



TeHCo
Grupo de Teoria e História dos Conhecimentos



Diagramas de Feynman como Modelo Científico

para o ensino de Física de Partículas nas Licenciaturas

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Sumário

- **O problema com a abordagem “zoológico de partículas”**
- **Uma alternativa a partir dos Diagramas de Feynman (DF)**
- **Características epistemológicas dos DF - Modelos Científicos**
- **Os DF nos livros didáticos e problemas a se evitar**



Abordagem “zoológico de partículas”

- Afastamento da epistemologia da Física de Partículas
- Física de Partículas “estática”
- Não articulação de teoria e experimento

Standard Model of Elementary Particles

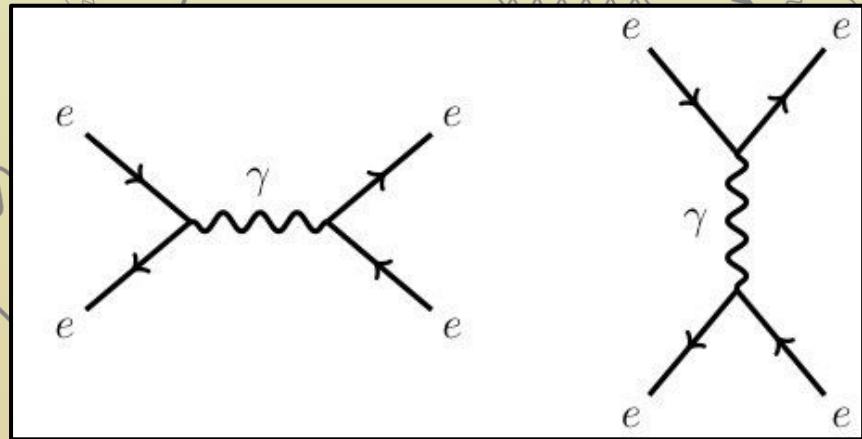
	three generations of matter (elementary fermions)			three generations of antimatter (elementary antifermions)			interactions / force carriers (elementary bosons)	
	I	II	III	I	II	III		
mass	≈ 2.2 MeV/c ²	≈ 1.28 GeV/c ²	≈ 173.1 GeV/c ²	≈ 2.2 MeV/c ²	≈ 1.28 GeV/c ²	≈ 173.1 GeV/c ²	0	≈ 124.97 GeV/c ²
charge	2/3	2/3	2/3	-2/3	-2/3	-2/3	0	0
spin	1/2	1/2	1/2	1/2	1/2	1/2	1	0
QUARKS	u up	c charm	t top	ū antiup	c̄ anticharm	t̄ antitop	g gluon	H higgs
	≈ 4.7 MeV/c ²	≈ 96 MeV/c ²	≈ 4.18 GeV/c ²	≈ 4.7 MeV/c ²	≈ 96 MeV/c ²	≈ 4.18 GeV/c ²	0	
	-1/3	-1/3	-1/3	1/3	1/3	1/3	0	
	1/2	1/2	1/2	1/2	1/2	1/2	1	
	d down	s strange	b bottom	d̄ antidown	s̄ antistrange	b̄ antibottom	γ photon	
LEPTONS	≈ 0.511 MeV/c ²	≈ 105.66 MeV/c ²	≈ 1.7768 GeV/c ²	≈ 0.511 MeV/c ²	≈ 105.66 MeV/c ²	≈ 1.7768 GeV/c ²	≈ 91.19 GeV/c ²	
	-1	-1	-1	1	1	1	1	
	1/2	1/2	1/2	1/2	1/2	1/2	1	
	e electron	μ muon	τ tau	e⁺ positron	μ̄ antimuon	τ̄ antitau	Z⁰ Z ⁰ boson	
	< 2.2 eV/c ²	< 0.17 MeV/c ²	< 18.2 MeV/c ²	< 2.2 eV/c ²	< 0.17 MeV/c ²	< 18.2 MeV/c ²	≈ 80.39 GeV/c ²	≈ 80.39 GeV/c ²
	0	0	0	0	0	0	1	-1
	1/2	1/2	1/2	1/2	1/2	1/2	1	1
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	ν̄_e electron antineutrino	ν̄_μ muon antineutrino	ν̄_τ tau antineutrino	W⁺ W ⁺ boson	W⁻ W ⁻ boson

**GAUGE BOSONS
VECTOR BOSONS** (red text)
SCALAR BOSONS (yellow text)



Os Diagramas de Feynman (DF)

- **Processos de Espalhamento em Eletrodinâmica Quântica (QED)**
- **Representação iconográfica de termos de cálculo perturbativo**
- **Base para o estudo de processos perturbativos e interações de campos em todas as Teorias Quânticas de Campos (QED; QCD)**





Características epistemológicas dos DF

(i) O cálculo de um processo de espalhamento;

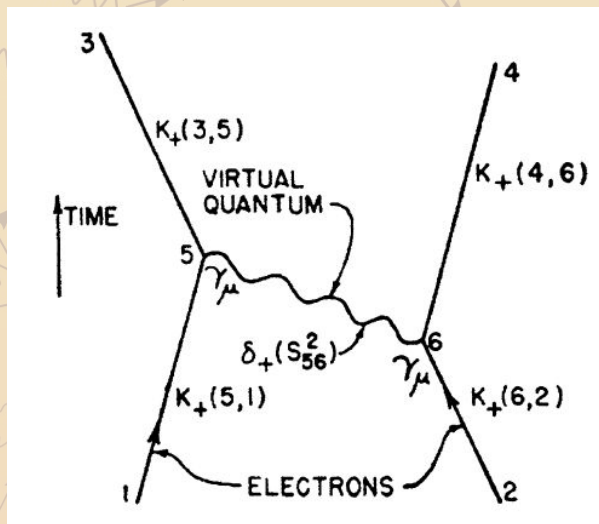


Fig. :Diagrama do espalhamento elétron-elétron com os termos de cálculo explicitados

Feynman Diagrams as Models

MICHAEL STÖLTZNER

STÖLTZNER, M. Feynman Diagrams as Models. Springer Science+Business Media New York, vol. 39, n. 2, 2017



Características epistemológicas dos DF

(ii) O termo mais importante da série representando todo um processo físico;

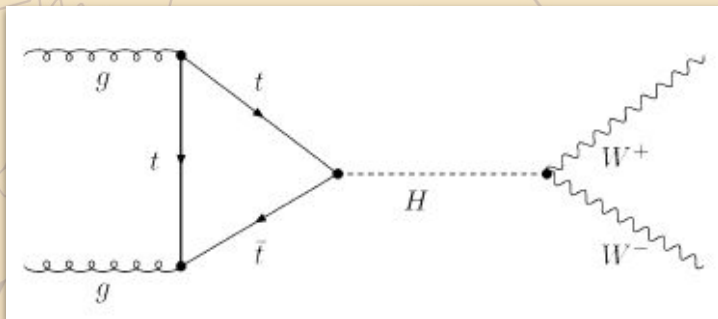


Fig. : Um canal de produção e decaimento do Bóson de Higgs

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STÖLTZNER, M. Feynman Diagrams as Models. **Springer Science+Business Media** New York, vol. 39, n. 2, 2017



Características epistemológicas dos DF

(iii) A expansão da matriz-S
(espalhamento) até um certo termo

Term of the Lamb shift	Value for the 1S level	Uncertainties
Self-energy (one-loop)	8 383 339.466 kHz	0.083 kHz
Vacuum polarization (one-loop)	-214 816.607 kHz	0.005 kHz
Recoil corrections	2 401.782 kHz	0.010 kHz
Proton size	1 253.000 kHz	50 kHz
Two-loop corrections	731.000 kHz	3.300 kHz
Radiative recoil corrections	-12.321 kHz	0.740 kHz
Vacuum polarization (muon)	-5.068 kHz	<0.001 kHz
Vacuum polarization (hadron)	-3.401 kHz	0.076 kHz
Proton self-energy	4.618 kHz	0.160 kHz
Three-loop corrections	1.800 kHz	1.000 kHz
Nuclear size corrections to SE and VP	-0.149 kHz	0.011 kHz
Proton polarization	-0.070 kHz	0.013 kHz
1S Lamb shift	8 172 894(51) kHz	

Fig. : Os termos mensuráveis da série representada pelo conjunto de DF's correspondendo ao “desvio de Lamb” da primeira linha espectral do Hidrogênio

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Características epistemológicas dos DF

(iv) A série infinita de DF's

Supostamente representaria o processo inteiro, “na realidade”, mas nem sempre é um objeto matemático bem definido.

Feynman Diagrams as Models

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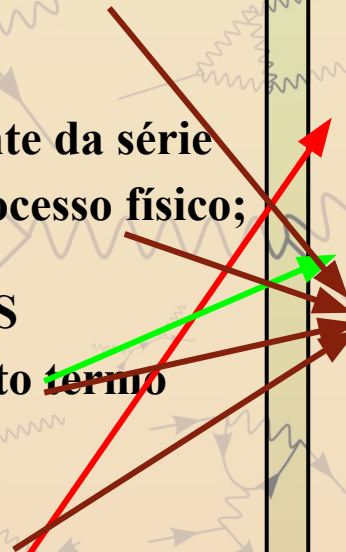


DF como Modelos Científicos

- (i) O cálculo de um processo de espalhamento;
- (ii) O termo mais importante da série representando todo um processo físico;
- (iii) A expansão da matriz-S (espalhamento) até um certo termo
- (iv) A série infinita de DF's

Modelos segundo Morgan e Morrison

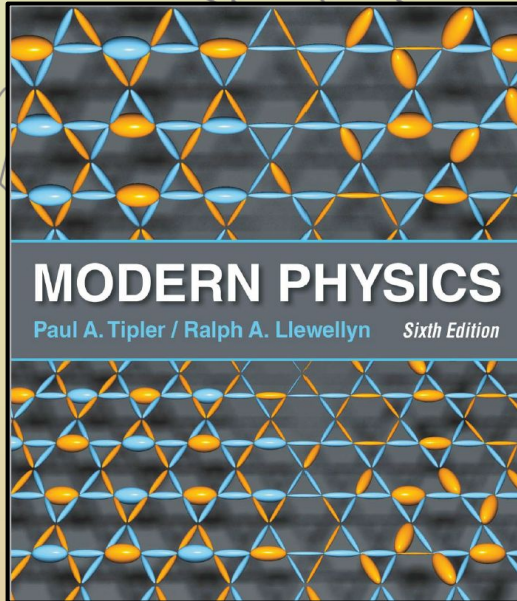
- Autônomos em relação a teoria e experimento;
- Mediam teoria e experimento
- Múltiplas dimensões de representação



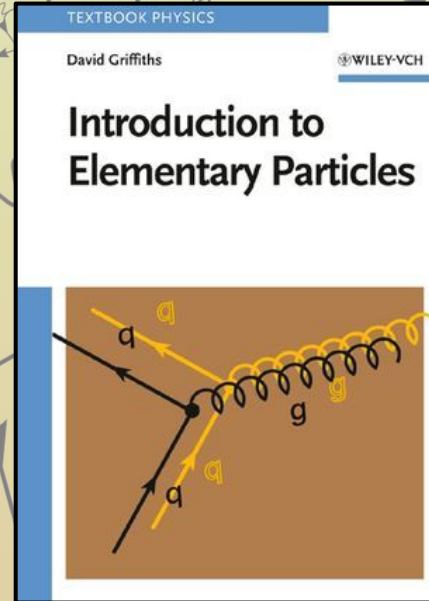
Assim, os DF são um ponto de partida possível para um ensino de Física de Partículas que inclua a epistemologia da prática dessa ciência



Onde estão os DF?



Tipler - Capítulo 12



Griffiths - Capítulo 2



12-2 Fundamental Interactions and the Force Carriers

All the different forces observed in nature, from ordinary friction to the tremendous forces involved in supernova explosions, can be understood in terms of the four basic interactions that occur among elementary particles. In order of decreasing strength, these are

1. The strong interaction
2. The electromagnetic interaction
3. The weak interaction
4. The gravitational interaction

(TIPLER & LLEWELLYN, p. 588, 2012)



the proton.

The need to transfer rapidly enormous volumes of data collected by detectors at the major particle physics laboratories throughout the world to the thousands of collaborating scientists in many countries led to the development of the World Wide Web at CERN.

Weak Interaction

All quarks and leptons participate in the weak interaction. The range of the weak force is about 10^{-18} m or about 10^{-3} fm, considerably smaller than the strong force. Example 12-3 shows how the range of the weak force is determined. Its characteristic interaction time varies from about 10^{-16} s to about 10^{-10} s. No particular name is given to the source of the weak force, although it is occasionally called the *weak charge* or *flavor charge*, in analogy with electric charge. The strength of the weak interaction relative to the strong interaction is about 10^{-5} . The weak force is carried by three particles, the *charged weak force* by the W^+ and W^- (W for “weak”) and the *neutral weak force* by the Z^0 (Z for “zero”). All three have spin 1 and thus are bosons. A very important aspect of the weak force is that interactions mediated by the W^\pm turn one quark flavor into another. The weak interaction does not, however, change the lepton flavor. The mediation of three typical weak interactions, the scattering of a muon neutrino by an electron, the scattering of an electron neutrino and a muon, and the inverse beta decay of a proton are illustrated in Figure 12-7.

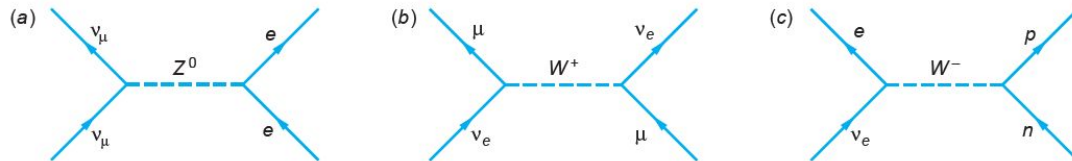


FIGURE 12-7 (a) The scattering of a muon neutrino from an electron involves the exchange of a Z^0 . Such an exchange is called a *neutral current* interaction. The interaction does not convert the electron into a muon neutrino. (b) The scattering of an electron neutrino from a muon may also occur via a neutral current interaction as in (a), but a *charged current* interaction in which a charged W is exchanged is also possible, and both would contribute to the cross section. Measuring the cross sections thus

(TIPLER & LLEWELLYN, p. 592, 2012)



2.1

The Four Forces

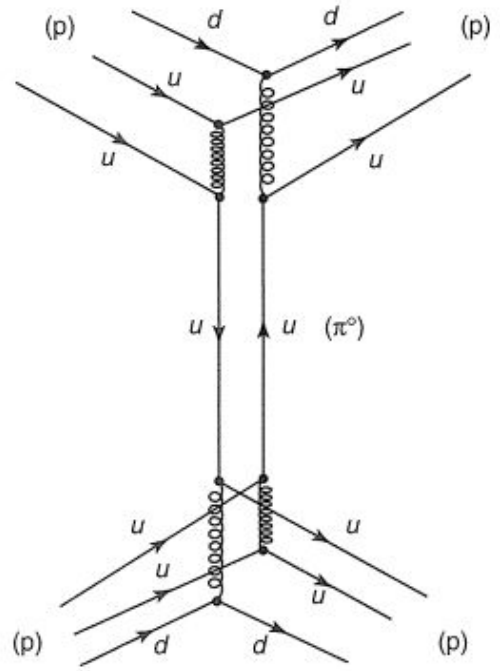
As far as we know, there are just four fundamental forces in nature: *strong*, *electromagnetic*, *weak*, and *gravitational*. They are listed in the following table in order of decreasing strength:*

Force	Strength	Theory	Mediator
Strong	10	Chromodynamics	Gluon
Electromagnetic	10^{-2}	Electrodynamics	Photon
Weak	10^{-13}	Flavordynamics	W and Z
Gravitational	10^{-42}	Geometrodynamics	Graviton

(GRIFFITHS, p. 71, 2012)



the following diagram:



(GRIFFITHS, p. 59, 2008)



O ensino dos DF enquanto modelos

- ❑ Livros não são específicos para a formação de licenciandos/as.
- ❑ Abordagem qualitativa visando as mais diferentes interações.
- ❑ Diagramas de Feynman como mediadores entre teoria e mundo.
- ❑ DF como ferramenta de investigação científica



Modelos no Ensino de Ciências

Adúriz-Bravo, 2012 - Argumentos adaptados.

- ❑ Modelos como representações teóricas do mundo
- ❑ Representação dos aspectos relevantes - “paradigmas”
- ❑ Diagramas de Feynman como mediadores entre teoria e mundo.
- ❑ DF como ferramenta de investigação científica



Referências

- ❑ ADÚRIZ-BRAVO, A. Algumas características clave de los modelos científicos para la educación química . *Educación Química*. publicado em línea el 26 de marzo de 2012
- ❑ KAISER, D. *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics*. The University of Chicago Press. 2005.
- ❑ PIETROCOLA, M. Inovação Curricular e Gerenciamento de Riscos Didático-Pedagógicos: o ensino de conteúdos de Física Moderna e Contemporânea na escola média. FEUSP, São Paulo. 2010 Oct.
- ❑ STÖLTZNER, M. Feynman Diagrams as Models. Springer Science+Business Media New York, vol. 39, n. 2, 2017.
- ❑ TIPLER, P.A. & LLEWELLYN, R.A. *Modern Physics*. 6th edition. W. H. Freeman and Company, New York. 2012.
- ❑ GRIFFITHS, David. Introduction to elementary particles. John Wiley & Sons, 2008.