Validity of optical theorem in elastic collisions of strongly interacting particles?

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Contents

1. Introduction

Aim of contemporary theoretical science

- mathematical models describing a group of experimental values
- no interest in assumption and physical mechanism!
- see: The Economist - October 16, 2013 [1]

Main mistakes in particle physics

- Bell's inequality: mistaking interpretation of Schroedinger equation
  mainly: limited structure of Hilbert space
- optical theorem (OT)
  - deforming impact to parametrization of hadronic differential cross section
    main consequence: unrealistic central elastic hadronic scattering even at $b = 0$
  - peripheral elastic hadronic collisions - average impact parameter: $\sqrt{\langle b^2 \rangle_{\mathrm{el}}} > \sqrt{\langle b^2 \rangle_{\mathrm{inel}}}$
    However: elastic events even at $b = 0$ (head-on collisions) remaining
    V. Kundrát, M. V. Lokajíček: Z. Phys. C **63** (1994), 619 [2, 3]
- both Bell's inequality and optical theorem influencing interpretation of elastic collisions

In the following: much deeply reasoned description

- Schroedinger equation and controversy between Einstein and Bohr
- strong interaction without optical theorem and further important consequences

2. Two different interpretations of Schroedinger equation

Schroedinger equation

$$i\hbar\frac{\partial\psi(x,t)}{\partial t} = \hat{H}\psi(x,t), \quad \hat{H} = -\frac{\hbar^2}{2m}\nabla^2 + \hat{V}(x) \tag{1}$$

$$\psi_E(x,t) = \lambda_E(x)e^{-iEt/\hbar}, \quad \hat{H}\lambda_E(x) = E\lambda_E(x) \tag{2}$$

- general solution
$$\psi(x,t) = \sum_E c_E\psi_E(x,t), \quad \sum_E |c_E|^2 = 1 \tag{3}$$
- time-dependent physical quantities
$$A(t) = \int \psi^*(x,t)\,\hat{A}\,\psi(x,t)\mathrm{d}x \tag{4}$$
- $\hat{A}$ - corresponding operators in Hilbert space formed by eigen functions $\psi_E(x,t)$

Classical interpretation of Schroedinger's approach

- two orthogonal Hilbert subspaces (in- and out- states)
  P. Lax, R. Phillips, Scattering theory for automorphic functions (Princeton, 1976) [4, 5]
- amplitude $\psi(x, t)$ - momentum direction indistinguished

Copenhagen quantum mechanics (Bohr's assumptions)

- only one subspace spanned on $\lambda_E(x)$, all vectors = pure states
- nonlocality or entanglement (in microscopic region)
- continuous time evolution abolished, contributions of opposite directions added!

Schroedinger equation and classical physics

- H. Ioannidou: Lett. al Nuovo Cim. **34** (1982), 453-8 [6]
  U. Hoyer: Synthetische Quantentheorie; Georg Olms Verlag, Hildesheim (2002) [7]
  (see also: M.V.L.: New Advances in Physics **1**, No. 1 (2007), 69; /arxiv/quant-ph/0611176 [8])
- Any solution in classical case ⇒ superposition of solutions of Hamilton equation(s)
- Easy extension to non-classical characteristics (e.g., spin)
- Consequence: All contemporary technological progress starts from classical physics!

Einstein's criticism of Bohr's theory (coincidence Gedankenexperiment) - whole story

- 1932: proper begin - von Neumann: no hidden variable in Schroed. equ.
- 1935: victory of Bohr in controversy with Einstein,
  even if Grete Herrmann: von Neumann's circular proof
- 1952: two different interpretations of Schroed. equ.
- 1964: Bell's inequality - extended coincidence experiment of Einstein
  (also spins of both the particles measured)
- 1982: violation of Bell's inequality in corresponding experiment
  $\Rightarrow$ decisive victory of CQM (Copenhagen quantum mech.) at present

However: Bell's inequality does not hold in probability experiment
$\Rightarrow$ ontological argument of Einstein justified (no argument supporting CQM)

M. V. L.: *Some Applications of Quantum Mechanics* (ed. M.R.Pahlavani), InTech Publisher (February 2012), 409 [9]

M. V. L., V. K., J. P.: in *Advances in Quantum Mechanics*, (ed. P. Bracken) InTech Publisher (April 2013), 105 [10]

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3. Argument of Einstein and mistaking assumption in Bell's inequality

Extended coincidence experiment (proposed originally by Einstein)
now also spin probability distribution measured (α, β polarizer angles)

$$\Big\| < - - |^{\beta} - - - o - - - |^{\alpha} - - > \Big\|$$

Bell's inequality

$$B = a_{\alpha_1} b_{\beta_1} + a_{\alpha_1} b_{\beta_2} + a_{\alpha_2} b_{\beta_1} - a_{\alpha_2} b_{\beta_2} \leq 2, \qquad a_{\alpha_1}, a_{\alpha_2},\ b_{\beta_1}, b_{\beta_2} \leq 1$$

- However, probability (dependence on spin) strongly limited (i.e., excluded) by an assumption
  Bell's inequality holding in Einstein's experiment, not in the extended one
  $\Rightarrow$ no support for CQM, Einstein's ontological argument fully justified
- Important consequence: All fundamental (basic) particle research practically stopped after victory of CQM
- Implication for optical theorem: derivation approach based on S-matrix - mistaking

Standardly used parametrization of elastic hadronic differential cross section at low $|t|$ based on optical theorem (no other fitting dependence admitted)

4. Different attempts to prove OT validity and strong interaction

Validity of OT in strong interaction?:

M.V.L., V.K.: arXiv:0906.3961 (2009) (see also Proc. of 13th Int. Conf., Blois Workshop; arXiv:1002.3527 [hep-ph]) [21]

M.V.L., V.K., J.P.: Elastic hadron scattering and optical theorem, arXiv:1403.1809 [nucl-th] (2014) [22]

S matrix theory and one Hilbert subspace:

V. Barone, E. Predazzi, High-energy particle diffraction; Springer-Verlag (2002) [23]

$|i\rangle$ - incoming states (center-of-mass energy and masses of colliding particles)

$|f\rangle$ - outgoing states: f_1 - elastic set, f_2 - inelastic set

- Probability defined by unitary S matrix:

$$|f\rangle = S\,|i\rangle\ , \qquad P_{i\to f} = |\langle f|\,S\,|i\rangle|^2\,; \qquad S^+S = S\,S^+ = I \tag{5}$$

- S matrix definition $\rightarrow$ optical theorem:

$$S = I + iT; \qquad \langle i|\,T^+T\,|i\rangle\ =\ \mathrm{i}\ \langle i|\,(\,T^+ - T\,)\,|i\rangle\ =\ 2\ \langle i|\,\mathrm{Im}\ T\,|i\rangle\ =\ \kappa\ >\ 0 \tag{6}$$

- Transition (probabilistic?) matrix T (if $N_{el} < N_{inel}$: $\kappa_1 < \kappa_2 = \kappa - \kappa_1$):

$$\sum_{f_{el}} |\,\langle i|\,T\,|f_{el}\rangle\,|^2\ =\ \kappa_1, \quad \langle i|\,T\,|i\rangle =??\quad (\text{what is } |i\rangle\ ?) \tag{7}$$

- additional assumption $|i\rangle = |f\rangle$ (only one Hilbert subspace) $\Rightarrow$ optical theorem:

$$\sigma_{tot} = \phi\,\langle i|\,\mathrm{Im}\ T\,|i\rangle\ =\ \kappa,\quad \sigma_{el}\ =\ \kappa_1 \tag{8}$$

where multiplication factor ϕ has been determined according to normalization of T amplitude (derived from differential elastic cross section)

S matrix theory and one Hilbert subspace?

- Main problem
  Probability represented by S-matrix elements only
  Physical definition of T matrix? Fundamental difference between initial and final "i"

- Main reason
  Unphysical definition of S-matrix and corresponding Hilbert space
  Incoming and outgoing states identified
  Symbol "i" represents 3 different kinds of states:
  - i_i - a state from incoming state set
  - f_o - a state from outgoing (non-interacting) state set
  - f_z - one special state (zero limit of scattering angle of elastic states)

- Actual requirements
  - Hilbert space must consist at least of two mutually orthogonal subspaces (see Sec. 2)
  - incoming and outgoing states must be distinguished
  - properly distinguishing also short-ranged hadronic interaction and long-ranged Coulomb one - two different interactions (optical theorem standardly applied to the hadronic interaction only)

$\Rightarrow$ Optical theorem as an approximation in Coulomb interaction but never in strong interaction!

S matrix and Hilbert space in real situation

- Two subspaces for two-particle elastic collisions (different states)

$$H = H_i \oplus H_f^{el} \tag{9}$$

specific characteristics for in- and out-states according to experimental setup; see also Sec. 2

- Incoming two-particle states i (center mass system): impact parameter value + mutual distance (in time units - negative values τ)
  $\Rightarrow$ analysis of probabilities under different experimental conditions
- Existence of inelastic states (the same incoming states, different kinds of outgoing states):

$$H = H_i \oplus H_{f_1}^{el} \oplus H_{f_2}^{inel} \tag{10}$$

$H_{f_2}^{inel}$ - sum of orthogonal subspaces corresponding to different inelastic processes, even if corresponding initial (incoming) states cannot be realized and do not exist
Structure of subspaces H^{inel} – open for theoretical analysis

- S matrix (transitions from H_i to other subspaces):

$$\sum_f |\langle f|\, S\, |i\rangle|^2 = 1, \qquad \sum_i |\langle i|\, S\, |f\rangle|^2 = 0 \tag{11}$$

i.e. distinguishing in- and out-states and time irreversibility

Aim of theoretical analysis of hadron collisions

internal evolution and structure of colliding objects + existence of contact forces

main attention: energy dependence of resonance collisions and diffraction scattering

Wave theory

$$U_{\rm in}(x,y,z) \;=\; U_0 e^{ikz}\,, \qquad U_f(x,y,z) \;=\; U_{\rm unsc}(x,y,z) + \; U_{\rm scatt}(x,y,z) \tag{12}$$

$$U_{\rm scatt} \;=\; U_0 f(q)\frac{e^{ikz}}{r}\,, \qquad f(\vec{q}) = \frac{ik}{2\pi}\int \mathrm{d}^2\vec{b}\;\Gamma(\vec{b})\; e^{-i\,(\vec{q}.\vec{b})} \tag{13}$$

$\Gamma(\vec{b})$ represents the profile of scattering center (obstacle).
The intensity of the incident and of the scattered wave:

$$I_{\rm in} = |U_{\rm in}|^2 = |U_0|^2\,, \qquad I_{\rm scatt} = |U_{\rm scatt}|^2 = |U_0|^2\frac{|f(\vec{q})|^2}{r^2} \tag{14}$$

differential elastic cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{I_{\rm scatt}\,r^2}{I_{\rm in}} = |f(\vec{q})|^2 \tag{15}$$

integrated elastic cross section

$$\sigma_{\rm el} = \frac{1}{k^2}\int |f(\vec{q})|^2 \mathrm{d}^2\vec{q} \cong \int \mathrm{d}^2\vec{b}\,|\Gamma(\vec{b})|^2 \tag{16}$$

or

$$\sigma_{\rm el} = \int \mathrm{d}^2\vec{b}\,|1 - S(\vec{b})|^2\,; \qquad \Gamma(\vec{b}) \;=\; 1 - S(\vec{b}) \tag{17}$$

Assumption: sum of final states for hole ($S(\vec{q})$) and obstacle ($\Gamma(\vec{q})$) equals original plane wave (no unscattered part)

$$\Rightarrow \quad \sigma_{\rm abs} = \int \mathrm{d}^2\vec{b}[2\,\mathrm{Re}\,\Gamma(\vec{b}) - |\Gamma(\vec{b})|^2] \tag{18}$$

$$\sigma_{\rm tot} = \sigma_{\rm el} + \sigma_{\rm abs} = 2\int \mathrm{d}^2\vec{b}\;\mathrm{Re}\,\Gamma(\vec{b}) \quad \Rightarrow \quad \sigma_{\rm tot} = \frac{4\pi}{k}\,\mathrm{Im}\,f(\vec{q}=0) \tag{19}$$

Initial plane wave $=$ sum of both parts

$\Rightarrow$ strong interaction excluded (great unscattered part!)
probably acceptable approximation in Coulomb interaction

5. Difference between the Coulomb and strong interaction

Coulomb interaction

- efficient at any distance (but the distance is limited in experiment)
- collisions with several targets in all collision experiments
  $\Rightarrow$ limited range of impact parameter (existence of finite maximal impact parameter)
  $\Rightarrow$ flat maximum of Coulomb differential cross section expected at very small (unmeasurable) scattering angles, singular point may exist at infinite distance only
- necessity of corresponding parameterization of Coulomb differential cross section (no divergence at $t = 0$)

Strong interaction

- exists at very low impact parameters only (practically zero above a certain distance)
  $\Rightarrow$ interaction at distance or rather a contact interaction?
- proper interaction influenced by distant Coulomb interaction
  $\Rightarrow$ determination of energy dependent corrections

Very different mechanism of Coulomb and strong interaction

Necessity to consider dependence of collisions on impact parameter and **impact parameter distribution of initial states** (linear increase with impact parameter value) to obtain some further particle (proton) characteristics!

6. New ontological model of elastic collision processes

causal ontological approach (the same basis as in classical physics)

Microscopic particles - ontological objects (basic characteristics)

- limited dimensions of hadron objects (protons)
  (maximal dimensions d_k of individual particles)
- decisive dependence of collisions on impact parameter b
  (zero strong interaction at $b > b_j^{\max} = (d_k + d_l)/2$)
- probability of elastic hadronic collisions: $P^{\rm el}(b) = P^{\rm tot}(b)\, P^{\rm rat}(b)$
  (monotonous functions: $P^{\rm tot}(b)$ - decreasing, $P^{\rm rat}(b) = P^{\rm el}(b)/P^{\rm tot}(b)$ - increasing)
- uniform distribution of incoming particles in two particle collisions in cross plane
  $\Rightarrow$ distribution of impact parameter rising linearly with b

Additional assumptions

- dynamical hadron objects $-$ changeable internal structure
  (existence of more collision channels for any colliding pair)
- frequency of internal states decreasing with smaller dimension
  (slowly decreasing maximal dimensions)

M. V. L., and V. K., Elastic pp scattering and the internal structure of colliding protons, arXiv:0909.3199 [hep-ph] (2009) [13]
M. V. L., V. K., J. P.: in *Advances in Quantum Mechanics*, (ed. P. Bracken) InTech Publisher (April 2013), 105 [10]

Basic relations and formulas

Simplifications (more detailed model being prepared)

- only average value of impact parameter $\bar{b}$ taken into account for a given momentum transfer $|t|$: monotonous function $\bar{b}(|t|)$ - decreasing
- influence of distant Coulomb interaction not taken into account

Measured elastic differential cross section of two charged hadrons interpreted as

$$\frac{\mathrm{d}\sigma^{C+N}(t)}{\mathrm{d}t} = \frac{\mathrm{d}\sigma^{N}(t)}{\mathrm{d}t} + \frac{\mathrm{d}\sigma^{C}(t)}{\mathrm{d}t} \tag{20}$$

$$\frac{\mathrm{d}\sigma^{N}(t)}{\mathrm{d}t} = \sum_j r_j \frac{\mathrm{d}\sigma_j^{N}(t)}{\mathrm{d}t}, \quad \text{where} \quad \frac{\mathrm{d}\sigma_j^{N}(t)}{\mathrm{d}t} = 2\pi\, P_j^{\mathrm{el}}\left(\bar{b}_j(t)\right) \bar{b}_j(t)\, \frac{\mathrm{d}\bar{b}_j(t)}{\mathrm{d}t} \tag{21}$$

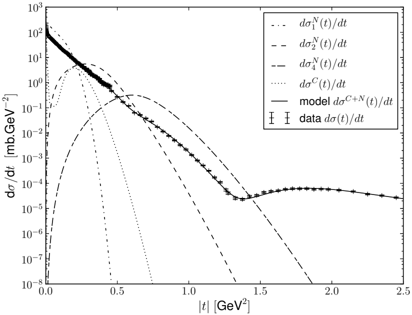
Integrated hadronic cross sections (X = tot, el, inel)

$$\sigma^{X,N} = \sum_j r_j \sigma_j^{X,N}, \quad \text{where} \quad \sigma_j^{X,N} = 2\pi \int_0^{b_j^{\max}} \mathrm{d}b\, b P_j^{X}(b). \tag{22}$$

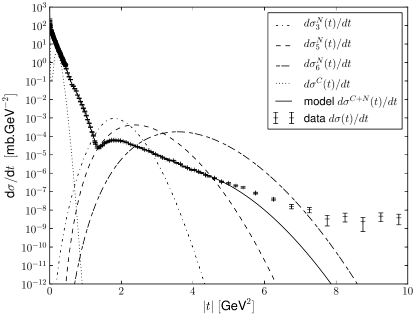
Function $\frac{\mathrm{d}\sigma^{C}(t)}{\mathrm{d}t}$ and monotonic functions P_j^{tot}, P_j^{rat} and $\bar{b}_j(t)$ parameterized and fitted to data (measured elastic differential cross section of two charged hadrons) together with frequency of internal particle states p_k (corresponding to r_j parameters) and maximal particle dimensions d_k

Fitted measured elastic pp differential cross section at 53 GeV

- preliminary probabilistic model fitted to measured proton-proton elastic differential cross section at ISR energy of 53 GeV in region $|t| \in (0.00125\ \text{GeV}^2, 5\ \text{GeV}^2)$
- 3 largest internal states of each colliding proton $\Rightarrow$ 6 collision channels



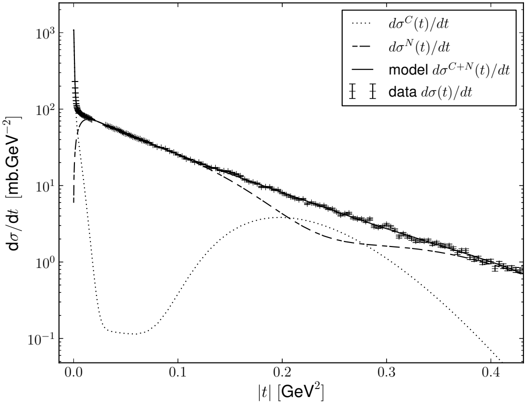
(a) $\mathrm{d}\sigma_j^N(t)/\mathrm{d}t$ for $j = 1, 2, 4$



(b) $\mathrm{d}\sigma_j^N(t)/\mathrm{d}t$ for $j = 3, 5, 6$

Figure: Proton-proton elastic differential cross sections at energy of 53 GeV. Individual points - experimental data, full line - probabilistic model fitted to the experimental data, dotted line - Coulomb differential cross section $\mathrm{d}\sigma^C(t)/\mathrm{d}t$, other lines - individual hadronic differential cross sections $\mathrm{d}\sigma_j^N(t)/\mathrm{d}t$.

Separated Coulomb and hadronic effects at low values of $|t|$



- non-exponential hadronic differential cross section at small values of $|t| \approx 0$
- Coulomb effect parameterized independently of standardly used diverging formula at $t = 0$
- significant non-hadronic (weak) interaction at $|t| \approx 0.25$ GeV^2?

pp hadronic cross sections of individual collision channels

Maximal dimensions of 3 largest proton states

$$d_1 = 1.970 \text{ fm}, \quad d_2 = 1.950 \text{ fm}, \quad d_3 = 1.939 \text{ fm}$$

Frequency of these states

$$p_1 = 0.60, \quad p_2 = 0.24, \quad p_3 = 0.090$$

Proton-proton hadronic cross sections

$$\sigma^{\text{tot,N}} = 58.2 \text{ mb}, \quad \sigma^{\text{el,N}} = 6.49 \text{ mb}, \quad \sigma^{\text{inel}} = 51.7 \text{ mb}$$

Cross sections in individual collision channels

j k, l		1 1,1	2 1,2	3 2,2	4 1,3	5 2,3	6 3,3	$\sum_{j=1}^{6}$
r_j	[1]	0.36	0.29	0.059	0.11	0.043	0.0080	0.87
b_j^{max}	[fm]	1.970	1.960	1.951	1.955	1.945	1.939	-
$\sigma_j^{\text{tot,N}}$	[mb]	86.9	57.0	55.3	44.9	33.7	32.5	-
$\sigma_j^{\text{el,N}}$	[mb]	16.5	1.56	6.96×10^{-4}	0.116	5.22×10^{-4}	3.04×10^{-4}	-
σ_j^{inel}	[mb]	70.4	55.5	55.3	44.8	33.7	32.5	-
$r_j\sigma_j^{\text{tot,N}}$	[mb]	31.7	16.7	3.25	4.86	1.46	0.260	58.2
$r_j\sigma_j^{\text{el,N}}$	[mb]	6.03	0.456	4.08×10^{-5}	1.26×10^{-2}	2.26×10^{-5}	2.43×10^{-6}	6.49
$r_j\sigma_j^{\text{inel}}$	[mb]	25.7	16.2	3.25	4.84	1.46	0.260	51.7

Probabilities in dependence on impact parameter b

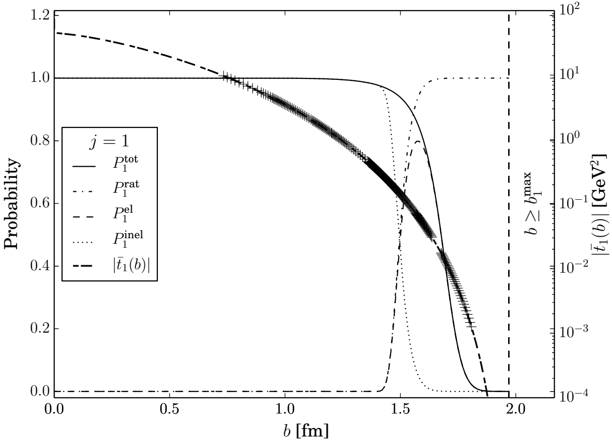


Figure: Probabilities in dependence on impact parameter b for hadronic collision state $j = 1$: full line - $P_1^{\mathrm{tot}}(b)$, dash-dotted line - $P_1^{\mathrm{rat}}(b)$, dashed line - $P_1^{\mathrm{el}}(b)$, dotted line - $P_1^{\mathrm{inel}}(b)$. Remaining line - function $|\bar{b}_1(t)|$; individual points represent then the interval of measured values of $|t|$.

7. Several concluding remarks

Contemporary status of (quantum) physics

1. Game with mathematical formulas - no interest in physical assumptions and mechanisms (see editorial article of The Economist [1])
2. Single support of Copenhagen QM alternative based on mistake (Bell's inequality does not hold in given experiment)
3. Fundamental (basic) particle research has been blocked fully in the second half of 20th century as the ontological approach has been completely excluded

Future basis

1. Return to ontology - Einstein was right (photon + locality) (all technological progress based still on classical ontology)
2. elastic collisions: optical theorem unacceptable for strong interaction $\Rightarrow$ new probabilistic ontological collision model

Some open questions concerning elastic (proton) collisions

1. Existence of contact forces and their description? (their effect in individual collision events?)
2. Effect of distant Coulomb forces on strong interaction? (exact trajectory in Coulomb case?)
3. Weak forces in collision processes at low energy values? (distances of strong interacting centers in solid matter?)
4. Internal states of protons and their structure? (properties being derived from collision processes?)

Backup

Invalidity of optical theorem (OT) for hadronic interaction

- in all widely used descriptions of elastic (short-ranged) hadronic scattering $\sigma^{\text{tot}} \propto \text{Im}\, F^N(\theta = 0)$
- OT taken from optics, formulated on the basis of some experimental data without theoretical reasoning
- attempts to derive it do not distinguish short-ranged scattering: namely hadronic scattering at limit $\theta = 0$ and the case of no interaction (also corresponding to zero "scattering angle"); all attempts for long-ranged interaction only
- OT never tested experimentally alone (always accompanied by other assumptions); problem of an extrapolation of the hadronic amplitude to unmeasurable limit point $\theta = 0$ (Coulomb effect is dominating the hadronic one at very small scattering angles in the case of pp scattering)
- OT may introduce very important unphysical limitation; it, e.g., also completely exclude possibility of having $\mathrm{d}\sigma/\mathrm{d}t = 0$ at zero scattering angle ($t = 0$)
- the initial and final states are to belong to mutually orthogonal subspaces of the corresponding Hilbert space if the collision processes are to be realistically interpreted while in the attempts to derive the OT the Hilbert space is spanned on one common basis only
- for more details see [21, 22, 10]

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