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Thought Experiments Combined with Materialist Dialectics in Teaching——Preparation of Ferrous Hydroxide

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Abstract: The preparation of ferrous hydroxide is an important inquiry activity in the high school chemistry unit "Iron and Its Compounds." However, the rapid oxidation of the white precipitate, the short observation window, and the difficulty of controlling conditions make it hard for students to establish causal reasoning between reaction conditions and products. This study combines thought experiments with materialist dialectics to construct a three-stage teaching model: thought-experiment rehearsal, experimental verification, and dialectical reflection and enhancement. In the rehearsal stage, students use the law of quantitative and qualitative change to analyze the critical values of NaOH dosage and concentration, and the law of the unity of opposites to analyze the contradiction between "oxygen exclusion" and "operational feasibility." In the experimental stage, hypotheses are tested through boiling for deoxygenation, liquid sealing, and adding iron powder. In the reflection stage, discrepancy analysis and metacognitive reflection are used to optimize the thought experiment, and students are guided to transfer their thinking methods to other experimental contexts. This model is expected to enhance students' scientific thinking, experimental design ability, and evidence-based reasoning, providing a reference for reforming chemistry experiment teaching.

1. Introduction

Materialist dialectics reveals the universal laws governing nature, human society, and thought, providing a fundamental methodology for understanding the contradictory movements, quantitative and qualitative changes, and the negation of the negation in chemical changes. Thought experiments use imagination to conduct experimental reasoning. Introducing them into chemistry experiment teaching allows students to complete a thought-experiment rehearsal before hands-on operation, which helps cultivate their scientific thinking ability. The Chemistry Curriculum Standards for Senior High School (2017 Edition, 2020 Revision) includes the preparation of ferrous hydroxide as an experiment and inquiry activity[1]. This experiment carries multiple educational functions: understanding the properties of iron compounds, comprehending redox reactions, and training

experimental operation skills. However, the white $Fe(OH)_2$ precipitate rapidly turns gray-green and then reddish-brown during preparation, making it nearly impossible for students to observe its true color. The contrast between experimental phenomena and theoretical expectations not only triggers cognitive conflict but also creates opportunities for deep teaching. Currently, students mostly follow prescribed steps mechanically and lack deep thinking about the logic of experimental design. This experiment involves precipitation reactions, redox reactions, and valence state transformations. The reducing property of Fe^{2+} and the oxidizing property of O_2 constitute a unity of opposites; precipitate formation and oxidative discoloration embody quantitative and qualitative changes; and the conversion of $Fe(OH)_2$ to $Fe(OH)_3$ presents a trajectory of the negation of the negation, providing an ideal vehicle for thought-experiment training and the infiltration of materialist dialectics.

2. The Internal Connection Between Thought Experiments and Materialist Dialectics

2.1. Conceptual Connotation and Educational Value of Thought Experiments

A thought experiment refers to a method in which researchers fully exercise their imagination to construct idealized experimental scenarios at the thinking level, and through rigorous logical deduction, simulate the complete implementation process, possible phenomena, and corresponding countermeasures, thereby improving experimental plans in advance[2]. Thought experiments rely on mental operations and logical reasoning, complementing the hands-on operation and instrument observation of actual experiments. Introducing thought experiments into chemistry experiment teaching has multiple educational values: helping students establish an overall picture of the experimental process and form a cognitive map before hands-on operation[3]; training students' logical reasoning ability by guiding them to reverse-deduce the design logic of experimental steps[4]; stimulating innovative thinking so that students dare to break conventions in thought and conceive new experimental schemes; and enhancing experimental safety awareness by identifying potential risks through thought-experiment rehearsal.

2.2. Main Laws of Materialist Dialectics and Their Manifestation in Chemistry

The main laws of materialist dialectics include the law of the unity of opposites, the law of quantitative and qualitative change, and the law of the negation of the negation. These laws are deeply reflected in the movements and changes of nature. The law of the unity of opposites is the fundamental driving force of things' development. In chemistry, oxidation and reduction, acid and base, precipitation and dissolution are all typical manifestations of the unity of opposites; the essence of redox reactions is electron transfer, and oxidation and reduction are mutually preconditioned and coexist in the same reaction process. The law of quantitative and qualitative change reveals the basic form of things' development: any change is triggered by the accumulation of quantitative changes. The precipitation process in chemistry is most typical—when the ion concentration product gradually increases and reaches the solubility product constant Ksp, a sudden change occurs and the precipitate rapidly forms. The law of the negation of the negation reveals the spiral ascent characteristic of things' development. In chemical reactions, the decomposition of old substances and the formation of new substances, and the formation and transformation of intermediate products, all embody the process of the negation of the negation.

2.3. Points of Convergence Between Thought Experiments and Materialist Dialectics

Thought experiments and materialist dialectics share deep commonalities. First, both emphasize grasping the essence through phenomena: thought experiments eliminate interfering factors through

idealized reasoning, while materialist dialectics requires identifying the principal contradiction and the principal aspect of the contradiction from complex phenomena. Second, both value the unity of logic and history: the logical reasoning of thought experiments should conform to the objective laws of things' development, and the laws revealed by materialist dialectics are precisely the fundamental basis for logical reasoning. Third, both focus on the analysis and transformation of contradictions: thought experiments often set extreme conditions to highlight contradictions, while materialist dialectics centers on contradiction analysis. In chemistry experiment teaching, thought experiments provide an operational vehicle for the infiltration of materialist dialectics, and materialist dialectics provides theoretical guidance for the reasoning of thought experiments. When students use thought experiments to rehearse experimental processes, they can employ the viewpoint of the unity of opposites to analyze interactions between reactants, the viewpoint of quantitative and qualitative change to predict the conditions for precipitate formation, and the viewpoint of the negation of the negation to understand the phased nature and continuity of reaction processes.

3. Dialectical Implications in the Ferrous Hydroxide Preparation Experiment

3.1. Manifestation of the Law of the Unity of Opposites

The core difficulty in preparing ferrous hydroxide lies in the extreme ease with which Fe^{2+} is oxidized by O_2 in air, a phenomenon that embodies the unity of opposites between oxidation and reduction. From the perspective of opposition, Fe^{2+} loses electrons and is oxidized to Fe^{3+}, while O_2 gains electrons and is reduced to OH^-; the two are opposite in direction and nature. From the perspective of unity, they coexist in the same reaction system: without the reduction of oxygen, there would be no oxidation of ferrous iron, and oxidation and reduction are mutually preconditioned and occur simultaneously. More profoundly, Fe^{2+} itself possesses both oxidizing and reducing properties, and this mechanism of multiple valence states based on the same element and their transformations confirms the dialectical principle that the two sides of a contradiction transform into each other under certain conditions.

3.2. Manifestation of the Law of Quantitative and Qualitative Change

The preparation of ferrous hydroxide contains two levels of quantitative-qualitative change relationships. The first level is the precipitation process. When alkali solution is added dropwise to a Fe^{2+} salt solution, the initially added OH^- combines with Fe^{2+} to form tiny crystal nuclei, and the precipitate is not obvious; as OH^- continues to be added, the crystal nuclei gradually grow, but the solution remains clear or slightly turbid; when the amount of OH^- reaches a critical point, a large amount of precipitate suddenly forms. The increase in OH^- concentration is quantitative change, and the precipitation is qualitative change; once the ion concentration product exceeds Ksp, the precipitate forms irreversibly. The second level is the oxidative discoloration process. After the white $Fe(OH)_2$ precipitate contacts air, it does not instantly and completely convert to $Fe(OH)_3$ but undergoes a gradual color change from white to gray-green to reddish-brown. The "gray-green" here is not a vague transition between $Fe(OH)_2$ and $Fe(OH)_3$ but green rust—a layered double hydroxide intermediate phase in which Fe(II) and Fe(III) coexist. The literature explicitly states: "Layered iron(II)-iron(III)-hydroxides (green rusts) are intermediate phases formed by partial oxidation of Fe(II)," and points out that under neutral to weakly alkaline conditions, the oxidation of dissolved Fe(II) always proceeds through a solid green rust phase; green rust has its own structural identity rather than being a simple mixture of the two hydroxides[5]. This indicates that the oxidation reaction is also a process in which qualitative change occurs only after quantitative accumulation reaches a certain level.

3.3. Manifestation of the Law of the Negation of the Negation

The process of preparing ferrous hydroxide from ferrous salt and its eventual oxidation to ferric hydroxide embodies a trajectory of the negation of the negation. The initial state is Fe^{2+} existing in an acidic solution; reaction with alkali first produces white $Fe(OH)_2$ precipitate, which is the first negation, as Fe^{2+} changes from free ions to precipitate; $Fe(OH)_2$ is then oxidized by oxygen in air to $Fe(OH)_3$, which is the second negation, ultimately producing the more stable reddish-brown $Fe(OH)_3$ precipitate. This process is not a simple return but a spiral ascent: $Fe(OH)_3$ is similar in composition to $Fe(OH)_2$—both are iron hydroxides—but the iron valence state rises from +2 to +3, and $Fe(OH)_3$ is more stable in properties.

4. Exploration of Teaching Design Based on Thought Experiments

This paper proposes a three-stage teaching model of "thought-experiment rehearsal—experimental verification—dialectical reflection and enhancement," integrating thought-experiment training and the infiltration of materialist dialectics throughout the entire process of the ferrous hydroxide preparation experiment.

4.1. Thought-Experiment Rehearsal Stage

The rehearsal stage is conducted before hands-on experiments. Students reason through the complete experimental process based on existing theoretical knowledge. The core task of this stage is to guide students to analyze contradictions in the experiment using the viewpoint of materialist dialectics and predict possible phenomena and problems[6]. The ability of thought experiments to serve this rehearsal function is not merely based on teaching intuition. In a controlled study of 100 students, Bascandziev et al. found that students who received thought-experiment training achieved learning gains comparable to those who received hands-on experiments; the researchers particularly noted that thought experiments are especially suitable for situations where hands-on experiments are impossible or where the conditions required for physical experiments are difficult to create. The unavailability of a strictly oxygen-free environment in ferrous hydroxide preparation precisely falls into this category[7].

The rehearsal stage includes five steps. Step 1: Construct an overall experimental picture—students select reagents based on the ionic composition of ferrous hydroxide and mentally "watch" the complete process from liquid extraction and mixing to precipitate formation and color change, drawing on the concept of "sandbox simulation" to establish overall cognition. Step 2: Analyze contradictory relationships—use question chains to guide students in thinking about the relationships between Fe^{2+} and OH^-, and between Fe^{2+} and O_2, analyzing the principal contradiction—the reducing property of Fe^{2+} versus the oxidizing property of O_2—and secondary contradictions such as precipitation rate and OH^- concentration. Step 3: Reason about possible changes—around questions such as "Can $Fe(OH)_2$ be successfully prepared by excluding oxygen?" and "How do changes in reagent dosage or concentration affect the precipitate?", allow students to rehearse multiple possibilities and train them to think using the viewpoint of quantitative and qualitative change. Step 4: Design optimization schemes—consider how to improve the experiment to observe stable white $Fe(OH)_2$ precipitate, such as boiling for deoxygenation, liquid sealing to exclude air, and adding reducing agents for protection. Step 5: Identify potential risks—rehearse safety issues such as alkali corrosiveness, solution splashing, and precipitate disposal, along with countermeasures.

4.2. Experimental Verification Stage

The experimental stage is the materialization and testing of the thought experiment, requiring actual operation according to the rehearsal plan and systematic comparison of experimental phenomena with thought-experiment results. At the observation and recording level, it is necessary to track the rate characteristics of precipitate formation, the color change trajectory, and precipitate morphology, clarifying whether the precipitate forms instantly or gradually, the color of the initial precipitate, and the stages and duration of the color change process. At the regulation and optimization level, hypotheses proposed in the thought experiment are tested through operations such as boiling the solution to remove dissolved oxygen, adding vegetable oil on the liquid surface to exclude air, adding iron powder to protect Fe^{2+}, and changing the dropping order. At the comparison level, phenomena observed in actual operation are compared with rehearsal content to identify which parts are consistent with expectations and which show unexpected discrepancies; for example, if the $Fe(OH)_2$ precipitate is expected to be pure white but a grayish tint is observed in actual operation, this discrepancy provides a factual basis for subsequent in-depth analysis. The entire experimental stage takes obtaining experimental facts as its core task, laying a practical foundation for dialectical reflection.

4.3. Dialectical Reflection and Enhancement Stage

The reflection stage aims to distill experimental gains from a philosophical perspective and promote the transformation of specific experience into general understanding. First, grasp the essence through phenomena: clarify the material forms corresponding to white, gray-green, and reddish-brown, and understand that the essence of the color change lies in the unfolding and movement of the redox contradiction; then use the law of quantitative and qualitative change to examine the critical conditions for qualitative change triggered by quantitative accumulation in precipitate formation and oxidative discoloration; on this basis, distinguish principal and secondary contradictions, clarifying that the principal contradiction lies in the irreversible tendency of ferrous ion oxidation, while secondary contradictions such as precipitation rate and concentration control affect the timing and observation of phenomena.

The core of the reflection stage is to test and optimize the thought experiment itself. Rehearsal results are compared with actual operation to analyze the accuracy of predictions and discrepancies, and to investigate whether discrepancies arise from insufficient knowledge, logical omissions, or neglect of certain key factors. However, this "comparison—correction" reflection does not occur naturally. Research by Walker et al. published in the *Journal of Chemical Education* shows that when experimental evidence conflicts with expected claims, students are not inclined to change their claims and do not regard "claim change" as a legitimate component of argumentation. This means that the "discrepancy analysis" link requires teachers to consciously counteract students' cognitive inertia of "maintaining the original claim" and cannot assume that reflection will automatically emerge from comparison[8]. On this basis, through metacognitive reflection, the quality of thought experiments and the effectiveness of thinking training are continuously improved. This design has empirical precedents in chemistry classrooms. Eyceyurt Türk et al. implemented a "thought experiment—argumentation" teaching intervention using 12th-grade organic chemistry concepts as a vehicle and found that students' critical thinking skills were enhanced through the process of argument construction, with the mechanism lying in students' examination and externalization of their own thinking strategies[9]. Finally, transfer of thinking methods is achieved, extending to other chemistry experiment scenarios such as the preparation of other easily oxidized substances and the synthesis of easily hydrolyzed substances.

5. Teaching Value of Integrating Thought Experiments with Materialist Dialectics

5.1. Significance and Value for Students

5.1.1. Contributing to the Development of Scientific Thinking

In traditional experiment teaching, students often play the role of "step-following executors," with thinking activities marginalized. The introduction of thought experiments enables students to achieve threefold thinking development. First, they gain a safe space for thinking rehearsal. Before actual operation, students can freely reason through experimental processes in their minds, try different operational schemes, and predict possible phenomena and problems; this thinking rehearsal consumes no reagents, produces no hazardous waste, yet enables students to establish an overall cognitive picture of the experimental process, so that when they enter the laboratory, they are no longer mechanically executing instructions but conducting purposeful inquiry with problem awareness and thinking expectations. Second, they develop a self-monitoring reflective habit. The comparison between thought experiments and experimental operations prompts students to constantly examine their own thinking methods, review cognitive strategies, discover thinking blind spots, and optimize thinking paths; once formed, this ability has lasting transfer value. Third, they experience the intellectual pleasure of scientific discovery. When students conceive ideal situations such as "completely oxygen-free environments" and "extreme concentration conditions" in thought experiments, their thinking breaks through the constraints of real conditions, and they are no longer passive knowledge recipients but active meaning constructors.

5.1.2. Contributing to the Development of Dialectical Thinking

Chemistry experiments are not only processes of observing phenomena and verifying conclusions but also cognitive fields for understanding natural laws and perceiving philosophical wisdom. First, students learn to grasp the key in contradiction analysis. Faced with the dilemma of "white precipitate instantly turning gray" in ferrous hydroxide preparation, students need to analyze the contradictory relationship between Fe^{2+} and O_2, distinguish principal and secondary contradictions, and understand the mutual transformation of the two sides of a contradiction under certain conditions, so that they are not satisfied with describing surface phenomena but inquire into the underlying contradictory relationships and seek the key fulcrum for solving problems. Second, students understand development laws through process tracking. From precipitate formation to color gradual change, from Fe^{2+} to $Fe(OH)_2$ to $Fe(OH)_3$, students track the trajectory of material form changes throughout the process, truly feeling how quantitative change accumulates, how qualitative change occurs, and how the negation of the negation drives things toward higher levels. Third, students acquire philosophical wisdom in specific contexts. When students personally operate, observe phenomena, and experience thinking conflicts, philosophical principles are no longer external dogmas but internalized as cognitive schemas for understanding the world.

5.2. Significance and Value for Teachers

5.2.1. Contributing to the Enhancement of Teaching Competence

The integration of thought experiments and materialist dialectics imposes new requirements on teachers' professional competence. First, the ability to deeply interpret teaching materials. The ferrous hydroxide preparation experiment appears simple, but to excavate its dialectical relationships, teachers need to consider what educational values beyond knowledge objectives this experiment carries, what philosophical implications lie behind the experimental phenomena, and how to guide

students from observing phenomena to understanding essence, thereby transforming from executors of teaching materials to developers. Second, the ability to design thinking activities. Thought experiments differ from free imagination and require teachers to design hierarchical and logical question chains to guide students progressively; how to set up contradictory situations to stimulate thinking and how to cultivate students' logical reasoning ability in the rehearsal stage both require careful design. Third, the ability to guide classroom dialogue. In the dialectical reflection stage, teachers need to guide students from phenomena to essence and from the specific to the general, requiring keen classroom insight and understanding of students' confusion and thinking obstacles. This competence transformation cannot be completed through conceptual renewal alone. The systematic review by Putri et al. identified that the core obstacles to argumentation-driven teaching in chemistry education lie precisely in insufficient teacher preparation and low student participation, and that effective teaching transformation requires targeted teacher training and curriculum-level integration. The "classroom dialogue guidance ability" and "thinking activity design ability" advocated in this paper are likewise identified in international chemistry education research as a systemic challenge rather than a skill threshold that individual teachers can cross in isolation[10]. Fourth, the vision of interdisciplinary integration. Integrating materialist dialectics into chemistry teaching requires teachers to understand basic philosophical principles and find appropriate ways to integrate the two, and this interdisciplinary exploration expands teachers' professional vision.

5.2.2. Contributing to the Realization of Teachers' Professional Value

The teaching integration of thought experiments and materialist dialectics also enhances teachers' professional identity. When teachers no longer repeat fixed teaching models but attempt to organically integrate philosophical thinking with scientific inquiry, teaching activities themselves become a creative act. When teachers see students' expressions of sudden enlightenment in the dialectical reflection stage and hear students say "It turns out chemistry and life are connected," they truly feel the power of education. In this teaching exploration, teachers gradually understand that the fundamental mission of education is not to cultivate operators who can repeat established knowledge but to nurture complete persons who can think independently, analyze dialectically, and explore innovatively.

6. Conclusions

To address the instructional challenges in the ferrous hydroxide preparation experiment, this paper constructs a three-stage teaching model comprising thought-experiment rehearsal, experimental verification, and dialectical reflection and enhancement. This model translates abstract materialist dialectics into specific cognitive tools for analyzing chemical phenomena. It not only guides students to deepen their evidence-based reasoning through mental rehearsal but also places new demands on teachers' interdisciplinary integration competence and classroom insight. The theoretical framework and teaching design proposed in this study provide a useful reference for reforming high school chemistry experiment teaching. Future work can further extend this model to other complex chemical experiment scenarios to test and enrich its practical value.

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