Physics Supernova: AI Agent Matches Elite Gold Medalists at IPhO 2025

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Abstract

Physics provides fundamental laws that describe and predict the natural world. AI systems aspiring toward more general, real-world intelligence must therefore demonstrate strong physics problem solving abilities: to formulate and apply physical laws for explaining and predicting physical processes. The International Physics Olympiad (IPhO)–the world's most prestigious physics competition–offers a rigorous benchmark for this purpose. We introduce Physics Supernova, an AI agent system with superior physics problem-solving abilities that match elite IPhO gold medalists. On the IPhO 2025 theory problems, Physics Supernova attains 23.5/30 points, ranking 14$^{\text{th}}$ of 406 contestants and surpassing the median performance of human gold medalists. We extensively analyzed Physics Supernova's capabilities and flexibility across diverse physics tasks. These results show that principled tool integration within agent systems can deliver competitive improvements in solving challenging science problems.[1]

1 Introduction

The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction.

Albert Einstein

Physics aims to compactly formulate the fundamental laws that govern the behavior of the universe [1, 2]. The mastery of physics entails constructing rigorous abstractions [3, 4]. As AI systems increasingly integrate into the physical world and advance toward Artificial General Intelligence (AGI) and potentially Artificial Super intelligence (ASI), a deep grounding in physics becomes a critical foundation for developing competent and reliable intelligence [5, 6, 7]. In this work, we investigate how to enhance AI systems' physics problem-solving capabilities with agent-based architectures. To assess progress in this challenging domain, we benchmark our models on the theory problems of the 2025 International Physics Olympiad (IPhO [8]) , a globally recognized competition that emphasizes deep conceptual understanding, abstraction, and advanced problem-solving in physics.

The International Physics Olympiad, or IPhO [8], is widely viewed as a prestigious physics competition. The 2025 International Physics Olympiad (IPhO) was held in July in France [9]. Unlike earlier benchmarks evaluating physics problem-solving abilities [10, 11, 12] that might risk data contamination, use coarse evaluation (e.g., final-answer-only scoring), offer limited novelty, and lack assessments of precise figure reading/measurement, etc., IPhO 2025 Theory Problems exhibit

[1]The codes are available at https://github.com/CharlesQ9/Physics-Supernova.

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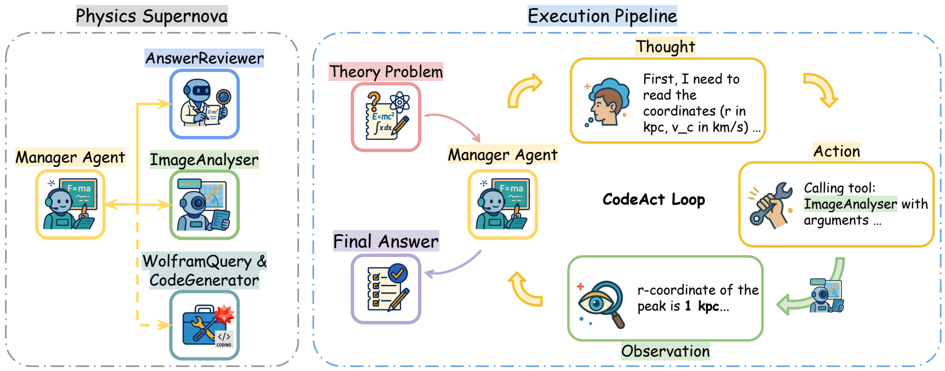

Figure 1: Our proposed agent system: Physics Supernova, for solving theory problems in physics.

several distinctive features: (1) new release date in July 2025 [9]; (2) fine-grained, part-level scoring, enabling detailed assessment; (3) uncommon physics models that challenge standard approaches; and (4) explicit figure-based measurement requirements (see Table 1). In this work, we utilize **IPhO 2025 Theory Problems** as the benchmark for evaluating AI's capability in physics. IPhO contestants are provided with calculators and fundamental constant tables; moreover, expert physicists routinely work with extra tools: these facts highlight the importance of external tool use for physicists in general. However, previous benchmarks mainly evaluate the performance of base LLMs, with limited integration of tools and limited evaluation of LLM-based agent systems [12, 13, 14].

LLM-based agent systems demonstrate significant advantages over LLM alone in planning, complex reasoning and tool using [15, 16]. ReAct [17] introduces the idea of Reasoning-Acting loop for agents. More recently, self-evolving agents have been proposed, with even fewer designs based on humans [18, 19, 20]. However, previous work mainly examines general-purpose agents with a focus on possible virtual-assisting style tasks (e.g., GAIA [21]) or other domains like math [22], history [23], etc., not covering the domain of complex physics problems.

In this work, with a focus on physics reasoning and problem-solving ability, we introduce **Physics Supernova**, an agent system equipped with physics-oriented tools targeting physics problem-solving. We equip LLMs with tools to improve physical reasoning ability: the Image Analyzer Tool to accurately extract data, and the Answer Reviewer Tool to self-review and refine. With these tools, Physics Supernova achieves **Gold Medal** in IPhO 2025 Theory Problems: it ranks top 10% on all three problems tested, and ranks 14^{th} among 406 human contestants in IPhO 2025 Theory Problems.

To conclude, we summarize our main contribution as follows: **(1)** We develop Physics Supernova, an agent system combining Large Language Models with physics-specific tools, exhibiting strong capabilities across a wide range of physics tasks. **(2)** We show that Physics Supernova achieves gold-medalist-level performance on IPhO 2025 Theory Problems, ranking 14^{th} among all 406 human contestants worldwide, exceeding the official gold medalist median score. **(3)** We conduct further analysis and experiments to show Physics Supernova's capability and flexibility for physics problem solving tasks.

2 Method

2.1 Agent Architecture

We introduce **Physics Supernova**, an AI agent system designed to solve complex physics theory problems. It follows the `CodeAgent` architecture from the `smolagents` framework [24]. As illustrated in Figure 1, the system consists of a **Manager Agent** $\mathcal{M}$ and a set of domain-specific tools $\mathcal{D} = \{d_i\}_{i=1}^{n}$, where each d_i is physics-problem-oriented tool.

Unlike prior work in mathematical problem-solving that often relies on fixed, manually hard-coded workflows [25, 26], our approach emphasizes **flexible self-planning**. The Manager Agent is granted access to the tool set $\mathcal{D}$ but is not provided with a hard-coded predefined execution graph or action script. The agent is able to call different Tools according to its progress made in its process of solving

Problem	Subpart	Subpart Content {# Scoring Points†}	Model Novelty	Computation Difficulty	Image Ability	Top 10% Score
Theory Problem 1 (Modern Physics)	Part A	Bohr Model {18}	Common	Low	No Image	9.0/10.0
	Part B	Rotation of a Galaxy {18}	Rare	Med	Accurate Meas	
	Part C	Mass Distribution of a Galaxy {24}	Rare	Med	Accurate Meas	
	Part D	Tully-Fisher Relation & MOND {23}	Novel	Med	Rough Meas	
Theory Problem 2 (Thermodynamics & Dynamics)	Part A	Pulling on a Submerged Tube {9}	Rare	Med	Understand	5.0/10.0
	Part B	Two-Part Barometric Tube {10}	Rare	High	Understand	
	Part C	Cox's Timepiece {38}	Novel	High	Understand	
Theory Problem 3 (Thermodynamics & Dynamics)	Part A	Nucleation & Growth of Bubbles {26}	Rare	Med	Rough Meas	8.0/10.0
	Part B	Acoustic Emission of Bubbles {20}	Rare	Med	Understand	
	Part C	Popping Champagne {19}	Rare	Med	Understand	

Table 1: Theory problems of IPhO 2025: Subpart contents (and number of scoring points† for each subpart, obtained from official solutions at `https://ipho.olimpicos.net/`), physics model novelty (among Physics Olympaids), computation difficulty levels, required image-reading skills, and top 10% human scores. For physics model novelty: Common, Rare and Novel represent how often such physical model appears in previous Physics Olympiads. For computation Difficulty: Low , Med and High show the requirement for tedious computation and careful attention for applying formulas. For Image reading requirements: No Image and Understand do not require measurements, while Rough Meas and Accurate Meas requires rough/accurate reading from the image. Examples of these problems are shown in Appendix A.

problems. Overall, the agent operates in an iterative **Reason–Act** loop. In each round, it generates a natural language-based reasoning step and justify the selection of tools $d \subseteq \mathcal{D}$ (*Reason*); it then produces code for calling tools, which are then called and produce intermediate observations (*Act*). These observations are then coorporated into next reasoning step, enabling refinement of agent's understanding.The loop continues until final answers are produced for all questions.

2.2 Physics-Problem-Oriented Toolset

We develop agent tools based on observations and experience on physics problems [9, 10, 12] and LLM agents [19, 23, 27]. Here, we discuss the physics-problems-oriented tools we equip the manager agent with: the *ImageAnalyzer* and the *AnswerReviewer*.[2]

ImageAnalyzer: Reading experimental results and extracting critical information from figures is important for expert physicists. To enhance image handling, ***ImageAnalyzer*** routes a high-res image to a dedicated Vision Language Model, addressing precise tasks such as reading numeric values and making measurements.

AnswerReviewer: Physicists routinely evaluate whether their theoretical results are physically meaningful. To enhance AI's ability of rethinking, ***AnswerReviewer*** is provided: it classifies likely error types and locates erroneous expressions through the process. We provide ablations studies where the reviewing tool improves performance in Section C.1.

With only ***ImageAnalyzer*** and ***AnswerReviewer***, Physics Supernova empowered by state-of-the-art LLM (Gemini 2.5 Pro [28]) can achieve medium gold-level performance in IPhO 2025 Theory Problems (Section 3). Moreover, this system supports the integration of additional advanced physics-related tools, such as the WolframAlpha question-answering engine (Section C.3) that can assist with computationally intensive physics tasks.

3 Experiment: Physics Supernova Excels in IPhO 2025 Theory Problems

3.1 Experiment Setup

Benchmarking Dataset IPhO 2025 has 3 theory problems and 2 experimental problems in which each problem counts for 10.0 points, adding up to 50.0 points in total. Among 406 contestants from more than 90 countries and regions, 37 ones with the highest total scores are awarded the Gold Medal. Theory score is the sum of all three theory problems. The minimum and median theory scores for gold medalists are 19.4 & 22.8. Table 1 shows the detailed contents of each theory problem.

[2]The tools and prompts are not specially tuned on IPhO 2025 problems to avoid data leakage. We run experiments on IPhO 2025 theory problems and report scores in Section 3 after creating these tools.

Problem	Part A	Part B	Part C	Part D	SUM
Theory 1 total score	2.2	2.5	3.0	2.3	10.0
LLM Only	2.20 ± 0.00	2.28 ± 0.04	2.06 ± 0.13	1.92 ± 0.11	8.46 ± 0.16
Physics Supernova	2.20 ± 0.00	2.20 ± 0.00	2.46 ± 0.05	2.16 ± 0.05	$\mathbf{9.02 \pm 0.11}$
Human Top 10%	/	/	/	/	~ 9.0
Theory 2 total score	1.3	2.0	6.7	/	10.0
LLM Only	1.16 ± 0.31	1.08 ± 0.19	3.04 ± 1.02	/	5.30 ± 0.99
Physics Supernova	1.30 ± 0.00	1.16 ± 0.22	3.62 ± 0.79	/	$\mathbf{6.08 \pm 0.77}$
Human Top 10%	/	/	/	/	~ 5.0
Theory 3 total score	4.3	3.3	2.4	/	10.0
LLM Only	3.70 ± 0.07	2.74 ± 0.36	1.22 ± 0.18	/	7.66 ± 0.51
Physics Supernova	4.02 ± 0.22	3.26 ± 0.09	1.12 ± 0.11	/	$\mathbf{8.40 \pm 0.27}$
Human Top 10%	/	/	/	/	~ 8.0
Theory Part total score	/	/	/	/	30.0
LLM Only	/	/	/	/	21.4 ± 1.1
Physics Supernova	/	/	/	/	$\mathbf{23.5 \pm 0.8}$
Gold Medalists (mediam)	/	/	/	/	22.8

Table 2: Experiment results for Physics Supernova (mean$\pm$std) across multiple problems and parts (with Gemini 2.5 Pro), for 5 rounds. Our agent results rank top 10% among human contestants on all three Theory problems.

Experiment Details We test Physics Supernova on each of the three theory problems, with chosen pre-defined tools. As smolagents [24] lack a built-in summarization memory, we implemented a lightweight summarizing tool to summarize existing progress, which is provided beside the ***Image-Analyzer*** and ***AnswerReviewer*** tools. [3]

3.2 Main Experimental Results

The results of our main experiments are shown in Table 2. The mean theory score of Gemini 2.5 Pro alone ranks 30$^{\text{th}}$ among 406 contestants, while the mean theory score of **Physics Supernova ranked 14$^{\text{th}}$ among all 406 contestants, surpassing the medium theory score of the gold medalists**. Noticeable, Physics Supernova ranks top 10% on all three Theory problems tested. Comparing Table 1 and Table 2, we make the following observations. **(1)** Physics Supernova successfully improves LLM performance on all three problems. **(2)** Larger advantages are achieved on more difficult problems (i.e., larger improvement is achieved on Problems 2 and 3). **(3)** Harder problems show larger variance (i.e. larger variance on Problem 2). We provide more analysis and results of additional tools targeting more general physics problems in Appendix C.

4 Conclusion

In this work, we introduce Physics Supernova, a flexible agent system for solving Olympiad-level physics problems and beyond. By providing task-specific tools including ImageAnalyzer, AnswerReviewer, etc., we extend the capability of state-of-the-art LLMs on physics problems. This aspect was previously viewed mostly as benchmarks of base, simple LLMs [10, 11, 12]. On the newly released IPhO 2025 theory problems, our agent system achieves gold-medal-level performance. Specifically, our method ranks top 10% among human contestants in all three theory problems. It achieves 23.5 points on the theory problems, ranks #14 among all 406 human contestants, and surpasses the median theory score of the gold medalists.

Overall, our proposed Physics Supernova successfully improves the physics problem solving ability of LLMs through agent paradigms. This shows the potential of agent systems to improve the capability of LLMs for scientific reasoning and physics-related tasks, and further implies their potential for developing super intelligence that embeds into the real world.

[3]Throughout the experiments, we use Gemini 2.5 Pro [28] for the agent system and all the LLM-requiring tools. For each problem, human experts score LLM answers in detail based on the official IPhO 2025 scoring criteria (we provide examples of scoring criteria in Appendix A)[4]. For each problem, the experiment is carried out 5 times, where mean and standard deviation are reported in Table2.

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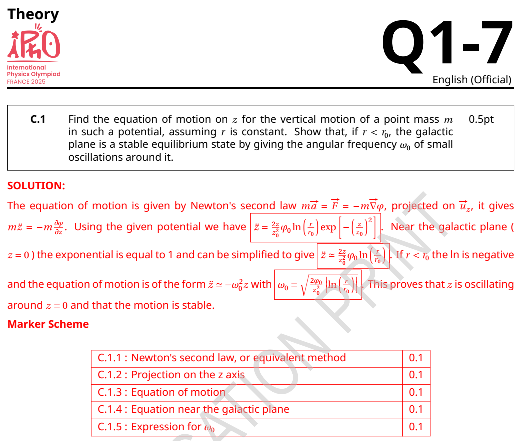
A Examples of IPhO 2025 Problems Scoring Criteria

We provide two example of the IPhO 2025 scoring criteria (corresponding to Theory Problem 1 Part C.1 and Theory Problem 3 Part C.2, correspondingly) in Figure 2, obtained from `https://ipho.olimpicos.net/`.



Theory

International Physics Olympiad FRANCE 2025

Q1-7

English (Official)

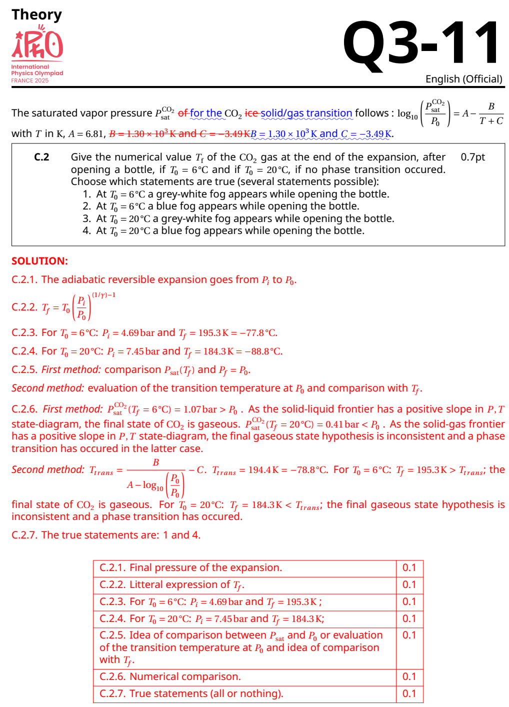
C.1	Find the equation of motion on z for the vertical motion of a point mass m in such a potential, assuming r is constant. Show that, if $r < r_0$, the galactic plane is a stable equilibrium state by giving the angular frequency ω_0 of small oscillations around it.	0.5pt

SOLUTION:

The equation of motion is given by Newton's second law $m\vec{a} = \vec{F} = -m\vec{\nabla}\varphi$, projected on $\vec{u}_z$, it gives $m\ddot{z} = -m\frac{\partial\varphi}{\partial z}$. Using the given potential we have $\boxed{\ddot{z} = \frac{2z}{z_0^2}\varphi_0 \ln\left(\frac{r}{r_0}\right)\exp\left[-\left(\frac{z}{z_0}\right)^2\right]}$. Near the galactic plane ($z = 0$) the exponential is equal to 1 and can be simplified to give $\boxed{\ddot{z} \simeq \frac{2z}{z_0^2}\varphi_0 \ln\left(\frac{r}{r_0}\right)}$. If $r < r_0$ the ln is negative and the equation of motion is of the form $\ddot{z} \simeq -\omega_0^2 z$ with $\boxed{\omega_0 = \sqrt{\frac{2\varphi_0}{z_0^2}\left|\ln\left(\frac{r}{r_0}\right)\right|}}$. This proves that z is oscillating around $z = 0$ and that the motion is stable.

Marker Scheme

C.1.1 : Newton's second law, or equivalent method	0.1
C.1.2 : Projection on the z axis	0.1
C.1.3 : Equation of motion	0.1
C.1.4 : Equation near the galactic plane	0.1
C.1.5 : Expression for ω_0	0.1



Theory

International Physics Olympiad FRANCE 2025

Q3-11

English (Official)

The saturated vapor pressure $P_{sat}^{CO_2}$ ~~of~~ for the CO_2 ~~ice~~ solid/gas transition follows : $\log_{10}\left(\frac{P_{sat}^{CO_2}}{P_0}\right) = A - \frac{B}{T+C}$ with T in K, $A = 6.81$, ~~$B = 1.30 \times 10^3$ K and $C = -3.49$ K~~ $B = 1.30 \times 10^3$ K and $C = -3.49$ K.

C.2	Give the numerical value T_f of the CO_2 gas at the end of the expansion, after opening a bottle, if $T_0 = 6$°C and if $T_0 = 20$°C, if no phase transition occured. Choose which statements are true (several statements possible): 1. At $T_0 = 6$°C a grey-white fog appears while opening the bottle. 2. At $T_0 = 6$°C a blue fog appears while opening the bottle. 3. At $T_0 = 20$°C a grey-white fog appears while opening the bottle. 4. At $T_0 = 20$°C a blue fog appears while opening the bottle.	0.7pt

SOLUTION:

C.2.1. The adiabatic reversible expansion goes from P_i to P_0.

C.2.2. $T_f = T_0\left(\frac{P_i}{P_0}\right)^{(1/\gamma)-1}$

C.2.3. For $T_0 = 6$°C: $P_i = 4.69$ bar and $T_f = 195.3$ K $= -77.8$°C.

C.2.4. For $T_0 = 20$°C: $P_i = 7.45$ bar and $T_f = 184.3$ K $= -88.8$°C.

C.2.5. *First method:* comparison $P_{sat}(T_f)$ and $P_f = P_0$.

Second method: evaluation of the transition temperature at P_0 and comparison with T_f.

C.2.6. *First method:* $P_{sat}^{CO_2}(T_f = 6°C) = 1.07\,\text{bar} > P_0$. As the solid-liquid frontier has a positive slope in P, T state-diagram, the final state of CO_2 is gaseous. $P_{sat}^{CO_2}(T_f = 20°C) = 0.41\,\text{bar} < P_0$. As the solid-gas frontier has a positive slope in P, T state-diagram, the final gaseous state hypothesis is inconsistent and a phase transition has occured in the latter case.

Second method: $T_{trans} = \frac{B}{A - \log_{10}\left(\frac{P_0}{P_0}\right)} - C$. $T_{trans} = 194.4$ K $= -78.8$°C. For $T_0 = 6$°C: $T_f = 195.3\,\text{K} > T_{trans}$; the final state of CO_2 is gaseous. For $T_0 = 20$°C: $T_f = 184.3\,\text{K} < T_{trans}$; the final gaseous state hypothesis is inconsistent and a phase transition has occured.

C.2.7. The true statements are: 1 and 4.

C.2.1. Final pressure of the expansion.	0.1
C.2.2. Litteral expression of T_f.	0.1
C.2.3. For $T_0 = 6$°C: $P_i = 4.69$ bar and $T_f = 195.3$ K ;	0.1
C.2.4. For $T_0 = 20$°C: $P_i = 7.45$ bar and $T_f = 184.3$ K;	0.1
C.2.5. Idea of comparison between P_{sat} and P_0 or evaluation of the transition temperature at P_0 and idea of comparison with T_f.	0.1
C.2.6. Numerical comparison.	0.1
C.2.7. True statements (all or nothing).	0.1

Figure 2: Two scoring criteria examples, for IPhO 2025 Theory Problem 1 Part C.1 and Theory Problem 3 Part C.2, correspondingly. As shown, there are 5 scoring criteria for Theory Problem 1 Part C.1, and 7 scoring criteria for Theory Problem 3 Part C.2.

As shown in Figure 2, for each problem, very detailed answers and scoring criteria are provided, making fine-grained scoring possible for answers. In Table 1 we count the number of scoring criteria for each part of each Theory Problem.

B Detailed Prompts

B.1 Image Analyzer Tool Prompt

The image analyzer tool utilizes an LLM provided with the image and question from the manager agent. Its task is to answer manager's questions based on provided information. It then returns an str-object of its measurements.

```
# input: manager_query: str, img_file: ImageFile, vision_expert_llm:
    LLMModel
IMG_SYSTEM_PROMPT = "You are an expert in dealing with image in
    Physics Olympiads."
messages = [
     ChatMessage(role=MessageRole.SYSTEM, content=IMG_SYSTEM_PROMPT),
     ChatMessage(role=MessageRole.USER, content=[
         {"type": "image", "image": img_file},
         {"type": "text", "text": question},
     ]),
]
output: str = vision_expert_llm.generate(messages)
```

B.2 Answer Reviewer Tool Prompt

The Answer Reviewer tool utilizes an LLM provided with: (1) manager agent's solution; (2) manager agent's notes; (3) the original problems (including texts and figures). It then returns an str-object representing its review results.

```
# input: agent_solution:str, agent_note:str, markdown_content:
    List[Dict[str, Any], review_expert_llm: LLMModel
# markdown_content includes markdown file text and image.
REVIEW_SYSTEM_PROMPT = (
    "You are an uncompromising Physics peer-reviewer. Your job is to
        find *every* logical, mathematical
error in the worker's answer. "
    "Check dimensional consistency, missing steps, incorrect sign
        conventions, numerical mistakes, and
unclear explanations. Focus especially on wrong answers, less on
    presentations."
    "Be extremely critical: if something is wrong, point it out and
        request clarification or correction.
Mainly focus on errors that would lead to a wrong result, rather than
    focusing extremely on presentation
or style."
    "It is possible that the worker's answer is not correct, so
        please be prepared to provide detailed
feedback. The worker's answer contains some error, so you must check
    and point it out. Also, if the
worker reads measurements from image, make sure to remind the worker
    that whenever it reads or measures
from image, it uses the ask_image_expert tool, or the readings might
    be very inaccurate.\n"
)

review_instruction = (
    f"Please review the following solution:\n\n"
    f"WORKER'S SOLUTION:\n{agent_solution}\n\n"
    f"WORKER'S NOTE: {agent_note}\n\n"
    f"Please provide detailed feedback on correctness. "
    f"Point out any errors, wrong steps, focus more on correctness
        rather than presentation."
    f"The original problem follows:"
)

combined_content : List[Dict[str, Any]] = [
    {"type": "text", "text": review_instruction}
] + markdown_content

messages = [
    ChatMessage(role=MessageRole.SYSTEM,
        content=REVIEW_SYSTEM_PROMPT),
    ChatMessage(role=MessageRole.USER, content=combined_content),
]
output: str = review_expert_llm.generate(messages)
```

C Analysis

C.1 Ablation Study

To study the impact of each tool on the final scores, we replicate the protocol described in Section 3, providing different tools for the agent system. We consider four settings: (1) Physics Supernova; (2) without *ImageAnalyzer* tool; (3) without *AnswerReviewer* tool; and (4) LLM only. For each theory problem, we perform 5 independent runs and report the mean and standard deviation. The agents are powered by Gemini 2.5 Pro. The results are shown in Table 3. Comparing Table 1 and Table3, we find:

Method	Theory 1	Theory 2	Theory 3	Theory Part
Total score	10.0	10.0	10.0	30.0
Physics Supernova	$\mathbf{9.02 \pm 0.11}$	$\mathbf{6.08 \pm 0.77}$	$\mathbf{8.40 \pm 0.27}$	$\mathbf{23.5 \pm 0.8}$
w.o.ImgTool	8.58 ± 0.19	5.98 ± 0.54	8.26 ± 0.24	22.8 ± 0.6
w.o.RevTool	8.62 ± 0.16	5.54 ± 0.61	8.26 ± 0.15	22.4 ± 0.6
LLM Only	8.46 ± 0.16	5.30 ± 0.99	7.66 ± 0.51	21.4 ± 1.1

Table 3: Ablation study results for four experiment settings: Physics Supernova, Physics Supernova without ***AnswerReviewer*** (RevTool), Physics Supernova without ***ImageAnalyzer*** (ImgTool), and using LLM only.

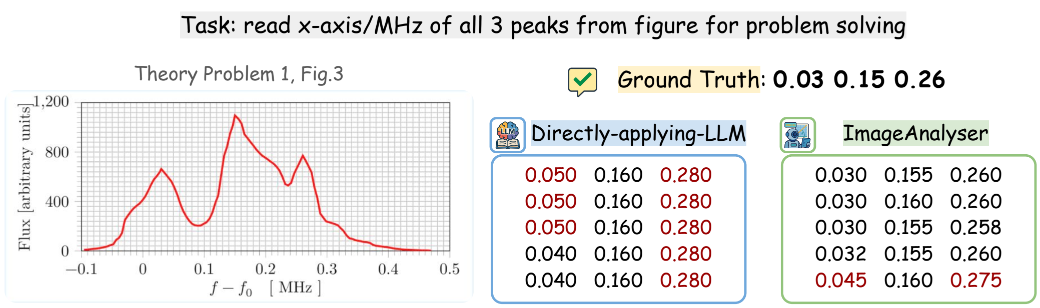


Figure 3: Effect of *ImageAnalyzer* on Theory Problem 1 Part C. The problem here requires accurate measurement from a figure (shown left). We show 5 repeated experiments of directly applying LLMs and using Image Analyzer Tool (shown right), with reading difference > 0.01MHZ colored in red. As shown, the improvement mainly comes from a reduction in measurement error.

ImageAnalyzer **helps with tasks requiring Accurate Image Measurements.** For example, as shown in Table 1, the theory problem requires accurate measurements from figures, and in this case, the Image Analyzer successfully improves the performance of the model. This indicates that delegating high-accuracy image analysis to *ImageAnalyzer* improves the overall score. We present a case study in Section C.2 for better illustration.

AnswerReviewer **raises overall scores via post-hoc review.** In most problems (especially non-easy ones), removing the Answer Reviewer reduces performance. For example, we see a performance drop for overall scores for all three theory problems after removing the Answer Reviewer. This implies that, equipped with *AnswerReviewer* for reviewing, locating errors and providing feedback, Physics Supernova can improve performance for many cases.

C.2 Case Study: Image Analyzer Tool

We zoom in on Theory Problem 1 Part C to see how Image Analyzer Tool helps improve scores. In particular, this problem requires the contestants to accurately read a figure to solve the problem. The specific task related to the image is shown in Figure 3.

As shown in Figure 3, using a specialized Image Reading LLM as Image Analyzer Tool excels directly exposing the manager agent to all images of a single problem, which reduces the mean absolute error (MAE) from 0.015 to 0.004. This example further shows that, by using Image Analyzer Tool, Physics Supernova improves its ability to accurately read from figures, thus improving its overall performance.

C.3 Domain-Specific Tools: WolframAlpha QA Tool

Physics research usually requires expert domain knowledge. In Physics Olympiads, some reference information (e.g., physical constants, specific physics formulas, etc.) is provided as information for

Problem Q4. Using the IAPWS-IF97 formulation for water/steam, compute the specific enthalpy of water at p = 15 MPa and T = 650 K (single-phase state as appropriate). Return a single number: the value in $kJkg^{-1}$, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 2.8686E+3 **w.o.wolfTool Answer:** 3.0462E+3 **w.wolfTool Answer:** 2.8690E+3

Problem Q5. Using NIST X-ray transition energies (or equivalent), determine the photon energy of the copper $\kappa\alpha_1$ (KL_3) line for elemental Cu at ambient conditions. Return a single number: the value in keV, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 8.0478E+0 **w.o.wolfTool Answer:** 8.0463E+0 **w.wolfTool Answer:** 8.0478E+0

Figure 4: Examples of 10 expert-knowledge-requiring problems we generate, listed in Appendix D. This example requires expert domain knowledge that can only be obtained through web search/expert database queries.

	w.o. WolframAlpha Tool	**w. WolframAlpha Tool**
# **3-digit Accurate Answers**	3/10	9/10
# **4-digit Accurate Answers**	2/10	6/10

Table 4: Number of accurate answers for expert-knowledge-requiring tasks shown in Appendix D. ('N-digit accurate' means that the answer differs from GT only by ± 1 on the $N-$th significant digit. For example, in Figure 4 Q4, the 'w.o.wolfTool Answer' is 1-digit accurate, while the 'w.wolfTool Answer' is 4-digit accurate, compared to the ground truth answer.)

contestants to use: this is not the case for more complicated Physics researches. In these expert-level cases, accessing domain knowledge is very important. Figure 4 provides examples of this case.

To better handle domain-specific queries in Physics Supernova, we further equip Physics Supernova with a question-answering (QA) tool for expert domain knowledge. To be specific, we utilize WolframAlpha [29]: a computational knowledge engine capable of providing accurate and concise results for science-related queries.

In order to study Physics Supernova's performance on more expert tasks with WolframAlpha QA Tool, we generate 10 problems which require expert knowledge (most efficiently obtained from standard references or WolframAlpha), listed in Appendix D. As shown in Figure 4 are examples of these problems. Table 4 reports the performance with and without the WolframAlpha tool. The result shows that WolframAlpha Tool improves the ability of Physics Supernova to solve problems that require expert physics knowledge.

In all: experiments presented in this Section C show that, by integrating appropriate tools into the AI agent system, we can significantly advance the capabilities of LLMs in solving complex and challenging physics problems. This enhancement improves the mastery of physics of the agent system without requiring any modifications to the underlying LLMs. In conclusion, our Physics Supernova emerges as a powerful, flexible, and extensible physics problem-solving framework built upon the agent-based paradigm.

D Expert-knowledge Requiring Tasks

We further generate several tasks requiring expert knowledge to test how integrating WolframAlpha would help Physics Supernova with accurate expert knowledge.

As shown in the following examples, **When given access to WolframAlpha Tools, the agent system provides more accurate answers.** In the experiments, we use Gemini 2.5 Pro as LLM and compare the result with and without WolframAlpha Tools, as shown below. The aggregated results are also shown in Table 4.

Problem Q1. Using the latest AME (Atomic Mass Evaluation) atomic masses, compute the Q-value of double beta decay $^{76}Ge \rightarrow^{76} Se + 2e^{-}$ (ground state ground state). Return a single number: the value in keV, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 2.0391E+3 **w.o.wolfTool Answer:** 2.0391E+3 **w.wolfTool Answer:** 2.0390E+3

Problem Q2. Using NIST XCOM (or an equivalent authoritative database), determine the mass attenuation coefficient μ/ρ of lead (Pb) for photons of energy 662.0 keV ($^{137}Cs\ \gamma$ line). Return a single number: the value in $cm^2 g^{-1}$, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 1.1105E-1 **w.o.wolfTool Answer:** 1.1352E-1 **w.wolfTool Answer:** 1.1150E-1

Problem Q3. Using the Ciddor (1996) refractive-index model for air, at wavelength $\lambda = 633nm$ (vacuum), P = 101325 Pa, T = 20 řC, RH = 50 , and CO_2 = 450 ppm, compute $n - 1$. Return a single number: the value (dimensionless), rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 2.7132E-4 **w.o.wolfTool Answer:** 2.6894E-4 **w.wolfTool Answer:** 2.7139E-4

Problem Q4. Using the IAPWS-IF97 formulation for water/steam, compute the specific enthalpy of water at p = 15 MPa and T = 650 K (single-phase state as appropriate). Return a single number: the value in $kJkg^{-1}$, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 2.8686E+3 **w.o.wolfTool Answer:** 3.0462E+3 **w.wolfTool Answer:** 2.8690E+3

Problem Q5. Using NIST X-ray transition energies (or equivalent), determine the photon energy of the copper $\kappa\alpha_1\ (KL_3)$ line for elemental Cu at ambient conditions. Return a single number: the value in keV, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 8.0478E+0 **w.o.wolfTool Answer:** 8.0463E+0 **w.wolfTool Answer:** 8.0478E+0

Problem Q6. Using the IGRF 13th generation (epoch 2025.0), compute the total geomagnetic field magnitude at (40.0140ř N, 105.2705ř W, altitude 1624 m) on 2025-01-01 00:00 UTC. Return a single number: the value in nT, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 5.1321E+4 **w.o.wolfTool Answer:** 4.9726E+4 **w.wolfTool Answer:** 5.1300E+4

Problem Q7. Using CODATA-2022 fundamental constants, compute the rest frequency of the neutral hydrogen 21 cm hyperfine transition (ground-state spin-flip). Return a single number: the value in Hz, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 1.4204E+9 **w.o.wolfTool Answer:** 1.4228E+9 **w.wolfTool Answer:** 1.4204E+9

Problem Q8. Using the NIST ESTAR database (or equivalent), determine the mass stopping power of aluminum (Al) for electrons of kinetic energy 1.000 MeV. Return a single number: the value in $MeVcm^2g^{-1}$, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

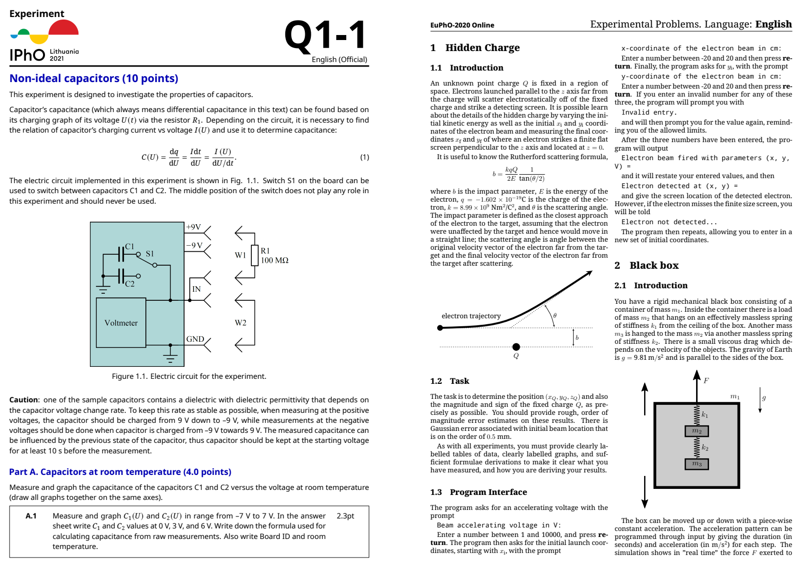
GT Answer: 1.4860E+0 **w.o.wolfTool Answer:** 1.5980E+0 **w.wolfTool Answer:** 1.5980E+0

Problem Q9. Using JANAF/NIST thermochemical data (ideal-gas heat capacities), determine the molar heat capacity at constant pressure, C_p, of nitrogen gas (N_2) at T = 1200 K (assume thermally perfect ideal gas, no dissociation). Return a single number: the value in $Jmol^{-1}K^{-1}$, rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 3.3723E+1 **w.o.wolfTool Answer:** 3.3540E+1 **w.wolfTool Answer:** 3.3724E+1

Problem Q10. For Beijing, China (39.9042ř N, 116.4074ř E, elevation 50 m), determine the umbral magnitude of the next lunar eclipse after 2025-08-09 that is at least partially visible from that location. Return a single number: the umbral magnitude (dimensionless), rounded to exactly 5 significant digits, in scientific notation. Do not include units or extra text.

GT Answer: 1.3638E+0 **w.o.wolfTool Answer:** 1.1510E+0 **w.wolfTool Answer:** 1.3680E+0



Experiment

IPhO Lithuania 2021

Q1-1

English (Official)

Non-ideal capacitors (10 points)

This experiment is designed to investigate the properties of capacitors.

Capacitor's capacitance (which always means differential capacitance in this text) can be found based on its charging graph of its voltage $U(t)$ via the resistor R_1. Depending on the circuit, it is necessary to find the relation of capacitor's charging current vs voltage $I(U)$ and use it to determine capacitance:

$$C(U) = \frac{dq}{dU} = \frac{I dt}{dU} = \frac{I(U)}{dU/dt}. \quad (1)$$

The electric circuit implemented in this experiment is shown in Fig. 1.1. Switch S1 on the board can be used to switch between capacitors C1 and C2. The middle position of the switch does not play any role in this experiment and should never be used.

Figure 1.1. Electric circuit for the experiment.

Caution: one of the sample capacitors contains a dielectric with dielectric permittivity that depends on the capacitor voltage change rate. To keep this rate as stable as possible, when measuring at the positive voltages, the capacitor should be charged from 9 V down to –9 V, while measurements at the negative voltages should be done when capacitor is charged from –9 V towards 9 V. The measured capacitance can be influenced by the previous state of the capacitor, thus capacitor should be kept at the starting voltage for at least 10 s before the measurement.

Part A. Capacitors at room temperature (4.0 points)

Measure and graph the capacitance of the capacitors C1 and C2 versus the voltage at room temperature (draw all graphs together on the same axes).

A.1	Measure and graph $C_1(U)$ and $C_2(U)$ in range from –7 V to 7 V. In the answer sheet write C_1 and C_2 values at 0 V, 3 V, and 6 V. Write down the formula used for calculating capacitance from raw measurements. Also write Board ID and room temperature.	2.3pt

EuPhO-2020 Online | Experimental Problems. Language: **English**

1 Hidden Charge

1.1 Introduction

An unknown point charge Q is fixed in a region of space. Electrons launched parallel to the z axis far from the charge will scatter electrostatically off of the fixed charge and strike a detecting screen. It is possible learn about the details of the hidden charge by varying the initial kinetic energy as well as the initial x_i and y_i coordinates of the electron beam and measuring the final coordinates x_f and y_f of where an electron strikes a finite flat screen perpendicular to the z axis and located at $z = 0$.

It is useful to know the Rutherford scattering formula,

$$b = \frac{kqQ}{2E}\frac{1}{\tan(\theta/2)}$$

where b is the impact parameter, E is the energy of the electron, $q = -1.602 \times 10^{-19}$C is the charge of the electron, $k = 8.99 \times 10^9$ Nm²/C², and θ is the scattering angle. The impact parameter is defined as the closest approach of the electron to the target, assuming that the electron were unaffected by the target and hence would move in a straight line; the scattering angle is angle between the original velocity vector of the electron far from the target and the final velocity vector of the electron far from the target after scattering.

1.2 Task

The task is to determine the position (x_Q, y_Q, z_Q) and also the magnitude and sign of the fixed charge Q, as precisely as possible. You should provide rough, order of magnitude error estimates on these results. There is Gaussian error associated with initial beam location that is on the order of 0.5 mm.

As with all experiments, you must provide clearly labelled tables of data, clearly labelled graphs, and sufficient formulae derivations to make it clear what you have measured, and how you are deriving your results.

1.3 Program Interface

The program asks for an accelerating voltage with the prompt

```
Beam accelerating voltage in V:
```

Enter a number between 1 and 10000, and press **return**. The program then asks for the initial launch coordinates, starting with x_i, with the prompt

```
x-coordinate of the electron beam in cm:
```

Enter a number between -20 and 20 and then press **return**. Finally, the program asks for y_i, with the prompt

```
y-coordinate of the electron beam in cm:
```

Enter a number between -20 and 20 and then press **return**. If you enter an invalid number for any of these three, the program will prompt you with

```
Invalid entry.
```

and will then prompt you for the value again, reminding you of the allowed limits.

After the three numbers have been entered, the program will output

```
Electron beam fired with parameters (x, y, V) =
```

and it will restate your entered values, and then

```
Electron detected at (x, y) =
```

and give the screen location of the detected electron. However, if the electron misses the finite size screen, you will be told

```
Electron not detected...
```

The program then repeats, allowing you to enter in a new set of initial coordinates.

2 Black box

2.1 Introduction

You have a rigid mechanical black box consisting of a container of mass m_1. Inside the container there is a load of mass m_2 that hangs on an effectively massless spring of stiffness k_1 from the ceiling of the box. Another mass m_3 is hanged to the mass m_2 via another massless spring of stiffness k_2. There is a small viscous drag which depends on the velocity of the objects. The gravity of Earth is $g = 9.81$ m/s² and is parallel to the sides of the box.

The box can be moved up or down with a piece-wise constant acceleration. The acceleration pattern can be programmed through input by giving the duration (in seconds) and acceleration (in m/s²) for each step. The simulation shows in "real time" the force F exerted to

Figure 5: Left: an instrument-based experiment example (IPhO 2021 experiment problem 1); Right: a program-based experiment example (EuPhO 2020 experiment problem 1). For IPhO 2021 experiment problem 1, a circuit board with electronic components to be measured inside it is provided, where contestants have to conduct measurements for these components: **this instrument-based experiment requires contestants to appropriately conduct manipulations on real experiment instruments, which is not tested in program-based experiments.** For EuPhO 2020 experiment problem 1, a program simulates experiments about detecting unknown charge with electron beams, similar to the Rutherford scattering experiment: **this program-simulated experiment is more related to modern physics, and it is impractical in a typical Olympiad venue due to cost and safety constraints.**

E Example of Instrument-based and Program-based experiments

We provide two examples of Instrument-based and Program-based experiments, as shown in Figure 5: the instrument-based experiment is IPhO 2021 experiment problem 1; and the program-based experiment is EuPhO 2020 experiment problem 1.

As shown and described in the caption of Figure 5, the program-based experiment can be more related to modern physics and bypasses the difficulties of cost and safety issues, although they are less real compared to instrument-based experiments.

F Related Work

F.1 Task Solving Agents

Since LLMs were shown to be capable of performing a wide range of tasks with appropriate prompts [30], researchers have been trying to enhance their capability and integration with tasks through prompt-based methods and tools. The concept of agent systems was then developed, exemplified by ReAct [17], in which LLMs iterate between reasoning and tool calls to perform more complicated tasks [31]. Later, agent-specific codebases have appeared: autogen [32] provides framework for creating multi-agent systems; smolagents [24] focuses more on code-related problem solving with defined domains. Upon these systems are more complicated general-purpose agent systems: for example, tool-creating agents like Alita [19] focus on creating and using tools for complex tasks with self-improvement; products like Openai Deep Research [33] and manus [34] focus on providing reliable research results to users. There has also been work focusing on optimizing the cost efficiency and effectiveness of agent systems [35, 36, 37]. These agent systems are mainly designed for general purpose tasks, with a focus on general virtual assistant related tasks represented by GAIA [21].

In addition to these general purpose agents, there is a growing body of work on domain-specific agents. For example, for math problems, some work has discussed the potential pipeline-based LLM approaches to mathematical problem solving [22, 25, 38]; for the humanities domain, HistAgent [23] introduces domain-specific high quality benchmarks and specially designed agent systems targeted at historical reasoning; for human-computer interaction and mental health, EmoAgent [39] studies the impact of LLM-based chat systems on users' mental health, and proposes agent-based methods to monitor users' mental states and ensure safer human-AI interactions. These domain-specific agents show the potential of agent systems in solving professional tasks requiring specialized domain knowledge; however, previous work rarely focuses on solving expert physics problems with agent systems.

F.2 Olympiads as Benchmarks

Olympiad competitions (e.g. IMO, IPhO, etc.) are widely regarded as challenging even to domain experts, and have been seen as challenging benchmarks for LLMs. Recent work shows progress in Math Olympiad problems, with both natural-language-based pipelines [25] and formal-language-based provers [26, 40].

Physics Olympiads have gradually drawn more attention in recent years as benchmarks for LLMs [11, 10, 12, 41, 42]. OlympiadBench [11] collects Olympiad problems across subjects, including physics. In 2025, SeePhysics [10] collects physics problems with images. Most benchmarks use publicly available problems from past Olympiads (e.g., prior IPhO problems). In contrast, PhyBench [12] curates an 'entirely original' dataset, aiming to minimize data leakage; it excludes images. Some other datasets, represented by PhysicsArena [42] and PhysReason [43], feature solutions with detailed reasoning processes. These benchmarks, though some contain problems that require image-related physics abilities, some require a high level of professional knowledge, and some require complicated reasoning and calculation, are primarily designed for nonagentic single-LLM settings.

G Discussions

G.1 Physics Experimental Exams: Instrument-based Exam and Program-based Exam as Proxies for Research-level Physics Experiments

Experiments are foundational to physics research [44]. In Physics Olympiads,**experimental exams** have served as proxies for research-level physics investigations. There are two common formats of Physics Olympiad experimental exams: **instrument-based Experiments** and **program-based Experiments**[5]. For the former, contestants are provided with (sometimes simplified) instruments and

[5]Most Physics Olympiads use instrument-based experiments, for example, current IPhO, APhO, EuPhO, etc. During the pandemic, some Olympiads utilize program-based experiments, for example, APhO 2021, EuPhO 2020, EuPhO 2021, etc.

are asked to plan and carry out experiments and measurements; for the latter, contestants design and carry out simulated experiments with programs, followed by data analysis.

In this work, we mainly focus on the IPhO 2025 Theory Problems, rather than the instrument-based experimental problems. This limitation is caused in part by limited access to the experiment instruments. We hope with advances in robotics future LLM-based agents may also work on these experimental exams. Moreover, we argue that program-based exams could also serve as good proxies for benchmarking current and near-future AI's ability in research-level experiments. Although instrument-based experiments are closer to real-world researches, there are **two aspects** where program-based experiments are potentially better:

Program-based experimental exams can simulate more advanced and complex experiments compared to instrument-based exams. For instrument-based exams, contestants have to design experiments, conduct manual operations and measurements, process data and answer questions. For program-based experiments, contestants run simulated experiments through programs: While manual experimentation is no longer required, critical challenges like experimental design and data analysis continue to play a central role in program-based assessments. One big advantage is that the program-based exams can access experiments that are more complex or require more sophisticated designing, because they are not limited by cost, safety concerns and other limiting factors for instrument-based experiments. We provide two examples for instrument-based experiments and program-based experiments in Figure 5, shown in Appendix E.

Program-based experimental exams can shift the focus from testing robotic manipulation of instruments to evaluating the ability in "physics". There has been work using robotic systems for implementing experiments in physics [45]; however, in all, current AI systems still fall short in conducting robotic tasks for manipulating instruments in experiments. This critical challenge will be addressed with advances in robotics research. With program-based experiments, we hope that in the near future one can already better evaluate essential abilities of AI systems in experimental physics.

We also emphasize that while program-based experiments have potential advantages in benchmarking AI's capability in experimental physics, the instrument-based tests are certainly essential ultimately. As AI systems advance toward ASI and daily use, one should not overlook the importance of instrument-based tests as they (1) yield a smaller deviation from real-world research; (2) provide a better metric for characterizing robotic capability; and (3) evaluate the performance better under extreme or unexpected conditions like instrument failure, etc.

G.2 Verifiable Physics Reasoning

In this work, we utilize an answer reviewer tool to verify the deductions of the worker, which is based purely on natural language. A huge step in automatic math proofs are **verifiable LLM-generated proofs** written in Lean [46]. Some previous work proposes to use Lean-like tools for verifiable physics formula deductions [47, 48]. However, the process of deriving physics formulas from natural-language-based problems, whether grounded in theoretical models or experimental observations, currently lacks reliable automatic verification through comparable processes. This limitation remains an open area for further research. Promising directions for future exploration include: (1) developing methods to verify the abstraction and transformation between formulas, physical representations, and intuitive reasoning; (2) establishing a more rigorous and transparent calculation framework that supports verifiability; and (3) enhancing answer-review systems with tools that possess broader and deeper expertise in physics.

The first direction represents a big challenge in symbolic AI [49]. In relation to developing verifiable physics calculations, extensive work has been done on machine-checked mathematics in Lean-like languages [50]. For example, Deepseek-Prover, Kimina-Prover and AlphaProof [51, 52, 38] use RL-based methods to train LLMs that excel in generating lean-based proofs. Others discuss test-time scaling methods through pipeline workflows [53, 54, 55]. Future work for solving physics problems might adopt similar methods to improve the ability to generate reliable and verifiable solutions.

In summary, we suggest future work on using AI systems for physics problem-solving to focus on: (1) program-based or instrument-based experiments; and (2) verifiable and reliable solution generation.