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Hadrons in Born approximation

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Hadrons have several remarkable features, which call for an understanding within QCD. In addition to confinement and chiral symmetry breaking these include:

- Hadrons can generally be classified as $q\bar{q}$ or qqq states. Sea quarks and gluons do not enrich the spectrum. Heavy quarkonia ($c\bar{c}$, $b\bar{b}$) are well described by the Schr\"odinger equation with a $V(r) = c\,r - C_F\alpha_s/r$ potential.
- The excitation energy of dynamical (transverse) gluons is $\geq$ 1 GeV. Glueballs and hybrids (if any) are heavy. Processes such as $\phi \to \pi\pi\pi$ that only proceed through gluonic intermediate states are suppressed (OZI rule).
- Perturbative parton dynamics mirrors non-perturbative hadron dynamics. Duality is pervasive and manifest even at low scales in DIS ($ep \to eX$) and in inclusive hadron production ($e^+e^- \to h + X$).
- Quenched lattice calculations give a better than 10% description of the hadron spectrum. The heavy quark potential calculated on the lattice agrees with the phenomenological quarkonium potential.

These observations motivate an approach to hadrons based on the number of loops, *i.e.,* an $\hbar$ expansion. In QED the description of Positronium given by the Schrödinger equation is of lowest order in $\hbar$ (whereas the wave function is non-polynomial in α). The Dirac equation provides a Born (tree-level) description of relativistic binding in an external field. Dirac bound states have Fock components with additional e^+e^- pairs, yet their spectrum is characterized by the quantum numbers of a single electron.

I consider a Hamiltonian description of QCD bound states at Born level. The color field in H_{QCD} is determined by the classical field equations. In the absence of quark and gluon loop corrections the Λ_{QCD} confinement scale arises from a boundary condition on the classical gauge field at spatial infinity. Translation invariance requires the strength of such a color field to be spatially constant, which implies an exactly linear confinement field $A_a^0($
$boldsymbolx)$. Explicit solutions are found for each $q_A\bar{q}_A$ and $q_Aq_Bq_C$ component of color singlet mesons and baryons, but not for states with a larger number of valence quarks. The total field obtained by a summing over quark colors vanishes since the states are (globally) color singlets. Hadrons therefore do not interact with each other via the confining field, only through perturbative gluon exchange and $q\bar{q}$ annihilation.

Born level hadrons have features which resemble dual models. For $m_q = 0$ the states lie on linear Regge trajectories with parallel daughter trajectories. Quark-hadron duality emerges analytically. Hadron decays occur via $q\bar{q}$ creation (string breaking) generated by the confining field, and can be addressed as an expansion in $1/N_c$, the number of colors. Iterations give rise to hadron loop contributions, allowing unitarity to be satisfied at $O(\hbar^0)$ for hadrons. Many further issues can be addressed, including scattering and chiral symmetry breaking. The approach leads to a Poincaré covariant example of confined bound states quantized at equal time. Provided higher orders of the $\hbar$ (loop) expansion can be included it may qualify as a first principles approach to hadrons in QCD.

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