



## MTHS24 – Exercise sheet 3

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## Lecture material

### Discussed topics:

- Partial waves
- Analyticity
- Unitarity

### References:

- A.D. Martin, T.D. Spearman, Elementary Particle Theory, [inSpire](#)
- Review on Novel approaches in hadron spectroscopy by JPAC, [inspire](#)

## Exercises

### 3.1 Amplitude analysis

Given the Omnès function:

$$\Omega(s) = \exp \left[ \frac{s}{\pi} \int_{4m_\pi^2}^\infty dz \frac{\delta(z)}{z(z-s)} \right], \quad (1)$$

(a) Consider the low-energy expansion of the pion form factor  $F_\pi(s) \equiv \Omega(s)$ :

$$F_\pi(s) = 1 + \frac{1}{6} \langle r_\pi^2 \rangle s + \mathcal{O}(s^2), \quad (2)$$

and deduce the sum rule:

$$\langle r_\pi^2 \rangle = \frac{6}{\pi} \int_{4m_\pi^2}^\infty dz \frac{\delta(z)}{z^2}. \quad (3)$$

The quantity  $\sqrt{\langle r_\pi^2 \rangle}$  is called charge radius of the pion, see [PDF](#) for summary of the experimental measurements.

(b) Assume that the phase shift  $\delta(s)$  reaches  $k\pi$  ( $k$  is an integer) at  $s = \Lambda^2$  and stays at that value for larger  $s$ . What is the behavior of  $\Omega(s)$  in the limit  $|s| \rightarrow \infty$ ?

(c) What is the resulting function  $\Omega(s)$  for an infinitely narrow resonance, i.e. consider  $\delta(s) = \pi\theta(s - M^2)$ ?

### 3.2 Isospin

The one-pion states are of the form  $|I, I_3\rangle$  with

$$|1, +1\rangle = |\pi^+\rangle, \quad |1, 0\rangle = |\pi^0\rangle, \quad |1, -1\rangle = |\pi^-\rangle. \quad (4)$$

(a) From the three pion flavors, construct the nine different two-pion states and their decomposition into isospin states.

(b) Invert the decomposition in (a) to get the decomposition of the isospin states into two pion states.

- (c) Do pions obey Bose statistics? What is the angular momentum (even or odd) for the states with  $I = 0, 1, 2$ ?