QUASIATOMIC SPECTROSCOPY AS A TOOL FOR DEEP INELASTIC COLLISIONS

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ABSTRACT

The \( ^t \) scaling model is extended for application to deep inelastic collisions with time varying shapes of nuclear charge distributions. The quasiatomic spectroscopy for very heavy systems is determined by the second moment of the charge distribution and is nearly independent of the position of the bound state energies. The sensitivity of this spectroscopy to the details of the evolution of charge distributions in deep inelastic collisions are exemplified.

1. INTRODUCTION

The purpose of this note is to review the \( ^t \) scaling model, often mentioned during this conference in connection with spectral shapes of electron and positron spectra (Oeschler et al., Senger et al). This model, introduced in 1978 (Ka 1978), is based on the theoretical approach of the Frankfurt group conducted by Prof. Greiner. It certainly can not achieve the accuracy of their rather involved calculations but its presentation may be justified by its simplicity by which the most relevant features and parameter dependencies of the quasiatomic spectroscopy are pointed out and by its use of experimentalists for numerically fast least square fitting procedures.

In this connection the treatment of deep inelastic collisions and the study of the dynamical evolution of the reaction is of particular interest. This new field of research has been presented by extensive contributions at this conference and in earlier publications (Backe et al., 1983, Krieg et al., 1986). The question to be answered is to what parameters is the quasiatomic spectroscopy sensitive and what can with what accuracy be measured with regard to the study of the time evolution of reactions in which two nuclei may form complicated shapes and eventually split into two or more clusters in the exit channel.

2. BASIC FEATURES OF THE \( ^t \) SCALING MODEL

In the semiclassical treatment the distance \( R \) between projectile of massnumber \( A_1 \) and charge \( Z_1 \) hitting a target nucleus \((A_2,Z_2)\) the minimum
distance in a coulombic collision is given by

\[ 2 a = \frac{e^2 Z_1 Z_2}{\mu E_1} \]

with \( e^2 = 1.44 \, \text{MeV/fm} \), \( \mu \) the reduced mass in the entrance channel, \( E_1 \) the energy per nucleon of the projectile. The velocity of the projectile long before the collision is

\[ v = \sqrt{\frac{2 E_1}{(A_1 + 931.5) \mu}} \cdot c. \]

With a scattering angle \( \delta_{\text{cm}} \) we obtain the eccentricity

\[ \epsilon = 1 / \sin(\delta_{\text{cm}} / 2), \]

and the impact parameter

\[ b = a \sqrt{\epsilon^2 - 1}, \]

the distance of minimum approach at this angle:

\[ R_m = a \left( \epsilon^2 - 1 \right). \]

There is no closed expression for the time dependence of the distance as a function of time, but vica versa with \( x = (R/a - 1) / \epsilon \)

\[ t = a / v \left[ \epsilon \sqrt{x^2 - 1} + \ln \left( x + \sqrt{x^2 - 1} \right) \right]. \]

We will see that the quantity

\[ \frac{\dot{R}}{R} = \frac{v}{R} \sqrt{1 - \frac{2 a}{R} - \frac{a^2 (\epsilon^2 - 1)}{R^2}} \]

will be of particular importance. This function is now very well approximated by the decisive formula:

\[ \frac{\dot{R}}{R} = \kappa \frac{t}{t^2 + \frac{\epsilon}{\epsilon^2}} \]

with \( \kappa = 1 + 0.174 / \epsilon \) and

\[ t = \frac{a}{v} \left( \epsilon + 1.60 + \frac{0.50}{\epsilon} \right) \]

the characteristic time constant of the coulombic motion. In the following we will use natural units of the electron (\( h = 1, c = 1, m c^2 = 1 \)), which are most useful in this context, where the lepton energies are experimentally of the order \( m c^2 \) and the times involved \( h / m c^2 = 1.29 \times 10^{-21} \, \text{s} \). The electromagnetic interaction induces transitions between electrons in bound states or in states of the upper continuum, the so-called \( \delta \)-electrons, or electrons in states in the lower continuum in the Dirac sea, the holes produced representing the positrons. In first order the amplitude for transitions between eigenstates \( E_i \) and \( E_f \) is:

\[ a(E_i, E_f) = \int dt \langle f \left| \frac{\partial}{\partial t} \right| i \rangle e^{-i \int R V(R, r) (E_f - E_i) \ dt}. \]

Using commutator relations and neglecting rotational coupling we get

\[ a(E_i, E_f) = \int dt R \left( \frac{\partial V}{\partial R} \left| \frac{1}{(E_f - E_i)} \right| \right) \frac{\dot{R}}{R} e^{-i \int R V(R, r) (E_f - E_i) \ dt}. \]

The potential \( V(R, r) \) depends on the distance \( R \) between the two nuclei and their charge distribution. The derivative of \( V(R, r) \) with respect to the