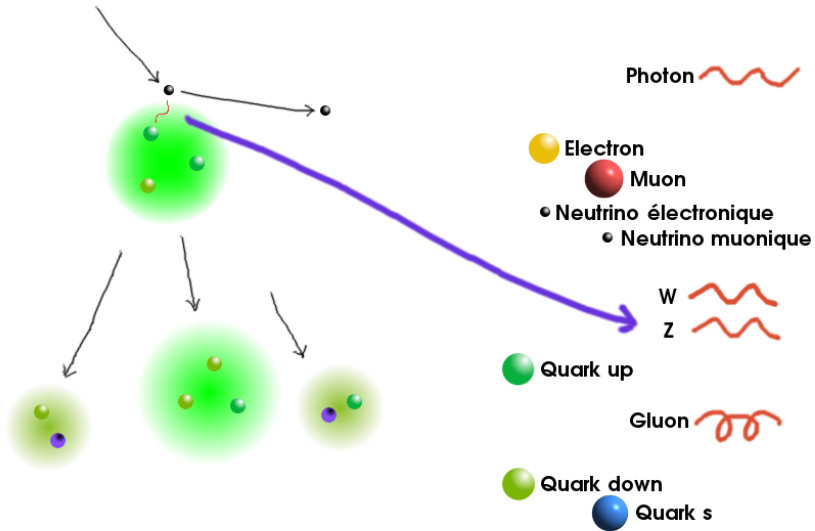
W 

 Quark up

Gluon 

 Quark down

 Quark s



Photon 

 Electron

 Muon

• Neutrino électronique

• Neutrino muonique


W 

Z 

 Quark up

Gluon 

 Quark down

 Quark s

  
Electron

Photon 

 Muon

- Neutrino électronique
- Neutrino muonique


W 

Z 

 Quark up

Gluon 

 Quark down

 Quark s

  
Muon

  
Electron

Photon 


- Neutrino électronique
- Neutrino muonique

W   
Z 

 Quark up

Gluon 

 Quark down

 Quark s



Neutrino mu Muon

Neutrino e Electron

Photon 

W   
Z 

 Quark up

Gluon 

 Quark down  
 Quark s

Neutrino mu Muon

Neutrino e Electron

Quark up Quark down

Photon 

W   
Z 

Gluon 

 Quark s

Neutrino mu Muon

Neutrino e Electron

Quark s  
Quark up Quark down

Photon 

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Z 

Gluon 

Neutrino mu Muon

Neutrino e Electron

Quark s  
Quark up Quark down

Gluon

Photon

W  
Z

Neutrino mu Muon

Neutrino e Electron

Quark s

Quark up Quark down

Photon 

  
Gluon

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Z 

Neutrino mu Muon

Neutrino e Electron

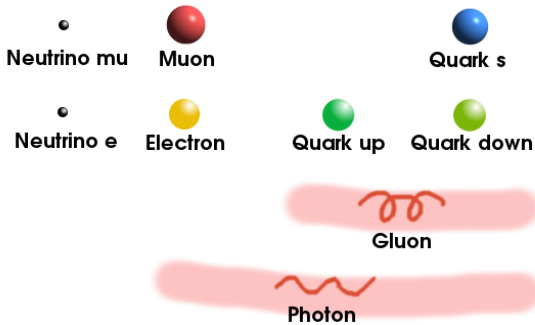
Quark s

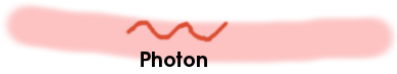
Quark up Quark down

Gluon

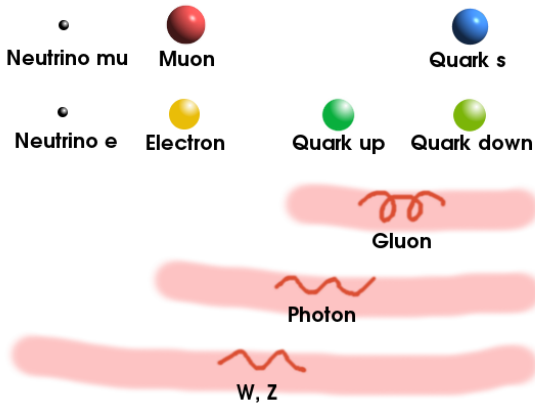
Photon

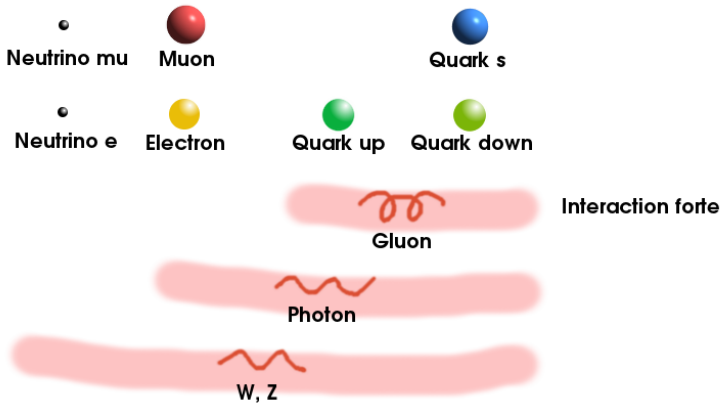
W Z













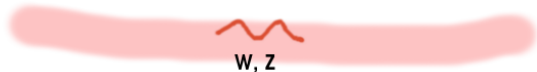
Interaction forte

Gluon



Interaction  
électromagnétique

Photon



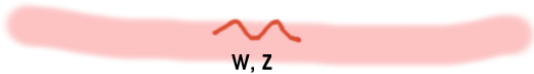
W, Z



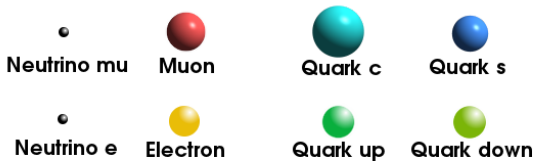
Interaction forte



Interaction  
électromagnétique



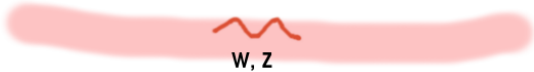
Interaction faible



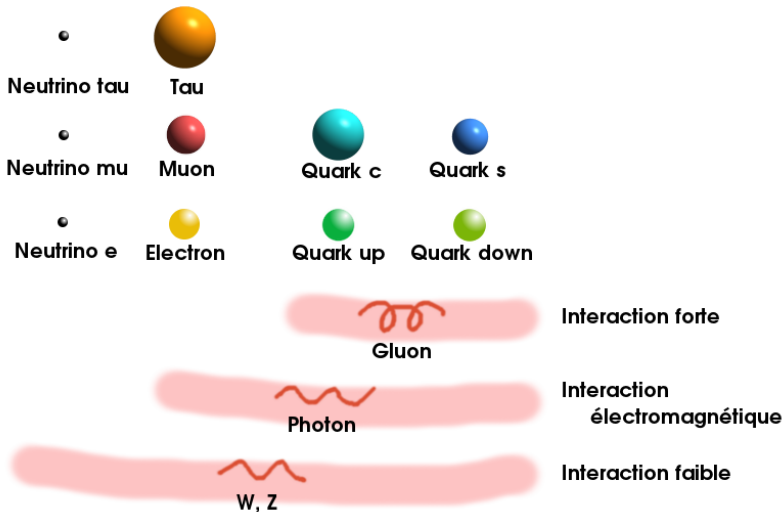
Interaction forte

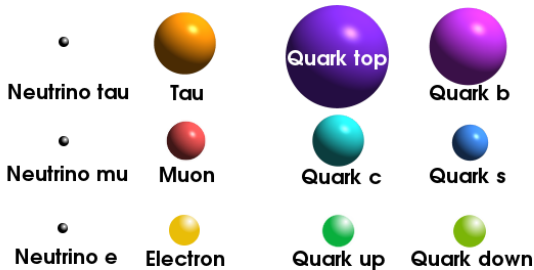


Interaction  
électromagnétique



Interaction faible

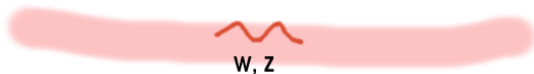




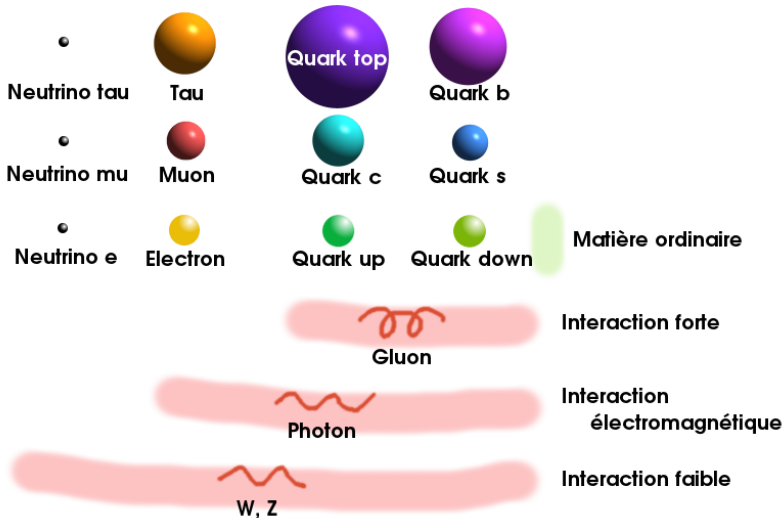
Interaction forte



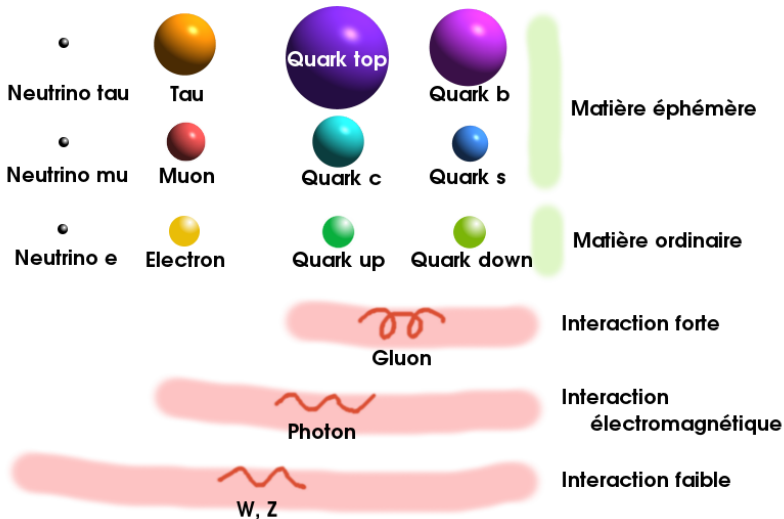
Interaction  
électromagnétique

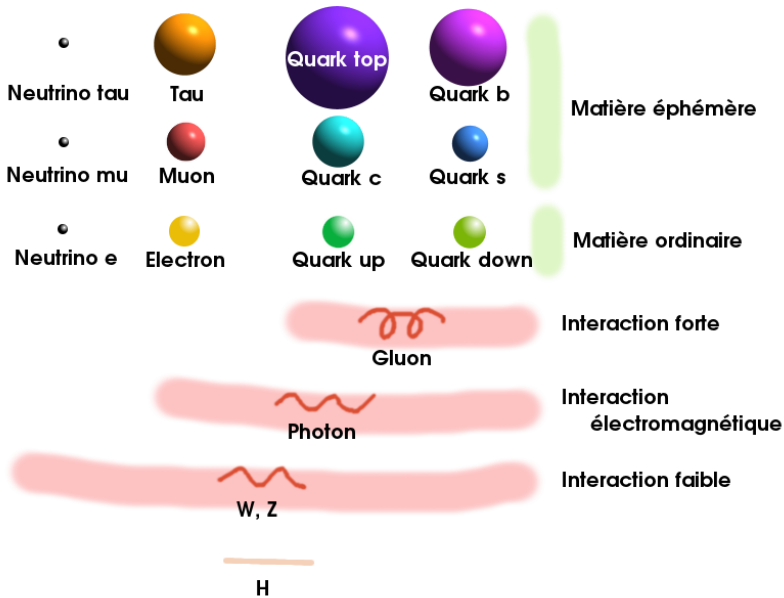


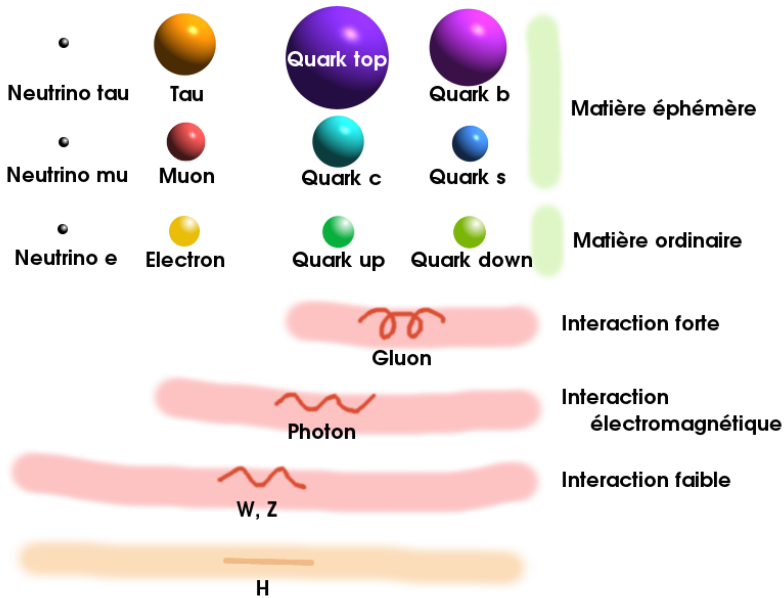
Interaction faible

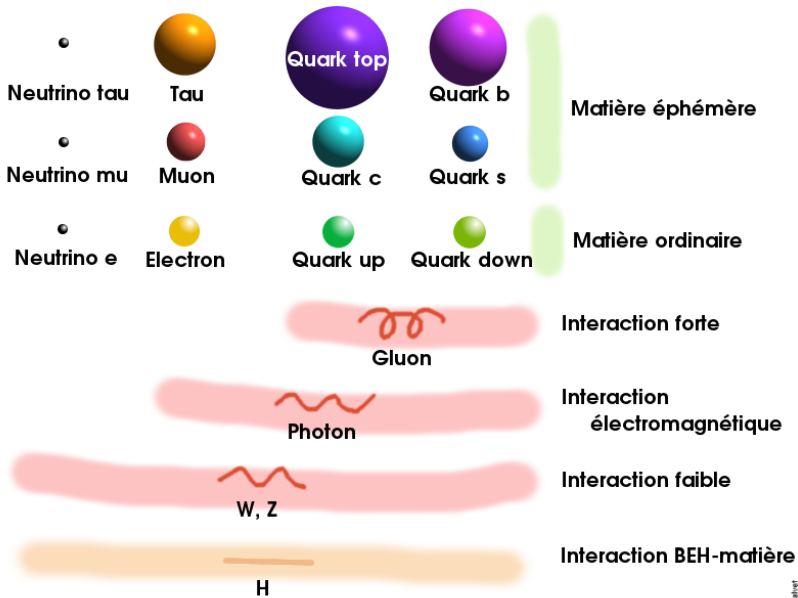












# Le Modèle Standard (simplifié)

$$\begin{aligned}
 \mathcal{L} = & -\frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} W_{\mu\nu}^a W_a^{\mu\nu} - \frac{1}{4} G_{\mu\nu}^a G_a^{\mu\nu} \\
 & + \sum_{\text{familles}} \left( i(\bar{\nu}_e \bar{e})_L \gamma_\mu D_L^\mu \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L + i\bar{e}_R \gamma_\mu D_R^\mu e_R + i(\bar{u} \bar{d})_L \gamma_\mu D_L^\mu \begin{pmatrix} u \\ d \end{pmatrix}_L + i \sum_{u,d} \bar{q}_R \gamma_\mu D_R^\mu q_R \right) \\
 & + \sum_{\text{quarks}} i(\bar{q}_R \bar{q}_V \bar{q}_B) \gamma_\mu D_C^\mu \begin{pmatrix} q_R \\ q_V \\ q_B \end{pmatrix} \\
 & - \sum_{\text{familles}} g_e \left( \bar{e}_R \Phi^\dagger \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L + (\bar{\nu}_e \bar{e})_L \Phi e_R \right) \\
 & - \sum_{\text{familles}} \left[ g_u \left( \bar{u}_R \check{\Phi}^\dagger \begin{pmatrix} u \\ d \end{pmatrix}_L + (\bar{u} \bar{d})_L \check{\Phi} u_R \right) + g_d \left( \bar{d}_R \Phi^\dagger \begin{pmatrix} u \\ d \end{pmatrix}_L + (\bar{u} \bar{d})_L \Phi d_R \right) \right] + \mathcal{L}_{\text{mélange}} \\
 & + (D_{L\mu} \Phi)^\dagger (D_L^\mu \Phi) - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2
 \end{aligned}$$

$$D_R^\mu = \partial^\mu + ig_1 \frac{Y_W}{2} B^\mu, D_L^\mu = \partial^\mu + ig_2 \frac{\sigma^a}{2} W_a^\mu + ig_1 \frac{Y_W}{2} B^\mu$$

$$D_C^\mu = \partial^\mu + ig_3 \frac{\lambda^a}{2} G_a^\mu$$