NURTURING THE FUTURE STARS OF PHYSICS THE INTERNATIONAL PHYSICS OLYMPIAD (IPhO)*

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Received 8 October 2024, accepted 9 October 2024,
published online 27 November 2024

Since its inception in 1967, the International Physics Olympiad (IPhO) has played a pivotal role in promoting physics and fostering global educational links. This paper provides an overview of IPhO's history, structure, and impact on the physics community, with a focus on the recent IPhO2023 held in Tokyo. The challenges and successes of organizing an IPhO event are also discussed.

DOI:10.5506/APhysPolBSupp.17.7-A5

1. Introduction

I am honored to have been invited to speak at the 5^{th} Jagiellonian Symposium on *Advances in Particle Physics and Medicine*, and I also congratulate that the first positronium image of the human brain, demonstrated by the J-PET group, was reported during the symposium [1]. At the previous symposia in 2014 and 2019, I had the opportunity to give public lectures on the Fukushima Daiichi nuclear power plant accident. This time, instead of discussing our long-term work on antimatter at CERN, I chose to talk about the International Physics Olympiad (IPhO) under the title «Nurturing the Future Stars of Physics».

The IPhO is an annual physics competition for high-school students from around the world. The discussion of the IPhO at the Jagiellonian Symposium 2024 in Poland has special significance, as the first IPhO was held in Poland in 1967. Since its inception, IPhO has grown into a prestigious event that promotes excellence in physics education and fosters international cooperation. I had the privilege of serving as the Chair of the Scientific Committee for IPhO2023, which was held in Tokyo. This role involved overseeing the preparation of exam questions, conducting the exams, grading, and finalizing the results. Based on my experience, I will discuss the importance of IPhO to the physics community.

* Invited presentation at the 5^{th} Jagiellonian Symposium on *Advances in Particle Physics and Medicine*, Cracow, Poland, June 29–July 7, 2024.

2. Historical development of IPhO

IPhO began in Poland in 1967 to promote physics education among high-school students. The inaugural IPhO in 1967 gathered participants from five countries, including Poland. In the 1970s and 1980s, Eastern Bloc countries mainly attended the event. However, after the fall of the Berlin Wall in 1989, the competition expanded globally. Today, the IPhO attracts participants from over 80 countries annually — establishing it as a truly international event (see Fig. 1).

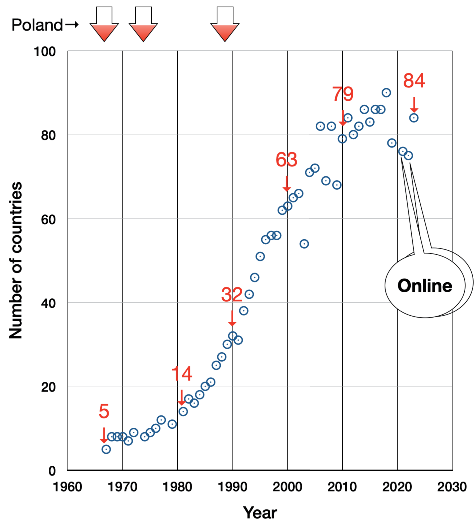

Fig. 1. Number of countries participating in IPhO by year.

In recent years, IPhO has faced significant challenges, particularly due to the COVID-19 pandemic. The 2020 competition, scheduled to be held in Lithuania, was postponed, and the 2021 event was conducted online for the first time in the IPhO history. The 2022 competition, originally scheduled to be held in Belarus, was canceled due to international circumstances, and an online event was hosted by Switzerland instead.

In 2023, despite the ongoing COVID-19 precautions, IPhO2023 was held in person in Tokyo, with approximately 400 students from 80 countries participating, reaching nearly pre-pandemic levels.

3. The structure of IPhO

Each country may send up to five students and two leaders to IPhO and also many observers attend. Students are selected through rigorous national competitions and receive extensive training before attending IPhO. The competition consists of two exams: an experimental exam and a theoretical exam, each with a duration of five hours.

A unique feature of the IPhO is its experimental exam. At IPhO2023, students worked on two experimental problems (worth 20 points) for five hours. After a one-day break, they worked on three theoretical problems for another five hours (worth 30 points). During the rest of the competition, students participated in tours and cultural activities organized by the host country, while we, the organizers, and the leaders from each country graded and finalized the results.

According to the IPhO Statutes [2], medals are awarded based on the combined scores of both exams as follows: the top 8% of the contestants receive gold medals, the next 17% (from 8 to 25%) receive silver medals, and the next 25% (from 25 to 50%) receive bronze medals. The next 17% (from 50 to 67%) receive honourable mentions. IPhO2023 also introduced "Diversity Commendations," which were awarded to four countries that excelled in both gender balance and performance.

3.1. IPhO syllabus

The IPhO syllabus, to which all IPhO problems must conform, covering theory, experiments, and mathematics, is published on the official IPhO website [3]. I will not reproduce it here, but for example, the theory syllabus includes integral forms of Maxwell's equations, special relativity, introductory quantum physics, and introductory statistical physics. The experimental syllabus includes handling experimental errors and data processing (although students are only allowed to use calculators without graphing or programming functions). The mathematics syllabus includes calculus. Although there may be slight differences between countries, the current IPhO syllabus includes the high-school physics with elements of undergraduate physics. Therefore, students practice using past problems and university-level textbooks to prepare for the exams.

4. Problem preparation and logistics

4.1. Problem preparation

The preparation of the IPhO2023 problems was a multi-year effort by my team. We prepared three theoretical problems and one reserve problem, as well as two experimental problems and 500 corresponding experimental setups. This is a considerable amount of work.

To ensure that the problems are neither too easy nor too difficult, we conducted a mock exam a year before the event with undergraduate and graduate students who had previously participated in IPhO, including some gold medallists. Based on the results, we adjusted the problems. Two months before the event, we trained a team of about 50 graduate students and postdocs from the University of Tokyo to grade the problems.

4.2. Confidentiality and translation

The problems are kept confidential until the day before the exam. For instance, on July 11, the day before the experimental exam, immediately after the opening ceremony, we held an international board meeting (IBM) with two leaders from each country. This was the first time the leaders saw the problems, the solutions, and the experimental setups. They (IBM members) were able to test the experimental setups and verify their functionality. They could also provide suggestions for revisions to the exam problems. We incorporated reasonable suggestions and updated the problems accordingly. Finally, the official English version of the problems was finalized through a vote at IBM. The same process was followed for the theoretical exam, with the official English version being finalized from morning until late at night the day before the exam.

Students take the exams in their native language. The leaders (and accompanying observers) translate the official English version into their native languages in parallel with IBM. Although some AI tools are now available, this is still a significant workload. The number of languages handled (including minor translations from official English to the country's English) is about 40 (see Fig. 2). Despite our hopes for an earlier completion, all translations were finally finished under immense pressure, just four hours before the exam started at 9 a.m.

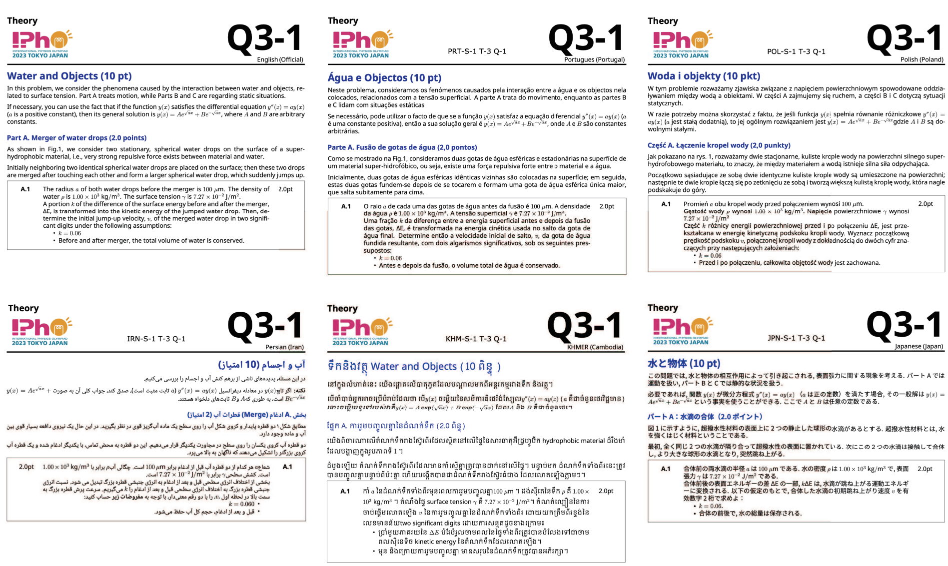

Fig. 2. Examples of translations of problem texts (IPhO2023 Theoretical Problem 3): from top left to bottom right, official English version, Portuguese, Polish, Persian, Khmer, and Japanese.

5. Exam logistics

Meanwhile, our team printed the translated problems (as well as the original English version), answer sheets, and worksheets for calculations and drafts, and distributed them to the exam booths. Each answer sheet and worksheet is personalized with a QR code for each student, for a total of about 40,000 sheets per exam. We conducted a rehearsal the day before the opening ceremony to make sure everything was ready for the 9 a.m. start.

As mentioned earlier, the exam lasts five hours. After the opening ceremony, we collected communication devices such as PCs and cell phones from the students. On the day of the exam, students had to leave their watches outside the exam booths and took the exam under strict supervision in individual booths. They could go to the bathroom with an invigilator and had water and snacks in the booth. After the exam, our team collected all the answer sheets and worksheets, transported them to the grading site, scanned them into the server, and printed them out for grading. One set was for our grading team and another set was for the leaders to grade their students' answers.

6. Grading and moderation

Our team spent about 12 hours each grading the experimental and theoretical answers, with each answer double-checked by two graders. In parallel, the leaders also graded the answers, but of course, the results did not always match.

Thus, on the day before the closing ceremony, we conducted a "moderation" session. At each table, two members of our grading team and two leaders from each respective country discussed and resolved discrepancies until an agreement was reached. In most of the previous IPhOs, the host grading team was divided by problem, so that the leaders had to jump between five tables (one for each problem) every 20 minutes. For IPhO2023, however, we adopted a system in which one team of two graders handled all the problems for one country, allowing the moderation to take place at the same table for about two hours.

In the evening, when all the scores were finalized, we proposed the medallists to IBM, who voted to accept them. This marked the conclusion of the Scientific Committee's role.

I should mention that the entire process of creating problems, revising, translating, printing, scanning answer sheets, entering scores, and finalizing results relies on an excellent IT infrastructure. We (and many other international science Olympiads) are grateful to use ExamTools [4], developed by the Swiss team for IPhO2015.

7. IPhO2023 problems

Finally, let me briefly touch on the IPhO problems. All problems and their sample solutions are available on the IPhO2023 website [5, 6].

Experiment 1 was inspired by the Kibble balance used in the 2019 revision of the SI unit system, which abolished the international kilogram prototype and defined the Planck constant (h). The problem was to determine the mass of a weight (washer) by balancing electromagnetic and gravitational forces and measuring the electromotive force of a moving coil.

Experiment 2 involved measuring the thickness of a sample (quartz plate) using birefringence. The students assembled an apparatus with a white light source (using blue LEDs invented by Akasaki, Amano, and Nakamura, who won the 2014 Nobel Prize in Physics), a diffraction grating, two polarizers (one fixed and one rotatable), a pair of lenses, and a light detector. The task was to measure the transmission intensity as a function of wavelength when the polarizers were parallel and perpendicular, and to determine the thickness of the quartz plate.

During the COVID-19 pandemic, computer simulations were sometimes used as a substitute for experimental tasks. This time, however, both experiments required students to assemble and adjust the apparatus themselves, testing not only their physics knowledge but also their experimental skills. Videos demonstrating the assembly of the apparatus are available at [5].

Theoretical Problem 1 dealt with the Brownian motion (Perrin's experiment) and culminated in a problem involving the coagulation of colloids in water (*e.g.*, adding electrolytes to dirty water to precipitate colloids and clarify the water), a method used widely to purify tap water.

Theoretical Problem 2 was related to neutron stars. It started with the mass formula of atomic nuclei, discussed the stability of neutron stars, and ended with the Shapiro delay phenomenon [7]. This phenomenon is the delay in the arrival of pulses from a neutron star pulsar when observed from Earth with a white dwarf in the line of sight. The problem was designed to be solvable using special relativity without requiring general relativity (which is not in the syllabus).

Theoretical Problem 3 focused on the "Cheerios effect", where objects floating on a liquid surface attract each other [8]. This phenomenon was modeled using two long rods floating on water, making it a two-dimensional problem that could be solved within the syllabus.

8. The final score distribution

The final score distribution is shown in Fig. 3. Fortunately, our problems were neither too hard nor too easy, resulting in a well-balanced score distribution.

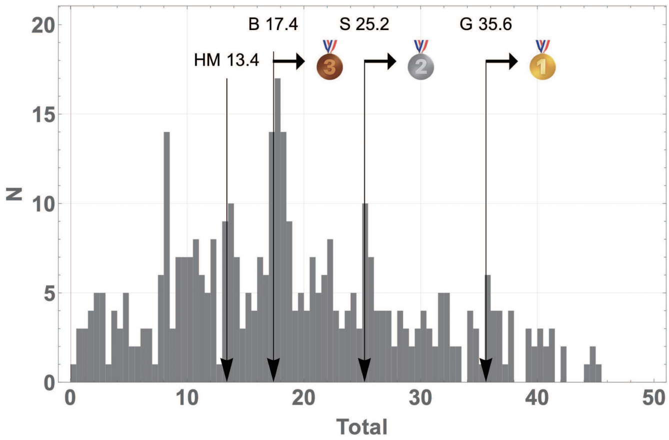

Fig. 3. Distribution of IPhO2023 total (experiment+theory) scores and medal award thresholds.

9. Conclusion

Many IPhO alumni have gone on to become prominent scientists, engineers, and educators. The competition provides a platform for young talents to showcase their skills and passion for physics, often leading to scholarships and opportunities at top universities. IPhO fosters a spirit of camaraderie and collaboration among participants from diverse backgrounds. It creates a network of young physicists who can work together on future scientific endeavors, contributing to global scientific progress. The rigorous preparation and challenging examinations push students to deepen their understanding of physics. This, in turn, raises the standard of physics education in their home countries as schools and teachers strive to prepare students for the competition.

As the Jagiellonian Symposium 2024 participants are leaders in their fields, I encourage you to mentor young physicists and share your expertise to inspire the next generation of scientists. If possible, consider mentoring students who aspire to participate in IPhO or similar competitions.

I would like to thank the members of the IPhO2023 Scientific Committee, all those involved in organizing the event, and all the students and country leaders who participated. The IPhO2023 Final Report is available at [9].

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