IV

Summary and Conclusion

This chapter summarizes the most important results on the properties of SU(3) baryons where a particular attention is paid to the members of the antidecuplet. The contents are subdivided in two sections, again in accordance with the two different approaches taken in the present thesis, the Chiral Quark-Soliton Model (χQSM) and the Isobaric Model.

IV.1 Chiral Quark-Soliton Model

There are two advantages offered by the *model-independent approach* in the χQSM. The first one is the fact that the very same set of dynamical model-parameters allows us to calculate the physical observables of all SU(3) baryons regardless of different $\mathrm{SU(3)_f}$ representations of baryons, namely octet, decuplet, antidecuplet, and so on. Secondly, these dynamical model-parameters can be adjusted to the experimental data of the baryon octet which are well established with high precisions.

Despite these advantages, all studies on the properties of SU(3) baryons conducted with model-independent solitonic approaches up to the present [127, 18, 44, 130, 35], give rather large uncertainties in their estimated values of physical observables. This is because there are three model-parameters, α, β, and γ, to be determined in the mass splittings and the calculations in Refs. [127, 18, 44, 130, 35] have only considered the effect of $\mathrm{SU(3)_f}$ symmetry breaking, thus leaving a relatively large uncertainty behind in model-parameter determination. In this thesis, however, not only the effect of $\mathrm{SU(3)_f}$ symmetry breaking has been taken into account, but also all the other effects, *i.e.*, those resulting from EM self-energy and isospin symmetry breaking (see Sec. II.1-1 and II.1-2). By doing so, the precision in model-parameter determination has been greatly improved. The reasons for this improvement are the following. Firstly, taking the additional contribution of isospin symmetry breaking into account enables us to make use of each and every single one of eight experimentally accessible values of the baryon octet mass while in all previous studies the masses of isospin multiplets were averaged and these averaged values were used for the calculations. Secondly, it has been pointed out in Sec. II.1-1 that the other contribution, namely the one of EM self-energy, is indeed very significant and thus cannot be neglected if the aim is to make the theoretical calculations as realistic as possible. This improved precision in the calculation has facilitated the comparison between theory and experiment and it turns out that the calculated mass differences of the baryon decuplet agree well with the experimental values as far as the mean values are concerned (see Tab. II-4 in Sec. II.1-1.2).

Furthermore, it is checked in this thesis whether the above-mentioned inclusion of the additional effects in the χQSM calculation contradicts the well-established mass relations. Firstly, the validity of the Coleman-Glashow relation, the derivation of which does not consider EM self-energy, turns out to be not affected at all even if EM self-energy is taken into account. Also, the Gell-Mann-Okubo and Guadagnini relations, which are originally known to result solely from $\mathrm{SU}(3)_{\mathrm{f}}$ symmetry breaking, are generalized by deriving them anew under the inclusion of isospin symmetry breaking. In particular, the inclusion of the effect of EM self-energy in the Guadagnini relation gives much better agreement with the experimental data ; see Eq. (II.1-104).

The inclusion of the effects of EM self-energy and isospin symmetry breaking is only a matter of the precision in parameter determination. However, there exists an intrinsic problem which cannot be solved by this, namely the general impossibility of the individual determination of the three parameters α, β, and γ, despite the existence of experimental values of the baryon octet and decuplet masses. The equations describing the relations between these parameters and experimental mass values permit the determination of only two of the three. So, there remains an ambiguity expressed by Eqs. (II.1-92), (II.1-93), and (II.1-98) in terms of two new parameters δ_1 and δ_2. For this reason, many researchers have tried to define a constraint for α, β, and γ using the experimental value of $\Sigma_{\pi N}$ as seen in Eq. (II.1-76), but there is a great discrepancy between the values of $\Sigma_{\pi N}$ measured by different experimental groups where the values are distributed in the range of $45 - 75$ MeV. The present thesis has provided a solution to this problem as well. The clue was given by the mass splitting of the baryon antidecuplet. This mass splitting cannot be expressed in term of δ_1 and δ_2 and, therefore, an additional parameter δ_3 needed to be introduced ; see Eq. (II.1-109). This has finally lifted the ambiguity and made the individual determination of the model-parameters α, β, and γ using Eqs. (II.1-93) and (II.1-108). The ingredients necessary for the solution are experimental data of the baryon octet (or decuplet)[1] and antidecuplet masses. The experimental

---

[1] The experimental uncertainties of decuplet baryons are larger than those of the baryon octet.

values of the baryon octet mass are well established. For the antidecuplet mass, on the other hand, this is not the case. Fortunately, the masses of two members of antidecuplet, Θ^+ and N^*, have recently been measured with the masses of $M_{\Theta^+} = 1524 \pm 0.005$ MeV [6] and $M_{N^*} = 1685 \pm 0.012$ MeV [20], respectively. Therefore, α, β, and γ could be unambiguously determined in this thesis. The values of α, β, and γ were then used to evaluate the masses of the baryon decuplet, antidecuplet (other than Θ^+ and N^*), and eikosiheptaplet. It turns out that these calculated mass values are in very good agreement with experimental data of the baryon octet and decuplet. Conversely, the fact that masses of the baryon octet and decuplet are well reproduced indicates that the experimental data of the Θ^+ and N^* masses are quite reliable.

The parameters α, β, and γ are connected not only to the mass splittings, but also to the wavefunction corrections of vector- and axial-vector transition constants as shown in Eq. (II.1-91). These wavefunction corrections also result from $\mathrm{SU}(3)_\mathrm{f}$ symmetry breaking and greatly influence important physical quantities, such as the magnetic moment of N^* and the decay width of Θ^+. Moreover, the most recent experiment showed an extremely small Θ^+ decay width of 0.36 ± 0.11 MeV [30]This is another reason why the precise determination of α, β, and γ is so crucial. By adjusting the parameters of vector transition (w_i), and of axial-vector transition (a_i) to the experimental data of magnetic moments and hyperon semileptonic decay constants of the baryon octet, respectively, magnetic moments of the baryon decuplet and antidecuplet are evaluated and those of the baryon decuplet are in very good agreement with the experimental data. The signs of the magnetic moments of the Θ^+ and p^* turn out to be opposite to that of the corresponding electric charges while the magnetic moments of the octet and decuplet baryons have the same signs as their respective electric charges. For axial-vector transitions, the calculation gives a Θ^+ decay width of about 1 MeV which is comparable to the experimental value of 0.36 ± 0.11 MeV obtained by the recent DIANA Collaboration [30]. Furthemore, if the decay width of Θ^+ is as small as about 1 MeV, the value of the singlet axial charge of proton $g_A^0 \approx 0.25$ which is used as input to determine a_i in Tab. II.3-1 can be considered to be acceptable within the framework of the χQSM accompanied with *the model-independent approach.*

IV.2 Isobaric Model

The experimental evidence for a narrow structure in the beam asymmetry data for the η photoproduction off free proton and its theoretical analysis have been dealt with in Chapter III. This structure is described by the contribution of a narrow resonance with the mass $M_{N^*} \sim 1685\,\mathrm{MeV}$ and the width $\Gamma \leq 25$ MeV in the Breit-Wigner framework [20]. Candidates are either the P_{11} or P_{13} or D_{13} states. Each state along with the electro- and magnetic multipole data from SAID partial wave analysis has been tested one by one in the Breit-Wigner form by the method of least squares in order to reproduce the polarized photon beam asymmetry Σ. The mass and width of the suggested nucleon resonance are consistent with the parameters of the peak observed in quasi-free cross section η photoproduction off neutron [20, 22, 23]. The explanation of the bump in the quasi-free neutron cross sections by the interference effects of known resonances [159, 166] predicts no narrow structure at all in the proton channel. The new Σ beam asymmetry data for η photoproduction off free proton does not support the explanation in Refs. [159, 166]. The most simple one of possible explanations for the observations made in Refs. [20, 22, 23] would be the existence of a narrow nucleon resonance $N^*(1685)$ with much stronger photocoupling to neutron than to proton. This thesis shows that the value of photocoupling constant for the narrow P_{11} resonance in Eq. (III.2-18) obtained by adjusting the parameters of the Isobaric model to the beam asymmetry data for the η photoproduction off free proton is in good agreement with the calculated value for the non-strange pentaquark from the antidecuplet performed in the χQSM (See Tab. II-18). This agreement indicates that the narrow resonance $N^*(1685)$ is a strong candidate for the non-strange member of the exotic anti-decuplet and the existence of $N^*(1685)$ is the necessary and sufficient condition for the existence of the exotic Θ^+ pentaquark. Presently, the majority of the community has jumped to the conclusion that Θ^+ does not exist (see e.g. Ref. [167]). However, the evidences for a new narrow nucleon resonance - good candidate for the non-strange pentaquark - presented here, encourage further search for the Θ^+ baryon. A new approach for this search is suggested in Ref. [168].

All experimental data that are available at present are based on the single polarization observables, such as the beam asymmetry, differential cross section, and so on. In this thesis, however, the double polarization observables of the η photoproduction off nucleon have been estimated and the results exhibit the same tendency as the ones from the study of the single polarization observables, *i.e.*, every estimated double polarization spectrum shows a significant narrow bump structure on neutron whereas the narrow bump structure on proton is much smaller, yet clearly visible (see Sec. B-2). According to the results in Sec. B-2, the shape of these bump structures in the double polarization observables is very sensitive to any changes in scattering angle and the bumps generally appear within a very narrow energy range. Therefore, high-resolution experiments are necessary for the verification of the existence of these bump structures, which will ultimatly provide us detailed information helpful for uniqely and unambiguously identifying the N^* resonance and studying its properties in more depth.