

Dynamical Structure of Baryons

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Electric and Magnetic Polarizabilities

Electric Polarizability



$$\vec{p} = 4\pi \alpha_E \vec{E}_0$$

Magnetic Polarizability



$$\vec{\mu} = 4\pi\beta_M \vec{H}_0$$

$$H_{eff} = -\frac{1}{2} 4\pi \alpha_E \vec{E}^2 - \frac{1}{2} 4\pi \beta_M \vec{H}^2$$

Electric and Magnetic polarizability is a measure of deformability of a system.





For spin 1/2 target, there exist 4 independent spin polarizabilities: $Y_{EIEI}, Y_{MIMI}, Y_{MIE2}, Y_{EIM2}$

Spin polarizabilities do not have such simple classical interpretation as electric and magnetic polarizabilities.

The presence of a time-varying electric(magnetic) fields in the plane of a rotating charge will lead to a charge(current) separation. The presence induced electric(magnetic) moments will produce the following effective Hamiltonian:

$$H_{eff}^{spin} = -\frac{1}{2} 4\pi \gamma_{E1E1} \ \vec{\sigma} \cdot (\vec{E} \times \dot{\vec{E}}) - \frac{1}{2} 4\pi \gamma_{M1M1} \ \vec{\sigma} \cdot (\vec{B} \times \dot{\vec{B}}) + 4\pi \gamma_{M1E2} \ \sigma_i B_j E_{ij} - 4\pi \gamma_{E1M2} \ \sigma_i E_j B_{ij}$$

$$T_{ij} = \frac{1}{2} (\partial_j T_j + \partial_j T_i)$$
$$\vec{T} = \vec{E}, \ \vec{B}$$

Spin Polarizabilities (γ_{EIEI} , γ_{MIMI} , γ_{MIE2} , γ_{EIM2}): a measure of stiffness of the spin of the system.





•Nucleon has a core of three light quarks.

- •Replace quark anti-quark pairs by a pion cloud.
- •We can use Chiral Perturbation Theory (ChPbTh):





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Compton Scattering and Polarizability (= | =>

$$\frac{1}{8\pi W} M(\gamma B \to \gamma' B) = \underline{R_1^B} (\boldsymbol{\epsilon}^{\prime *} \cdot \boldsymbol{\epsilon}) + \underline{R_2^B} (\mathbf{s}^{\prime *} \cdot \mathbf{s}) + \underline{R_3^B} i\boldsymbol{\sigma} \cdot (\boldsymbol{\epsilon}^{\prime *} \times \boldsymbol{\epsilon}) + R_4^B i\boldsymbol{\sigma} \cdot (\mathbf{s}^{\prime *} \times \mathbf{s}) + \underline{R_2^B} (\mathbf{s}^{\prime *} \cdot \mathbf{s}) + \underline{R_3^B} (\mathbf{s}^{\prime *} \times \boldsymbol{\epsilon}) + R_4^B i\boldsymbol{\sigma} \cdot (\mathbf{s}^{\prime *} \times \mathbf{s}) + \underline{R_3^B} (\mathbf{s}^{\prime *} \cdot \mathbf{s}) + \underline{R_3^B} (\mathbf{s}^{\prime *} \times \boldsymbol{\epsilon}) + R_4^B i\boldsymbol{\sigma} \cdot (\mathbf{s}^{\prime *} \times \mathbf{s}) + \underline{R_3^B} (\mathbf{s}^{\prime *} \cdot \mathbf{s}) + \underline{R_3^B} ($$

 $\underline{R_5^B} i((\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}) \ (\mathbf{s'^*} \cdot \boldsymbol{\epsilon}) - (\boldsymbol{\sigma} \cdot \hat{\mathbf{k}'}) \ (\mathbf{s} \cdot \boldsymbol{\epsilon'^*})) \ + \underline{R_6^B} i((\boldsymbol{\sigma} \cdot \hat{\mathbf{k}'}) \ (\mathbf{s'^*} \cdot \boldsymbol{\epsilon}) - (\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}) \ (\mathbf{s} \cdot \boldsymbol{\epsilon'^*}))$

$$W = \omega + \sqrt{\omega^2 + m^2}; \quad \hat{\mathbf{k}} = \frac{\mathbf{k}}{k}; \quad \mathbf{s} = (\hat{\mathbf{k}} \times \boldsymbol{\epsilon})$$

$$r = w + \sqrt{\omega^2 + m^2}; \quad \hat{\mathbf{k}} = \frac{\mathbf{k}}{k}; \quad \mathbf{s} = (\hat{\mathbf{k}} \times \boldsymbol{\epsilon})$$

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$$R_{3}^{B} = -r_{0}\frac{\omega}{2m} + \mathcal{O}(\omega^{2}); \quad R_{4}^{B} = -r_{0}\frac{\omega}{m} + \mathcal{O}(\omega^{2}); \quad R_{5}^{B} = \mathcal{O}(\omega^{2}); \quad R_{6}^{B} = r_{0}\frac{\omega}{m} + \mathcal{O}(\omega^{2});$$

$$r_0 = \frac{e^2}{4\pi m}; \quad x = \cos(\theta)$$





$$\frac{1}{8\pi W} M(\gamma B \to \gamma' B) = R_1^{NB} (\epsilon'^* \cdot \epsilon) + R_2^{NB} (\mathbf{s}'^* \cdot \mathbf{s}) + R_3^{NB} i\boldsymbol{\sigma} \cdot (\epsilon'^* \times \epsilon) + R_4^{NB} i\boldsymbol{\sigma} \cdot (\mathbf{s}'^* \times \mathbf{s}) + R_5^{NB} i((\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}) (\mathbf{s}'^* \cdot \epsilon) - (\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}') (\mathbf{s} \cdot \epsilon'^*)) + R_6^{NB} i((\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}') (\mathbf{s}'^* \cdot \epsilon) - (\boldsymbol{\sigma} \cdot \hat{\mathbf{k}}) (\mathbf{s} \cdot \epsilon'^*))$$

$$R_1^{NB} = \omega^2 \alpha_{E}; \quad R_2^{NB} = \omega^2 \beta_{M}; \quad R_3^{NB} = \omega^3 (-\gamma_{E1E1} + \gamma_{E1M2});$$

$$R_1^{NB} = \omega^3 (-\gamma_{M1M1} + \gamma_{M1E2}); \quad R_5^{NB} = -\omega^3 \gamma_{M1E2}; \quad R_6^{NB} = -\omega^3 \gamma_{E1M2}$$

$$M_1^{\mu\nu} = \frac{1}{2m} \frac{\not{p} + m}{p^2 - m^2 + im\Gamma} \left(g^{\mu\nu} - \frac{1}{3} \gamma^{\mu} \gamma^{\nu} - \frac{2p^{\mu}p^{\nu}}{3m^2} + \frac{p^{\mu} \gamma^{\nu} - p^{\nu} \gamma^{\mu}}{3m} \right)$$



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Dynamical versus Static Polarizabilities

•The Compton scattering experiments were performed with 50 to 800 MeV photons and hence require an additional theoretical input to relate the results to zero-energy parameters.

- A composite object has energy-dependent polarizabilities.
- It is well known that polarizabilities can become energy-dependent due to internal relaxation mechanisms, resonances, and particle production thresholds in a physical system.

$$R_i^{NB} \to R_i^{NB}(\omega)$$

$$\alpha_{E1}(\omega) = \frac{R_1^{NB}(\omega)}{\omega^2}; \quad \beta_{M1}(\omega) = \frac{R_2^{NB}(\omega)}{\omega^2};$$
$$\gamma_{E1E1}(\omega) = -\frac{R_3^{NB}(\omega)}{\omega^3} + \gamma_{E1M2}(\omega); \quad \gamma_{M1M1}(\omega) = -\frac{R_4^{NB}(\omega)}{\omega^3} + \gamma_{M1E2}(\omega);$$

$$\gamma_{M1E2}(\omega) = -\frac{R_5^{NB}(\omega)}{\omega^3}; \quad \gamma_{E1M2}(\omega) = -\frac{R_6^{NB}(\omega)}{\omega^3}$$



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Computational Hadronic Model (CHM) Aleksejevs&Butler, J.Phys.G37,035002 (2010) $B = \begin{pmatrix} \frac{1}{\sqrt{2}} \sum^{0} + \frac{1}{\sqrt{6}} \Lambda & \sum^{+} & p \\ \sum^{-} & -\frac{1}{\sqrt{2}} \sum^{0} + \frac{1}{\sqrt{6}} \Lambda & n \\ \Xi^{-} & \Xi^{0} & -\frac{2}{\sqrt{5}} \Lambda \end{pmatrix} \qquad P = \begin{pmatrix} \frac{1}{\sqrt{6}} \eta + \frac{1}{\sqrt{2}} \pi & \pi^{+} & K^{+} \\ \pi^{-} & \frac{1}{\sqrt{6}} \eta - \frac{1}{\sqrt{2}} \pi & K^{0} \\ K^{-} & \overline{K}^{0} & -\frac{2}{\sqrt{5}} \eta \end{pmatrix}$ $\mathfrak{L}_{\pi\pi}^{(8)} = \frac{f_{\pi}^2}{\mathfrak{q}} Tr \left[D^{\mu} \sum^{\dagger} D_{\mu} \sum \right] + \dots \qquad \sum = e^{2iP/f_{\pi}}$ $\mathfrak{L}_{B\pi}^{(8)} = -iTr\,\bar{B}\,\mathcal{D}B + m_BTr\,\bar{B}B + 2D\,Tr\,\bar{B}\gamma^{\mu}\gamma_5\,\{A_{\mu},B\} + 2F\,Tr\,\bar{B}\gamma^{\mu}\gamma_5\,[A_{\mu},B]$ $\mathfrak{L}_{T\pi}^{(10)} = -i\bar{T}^{\mu}\,\mathfrak{D}T_{\mu} + m_{T}\bar{T}^{\mu}T_{\mu} + \mathcal{C}\left(\bar{B}A_{\mu}\gamma_{5}T + \bar{T}^{\mu}A_{\mu}B\right) + 2\mathcal{H}\bar{T}^{\mu}\gamma^{\nu}\gamma_{5}A_{\nu}\Gamma_{5}T_{\mu}$ $\mathfrak{L}^{TB\gamma} = i\Theta \frac{e}{\Lambda_{\gamma}} \overline{B} \gamma^{\mu} \gamma_5 Q T^{\nu} F_{\mu\nu}.$ $V_{\mu} = \frac{1}{2} \left(\xi D_{\mu} \xi^{\dagger} + \xi^{\dagger} D_{\mu} \xi \right) \qquad A_{\mu} = \frac{i}{2} \left(\xi D_{\mu} \xi^{\dagger} - \xi^{\dagger} D_{\mu} \xi \right) \qquad \xi^{2} = \sum$ $\mathfrak{D} = \partial_{\mu} + [V_{\mu}, \ldots] \quad D_{\mu} = \partial_{\mu} + i\mathcal{A}_{\mu} [Q, \ldots]$





∧ Nucleon EM Dynamical Polarizability: (10⁻⁴ fm³)

•All our results (red solid line) are relativistic SU(3) calculations of order of $O(p^4)$

•Pole-type delta resonance contribution to nucleon polarizabilities is included

•Contribution to EM nucleon polarizabilities coming from the resonances in the loops borrowed from SSE framework



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Mucleon Dynamical Spin Polarizability: (10⁻⁴ fm⁴) < ↓ ↓</p>

•Pion pole contribution is not included.

•Only pole-type delta resonance contribution to nucleon spin polarizabilities is considered.



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MEMORIA

Nucleon Dynamical Spin Polarizability: (10⁻⁴ fm⁴)

•Pion pole contribution is not included.

•Only pole type delta resonance contribution to nucleon spin polarizabilities is considered.





EMORI



G Hyperon Dynamical EM Polarizability: (10⁻⁴ fm³) < ↓ ↓</p>

•No resonance contribution to hyperon EM dynamical polarizabilities is considered.





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(Hyperon Spin Dependent Forward Polarizability: (10⁻⁴ fm⁴)



Hyperon Spin Dependent Backward Polarizability: (10-4 fm⁴)





Summary

•The electric and magnetic polarizabilities exhibit mostly static behaviour below the pion production threshold.

•The electric polarizability has a resonant-type behaviour near meson production thresholds.

•The magnetic polarizability shows a change of slope at the production energy.

•Spin dependent dynamical polarizabilities have the similar shapes, but have systematic differences in all models.

•Resonances in loops should be considered as well.



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Thank You!



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Nucleon Spin Polarizability: (10⁻⁴ fm⁴)





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