A Detailed Statistics of the Benchmark

A.1 Distribution of Problems

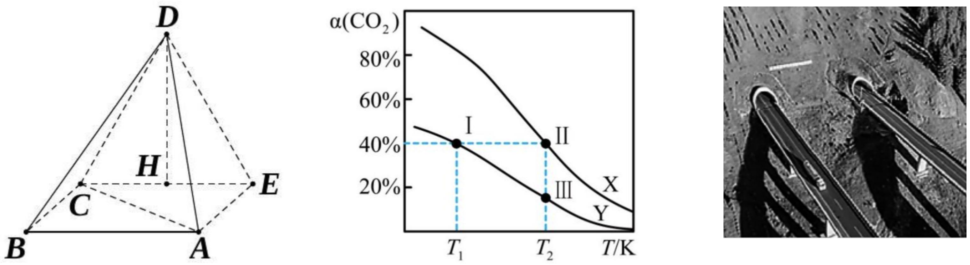
Our benchmark collects data from various competitions. The detailed list can be found in Table 4. Note that a small portion of the problems are sampled from other related benchmarks which are marked in the table. The subfields covered by each competition subject are shown in Table 5. Additionally, the distribution information of our benchmark across different languages and modalities is presented in Table 6.

A.2 Answer Types

Through extensive observation of a large number of problems and a thorough examination of multiple previous benchmarks, we have finally distilled 13 comprehensive answer types. These types are designed to cover as many problems as possible. The specific definitions for each answer type are provided in Table 7.

A.3 Image Types

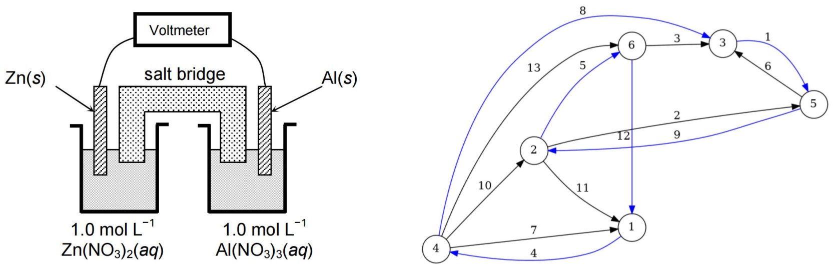
We categorize and summarize the five most common types of images in our multimodal scientific problems. The definitions of these types can be found in Table 8, and examples are provided in Figure 5. The distribution of different image types in our benchmark is shown in Figure 6.



Geometric and Mathematical Diagrams

Statistical and Data Representation

Natural and Environmental Images


Voltmeter
salt bridge
Zn(s)
Al(s)
1.0 mol L^{-1} Zn(NO$_3$)$_2$(aq)
1.0 mol L^{-1} Al(NO$_3$)$_3$(aq)
8
13
5
3
1
6
2
12
9
10
11
7
4

Scientific and Technical Diagrams

Abstract and Conceptual Visuals

Figure 5: Examples of Image Types

Table 4: List of competitions included in OlympicArena. Competitions marked with * are partially sourced from OlympiadBench [17], and those marked with † are partially sourced from MMcode [27].

Competition Name	**Abbreviation**	**Subject**	**# Problems**
UK Senior Kangaroo	UKMT_SK	Math	20
Math Majors of America Tournament for High Schools	MMATHS	Math	47
Math Kangaroo	MK	Math	35
Euclid Mathematics Contest	EMC	Math	215
Canadian Open Mathematics Challenge	COMC	Math	26
Johns Hopkins Mathematics Tournament	JHMT	Math	100
Berkeley Math Tournament	BMT	Math	93
Stanford Mathematics Tournament	SMT	Math	473
Chinese High School Mathematics League (Pre Round)	ZH_Math_PRE	Math	546
Chinese High School Mathematics League (1st&2nd Round)	ZH_Math_12	Math	279
Duke University Math Meet	DMM	Math	107
The Princeton University Mathematics Competition	PUMaC	Math	296
Harvard-MIT Mathematics Tournament	HMMT	Math	392
William Lowell Putnam Mathematics Competition	Putnam	Math	136
International Mathematical Olympiad*	IMO	Math	79
Romanian Master of Mathematics*	RMM	Math	8
American Regions Mathematics League*	ARML	Math	374
Euclid Mathematics Competition*	EMC	Math	215
European Girls' Mathematical Olympiad*	EGMO	Math	7
F=MA	FMA	Physics	122
Intermediate Physics Challenge (Y11)	BPhO_IPC	Physics	50
Senior Physics Challenge	BPhO_SPC	Physics	38
Australian Science Olympaids Physics	ASOP	Physics	48
European Physics Olympiad	EPhO	Physics	15
Nordic-Baltic Physics Olympiad	NBPhO	Physics	102
World Physics Olympics	WoPhO	Physics	38
Asian Physics Olympiad	APhO	Physics	126
International Physics Olympiad	IPhO	Physics	307
Canadian Association of Physicists	CAP	Physics	100
Physics Bowl	PB	Physics	100
USA Physics Olympiad	USAPhO	Physics	188
Chinese Physics Olympiad	CPhO	Physics	462
Physics Challenge (Y13)	PCY13	Physics	44
Chinese High School Biology Challenge	GAOKAO_Bio	Biology	652
International Biology Olympiad	IBO	Biology	300
The USA Biology Olympiad	USABO	Biology	96
Indian Biology Olympiad	INBO	Biology	86
Australian Science Olympiad Biology	ASOB	Biology	119
British Biology Olympiad	BBO	Biology	82
New Zealand Biology Olympiad	NZIBO	Biology	223
Chem 13 News	Chem13News	Chemistry	56
Avogadro	Avogadro	Chemistry	55
U.S. National Chemistry Olympiad (local)	USNCO (local)	Chemistry	54
U.S. National Chemistry Olympiad	USNCO	Chemistry	98
Chinese High School Chemistry Challenge	GAOKAO_Chem	Chemistry	568
Canadian Chemistry Olympic	CCO	Chemistry	100
Australian Science Olympiad Chemistry	ASOC	Chemistry	91
Cambridge Chemistry Challenge	C3H6	Chemistry	61
UK Chemistry Olympiad	UKChO	Chemistry	100
International Chemistry Olympiad	IChO	Chemistry	402
Chinese High School Geography Challenge	GAOKAO_Geo	Geography	862
US Earth Science Organization	USESO	Geography	301
Australian Science Olympiad Earth Science	ASOE	Geography	100
The International Geography Olympaid	IGeO	Geography	327
Chinese High School Astronomy Challenge	GAOKAO_Astro	Astronomy	740
The International Astronomy and Astrophysics Competition	IAAC	Astronomy	50
USA Astronomy and Astrophysics Organization	USAAAO	Astronomy	100
British Astronomy and Astrophysics Olympaid Challenge	BAAO_challenge	Astronomy	148
British Astronomy and Astrophysics Olympaid-round2	BAAO	Astronomy	185
USA Computing Olympiad	USACO	CS	48
Atcoder	Atcoder	CS	48
Codeforces†	CF	CS	138

Table 5: Subfields of each subject included in OlympicArena.

Subject	**Subfields**
Math	Algebra, Geometry, Number Theory, Combinatorics
Physics	Mechanics, Electricity and Magnetism, Waves and Optics, Thermodynamics, Modern Physics, Fluid Mechanics
Chemistry	General Chemistry, Organic Chemistry, Inorganic Chemistry, Analytical Chemistry, Physical Chemistry, Environmental Chemistry
Biology	Cell biology, Plant Anatomy and Physiology, Animal Anatomy and Physiology, Ethology, Genetics and Evolution, Ecology , Biosystematics
Geography	Physical Geography, Human Geography, Regional Geography, Environmental Geography, Geospatial Techniques
Astronomy	Fundamentals of Astronomy, Stellar Astronomy, Galactic and Extragalactic Astronomy, Astrophysics
CS	Data Structures, Algorithm

Table 6: Statistics of OlympicArena benchmark across different disciplines and modalities.

	Mathematics	**Physics**	**Chemistry**	**Biology**	**Geography**	**Astronomy**	**CS**
EN & text	2215	632	782	352	211	219	90
EN & multi-modal	193	646	235	554	517	264	144
ZH & text	780	164	124	312	58	264	0
ZH & multi-modal	45	298	444	340	804	476	0
Total EN	2408	1278	1017	906	728	483	234
Total ZH	825	462	568	652	862	740	0
Total text	2995	796	906	664	269	483	90
Total multi-modal	238	944	679	894	1321	740	144
Grand Total	3233	1740	1585	1558	1590	1223	234

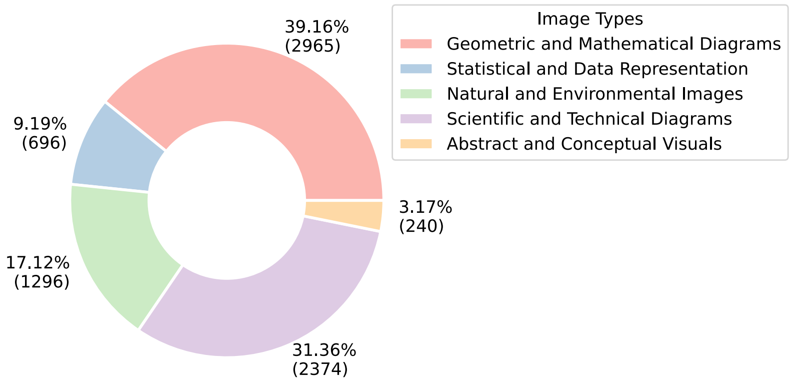


Figure 6: Distribution of Image Types

Table 7: Answer Types and Definitions

Answer Type	**Definition**
Single Choice (SC)	Problems with only one correct option (e.g., one out of four, one out of five, etc.).
Multiple-choice (MC)	Problems with multiple correct options (e.g., two out of four, two out of five, two out of six, etc.).
True/False (TF)	Problems where the answer is either True or False.
Numerical Value (NV)	Problems where the answer is a numerical value, including special values like π, e, $\sqrt{7}$, $\log_2 9$, etc., represented in LaTeX.
Set (SET)	Problems where the answer is a set, such as $\{1, 2, 3\}$.
Interval (IN)	Problems where the answer is a range of values, represented as an interval in LaTeX.
Expression (EX)	Problems requiring an expression containing variables, represented in LaTeX.
Equation (EQ)	Problems requiring an equation containing variables, represented in LaTeX.
Tuple (TUP)	Problems requiring a tuple, usually representing a pair of numbers, such as (x, y).
Multi-part Value (MPV)	Problems requiring multiple quantities to be determined within a single sub-problem, such as solving both velocity and time in a physics problem.
Multiple Answers (MA)	Problems with multiple solutions for a single sub-problem, such as a math fill-in-the-blank problem with answers 1 or -2.
Code Generation (CODE)	Problems where the answer is a piece of code, requiring the generation of functional code snippets or complete programs to solve the given task.
Others (OT)	Problems that do not fit into the above categories, such as writing chemical equations or explaining reasons, which require human expert evaluation.

Table 8: Definitions and examples of five image types in our multi-modal scientific problems.

Image Type	**Definition**
Geometric and Mathematical Diagrams	Includes diagrams representing mathematical concepts, such as 2D and 3D shapes, mathematical notations, function plots.
Statistical and Data Representation	Visualizations for statistical or data information, including multivariate plots, tables, charts (histograms, bar charts, line plots), and infographics.
Natural and Environmental Images	Images of natural scenes or phenomena, including environmental studies visualizations, geological and geographical maps, and satellite images.
Scientific and Technical Diagrams	Diagrams used in science, such as cell structures and genetic diagrams in Biology, molecular structures and reaction pathways in Chemistry, force diagrams, circuit diagrams, and astrophysical maps in Physics and Astronomy.
Abstract and Conceptual Visuals	Visuals explaining theories and concepts, including flowcharts, algorithms, logic models, and symbolic diagrams.

B Data Annotation

B.1 Problem Extraction and Annotation

We develop a simple and practical annotation interface using Streamlit[11] (as shown in Figure 7). Approximately 30 university students are employed to use this interface for annotation. We provide each annotator with a wage higher than the local average hourly rate. The specific fields annotated are shown in Figure 8. We use image URLs to represent pictures, which allows for efficient storage and easy access without embedding large image files directly in the dataset. Each annotated problem is ultimately stored as a JSON file, facilitating subsequent processing. It is worth mentioning that we embed several rule-based checks and filtering mechanisms in the annotation interface to minimize noise from the annotations. When the following situations arise, we promptly identify and correct the annotations:

1) When the answer type is **Numerical Value**, and the annotated answer contains a variable.

2) When the answer type is not **Numerical Value**, but the annotated answer can be parsed as a numerical value.

3) When the answer type is **Expression**, and the annotated answer contains an equals sign.

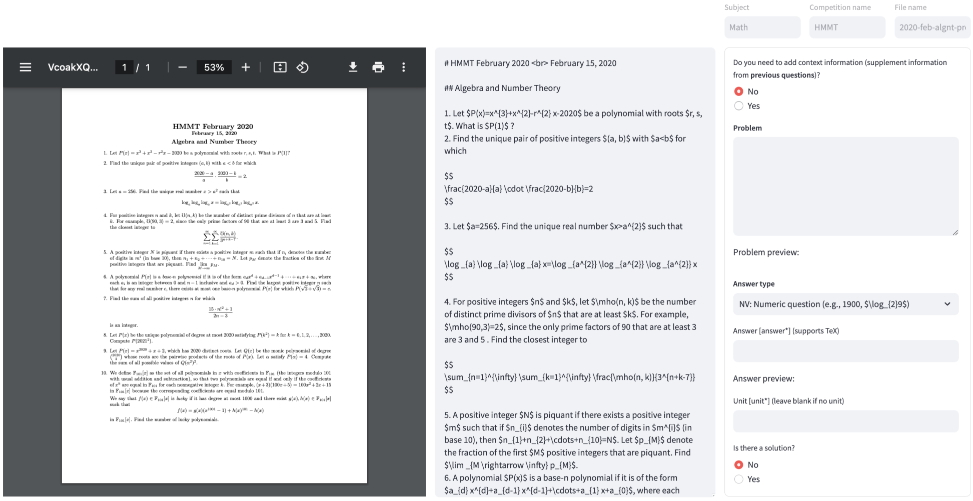
4) When the answer type is **Equation**, and the annotated answer does not contain an equals sign.

5) When the annotated answer contains images that should not be present.

6) When the annotated answer contains units (since units are a separate field according to Figure 8, we compile a list of common units and manually check and correct answers when suspected units are detected).

7) When the annotated image links cannot be previewed properly.

Additionally, we implement a multi-step validation process after the initial annotation is completed. First, we conduct a preliminary check using predefined rules to identify any error data, which is then corrected. Following this, a secondary review is performed by different annotators to further check and correct any errors in the annotations. This cross-checking mechanism helps ensure the accuracy and consistency of the annotations.



```
# HMMT February 2020 <br> February 15, 2020

## Algebra and Number Theory

1. Let $P(x)=x^{3}+x^{2}-r^{2} x-2020$ be a polynomial with roots $r, s, t$. What is $P(1)$ ?
2. Find the unique pair of positive integers $(a, b)$ with $a<b$ for which

$$
\frac{2020-a}{a} \cdot \frac{2020-b}{b}=2
$$

3. Let $a=256$. Find the unique real number $x>a^{2}$ such that

$$
\log _{a} \log _{a} \log _{a} x=\log _{a^{2}} \log _{a^{2}} \log _{a^{2}} x
$$

4. For positive integers $n$ and $k$, let $\mho(n, k)$ be the number of distinct prime divisors of $n$ that are at least $k$. For example, $\mho(90,3)=2$, since the only prime factors of 90 that are at least 3 are 3 and 5 . Find the closest integer to

$$
\sum_{n=1}^{\infty} \sum_{k=1}^{\infty} \frac{\mho(n, k)}{3^{n+k-7}}
$$

5. A positive integer $N$ is piquant if there exists a positive integer $m$ such that if $n_{i}$ denotes the number of digits in $m^{i}$ (in base 10), then $n_{1}+n_{2}+\cdots+n_{10}=N$. Let $p_{M}$ denote the fraction of the first $M$ positive integers that are piquant. Find $\lim _{M \rightarrow \infty} p_{M}$.
6. A polynomial $P(x)$ is a base-n polynomial if it is of the form $a_{d} x^{d}+a_{d-1} x^{d-1}+\cdots+a_{1} x+a_{0}$, where each
```

Subject: Math
Competition name: HMMT
File name: 2020-feb-algnt-pr

Do you need to add context information (supplement information from **previous questions**)?
● No
○ Yes

Problem

Problem preview:

Answer type
NV: Numeric question (e.g., 1900, $\log_{2}9$)

Answer [answer*] (supports TeX)

Answer preview:

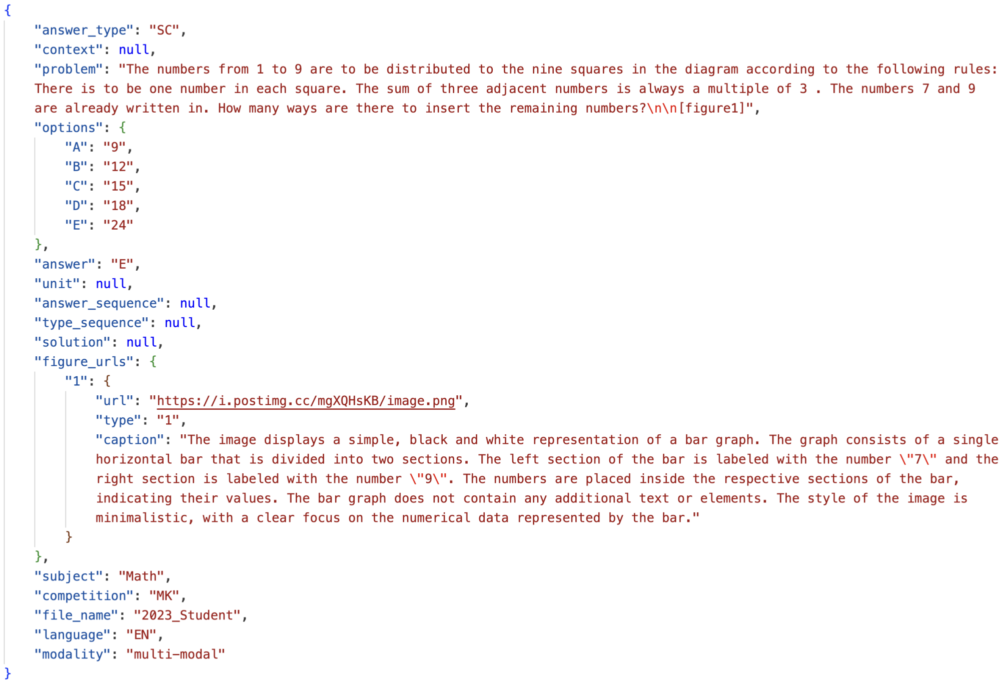
Unit [unit*] (leave blank if no unit)

Is there a solution?
● No
○ Yes

Figure 7: Annotation Page

---

[11] https://streamlit.io/



```
{
    "answer_type": "SC",
    "context": null,
    "problem": "The numbers from 1 to 9 are to be distributed to the nine squares in the diagram according to the following rules:
    There is to be one number in each square. The sum of three adjacent numbers is always a multiple of 3 . The numbers 7 and 9
    are already written in. How many ways are there to insert the remaining numbers?\n\n[figure1]",
    "options": {
        "A": "9",
        "B": "12",
        "C": "15",
        "D": "18",
        "E": "24"
    },
    "answer": "E",
    "unit": null,
    "answer_sequence": null,
    "type_sequence": null,
    "solution": null,
    "figure_urls": {
        "1": {
            "url": "https://i.postimg.cc/mgXQHsKB/image.png",
            "type": "1",
            "caption": "The image displays a simple, black and white representation of a bar graph. The graph consists of a single
            horizontal bar that is divided into two sections. The left section of the bar is labeled with the number \"7\" and the
            right section is labeled with the number \"9\". The numbers are placed inside the respective sections of the bar,
            indicating their values. The bar graph does not contain any additional text or elements. The style of the image is
            minimalistic, with a clear focus on the numerical data represented by the bar."
        }
    },
    "subject": "Math",
    "competition": "MK",
    "file_name": "2023_Student",
    "language": "EN",
    "modality": "multi-modal"
}
```

Figure 8: Example of a json-formatted representation of an annotated problem.

B.2 Annotation for Difficulty Levels

The definitions of three levels of difficulty are as follows:

1) **Knowledge Recall:** This involves the direct recall of factual information and well-defined procedures. It examines the memory of simple knowledge points, i.e., whether certain information is known.

2) **Concept Application:** This category covers the very basic use of simple concepts to solve easy problems or perform straightforward calculations. It involves applying known information to situations without any complex or multi-step reasoning. The focus is on straightforward application rather than reasoning.

3) **Cognitive Reasoning:** This involves the use of logical reasoning or visual reasoning to solve problems. It includes problems that require clear thinking and problem-solving techniques. It focuses on the ability to reason and analyze to understand and address the issues.

The prompt we use for categorizing each problem is shown in Figure 9.

B.3 Cognitive Reasoning Abilities Annotation

We provide detailed definitions for each of these cognitive reasoning abilities.

The logical reasoning abilities:

1) **Deductive Reasoning** involves starting with a general principle or hypothesis and logically deriving specific conclusions. This process ensures that the conclusion necessarily follows from the premises.

2) **Inductive Reasoning** involves making broad generalizations from specific observations. This type of reasoning infers general principles from specific instances, enhancing our confidence in the generality of certain phenomena.

Problem description:
{problem}

Answer:
{answer}

Solution:
{solution}*

Classification Categories:
1. Knowledge Recall: Direct recall of factual information and well-defined procedures. This category examines the memory of simple knowledge points, i.e., whether certain information is known.
2. Concept Application: Very basic use of simple concepts to solve easy problems or do straightforward calculations. This involves applying known information to situations without any complex or multi-step reasoning. The focus is on straightforward application rather than reasoning.
3. Cognitive Reasoning: Use of logical reasoning or visual reasoning to solve problems. This category includes problems that require clear thinking and problem-solving techniques. It focuses on the ability to reason and analyze to understand and address the issues.

Instructions for Classification: Please classify the above problem by selecting the most appropriate category that best represents the type of thinking and approach required to address the problem. Consider the complexity, the need for creativity, and the depth of knowledge required. You should conclude your response with "So, the problem can be categorized as $\boxed{ANSWER}$.", where ANSWER should be one of the indexes in 1, 2, 3.

Figure 9: The prompt template used for annotating the difficulty level of problems. The "solution" part marked with * is optional.

3) **Abductive Reasoning** starts with incomplete observations and seeks the most likely explanation. It is used to form hypotheses that best explain the available data.

4) **Analogical Reasoning** involves using knowledge from one situation to solve problems in a similar situation by drawing parallels.

5) **Cause-and-Effect Reasoning** identifies the reasons behind occurrences and their consequences. This reasoning establishes causal relationships between events.

6) **Critical Thinking** involves objectively analyzing and evaluating information to form a reasoned judgment. It encompasses questioning assumptions and considering alternative explanations.

7) **Decompositional Reasoning** breaks down complex problems or information into smaller, more manageable parts for detailed analysis.

8) **Quantitative Reasoning** involves using mathematical skills to handle quantities and numerical concepts, essential for interpreting data and performing calculations.

The visual reasoning abilities:

1) **Pattern Recognition** is the ability to identify and understand repeating forms, structures, or recurring themes, especially when presented visually. This skill is critical in subjects like Chemistry for recognizing molecular structures, Biology for identifying cellular components, and Geography for interpreting topographic maps.

2) **Spatial Reasoning** is the ability to understand objects in both two and three-dimensional terms and draw conclusions about them with limited information. This skill is often applied in subjects like Math.

Table 9: LMMs and their corresponding LLMs.

LMM	LLM
GPT-4o	GPT-4o
GPT-4v	GPT-4
Claude3 Sonnet	Claude3 Sonnet
Gemini Pro Vision	Gemini Pro
LLaVA-NeXT-34B	Nous-Hermes-2-Yi-34B
InternVL-Chat-V1.5	InternLM2-20B-Chat
Yi-VL-34B	Yi-34B-Chat
Qwen-VL-Chat	Qwen-7B-Chat

Two-Dimensional Examples: Plane geometry, segments, lengths.

Three-Dimensional Examples: Solid geometry, spatial visualization

3) **Diagrammatic Reasoning** represents the capability to solve problems expressed in diagrammatic form, understanding the logical connections between shapes, symbols, and texts.

Examples: Reading various forms of charts and graphs, obtaining and analyzing statistical information from diagrams.

4) **Symbol Interpretation** is the ability to decode and understand abstract and symbolic visual information. Examples: Understanding abstract diagrams, interpreting symbols, including representations of data structures such as graphs and linked lists

5) **Comparative Visualization** represents comparing and contrasting visual elements to discern differences or similarities, often required in problem-solving to determine the relationship between variable components.

The prompt we use for annotating different logical reasoning abilities and visual reasoning abilities are shown separately in Figure 10 and Figure 11.

C Experiment Details

C.1 Prompt for Image Caption

The prompt we use for captioning each image in the benchmark for LMMs is shown in Figure 12.

C.2 Models

In our experiments, we evaluate a range of both open-source and proprietary LMMs and LLMs. For LMMs, we select the newly released GPT-4o [36] and the powerful GPT-4V [1] from OpenAI. Additionally, we include Claude3 Sonnet [3] from Anthropic, and Gemini Pro Vision[12] [45] from Google, and Qwen-VL-Max [6] from Alibaba. We also evaluate several open-source models, including LLaVA-NeXT-34B [31], InternVL-Chat-V1.5 [12], Yi-VL-34B [55], and Qwen-VL-Chat [7]. For LLMs, we primarily select the corresponding text models of the aforementioned LMMs, such as GPT-4 [2]. Additionally, we include open-source models like Qwen-7B-Chat, Qwen1.5-32B-Chat [5], Yi-34B-Chat [55], and InternLM2-Chat-20B [8]. Table 9 shows the relationship between LMMs and their corresponding LLMs. For the proprietary models, we call the APIs, while for the open-source models, we run them on an 8-card A800 cluster.

---

[12] We do not test Gemini-1.5-pro [39] as there are significant rate limits on accessing the model's API during the time we do experiments.

Problem description:
{problem}

Answer:
{answer}

Solution:
{solution}*

You need to identify and select the specific types of logical reasoning abilities required to solve the question from the list provided below.

Logical Reasoning Abilities:

1. Deductive Reasoning: Deductive reasoning involves starting with a general principle or hypothesis and logically deriving specific conclusions. This process ensures that the conclusion necessarily follows from the premises.
2. Inductive Reasoning: Inductive reasoning involves making broad generalizations from specific observations. This type of reasoning infers general principles from specific instances, enhancing our confidence in the generality of certain phenomena.
3. Abductive Reasoning: Abductive reasoning starts with incomplete observations and seeks the most likely explanation. It is used to form hypotheses that best explain the available data.
4. Analogical Reasoning: Analogical reasoning involves using knowledge from one situation to solve problems in a similar situation by drawing parallels.
5. Cause-and-Effect Reasoning: Cause-and-effect reasoning identifies the reasons behind occurrences and their consequences. This reasoning establishes causal relationships between events.
6. Critical Thinking: Critical thinking involves objectively analyzing and evaluating information to form a reasoned judgment. It encompasses questioning assumptions and considering alternative explanations.
7. Decompositional Reasoning: Decompositional reasoning breaks down complex problems or information into smaller, more manageable parts for detailed analysis.
8. Quantitative Reasoning: Quantitative reasoning involves using mathematical skills to handle quantities and numerical concepts, essential for interpreting data and performing calculations.

Analyze the question, its answer and explanation (if provided) to determine which of the above reasoning abilities are necessary. Conclude by clearly stating which reasoning abilities are involved in solving the question using "So, the involved reasoning abilities are $\boxed{ABILITIES}$", where "ABILITIES" represents the numbers corresponding to the list above, separated by commas if multiple abilities are relevant.

Figure 10: The prompt template used for annotating different logical reasoning abilities of problems. The "solution" part marked with * is optional.

C.3 Evaluation Prompts

We meticulously design the prompts used for model input during experiments. These prompts are tailored to different answer types, with specific output formats specified for each type. The detailed prompt templates are shown in Figure 13, and the different instructions for each answer type are provided in Table 10.

C.4 Model Hyperparameters

For all models, we set the maximum number of output tokens to 2048 and the temperature to 0.0. When performing code generation **(CODE)** tasks, the temperature is set to 0.2.

Problem description:
{problem}

Answer:
{answer}

Solution:
{solution}*

You need to identify and select the specific types of visual reasoning abilities required to solve the question from the list provided below.

Visual Reasoning Abilities:

1. Pattern Recognition: The ability to identify and understand repeating forms, structures, or recurring themes, especially when presented visually. This skill is critical in subjects like Chemistry for recognizing molecular structures, Biology for identifying cellular components, and Geography for interpreting topographic maps.
2. Spatial Reasoning: Spatial reasoning is the ability to understand objects in both two and three-dimensional terms and draw conclusions about them with limited information. This skill is often applied in subjects like Math. Two-Dimensional Examples: Plane geometry, segments, lengths Three-Dimensional Examples: Solid geometry, spatial visualization
3. Diagrammatic Reasoning: The capability to solve problems expressed in diagrammatic form, understanding the logical connections between shapes, symbols, and texts. Examples: Reading various forms of charts and graphs, obtaining and analyzing statistical information from diagrams
4. Symbol Interpretation: The ability to decode and understand abstract and symbolic visual information. Examples: Understanding abstract diagrams, interpreting symbols, including representations of data structures such as graphs and linked lists
5. Comparative Visualization: Comparing and contrasting visual elements to discern differences or similarities, often required in problem-solving to determine the relationship between variable components.

Analyze the question, its answer, and any explanation provided to determine which of the above reasoning abilities are necessary. Conclude by clearly stating which reasoning abilities are involved in solving the question using "So, the involved reasoning abilities are $\boxed{ABILITIES}$", where "ABILITIES" represents the numbers corresponding to the list above, separated by commas if multiple abilities are relevant.

Figure 11: The prompt template used for annotating different visual reasoning abilities of problems which have multi-modal inputs. The "solution" part marked with * is optional.

C.5 Answer-level Evaluation Protocols

Rule-based Evaluation For problems with fixed answers, we extract the final answer enclosed in "\boxed{ }" (using prompts to instruct models to conclude their final answers with boxes) and perform rule-based matching according to the answer type.

1) For numerical value **(NV)** answers, we handle units by explicitly stating them in the prompts provided to the model, if applicable. During evaluation, we assess only the numerical value output by the model, disregarding the unit. In cases where numerical answers are subject to estimation, such as in physics or chemistry problems, we convert both the model's output and the correct answer to scientific notation. If the exponent of 10 is the same for both, we allow a deviation of 0.1 in the coefficient before the exponent, accounting for minor estimation errors in the model's calculations.

[Image]

Describe the fine-grained content of the image or figure, including scenes, objects, relationships, and any text present.

Figure 12: The prompt template used for image caption.

You are participating in an international {subject} competition and need to solve the following question.

{answer type description}

Here is some context information for this question, which might assist you in solving it: {context}*

Problem:
{problem}

All mathematical formulas and symbols you output should be represented with LaTeX. You can solve it step by step and please end your response with: {answer format instruction}.

Figure 13: The prompt template used for problem input. The "context" part marked with * is optional and refers to supplementary information provided during manual annotation when the problem relies on conclusions from previous questions. The {answer type description} and {answer format instruction} are specified in Table 10.

2) For problems where the answer type is an expression **(EX)** or an equation **(EQ)**, we use the SymPy[13] library for comparison. This allows us to accurately assess the equivalence of algebraic expressions and equations by symbolic computation.

3) For problems requiring the solution of multiple quantities **(MPV)**, our evaluation strictly follows the order of output specified in the prompt, ensuring consistency and correctness in the sequence of results.

4) In the case of problems with multiple answers **(MA)**, we require the model to output all possible answers, adequately considering various scenarios.

5) For problems where the answer type is an interval **(IN)**, we strictly compare the open and closed intervals as well as the boundary values of the endpoints.

6) For problems where the answer type is a set **(SET)**, we compare the set output by the model with the standard answer set to ensure they are completely identical. For problems where the answer type is a tuple **(TUP)**, we compare the tuple output by the model with the standard answer tuple to ensure that each corresponding position is exactly equal.

7) For code generation **(CODE)** problems, we extract the code output by the model and test it through all provided test cases. Specifically, we use the unbiased pass@k metric,

$$\text{pass}@k := \mathop{\mathbb{E}}_{\text{Problems}}\left[1 - \frac{\binom{n-c}{k}}{\binom{n}{k}}\right] \tag{1}$$

where we set $k = 1$ and $n = 5$, and c indicates the number of correct samples that pass all test cases.

---

[13] https://www.sympy.org/

Model-based Evaluation To deal with those problems with answer types that cannot be appropriately evaluated using rule-based matching, we employ model-based evaluation. In this approach, we utilize GPT-4V as the evaluator. We design prompts that include the problem, the correct answer, the solution (if provided), and the response from the model being tested (see Figure 14 for details). The evaluator model then judges the correctness of the tested model's response.

To further ensure the reliability of using a model as an evaluator, we uniformly sampled 100 problems across various subjects that involved model evaluation. We have several students with backgrounds in science and engineering independently conduct manual evaluations. It turns out that out of the 100 sampled problems, there is nearly 80% agreement between the human evaluations and the model evaluations. Considering that problems requiring model-based evaluation account for approximately 5% of the total, the error rate can be controlled at around $20\% \times 5\%$, which is approximately 1%. Therefore, we consider this method to be reliable.

> You are an experienced teacher tasked with grading an Olympic-level {subject} exam paper.
>
> The problem's context:
> {context}*
>
> Problem:
> {problem}
>
> The student's answer:
> {the tested model's response}
>
> The reference answer:
> {the reference answer}
>
> The reference solution:
> {the reference solution}*
>
> Note:
> (1) You can tolerate some markdown formatting issues.
> (2) You need to make judgments based on the provided reference answer and reference solution (if provided).
> You can analyze the answer step by step, and then output $\boxed{correct}$ or $\boxed{incorrect}$ at the end to express your final judgment.

Figure 14: The prompt used for model-based evaluation. The "context" and "the reference solution" parts marked with * are optional.

C.6 Process-level Evaluation Protocols

To conduct the process-level evaluation, we utilize a method based on GPT-4V. First, we reformat both the gold solution and the model-generated solution for the sampled problems into a neat step-by-step format using GPT-4. Then, we employ a carefully designed prompt(see Figure 15) to guide GPT-4V using the reformatted gold solution to evaluate the correctness of each step in the model's output, assigning a score of 0 for incorrect and 1 for correct steps. The final process-level score for each problem is determined by averaging the scores of all the steps.

You are a teacher skilled in evaluating the intermediate steps of a student's solution to a given problem.

You are given two types of step-by-step solutions: one from the reference answer and the other from the student. Your task is to evaluate the correctness of each step in the student's solutions using binary scoring: assign a score of 1 for correct steps and 0 for incorrect steps. Use the reference solutions to guide your evaluation.
Follow the format:
Step 1: ...
Step 2: ...
Step 3: ...
Please provide the results directly, omitting any introductory or concluding remarks.
# The given question

{the question}

# The reference solution

{the reference solution}

# The student's solution

{the model's solution}

# Your scores for each step of the student's solutions

Figure 15: The prompt used for process-level evaluation.

D Fine-grained Results

D.1 Results across Logical and Visual Reasoning Abilities

Table 11 and Table 12 show the performance of different models across various logical and visual reasoning abilities separately.

D.2 Results on Multimodal Problems

Table 13 shows the performance of different models on multimodal problems across different subjects.

D.3 Process-level Evaluation Results

Table 14 shows process-level results of different models across different subjects.

D.4 Results across Different Languages

Table 15 shows results of different models in different languages.

D.5 Error Analysis

We sample incorrect responses from GPT-4V (16 problems per subject, with 8 text-only and 8 multimodal) and have human evaluators analyze and annotate the reasons for these errors. As depicted in Figure 16, reasoning errors (both logical and visual) constitute the largest category, indicating that our benchmark effectively highlights the current models' deficiencies in cognitive reasoning abilities. Additionally, a significant portion of errors stem from knowledge deficits, suggesting that current models still lack expert-level domain knowledge and the ability to leverage this knowledge to assist

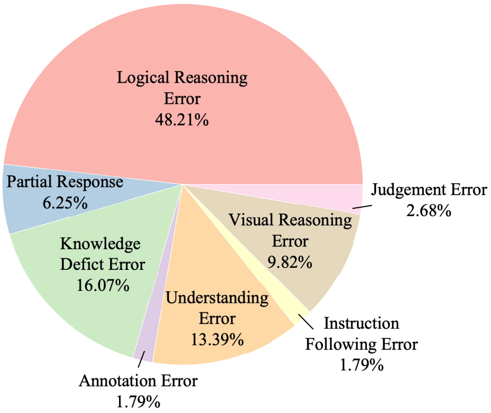


Figure 16: The distribution of error types of 112 sampled problems where GPT-4V makes errors.

in reasoning. Another category of errors arise from understanding biases, which can be attributed to the models' misinterpretation of context and difficulties in integrating complex language structures and multimodal information. More relevant cases are shown in Appendix F.1.

E Data Leakage Detection Details

We combine the questions and detailed solutions (or answers if there are no steps) of the problems, then use the n-gram prediction accuracy metric. Specifically, for each sample, we sample k starting points and predict the next 5-gram each time. To evaluate whether the n-gram prediction is correct, we use exact match and more lenient metrics such as edit distance and ROUGE-L. Here, we consider a prediction correct if either the edit distance or ROUGE-L similarity exceeds 75%, to mitigate some reformatting issues during pre-training. We take the union of instances detected by different metrics to obtain the final set of detected instances.

As shown in Tables 16, 17, and 18, the experimental results reveal that indeed, different models exhibit minor leakage across different subjects. An interesting observation is that some leakages detected by the base model are no longer detectable when using the chat model based on the same base model. We hypothesize that optimization for dialogue capabilities potentially impacts the model's ability and performance on the next token prediction. Another similar observation is that leakages detected by text-only chat models tend to decrease when evaluated on multimodal chat models based on the same chat models. Figure 17 presents a data leakage case from Qwen1.5-32B-Chat.

An exact match case of Qwen1.5-32B-Chat

Text: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-31} … 1.6 \times 10^{-19} … \mathrm{~J}$$

Prompt: The fractional
Prediction: The fractional quantum Hall effect (F

Prompt: The fractional quantum Hall effect (FQHE) was … fraction
Prediction: The fractional quantum Hall effect (FQHE) was … fractionally charged quasip

Prompt: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times
Prediction: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-3

Prompt: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-31} … 1.
Prediction: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-31} … 1.6 \times 1

Prompt: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-31} … 1.6 \times 10^{-19} … \mathrm
Prediction: The fractional quantum Hall effect (FQHE) was … fractionally charged quasiparticles … \times 10^{-31} … 1.6 \times 10^{-19} … \mathrm{~J}$$

Figure 17: A potential data leakage case of Qwen1.5-32B-Chat which is presented with the original problem and solution concatenated, separated by a space.

Table 10: Descriptions of answer types and corresponding format instructions included in the problem input prompts. Specifically, {unit description} indicates: "Remember, your answer should be calculated in the unit of {unit}, but do not include the unit in your final answer."

Answer Type	Answer Type Description	Answer Format Instruction
SC	This is a multiple choice question (only one correct answer).	Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER should be one of the options: {the options of the problem}.
MC	This is a multiple choice question (more than one correct answer).	Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER should be two or more of the options: {the options of the problem}.
TF	This is a True or False question.	Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER should be either "True" or "False".
NV	The answer to this question is a numerical value.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is the numerical value without any units.
SET	The answer to this question is a set.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is the set of all distinct answers, each expressed as a numerical value without any units, e.g. ANSWER = {3, 4, 5}.
IN	The answer to this question is a range interval.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is an interval without any units, e.g. ANSWER = $(1, 2] \cup [7, +\infty)$.
EX	The answer to this question is an expression.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is an expression without any units and equals signs, e.g. ANSWER = $\frac{1}{2}gt^2$.
EQ	The answer to this question is an equation.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is an equation without any units, e.g. ANSWER = $\frac{x^2}{4} + \frac{y^2}{2} = 1$.
TUP	The answer to this question is a tuple.	{unit instruction} Please end your response with: "The final answer is $\boxed{ANSWER}$", where ANSWER is a tuple without any units, e.g. ANSWER=(3, 5).
MPV	This question involves multiple quantities to be determined.	Your final quantities should be output in the following order: {the ordered sequence of the name of multiple quantities}. Their units are, in order, {the ordered sequence of the units}, but units shouldn't be included in your concluded answer. Their answer types are, in order, {the ordered sequence of answer types}. Please end your response with: "The final answers are $\boxed{ANSWER}$", where ANSWER should be the sequence of your final answers, separated by commas, for example: 5, 7, 2.5.
MA	This question has more than one correct answer, you need to include them all.	Their units are, in order, {the ordered sequence of the units}, but units shouldn't be included in your concluded answer. Their answer types are, in order, {the ordered sequence of answer types}. Please end your response with: "The final answers are $\boxed{ANSWER}$", where ANSWER should be the sequence of your final answers, separated by commas, for example: 5, 7, 2.5.
CODE	Write a Python program to solve the given competitive programming problem using standard input and output methods. Pay attention to time and space complexities to ensure efficiency.	Notes: (1) Your solution must handle standard input and output. Use `input()` for reading input and `print()` for output. (2) Be mindful of the problem's time and space complexity. The solution should be efficient and designed to handle the upper limits of input sizes within the given constraints. (3) It's encouraged to analyze and reason about the problem before coding. You can think step by step, and finally output your final code in the following format: `Your Python code here`
OT	-	-

Table 11: Experimental results across different logical reasoning abilities on OlympicArena benchmark, expressed as percentages, with the highest score in each setting underlined and the highest scores across all settings bolded. **DED**: Deductive Reasoning, **IND**: Inductive Reasoning, **ABD**: Abductive Reasoning, **ANA**: Analogical Reasoning, **CAE**: Cause-and-Effect Reasoning, **CT**: Critical Thinking, **DEC**: Decompositional Reasoning, **QUA**: Quantitative Reasoning.

Model	**DED**	**IND**	**ABD**	**ANA**	**CAE**	**CT**	**DEC**	**QUA**
	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy
LLMs								
Qwen-7B-Chat	4.85	4.18	4.84	5.29	5.54	5.16	4.09	4.64
Yi-34B-Chat	19.65	13.84	26.82	18.73	26.51	25.71	15.00	15.55
Internlm2-20B-Chat	17.43	13.12	24.74	16.30	22.81	22.51	13.03	13.42
Qwen1.5-32B-Chat	25.94	21.20	33.39	24.87	32.33	31.82	20.19	22.19
GPT-3.5	19.38	13.19	26.64	16.30	23.32	24.31	14.43	17.35
Claude3 Sonnet	25.40	17.88	34.78	23.28	30.64	31.15	18.59	22.67
GPT-4	33.93	24.80	40.66	33.33	38.48	39.32	26.84	31.72
GPT-4o	39.1	30.14	43.43	37.78	42.89	44.06	31.79	36.56
Image caption + LLMs								
Qwen-7B-Chat	5.66	4.69	7.27	6.88	6.66	6.02	4.60	4.81
Yi-34B-Chat	19.08	13.34	29.24	20.11	25.53	24.91	13.79	14.64
Internlm2-20B-Chat	18.25	12.69	28.37	17.67	23.84	23.35	13.40	14.52
Qwen1.5-32B-Chat	25.50	20.55	35.81	26.35	31.35	31.39	19.55	21.51
GPT-3.5	20.71	13.91	29.76	17.78	25.72	26.01	15.74	17.73
Claude3 Sonnet	25.69	19.11	35.12	24.02	30.88	31.55	18.71	22.89
GPT-4	35.06	24.44	41.35	34.39	40.17	40.72	27.26	32.47
GPT-4o	39.26	30.93	45.50	39.37	43.17	44.19	31.35	36.56
LMMs								
Qwen-VL-Chat	7.87	6.06	12.80	8.68	9.90	9.92	5.29	6.29
Yi-VL-34B	16.30	10.60	21.11	16.40	21.35	20.76	11.89	13.42
InternVL-Chat-V1.5	17.65	12.55	30.28	17.25	22.06	22.70	12.56	14.37
LLaVA-NeXT-34B	19.72	14.70	30.62	19.37	27.40	25.39	13.62	14.79
Qwen-VL-Max	22.97	16.87	33.91	21.38	29.28	28.51	17.26	18.13
Gemini Pro Vision	22.45	17.16	35.47	21.59	25.67	27.54	17.24	18.91
Claude3 Sonnet	25.59	18.89	36.51	23.70	29.89	31.71	18.99	22.87
GPT-4V	34.59	25.59	46.54	33.33	39.61	41.15	26.47	30.79
GPT-4o	**41.18**	**32.73**	**50.35**	**40.53**	**45.94**	**47.12**	**33.17**	**37.58**

Table 12: Experimental results across different visual reasoning abilities on OlympicArena benchmark, expressed as percentages, with the highest score in each setting underlined and the highest scores across all settings bolded. **PR**: Pattern Recognition, **SPA**: Spatial Reasoning, **DIA**: Diagrammatic Reasoning, **SYB**: Symbol Interpretation, **COM**: Comparative Visualization.

Model	**PR**	**SPA**	**DIA**	**SYB**	**COM**
	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy
LLMs					
Qwen-7B-Chat	4.59	2.64	4.26	4.01	4.66
Yi-34B-Chat	23.70	13.58	19.56	17.61	22.37
Internlm2-20B-Chat	22.89	13.06	18.63	15.73	21.16
Qwen1.5-32B-Chat	28.93	17.94	24.67	22.18	27.83
GPT-3.5	22.33	13.27	18.40	16.05	21.05
Claude3 Sonnet	26.88	17.60	22.86	20.49	25.98
GPT-4	33.65	23.99	30.09	27.94	32.54
GPT-4o	35.96	28.71	33.29	31.54	35.00
Image caption + LLMs					
Qwen-7B-Chat	5.96	4.11	5.21	5.11	6.30
Yi-34B-Chat	21.69	21.19	18.01	14.92	20.48
Internlm2-20B-Chat	22.97	12.75	18.27	15.49	21.05
Qwen1.5-32B-Chat	28.59	17.81	23.90	20.95	26.73
GPT-3.5	23.96	15.26	19.72	17.34	22.30
Claude3 Sonnet	27.60	17.03	22.84	20.17	26.28
GPT-4	34.29	26.07	31.07	28.61	33.11
GPT-4o	37.08	29.10	33.60	31.22	35.91
LMMs					
Qwen-VL-Chat	9.90	4.93	7.46	6.48	8.91
Yi-VL-34B	16.72	9.60	13.78	12.10	15.09
InternVL-Chat-V1.5	22.85	12.11	17.68	15.11	21.27
LLaVA-NeXT-34B	24.69	12.75	19.72	16.38	22.90
Qwen-VL-Max	27.43	16.26	22.35	19.47	26.01
Gemini Pro Vision	28.98	14.83	21.65	19.79	26.13
Claude3 Sonnet	27.18	17.55	22.43	20.84	25.56
GPT-4V	35.28	23.91	30.25	27.70	34.40
GPT-4o	**41.49**	**30.65**	**36.98**	**33.91**	**40.58**

Table 13: Experimental results on multimodal problems on OlympicArena benchmark, expressed as percentages, with the highest score in each setting underlined and the highest scores across all settings bolded.

Model	**Math**	**Physics**	**Chemistry**	**Biology**	**Geography**	**Astronomy**	**CS**	**Overall**
	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Accuracy	Pass@1	Accuracy
LLMs								
Qwen-7B-Chat	1.26	2.54	6.92	5.59	4.16	2.70	0	4.01
Yi-34B-Chat	5.04	6.14	19.15	27.40	33.91	10.00	0.28	19.54
Internlm2-20B-Chat	6.30	6.46	15.76	26.96	31.87	9.19	0.97	18.51
Qwen1.5-32B-Chat	7.98	8.90	23.86	32.21	39.74	18.65	0.83	24.58
GPT-3.5	6.30	7.20	15.46	26.85	30.66	11.62	6.25	18.79
Claude3 Sonnet	8.82	11.76	19.59	31.99	38.00	15.68	2.64	23.79
GPT-4	16.81	18.43	32.11	39.71	41.26	23.92	12.50	31.05
GPT-4o	21.85	21.82	32.11	42.17	44.28	30.68	12.78	34.11
Image caption + LLMs								
Qwen-7B-Chat	3.78	2.22	6.19	6.49	7.34	5.00	0	5.32
Yi-34B-Chat	5.04	6.57	14.29	24.94	33.61	8.78	0.28	18.25
Internlm2-20B-Chat	6.72	6.89	16.35	25.39	31.26	10.27	1.18	18.41
Qwen1.5-32B-Chat	6.72	8.69	21.80	32.10	39.82	17.30	0.97	23.99
GPT-3.5	4.20	12.39	18.11	25.73	32.32	9.73	7.64	20.04
Claude3 Sonnet	5.46	13.35	20.47	32.89	38.23	13.38	3.89	23.97
GPT-4	16.81	20.44	29.90	38.7	45.12	26.62	12.26	32.36
GPT-4o	21.01	22.14	31.22	45.19	45.19	30.54	**14.58**	34.86
LMMs								
Qwen-VL-Chat	3.36	2.65	6.63	9.84	13.85	5.27	0	7.82
Yi-VL-34B	3.36	6.46	9.13	18.79	22.03	7.43	0	13.00
InternVL-Chat-V1.5	7.56	6.25	16.05	24.94	32.55	9.73	0.62	18.43
LLaVA-NeXT-34B	4.62	6.46	14.43	28.30	36.11	10.00	0.28	19.66
Qwen-VL-Max	6.30	7.63	17.82	28.86	40.05	15.14	1.25	22.38
Gemini Pro Vision	7.56	9.11	24.30	32.55	35.81	11.22	2.36	22.58
Claude3 Sonnet	5.46	13.45	19.15	33.22	37.02	17.30	2.36	24.05
GPT-4V	13.87	18.22	29.31	40.27	46.86	22.43	11.25	31.81
GPT-4o	**26.47**	**22.14**	**33.14**	**46.98**	**53.75**	**31.76**	13.61	**38.17**

Table 14: Results of the process-level evaluation on our comprehensive OlympicArena benchmark. Each step of every problem is assigned a score of 0 (indicating incorrect) or 1 (indicating correct), with the highest score in each setting underlined and the highest scores across all settings highlighted in bold. The subject of computer science is neglected in this part due to the lack of solutions.

Model	**Math**	**Physics**	**Chemistry**	**Biology**	**Geography**	**Astronomy**	**Overall**
	Score	Score	Score	Score	Score	Score	Score
LLMs							
Qwen-7B-Chat	18.7	43.7	35.1	18.9	34.5	31.5	30.4
Yi-34B-Chat	30.2	51.0	54.0	31.9	36.5	40.3	40.7
Internlm2-20B-Chat	21.2	35.0	51.2	22.7	32.9	33.3	32.7
Qwen1.5-32B-Chat	32.0	44.0	61.1	32.0	45.2	48.6	43.8
GPT-3.5	37.6	46.9	32.7	30.2	38.7	26.7	35.4
Claude3 Sonnet	40.8	42.7	65.3	30.8	52.6	50.5	47.1
GPT-4	57.0	53.8	73.6	50.0	50.1	65.0	58.2
GPT-4o	59.9	**65.9**	67.4	49.6	**61.4**	69.5	62.3
Image caption + LLMs							
Qwen-7B-Chat	23.0	42.6	34.6	17.4	34.4	32.3	30.7
Yi-34B-Chat	26.3	45.6	49.5	20.0	45.7	42.0	38.2
Internlm2-20B-Chat	27.7	42.6	46.3	19.4	25.5	43.1	34.1
Qwen1.5-32B-Chat	35.9	49.7	56.8	33.5	43.6	51.4	45.1
GPT-3.5	32.1	46.7	51.2	29.1	38.4	38.2	39.3
Claude3 Sonnet	50.7	51.7	66.1	33.4	55.8	52.2	51.7
GPT-4	61.4	53.8	62.7	51.1	52.0	62.2	57.2
GPT-4o	54.3	63.3	71.8	**58.6**	56.6	72.6	**62.9**
LMMs							
Qwen-VL-Chat	14.3	41.7	35.7	21.0	31.0	23.6	27.9
Yi-VL-34B	28.9	41.0	44.2	18.7	30.2	40.3	33.9
InternVL-Chat-V1.5	26.6	40.5	42.7	29.4	43.1	44.8	37.8
LLaVA-NeXT-34B	30.2	47.1	50.1	19.0	40.6	47.1	39.0
Qwen-VL-Max	27.5	52.4	65.5	24.3	36.0	48.4	42.3
Gemini Pro Vision	28.5	46.4	45.2	19.9	33.5	40.5	35.7
Claude3 Sonnet	47.3	46.8	63.2	24.2	43.2	48.1	45.5
GPT-4V	49.9	54.0	71.1	51.4	56.3	64.3	57.8
GPT-4o	**60.2**	54.8	**72.2**	51.6	59.6	**74.4**	62.1

Table 15: Experimental results across different languages (English and Chinese) on OlympicArena benchmark, expressed as percentages, with the highest score in each setting underlined and the highest scores across all settings bolded.

Model	**English**	**Chinese**
	Accuracy	Accuracy
LLMs		
Qwen-7B-Chat	4.17	4.55
Yi-34B-Chat	16.37	18.89
Internlm2-20B-Chat	16.56	16.62
Qwen1.5-32B-Chat	22.73	25.29
GPT-3.5	19.83	15.50
Claude3 Sonnet	25.73	18.20
GPT-4	35.13	27.31
GPT-4o	40.65	33.66
Image caption + LLMs		
Qwen-7B-Chat	4.71	5.21
Yi-34B-Chat	16.96	16.26
Internlm2-20B-Chat	17.40	16.43
Qwen1.5-32B-Chat	22.93	24.24
GPT-3.5	20.56	15.77
Claude3 Sonnet	26.31	17.43
GPT-4	36.08	27.40
GPT-4o	41.50	33.07
LMMs		
Qwen-VL-Chat	7.70	5.55
Yi-VL-34B	17.34	14.68
InternVL-Chat-V1.5	17.07	15.82
LLaVA-NeXT-34B	17.74	16.74
Qwen-VL-Max	20.14	21.49
Gemini Pro Vision	21.61	18.76
Claude3 Sonnet	26.52	17.21
GPT-4V	36.18	26.55
GPT-4o	**43.04**	**34.39**

Table 16: Full results of Data Leakage Detection on the base models or text-only chat models behind the evaluated models (continued). The “Correspondence” column indicates the text-only chat model and multimodal (MM) chat model corresponding to the model being detected. “# Leak.” denotes the number of leakage instances. “# T” represents the number of instances correctly answered among these leaks by the text-only chat model, while “# MM” represents the number of instances correctly answered among these leaks by the multimodal chat model.

Model to-be-detected	**Correspondence**		**Math**			**Physics**			**Chemistry**		
	Text-only Chat Model	**MM Chat Model**	**# Leak.**	**# T**	**# MM**	**# Leak.**	**# T**	**# MM**	**# Leak.**	**# T**	**# MM**
InternLM2-20B	InternLM2-20B-Chat	InternVL-Chat-1.5	14	1	2	3	0	0	0	0	0
internLM2-20B-Chat	InternLM2-20B-Chat	InternVL-Chat1.5	17	1	0	0	0	0	1	1	1
Yi-34B	Yi-34B-Chat	Yi-VL-34B	10	2	2	1	0	0	0	0	0
Yi-34B-Chat	Yi-34B-Chat	Yi-VL-34B	2	0	0	0	0	0	0	0	0
Nous-Hermes-2-Yi-34B	-	LLaVA-NeXT-34B	0	-	0	0	-	0	0	-	0
Qwen-7B	Qwen-7B-Chat	Qwen-VL-Chat	8	0	0	1	1	0	0	0	0
Qwen1.5-32B	Qwen1.5-32B-Chat	-	24	3	-	3	1	-	1	0	-
Qwen1.5-32B-Chat	Qwen1.5-32B-Chat	-	19	2	-	4	2	-	3	1	-
GPT-4o	GPT-4o	GPT-4o	0	0	0	0	0	0	0	0	0

Table 17: Full results of Data Leakage Detection on the base models or text-only chat models behind the evaluated models (continued). The “Correspondence” column indicates the text-only chat model and multimodal (MM) chat model corresponding to the model being detected. “# Leak.” denotes the number of leakage instances. “# T” represents the number of instances correctly answered among these leaks by the text-only chat model, while “# MM” represents the number of instances correctly answered among these leaks by the multimodal chat model.

Model to-be-detected	**Correspondence**		**Biology**			**Geography**			**Astronomy**		
	Text-only Chat Model	**MM Chat Model**	**# Leak.**	**# T**	**# MM**	**# Leak.**	**# T**	**# MM**	**# Leak.**	**# T**	**# MM**
InternLM2-20B	InternLM2-20B-Chat	InternVL-Chat-1.5	0	0	0	0	0	0	1	0	0
InternLM2-20B-Chat	InternLM2-20B-Chat	InternVL-Chat-1.5	0	0	0	0	0	0	0	0	0
Yi-34B	Yi-34B-Chat	Yi-VL-34B	1	0	0	0	0	0	0	0	0
Yi-34B-Chat	Yi-34B-Chat	Yi-VL-34B	0	0	0	0	0	0	0	0	0
Nous-Hermes-2-Yi-34B	-	LLaVA-NeXT-34B	0	-	0	0	-	0	0	-	0
Qwen-7B	Qwen-7B-Chat	Qwen-VL-Chat	0	0	0	0	0	0	1	0	0
Qwen1.5-32B	Qwen1.5-32B-Chat	-	1	0	-	0	0	-	5	1	-
Qwen1.5-32B-Chat	Qwen1.5-32B-Chat	-	1	0	-	0	0	-	0	0	-
GPT-4o	GPT-4o	GPT-4o	0	0	0	0	0	0	0	0	0

Table 18: Full results of Data Leakage Detection on the base models or text-only chat models behind the evaluated models (continued). The “Correspondence” column indicates the text-only chat model and multimodal (MM) chat model corresponding to the model being detected. “# Leak.” denotes the number of leakage instances. “# T” represents the number of instances correctly answered among these leaks by the text-only chat model, while “# MM” represents the number of instances correctly answered among these leaks by the multimodal chat model.

Model to-be-detected	**Correspondence**		**CS**			**Overall**		
	Text-only Chat Model	**MM Chat Model**	**# Leak.**	**# T**	**# MM**	**# Leak.**	**# T**	**# MM**
InternLM2-20B	InternLM2-20B-Chat	InternVL-Chat-1.5	1	1	1	19	2	3
InternLM2-20B-Chat	InternLM2-20B-Chat	InternVL-Chat-1.5	1	1	1	19	3	2
Yi-34B	Yi-34B-Chat	Yi-VL-34B	0	0	0	12	2	2
Yi-34B-Chat	Yi-34B-Chat	Yi-VL-34B	0	0	0	2	0	0
Nous-Hermes-2-Yi-34B	-	LLaVA-NeXT-34B	0	-	0	0	0	0
Qwen-7B	Qwen-7B-Chat	Qwen-VL-Chat	1	1	1	11	2	1
Qwen1.5-32B	Qwen1.5-32B-Chat	-	9	-	-	43	14	0
Qwen1.5-32B-Chat	Qwen1.5-32B-Chat	-	3	3	-	30	8	0
GPT-4o	GPT-4o	GPT-4o	0	0	0	0	0	0

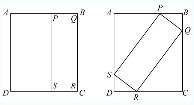
F Case Study

F.1 Cases for Error Analysis

From Figure 18 to Figure 24, we showcase examples of various error types across different disciplines.

Math - Logical Reasoning Error

Problem:
In the diagram, rectangle $PQRS$ is placed inside rectangle $ABCD$ in two different ways: first, with Q at B and R at C; second, with P on AB, Q on BC, R on CD, and S on DA. [figure1]. If $AB = 718$ and $PQ = 250$, determine the length of BC.



[figure1]

Solution:
Let $BC = x$, $PB = b$, and $BQ = a$. Since $BC = x$, then $AD = PS = QR = x$. Since $BC = x$ and $BQ = a$, then $QC = x - a$. Since $AB = 718$ and $PB = b$, then $AP = 718 - b$. Note that $PQ = SR = 250$. Let $\angle BQP = \theta$. Since $\triangle PBQ$ is right-angled at B, then $\angle BPQ = 90^\circ - \theta$. Since BQC is a straight angle and $\angle PQR = 90^\circ$, then $\angle RQC = 180^\circ - 90^\circ - \theta = 90^\circ - \theta$. Since APB is a straight angle and $\angle SPQ = 90^\circ$, then $\angle APS = 180^\circ - 90^\circ - \left(90^\circ - \theta\right) = \theta$. Since $\triangle SAP$ and $\triangle QCR$ are each right-angled and have another angle in common with $\triangle PBQ$, then these three triangles are similar. Continuing in the same way, we can show that $\triangle RDS$ is also similar to these three triangles. Since $RS = PQ$, then $\triangle RDS$ is actually congruent to $\triangle PBQ$ (angle-side-angle). Similarly, $\triangle SAP$ is congruent to $\triangle QCR$. In particular, this means that $AS = x - a$, $SD = a$, $DR = b$, and $RC = 718 - b$. Since $\triangle SAP$ and $\triangle PBQ$ are similar, then $\frac{SA}{PB} = \frac{AP}{BQ} = \frac{SP}{PQ}$. Thus, $\frac{x-a}{b} = \frac{718-b}{a} = \frac{x}{250}$. Also, by the Pythagorean Theorem in $\triangle PBQ$, we obtain $a^2 + b^2 = 250^2$. By the Pythagorean Theorem in $\triangle SAP$,

$$\begin{aligned}
x^2 &= (x-a)^2 + (718-b)^2 \\
x^2 &= x^2 - 2ax + a^2 + (718-b)^2 \\
0 &= -2ax + a^2 + (718-b)^2
\end{aligned}$$

Since $a^2 + b^2 = 250^2$, then $a^2 = 250^2 - b^2$. Since $\frac{718-b}{a} = \frac{x}{250}$, then $ax = 250(718-b)$. Therefore, substituting into $(*)$, we obtain

$$\begin{aligned}
0 &= -2(250)(718-b) + 250^2 - b^2 + (718-b)^2 \\
b^2 &= 250^2 - 2(250)(718-b) + (718-b)^2 \\
b^2 &= ((718-b) - 250)^2 \quad \left(\text{since } y^2 - 2yz + z^2 = (y-z)^2\right) \\
b^2 &= (468-b)^2 \\
b &= 468 - b \quad (\text{ since } b \neq b - 468) \\
2b &= 468 \\
b &= 234
\end{aligned}$$

Therefore, $a^2 = 250^2 - b^2 = 250^2 - 234^2 = (250+234)(250-234) = 484 \cdot 16 = 22^2 \cdot 4^2 = 88^2$ and so $a = 88$.
Finally, $x = \frac{250(718-b)}{a} = \frac{250 \cdot 484}{88} = 1375$. Therefore, $BC = \boxed{1375}$.

GPT 4V's output:
To solve this problem, we can use the Pythagorean theorem. In the first placement of rectangle $PQRS$ inside rectangle $ABCD$, we see that PQ is parallel to AB and QR is parallel to BC. Since $PQ = 250$ and $AB = 718$, we can denote the length of BC as x. In the second placement, the rectangle $PQRS$ is rotated such that its corners touch the sides of rectangle $ABCD$. The diagonal PR of rectangle $PQRS$ becomes the diameter of an inscribed circle within rectangle $ABCD$. This means that the diagonal PR is the hypotenuse of a right triangle with sides PQ and QR. Since $PQRS$ is a rectangle, $PQ = RS$ and $PS = QR$. Therefore, the length of QR is also x. Now we have a right triangle with sides 250 and x, and the hypotenuse is the diagonal PR. Using the Pythagorean theorem, we have:

$$\begin{aligned}
PR^2 &= PQ^2 + QR^2 \\
PR^2 &= 250^2 + x^2 \\
PR^2 &= 62500 + x^2
\end{aligned}$$

The diagonal PR also bisects rectangle $ABCD$ into two right triangles, each with sides AB and BC. Therefore, the length of the diagonal PR can also be calculated using the Pythagorean theorem with sides AB and BC:

$$PR^2 = AB^2 + BC^2$$

$$\begin{aligned}
PR^2 &= 718^2 + x^2 \\
PR^2 &= 515524 + x^2
\end{aligned}$$

Since both expressions represent PR^2, we can set them equal to each other:

$$62500 + x^2 = 515524 + x^2$$

Subtract x^2 from both sides:

$$62500 = 515524$$

Now we see that there is a mistake in the calculation because the left side should not equal the right side directly. We need to subtract 62500 from 515524 to find the value of x^2:

$$\begin{aligned}
x^2 &= 515524 - 62500 \\
x^2 &= 453024
\end{aligned}$$

Now we take the square root of both sides to find x:

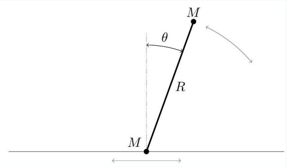
$$\begin{aligned}
x &= \sqrt{453024} \\
x &= 673
\end{aligned}$$

Therefore, the length of BC is 673. The final answer is $\boxed{673}$.

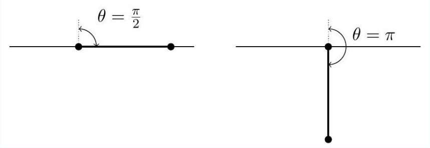
Figure 18: An example of a math problem with a logical reasoning error.

Physics - Logical Reasoning Error

Problem:
A bead is placed on a horizontal rail, along which it can slide frictionlessly. It is attached to the end of a rigid, massless rod of length R. A ball is attached at the other end. Both the bead and the ball have mass M. The system is initially stationary, with the ball directly above the bead. The ball is then given an infinitesimal push, parallel to the rail.[figure1] Assume that the rod and ball are designed in such a way (not shown explicitly in the diagram) so that they can pass through the rail without hitting it. In other words, the rail only constrains the motion of the bead. Two subsequent states of the system are shown below.[figure2] Derive an expression for the force in the rod when the ball is directly below the bead, as shown at right above.



[figure1]



[figure2]

Solution:
At this point the released gravitational potential energy is $2MgR$, and both masses are moving horizontally with speed v, where

$$2\frac{1}{2}Mv^2 = 2MgR \quad \Rightarrow \quad v = \sqrt{2gR}$$

Work in the frame moving to the right with speed v. In this frame the bead is stationary and the ball has velocity $2v$ and is instantaneously rotating about the bead, so it must be experiencing a centripetal force

$$\frac{M(2v)^2}{R} = 8Mg$$

Unlike in part (a), there are no additional contribution from the acceleration of the rotation center, because the bead can only ever accelerate horizontally, and the force in the rod at this moment is vertical. Since the ball also experiences a downward force of Mg due to gravity, the force in the rod is a tension

$$T = \boxed{9Mg}$$

GPT 4V's output:
To derive an expression for the force in the rod when the ball is directly below the bead, we can employ the conservation of energy and principles from circular motion.
Since the bead and ball are on a frictionless rail and assuming no other non-conservative forces are acting on the system, the total mechanical energy is conserved. The initial potential energy of the ball when it is given an infinitesimal push will convert into kinetic energy as the ball swings down.
At the top position (initial state), the potential energy (PE) is maximum and kinetic energy (KE) is zero. We define the gravitational potential energy to be zero at the lowest point. At the highest point, the potential energy is MgR because the height of the ball above the lowest point is R.
Hence, $PE_{\text{initial}} = MgR$.
At the bottom position (final state), when the ball is directly below the bead, all the potential energy will have been converted to kinetic energy (assuming conservation of energy). If v is the velocity of the ball at the bottom, then $KE_{\text{final}} = \frac{1}{2}Mv^2$.
Since energy is conserved, $PE_{\text{initial}} = KE_{\text{final}}$. Thus,

$$MgR = \frac{1}{2}Mv^2$$

$$2gR = v^2$$

$$v = \sqrt{2gR}$$

Now, let us consider the forces acting on the ball at the bottom position. We have the gravitational force Mg acting downwards and the force in the rod F acting upwards. When the ball is at the bottom, it is in circular motion and the centripetal force required to keep it in circular motion is provided entirely by the force in the rod, which is the centripetal force $F_{\text{centripetal}}$, since gravity acts in the same direction as the centripetal acceleration at this point.

The centripetal force is given by $F_{\text{centripetal}} = \frac{Mv^2}{R}$.
Substituting $v = \sqrt{2gR}$ into the above equation, we get

$$F_{\text{centripetal}} = \frac{M(2gR)}{R}$$

$$F_{\text{centripetal}} = 2Mg$$

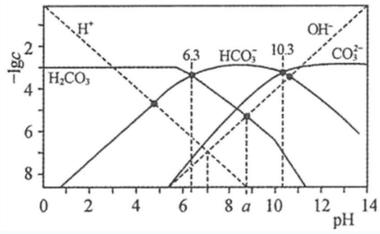
Since the centripetal force is provided by the force in the rod and directed towards the center of the circular motion (upwards towards the ball), at this moment, the rod is under tension, not compression.
Thus, the force in the rod when the ball is directly below the bead and in tension is $F = 2Mg$.

The final answer is $\boxed{2Mg}$.

Figure 19: An example of a physics problem with a logical reasoning error.

Chemistry - Visual Reasoning Error

Problem:
At temperature $\mathrm{t}^{\circ}\mathrm{C}$, a solution is prepared such that $\mathrm{c}\left(\mathrm{H_2CO_3}\right)+\mathrm{c}\left(\mathrm{HCO_3^-}\right)+\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=1.000\times10^{-3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. This solution is a mixture of $\mathrm{H_2CO_3}$ and HCl or $\mathrm{H_2CO_3}$ and NaOH. The negative logarithms of the concentrations of some particles in the solution $(-\mathrm{lgc})$ versus pH are shown in the figure. Which of the following statements are incorrect:



[figure1]

A: In the solution with $\mathrm{pH}=\mathrm{a}$: $\mathrm{c}\left(\mathrm{HCO_3^-}\right)>\mathrm{c}\left(\mathrm{H_2CO_3}\right)>\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)>\mathrm{c}\left(\mathrm{H^+}\right)$

B: In the solution with $\mathrm{pH}=7$: $\mathrm{c}\left(\mathrm{Na^+}\right)>\mathrm{c}\left(\mathrm{H_2CO_3}\right)$

C: In the solution with $\mathrm{pH}=10.3$: $\mathrm{c}\left(\mathrm{Na^+}\right)<1.000\times10^{-3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$

D: At $25^{\circ}\mathrm{C}$, the equilibrium constant for the reaction $\mathrm{H_2CO_3}+\mathrm{CO_3^{2-}}\rightleftharpoons2\mathrm{HCO_3^-}$ is 1.0×10^{4}

Solution:
A. According to the information from the figure, in the solution with $\mathrm{pH}=\mathrm{a}$, $\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)>\mathrm{c}\left(\mathrm{H_2CO_3}\right)$, so statement A is incorrect.

B. In the solution with $\mathrm{pH}=7$, according to the information from the figure, $\mathrm{c}\left(\mathrm{HCO_3^-}\right)>\mathrm{c}\left(\mathrm{H_2CO_3}\right)>\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)$. According to charge conservation and $\mathrm{pH}=7$, $\mathrm{c}\left(\mathrm{Na^+}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)+2\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)$, so $\mathrm{c}\left(\mathrm{Na^+}\right)>\mathrm{c}\left(\mathrm{H_2CO_3}\right)$. Therefore, statement B is correct.

C. At $25^{\circ}\mathrm{C}$, when $\mathrm{pH}=6.3$, $\mathrm{c}\left(\mathrm{H_2CO_3}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)$, then $K_a\left(\mathrm{H_2CO_3}\right)=\mathrm{c}\left(\mathrm{H^+}\right)=1.000\times10^{-6.3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. In the solution with $\mathrm{pH}=10.3$, $\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)$, $K_a\left(\mathrm{HCO_3^-}\right)=\mathrm{c}\left(\mathrm{H^+}\right)=1.000\times10^{-10.3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. Then $K_a\left(\mathrm{H_2CO_3}\right)=\frac{\mathrm{c}\left(\mathrm{HCO_3^-}\right)\times\mathrm{c}\left(\mathrm{H^+}\right)}{\mathrm{c}\left(\mathrm{H_2CO_3}\right)}=\frac{\mathrm{c}\left(\mathrm{HCO_3^-}\right)\times10^{-10.3}}{\mathrm{c}\left(\mathrm{H_2CO_3}\right)}=10^{-6.3}$. When $\mathrm{pH}=10.3$, $\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)$, so $\frac{\mathrm{c}\left(\mathrm{HCO_3^-}\right)+\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)}{\mathrm{c}\left(\mathrm{H_2CO_3}\right)}=2\times10^{4}$, $\mathrm{c}\left(\mathrm{H_2CO_3}\right)+\mathrm{c}\left(\mathrm{HCO_3^-}\right)+\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=1.000\times10^{-3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. Therefore, $\mathrm{c}\left(\mathrm{H_2CO_3}\right)=5.000\times10^{-8}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$, and $2\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=1.000\times10^{-3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}-5.000\times10^{-8}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. According to charge conservation, $\mathrm{c}\left(\mathrm{Na^+}\right)>\mathrm{c}\left(\mathrm{HCO_3^-}\right)+2\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)$, i.e., $\mathrm{c}\left(\mathrm{Na^+}\right)>3\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)$, and $\mathrm{c}\left(\mathrm{Na^+}\right)>1.000\times10^{-3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. Therefore, statement C is incorrect.

D. At $25^{\circ}\mathrm{C}$, when $\mathrm{pH}=6.3$, $\mathrm{c}\left(\mathrm{H_2CO_3}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)$, then $K_a\left(\mathrm{H_2CO_3}\right)=\mathrm{c}\left(\mathrm{H^+}\right)=1.000\times10^{-6.3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. Similarly, at $\mathrm{pH}=10.3$, $\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)=\mathrm{c}\left(\mathrm{HCO_3^-}\right)$, then $K_a\left(\mathrm{HCO_3^-}\right)=\mathrm{c}\left(\mathrm{H^+}\right)=1.000\times10^{-10.3}\ \mathrm{mol}\cdot\mathrm{L}^{-1}$. The equilibrium constant for the reaction $\mathrm{H_2CO_3}+\mathrm{CO_3^{2-}}\rightleftharpoons2\mathrm{HCO_3^-}$ is:

$$K=\frac{\mathrm{c}^2\left(\mathrm{HCO_3^-}\right)}{\mathrm{c}\left(\mathrm{H_2CO_3}\right)\times\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)}=\frac{\mathrm{c}\left(\mathrm{HCO_3^-}\right)\times\mathrm{c}\left(\mathrm{HCO_3^-}\right)\times\mathrm{c}\left(\mathrm{H^+}\right)}{\mathrm{c}\left(\mathrm{H_2CO_3}\right)\times\mathrm{c}\left(\mathrm{CO_3^{2-}}\right)\times\mathrm{c}\left(\mathrm{H^+}\right)}=\frac{K_a\left(\mathrm{H_2CO_3}\right)}{K_a\left(\mathrm{HCO_3^-}\right)}=\frac{10^{-6.3}}{10^{-10.3}}=1\times10^{4}$$

Therefore, statement D is correct.

In conclusion, the answer is $\boxed{A, C}$.

GPT 4V's output:
First, we need to analyze the chart, which shows the variation of the negative logarithm of concentrations (-lgc) of $\mathrm{H_2CO_3}$, $\mathrm{HCO_3}^-$, $\mathrm{CO_3}^{2-}$, and H^+ at different pH values. This chart is a typical acid-base titration curve where $\mathrm{H_2CO_3}$ is a diprotic weak acid that can dissociate into $\mathrm{HCO_3}^-$ and $\mathrm{CO_3}^{2-}$.
Option A: At pH = a, according to the chart, the concentration of $\mathrm{HCO_3}^-$ is the highest, followed by $\mathrm{H_2CO_3}$, then $\mathrm{CO_3}^{2-}$, and the concentration of H^+ is the lowest. This is consistent with the chart.
Option B: At pH = 7, the concentration of $\mathrm{H_2CO_3}$ should be relatively low because it is a weak acid and does not dissociate completely at neutral pH. The concentration of Na^+ depends on whether NaOH has been added. If NaOH has been added, the concentration of Na^+ will increase. However, this option does not provide enough information to determine the exact concentration relationship between Na^+ and $\mathrm{H_2CO_3}$, so we cannot confirm if this option is correct.
Option C: At pH = 10.3, according to the chart, the concentration of $\mathrm{CO_3}^{2-}$ is the highest, and the concentration of $\mathrm{HCO_3}^-$ is very low at this pH. If NaOH is added to the solution, the concentration of Na^+ will increase. However, since the total concentration $c(\mathrm{H_2CO_3})+c(\mathrm{HCO_3^-})+c(\mathrm{CO_3^{2-}})=1.000\times10^{-3}$ mol·L^{-1}, the concentration of Na^+ cannot be lower than this value. Therefore, this option is incorrect.
Option D: The equilibrium constant K for the reaction $\mathrm{H_2CO_3}+\mathrm{CO_3^{2-}}\rightleftharpoons2\mathrm{HCO_3^-}$ can be expressed by the following equation:

$$K=\frac{[\mathrm{HCO_3^-}]^2}{[\mathrm{H_2CO_3}][\mathrm{CO_3^{2-}}]}$$

According to the chart, at pH = 10.3, the concentrations of $\mathrm{HCO_3}^-$ and $\mathrm{CO_3}^{2-}$ are equal, which means $K=1.0\times10^{4}$ is impossible because this would require $[\mathrm{HCO_3^-}]$ to be much greater than $[\mathrm{CO_3^{2-}}]$. Therefore, this option is also incorrect.

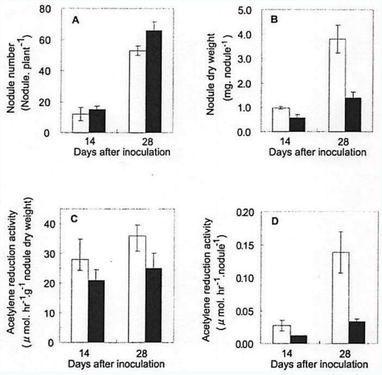
In summary, options C and D are incorrect. So the final answer is $\boxed{C, D}$

Figure 20: An example of a chemistry problem with a visual reasoning error.

Biology - Logical Reasoning Error

Problem:

The bacterium Bradyrhizobium japonicum can infect soybean (Glycine max) roots and form nodules. The nitrogen fixation catalyzed by nitrogenase occurs in the nodules and the nitrogenase activity can be measured easily by acetylene reduction instead of nitrogen reduction. Scientists generated a defective mutation of NAD^{+}-dependent malic enzyme, the enzyme that generates pyruvate and NADH, and infected soybean seedling roots with wildtype and mutant bacteria. The seedlings were grown in nitrogen-free media. After 14 and 28 days of inoculation, the number and weight of nodules in the seedlings and acetylene reduction activity were recorded [figure1]. Which of the following statements are correct:



[figure1]: Nodule number and dry weight and acetylene reduction acitivity of soybean. Soybean nodules infected with wild-type B. japonicum (open bars) and the dme mutant (solid bars) are presented.

A: Nitrogen fixation activity in nodules of the same treament at 28 days after inoculation is higher than that at 14 days after inoculation.
B: Both number and size of nodules increase with time from 14 to 28 days after inoculation with B. japonicum.
C: The reduction in nitrogen-fixing activity of nodules infected by the mutant at 28 days after inoculation compared to those at 14 days after inoculation is due to the reduction of nitrogenase activity and nodule formation.
D: Nitrogen fixation in B. japonicum -induced nodule is down-regulated by NAD^{+}dependent malic enzyme.

Solution:

A. True. As shown in the figure, in both wildtype and mutant treaments, acetylene reduction activity in nodules at 28 days after inoculation is higher than that at 14 days after inoculation, indicating higher nitrogen fixation actitity.
B. True. In both treaments, number and size of nodules are higher at 28 days compared to those at 14 days after inoculation
C. False. Number of nodules at 28 days after inoculation is higher than at 14 days after inoculation
D. False. The mutation of NAD^{+}-dependent malic enzyme in the bacteria results in a reduction of acetylene reduction, indicating that the enzyme (in wildtype) up-regulates the nitrogen fixation.

So we choose $\boxed{A, B}$.

GPT 4V's output:

Let's analyze the data presented in Fig.Q13 step by step:
A: We need to determine if nitrogen fixation activity in nodules of the same treatment at 28 days after inoculation is higher than that at 14 days after inoculation. Looking at the graphs C and D, which represent acetylene reduction activity (a proxy for nitrogen fixation activity), we can see that for both wild-type (open bars) and mutant (solid bars) B. japonicum, the activity is higher at 28 days than at 14 days. This is true for both per gram of nodule dry weight (graph C) and per nodule (graph D). Therefore, statement A is correct.
B: To assess this statement, we need to look at graphs A and B. Graph A shows the nodule number per plant, and graph B shows the nodule dry weight. For both wild-type and mutant B. japonicum, the number and size (weight) of nodules increase from 14 to 28 days after inoculation. Therefore, statement B is correct.
C: This statement suggests that the reduction in nitrogen-fixing activity of nodules infected by the mutant at 28 days after inoculation compared to those at 14 days is due to the reduction of nitrogenase activity and nodule formation. From graph C, we can see that the acetylene reduction activity per gram of nodule dry weight for the mutant does decrease from 14 to 28 days, indicating a reduction in nitrogenase activity. However, graph A shows that the number of nodules actually increases for the mutant from 14 to 28 days, which contradicts the second part of the statement. Therefore, statement C is not entirely correct.
D: The statement suggests that nitrogen fixation in B. japonicum-induced nodules is down-regulated by NAD+-dependent malic enzyme. The mutant, which has a defective mutation in the NAD+-dependent malic enzyme, shows lower acetylene reduction activity compared to the wild-type in both graphs C and D at both time points. This suggests that the enzyme plays a role in nitrogen fixation, and its absence (or defectiveness) leads to down-regulation of nitrogen fixation. Therefore, statement D is correct.

The final answer is $\boxed{A, B, D}$.

Figure 21: An example of a biology problem with a logical reasoning error.

Geography - Knowledge Deficit Error

Problem:
From December 17 to 20, 2020, the Beijing team went to Tengchong, Yunnan to participate in the study tour course design competition, using the Beihai Wetland in Tengchong, known for its plateau volcanic dammed lakes, as the theme of the study tour course design. Based on this, complete the following small questions. During the study tour, the team members found that compared to Beijing, Tengchong has ( ).

A. The tree shadows at sunrise are more towards the north.
B. The temperature difference between day and night is larger.
C. The sunset time is earlier.
D. The tree shadows at noon are shorter.

Solution:
According to the material, Tengchong $\left(25^{\circ}\mathrm{N}, 98^{\circ}\mathrm{E}\right)$ belongs to Yunnan and is located to the southwest of Beijing $\left(39^{\circ}\mathrm{N}, 116^{\circ}\mathrm{E}\right)$. From December 17 to 20, 2020, it was winter, around the winter solstice, with the sun rising in the southeast and the shadow at sunrise being in the northwest. Beijing is at a higher latitude than Tengchong, causing a greater shadow deviation, so A is incorrect. Tengchong is located near a plateau volcanic dammed lake, rich in geothermal energy, resulting in high nighttime temperatures and smaller temperature differences between day and night, so B is incorrect. Tengchong, being at a lower latitude, has longer daylight hours and a later sunset time, making C incorrect. Tengchong's lower latitude also means a larger solar altitude angle at noon, leading to shorter tree shadows, so $\boxed{D}$ is correct.

GPT 4V's output:
First, we need to understand the geographical locations of Beijing and Tengchong. Beijing is in the northern part of China, while Tengchong is in the southwestern part of China, near the Myanmar border. This means that Tengchong is to the southwest of Beijing.
A. The tree shadows at sunrise are more towards the north - Due to the Earth's rotation, the direction of tree shadows at sunrise is mainly determined by latitude, not by the east-west position. Therefore, this option is incorrect.
B. The temperature difference between day and night is larger - Tengchong is located in a plateau area, while Beijing is in a plain area. Generally, the temperature difference between day and night in plateau areas is larger than in plain areas because high-altitude areas cool down quickly at night and receive strong solar radiation during the day. Therefore, this option might be correct.
C. The sunset time is earlier - The sunset time is mainly determined by longitude, as the Earth rotates from west to east. Tengchong is to the southwest of Beijing, but this does not necessarily mean that the sunset time is earlier. This option requires more information to determine.
D. The tree shadows at noon are shorter - The solar altitude angle at noon depends on latitude; the lower the latitude, the higher the solar altitude angle, and the shorter the tree shadows. Tengchong has a lower latitude than Beijing, so the tree shadows at noon should be shorter.
In summary, options B and D are both possible. However, we need to determine which one is most related to the "plateau volcanic dammed lake" mentioned in the problem. Since this description emphasizes the plateau characteristics of Tengchong, we can reasonably infer that the larger temperature difference between day and night is most relevant to this characteristic. Therefore, the final answer is $\boxed{B}$.

Figure 22: An example of a geography problem with a knowledge deficit error.

Astronomy - Incomplete Response

Problem:
In order to move a spacecraft between orbits we must apply a thrust using rockets, which changes the velocity of the spacecraft by Δv. In this question we will ignore changes in the mass of the spacecraft due to the burning of fuel. For an object of mass m in a circular orbit of radius r around an object with mass M (where $m \ll M$) the orbital velocity, v_{orb} , is given by the formula $v_{\text{orb}} = \sqrt{\frac{GM}{r}}$. Approximating Mars' orbit as circular with a radius of 1.52AU, calculate the $\triangle v$ to go from Earth LEO to Mars i.e. $\Delta v = |\Delta v_A| + |\Delta v_B|$. Compare your answer to the Δv to reach Earth LEO.

Solution:

$$\begin{aligned}
\Delta v_{\text{A}} &= \sqrt{\frac{6.67 \times 10^{-11} \times 1.99 \times 10^{30}}{1.49 \times 10^{11}}} \left(\sqrt{\frac{2 \times 1.52}{1 + 1.52}} - 1\right) \\
&= 2935 \text{ m s}^{-1} \left(= 2.94 \text{ km s}^{-1}\right) \\
\Delta v_{\text{B}} &= \sqrt{\frac{6.67 \times 10^{-11} \times 1.99 \times 10^{30}}{1.52 \times 1.49 \times 10^{11}}} \left(1 - \sqrt{\frac{2 \times 1}{1 + 1.52}}\right) \\
&= 2642 \text{ m s}^{-1} \left(= 2.64 \text{ km s}^{-1}\right) \\
\Delta v &= 2.94 + 2.64 \\
&= \boxed{5.58} \text{ km s}^{-1}
\end{aligned}$$

[The Δv calculated here would be for the spacecraft to enter a circular orbit around the Sun at the same distance as Mars, but this would not constitute landing - the extra Δv to get to the Martian surface increases the total for the whole transfer to roughly 8 km s^{-1} (same as to get into LEO). Other, more complicated routes can be taken, some of which offer substantial efficiencies so the Δv for the trip can be much lower (although the time taken to complete the manoeuvre will be longer, and the Δv to reach LEO will still be the biggest single step)]

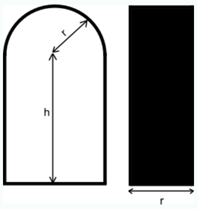
GPT 4V's output:
To calculate the Δv to go from Earth Low Earth Orbit (LEO) to Mars, we need to consider two main maneuvers: the transfer from Earth's orbit to the transfer orbit (Hohmann transfer orbit), and then from the transfer orbit to Mars' orbit.
1. The first part of the Δv, denoted as Δv_A, is the change in velocity needed to move from Earth's orbit to the transfer orbit. This is the velocity at perihelion of the transfer orbit minus the Earth's orbital velocity.
2. The second part, Δv_B, is the change in velocity needed to move from the transfer orbit to Mars' orbit. This is Mars' orbital velocity minus the velocity at aphelion of the transfer orbit.
The Hohmann transfer orbit is an elliptical orbit that touches Earth's orbit at its closest point to the Sun (perihelion) and Mars' orbit at its farthest point from the Sun (aphelion).
The semi-major axis of the transfer orbit (a_t) is the average of the Earth's orbital radius (r_E) and Mars' orbital radius (r_M). Given that 1 AU (Astronomical Unit) is approximately 1.496×10^8 km, we have:
$r_E = 1 \times 1.496 \times 10^8$ km (Earth's orbit radius) $r_M = 1.52 \times 1.496 \times 10^8$ km (Mars' orbit radius)
$a_t = \frac{r_E + r_M}{2}$
The orbital velocity of an object is given by $v_{\text{orb}} = \sqrt{\frac{GM}{r}}$, where G is the gravitational constant and M is the mass of the central object (in this case, the Sun).
The velocity at perihelion of the transfer orbit ($v_{p,t}$) is given by:
$v_{p,t} = \sqrt{\frac{GM}{r_E}} \times \sqrt{\frac{2r_M}{r_E + r_M}}$
The velocity at aphelion of the transfer orbit ($v_{a,t}$) is given by:
$v_{a,t} = \sqrt{\frac{GM}{r_M}} \times \sqrt{\frac{2r_E}{r_E + r_M}}$
The Earth's orbital velocity (v_E) is:
$v_E = \sqrt{\frac{GM}{r_E}}$
Mars' orbital velocity (v_M) is:
$v_M = \sqrt{\frac{GM}{r_M}}$
Now we can calculate Δv_A and Δv_B:
$\Delta v_A = v_{p,t} - v_E$ $\Delta v_B = v_M - v_{a,t}$
And the total Δv is:
$\Delta v = |\Delta v_A| + |\Delta v_B|$
Let's calculate these values step by step. We will use the gravitational constant $G = 6.674 \times 10^{-20}$ km^{3}kg^{-1}s^{-2} and the mass of the Sun $M = 1.989 \times 10^{30}$ kg.
First, we calculate the semi-major axis of the transfer orbit:
$a_t = \frac{1 \times 1.496 \times 10^8 + 1.52 \times 1.496 \times 10^8}{2}$
Now, we calculate the velocities:
$v_{p,t} = \sqrt{\frac{6.674 \times 10^{-20} \times 1.989 \times 10^{30}}{1.496 \times 10^8}} \times \sqrt{\frac{2 \times 1.52 \times 1.496 \times 10^8}{1.496 \times 10^8 + 1.52 \times 1.496 \times 10^8}}$
$v_{a,t} = \sqrt{\frac{6.674 \times 10^{-20} \times 1.989 \times 10^{30}}{1.52 \times 1.496 \times 10^8}} \times \sqrt{\frac{2 \times 1.496 \times 10^8}{1.496 \times 10^8 + 1.52 \times 1.496 \times 10^8}}$
$v_E = \sqrt{\frac{6.674 \times 10^{-20} \times 1.989 \times 10^{30}}{1.496 \times 10^8}}$
$v_M = \sqrt{\frac{6.674 \times 10^{-20} \times 1.989 \times 10^{30}}{1.52 \times 1.496 \times 10^8}}$
Now we can calculate Δv_A and Δv_B:
$\Delta v_A = v_{p,t} - v_E$
$\Delta v_B = v_M - v_{a,t}$
And finally, the total Δv:
$\Delta v = |\Delta v_A| + |\Delta v_B|$
Let's calculate these values.

Figure 23: An example of an astronomy problem with an incomplete response.

Computer Science - Understanding Error

Problem:

A girl named Xenia has a cupboard that looks like an arc from ahead. The arc is made of a semicircle with radius r (the cupboard's top) and two walls of height h (the cupboard's sides). The cupboard's depth is r, that is, it looks like a rectangle with base r and height h+r from the sides. The figure below shows what the cupboard looks like (the front view is on the left, the side view is on the right). Xenia got lots of balloons for her birthday. The girl hates the mess, so she wants to store the balloons in the cupboard. Luckily, each balloon is a sphere with radius. Help Xenia calculate the maximum number of balloons she can put in her cupboard. [figure1] You can say that a balloon is in the cupboard if you can't see any part of the balloon on the left or right view. The balloons in the cupboard can touch each other. It is not allowed to squeeze the balloons or deform them in any way. You can assume that the cupboard's walls are negligibly thin.



[figure1]

Input
The single line contains two integers r, h (1 <= r, h <= 10^7)

Output
Print a single integer — the maximum number of balloons Xenia can put in the cupboard.

Examples

Input
1 1

Output
3

Input
1 2

Output
5

Input
2 1

Output
2

time limit: 2 seconds
memory limit: 256 megabytes

GPT 4V's output:

```
import math

# Function to calculate the maximum number of balloons
def max_balloons(r, h):
    # Calculate the number of balloons that fit in the height of the walls
    balloons_in_height = (2 * h) // r

    # Calculate the number of balloons that fit in the semicircle on top
    # The diameter of the semicircle is r, so it can fit one balloon of radius r/2
    # The remaining height in the semicircle is r/2, which can fit another balloon
    balloons_in_semicircle = 1 + (h * 2 + r) // r

    # Calculate the number of additional balloons that can fit in the corners of the semicircle
    # This is the number of full r/2 radii that fit into the remaining arc length after placing
    # the first balloon in the semicircle
    remaining_arc_length = (math.pi * r / 2) - (r / 2)
    additional_balloons = int(remaining_arc_length // (r / 2))

    # The total number of balloons is the sum of the above calculated values
    total_balloons = balloons_in_height + balloons_in_semicircle + additional_balloons

    return total_balloons

# Read input
r, h = map(int, input().split())

# Calculate and print the result
print(max_balloons(r, h))
```

This program defines a function "max balloons" that calculates the maximum number of balloons that can fit in the cupboard based on the given dimensions. It then reads the input values for "r" and "h", calls the function with these values, and prints the result. The program takes into account the balloons that fit in the height of the walls, the semicircle on top, and additional balloons that can fit in the corners of the semicircle.

Figure 24: An example of a programming problem with an understanding error.

G Consideration for Social Impact

Certainly, it is essential to point out that as AI performs increasingly well on our benchmark, potentially even surpassing human capabilities, there are some potential ethical and moral risks that require collective oversight.

H Limitations and Future Work

Despite the value of this benchmark, there remains work to be done in the future. Firstly, our benchmark inevitably introduces some noisy problems, we will actively utilize community feedback to continuously refine it. Additionally, we aim to release new versions of the benchmark annually to mitigate issues related to data leakage. Moreover, this benchmark is currently limited to evaluating models' abilities to solve complex problems. In the future, we aspire for AI to assist with complex tasks and demonstrate value in real-world applications such as AI4Science and AI4Engineering rather than just problem-solving. This will be the goal of our future benchmark designs for evaluating AI capabilities. Nonetheless, at present, OlympicArena plays an essential role as a catalyst for further advancements.