N°5
Tuesday, July 22ND

PHYSICS BEYOND FRONTIERS

International Physics Olympiad
FRANCE 2025

After the Bang

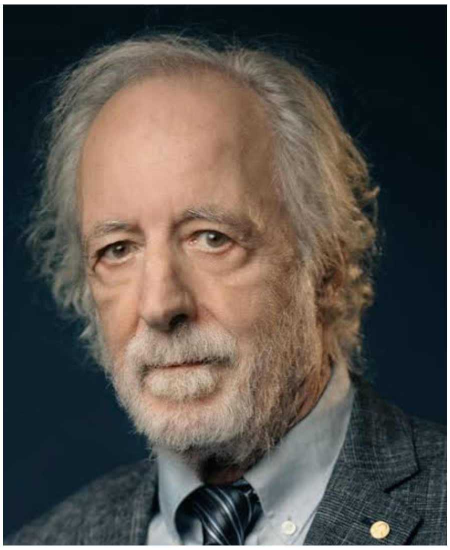
Look back at the theoretical exam

The IPhO – France 2025 anthem

Mid term party

EDITO

Attosecond pulses as a blueprint of physics research



This July 22 marks the end of the 2025 International Olympiads of Physics experimental and theoretical tests. It is also very close to the 65th anniversary of the first laser operation by Theodore Maiman on May 16, 1960. Since then, laser pulses have steadily contracted from microseconds to attoseconds, a staggering 12 orders of magnitude decrease, through many inventions which I witnessed during my carrier. The last step, from femtoseconds to attoseconds, happened 25 years ago, thanks to the discovery of High Harmonics by Anne L'Huillier (2023 Nobel Prize in Physics) in 1987, a little after her PhD. Anne and I were working in the same group at CEA Saclay, and I can attest that nobody was thinking of attoseconds at that time. It took a few years to Farkas and Toth to realize the potential the harmonics spectrum had in the time domain, and almost 15 years to imagine an experimental proof. This proof works in the spectral domain and uses Above-Threshold Ionization (ATI, observed for the first time at Saclay in 1979, with a nanosecond laser!) as a necessary non-linear device. So, both main ingredients of attosecond pulses were studied as fundamental processes independently of the attosecond "application".

I believe this is a general rule in research: fundamentals first! If I look at the blatant unsolved problems in Physics right now (dark matter, dark energy, vacuum energy), they appear out of reach to us. These problems come all from the astronomy observation, at a very large scale. The situation is not unlike that of Physics at the end of the 19th century when the simple existence of matter seemed to threaten the whole edifice of "classical" physics. Interestingly, these problems started "innocently" from the observation of dark lines in the sun spectrum by Wollaston and Fraunhofer before leading to the universe of "quantum" one century after.

Fortunately, young talented physicists are on their way, as shown by the participants to the 2025 Olympiads, and it is possible that one of them will, one day, invent a solution that nobody thinks of now. Physics, with chemistry and biology, is the best explanation of our world, and I am confident that the current challenges will eventually be met.

Pierre Agostini
2023 Nobel Prize in Physics

YESTERDAY'S HIGHLIGHTS

Look back at the theoretical exam

From hydrogen to galaxies

How can we determine the structural and dynamical properties of our galaxy from a planet orbiting a star located within its plane? This is one of the challenges at the heart of theoretical problem 1 of the IPhO France 2025; the other is to explore the complex physics of galaxies.

NGC 4414: A Flocculent Spiral Galaxy © ESA/Hubble & NASA, O. Graur, S. W. Jha, A. Filippenko

The observation method is based on detecting the hydrogen 21 cm wavelength line, as galaxies are transparent to this radio emission from stars and the interstellar medium. The flip of the electron spin in the hydrogen atom, analyzed here using the semi-classical Bohr model, results in the emission of the 21 cm wavelength line.

Measurements of the rotational velocity of stars around the galactic center show that the galaxy's mass is not concentrated solely in the bulge, indicating the presence of dark matter. A dark matter model is then studied in the IPhO problem.

By observing the galactic plane in a given direction and measuring the 21 cm Doppler frequency shift from hydrogen-containing sources such as star clouds and nebulae, we can reconstruct their radial velocities around the galactic center and their distances from it. Scanning the galactic plane allows us to determine the mass distribution within the galaxy and model its gravitational potential.

Even more exciting is the possibility that galaxies could lead us to new physics beyond the current principles of mechanics. In fact, the dark matter model fails to explain the relationship between mass and the high radial velocities observed in galaxies, known as the Tully-Fisher relation. The Mond theory, which modifies Newton's second law in a low-acceleration regime, could reconcile theory with observations.

Pressure powered clock

© Victoria and Albert Museum, London

In the 1760s, the British craftsman James Cox, renowned for the Peacock Clock on display at the Hermitage Museum in Saint Petersburg, Russia, conceived a clock that wound itself automatically using atmospheric pressure variations. Really?

Using nature as a source of energy is a very contemporary concern. But as early as the 18^{th} century, it was also central to the reflections of clockmakers and scholars who sought to create a perpetually moving clock. In this (ultimately impossible) quest for perpetual motion, physicists and engineers competed in ingenuity to design devices that exploited atmospheric changes. One clock — still quite incredible — apparently operated solely on atmospheric pressure variations: it was imagined around 1760 by the Englishman James Cox, and its core was a barometer filled with 5 liters of mercury, or 68 kilograms. The historical documents available have made it possible to produce a physical model of this clock. The study of this model, as presented in the second theoretical question (T2) of this IPhO, suggests that this clock retains an element of mystery. Why? Because its mechanism is intrinsically unstable.

This clock relies on the mercury barometer principle: when a long glass tube filled with mercury is inverted into a mercury cistern, the liquid does not fill the entire tube. Instead, it settles at a height—typically 76 cm for 1,013 hPa—above the cistern level, held up by atmospheric pressure. The space above the mercury is nearly a vacuum.

In Cox's clock, we find both of these elements—the inverted tube and the cistern—but with notable adaptations. First, both the tube and the cistern are suspended by chains from a device resembling the beam of a balance (modeled by cables in problem T2): when the tube lowers, the cistern rises, and vice versa. Furthermore, the lower part of the tube has a small diameter, but it bulges significantly at the top to form a sphere 17 centimeters in diameter.

The principle seems simple: when atmospheric pressure increases, the mercury rises in the tube; the tube therefore becomes heavier, while the cistern—containing less mercury—becomes lighter. These movements are harnessed by an ingenious mechanism invented by physicist Christiaan Huygens to wind the weight that powers the clock's movement, all while allowing it to continue operating.

To provide enough energy to the clock, one must ensure a large change in weight for a given pressure variation—thus a design that maximizes the volume displaced. This explains Cox's choice of shape: starting from a state where the spherical container is half-filled with mercury, 5 hPa pressure change causes a weight change of 1 kilogram. To maintain pressure equilibrium, the tube gets heavier and the cistern lighter.

This is where a subtlety comes in: if the tube descends into the cistern, the mass of mercury inside it will increase. Indeed, the narrow part of the tube plunges deeper, so the wider (spherical) part must fill more to maintain the same mercury level relative to the free surface in the cistern (which is fixed by atmospheric pressure). Thus, the tube keeps getting heavier and the cistern lighter, causing the balance to tilt more and more. How far? Since the barometric mechanism is intrinsically unstable, the balance must eventually reach a limit stop unless a stabilizing mechanism is added. Perhaps this is why the archives mention that in an early version of the clock, the system was too effective: the driving weight was constantly raised to the top position, and a disengagement mechanism had to be added to prevent the chains from breaking due to excessive tension.
If the clock did indeed function, we suspect it used a bistable system: the balance shifting from one stop to the other whenever pressure increased or decreased beyond a certain threshold. Each shift would cause a mechanical shock when the stop is hit, potentially damaging or breaking the mechanism.

Unfortunately, we cannot settle the question today: the clock is now kept at the Victoria and Albert Museum in London, but it has been emptied of its mercury. When will it be restarted to test the conclusions of question T2?

Champagne!

Champagne is a sparkling wine produced in the region of the same name in north-eastern France using Pinot Meunier, Pinot Noir or Chardonnay grapes grown in the area (fig 1). Its elaboration, known as méthode champenoise, follows two steps: after a first alcoholic fermentation, yeasts and sugar are added, followed by a second fermentation in bottles. After aging, the bottles are quickly reopened two remove the yeast (dégorgement) and then corked. In a standard Champagne bottle, ≃0,2 mol of CO_2 are trapped either in the liquid phase or in the gaseous phase present in the bottle neck (with a pressure of around 6 bars).

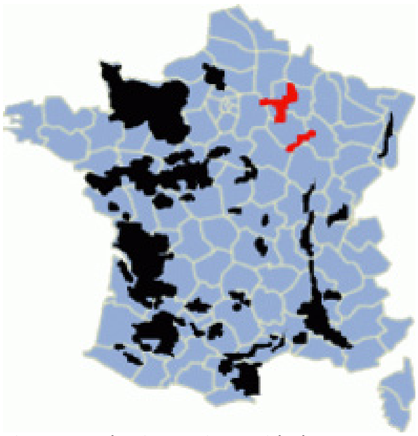


Fig 1: French wine regions with the Champagne appellation in red

Fig 2: Two different plumes observed after opening a bottle stored at 6 °C (left) or at 20 °C (right) (from [1]).

When the bottle is opened, the quick adiabatic expansion of CO_2 results in a drastic cooling. Surrounding water vapor immediately condenses, creating a grey-white plume characteristic of Mie diffusion (fig 2, left). In contrast, for bottles stored at temperatures above 12 °C a blue haze appears during a few milliseconds (fig 2, right). Paradoxically, for higher initial temperatures, the expansion leads to final temperatures low enough to allow the crystallization of CO_2 [1]. Small CO_2 crystals, nucleated on residual solidified water, are responsible for this blue Rayleigh diffusion. This behaviour is not seen for lower storage temperatures.

Champagne poured in a flute glass is in a non-equilibrium state since initially dissolved CO_2 gas molecules (concentration cL) are in excess compared to the equilibrium concentration expected when the liquid is under atmospheric pressure P_0. c_L decreases due to bubbling (≃20%) and diffusion at the free surface (≃80%) [2].

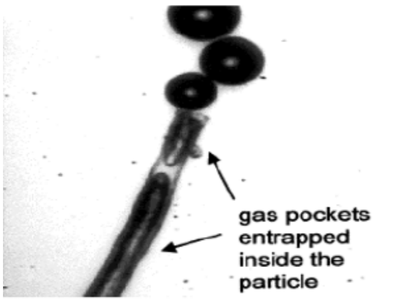


Fig 3: Bubble nucleation in a pre-existing gas cavity (from [3])

Bubbles are mainly created in pre-existing cavities where gas was trapped when the glass was filled (mostly around cellulose fibers coming from the surrounding air or from when the glass is cleaned; fig 3). These gas cavities have a radius of curvature high enough such that the extra Laplace pressure does not prevent dissolved CO_2 gas from entering [3]. Once buoyancy overcomes the capillary force, the bubble can rise. During this movement, CO_2 transfer from the surrounding supersaturated liquid (concentration c_L) to the bubble surface (concentration c_B) is shown to be proportional to c_L-c_B. As a result, the bubble radius R grows linearly with time.

The speed at which a bubble rises is observed to be proportional to R^2, which can be explained by a Stokes drag force (Reynolds number typically ranges between 0.2 and 90) and by the fact that the inertial contribution is negligible compared to buoyancy [4]. Bubble growth therefore leads to accelerating rise. During ascent, a displacement of the surrounding liquid leads to an "added mass" effect. This contribution is nevertheless negligible compared to buoyancy.

At the free liquid surface, the bubble does not emerge immediately; surface tension keeps it separated from the surrounding air by a thin liquid film (thickness around 1 µm for millimetric bubbles). Due to capillary drainage, this film thins progressively and eventually forms a hole with a rim, which retracts in ≃100 µs for millimetric bubbles. Within the next few milliseconds, the bubble then collapses. It has been shown experimentally [5], for water with a surfactant, that modeling the bubble as a Helmholtz resonator quantitatively explains the airborne acoustic pressure signal emitted by the bubble. In the case of champagne, most of the acoustic signal is ultrasonic but the frequency chirp observed due to the rim retraction could explain the high-frequency acoustic signal heard when Champagne is poured in a glass. The collapse of the bubble projects a liquid jet into the air which, because of Rayleigh-Plateau instability, breaks into small droplets (fig 4). This aerosol is responsible for the especially refreshing sensation of Champagne.

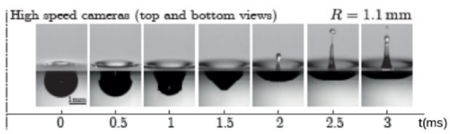


Fig 4: Collapsing air bubble (radius R) in tap water with droplet emission (from [5])

[1] Liger-Belair G. et al., Scientific Reports 7:10938 (2017)

[2] Voisin C., Ph. D. dissertation, Laboratoire d'Oenologie et de Chimie Appliquée, Université de Reims, France, 2005.

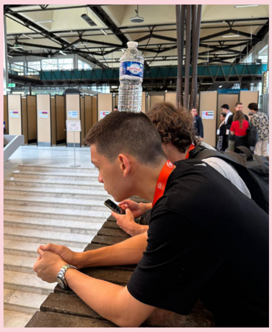
[3] Liger-Belair G. et al., Langmuir 18: 1294-1301 (2002)

[4] Liger-Belair G. et al. Langmuir 16 : 1899-1895 (2000)

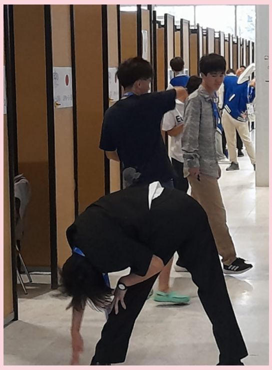
[5] Poujol M. et al., Phys. Rev. Fluids 6(1), 10.1103 (2021)

Stress: Your style!

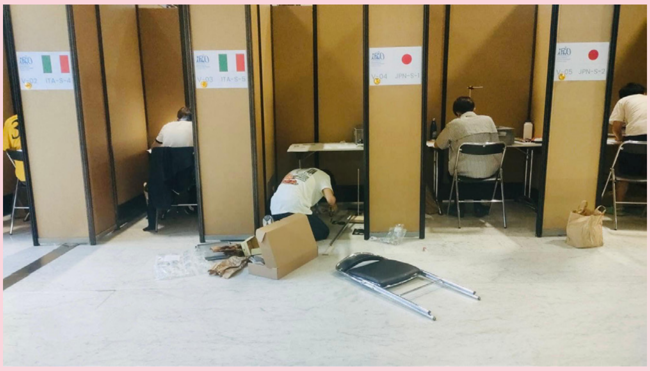








Inside the test boxes



Tiny talk, huge records!

On Monday afternoon, physicist Julien Bobroff from Université Paris-Saclay gave a talk on world records in physics — while breaking one himself: he delivered the world's smallest presentation, with all his materials fitting into a matchbox!

J.Bobroff interviewed scientists around the world who had broken records, trying to understand how and why they did it. He chose to share three of his favorites.

The first was the highest pressure ever achieved. Creating extreme pressure means applying the greatest possible force on the smallest possible surface. In France, researchers pressed objects between two diamond tips, reaching 9 million bars — three times the pressure at Earth's core. Meanwhile, in Livermore, scientists focused 300 laser beams onto a diamond sample and achieved 30 million bars. Amazingly, the diamond did not explode!

Next came the roundest object ever made. A few years ago, scientists realized the standard kilogram wasn't as precise as they thought. They decided to define the kilogram by counting atoms. To do this, they needed the purest silicon sample, shaped into a perfect sphere. The volume of the sphere could then be compared to the volume of a single atom to determine how many it contained. To be accurate, the sphere had to be incredibly round — polished to within just 1 nanometer. One researcher spent three months achieving this!

The final record was for the coldest gas on Earth. The physicist behind the experiment didn't even know he had set a record until J.Bobroff contacted him. He had created a Bose-Einstein condensate to recreate the falling-body experiment with atoms. The resulting gas reached a temperature of just 38 picokelvin — a world record!

What stands out is that breaking records isn't the goal. These feats are stepping stones, enabling scientists to explore phenomena never seen before.

J.Bobroff concluded by emphasizing what these record-breaking experiments share: advanced technology, patience, perseverance, and global collaboration. That's the formula for pushing the limits of physics. Now — it's your turn!

From chaos to harmony

During the drum workshop, IPhO participants explored rhythm and collaboration : starting with a chaotic blend of sounds that evolved into a stirring final performance: **the IPhO anthem!**

Relive this moment by scanning the QR code

Feedback on the Midterm Party

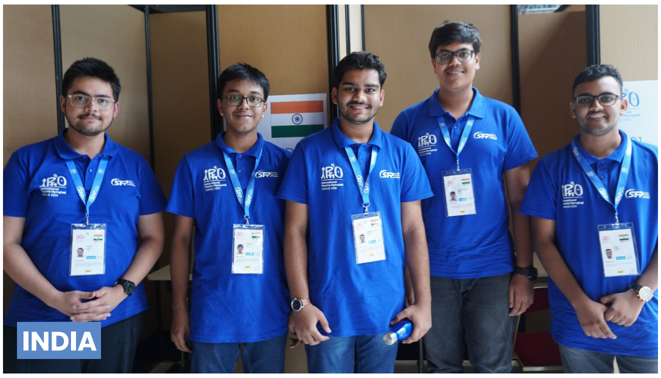
The Midterm Party is an evening event that takes place halfway through the IPhO week and marks the end of the experimental and theoretical tests for students. It took place on Monday, July 21, in the grand hall of the École Polytechnique, where hundreds of boxes had been stored just a few hours earlier!

The stress evaporates and tensions disappear, giving way to a moment of conviviality and a wonderful atmosphere. After happily retrieving their connected devices, the students reunite with their leaders to share in the celebration. Countries mix, students mingle with leaders and volunteers.

With a lively concert by the Drumteam Paris percussion company, some danced to their hearts' content while others enjoyed a hearty buffet. Relaxation and good humor were in the air, with laughter and clapping. A giant conga line of students formed in the middle of the Grand Hall.

Tomorrow, the leaders will have to resume marking their teams' papers, just like all French markers, while the students will be able to enjoy some fantastic scientific and cultural visits in the Paris region!

Now it's time to relax and explore. The last big thrill: the medal and award ceremony! WHO WILL WIN GOLD?


INDIA

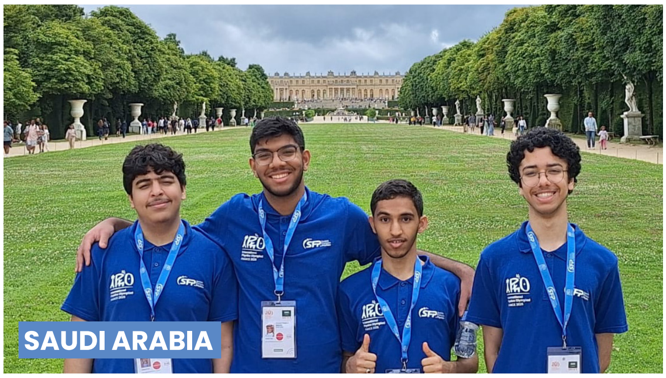
MONGOLIA

IRAN

Rendre hommage aux disparus
BULGARIA

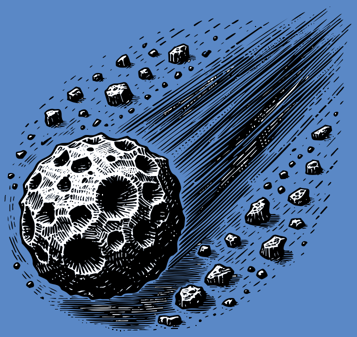
BOLIVIA

KOREA

SWITZERLAND

SAUDI ARABIA

Physics on this day

JULY 22, 1994



The last fragment of the Schoemaker-Levy comet falls on Jupiter

This comet (D/1993 F2) was discovered by Carolyn and Eugene M. Shoemaker, David Levy and Philippe Bendjoya on March 24, 1993. Unlike other comets, it orbited Jupiter, having probably been captured between the mid-1960s and 1970s.

By studying the variation of its orbit, it was possible to predict a collision in July 1994, and to know that the comet was fragmented due to Jupiter's gravity, and that the fragments would fall in July 1994.

On July 16, the first fragment of the comet was observed by the Galileo probe and the Hubble Space Telescope.

Schedule

Tuesday, July 22

Student

9:00AM – 5:30PM: Laboratory visits

8:30PM-10:00PM: French style meal provided by Air Liquide

Leaders & observators

8:30AM: - 7:30PM: Hotel - Grading

Join us on : **@ipho_2025**

Happy birthday to

Richard Dudek
from Slovakia

Jussi Vilho Kalervo Pyysalo
from Finland

Tsotne Giorgadze
from Georgia

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