# P-wave mass spectrum of exotic mesons

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## Introduction

In order to accommodate an explanation for all the existing and ever growing list of elementary particles in terms of few basic ingredients, Murry Gell-man in 1964 proposed the constituent quark model (CQM) [1]. Well established procedures can guide us to properties pertaining to quarkonium states and is called standard model [2]. However the existence of a state such as X(3872) [3] and other subsequent states,[4, 5] when carefully analyzed using conventional techniques failed to predict the parameters. Consequent discoveries by various other sources tended to confirm the same inefficiency of the conventional methods to predict the masses of these newly discovered states . Since then there have been many such discoveries which challenge the conventional quark model (QM). Such mesons which are non-conventional (whose properties can't be explained on the basis of QM) mesons are called "Exotic Mesons" [6]. In the present study we have assumed that the exotic systems are meson molecules to arrive at the masses of XYZ exotic mesons.We treat exotic system like a meson molecule complying with non relativistic quark model (NRQM) .

## Theoretical Background

### A. The Hamiltonian

The typical Hamiltonian of a typical NRQM is of the form

$$H = K + V_{int} + V_{conf} - K_{CM}$$

where, K is the kinetic energy, V is the potential energy and $K_{CM}$ is the kinetic energy of the center of mass of the system.

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TABLE I: Masses of P-wave exotic XYZ states in MeV

| $n\ ^{2S+1}L_J$ (c$\bar{d}$-$\bar{c}$d) | Calculated mass | $J^{PC}$ | Exp.mass [5] | Name [5] |
|---|---|---|---|---|
| $1\ ^1P_1$ | 3888.84 | $1^{++}$ | 3871.61±1.2 | X(3872) |
| | | | 3883.61±4.2 | $Z_c(3885)$ |
| $1\ ^3P_2$ | 3907.3 | $2^{++}$ | 3918.4±1.9 | X(3915) |
| $1\ ^3P_1$ | 3885.61 | $1^{+-}$ | | |
| $1\ ^3P_0$ | 3831.39 | $0^{++}$ | | |
| $1\ ^5P_3$ | 3947.84 | $3^{+-}$ | | |
| $1\ ^5P_2$ | 3929.76 | $2^{++}$ | | |
| $1\ ^5P_1$ | 3893.61 | $1^{+-}$ | 3886.61±2.4 | X(3900) |
| $2\ ^1P_1$ | 3981.4 | $1^{++}$ | | |
| $2\ ^3P_2$ | 3996.74 | $2^{++}$ | | |
| $2\ ^3P_1$ | 3977.74 | $1^{+-}$ | | |
| $2\ ^3P_0$ | 3977.32 | $0^{++}$ | 3918.4±1.9 | X(3915) |
| $2\ ^5P_3$ | 4030.66 | $3^{+-}$ | | |
| $2\ ^5P_2$ | 4014.47 | $2^{++}$ | 4024.1±1.9 | $Z_c(4020)$ |
| $2\ ^5P_1$ | 3982.1 | $1^{+-}$ | | |
| $3\ ^1P_1$ | 4068.69 | $1^{++}$ | 3883.61±4.2 | $Z_c(3885)$ |
| $3\ ^3P_2$ | 4082.47 | $2^{++}$ | | |
| $3\ ^3P_1$ | 4064.53 | $1^{+-}$ | | |
| $3\ ^3P_0$ | 4019.66 | $0^{++}$ | 4024.1±1.9 | $Z_c(4020)$ |
| $3\ ^5P_3$ | 4133.02 | $3^{+-}$ | | |
| $3\ ^5P_2$ | 4098.06 | $2^{++}$ | | |
| $3\ ^5P_1$ | 4068.15 | $1^{+-}$ | 3899.61±4.9 | $Z_c(3900)$ |
| $4\ ^1P_1$ | 4149.61 | $1^{++}$ | 4146.9±3 | X(4140) |
| $4\ ^3P_2$ | 4162.17 | $2^{++}$ | 4160±2.2 | X(4160) |
| $4\ ^3P_1$ | 4590.57 | $1^{+-}$ | | |
| $4\ ^3P_0$ | 4104.04 | $0^{++}$ | | |
| $4\ ^5P_3$ | 4190.07 | $3^{+-}$ | | |
| $4\ ^5P_2$ | 4176.23 | $2^{++}$ | | |
| $4\ ^5P_1$ | 4148.55 | $1^{+-}$ | | |
| $5\ ^1P_1$ | 4230.07 | $1^{++}$ | | |
| $5\ ^3P_2$ | 4242.2 | $2^{++}$ | | |
| $5\ ^3P_1$ | 4226.02 | $1^{+-}$ | | |
| $5\ ^3P_0$ | 4185.56 | $0^{++}$ | | |
| $5\ ^5P_3$ | 4129.17 | $3^{+-}$ | | |
| $5\ ^5P_2$ | 4255.68 | $2^{++}$ | | |
| $5\ ^5P_1$ | 4228.71 | $1^{+-}$ | | |

### B. Spin dependent and tensor interactions

In order to factor in the hyperfine splitting and fine structure of spectrum one adds spin dependent potential term ($V_{SD}$) ,which includes spin-spin interaction ($V_{SS}^{ij}$), spin-orbit interaction ( $V_{LS}^{ij}$) and tensor term ($V_T^{ij}$) separately to the Hamiltonian [7]. In NQRM framework, these connections can be written in the following form

$$V_{SD} = V_{SS}^{ij}\Big[\frac{1}{2}\Big(S(S+1) - \frac{3}{2}\Big]$$
$$+V_{LS}^{ij}\Big[\frac{1}{2}(J(J+1) - S(S+1) - L(L+1))\Big]$$
$$+V_T^{ij}\Big[12\Big(\frac{(\vec{S_1}\cdot\vec{r})(\vec{S_2}\cdot\vec{r})}{r^2} - \frac{1}{3}(\vec{S_1}\cdot\vec{S_2})\Big)\Big] \quad (1)$$

we have assumed a similar scenario dictated by Yukawa potential [8, 9] for interaction and is given by

$$V_Y(\vec{r}) = -m_0\frac{\exp(-rm)}{r} \quad (2)$$

$$H|\psi\rangle = E|\psi\rangle \quad (3)$$

The energy eigen value calculation of the Hamiltonian is done in the harmonic oscillator basis.

**Results and Conclusion**

The study calculates P-wave masses of ground as well as exited states using the meson molecular theoretical framework . The results are shwon in table 1 . Our calculations show that some of the experimentally confirmed states of exotic mesons (X,Y,Z) could be the radially excited states of a fundamental molecular state. Some of the theoretically found masses are in very good agreement with the experimentally observed masses.

**References**


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