Università degli Studi di Bari

Dipartimento Interateneo di Fisica "M. Merlin"

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Spectroscopy of Charmed Hadrons: Facing the Latest Experimental Results with the Theory

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Chapter 1

Heavy Quark and Chiral Symmetries

1.1 Heavy Quark Effective Theory

There is a strong analogy between the Heavy Quark Effective Theory (HQET) and the non-relativistic limit of a Dirac spinor interacting with the electromagnetic field. Lets briefly review the latter. The Lagrangian density for such a particle is

$$\mathcal{L} = \psi^\dagger \left(\left(i\hbar \frac{\partial}{\partial t} - e\phi \right) - c\boldsymbol{\alpha} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) - \beta m_0 c^2 \right) \psi \tag{1.1}$$

and the equation of motion is

$$i\hbar \frac{\partial}{\partial t}\psi = \left(e\phi + c\boldsymbol{\alpha} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) + \beta m_0 c^2 \right) \psi \quad . \tag{1.2}$$

Now, in order to take the non-relativistic limit, one consider a particle with four-momentum $p_\mu = m_0 c \delta_{\mu 0} + k_\mu$ where k_μ is small compared to $m_0 c$. To this end is convenient to drop out the rest-frame oscillating phase contribution and write explicitly the lower and upper spinor components.

$$\psi = \exp\left(-\frac{i}{\hbar} m_0 c^2 t \right) \begin{pmatrix} \varphi \\ \chi \end{pmatrix} \quad . \tag{1.3}$$

In terms of φ and χ the Lagrangian becomes

$$\begin{aligned} \mathcal{L} = \varphi^\dagger \left(i\hbar \frac{\partial}{\partial t} - e\phi \right) \varphi + \chi^\dagger \left(i\hbar \frac{\partial}{\partial t} - e\phi - 2m_0 c^2 \right) \chi \\ -\varphi^\dagger c\boldsymbol{\alpha} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) \chi - \chi^\dagger c\boldsymbol{\alpha} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) \varphi \quad , \end{aligned} \tag{1.4}$$

and the equation of motion

$$\begin{cases} i\hbar \frac{\partial}{\partial t}\varphi - e\phi\varphi = \boldsymbol{\sigma} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) \chi \\ i\hbar \frac{\partial}{\partial t}\chi - 2m_0 c^2 \chi - e\varphi\chi = \boldsymbol{\sigma} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) \varphi \end{cases} \tag{1.5}$$

If $|i\hbar \frac{\partial}{\partial t}\chi|, |e\phi\chi| \ll |2m_0 c^2 \chi|$ then one can express the latter in the following way:

$$\chi = -\frac{1}{2m_0 c^2} \left[1 + \left(\frac{i\hbar}{2m_0 c^2} \frac{\partial}{\partial t} - \frac{e\phi}{2m_0 c^2} \right) + \mathcal{O}\left(\frac{1}{m_0^2} \right) \right] \boldsymbol{\sigma} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c}\mathbf{A} \right) \tag{1.6}$$

to the leading order the lagrangian becomes

$$
\begin{aligned}
\mathcal{L} &= \varphi^\dagger \left(i\hbar \frac{\partial}{\partial t} - e\phi \right) \varphi + \frac{1}{2m_0c^2} \varphi^\dagger \left(\boldsymbol{\sigma} \cdot \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c} \mathbf{A} \right) \right)^2 \varphi \\
&= \varphi^\dagger \left(i\hbar \frac{\partial}{\partial t} - e\phi \right) \varphi + \frac{1}{2m_0c^2} \varphi^\dagger \left(-i\hbar \boldsymbol{\nabla} - \frac{e}{c} \mathbf{A} \right)^2 \varphi - \frac{e\hbar}{c} \boldsymbol{\sigma} \cdot \mathbf{B}
\end{aligned}
\tag{1.7}
$$