NUCLEAR PHYSICS (16)

Tensor forces

$\Rightarrow$

One boson exchange model

$\Rightarrow$

RECAP Previous lesson → T-matrix (Review)

(*) $f(\Omega) = -\frac{\mu}{2\pi}\langle \vec{k}' | T(E) | \vec{k} \rangle$, $\frac{d\sigma}{d\Omega} = |f(\Omega)|^2$

$T(E) = V + V G_0(E) T(E)$ Lippmann-Schwinger equation

(*) T-matrix is easy to solve for a particular type of potentials (separable potentials)

$$\langle \vec{p}\,' | V | \vec{p} \rangle = \lambda\, g(p)\, g(p')$$

(definition of a separable potential)

$$T = V + V G_0 T$$

$$\langle \vec{p}\,' | t(E) | \vec{p} \rangle = \tau(E)\, g(p)\, g(p')$$

$$\tau(E) = \frac{1}{1/\lambda - J(E)} \qquad J(E) = \int \frac{d^3\vec{q}}{(2\pi)^3} \frac{g^2(q)}{E - \frac{q^2}{2\mu}}$$

Lippmann-Schwinger equation (for T-matrix) → Separable potentials → Simple T-matrix

→ This is also useful for contact-range theories

universal low-energy theories

Contact-range

$$\langle \vec{p}' | V | \vec{p} \rangle = C_0(\Lambda) \underbrace{f\left(\frac{p'}{\Lambda}\right) f\left(\frac{p}{\Lambda}\right)}_{V \text{ depends on } \Lambda}$$

($f(x)$ labels each of the two factors $f(p'/\Lambda)$ and $f(p/\Lambda)$)

$\rightarrow \begin{cases} f(x) \rightarrow 1, & x \rightarrow 0 \\ f(x) \rightarrow 0, & x \rightarrow \infty \end{cases}$

Kill the unwanted high-energy modes

$$C_0(\Lambda) \rightarrow \tau(\Lambda)$$

$$\frac{d}{d\Lambda} \tau(\Lambda) = 0$$

Example $\to$ $\sigma \to 4\pi |a_0|^2$, $E \to 0$ $\Big\}$ $\tau(E) + \frac{d}{d\Lambda}\tau(E) = 0$

$$\Rightarrow \boxed{\frac{1}{C_0(\Lambda)} = \frac{\mu}{2\pi}\left(\frac{1}{a_0} - \beta\Lambda\right)}$$

Family of solutions that we will get

if $f(x) = \Theta(1-x)$ $\Rightarrow$ $\beta = \frac{2}{\pi}$

(sharp cutoff)

⊛ Bound states w/ T-matrix

$$T(E) \xrightarrow[E \to E_B]{} \frac{\mathrm{Res}\,T(E_B)}{E - E_B}, \quad \mathrm{Res}\,T = V|B\rangle\langle B|V$$

$$= G_0^{-1}(E_B)|B\rangle\langle B|G_0^{-1}(E_B)$$

$$\langle \vec{p}\,'|V|\vec{p}\rangle = C_0 f\left(\frac{p}{\Lambda}\right) f\left(\frac{p'}{\Lambda}\right) \quad \& \quad \Lambda \to \infty \quad \& \quad a_0 \text{ fixed}$$

$$\psi_B(\vec{p}) = \langle \vec{p}|B\rangle = \frac{\sqrt{8\pi\gamma}}{p^2+\gamma^2}, \quad \gamma = \frac{1}{a_0}$$

→ These were the most important points to remember about the T-matrix ←

TENSOR FORCE | What is it?

1) Yukawa's idea to explain nuclear forces

$$V_Y(\vec{r}) = -g_Y^2 \frac{e^{-mr}}{4\pi r} \qquad \text{meson} \qquad (J^P = 0^+)$$

But $\exists$ a problem $\rightarrow$ deuteron quadrupole moment

Deuteron quadrupole moment → $Q_d \simeq 0.28\,\text{fm}^2 e$

$\boxed{Q_d \neq 0}$ ⇒ Deuteron contains a D-wave component

Ψ_d / S-wave $(\psi(\vec{r}) = \psi(r))$

$Q_d \propto (3z^2 - r^2)$ ⇒ $\langle\psi|Q_d|\psi\rangle = 0$

$\left(\langle z^2\rangle = \frac{1}{3}\langle r^2\rangle\right)$

[∃ D-wave component] ⇐

2) Usual explanation is a $J^P = 0^-$ meson exchange

OPE → One pion exchange (pion)

$$V_{OPE}(\vec{q}) = -\frac{g_A^2}{4 f_\pi^2} \vec{\tau}_1 \cdot \vec{\tau}_2 \frac{\vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_2 \cdot \vec{q}}{\vec{q}^2 + m_\pi^2} \quad (\star)$$

$[\, g_A \simeq 1.26 ,\ f_\pi \simeq 92.4 \text{ MeV} ,\ m_\pi \simeq 138 \text{ MeV} \,]$

$\circledast \Rightarrow \vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_1 \cdot \vec{q} = \sigma_{1i}\sigma_{2j}\, q_i q_j = \}\, q_i q_j$

$\circledast = \sigma_{1i}\sigma_{2j}\Big[\frac{q^2}{3}\delta_{ij}$ 0_S

$1 \otimes 1 = 0_S \oplus 1_A \oplus 2_S$

$q_i q_j = q_j q_i \to S$ $\Big\} = \circledast$

2_S

$+ \left(q_i q_j - \frac{1}{3} q^2 \delta_{ij}\right)\Big] = \circledast$

$\circledast = \frac{1}{3}\vec{\sigma}_1 \cdot \vec{\sigma}_2\, q^2 + \left(3\vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_2 \cdot \vec{q} - \frac{1}{3}\vec{\sigma}_1 \cdot \vec{\sigma}_2 q^2\right)$

$$\vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_2 \cdot \vec{q} = \underbrace{\frac{1}{3} \vec{\sigma}_1 \cdot \vec{\sigma}_2\, q^2}_{\text{spin-spin operator } (L=0)} + \underbrace{\left(\vec{\sigma}_1 \cdot \vec{q}\, \vec{\sigma}_2 \cdot \vec{q} - \frac{1}{3} \vec{\sigma}_1 \cdot \vec{\sigma}_2\, q^2\right)}_{\text{tensor operator } (L=2)}$$

spin-spin operator ($L=0$)

tensor operator ($L=2$)

⇓

Deuteron will have an $L=2$ component

[configuration space] (r-space)

$$V_{OPE}(\vec{r}) = \frac{g_A^2 m_\pi^3}{48\pi f_\pi^2} \vec{\tau}_1 \cdot \vec{\tau}_2 \left[\underbrace{\vec{\sigma}_1 \cdot \vec{\sigma}_2}_{(1)} W_C(r) + \underbrace{S_{12}(\hat{r})}_{(2)} W_T(r) \right]$$

$$\left[S_{12}(\hat{r}) = 3\, \vec{\sigma}_1 \cdot \hat{r}\, \vec{\sigma}_2 \cdot \hat{r} - \vec{\sigma}_1 \cdot \vec{\sigma}_2 \right]$$

usual definition of tensor operator

(1) (spin-spin) $\vec{\sigma}_1 \cdot \vec{\sigma}_2 = \begin{cases} 1 & S=1 \\ -3 & S=0 \end{cases}$

(2) (tensor) $S_{12}(\hat{r})$ a) $[S_{12}, \vec{L}^2] \neq 0$

$[S_{12}, \vec{S}^2] = 0$ (*)

$[S_{12}, \vec{J}^2] = 0$

} b, c

a) $\Rightarrow S_{12}$ mixes different values of L

b, c) $\Rightarrow S_{12}$ conserves S, J

(*) only happen if $S < 2$ Always happens in NN

$S_{12}(\hat{r}) \rightarrow \left[\begin{array}{l} \text{matrix in } \ell \\ \text{scalar in } s, j \end{array} \right)$

$\rightarrow$ (when computing its matrix elements)

$$\langle (s'\ell')j'm' | S_{12}(\hat{r}) | (s\ell)jm \rangle = S^{js}_{\ell\ell'} \delta_{jj'} \delta_{mm'} \delta_{ss'}$$

$\downarrow$

we can drop this, because $s=1$ for $\langle S_{12} \rangle \neq 0$

Additional simplification:

$S=0 \Rightarrow \langle S_{12} \rangle = 0$ Why?

$S_{12}(r) = 3\,\vec{\sigma}_1\cdot\hat{r}\;\vec{\sigma}_2\cdot\hat{r} - \vec{\sigma}_1\cdot\vec{\sigma}_2$

if we exchange spins: $S_{12} \to S_{12}$

$S=0 \to |00\rangle = \frac{1}{\sqrt{2}}\left(|+-\rangle - |-+\rangle\right)$ $|00\rangle \to -|00\rangle$

$S_{12}|00\rangle = -S_{12}|00\rangle \Rightarrow S_{12}|00\rangle = 0$

(this explanation is a bit wacky)

$S = 1 \Rightarrow \langle S_{12}\rangle \neq 0 \quad (L \neq L' \neq 0)$

$L = 0$

$L' = 0$

$$\int d^2\hat{r}\,(3\vec{\sigma}_1\cdot\hat{r}\,\vec{\sigma}_2\cdot\hat{r} - \vec{\sigma}_1\vec{\sigma}_2) = 0$$

$\rightarrow \vec{\sigma}_1\cdot\vec{\sigma}_2$

$$\langle S=0 | S_{12} | S=0 \rangle = 0$$

$$\langle P=0 | S_{12} | P=0 \rangle = 0$$

How to calculate $S_{12}(\hat{r})$?

$[S_{12}(\hat{r}), \vec{J}] = 0 \longrightarrow$ Define states w/ good J

$|(SL)\,J\,M\rangle$

wo/ tensor force →

$$|\ell m_\ell\rangle|s m_s\rangle = Y_{\ell m_\ell}(\hat{r})|s m_s\rangle$$

w/ tensor force → $|(\ell s) j m\rangle$

$$|(\ell s) j m\rangle = \sum_{\substack{s m_s \\ \ell m_\ell}} Y_{\ell m_\ell}(\hat{r})|s m_s\rangle$$

$$\times \langle \ell m_\ell s m_s | j m\rangle$$

Clebsch-Gordan coefficient ← (new part)

$$\langle (s'l')jm' | S_{12}(\hat{r}) | (sl)jm \rangle$$

$$= \delta_{ll'} \, \delta_{ss'} \, \delta_{jj'} \, \delta_{mm'}$$

assumes $s < 2$

(which is true for the NN system)

How does this look for the deuteron?

w/o tensor force

$$\psi_d(\vec{r}) = \frac{u(r)}{r} Y_{00}(\hat{r}) \, |1 \, m_d\rangle$$

$$|1\,1\rangle = |{+}{+}\rangle$$

$$|1\,0\rangle = \frac{1}{\sqrt{2}}\left(|{+}{-}\rangle + |{-}{+}\rangle\right)$$

$$|1\,{-1}\rangle = |{-}{-}\rangle$$

(very simple wave function)

w/ tensorforce

$|S m_S\rangle\langle S m_S\, 0 0 | 1 m_d\rangle = |S m_S\rangle$

$$\psi_d(\vec{r}) = \frac{u(r)}{r} \Sigma_{00}(\vec{r})\, |1 m_d\rangle$$

$$+ \left[\frac{w(r)}{r} \sum_{m_S, m_\ell} \Sigma_{2 m_\ell}(\hat{r})\, |1 m_S\rangle \langle 2 m_\ell\, 1 m_S | 1 m_d\rangle \right]$$

D-wave component

$$\psi_d(\vec{r}) = \frac{u(r)}{r} |S(1 m_d)\rangle + \frac{w(r)}{r} |D(1 m_d)\rangle$$

$$\Rightarrow \langle S_{12}(\hat{r}) \rangle = \begin{pmatrix} \langle S|S_{12}|S\rangle & \langle S|S_{12}|D\rangle \\ \langle D|S_{12}|S\rangle & \langle D|S_{12}|D\rangle \end{pmatrix}$$

$$= \begin{pmatrix} 0 & 2\sqrt{2} \\ 2\sqrt{2} & -2 \end{pmatrix}$$

For the deuteron:

$$S_{12} = \begin{pmatrix} 0 & 2\sqrt{2} \\ 2\sqrt{2} & -2 \end{pmatrix}$$

Knowing this, we can write a Schrödinger equation for $u(r), w(r)$

w/o tensor: $V(r) = V_c(r)$ (might include spin-spin)

$$\left[-u''(r) + 2\mu V(r) u(r) = -\gamma^2 u(r) \right]$$

it was a very simple differential equation w/ tensor $\quad V(\vec{r}) = V_c(r) + S_{12}(\hat{r})\, V_T(r)$

$$-u''(r) + 2\mu\left[V_c(r)\, u + 2\sqrt{2}\, V_T(r)\, w\right] = -\gamma^2 u(r)$$

$$\begin{pmatrix} 0 & 2\sqrt{2} \\ 2\sqrt{2} & -2 \end{pmatrix}$$

$$-w''(r) + \frac{6}{r^2} w(r) + 2\mu\left[2\sqrt{2}\, V_T(r)\, u + (V_c - 2V_T)\, w(r)\right] = -\gamma^2 w(r)$$

More compact in matrix form.

$$-\begin{pmatrix} u \\ w \end{pmatrix}'' + 2\mu \begin{pmatrix} V_c & 2\sqrt{2}\,V_T \\ 2\sqrt{2}\,V_T & (V_c - 2V_T) \end{pmatrix} \begin{pmatrix} u \\ w \end{pmatrix}$$

$$+ \underbrace{\begin{pmatrix} 0 & 0 \\ 0 & 6/r^2 \end{pmatrix}} \begin{pmatrix} u \\ w \end{pmatrix} = -\gamma^2 \begin{pmatrix} u \\ w \end{pmatrix}$$

$$\frac{\ell(\ell+1)}{r^2} \longrightarrow \text{centrifugal barrier}$$

this also changes the asymptotic behavior

$$u(r) \to A_S e^{-\gamma r}$$ → dominant comp.

$$w(r) \to A_D e^{-\gamma r}\left(1 + \frac{3}{\gamma r} + \frac{3}{(\gamma r)^2}\right)$$

$r \to \infty$

$$\frac{A_D}{A_S} \simeq 0.0256$$

Normalization →

$$\int_0^\infty u^2(r)\,dr = 1 \quad \Rightarrow \int_0^\infty \left(u^2(r) + w^2(r)\right) dr = 1$$

Observables →

$$\langle r_m^2 \rangle = \frac{1}{4} \langle r^2 \rangle \qquad \Rightarrow \langle r_m^2 \rangle = \frac{1}{4} \times$$

$$= \frac{1}{4} \int_0^\infty r^2 u^2(r)\,dr \qquad \times \int_0^\infty r^2 \left(u^2(r) + w^2(r)\right) dr$$

Quadrupole moment:

$$\langle Q_d \rangle = 0 \Rightarrow \langle Q_d \rangle = \frac{1}{20}\int_0^\infty r^2 w(r) \times \left(2\sqrt{2}\,u(r) - w(r)\right) dr$$

If $w(r) = 0 \Rightarrow Q_d = 0$

D-wave probability:

$$P_D = \int_0^\infty w^2(r)\,dr$$

$$\boxed{P_D \sim (3-5)\%}$$

⟹ (only an observable until we include quantum corrections to e.m. observables)

Review of deuteron observables:

$$r_m = 1{,}97\,54(9)\ \text{fm}$$

$$Q_d = 0{,}2859(3)\ \text{fm}$$

$$P_D \sim (3\text{-}5)\,\%$$

$$\eta = \frac{A_D}{A_S} = 0.0256(4)$$

[TENSOR FORCE]

→ more complicated deuteron
(now it contains a D-wave)

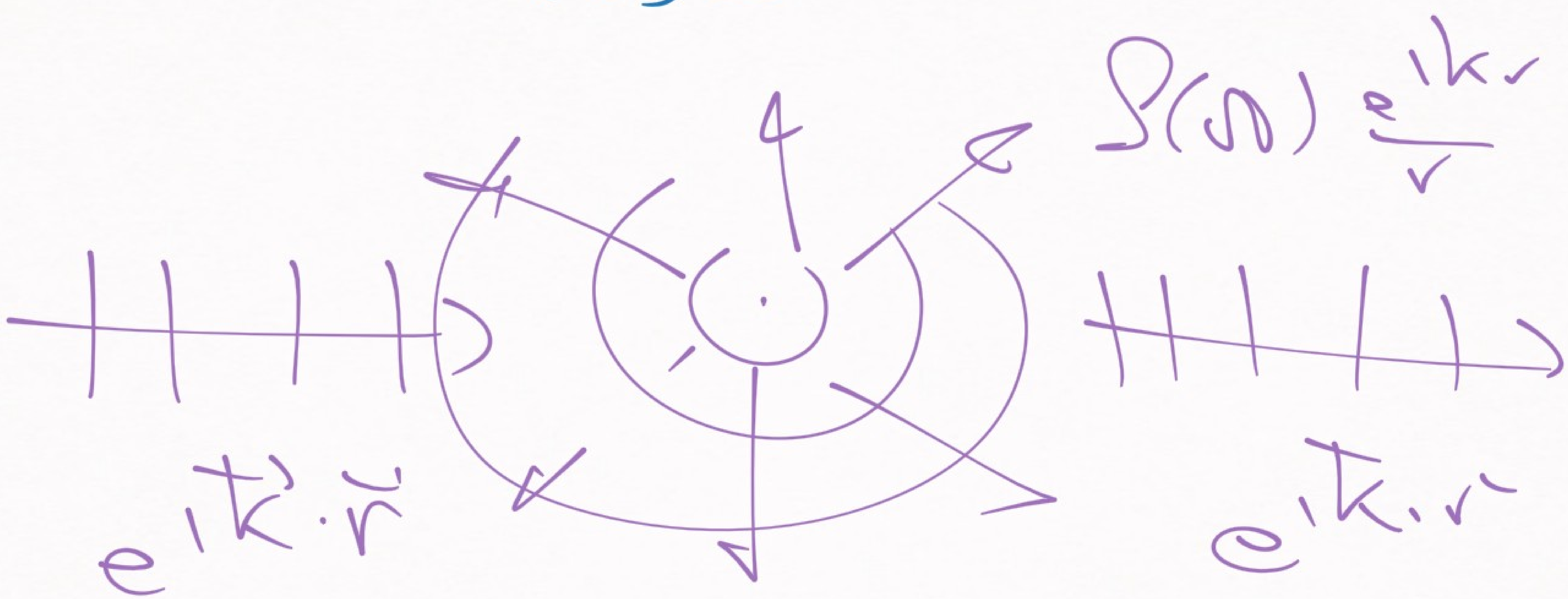
→ also changes scattering
amplitudes & phase shifts
(really complicate)

tensor force + scattering

→ very simplified overview

Effect of including spin in scattering

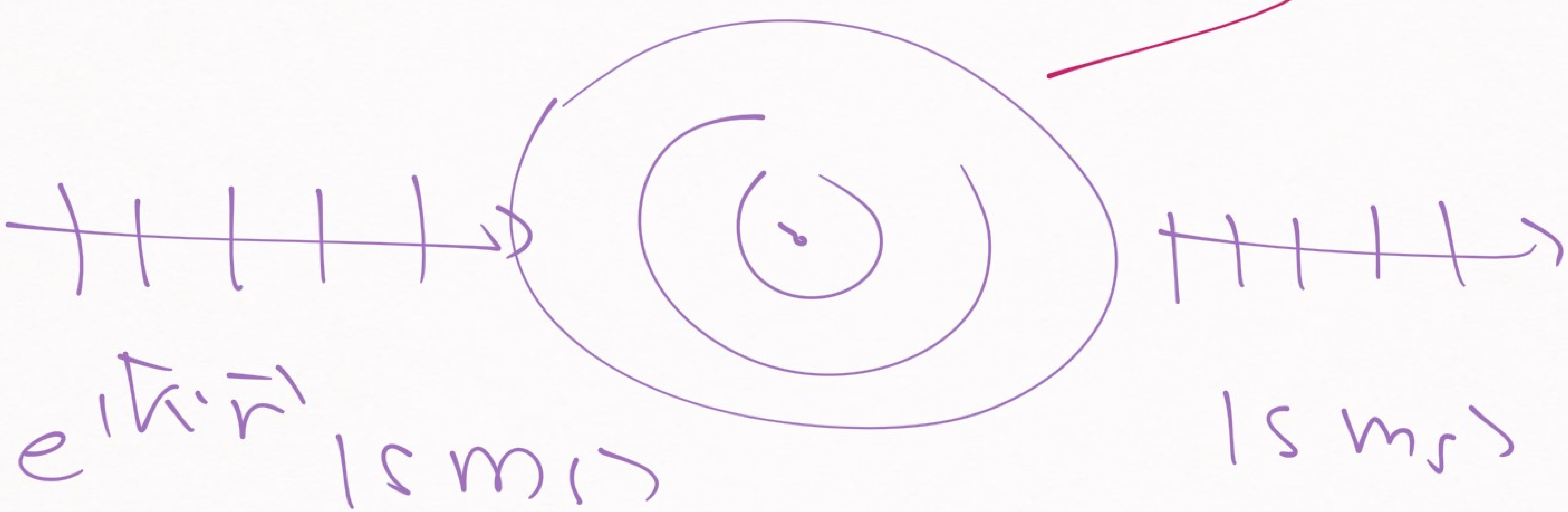
w/o spin → $\psi(\vec{r}) \xrightarrow[r\to\infty]{} e^{i\vec{k}\cdot\vec{r}} + f(\Omega)\frac{e^{ikr}}{r}$



w/spin

$$\psi(\vec{r}) \rightarrow e^{i\vec{k}\cdot\vec{r}}|s\,m_s\rangle + f_{m_s' m_s}(\theta)\frac{e^{ikr}}{r}|s\,m_s'\rangle$$

(assumes $s' = s$)



w/o spin → $f(\Omega) = \sum_{\ell} (2\ell+1) f_\ell P_\ell(\cos\theta)$

$f_\ell(k) = \frac{e^{2i\delta_\ell} - 1}{2ik}$ — δ_ℓ → phase shift

w/ spin → $f_{m_s m_s'}(\Omega) = \sum_{j\ell} \underbrace{(\ldots\ldots)}_{m_s', m_\ell, \ell, j} f^{j}_{s\ell}(k)$

$$f^J_{\ell s}(k) = \frac{e^{2i\delta^J_{\ell s}(k)} - 1}{2ik}$$

↳ this assumes $j' = j$, $\ell' = \ell$, $s' = s$

✓

If I break any of these assumptions

⇒ f will become a matrix

tensor force → $\ell \neq \ell'$

$$f^J_{\ell s}(k) = \frac{e^{2i\delta^J_{\ell s}(k)} - 1}{2ik} \rightarrow f^J_{\ell'\ell} = \frac{1}{2ik}\left(S^J_{\ell\ell'}(k) - \delta_{\ell\ell'}\right)$$

I ignore s because $s = s' = 1$

$$\rho^{J}_{\ell\ell'} = \frac{1}{2ik}\left(S^{J}_{\ell\ell'}(k) - \delta_{\ell\ell'}\right)$$

$$\rho_{\ell}(k) = \frac{1}{2ik}\left(S_{\ell}(k) - 1\right)$$

$$S^{J}(S^{J})^{+} = 1$$

$$S_\ell S_\ell^{+} = 1$$

$$\Rightarrow S_\ell(k) = e^{2i\delta_\ell(k)}$$

$S^{J}_{\ell\ell'}(k)$ unitary in L^2-space

$$S^j(k) = \begin{pmatrix} 2\times 2 & \\ & 1\times 1 \end{pmatrix}$$

2×2 → $L = J \pm 1$

2×2 → $S = 1,\ L = J \pm 1,\ J$

different parities

1×1 → $L = J$

→ exactly identical to standard scattering

$L = J \pm 1$

$$S^J(k) = R D R^{-1}$$

D → diagonal matrix (unitary)

R → rotation matrix

$$= \begin{pmatrix} \cos\epsilon_J & -\sin\epsilon_J \\ \sin\epsilon_J & \cos\epsilon_J \end{pmatrix} \begin{pmatrix} e^{2i\delta_1} & 0 \\ 0 & e^{2i\delta_2} \end{pmatrix} \begin{pmatrix} \cos\epsilon_J & +\sin\epsilon_J \\ -\sin\epsilon_J & \cos\epsilon_J \end{pmatrix}$$

→ Eigen phase shifts

$$S^J(k) = R(E)\, D\, R^T(E)$$

(see previous page)

→ intuitive parametrization

→ Nuclear bar

$$\underline{\underline{SU(K)}} = \begin{pmatrix} e^{i\overline{\delta}_1} & 0 \\ 0 & e^{i\overline{\delta}_2} \end{pmatrix} \begin{pmatrix} \cos 2\overline{\epsilon}_j & i\sin 2\overline{\epsilon}_j \\ i\sin 2\overline{\epsilon}_j & \cos 2\overline{\epsilon}_j \end{pmatrix}$$

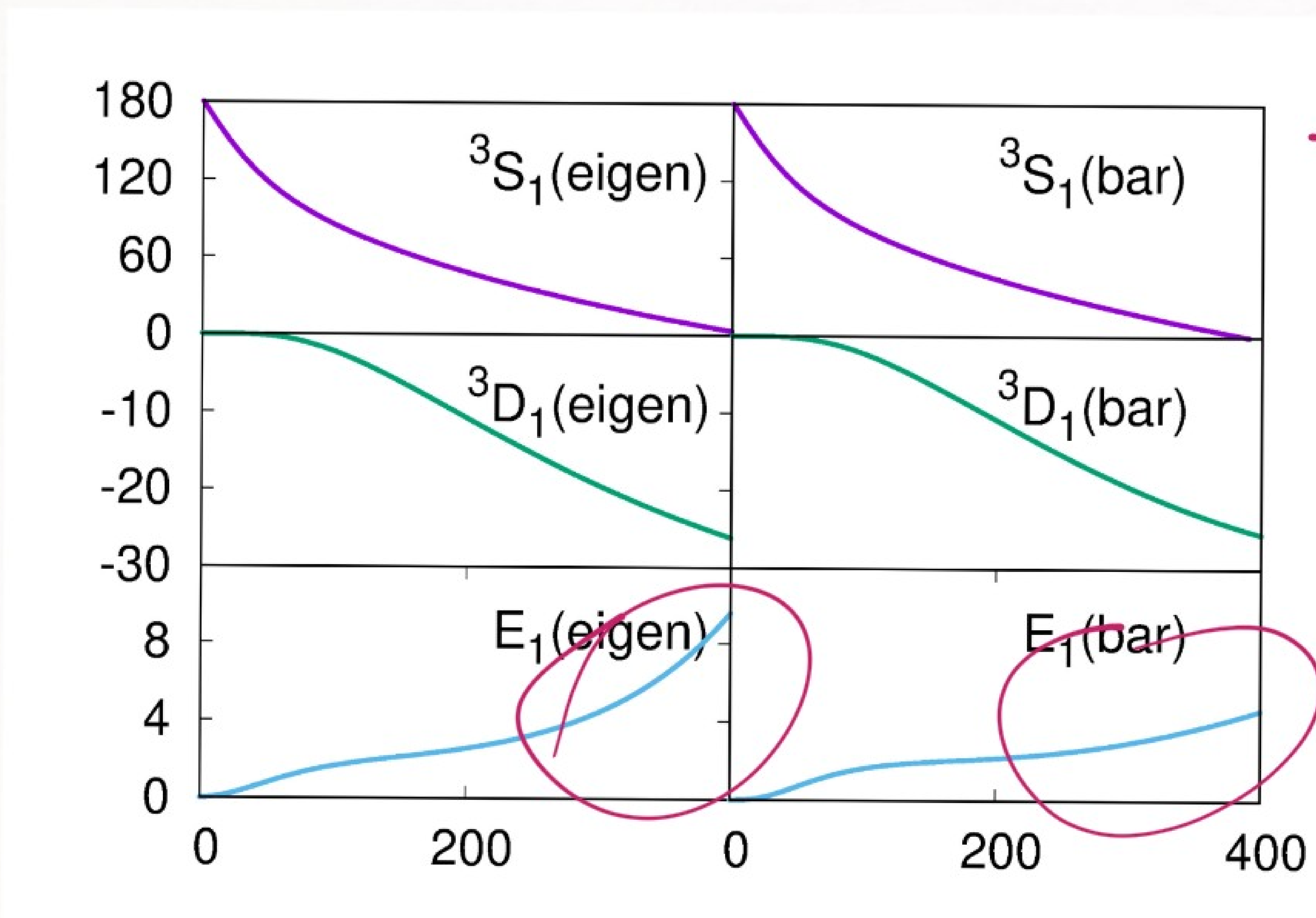
↓

∀ the same, $\begin{pmatrix} e^{i\overline{\delta}_1} & 0 \\ 0 & e^{i\overline{\delta}_2} \end{pmatrix}$

but can be written in many forms

→ these are the most used parametrization

(∃ as many as you want)



→ Deuteron channel $^3S_1 - ^3D_1$

→ only important difference

TO SUMMARIZE

→ tensor force creates a few technical complication for the phase shifts

(important if you study NN in detail)

— ⊖ —

OBE MODEL

We have seen a lot about the generic description of the two nucleon system

[One boson exchange (OBE) model]

first qualitatively successful description of the nuclear force

→ very intuitive (direct extension of Yukawa's idea of meson exchange)

Historical notes

1) Before QCD

1.a) Pion theories of the 50's → failed

1.b) OBE model → works ← easy

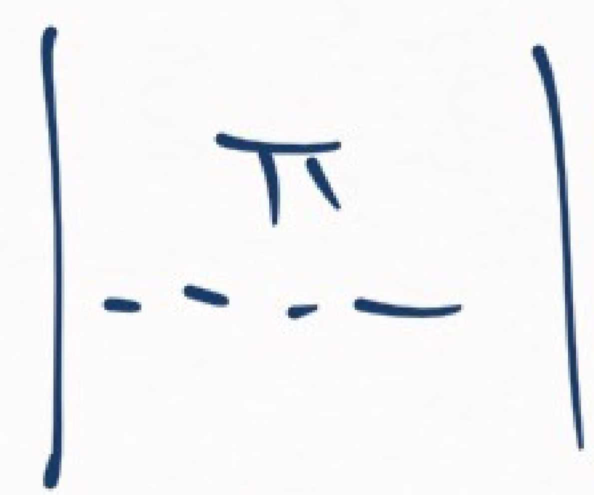
2) After QCD difficult

2.a) QCD-inspired models ↙

2.b) EFT methods (ongoing, seems to work)

OBE model → easy-to-understand description

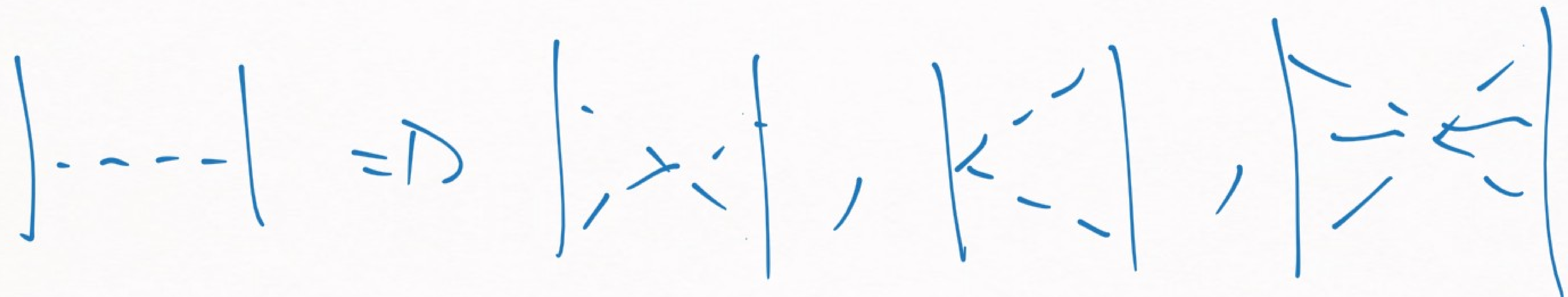
↳ Why was it proposed?

1) Yukawa's idea: 

→ first step in NN description

2) How to go beyond this?

2.a) Multi-pion theories

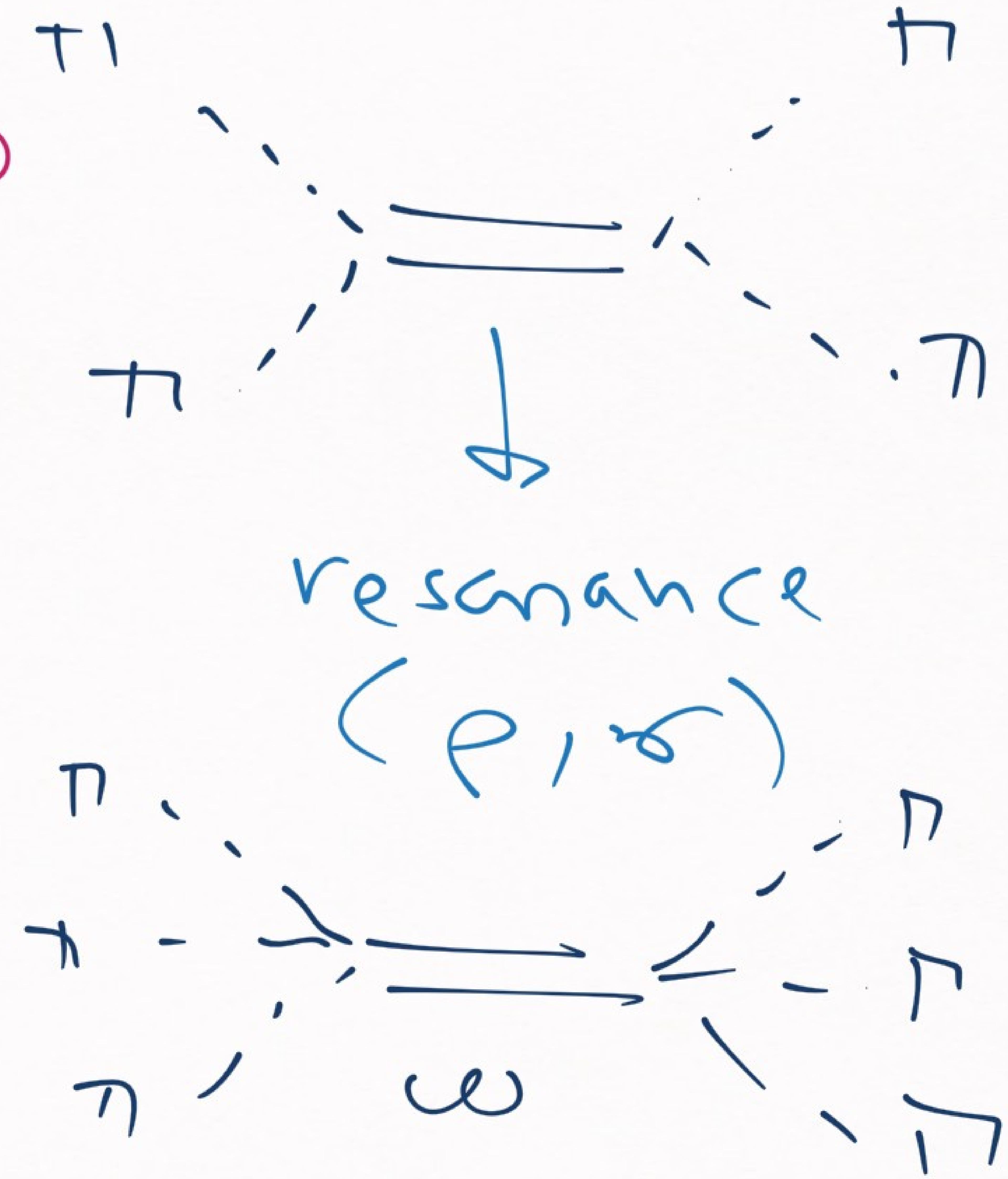


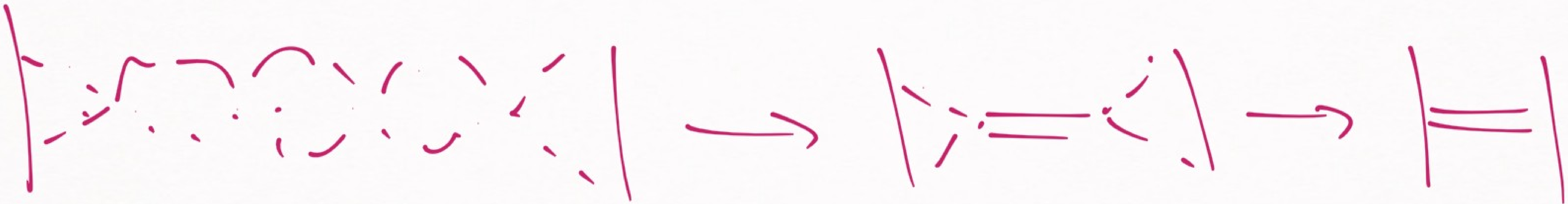
more pions → conceptually straightforward

In the 50's people didn't understand pion dynamics / renormalization

→ failed

2.b) OBE model



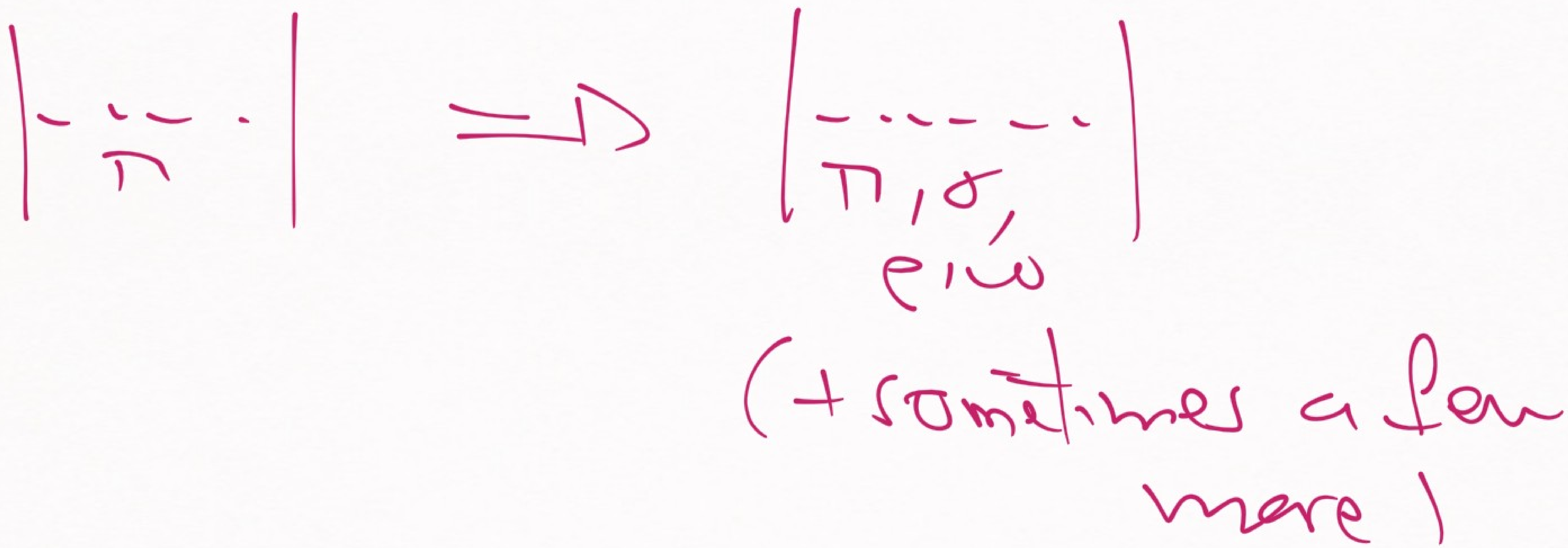


IDEA

reduce multi-pion exchange

→ exchange of a single meson

RESULT OF THIS IDEA IS REALLY EASY:



Who are the important mesons?

1) The pion (π) : $J^P = 0^-$, $I = 1$, $m_\pi = 140\,\text{MeV}$

(Job → explain Q_d in the deuteron)

2) The sigma (σ) : $J^P = 0^+$, $I = 0$, $m_\sigma \simeq 500\,\text{MeV}$

(Job → strong mid-range attraction)

3) The rho(ρ) : $J^P = 1^-$, $I = 1$, $m_\rho = 770\,MeV$

(Job → the tensor force of the pion is too strong & the rho counters it)

4) The omega(ω) : $J^P = 1^-$, $I = 0$, $m_\omega = 780\,MeV$

(Job → provide short-range repulsion)

OBE Potential:

$$V_{OBE} = V_\pi + V_\rho + V_\omega + V_\sigma + \dots$$

→ sum of individual contributions

→ Very simple description of NN forces

$V_{\pi}(\underline{q}) \rightarrow$ (we have shown it before)

$$V_{\sigma}(\underline{q}) = -\frac{g_{\sigma}^2}{\underline{q}^2 + m_{\sigma}^2}$$

$$V_{\omega}(\underline{q}) = \frac{g_{\omega}^2}{\underline{q}^2 + m_{\omega}^2} + \frac{(f_{\omega} + g_{\omega})^2}{4M_N^2} \frac{(\vec{\sigma}_1 \wedge \vec{q}) \cdot (\vec{\sigma}_2 \wedge \vec{q})}{\underline{q}^2 + m_{\omega}^2}$$

$$V_{\rho}(\underline{q}) = \vec{\tau}_1 \cdot \vec{\tau}_2 \cdot \left[V_{\omega} / g_{\omega} \rightarrow g_{\rho},\ f_{\omega} \rightarrow f_{\rho},\ m_{\omega} \rightarrow m_{\rho} \right]$$

Some simplifications

→ $\rho_e \gg g_r \Rightarrow g_r \simeq 0$

$f_w \ll g_w \Rightarrow g_w \simeq 0$

→ Very common simplifications

[OBE potential] → some contributions to the potential are singular

V_π, V_ρ, V_ω (tensor forces) $\} \sim 1/r^3$ at short-distances

→ Regularization → Form factors

FORM FACTORS (avoid $1/r^3$ singular behavior)

↓

since hadrons have a finite-size, we can include this effect in the potential

$$V_M(\vec{q}) \to V_M(\vec{q}) F_M^2(\vec{q})$$

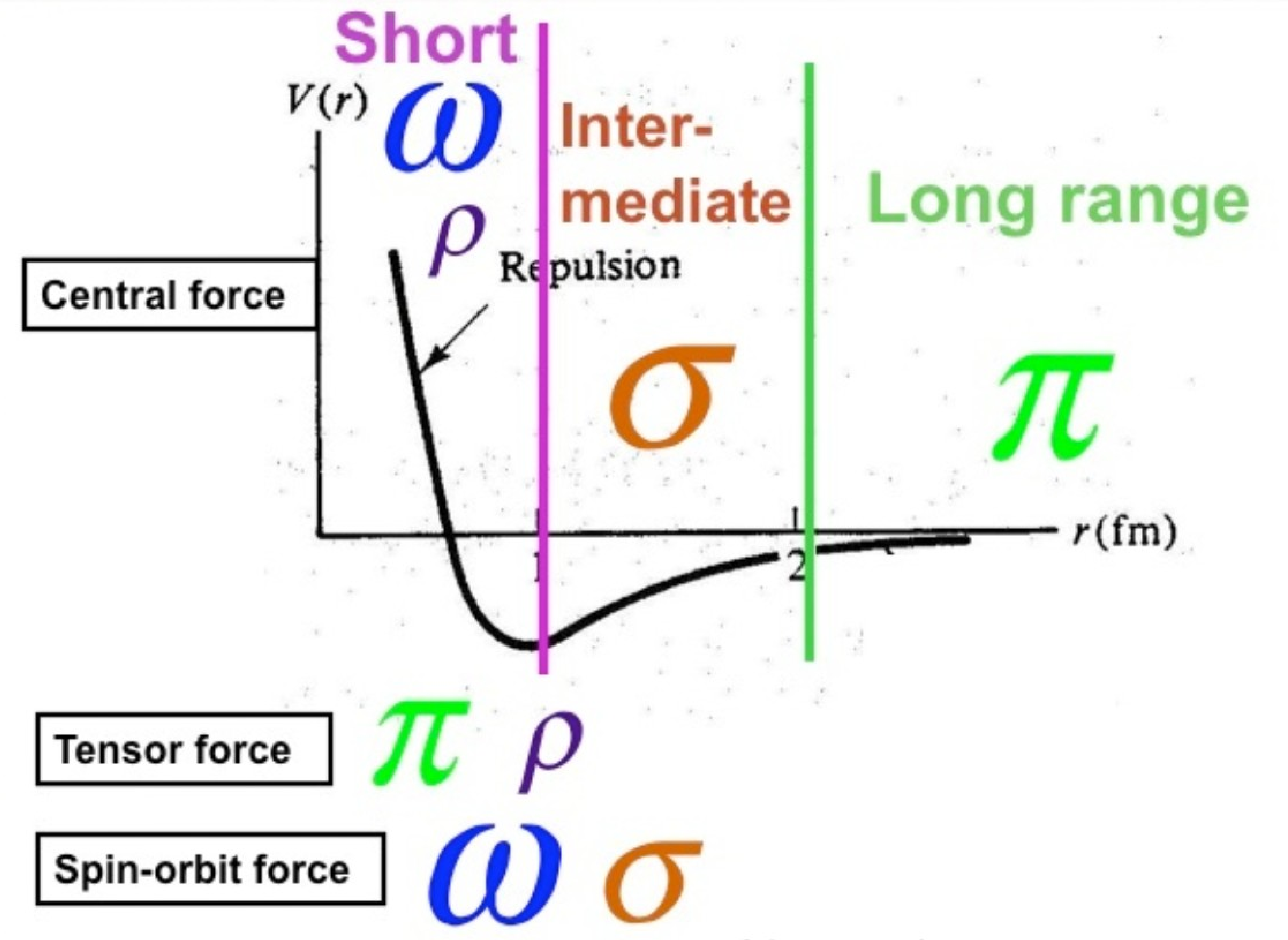
to account for hadron finite-size

$$F_M(\vec{q}) = \left(\frac{\Lambda^2 - m^2}{\Lambda^2 + \vec{q}^2}\right)^\alpha \to \text{multipolar form-factor}$$

$\exists$ also relativistic corrections

$\boxed{\sigma, \omega}$ → rel. corrections generate a spin orbit force

→ important for a few partial waves



Summary of OBE model ⇒

Scholarpedia → Nuclear Forces by Machleidt

Table 1: The four most important mesons and the main characteristics of their contributions to components of the nuclear force.

Meson	Central	Spin-Spin	Tensor	Spin-Orbit
$\pi(138)$	---	weak, long-ranged	**strong**, long-ranged	---
$\sigma(500)$	**strong, attractive**, intermediate-ranged	---	---	moderate, intermediate-ranged
$\omega(782)$	**strong, repulsive**, short-ranged	---	---	**strong**, short-ranged, coherent with σ
$\rho(770)$	---	weak, short-ranged, coherent with π	moderate, short-ranged, **opposite to** π	---

→ Summary of the job done by every meson //

→ In summary, it's an easy and intuitive model!

⇒

→ **SEE YOU ON TUESDAY**