

A Comprehensive Review of Nickel Boride: Synthesis, Structure, and Applications

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Abstract—Over the past few decades, nickel boride has emerged as a versatile reagent. It is used for reduction, dehalogenation, desulfurization, deoxygenation of chalcogen mono- and dioxides, and many deprotection reactions, such as deprotection of carbonyl, carboxy, ester, and amino groups. The ease of preparation, stability, low cost, and facile removal make nickel boride superior to alternative reagents. Reactions are catalyzed at ambient temperature in various solvents, including methanol, ethanol, THF, and water–methanol mixtures. There is significant potential for expanding its use in various areas of organic synthesis. This review highlights the evolution of nickel boride from a classical reducing agent to a modern nanocatalyst, underscoring its growing importance in sustainable synthetic methodologies.

Keywords: nickel boride, nickel chloride, sodium borohydride, reduction, desulfurization, deprotection

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1. INTRODUCTION

Transition metal borides, particularly nickel boride, have become a crucial and integral part of organic chemistry over the past few decades. Although first reported and used as early as 1950 by Schlesinger and Brown [1], scientists continue to explore their potential in organic transformations and synthesis. Due to its stability, nickel boride can be employed in various solvents, including methanol, ethanol, THF, and alcohol–water mixtures. Furthermore, these transition metal borides, generated in situ from metal salts and complex hydrides, are known for their regioselectivity

and stereoselectivity in various reductions. The objective of this review is to elaborate on the preparation methods and applications of nickel boride in various reactions, including its use in the synthesis of novel heterocyclic compounds. As the utilization of this reagent was last reviewed some time ago [2, 3], this literature survey covers publications up to June 2025.

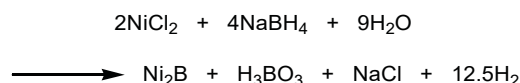
To conduct this literature study on nickel boride, a thorough search was performed using databases such as SciFinder, Scopus, PubMed, and Google Scholar. Relevant publications were extracted using keywords and phrases including “nickel boride,” “nickel boride in organic synthesis,” and “nickel boride as a reducing

agent.” Reports suggesting its use in commercial processes have also been included. This review emphasizes the synthesis of the reagent, synthetic schemes involving its application, and detailed reaction protocols.

2. PREPARATION OF NICKEL BORIDE

Transition metal borides are typically prepared by adding sodium borohydride to a solution of nickel(II) chloride, nickel acetate, or copper(II) salts. The reaction of the metal ion with sodium borohydride in protic solvents yields a black precipitate containing borides as well as adsorbed hydrogen. In the case of copper(II), this black precipitate may consist of a mixture of zero-valent metal and borides. This precipitate can catalyze hydrogenation reactions. Nickel boride is known to decompose sodium borohydride slowly and can therefore serve as a controlled source of hydrogen [1] (Scheme 1).

Scheme 1.



The preparation of this versatile reducing agent is straightforward: simply adding sodium borohydride to a nickel(II) salt leads to the deposition of a finely divided black precipitate of nickel boride alongside the evolution of hydrogen gas. It is noteworthy that even minor variations in the preparation procedure can drastically alter the reactivity, selectivity, and physical and chemical properties of the reagent. The most prominent forms of nickel boride (often represented as Ni_xB_y), such as P-1, P-2, and P-2W, which vary in composition, catalytic activity, and magnetic properties, are prepared in different solvents and sometimes at different temperatures. P-1 nickel boride is less reactive than Raney nickel for the hydrogenation of carbon–carbon double bonds. P-2 nickel boride, prepared in 95% ethanol, yields a nearly black colloidal suspension that is more active for C=C bond hydrogenation. The role of water is crucial in determining the type of nickel boride produced. For instance, a P-1.5 nickel catalyst is formed when a 50% ethanol–water mixture is used as the solvent. This vigorous reaction can be controlled by modifying the solvent, cooling the mixture, providing an inert atmosphere, or adding the borohydride in small portions. Currently, nickel boride is used alongside other metal ions to carry out various transformations. The actual composition of borides synthesized from

a metal salt depends largely on the specific synthetic conditions.

Maybury et al. [4] analyzed the product from the reaction of nickel chloride with a threefold excess of sodium borohydride in ethanol under an inert atmosphere. They concluded that the formula Ni_2B unsatisfactorily represents its composition. In addition to solvent and adsorbed hydrogen (released upon heating), the solid was intermixed with occluded sodium chloride. Based on the metal-to-boron ratio and the moles of hydrogen gas evolved, a general formula of $(\text{Ni}_2\text{B})_2\text{H}_3$ was proposed. Nickel boride is typically amorphous, as revealed by XRD; however, crystalline forms may be obtained under higher temperature conditions, likely due to oxidation of the material by adsorbed water. Apart from nickel, two forms of boron have been detected: B-1 (nickel-bound boron) and B-2 (in the form of BO_2). The B-2 form is a byproduct of the reaction between nickel(II) salts and sodium borohydride [3].

An alternative method for preparing nickel boride uses diborane as the reductant. The nickel boride (DBNi) thus produced differs from the conventional catalysts (discussed earlier) in parameters such as its Ni/B ratio, catalytic activity, and magnetic properties. In some cases, Ni_2B -mediated reductions of substrates like nitrobenzene and cyclohexanone are more efficient than with the conventional catalyst forms. Nevertheless, the hydrogenation of olefinic compounds such as benzene, cyclohexene, and styrene is only slightly more efficient than with P-1 nickel boride [5].

The varying activity of the catalyst with the method of preparation is attributed to ions (e.g., sodium, chloride) present on the catalyst surface. Due to their low solubility in the protic solvent used for boride formation, these ions tend to accumulate on the boride surface, thereby reducing its activity. Both the nickel salt and the solvent govern the activity of nickel boride. It has been reported that nickel boride with a higher concentration of B-1 boron content is more active, and that P-1 nickel boride is more active than P-2 nickel boride for certain transformations. The best results are usually obtained with nickel chloride [3].

The activity of P-1, P-2, and P-2W forms of nickel boride catalysts can be enhanced by adding promoters such as cobalt, chromium, and ruthenium ions [6]. The effects of these promoters on nickel borides were observed for the hydrogenation of cyclohexanone and cyclohexene. Cobalt, chromium, and ruthenium ions increase the activity of all nickel boride types for cyclohexanone hydrogenation, while rhodium is additionally

advantageous for all nickel borides in cyclohexene hydrogenation. Chromium and cobalt are only effective for P-2W and P-1 nickel borides, respectively.

Nickel boride can also serve as an alternative capacitor material owing to its high charge/discharge capacity. To address its tendency to aggregate and relatively poor stability, Liu et al. [7] coupled nickel boride with graphene to create a high-performance supercapacitor.

3. REACTIONS INVOLVING NICKEL BORIDE

3.1. Reduction of Nitrogen-Containing Functional Groups

Nitriles constitute a synthetically important class of nitrogen-containing compounds found in many natural products, biologically active molecules, and organic chemicals. Their reduction typically requires strong acids, bases, and harsh conditions. Numerous homogeneous and heterogeneous methods are known for the reduction of nitriles to various products [8]. Nickel boride is one of such reagents with the potential to reduce nitriles to various important moieties. Selected examples are listed herein.

Kukreja and Khurana [9] reduced nitriles to the corresponding primary amines using nickel boride, prepared in situ from anhydrous nickel chloride and sodium borohydride in anhydrous ethanol at room temperature. The substrate to nickel chloride molar ratio was 1:1. All reactions were chemoselective and rapid (Scheme 2).

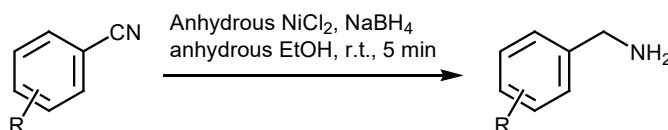
Subsequently, Zhou and Ke [10] carried out the catalytic hydrogenation of imines, nitriles, aldehydes, and nitro compounds using a supported nickel boride catalyst. In each case, the catalyst was evaluated under different temperatures, hydrogen pressures, and in the presence of various additives and solvents (Scheme 3). Their results indicated that the $\text{Ni}_{12.4}\text{B}_{30}$ catalyst (likely referring to a specific Ni-B composition) was highly reactive toward all reaction types and remained active even after fifteen cycles. This catalyst system showed better performance and safer storage characteristics compared to Raney nickel.

4-Hydrazinoquinolines were reduced using this versatile reagent to yield 4-aminoquinolines which are important antimalarial precursors [11]. The procedure included two steps: first, a 4-chloroquinoline derivative was converted to a 4-hydrazinoquinoline under microwave conditions, followed by reduction of the hydrazino derivative using nickel boride generated in situ from anhydrous nickel chloride and sodium borohydride.

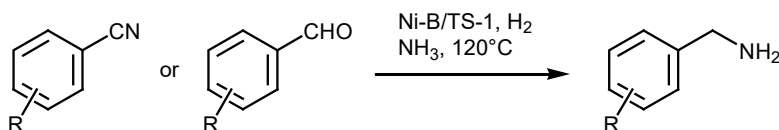
Recently, Bera et al. [12] reported the use of nickel boride as a hydride source for the reduction of α,β -unsaturated amides (both aliphatic and aromatic). The reaction involves the in situ generation of nickel boride from NiCl_2 and sodium borohydride (Scheme 4). The reduction proceeds smoothly for a wide range of substrates under an inert atmosphere, providing moderate to good yields.

Khurana et al. [13] reported the reduction of arene-diazonium tetrafluoroborates to the corresponding anilines or hydrazines using nickel boride generated in

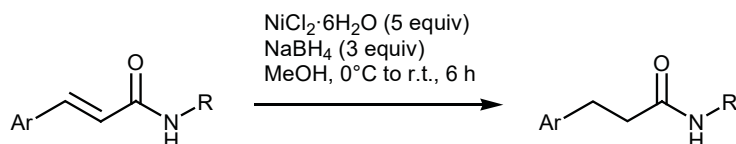
Scheme 2.

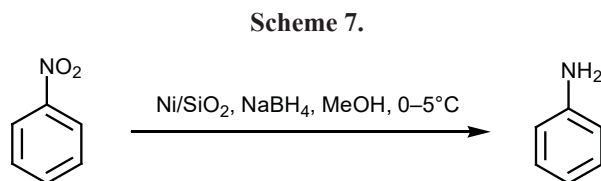
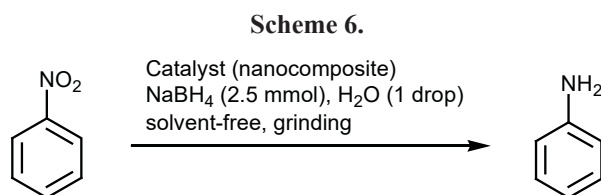
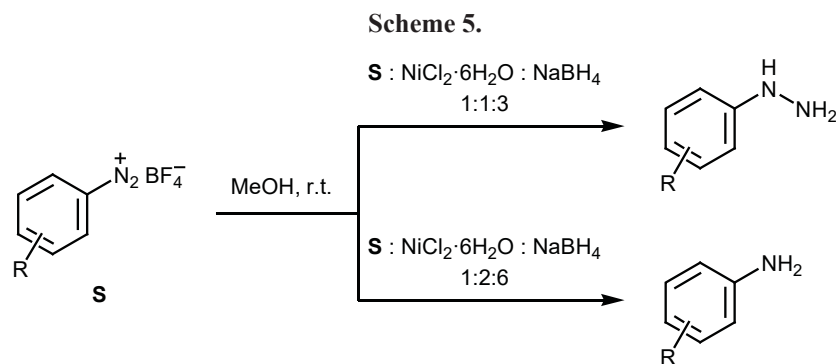


Scheme 3.



Scheme 4.





situ from hydrated nickel chloride and sodium borohydride (Scheme 5). The reaction is facile, efficient, and chemoselective, leaving halo, carboxy, ethoxycarbonyl, and methoxy groups unaffected. The easy workup, which does not require column chromatography for product separation, indicates that this method is advantageous over other reported procedures.

Esmati et al. [14] investigated the catalytic application of nickel boride-based nanocomposites with zirconium chloride, copper oxides, copper chloride, and ferric chloride. All these nanocomposites reduced aromatic nitro compounds to arylamines using sodium borohydride under solvent-free conditions via a mechanochemical grinding technique (Scheme 6). The recovery and reusability of the nanocomposites were also investigated. The described technique was effective for a wide range of substrates with short reaction times (1–5 min) and 100% conversion. According to [14], the conversion rate was only 50% when nickel boride alone was used. The article demonstrates that the composite materials are responsible for the 100% conversion rate and shorter reaction times. Control reactions with only ZrCl_4 , Cu_2O , CuCl_2 , or FeCl_3 salts gave merely a 5% yield, while a physical mixture of these salts with nickel boride gave only a 50–65% conversion rate.

A system consisting of a Ni– SiO_2 catalyst (5 wt %), NaBH_4 , and in situ produced nickel boride was used by Jonnalagadda and Rehman [15] to successfully reduce a variety of nitroaromatics to amines with 100% conversion and selectivity in methanol at low temperatures ($\sim 5^\circ\text{C}$). The reduction of nitrobenzene (as a model substrate) was examined with varying Ni loadings (5, 10, and 15%) on titania or silica supports (Scheme 7). In this study, systems using nickel salt–titania with NaBH_4 showed low conversion and selectivity. The attachment of nickel boride to silica, which lacks free surface OH groups, was found to facilitate the reaction.

Later, Dinér et al. [16] reported a greener and facile reduction of organic azides (both aromatic and aliphatic) using nickel boride generated in situ in methanol. This method used substantially lower catalyst loading. The azides were reduced, and the protocol is compatible with a one-pot Boc-protection of the resulting amine, yielding the corresponding carbamates. Ultimately, the Ni–B catalyst was supported on bacterial crystalline nanocellulose to facilitate easy recovery and reuse in subsequent reduction cycles (Schemes 8, 9).

Apart from the above-mentioned reactions, Krishnan et al. [17] investigated the use of nickel boride supported on graphitic carbon nitride (Ni–B/g- C_3N_4) as a catalyst

for the reduction of aromatic nitroarenes to aromatic amines via transfer hydrogenation (Scheme 10). The optimized catalyst showed good recyclability and stability for up to four reaction cycles. The reaction conditions, including time, catalyst loading, hydrogen source amount, and temperature, were optimized, yielding promising results.

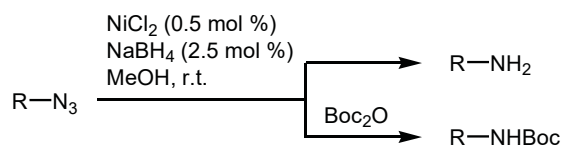
Dinér et al. [18] reported a mild and effective technique involving the in situ generation of nickel boride from NiCl_2 and sodium borohydride in a TEMPO-oxidized aqueous nanocellulose solution (0.01 wt %). This system was used to produce amines by the reduction of a variety of nitroarenes and aliphatic nitro compounds with excellent yields. Here, nanocellulose acts as a stabilizing agent, increasing the yield and allowing for low catalyst loading (0.1–0.25 mol % NiCl_2). In this

process, two tandem pathways were established wherein the amines generated in situ were either Boc-protected to yield carbamates (Scheme 11) or reacted with an epoxide to produce β -amino alcohols in good yields.

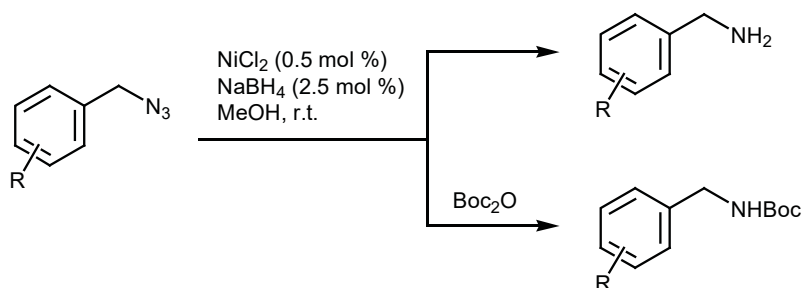
Santos et al. [19] utilized nickel boride (Ni_2B) for the reduction of azides to amines in the synthesis of aromatic amines, pyrrolobenzodiazepines, and pyrroloquinazolinones under microwave irradiation. The group synthesized substituted pyrrolo[2,1-*c*][1,4]benzodiazepines (PBDs) and pyrroloquinazolinones in a one-pot process combining resin cleavage, azide reduction, and cyclization. These microwave-assisted procedures afforded higher yields with significantly shorter reaction times compared to traditional thermal methods.

Nickel boride has also been applied to the removal of micropollutants from water sources. Strathmann

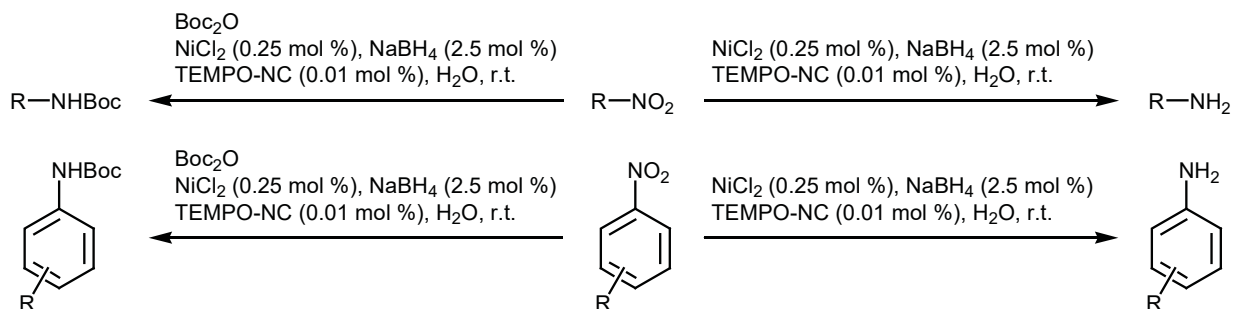
Scheme 8.



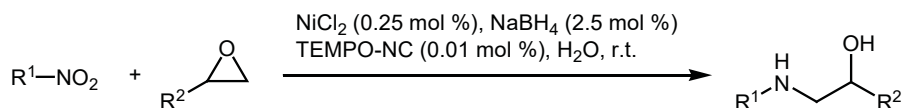
Scheme 9.



Scheme 10.



Scheme 11.



et al. [20] reported the conversion of *N*-nitrosodimethylamine (NDMA), a toxic byproduct of water disinfection and a groundwater contaminant, into less toxic compounds such as dimethylamine and ammonia.

3.2. Reduction of Carbonyl Group

Khurana and Chauhan [21] reported the reduction of a variety of carbonyl compounds to the corresponding alcohols using nickel boride generated in situ in THF. Benzopyrones, for example, flavanones, chromones, isoflavones, and flavones, which are insoluble in THF, were reduced to the corresponding benzopyran-4-ols using nickel boride in methanol at ambient temperature [22]. Under these conditions, ether linkages remain unaffected. The resulting benzopyran-4-ols were formed as *cis* stereoisomers, which is consistent with a half-chair or sofa conformation of the heterocycle where the 2-aryl group occupies an equatorial position. However, selective reduction of the carbon–carbon double bond in flavones, chromones, and isoflavones could not be achieved under these conditions. We have also reported the rapid reduction of chalcones to tetrahydrochalcones using nickel boride generated in situ from anhydrous nickel chloride and sodium borohydride. This method yielded several novel tetrahydrochalcones in high yields [23] (Scheme 12). This work was later extended to accomplish a two-step 1,3-allylic transposition of chalcones [24] (Scheme 13).

Chemoselective reduction of the carbon–carbon double bond in chalcones and α,β -unsaturated aldehydes, ketones, carboxylic acids, and esters using nickel boride in a methanol–water system was also reported by Khurana and Sharma [25] (Scheme 14).

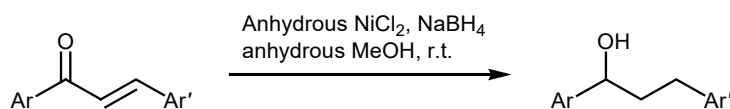
Jonnalagadda et al. [26] reported the reduction of a range of aliphatic and aromatic functional groups, including C=O, C=C, and C–X bonds, to their corresponding reduced forms using a 5% Ni/SiO₂ catalyst and NaBH₄ (Scheme 15). These reactions, achieving 100% conversion and selectivity, were accomplished by the in situ generation of nickel boride in methanol at low temperature ($\sim 0^\circ\text{C}$) within a short reaction time (5 min). In the case of phenol, although the conversion was only 20%, the selectivity for cyclohexanol was 100%.

Using a chemical reduction method, nickel boride alloy catalysts, prepared both in situ and ex situ, were used in the hydrodeoxygenation of phenol and the hydrogenation of C=C double bonds. The presence of water was reported to reduce the activity of nickel boride in these reactions [27].

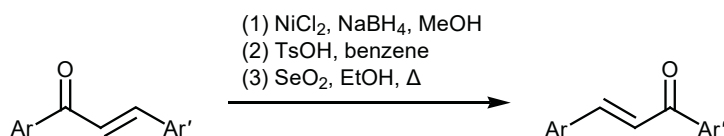
3.3. Desulfurization Reactions

The desulfurization of thioacetals and thioketals has been known for a long time [28] (Scheme 16). The reduction of α,β -unsaturated thioketals to the corresponding olefins has also been reported [29]. This

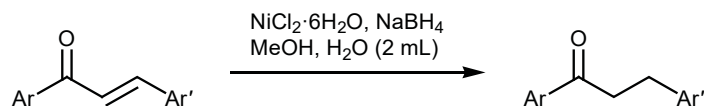
Scheme 12.



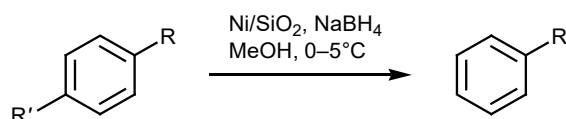
Scheme 13.



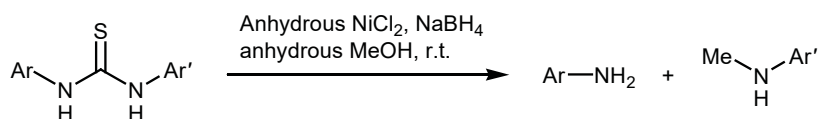
Scheme 14.



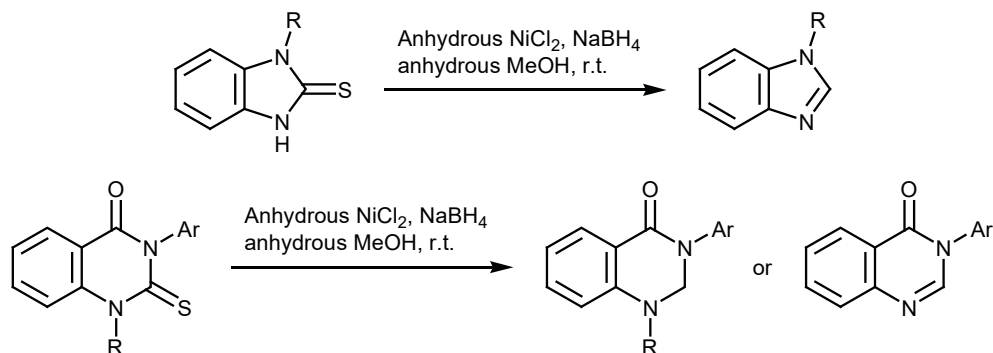
Scheme 15.



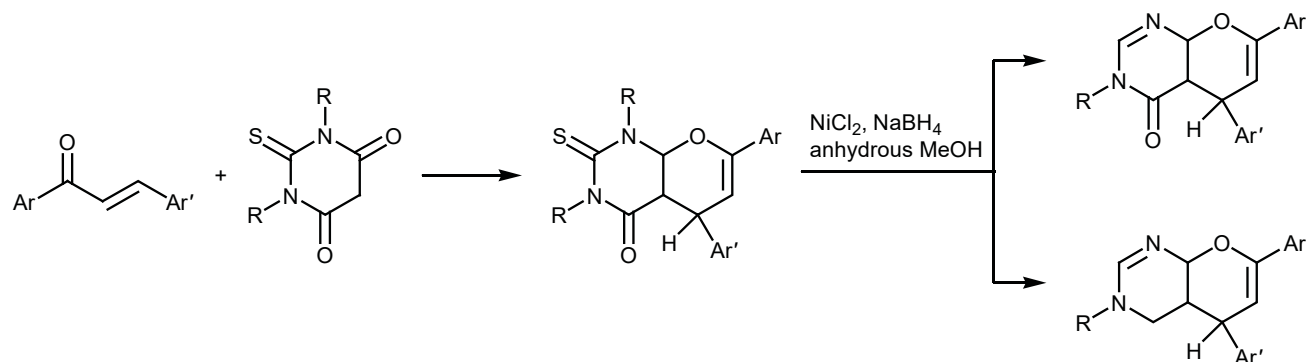
Scheme 16.



Scheme 17.



Scheme 18.



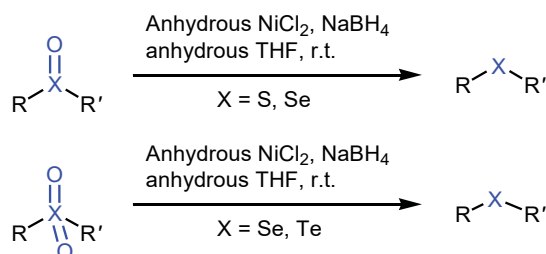
desulfurization method was later extended to thioethers [30], benzothiophenes and dibenzothiophenes [31], as well as thiols, sulfides, and sulfoxides [32]. All these desulfurization protocols using nickel boride offer various advantages over Raney nickel, such as the ease of handling. Khurana and Kukreja [33] reported the reductive cleavage of diaryl and monoaryl thioureas to anilines and *N*-methylaniline, the reductive desulfurization of dialkyl thioureas to formamidines, and the conversion of benzimidazole-2(1*H*)-thiones to benzimidazoles and 1,3-dihydro-2,3-diaryl-2-sulfanylidene-pyrimidine-4,6(2*H*,5*H*)-diones in dry methanol using nickel boride generated in situ.

The reductive desulfurization of 1,3-dihydro-1,3-diaryl-2-sulfanylidene-pyrimidine-4,6(2*H*,5*H*)-diones and 2-sulfanylidenequinazolin-4(3*H*)-ones with nickel boride in methanol at ambient temperature has also been reported [34] (Scheme 17).

Khurana and Sharma reported the synthesis of 2-substituted 2*H*-imidazo[1,5-*b*]isoquinoline-1,5-diones by in situ desulfurization using Ni_2B [35]. A two-step synthesis of 3,4-dihydro-4-oxo-5*H*-pyrano[2,3-*d*]pyrimidines, involving the condensation of variously substituted chalcones with thiobarbiturates, followed by reductive desulfurization of the intermediate using nickel boride generated in situ, was described in [36]. In this way, desulfurization using Ni_2B has contributed to the synthesis of various novel heterocyclic compounds (Scheme 18).

Schouten et al. [29] extended the reductive desulfurization of aromatic sulfides using nickel boride in deep eutectic solvents. Beyond synthetic organic laboratories, nickel boride is also used for the desulfurization of diesel fuel to improve its quality [37]. Various nickel salts were tested in these studies, and nickel chloride was found to be the most effective.

Scheme 19.



3.4. Deoxygenation of Chalcogen Oxides and Dioxides

Khurana and Singh [32] reported the deoxygenation of a variety of acyclic sulfoxides and selenoxides using nickel boride in THF at 0–5°C in nearly quantitative yields (Scheme 19). The deoxygenations were proposed to proceed via an oxidative addition/reductive elimination mechanism. Khurana and Lumb [38] later extended this work to the deoxygenation of telluroxides, tellurones, and selenones, achieving positive results in dry THF at ambient temperature.

3.5. Deprotection of Carbonyl and Other Functional Groups

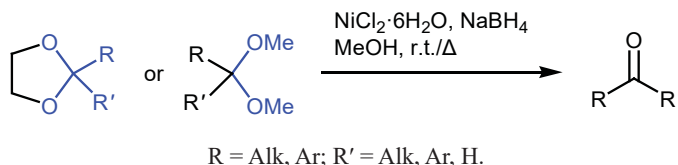
The protection and deprotection of carbonyl groups are important transformations in organic synthesis. Typically, deprotection is an acid-catalyzed reaction. Using nickel boride, our research group has reported the unprecedented deprotection of 1,3-dioxolanes, acetals, and ketals under neutral conditions at ambient tempera-

ture [39] (Scheme 20). A variety of cyclic acetal and ketal substrates were efficiently deprotected using methanol as a solvent. The reactions were chemoselective, with alkyl, halo, and alkoxy groups remaining unaffected under these conditions.

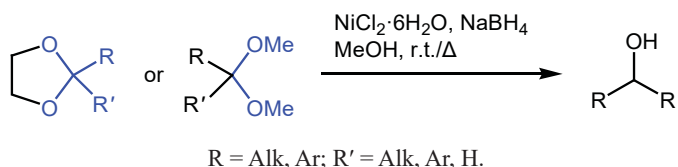
Deprotection, along with concomitant reduction to the corresponding alcohols, was achieved by varying the molar ratios of substrate to $\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$ and NaBH_4 . The initially formed deprotected carbonyl compound was reduced in situ to the corresponding alcohol (Scheme 21). Undoubtedly, these reactions are mediated by nickel boride, as control reactions using only nickel chloride or sodium borohydride independently gave no product, and the starting material was recovered unchanged.

1,3-Oxathiolanes were rapidly cleaved by nickel boride generated in situ from nickel chloride hexahydrate and sodium borohydride, regenerating the parent carbonyl compounds [40] (Scheme 22). The reactions were rapid at ambient temperature and did not require an inert atmosphere. Relatively mild conditions, easy

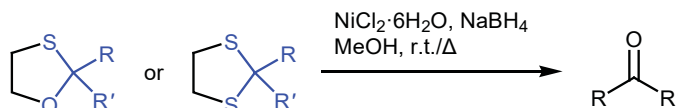
Scheme 20.



Scheme 21.



Scheme 22.



workup, no need for tedious purification methods, and quantitative yields are the main advantages of this procedure. Later, this work was extended to the nickel boride-mediated cleavage of 1,3-dithiolanes, yielding the corresponding carbonyl compounds in high yields [41].

Nickel boride has also been employed for the deprotection of carboxylic acids and amines from the corresponding benzyl esters [42]. Furthermore, it facilitates the regioselective reduction of conjugated dienes and the reductive cleavage of allyl esters [43]. *N*-Benzyloxycarbonyl (Cbz) and *O*-benzyloxycarbonyl protecting groups were removed using nickel boride in methanol at room temperature to yield the corresponding amines and phenols, respectively [44]. Various 1,1-di-acetates were successfully and selectively converted to the corresponding aldehydes. Moreover, by varying the amounts of sodium borohydride and nickel(II) chloride in methanol, these aldehydes could be further reduced to the corresponding alcohols. All substrates afforded quantitative yields at room temperature. This method is efficient for deprotecting and reducing various aromatic, aliphatic, and heterocyclic acylals. Mild reaction conditions, a simple workup process, high yields, and high selectivity are the key features of this protocol [45].

Recently, a modified nickel boride-based amorphous chromium-doped alloy catalyst was prepared using cetyltrimethylammonium bromide (CTAB). This catalyst assists in microwave-assisted catalytic transfer hydrogenation of fatty acid methyl esters [46].

3.6. Dehalogenation Reactions

Khurana et al. [47] reported a one-pot debromination of vicinal dibromides with concomitant reduction,

leading to the formation of dihydro products, using nickel boride at ambient temperature (Scheme 23). α,β -Dibromoketones also gave the corresponding alcohols in high yields. Furthermore, the authors effectively carried out the dehydrohalogenation of various aryl, alkyl, allyl, and benzyl halides, specifically chlorides, bromides, and iodides, using nickel boride in methanol at room temperature, resulting in product formation via hydrogen/halogen exchange. Later, a facile dehalogenation of aryl halides was carried out with nickel boride and sodium borohydride in methanol at room temperature [48].

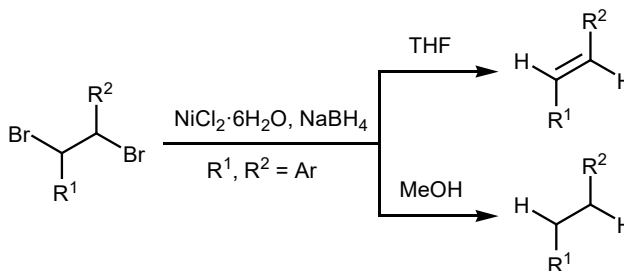
Chelucci [49] reported a one-step hydrodebromination–hydrogenation of 1-bromo-1-alkenes to afford the corresponding alkanes using nickel chloride hexahydrate and sodium borohydride at ambient temperature in a THF–methanol solvent system. This process offers a promising route for converting aldehydes, via their bromoalkene derivatives, into various 1,2-disubstituted ethanes (Scheme 24).

3.7. Multicomponent Reactions

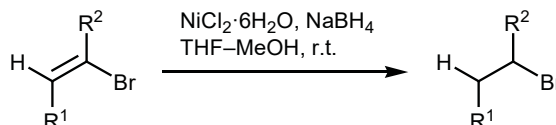
Recently, the role of nickel boride has evolved from a stoichiometric reagent to a catalyst and, now, a component of nanocomposites. Following extensive investigation into composite materials, researchers have demonstrated the applicability of nickel boride supported on carbon nanotubes in multicomponent reactions [50] (Scheme 25).

Nickel boride was chosen due to the unique metalloid nature of boron, which is comparable to that of transition metals. Its high microhardness, excellent selectivity and activity in liquid-phase reactions, potential applicability in biochemistry, and high chemical and thermal stability

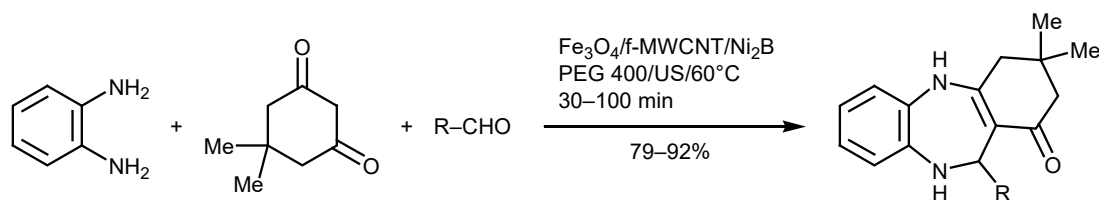
Scheme 23.



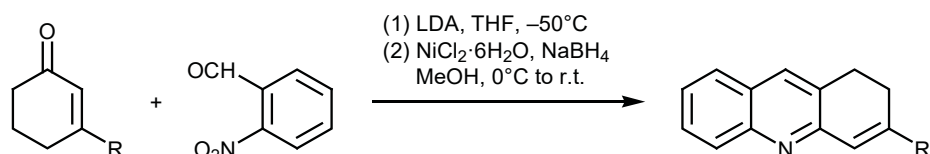
Scheme 24.



Scheme 25.



Scheme 26.



are key features that make nanostructured nickel boride suitable for these applications. The group designed a multicomponent reaction using a nanocomposite of nickel boride decorated on magnetic multiwalled carbon nanotubes. Easy workup and catalyst recyclability are notable advantages of this system. Another application of nickel boride in a reductive cyclization process for the synthesis of an acridine framework was reported by Bera et al. [51] (Scheme 26).

The aldol adducts of *o*-nitrobenzaldehyde and cyclohexanone undergo reductive cyclization via in situ-generated nickel boride at ambient temperature under acid-free conditions. This simple and efficient pathway is notable for its scalability, high yields, easy workup, and broad substrate scope.

4. CONCLUSIONS

In conclusion, nickel boride is a versatile reagent applicable to the reduction of double bonds, carbonyl groups, nitriles, nitro compounds, azides, and hydrazines, as well as to dehalogenation and deprotection of carbonyls from acetals, ketals, and oxathiolanes. It is also effective for the removal of benzyl esters and similar protecting groups. Its utility extends to the desulfurization of various sulfur compounds, including heterocycles. The potential of nickel boride has been explored in several industrial processes with beneficial applications. The ease of use, low cost, non-pyrophoric nature, simple workup, and mild reaction conditions make it a superior reagent compared to many contemporary alternatives. The broad scope of applications for this reagent continues to drive future research in this field.

Future research is likely to focus on the design of asymmetric versions of these reactions, the application

of nickel boride nanocomposites in flow chemistry, and a deeper mechanistic understanding using in situ spectroscopic techniques.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Scheisinger, H.I. and Brown, H.C., US Patent no. 2461661, 1949.
2. Khurana, J.M. and Gogia, A., *Org. Prep. Proced. Int.*, 1997, vol. 29, p. 1.
<https://doi.org/10.1080/00304949709355171>
3. Magoo, D., Synlett, 2010, vol. 2010, p. 2525.
<https://doi.org/10.1055/s-0030-1258550>
4. Maybury, P.C., Mitchell, R.W., and Hawthorne, M.F., *J. Chem. Soc., Chem. Commun.*, 1974, p. 534.
<https://doi.org/10.1039/C39740000534>
5. Rei, M.H., Sheu, L.L., and Chen, Y.Z., *Appl. Catal.*, 1986, vol. 23, p. 281.
[https://doi.org/10.1016/S0166-9834\(00\)81298-1](https://doi.org/10.1016/S0166-9834(00)81298-1)

6. Chen, Y.-Z., Sheu, L.-L., and Rei, M.-H., *J. Chin. Chem. Soc.*, 1989, vol. 36, p. 67.
<https://doi.org/10.1002/jccs.198900011>
7. Cao, X., Wang, X., Cui, L., Jiang, D., Zheng, Y., and Liu, J., *Chem. Eng. J.*, 2017, vol. 327, p. 1085.
<https://doi.org/10.1016/j.cej.2017.07.010>
8. Xia, Y., Jiang, H., and Wu, W., *Eur. J. Org. Chem.*, 2021, vol. 2021, p. 6658.
<https://doi.org/10.1002/ejoc.202101196>
9. Khurana, J.M. and Kukreja, G., *Synth. Commun.*, 2002, vol. 32, p. 1265.
<https://doi.org/10.1081/SCC-120003619>
10. Ke, D. and Zhou, S., *Int. J. Mol. Sci.*, 2022, vol. 23, article no. 9337.
<https://doi.org/10.3390/ijms23169337>
11. Gemma, S., Kukreja, G., Tripaldi, P., Altarelli, M., Bernetti, M., Franceschini, S., Savini, L., Campiani, G., Fattorusso, C., and Butini, S., *Tetrahedron Lett.*, 2008, vol. 49, p. 2074.
<https://doi.org/10.1016/j.tetlet.2008.01.128>
12. Sarkar, R., Menon, A.M., Chopra, D., and Bera, M.K., *ChemistrySelect*, 2024, vol. 9, article ID: e202404235.
<https://doi.org/10.1002/slct.202404235>
13. Bartwal, G., Saroha, M., and Khurana, J.M., *ChemistrySelect*, 2018, vol. 3, p. 12600.
<https://doi.org/10.1002/slct.201802436>
14. Mousavi, H., Zeynizadeh, B., Younesi, R., and Esmati, M., *Aust. J. Chem.*, 2018, vol. 71, p. 595.
<https://doi.org/10.1071/CH18200>
15. Rahman, A. and Jonnalagadda, S.B., *Catal. Lett.*, 2008, vol. 123, p. 264.
<https://doi.org/10.1007/s10562-008-9417-5>
16. Proietti, G., Prathap, K.J., Ye, X., Olsson, R.T., and Dinér, P., *Synthesis*, 2022, vol. 54, p. 133.
<https://doi.org/10.1055/a-1579-2190>
17. Kashyap, B., Kumar, S., Sharma, D., and Krishnan, V., *ChemNanoMat*, 2025, vol. 11, article ID: e202500117.
<https://doi.org/10.1002/cnma.202500117>
18. Prathap, K.J., Wu, Q., Olsson, R.T., and Dinér, P., *Org. Lett.*, 2017, vol. 19, p. 4746.
<https://doi.org/10.1021/acs.orglett.7b02090>
19. Shankaraiah, N., Markandeya, N., Espinoza-Moraga, M., Arancibia, C., Kamal, A., and Santos, L.S., *Synthesis*, 2009, vol. 2009, p. 2163.
<https://doi.org/10.1055/s-0029-1216831>
20. Frierdich, A.J., Joseph, C.E., and Strathmann, T.J., *Appl. Catal., B*, 2009, vol. 90, p. 175.
<https://doi.org/10.1016/j.apcatb.2009.03.007>
21. Khurana, J.M. and Chauhan, S., *Synth. Commun.*, 2001, vol. 31, p. 3485.
<https://doi.org/10.1081/SCC-100106209>
22. Khurana, J.M. and Chauhan, S., *J. Chem. Res., Synop.*, 2002, p. 201.
<https://doi.org/10.3184/030823402103171852>
23. Khurana, J.M. and Kiran, *J. Chem. Res.*, 2006, p. 374.
<https://doi.org/10.3184/03082340677946851>
24. Khurana, J.M., Dawra, K., and Majumdar, S., *Monatsh. Chem.*, 2009, vol. 140, p. 69.
<https://doi.org/10.1007/s00706-008-0019-0>
25. Khurana, J.M. and Sharma, P., *Bull. Chem. Soc. Jpn.*, 2004, vol. 77, p. 549.
<https://doi.org/10.1246/bcsj.77.549>
26. Rahman, A. and Jonnalagadda, S.B., *J. Mol. Catal. A: Chem.*, 2009, vol. 299, p. 98.
<https://doi.org/10.1016/j.molcata.2008.10.022>
27. Li, G., Salas, T., Sun, S., Wang, B., Komarneni, M.R., and Resasco, D.E., *J. Catal.*, 2024, vol. 431, article ID: 115384.
<https://doi.org/10.1016/j.jcat.2024.115384>
28. Truce, W.E. and Roberts, F.E., *J. Org. Chem.*, 1963, vol. 28, p. 961.
<https://doi.org/10.1021/jo01039a020>
29. Schouten, S., Pavlović, D., Damsté, J.S.S., and de Leeuw, J.W., *Org. Geochem.*, 1993, vol. 20, p. 901.
[https://doi.org/10.1016/0146-6380\(93\)90101-G](https://doi.org/10.1016/0146-6380(93)90101-G)
30. Euerby, M.R. and Waigh, R.D., *Synth. Commun.*, 1986, vol. 16, p. 779.
<https://doi.org/10.1080/00397918608059658>
31. Back, T.G., Yang, K., and Krouse, H.R., *J. Org. Chem.*, 1992, vol. 57, p. 1986.
<https://doi.org/10.1021/jo00033a017>
32. Khurana, J.M., Ray, A., and Singh, S., *Tetrahedron Lett.*, 1998, vol. 39, p. 3829.
[https://doi.org/10.1016/S0040-4039\(98\)00623-6](https://doi.org/10.1016/S0040-4039(98)00623-6)
33. Khurana, J.M., Kukreja, G., and Bansal, G., *J. Chem. Soc., Perkin Trans. 1*, 2002, p. 2520.
<https://doi.org/10.1039/B206398K>
34. Khurana, J.M. and Kukreja, G., *J. Heterocycl. Chem.*, 2003, vol. 40, p. 677.
<https://doi.org/10.1002/jhet.5570400419>
35. Khurana, J.M. and Sharma, V., *Chem. Heterocycl. Compd.*, 2008, vol. 44, p. 309.
<https://doi.org/10.1007/s10593-008-0045-1>
36. Khurana, J.M., Agrawal, A., and Kukreja, G., *Heterocycles*, 2006, vol. 68, p. 1885.
<https://doi.org/10.3987/COM-06-10788>
37. Shu, C., Sun, T., Guo, Q., Jia, J., and Lou, Z., *Green Chem.*, 2014, vol. 16, p. 3881.
<https://doi.org/10.1039/C4GC00695J>
38. Khurana, J.M. and Lumb, A., *Org. Prep. Proced. Int.*, 2012, vol. 44, p. 96.
<https://doi.org/10.1080/00304948.2012.643702>
39. Khurana, J.M., Dawra, K., and Sharma, P., *RSC Adv.*, 2015, vol. 5, p. 12048.
<https://doi.org/10.1039/C4RA15404E>
40. Khurana, J.M., Magoo, D., and Dawra, K., *Monatsh. Chem.*, 2016, vol. 147, p. 1113.
<https://doi.org/10.1007/s00706-015-1608-3>
41. Khurana, J.M. and Magoo, D., *Synth. Commun.*, 2010, vol. 40, p. 2908.
<https://doi.org/10.1080/00397910903340652>

42. Khurana, J.M. and Arora, R., *Synthesis*, 2009, vol. 2009, p. 1127.
<https://doi.org/10.1055/s-0028-1087982>
43. Yin, B.-L., Cai, C.-B., Lai, J.-Q., Zhang, Z.-R., Huang, L., Xu, L.-W., and Jiang, H.-F., *Adv. Synth. Catal.*, 2011, vol. 353, p. 3319.
<https://doi.org/10.1002/adsc.201100612>
44. Saroha, M., Aggarwal, K., Bartwal, G., and Khurana, J.M., *Monatsh. Chem.*, 2018, vol. 149, p. 2231.
<https://doi.org/10.1007/s00706-018-2276-x>
45. Bartwal, G., Saroha, M., and Khurana, J.M., *Synth. Commun.*, 2018, vol. 48, p. 97.
<https://doi.org/10.1080/00397911.2017.1390687>
46. Gao, L., Liu, K., Zhang, L., Xin, Z., Yang, Y., Wei, G., and Yuan, T., *Int. J. Energy Res.*, 2021, vol. 45, p. 13098.
<https://doi.org/10.1002/er.6636>
47. Khurana, J.M., Kandpal, B.M., Kukreja, G., and Sharma, P., *Can. J. Chem.*, 2006, vol. 84, p. 1019.
<https://doi.org/10.1139/v06-125>
48. Khurana, J.M., Kumar, S., and Nand, B., *Can. J. Chem.*, 2008, vol. 86, p. 1052.
<https://doi.org/10.1139/v08-156>
49. Chelucci, G., *ChemistrySelect*, 2016, vol. 1, p. 3699.
<https://doi.org/10.1002/slct.201600769>
50. Aminzadeh, F.M. and Zeynizadeh, B., *Nanoscale Adv.*, 2023, vol. 5, p. 4499.
<https://doi.org/10.1039/D3NA00415E>
51. Sarkar, R., Samanta, S.K., Hasija, A., Chopra, D., Ganguly, D., and Bera, M.K., *New J. Chem.*, 2022, vol. 46, p. 7168.
<https://doi.org/10.1039/D1NJ05196B>

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