QUARK MODEL PERSPECTIVES ON PENTAQUARK EXOTICS

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I discuss the expectations and predictions for pentaquark exotics based on the quark model perspective. Recent quark model scenarios, and calculations performed in different realizations of the quark model approach, up to the end of March 2004, are also discussed.

1. Introduction

A large number of experiments now appear to confirm the existence of the exotic, strangeness +1 \( \theta \) baryon\(^1\). The \( I = 3/2 \) exotic \( \Xi_{3/2} \) signal observed by NA49 remains to be confirmed (it is not seen by HERA-B, and its compatibility with earlier high statistics \( \Xi \) production experiments has also been questioned)\(^2\). Recently, H1 reported evidence for an anti-charmed exotic, though this state was not seen by ZEUS\(^3\).

Whether or not the NA49 and H1 signals are confirmed by subsequent experiments, the existence of the \( \theta \) makes a rethinking of our understanding of the excited baryon spectrum inevitable. If the \( \theta \) has \( I = 0 \), and lies in a \( 10_F \) multiplet, for example, exotic pentaquark partners having \( N \) and \( \Sigma \) quantum numbers necessarily also exist. These should sit in the same region as the 3q radial excitations of the \( N \) and \( \Sigma \) ground states and, unavoidably, mix with them\(^a\). This immediately calls into question past quark model

\(^a\)Mixing between non-exotic radial excitations and the corresponding states in the exotic \( 10_F \) and \( 27_F \) multiplets is also significant in the chiral soliton model\(^4\). In the quark model, where additional non-exotic pentaquark states are expected, the mixing will be even more complicated. Phenomenologically, a more complicated mixing pattern than just ideal mixing between \( 10_F \) and \( 8_F \) pentaquark multiplets\(^5\) is likely required to account for the \( N(1440) \) and \( N(1710) \) masses and decay patterns\(^6\).
treatments of the excited, positive parity baryon spectrum which included only $3q$ configurations. It also undercuts one of the main phenomenological motivations for the effective Goldstone boson (GB) exchange model of the baryon spectrum\textsuperscript{7}, i.e., the failure of the $3q$ Isgur-Karl (effective color-magnetic (CM) exchange) approach to successfully reproduce the low-lying $P = +$ Roper-like resonances. The existence of the $\theta$ does not, of course, invalidate the GB model, but does suggest that any differences between GB and CM model predictions in the exotic sector become of heightened phenomenological interest.

Below, we discuss recent scenarios, and some qualitative features of pentaquark states expected in the quark model (QM) framework. Comparisons to the results of the chiral soliton model (CSM) approach\textsuperscript{8,9,10,11}, whose prediction of a low-lying, narrow $\theta^0$ was a primary motivation for the initial LEPS search, will also be made.

2. The $\theta$ Parity and Other Discrete Quantum Numbers

The CSM approach unambiguously predicts that the lowest lying $S = +1$ exotic state should lie in the $10^F$ multiplet and have $I = 0, J^P = 1/2^+$. It has sometimes been stated that the naive quark model “predicts” $P = -$ for the lowest lying exotic baryon state. This statement is incorrect and has led to some confusion in the literature. It should actually be rephrased to state that the quark model “might naively be guessed to produce $P = -$” for the lowest-lying exotic state. Whether or not this guess is correct is a dynamical question. In fact, it turns out that a competition exists between the additional orbital excitation needed for the $P = +$ sector and the decreased spin-dependent (generically, “hyperfine”) expectation available in this sector.

The following qualitative argument, given by Jaffe and Wilczek (JW)\textsuperscript{6,12}, shows why the $P = +$ sector might be favored. The $F = 3, J = 0, C = \bar{3}$ $qq$ configuration is known to be very attractive in QCD. It is also the most attractive $qq$ correlation in a number of QCD-inspired models (the GB and CM models, as well as models based on instanton-induced effective interactions). Assuming pentaquark states are dominated by optimal two-quark correlations, one expects a state with two such pairs to be particularly low-lying. Such a state is Pauli forbidden unless the two pairs are in an odd relative orbital state\textsuperscript{6}. To take advantage of this optimal $qq$ pairing, one must thus go to the $P = +$ sector. The lowest-lying exotic configuration is then necessarily the $S = +, I = 0$ member of a $10^F$, \ldots
$J^P = 1/2^+$ multiplet, as in the CSM picture.

A qualitative understanding of why the hyperfine energy might be significantly lowered in the $P = +$ sector, and hence win out over the orbital excitation, can also be arrived at using the “schematic approximation” to the GB and CM models, in which the spatial dependence of the spin-dependent operators is neglected\(^b\). In this approximation, the expectations of the flavor-spin (FS) (GB case) or color-spin (CS) (CM case) dependent interactions can be worked out by group-theoretic methods, even in the $P = +$ sector. In both models, higher FS or CS symmetries produce more attractive hyperfine expectations. For the GB case, the highest FS symmetry for the spatially-unexcited $[4]_L$ orbital $q^4$ configuration is $[31]_{FS}$, while for the $[31]_L$ configuration it is $[4]_{FS}$. Similarly, for the multiplets containing exotic states in the CM case, the highest CS symmetries are $[22]_{CS}$ for the $[4]_L$ and $[31]_{CS}$ for the $[31]_L$ configuration. In both cases one thus expects a significant gain in hyperfine energy in going from the $P = -$ to the $P = +$ sector. Explicit dynamical model calculations bear this out\(^14\).

Dynamically, it need not be the case that $qq$ correlations are dominant. Indeed, in the CM model, as pointed out by Karliner and Lipkin (KL)\(^15\), a more complicated correlation, consisting of one $F = \bar{3}$, $C = \bar{3}$, $J = 0$ pair (as in the JW scenario) and one $F = 3$, $C = 3$ pair with the $qq$ spin flipped to $J = 1$ and anti-aligned to the $\bar{s}$ spin, yields a lower hyperfine energy for the $\theta$ than does the JW correlation. (Such a configuration is also favored in a model with effective instanton-induced interactions\(^16\).) Mixing between the JW and KL correlations in the CM model, induced by the same $q\bar{s}$ interactions responsible for favoring the KL $qq\bar{s}$ correlation, actually leads to an even lower-lying state, which is nearly an equal mixture of the JW and KL correlations\(^14\).

It should be stressed that, while in the JW and KL scenarios it has been argued that intercluster interactions and antisymmetrization effects will be suppressed by the relative $p$-wave between the clusters, it is only in particular dynamical models that these effects can be explicitly calculated. Such a calculation was performed for the GB and CM models in Ref. [14]. In such calculations, one can directly compare the hyperfine expectations in the $P = -$ and $P = +$ sectors. As shown in Ref. [14], at least for the GB and CM models, the increase in hyperfine attraction in the optimal

\(^b\)The approximation has also been employed quantitatively in a number of recent calculations\(^13\). However, although it successfully identifies optimally attractive channels, it turns out to be quantitatively unreliable (see Ref. [14] for more details).
(CSM quantum numbers) $P = +$ channel, as compared to that in the optimal non-fall-apart $P = -$ channel, is such that, with expectations for the orbital excitation energy based on experience from the baryon sector\textsuperscript{15}, the lowest-lying exotic state is expected to have $P = +$ and NOT $P = -$, with other quantum numbers also agreeing with the CSM prediction\textsuperscript{c}.

Two important qualitative differences do exist between the CSM and QM pictures. The first difference concerns “flavor partners”. In the QM picture, in the absence of flavor-dependent $q\bar{q}$ interactions, the exotic flavor multiplets come accompanied by non-exotic flavor partners with which they are degenerate in the $SU(3)_F$ limit. For example, the $4q$ flavor configuration in the $10_F$ multiplet is $[22]_F$. Combining this with the $[11]_F \bar{q}$ configuration yields

$$[22]_F \otimes [11]_F = \overline{10}_F \oplus 8_F,$$

i.e., the $\overline{10}_F$ pentaquark multiplet containing the $\theta$ is accompanied by an $8_F$ pentaquark multiplet\textsuperscript{d}. When $SU(3)_F$ breaking is turned on, the $N$ and $\Sigma$ partners of the $\theta$, the members of the pentaquark $8_F$, and the radially excited $3q$ configurations will all mix. Thus, if the $\theta$ is, indeed, real, the $P = +$ excited baryon sector becomes very complicated in the QM picture.

The second difference between the QM and CSM pictures is that $P = +$ pentaquarks in the QM approach are accompanied by spin-orbit partners not present in the CSM. For the $\theta$, for example, the intrinsic spin of $1/2$, coupled to the $L = 1$ of the orbital excitation in the $P = +$ sector, leads to both $J^P = 1/2^+$ and $3/2^+$ states. While a low-lying $S = +$, $J^P = 3/2^+$ state is predicted in the CSM approach, it lies in a $27_F$, and has $I = 1$, not $I = 0$. An estimate of the expected splitting of the $J^P = 3/2^+$ partner of the $\theta$ in the CM model suggests it should be rather small, $\sim$ several 10’s of MeV, with a conservative maximum of 150 MeV\textsuperscript{17}. Such observations make the importance of searches for excitations of the $\theta$ obvious.

3. Masses of Exotic States

The CSM approach naturally predicts a low-lying $S = +$ exotic with a mass in the region of the observed experimental $\theta$ signal (see Ref. [11]

\textsuperscript{c}An even stronger statement is true in the CM model. There, even if one argues that the approach used in Ref. [15] might mis-estimate the orbital excitation energy, the model allows no phenomenologically acceptable $P = -$ assignment for the $\theta$\textsuperscript{14}.

\textsuperscript{d}The exotic $27_F$ pentaquark multiplet similarly comes accompanied by a $10_F$ and an $8_F$, the $35_F$ pentaquark multiplet by a $10_F$. 
for a detailed discussion of this point). In contrast, simple extensions of constituent quark model calculations from the non-exotic $3q$ baryon sector to the exotic sector will produce a mass for the lowest such exotic which is too high.

It is important to bear in mind that, although it is not unreasonable to attempt such calculations as an exploratory first stage, there are good reasons for expecting them to be physically unreliable, even if the underlying models on which they are based are reasonable. The reason is that the models typically lack a representation of physical effects which one expects to be present and to, potentially, have a significant impact on the values of one-body energies. An example of such effects is provided by the bag model. In going from the $3q$ to $6q$ sector, for example, the equilibrium bag radius increases, reducing the quark kinetic energies. This effect is counterbalanced by the change in the phenomenological $Z/R$ term, meant to represent the effects of zero point motion and corrections for CM motion in the bag. It turns out that each of these changes is large ($\sim 400 - 450$ MeV) on the scale of baryon splittings, and that the level of cancellation between them is a very sensitive function of the bag parameter $B^{18}$. Such effects are almost certainly present physically, and in need of representation if one wants to generalize calculations from the $3q$ to the $4q\bar{q}$ sector. They are not, however, represented at all in constituent quark model approaches such as those of the GM and CM models. As a result, one would not generally expect the one-body energies, calculated in those versions of the models calibrated in the $3q$ sector, to be reliable in the pentaquark sector. It thus appears fair to say both that the $\theta$ mass has not been predicted, and that it most likely cannot be sensibly predicted, in the QM framework.

This does not mean that the various quark models cannot make any predictions in the pentaquark sector, only that, realistically, they lack the features required to allow them to have a chance of successfully predicting the splitting between (exotic) pentaquark and (non-exotic) $3q$ states. For example, one of the assumptions of the models is that the spin-dependent interactions can, to a good approximation, be treated perturbatively. If this is the case, then the splittings between different spin-flavor channels, all within the pentaquark sector, should still be predictable by the models. Failure of experiment to reproduce these splittings would then allow one to rule out a given model, or models.

The minimal model-dependence for such predicted splittings occurs for $4q\bar{q}'$ states where all of the four quarks are $u$ and/or $d$. When there are both $u$ (or $d$) and $s$ quarks among the four quarks, there can be a model-
dependent interplay between the flavor-breaking in the hyperfine expectations and the lowering of orbital excitation energies for relative coordinates involving the heavier $s$ quark(s). One of the interesting predictions, of the minimally-model-dependent type, is that, as in the CSM, a rather low-lying $I = 1, S = +$ excitation, $\theta_1$, of the $\theta$ should exist in both the GB and CM models. In the GB model there is actually a degenerate pair with $(I, J_q^P) = (1, 1/2^+)$ and $(1, 3/2^+)$, where $J_q$ is the total quark spin (still to be combined with the orbital $L = 1$ to produce the total spin). In the CM model, the lowest excitation of the $\theta$ has $(I, J_q^P) = (1, 1/2^+)$. Using non-exotic baryon values of the pair hyperfine matrix elements to estimate the hyperfine energies one finds

$$m_{\theta_1} - m_{\theta} \simeq 60 - 90 \text{ MeV (CM)}$$
$$m_{\theta_1} - m_{\theta} \simeq 140 \text{ MeV (GB)},$$

(2)

to be compared to $\simeq 55 - 85$ MeV in the rigid rotor version of the CSM approach. Estimates for the splitting between the $\theta$ and its $I = 3/2 \Xi_{3/2}^+ \Pi_F$ partner have been made in both the JW and KL scenarios. Both the original version of the JW estimate and the KL estimate, which yielded $m_{\Xi_{3/2}^+} \simeq 1750$ MeV and $\simeq 1720$ MeV, respectively, were based on the assumption that the pair matrix elements for the spin-dependent interactions, and the cost of the replacement $d \leftrightarrow s$, could be estimated using the analogous quantities from the non-exotic baryon sector. The JW estimate can be raised to $\sim 1850$, more in line with the NA49 observation, if one allows significant deviations from the non-exotic baryon sector parameter values. One should again bear in mind that cross-cluster interaction and antisymmetrization effects, where novel flavor-breaking contributions might be generated, are implicitly neglected in these estimates. More detailed dynamical model estimates will be subject to the model-dependence noted above, associated with the need to estimate flavor-breaking effects on the one-body energies. One such dynamical calculation has been performed, for the GB model, in Ref. [20], with the result $m_{\Xi_{3/2}^+} \simeq 1960$ MeV. Note, however, that, while the actual calculation is non-schematic, the wavefunction is restricted to the single component which lies lowest in the schematic approximation. While, for technical reasons having to do with the explicit form of the flavor-spin interactions employed in the model, this approximation is a good one for the $S = +$ sector (where all four quarks have equal mass), there are reasons to expect much more significant mixing in the $\Xi_{3/2}$ sector once the schematic approximation is relaxed. Allowing ad-
ditional components in the wavefunction will lower the mass. The size of this effect is not known at present.

The lowest $I = 2$ $S = +$ exotics, using non-exotic baryon values for the two-body spin-dependent matrix elements, are predicted to lie around $\sim 1980$ MeV in both the GB and CM models, similar to the values obtained in the CSM approach. Both experiment and theory, therefore, strongly disfavor an $I = 2$ interpretation of the $\theta$.

4. The $\theta$ Width

One of the striking predictions of the CSM calculation of Ref. [9] was that the $\theta$ should be naturally narrow ($\sim$ a few 10's of MeV or less) in the CSM picture, as subsequently observed experimentally. Some initial speculations, based on the observed widths of known, non-exotic baryons a comparable distance above their own two-body decay thresholds, suggested that the $\theta$ should be relatively broad in the QM picture. Such arguments, however, are necessarily unreliable since the decay mechanism for the non-exotic $3q$ and exotic pentaquark baryons in the quark model cannot be the same. Indeed, for two-body decays of a $3q$ baryon, a pair creation is required whereas, for the decay of a pentaquark state, the number of constituents is the same in the initial and final states.

If one considers $KN$ scattering, and the possibility of forming an $S = +$ exotic resonance as a result of the residual short-range interaction among the fixed number of constituents, one realizes that an above-threshold resonance can only be formed in a $p$-wave or higher. The reason, as stressed in Ref. [6], is that a single-range residual $s$-wave interaction insufficiently strong to bind produces no resonance behavior, only positive phase motion. In contrast, for $p$-wave (and higher) scattering, a residual short-range attraction can play off against the peripheral centrifugal barrier to produce resonance behavior. One can make a rough estimate for the width of such a resonance as follows. It is straightforward to verify that the intrinsic width for a $KN$ resonance at the observed mass of the $\theta$ produced by an attractive $KN$ square-well potential of hadronic size is $\sim 200$ MeV$^6$. Thus, if one has a pentaquark configuration with overlap $f$ to the short-range $KN$ configuration, one expects a width, for a $p$-wave resonance, of order

$$\Gamma_\theta \sim 200 f^2 \text{ MeV}.$$  \hfill (3)

Whether or not the small widths compatible with experimental observations are natural in the QM picture is then a matter of how large or small the overlap factor $f$ is.
It turns out that, for the JW correlation, the isospin-spin-color part of the overlap factor is rather small, 
\[ f_{\text{JW}}^{\text{ISC}} = \frac{1}{24}, \]
A similar value, 
\[ f_{\text{CM}}^{\text{ISC}} \approx \frac{1}{25}, \]
is obtained for the optimized combination of the JW and KL correlations in the CM model. Since these results do not include any further reduction associated with the mismatch between the spatial configurations (which can be numerically quite significant), the natural width of the \( \theta \) in the QM picture is, in fact, quite small. Indeed, a width greater than \( \sim 10 \) MeV would be very difficult to accommodate. \( SU(3) \) arguments then require the width of the \( \Xi_{3/2} \) partner of the \( \theta \) to also be small.

It is obvious that the above width estimate is at best semi-quantitative. Unfortunately, it seems unlikely that significant improvements can be made to it. The most natural improvement one could envisage, in the GB and CM models, would be to use the non-relativistic constituent QM framework, where CM motion can be cleanly separated, and do a scattering calculation of the resonating group type. The obvious difficulty with this approach is that the one-body operators enter such a calculation in a non-trivial fashion. The existence of problems with the one-body energies in such models thus means that resonance widths obtained in such a calculation could not be treated as reliable.

Finally, it should be mentioned that a common coupling of nearby states to the same decay channel can lead, through mixing, to one of the mixed states having a width much narrower than the natural width of either state. To produce a significant narrowing, the mechanism requires the two states, before mixing, to be relatively close together. For the GB and CM models, the next excitation with \( \theta \) quantum numbers lies \( \sim 330 \) MeV (GB) and \( \sim 230 \) MeV (CM) above the \( \theta \). In these models, therefore, the mixing mechanism is unlikely to play a significant role in generating the narrow \( \theta \) width. This does not, of course, preclude the possibility that the mixing mechanism might be important in other realizations of the QM approach.

\[ \text{The discussion of Ref. [11] shows that, because of cancellations between nominally leading-order contributions to the widths of the } \Omega_F \text{ states, it is similarly difficult to provide a quantitatively reliable prediction for these widths in the CSM approach. Such cancellations can also amplify the impact of higher order } SU(3)_{\text{F}} \text{-breaking effects on the relation between the } \theta \text{ and } \Xi_{3/2} \text{ widths.} \]
5. Heavy Quark Analogues of the $\theta$

Interest in heavy pentaquarks ($Qq^4$, where $q = u, d, s$ and $Q = \bar{c}, \bar{b}$), was initially aroused by the observation that the $\bar{Q}s\ell^3$ ($\ell = u, d$) states with $I = 1/2$, $J^P = 1/2^-$ have strong hyperfine attraction relative to that of their two-body decay thresholds, $N\Delta_s$, $N\Lambda_s$, in the CM model, in the $m_{\bar{Q}} \to \infty$ limit. Subsequent work, however, showed that decreased binding from $SU(3)_F$ breaking, kinetic energy, confinement and $m_{\bar{Q}} \neq \infty$ effects was likely sufficient to make all of these states unbound. Predictions turned out to be very different in the GB model, with the $P = +$ states lying several 100 MeV above threshold. Only the $\bar{Q}\ell^4$ $P = 0^+$ states were found to be bound, with binding energies of 75–95 MeV.

An experimental search for the predicted anticharmed, strange state, covering the mass range 2.75–2.91 GeV, was performed by the E791 Collaboration, with negative results.

Interest in heavy pentaquark states has been greatly revived by the discovery of the $\theta$. If, as is now generally assumed, the parity of the $\theta$ is indeed positive, then the same mechanism which makes the $\theta$ narrow is expected to also make its heavy quark analogues narrow, even if they lie above the relevant nucleon-plus-heavy-pseudoscalar decay threshold. The situation for the $P = -$ heavy pentaquarks is less clear. Models, as well as a JW-like scenario for the $\bar{Q}s\ell^3$ states, suggest that the lowest-lying of these states should have $J = 1/2$. Unless such a state is bound, it will have an $s$-wave fall-apart decay and hence almost certainly be non-resonant.

A number of recent estimates exist for the $P = +$ heavy pentaquark masses. These are typically produced by extensions of the scenarios for the $\theta$ based on the assumption that a reasonable approximation to the splitting between the $\theta$ and its $I = 0$, $J^P = 1/2^+$ analogue, $\theta_c$ or $\theta_b$, should be obtainable using the “corresponding” splitting between the $\Lambda$ and $\Lambda_c$ or $\Lambda_b$, supplemented by an estimate for the change (if any) in the spin-dependent quark-antiquark interactions in going from the $\theta$ to the heavy quark system. Since, in the JW scenario, the diquarks are assumed to have spin zero and be tightly bound, there is no such quark-antiquark interaction, and hence no spin-dependent correction to be made. The resulting estimates are

$$m_{\theta_c} \simeq 2710 \text{ MeV}; \quad m_{\theta_b} \simeq 6050 \text{ MeV},$$

\(~100 \text{ and } 170 \text{ MeV below the relevant strong decay thresholds. If one assumes that the same diquark-triquark clustering postulated in the KL}$$
scenario for the $\theta$ persists for heavy systems, one obtains, after taking into account the reduced strength of the $Q\ell$, relative to $s\ell$, hyperfine interaction,

$$m_{\theta_c} \simeq 2985 \text{ MeV}; \quad m_{\theta_b} \simeq 6400 \text{ MeV},$$  \hspace{1cm} (5)

now $\simeq 180$ MeV above the relevant strong decay thresholds. The estimate of Ref. [28] for the low-lying $Qs\ell^3$, $P = -$ states is based on the JW scenario, and the JW estimate for the $P = +$ states. Estimates for the reduction in mass associated with the absence of an orbital excitation, and the increase in mass associated with changing one of the $u, d$ quarks of the $\theta_c$ to an $s$, both are taken from analogous splittings in the ordinary charmed and charm-strange baryon spectrum. While the neglect of cross-cluster interactions and antisymmetrization effects is more questionable when the diquark clusters are in a relative $s$-wave, the resulting estimate is of interest since it puts the $Qs\ell^3$ states not only below strong decay thresholds (at 2580 and 5920 MeV for $Q = c, b$, respectively) but also below the lower edge of the E791 search window in the $Q = c$ case.

It should be pointed out that the KL assumption that the same diquark-triquark clustering is present in both the heavy quark and $\theta$ systems requires some deviation from the strict CM model picture. The reason is that the constituent charm quark mass is sufficiently heavy that, already in the charm system, the KL correlation has become less attractive than the JW correlation. The strict CM picture would thus predict different structures for the $\theta$ and its heavy quark analogues. This does not mean that the CM picture would yield the JW mass estimates given in Eq. (4). Indeed, the JW correlation, which would dominate the heavy quark system, produces only a portion of the hyperfine attraction in the $\theta$ for CM interactions. Thus, in the CM model, a correction for the reduction in the hyperfine expectation in the heavy quark system would need to be added to the JW estimates. This correction to the JW value moves the estimated $\theta_c$ mass to $\sim 20$ MeV above the strong decay threshold. This effect, if present, would also impact the estimates of Ref. [28] for the $P = -$, $Qs\ell^3$ states.

Interesting predictions of the minimally-model-dependent type can be made for the $P = +$, $Q\ell^4$ states in the GB and CM models. The low-lying spin-flavor excitations for the two models are shown in the table below. Numerical values for the splittings from the ground-state pentaquark configuration have been obtained by fully diagonalizing in the space of all Pauli-allowed, fully antisymmetrized states for each channel, and using the pair matrix elements from the baryon spectrum to estimate the overall scale. One sees that a rather dense spectrum of excitations is predicted,
especially in the CM model, and that the pattern of excitations is very different for the two models. It also turns out that the overlaps to the nucleon-plus-heavy-pseudoscalar decay channel are roughly comparable for all states listed (with the exception of one channel for the CM interactions where the overlap is strongly suppressed). Since the relative strengths of the couplings to the decay products are expected to be given by the ratio of the corresponding overlap factors\(^{32}\), one expects a rich spectrum of experimentally observable excited states. Such predictions should be rather easy to confirm or rule out, assuming any of the predicted states can be found experimentally.

Table 1. Low-lying positive parity excitations of the \(\theta_Q\) in the GB and CM models, in the \(m_Q \to \infty\) limit. \(E_{ex}\) is the excitation energy in MeV.

| \((I, J)\) | \(E_{ex}\) (GB) | \(E_{ex}\) (CM) |
|-----------|----------------|----------------|
| (0,1/2)   | 0              | 0              |
| (0,1/2)   | 330            | 90             |
| (0,3/2)   | 330            | 90             |
| (1,1/2)   | 150            | 120            |
| (1,1/2)   | 350            | 130            |
| (1,3/2)   | 150            | 120            |

Acknowledgments

The ongoing support of the Natural Sciences and Research Engineering Council of Canada is gratefully acknowledged. There are many topics and recent papers I have been unable to discuss due to space restrictions. Apologies in advance to the authors of those works.

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