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Evidence for Functional Charge Transfer in Carbon-Dot/Nickel-Hydroxide Composites: A Critical Review of Photoactive and Electrochemical Systems

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Abstract

Carbon dots (CDs)—a family that includes carbon quantum dots (CQDs)—have been incorporated into nickel-hydroxide-based materials for optical, catalytic and electrochemical programs. Reports of improved performance are regularly interpreted as evidence of more effective charge transfer, but that interpretation isn't always automatic: modifications in particle growth, phase composition, available surface area, electrolyte access and the supporting electrode can produce comparable effects. This critical review examines what typically used measurements can set up, where alternative motives stay manageable, and what mixtures of controls might make mechanistic claims extra convincing.

Keywords: carbon dots; carbon quantum dots; nickel hydroxide; interfacial charge transfer; photoelectrochemistry; oxygen evolution; electrochemical energy storage

1. Introduction

Carbon dots are nanoscale carbon substances, however their behaviour is strongly fashioned by way of how they're made. Precursor choice, response conditions, heteroatom incorporation and surface chemistry can all alternate their optical reaction and interactions with neighbouring levels. when CDs are added right into a composite, they may adjust nucleation and growth, create or adjust interfaces, have an effect on light absorption, or change transport via an electrode. those consequences can arise together, so an found development have to not be assigned to charge transfer with out examining other variables. "Carbon dot" is a large substances label as opposed to a guarantee of a unmarried shape or electronic configuration. depending on synthesis and purification, a sample can also comprise contributions from carbon-core states, surface defects and molecular-like fluorescent species. Likewise, describing a fabric as nitrogen-doped does now not, via itself, specify its band alignment or prove that a selected provider-transfer direction is lively. Mechanistic interpretation therefore needs to be tied to the characterization without a doubt suggested for every sample.

Efficiently identifying the nickel-containing phase is vital to a truthful evaluation. Nickel hydroxide, nickel oxide, non-stoichiometric NiO_x, Ni–Al layered double hydroxides and Ni–Co hydroxides range in composition and electrochemical behaviour. Ternary structures along with CQDs/Ni(OH)₂ /BiVO₄ additionally include additional components that may have an impact on the measured response. effects from these architectures can tell the broader dialogue, but ought to not be dealt with as interchangeable evidence for a binary CD/Ni(OH)₂ interface.

This evaluation does not aim to provide any other huge catalogue of carbon-dot packages. Its specific contribution is to evaluate the electricity of mechanistic claims throughout photoactive and electrochemical CD/nickel-hydroxide structures, while retaining nickel segment and tool architecture express. The critical question is whether or not an observed improvement directly supports functional fee transfer or is likewise steady with changes in morphology, section, surface accessibility, ionic delivery or the substrate.

2. Review Question and Literature Identification

The analysis is prepared around 3 styles of observations: photoactive measurements (which include regular-kingdom and time-resolved photoluminescence, EPR, reactive-species assays and photoelectrochemical response); electrochemical measurements (consisting of contemporary-capacity behaviour, impedance, capacitance or ability, and stability); and structural or chemical characterization (inclusive of section, morphology, surface area and nickel oxidation nation). these companies are assessed collectively because no unmarried dimension usually resolves the mechanism on its personal.

On 23 October 2026, a centered exploratory seek became executed the usage of trendy internet seek and on hand writer, PubMed/percent and bibliographic information. seek phrases paired “carbon dots”, “carbon quantum dots” or “CQDs” with “nickel hydroxide” or “Ni(OH)₂”, then introduced software phrases in which relevant. This was a selective narrative search, no longer a systematic overview: it did now not use a preregistered protocol, certified database exports, formal replica elimination or twin-reviewer screening.

3. Interpreting Evidence for Charge Transfer

3.1 Steady-state and time-resolved photoluminescence

While regular-state photoluminescence (PL) weakens after a 2d aspect is introduced, interfacial quenching is one possible explanation—but it is not the handiest one. changes in absorbance, scattering, reabsorption, awareness, internal-filter results, defect populations or non-radiative pathways also can reduce the measured sign. PL quenching need to consequently be treated as a clue that calls for corroboration, in place of as standalone proof of productive charge separation.

A alternate in time-resolved PL lifetime indicates that the measured excited-country decay has changed underneath the chosen fitting version. A shorter lifetime may be steady with quicker switch, but it may additionally get up from additional non-radiative loss; a longer lifetime may also indicate decreased recombination or a specific emissive population. Lifetime values need interpretation along fitting assumptions, spectral behaviour and independent measurements.

3.2 EPR and reactive-species assays

EPR spin-trapping and scavenger assessments can offer evidence that reactive species form beneath the tested conditions. On their personal, but, they do now not map the complete interfacial electron pathway or perceive the rate-limiting step. stronger interpretation calls for suitable mild/darkish controls, element-most effective controls, checks for probe artefacts and a clean hyperlink among the detected species and the measured response.

3.3 Band energetics and structural evidence

Tauc evaluation, Mott–Schottky measurements and u.s.XPS can every make a contribution constraints on feasible band energetics, however they measure exclusive quantities and depend upon extraordinary assumptions. specially, a Tauc-derived optical gap does now not at once provide absolute conduction- and valence-band positions. floor states, sample morphology, electrolyte conditions and measurement selections can affect inferred values, so a proposed band diagram need to be provided with its assumptions and uncertainty.

3.4 Electrochemical performance and stability

A decrease in impedance or a larger current might also imply a better electrode-level reaction in a selected setup, however neither remark uniquely identifies the underlying motive. Electrolyte, applied potential, equivalent-circuit preference, loading, electrode geometry and substrate all have an effect on the result. better present day or capacity also can mirror greater reachable active fabric in preference to quicker interfacial charge switch.

Comparisons ought to file the reference electrode and capacity scale, electrolyte, activematerial loading, geometric area, substrate instruction, iR-correction coverage, EIS ability and becoming motive. balance claims need to state the electrolyte, current or potential, check duration, cycle count, retention definition and replicate uncertainty. brief-term present day retention isn't always enough to set up industrial durability.

4. Comparative evidence from representative studies

Table 1 collects decided on outcomes from the research discussed here. The suggested numbers are retained in their original context as opposed to normalized right into a unmarried rating, because the research use exclusive architectures, take a look at protocols and reporting bases. mainly, binary CD/Ni(OH)₂ composites ought to be distinguished from ternary photoanodes, combined-metallic hydroxides and nickel-oxide systems.

Table 1. Selected reported outcomes and interpretation limits. Values are reproduced as reported in the cited studies; differences in architecture, test conditions and normalization prevent direct ranking.

Architecture / reference	Reported observation	What it supports	Main interpretive limitation
Ni(OH) ₂ -CD [1]	365 nm antibacterial test; growth lag 7→15 h; ~15% lower growth rate; PL/EPR reported	Photoactivated antibacterial outcome under reported conditions	Does not establish a unique transfer route; ion release, contact and light effects need controls
HO-CDs/Ni(OH) ₂ on Ni foam [2]	353 mV at 50 mA cm ⁻² ; Tafel slope 81.2 mV dec ⁻¹ ; 92% current after 24 h	OER electrode performance and short-term stability	Morphology, nickel foam and nickel chemistry may co-vary
CD-doped Ni(OH) ₂ film [3]	Crystallites 5–10 nm vs 30–50 nm; 155.57 mAh g ⁻¹ at 40 A g ⁻¹ ; device reports 77.5 Wh kg ⁻¹ at 45.0 kW kg ⁻¹	CD-associated changes in growth and electrode response	Structural variables and device mass basis affect interpretation
N-CD/Ni(OH) ₂ nanosheets [4]	~1711.2 F g ⁻¹ at 1 A g ⁻¹ ; hybrid-device energy density reported	Composite architecture and storage performance	Loading and device calculations require source-level audit
CQDs/Ni–Al LDH [5]	1794 F g ⁻¹ at 2 A g ⁻¹ ; 967 F g ⁻¹ at 20 A g ⁻¹ ; ~93% after 1500 cycles	Performance of a mixed-metal layered hydroxide	Not pure Ni(OH) ₂ ; surface area and morphology contribute
CDs–Co/Ni(OH) ₂ [6]	338.6 mAh g ⁻¹ at 5 A g ⁻¹ ; 84.6% retention after 1000 cycles at 40 A g ⁻¹ ; device energy density 281.2 Wh kg ⁻¹ at 57.2 kW kg ⁻¹	Co-containing hydroxide electrode performance	Cobalt and architecture prevent attribution to CDs alone
CQDs + Ni(OH) ₂ /BiVO ₄ [7]	3.05 mA cm ⁻² at 1.23 V vs RHE; ~2.5× BiVO ₄ ; 65% injection efficiency	Ternary photoanode response and charge-injection behaviour	BiVO ₄ , hydroxide and CQDs all contribute
Ni-CDs/graphene [8]	α/β-Ni(OH) ₂ ratio and nickel d-band centre reportedly regulated during methanol electrooxidation	Association between additive, phase/electronic structure and a specific reaction	Graphene architecture and reaction conditions limit generalization
CQD-doped Ni(OH) ₂ on nickel foam [9]	HER overpotential 90 mV at 10 mA cm ⁻² under illumination; OER overpotential 101 mV at 10 mA cm ⁻²	Illumination-associated response in a specific electrode setup	HER and OER must remain distinct; substrate treatment can affect active area
GQDs/Ni(OH) ₂ on carbon cloth [13]	1825 F g ⁻¹ at 1 A g ⁻¹ ; 83.5% retention after 8000 cycles; device 80.8 Wh kg ⁻¹ at 2021 W kg ⁻¹	GQD-associated electrode/device performance in a binder-free architecture	GQDs and conductive carbon cloth are both relevant; does not isolate a unique interfacial transfer mechanism
N,P-CD-assisted porous α-Ni(OH) ₂ [14]	BET area 454 m ² g ⁻¹ (~32× pristine Ni(OH) ₂); 632 C g ⁻¹ vs 107 C g ⁻¹ ;	CD-assisted synthesis and porosity-associated storage performance	Large surface-area and pore-accessibility changes are major alternative explanations for

	device 31 Wh kg ⁻¹ at 0.76 kW kg ⁻¹		improved performance
CQDs/NiO nanorods [15]	1858 F g ⁻¹ at 1 A g ⁻¹ ; 93% retention after 1000 cycles at 2 A g ⁻¹	Adjacent nickel-oxide/carbon-dot electrode evidence	NiO is an oxide, not Ni(OH) ₂ ; context for phase comparison, not direct hydroxide evidence

5. Cross-study synthesis

5.1 Photoactivated antibacterial activity

The Ni(OH)₂ –CD look at 1 links PL/EPR observations with a biological reaction under 365 nm irradiation. An extended growth lag and decreased increase charge aid an altered growth trajectory under the tested situations, but do no longer isolate reactive oxygen species from direct touch, ion launch, adsorption or neighborhood heating. stronger causal attribution might require matched light/darkish controls, issue-handiest samples, quantified illumination and direct checks of whether the biological response follows independently measured reactive species.

5.2 Oxygen evolution and energy storage

The HO-CDs/Ni(OH)₂ electrode 2 and CD-doped Ni(OH)₂ films 3 report improved electrode outcomes, but their interpretation depends on the substrate, loading, morphology, active-site population and nickel chemistry. In the thin-film study, the reported crystallite-size and porosity changes provide plausible structural explanations for altered ion access and accessible sites. These structural effects should be considered alongside, rather than replaced by, an electronictransfer explanation.

Additional studies reinforce the need to separate morphology, phase and substrate effects. Graphene quantum dots on carbon cloth have been reported to deliver 1825 F g⁻¹ at 1 A g⁻¹ and 83.5% retention after 8000⁺ cycles, but the binder-free carbon-cloth architecture itself contributes to transport and electrode design 13.

N,P-functionalized carbon dots used during synthesis of porous α-Ni(OH)₂ were associated with a BET surface area of 454 m² g⁻¹ and a specific capacity of 632 C g⁻¹, compared with 107 C g⁻¹ for pristine Ni(OH)₂ ; The authors attribute the ⁺⁺ improvement in part to electrolyte-ion intercalation/deintercalation through suitable pore volumes 14. This is important evidence for CD-assisted synthesis, but it does not isolate electronic charge transfer from porosity and accessible-site effects. Earlier CQDs/NiO nanorods provide an adjacent oxide comparison (1858 F g⁻¹ at 1 A g⁻¹), yet NiO must not be treated as chemically ⁺⁺ interchangeable with Ni(OH)₂ 15.

The N-doped-CD/Ni(OH)₂ nanosheet system 4, CQDs–Ni–Al LDH 5 and CDs–Co/Ni(OH)₂ electrode 6 illustrate why architecture matters. Ni–Al LDH and Co-containing hydroxides are not chemically equivalent to pure Ni(OH)₂ . Gravimetric capacitance, capacity, cycling retention and full-device energy density also depend on different normalization and cell configurations. Crosspaper numerical rankings are not appropriate without comparable protocols and mass bases.

5.3 Photoelectrochemical water oxidation and electrocatalysis

The CQDs + Ni(OH)₂ /BiVO₄ photoanode 7 is a ternary architecture in which BiVO₄ is the light absorber and the hydroxide and CQDs can also have an effect on floor reactions or interfacial techniques. The suggested photocurrent and injection efficiency are useful software observations, however causal attribution calls formcontrols isolating every factor. in addition, Ni-CDs/graphene for methanol electrooxidation eight and CQD- doped Ni(OH)₂ for hydrogen evolution nine cope with awesome reaction instructions. Their outcomes ought to now not be used as direct proof for one standard charge-transfer mechanism throughout photoactive and electrochemical structures.

6. A Claim-to-Evidence Framework

Figure 1: presents a conceptual summary of the possible mechanisms and the proposed hierarchy of evidence; it is intended as a framework for interpretation rather than a universal mechanistic assignment.

Functional Charge Transfer in Carbon-Dot/Ni(OH)₂ Composites

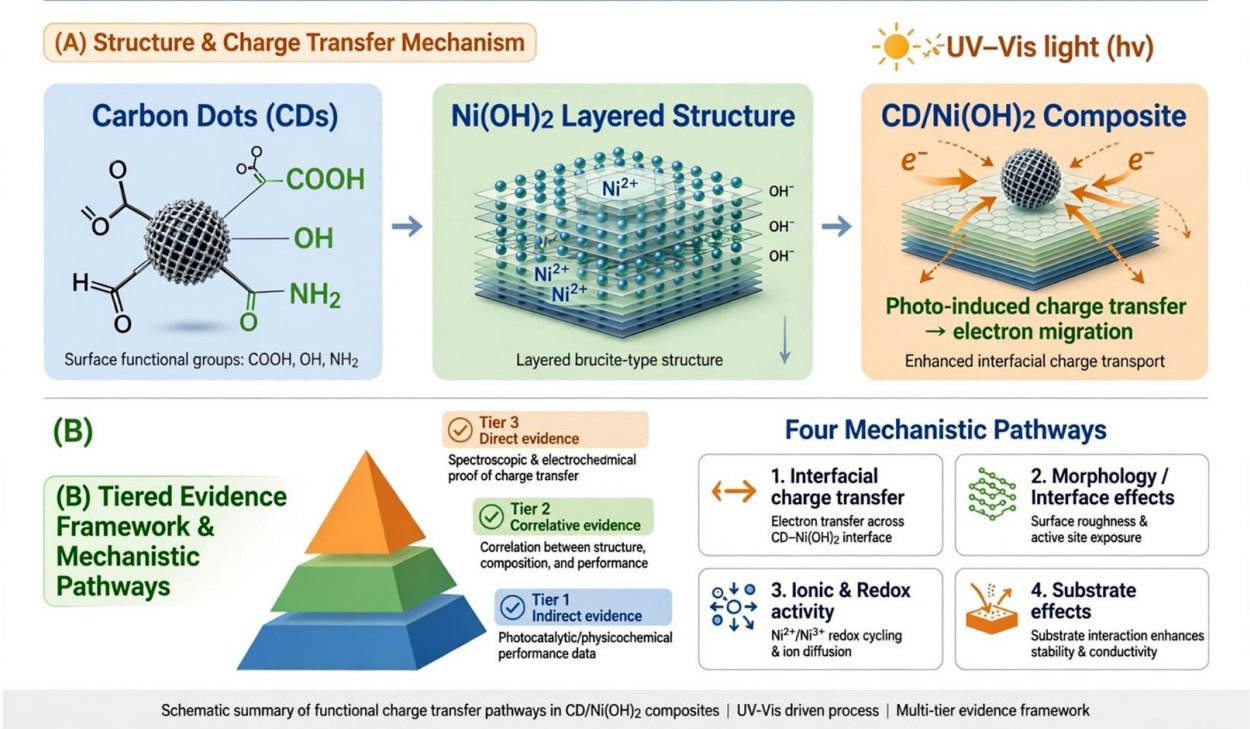


Figure 1. Conceptual assessment of proposed CD/Ni(OH)₂ mechanisms and a tiered framework for evaluating charge-transfer evidence. The pathways are schematic possibilities, now not proof that any unique mechanism operates in each mentioned composite

Claim-to-Evidence Tiers for Interpreting Proposed Charge-Transfer Mechanisms

Evidence tier	Typical evidence	Permitted interpretation
Tier 1: application outcome	Photocurrent, catalytic current, capacitance/capacity, bacterial-growth response	Demonstrates performance under the reported conditions; does not identify mechanism by itself.
Tier 2: mechanistically relevant correlation	PL change, EIS resistance, surface area, nickel oxidation-state change	Narrows plausible explanations but may retain confounding variables.
Tier 3: convergent causal evidence	Matched controls plus independent carrier/operando probes, quantified products and exclusion of morphology/loading/substrate alternatives	Provides stronger support for a specific mechanism within the tested system.

Every paper have to be coded via (a) precise composition and phase, (b) direct statement, (c) authors’ mechanistic interpretation, (d) achievable opportunity causes, (e) controls, and (f) utility outcome. This makes the evaluate reproducible at the extent of proof best without pretending that in contrast to numerical metrics are interchangeable.

7. Minimum Reporting Checklist and Research Priorities

- Identify specific phase and composition the use of complementary structural and chemical measurements.
- Include CDs-handiest, hydroxide-handiest, physical-combination and substrate-only controls where appropriate.
- File loading, geometric region, electrolyte, potential reference, illumination spectrum/depth and mobile geometry.
- Normalize optical indicators and expose PL/TRPL fitting methods and uncertainty.
- Use a justified EIS equivalent circuit and report dimension capability and frequency range.

- Quantify response products or Faradaic performance for catalytic claims in which applicable.
- File reflect count number, error bars and specific balance-check situations.
- Symbolize the electrode after operation to study phase reconstruction or dissolution.
- Separate binary CD/Ni(OH)₂ from Ni–Al LDH, Ni–Co hydroxide, NiO/NiO_x and ternary systems in the proof map.

The most actionable research precedence is a matched-manage take a look at wherein segment, morphology, loading and substrate are held as consistent as viable while CD content is varied. Photoactive research need to integrate calibrated light-on/mild-off measurements, impartial provider-dynamics probes and quantified response merchandise. Electrochemical research have to document cell geometry, normalization, impedance-fit rationale and submit-operation segment characterization.

8. Limitations

The evidence base is selective and exploratory; it became not assembled thru certified database exports, formal deduplication or systematic screening. some numerical values have been taken from accessible abstracts or writer statistics as opposed to checked line with the aid of line in opposition to each full text and supplementary document. accordingly, the existing synthesis should be study as a essential interpretation of decided on reviews, no longer as an exhaustive quantitative evaluate.

The chosen research also record one-of-a-kind bodily portions, response instructions, electrode architectures and normalization bases. particular capacitance, specific capability, photocurrent density, overpotential and complete-device energy density need to now not be mixed right into a single ranking. The primary conclusions are therefore conditional on every take a look at's stated fabric and experimental configuration.

9. Conclusion

The literature taken into consideration here helps a careful end: carbon dots may be related to changes in nickel-hydroxide composite performance, however the dominant contribution may also vary by using fabric and alertness. viable impacts include crystal increase, available surface location, phase distribution, optical excitation and electrode shipping. PL quenching, impedance adjustments or stepped forward device metrics by myself do no longer establish a unique charge-switch pathway. more decisive proof will require section- aware characterization, matched controls and unbiased measurements that separate interfacial strategies from morphology, loading, ionic get admission to and substrate consequences.

7. Declarations

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- **Records availability:** No new experimental datasets have been generated for this overview. The proof discussed is drawn from the cited publications and associated supplementary information where to be had.
- **Ethics approval:** not relevant to this literature-primarily based evaluate.

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