6 Polarizabilities of the Nucleon

The experiments on Compton scattering from the proton, i.e. the TAPS experiment at low incident photon energies, and the CATS NaI(Tl) and LARA experiments in the $\Delta$-resonance region, cover an energy range of 55 MeV to 460 MeV and photon scattering angles ranging from 44° to 155°. The low-energy data measured with TAPS reveal good agreement with the experiments of [1, 2]. The global average of the electromagnetic polarizabilities of the proton has been determined with an improved precision. The difficulty arising is that the uncertainties are determined mainly by the systematic uncertainties of the experiment and by the model-dependent uncertainties. The latter are related to the $\pi$ photoproduction amplitudes used within the dispersion relation approach. Thus, any further improvement would require a drastic reduction of all these uncertainties.

In the $\Delta$-resonance region, the results of the earlier experiments [3, 4, 5] performed at the MAMI photon beam have been confirmed. Whereas at forward angles the agreement with the LEGS data [6, 7, 8] is satisfactory, there is a significant discrepancy at backward angles. The same feature is also present in experiments on $\pi$ photoproduction [9, 10]. The authors of [6, 8] used their own partial-wave analysis to describe their results on $\pi$ photoproduction and Compton scattering simultaneously. From that analysis, the electromagnetic polarizabilities and the backward spin polarizability were extracted as [6]

\[
\alpha_p + \beta_p = 13.23 \pm 0.86^{+0.20}_{-0.29}, \\
\alpha_p - \beta_p = 10.11 \pm 1.74^{+1.22}_{-0.86}, \\
\gamma_p = -27.1 \pm 2.2^{+2.8}_{-2.4}.
\] (6.1)

As far as $\alpha_p$ and $\beta_p$ are concerned, the new results presented in this book and the LEGS results seem to be in agreement. But the significant difference in the backward spin polarizability, where $\gamma_p = -38.7 \pm 1.8$ is the combined result of the TAPS, LARA and CATS NaI(Tl) experiments [11], reflects the disagreement of the measured differential cross sections. The new experimental results presented in this book and their interpretation in terms of dispersion theory do not leave any space for an additional contribution to the amplitude $A_2$, as proposed by the LEGS group. This statement is also
supported by a new sum rule for $\gamma_\pi^{(p)}$ evaluated by L’vov and Nathan [12], with the value $\gamma_\pi^{(p)} = -39.5 \pm 2.4$.

The experiment on quasi-free Compton scattering from the neutron bound in the deuteron presented in Sect. 5.4.1 [11, 13, 14, 15, 16] was the very first experiment on Compton scattering from the neutron covering the entire $\Delta$-resonance region. For the first time, definite values for the electromagnetic polarizabilities of the neutron could be extracted from such an experiment. Since the earlier results obtained by Rose et al. [17] at photon energies below the $\pi$ production threshold suffered from too large a statistical uncertainty, only an upper bound could be determined. The recent experiment on quasi-free scattering from the neutron by Kolb et al. [18] was the first experiment above $\pi$ production threshold. The disadvantage of this experiment was that the differential cross section was measured at only one energy, i.e. at $\omega = 247$ MeV. By combining these two experimental results, Kolb et al. concluded that the valid ranges for the electromagnetic polarizabilities were

$$\alpha_n = 7.6 - 14.0 \quad \text{and} \quad \beta_n = 1.2 - 7.6 \,.$$  \hspace{1cm} (6.2)

The result $\alpha_n - \beta_n = 9.8 \pm 3.6(\text{stat.})^{+2.1}_{-1.7}(\text{syst.}) \pm 2.2(\text{mod.})$ obtained by the CATS NaI(Tl)/SENECA experiment (5.18) was a major step forward which allows a detailed discussion of the various contributions, as in the case of the proton.

For the purpose of the following discussion, the contributions to the polarizabilities of the proton and neutron were evaluated using the SAID SM99K $\pi$ photoproduction multipoles. The numbers obtained are slightly modified if other multipoles are used, for example those of MAID2000. The results of the dispersion theory given in Table 6.3 and Table 6.4 were obtained by averaging the numbers obtained using the SAID-SM99K [19] and MAID2000 [20] multipoles.

### 6.1 Polarizabilities of the Proton

#### 6.1.1 Contributions to the Electromagnetic Polarizabilities

The electromagnetic polarizabilities $\alpha_p$ and $\beta_p$ were obtained from low-energy Compton scattering (Sect. 4.1.2) and the reevaluation of the Baldin sum rule (Sect. 3.1.3). The global average was deduced to be

$$\alpha_p + \beta_p = 13.8 \pm 0.4 \,,$$  \hspace{1cm} (6.3)

$$\alpha_p - \beta_p = 10.5 \pm 0.9(\text{stat. + syst.}) \pm 0.7(\text{mod.}) \,.$$  \hspace{1cm} (6.4)

In order to obtain more detailed insight into the internal decomposition of $\alpha_p$ and $\beta_p$ [21], the constraints on the invariant amplitudes at forward and backward angles will be used. According to (3.74) and (3.89), one may split the contributions into an integral and an asymptotic part: