{jIAPS} 2016

ICPS edition

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Editor-in-chief	Ivana Kurecic
Editors	Henrik Siboni
	Sofie Metzchen
Spell checking	Gönenc Mogol
	Moeen Ghafoor
Cover page image	Berit Watkin

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EDITOR'S NOTE

Dear colleagues and friends,
I would like to welcome you to the ICPS 2016 edition of the journal of the International Association of Physics Students - **jIAPS**.

This magazine brings you articles written especially for you, physics students, by your colleagues from around the world. You will read about some of the wonderful trips and activities organized and attended by the members of the International Association of Physics Students (IAPS), find out what it's like to cooperate and collaborate with your peers on an international level, and learn about new topics in physics, guided by students such as yourselves.

In this issue, the Executive Committee of IAPS would like to congratulate Baptiste Ravina for winning this year's jIAPS Article Contest, with his contribution titled "Solving Problems in Theoretical Physics," for which he will be awarded the full ICPS participation fee! You can find his article (and other selected submissions) on the following pages.

In conclusion, I would like to express my sincere gratitude to everyone who helped form this issue -- most of all our PR Manager Henrik Siboni, and Sofie Metzchen Andersen of the PR Subcommittee, who spent long hours to put together what you see here. A grateful mention goes to the whole PR Subcommittee and all contributors to this edition!
More articles can be found at **jiaps.org**.

Ivana Kurecic
Editor-in-chief

PRESIDENT'S LETTER

Dear reader,
Before you is a balanced mix of everything a physics student needs – scientific articles, opportunities for improvement, reports from interesting events and member articles through which you can get to know you fellow physics students from around the globe. This year, IAPS has really spread its international wings – gaining 6 new members in 5 new countries across 3 continents. In this edition, you will read about our new National Committee in Mexico. Their country was the host of the International Year of Light Closing Ceremony which IAPS volunteers attended – you will find their experiences here as well. Even though it is over, IYL will leave a mark on IAPS with the start of the annual School Day project – with reports from our German and Iranian members on their experiences. However, these are not the only articles on educational projects so you have plenty to read. If you are looking for an opportunity to learn and visit some awesome labs, check out our articles on iaps2CERN, Lights of Tuscany and iaps@GranSasso. Last but not least, the variety of scientific articles this year should tickle anyone's fancy and give a good overview of the full potential of physics for those just starting. After all this, make sure you don't forget to check out our featured ICPS and PLANCKS articles!
A special thanks goes to everyone involved in process of putting this edition of jIAPS together. I hope you have learned something new in the process. This is the whole point of student involvement so IAPS and myself eagerly await more.

Ana Milinović
President

Connected by light- IYL Closing Ceremony

2015 was announced to be the International Year of Light (IYL) by the United Nations. This year came to an end in the beginning of 2016. People from all over the world were invited to meet in Mérida, Mexico from February 3 to 6 for this occasion.

An article in the last issue of jIAPS reported on the Opening Ceremony in Paris, France. Similar as it was the case for that event, the organisers reached out to IAPS asking for student volunteers. Nine students from six different countries were found to complete the team of almost 30 volunteers.

Travel expenses weren't covered by the organisers, which caused the rather low number of IAPS volunteers. However, sponsors were found from universities, societies or by similar means, one of which was the The Optical Society, which made the attendance possible for two of the IAPS members. We also want to thank the Danish Physical Society, SPS, the Student Union in Graz, the Farhangian University and IYL Secretariat.
The team of volunteers from five different continents was working very well together. The registration, technical support and guidance of the participants were the main tasks. But luckily we had the chance to attend most of the program. The Closing Ceremony was opened with a message of the Secretary General of the United Nations, Ban Ki Moon.

During the official program John Dudley, who is the chairman of the Steering Committee of the IYL, gave a feedback on the International Year of Light and Light-based Technologies naming also a garden society as an organiser of light events . He summarized the significant effect of the IYL on the world. There were more than 5000 activities in 148 countries and 15.000 media mentions in 120 countries.

Two Nobel laureates were invited as guest speakers, namely Shuji Nakamura, the inventor of blue LED and John C. Mather, who was the leading scientist behind COBE satellite that investigated the Cosmic Microwave Background. He is currently the project scientist of the James Webb Space Telescope. The ceremony did not only catch the physical aspect of light but it also covered light in architecture, light in arts and air pollution by light. Workshops and coffee breaks between the plenary and panel sessions allowed the participants and volunteers to make contacts that might help in the future.
The evenings were covered by a visit to the Gran Museo del Mundo Maya, open-air light exhibitions in the streets of Merida, and time spend together with the volunteers in either the hotel lobby or at a local bar.

The ceremony ended with a cultural trip to the beautiful sights of Izamal and Chichén Itza. Two lectures on Mayan culture were held in the foreground of the pyramid El Castillo illuminated with different colours. Appropriate for the International Year of Light and Light-based Technologies, the event was completed by the Chichén Itza Light Show.

The Closing Ceremony made a very memorable impression on us We became a part of a team of international volunteers, who are committed to popularize science. Hopefully we all stay connected and we will meet again, let it be at an IAPS event or at another similar event as a volunteer.

Gábor Galgóczi is active in the Hungarian NC and is currently working on particle detectors.
Sabrina Gronow is an active part of NC Germany and the IAPS EC. Her thesis is on the astrophysics of stellar objects.

The IAPS School Day

The past academic year marked the beginning of a new concept - the IAPS School Day! 10 November - to be specific - in an effort to improve our standing in outreach and education, we invited members to spread interest in physics amongst the local school pupils. In the end, the event reached eight different countries, probably resulting in the most spread out, simultaneous IAPS activity ever. Some places showed the wonders of physics to just a few kids while others managed to reach hundreds.
No matter the amount, we are thankful to everyone who joined and it has certainly helped create the next generation of physics students as well as strengthen the international bonds between the current member community. We hope that it will become a tradition and grow with each passing year. If you are interested in hearing about the next edition of the School Day, you are always welcome to contact IAPS as ec@iaps.info. We have also put a guideline up on our webpage with possible experiments and more. Find more information here:
iaps.info/activities/iyl/school-day

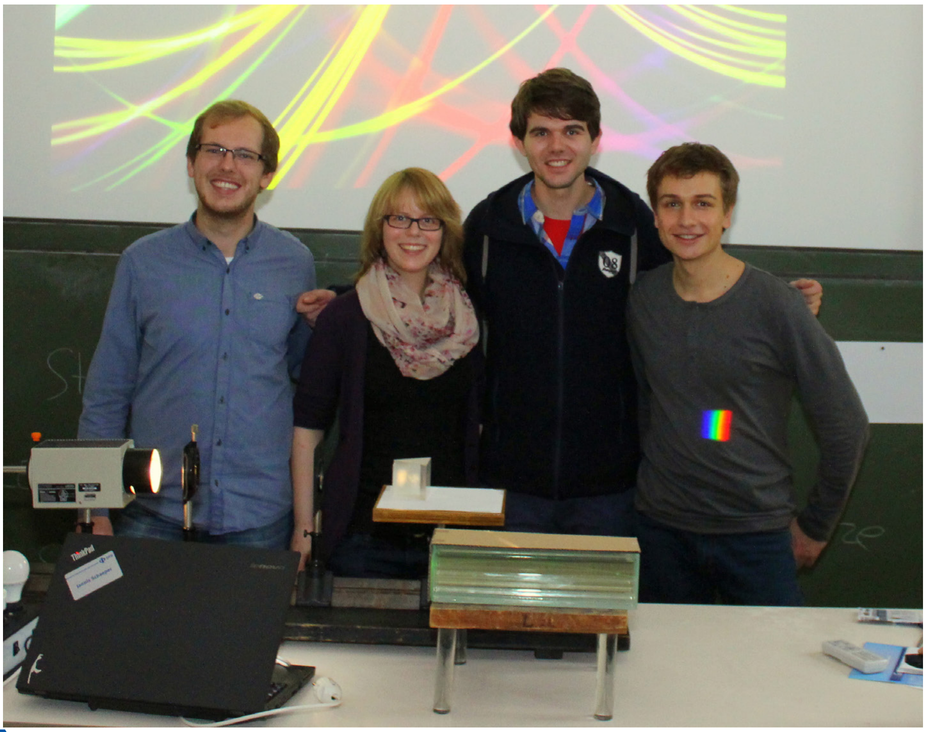
As a thank you to this year's participants, and as an inspiration, we have gathered two stories from the special day on these two pages.
Enjoy!

With the jDPG

Light! - all present but still unimaginable and fascinating. Pupils of five different schools all over Germany had the opportunity to do hands on experiments teaching the physics of light. In occasion of the “International Year of Light” the regional Groups of Dortmund, Göttingen, Hannover, Karlsruhe and Ulm visited several high schools to conduct simple “light-experiments” with interested students.

Teens in Göttingen and in Ulm explored optical phenomena and answered questions like “is white a color?” or “How do 3D glasses work?”. Other pupils in Hannover learned how light can be used to detect gravitational waves, while those in Dortmund did an experiment on sky’s color using an old aquarium. They learned a lot about scattering by observing red and blue light, developed from the white light of an overhead projector on different sides of the aquarium. Due to high demand students in Karlsruhe were allowed to build a sundial and several optical setups two days in a row.

Particularly, the opportunity to work with high-quality instruments in small, independent groups is not possible in everydays classroom, explained Mrs Redeker-Borsch, physics teacher in Dortmund. At all participating schools, teachers expressed their praise to the students and invited them to repeat such an event in the coming year. The experiments, as well as exchanges between young people and students was thus a valuable addition to regular physics lessons and has even encouraged some of the pupils to study physics.



Annika Tebben is currently doing her Master studies in Physics at Heidelberg University. As a member of the EC of the NC Germany, she is responsible for the physics education and young people section.
Stina Scheer is currently writing her bachelor thesis on theoretical quantum optics and leads the local group of NC Germany in Hannover.
Translation by **Michael Bornholdt** and **Sören Kotlewski**.

With the FAPS

After the approval of the Supreme Cultural Revolution Council (SCRC) in 2011 in Iran, and the aggregation of all teacher training centers, the Farhangian University (Teacher Education University) was established and began its activities in January 2012. It represents a critical point in the almost one century long tradition of teacher education in Iran. It is an umbrella organization with around 70 branches and 100,000 enrolled teacher students in various disciplines throughout the country. The Farhangian Association of Physics Students (FAPS) was founded legally, began its formal activities in January 2016 and joined IAPS as a Provisional Local Committee in March 2016 but in the other hand its informal activities started in just two years after Farhangian University was established, with more than 20 fantastic physics gatherings and events until now.

The IAPS IYL School Day was a great opportunity to share our knowledge and raise awareness about this day in schools. Inviting pupils and teaching them physical aspects of light and making more of them interested in physics were our goals for this international event.

Having been in the International Year of Light 2015, the focus was on light and light based technologies. Therefore, the society of Farhangian physics students on November 6th, just a few days before the IAPS IYL School Day, decided to organize a meeting with a few invited professors, teachers and more than 80 physics students at the Esfahan branch to celebrate and inform them about the School Day.

In our meeting. we:

- presented a very good lecture about IYL agendas, aims and goals of this year by the student Mr. Javid Fajamnia.
- presented what we did during the 2015 International Year of Light and Light-based Technologies to promote its goals.

- introduced the guideline for the IYL School Day and how students can creatively share their own knowledge and work with the pupils at schools, showing them exciting physics experiments in order to secure a continued and growing interest in physics, especially light, and science.
- reviewed the guideline for the IYL School Day at different levels for the students to help them understand the importance of physics for development and society through education and experiments.
- discussed the best ways to organise the School Day with students, invited professors, and teachers from November 10th-12th in schools.
- divided the students into different high schools throughout Esfahan and answered their questions about this day.

Besides professional lectures and speeches, we placed great emphasis on marginalised programmes in order to create a cohesive community among physics professors, students and teachers. At the end, we served a big IYL School Day cake that the FAPS EC had cooked and designed especially for this day and celebrated in a very warm and friendly atmosphere.

At the conclusion of this gathering from November 10th-12th, from the exact date of the IYL School Day to two days more, we covered more than 80 high schools throughout Esfahan. Most of the students were undergraduates and we hope that this programme provided a very good opportunity for them to be more active and become more close to the pupils in schools . We hope that we improved the pupils understanding of the central role of light in the modern world from the first studies of optics 1,000 years ago to the discoveries in optical communication that power the internet today.

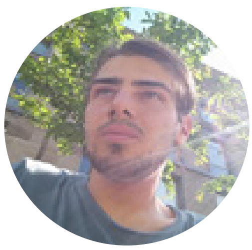
At the end we must thank all of the students who helped us make this programme come true and especially the ones who paid for this event out of their own pockets.

Amirhossein Payandeh started his BSc in Physics in 2013 at the Farhangian University, Esfahan, Iran. He was also elected as the president of the 2016 Farhangian Association of Physics Students. One day, he wishes to be a very good and lovable physics teacher. Like most IAPS members, he is counting the days until he arrives in Malta for the ICPS.

Lights of Tuscany

Lights of Tuscany 2015 - 17th to 21st December - brought a party of 43 students of 14 different nationalities in Pisa and Florence to visit some top physics research facilities in central Italy. I had the luck of being among them, together with some colleagues from my university, somebody I already knew from other IAPS events and a lot of new interesting people to meet.
The event was organized by AISF (IAPS Italian NC), in the framework of the International Year of Light, and has for sure been a success.
We were lodging in Pisa, in a small hotel next to the station. The town is small - we could reach any place in Pisa by foot – while we had a bus bring us to LENS and VIRGO, and we took a train to Florence for the day dedicated to tourism.
I want to tell you something about the event with this notes I wrote just back home after the event for AISF, revised and added with some parts
that's the word that first comes to my mind: to be referred to the physical effort, to the emotions, and of course to the scientific programme.
The day at LENS we had a set of short talks and visited about a dozen laboratories carrying out top notch research in fields ranging from quantum optics to biophotonics, from cold atoms to extreme laser physics. I was pleased to see how friendly and young (average age: 35) the environment was, and how willing the researchers were to tell us about their work.
LENS (European Laboratory of Nonlinear Spectroscopy) is linked to the Florence university, next to the physics, chemistry and biology departments. What's great is researchers in all these disciplines work there, collaborating to explore light from fundaments to most recent applications. I still remember that day and lots of the laboratories we visited, where I could see both realizations of things I studied in my courses and experiments in fields I did never hear of before.
Because we can never get enough, the day after we woke up quite early to visit the labs in Pisa physics department, containing a laser gyroscope and an advanced crystal growth facility. Here we shot the group picture, freezing in the Italian winter wearing just the beautiful event t-shirts.
Just a sandwich before heading to VIRGO: the large-scale Michelson interferometer looking for gravitational waves that is currently undergoing a big upgrade. Impressive as you can imagine.
It was just before VIRGO rose to worldwide attention when its American brother LIGO detected spacetime-bending waves from a black hole merger for the first time ever. In that period, the interferometer was shut down, undergoing a major technical upgrade that will enable it to see even more gravitational waves-producing events, and better.
Professor Cella and his little son, after a talk on the state of research on GW, guided us on a tour of the place and we could also enter areas that are off-limits when the experiment is operating.
Last day, still in Pisa, the group split to listen to conferences and visit laboratories at NEST, nanotech lab of Scuola Normale Superiore, and the photonic circuit facility at TeCIP, Sant'Anna school.
Normale and Sant'Anna are higher educational institutions, very selective and with a fame of being very tough. These and the University, as old ad 1343, attract a large number of students to the small town of the leaning tower. In the weekend nights the alleys of the Old Town and the banks of the river Arno are crowded with young people, in a festive atmosphere we had the pleasure to enjoy almost every evening.
For those that are into experimental matter physics, photonics, and for all the LASER-lovers out there this trip is essential. The astrophysicists could enjoy a conference on gravitational waves and see with their eyes how they're actually detected. But science is interesting on its own: during the LightTalks that served as event opening, we could also discover something about medical and artistic applications of optics.
We were also presented good opportunities for PhD, internships, and thesis projects in almost all of the places we visited.
What I can say by my side is I'm going to LENS for my bachelor's thesis, I really liked that place and caught the chance they gave me. I know some people were considering PhDs there and in Pisa. This is a good goal for an IAPS event, it's a proof that the network created by the association generates professional opportunities.
Since its inception AISF has been active in searching and creating opportunities in Italy and abroad, and linking them to students, with a project called FERMI.

The young Italian committee AISF is doing a great work: this is the second international event ending with a big success, and that we hope to replicate next year, while we are planning ICPS2017.
Thorough thanks would take a page, but at least I need to thank Marco Morrone, Giulio Pasqualetti, Francesco Sciortino and the other organisers for their hard work, and all the professors and researchers that invested their time for inspiring us.



Stefano Polla is on the last year of his bachelor at University of Milan. He took part in Lights of Tuscany, IAPS for Fusion and Balaton Summer School. Active in his local committee.

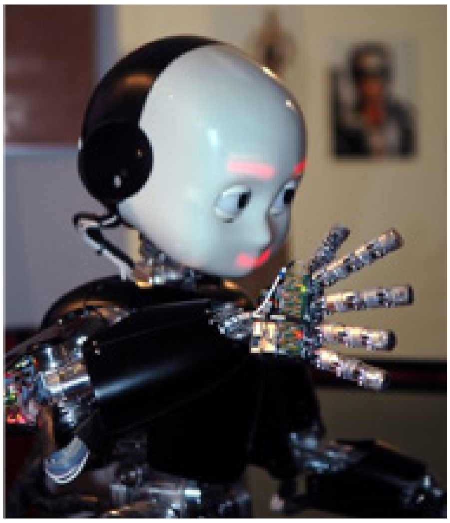
Next Summer, Italy Will Impress you

ICPS 2017 TORINO

Turin, a city in north-western Italy not far from the border with France and Switzerland, is hosting the XXXII ICPS in August 2017. Turin was the first capital when the country unified in 1861 and it will be the first Italian city to host this major event. We certainly hope that it will unleash in all participants the desire to come back for more of our *Bel Paese*!

The organizing committee has been working tirelessly to ensure that the spectacular "Einaudi Campus" can be used for the event and thanks to the support of the University of Turin it now seems overwhelmingly likely that this will be the case. Turin has been an important center for European science since the 18th century and boasts among its scientists and mathematicians Avogadro and Lagrange - yes, he was Italian *and not French*. This tradition has continued throughout the centuries and Turin together with its region hosts today some of most prominent Italian universities and research centers, including the renowned *Politecnico*, which thrived thanks to the close collaboration with the industry and in particular the FIAT carmaker. We are planning visits to headquarters of heavily R&D-oriented companies, such as *Thales Alenia Space*, as well as several research centers, among others the *Center for Space Human Robotics* and the *Italian Institute of Technology*, two leading centers for robotics. A *careers fair*, organized within the conference, will give the participants the opportunity to learn more about Italian and international companies that are very interested in hiring young, talented physicist. Large corporations as well as smaller but thriving companies will be represented, thus allowing you to discover some hidden gems. A prominent example is AizoOn, an innovation management consulting firm, which is proud of an outstanding record of achievement, growth and professional development for its employees.

Obviously, ICPS2017 is not going to be all about science and technology! You will definitely enjoy some of the best food and wine in the world - a visit to the famous *Cantina* is being planned - and bask in the glory of absolutely beautiful locations, such as



Source: Wikimedia Commons

the Turin University *Rector's Palace*, where participants will enjoy an Italian-style *Aperitivo* after the opening ceremony. If you fancy going to the seaside, there will be of course an occasion to do that and in the extremely unlikely case you get sick of Turin, a day trip to the lovely Pavia (in Lombardy) is being planned. For the most fun-minded of you, rowing on the Po river and laser-gun battles are on offer.

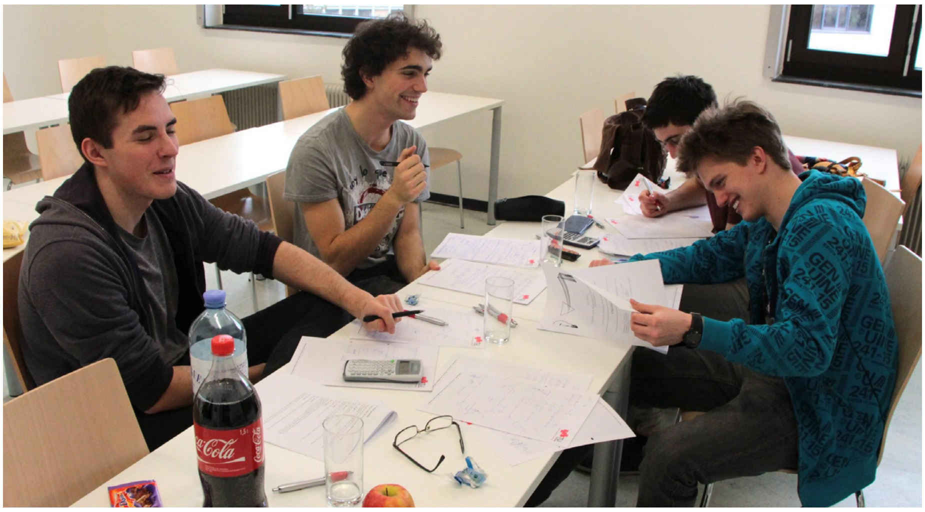
All in all, the XXXII ICPS in Turin will have something on offer for everyone, from the most sophisticated physics student to the "I-am-*almost*-on-holiday" participant, and the Organizing Committee is working hard to make sure that all participants enjoy the best possible experience. We very much look forward to welcoming you to Italy in August 2017!

Source: Universita' degli Studi di Torino

Lucio Milanese completed his MSci at Imperial College in 2016 and he is now a PhD student at MIT working on fusion-related plasma physics research.

PLANCKS - Be Part of It!

What is PLANCKS? Well it is an acronym for Physics League Across Numerous Countries for Kick-ass Students and it is THE competition for undergraduates and graduates in the field of physics worldwide. Its main event is the competition, but there are also side events like the scientific symposium, lab tours, excursions to companies, cultural activities, a social programme and so on, creating something that you can call a small ICPS - at the end of this article, you can find all information about what you can expect in 2017 in Graz.



Talented physics students competing during PLANCKS.

The competition

You work in teams of 4 students that have to qualify in so called preliminaries, the best two teams of each country are sent to the final PLANCKS competition (26th to 28th of May, 2017 in Graz, Austria).
There are 10 problems to be solved in 4 hours not using any tools, like books, internet or computers.

As you may guess, it is an IAPS event using an international network of encouraged National Committees (NCs) to spread this fabulous and amazing event amongst all physics students.

Participating countries 2016	
1 team	**2 teams**
Austria	Croatia
Czech Republic	Poland
Denmark	Hungary
Germany	Italy
The UK	Singapore
Finland	Spain
Romania	The Netherlands
Slovakia	

Why should you participate?

What is so special about this competition that you should spend your time trying to participate? That is an important question and we tried to find the three major arguments why PLANCKS is such a great opportunity for physicists which they should fetch.
The best teams of the world compete in 10 challenging problems. You can try hard in exams, you can read a lot, but you can proof your genius just in competition – and it's kind of a social competition, it's not about you alone – it is a team challenge.
So, why should you go there, there will be so many strange people you don't know. That is actually a very good thing, first of all they are all physicists and you can share the jokes your non-physicist friends won't understand. Second it is really a good thing to get to know other people from around the world to share ideas to compare for example your curricula to establish networks and so on – your chance, take it!
Why leave your comfortable flat to travel somewhere else, why can't you participate online?
We cannot control if you cheat then, and travelling to Graz, Austria is definitely worth it. You cannot experience the local culture, the food, the nice wine hills, the chocolate factory, the delicious beer via the internet – so pack your suitcase, you won't regret.

Previous PLANCKS competitions

The next edition of PLANCKS in 2017 will be the fourth one. It started 2014 in Leiden, moved 2015 to Utrecht, and was hosted this year in Bukarest. The number of participating teams and countries increased quite continuously and we hope to continue this trend.
PLANCKS has seen very prominent key lecturers, like Stephen Hawking and Gerard 't Hooft, we are also trying hard to win such high-profile speakers.

Why not organize it?

And now there is the part where we need you: we (this year's Organizing Committee of PLANCKS 2017 in Graz, Austria – see picture below) are looking for help to attract more physics students to this event. Currently about 25 teams of all over the world participate, but we would like to have more – so if you cannot find your country on the list of participating teams or you see, that your country only sent one team, then this is your opportunity to change this – and we would be glad to help you.

Preliminiary

Best way to participate as a country in PLANCKS is organizing a pre-

liminary PLANCKS competition in your country. The best two teams of this preliminary are then qualified to come to the international competition PLANCKS 2017 (next year in Graz).
We would be glad to support you, we want to establish a network, so all NCs can share experience in organizing this small national competitions and share the problems to solve at the competition.
In principle you just need three things to organise such a preliminary:
1. one day
2. enough rooms for the competition
3. make enough advertisement to attract your students

Fact box: PLANCKS 2017
Theoretical competition covering all fields of physics
The best physics students in the world
Teams of 4 students
10 problems
4 hours time to solve them
No tools (books, computer, internet, etc.) allowed
26-28 May 2017 in Graz, Austria

What can you expect in Graz?

Well we are hard working to make

The 2017 Organising Committee.

this competition a lifetime experience for you. Not only the adrenalin kick you get when the problems are challenging you, or the exhilarating feeling when your team is receiving the first price, but also the beautiful city of Graz with all it's culture and delicious traditional Austrian food will memorize so hard, that later on you surely will like to return.
Beside the core of this event, the actual competition we will also care for an interesting and exciting **scientific programme**, including three key lecturers (we are trying hard to win some Nobel price winners, which are also inspiring speakers, to come to Graz), lab tours and excursions to companies.
Not to forget the social programme! There will be time to discuss your solutions with the other teams and some professors in the **scientific discussion session** before you have a nice opportunity to socialize with the other participants at the **barbecue party**.
At the third day, the results will be announced to laureate the winners of PLANCKS 2017, the winning team **will** expect some **thousand Euros!!!** Finally you can **enjoy Graz** and it's world heritage protected city centre before exploring it's nightlife at a pub crawl.
At the fourth (optional) day, you have the chance to visit some of Austria's most famous research facilities and participate in **excursions** to some international high-technology companies.
As the final highlight we follow the track of Willy Wonka to the local (and really famous) **chocolate factory**. Experience the long journey of a chocolate bean from Latin America and Africa feeling all the process steps at first hand having the chance to taste it at each phase in all its manifolds.

The lively city centre in Graz.

Gerhard Dorn (gerhard.dorn@tugraz.at) is currently working on his PhD thesis at the TU Graz, Austria.
He was president of the local student union Basisgruppe Physik, is an ICPS veteran (you may know him from the Nations Party with this spicy chilly stuff) and now president of the Organizing Committee of next year's PLANCKS in Graz, 2017.

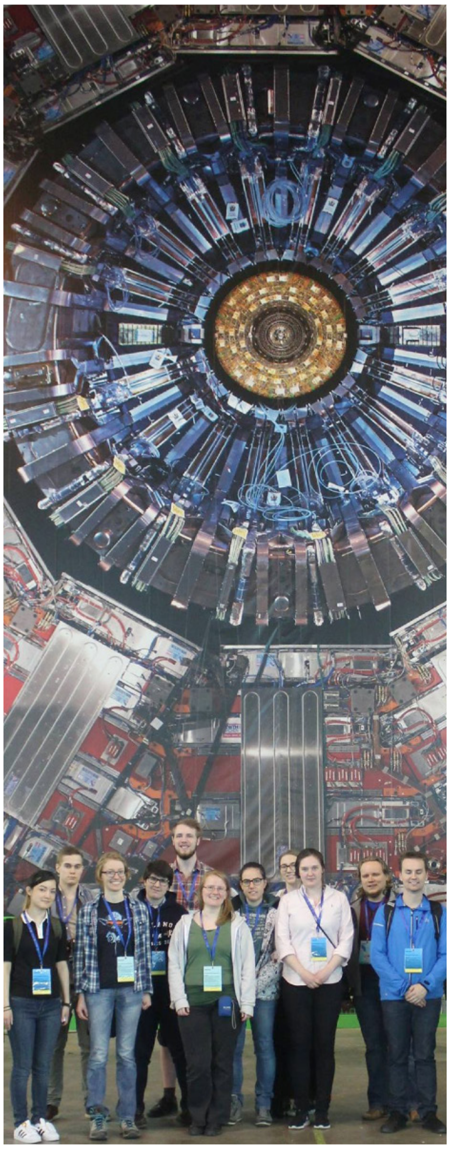
IAPS2CERN 25-28 April

The trip to CERN was amazing. Even though my expectations were high, the experience lived up to its purpose and more. Almost fifty participants from fifteen different countries all around the world joined the trip!

IAPS gave us a very friendly welcome at the hostel and everyone was really quick to include everyone in the group. The sun shined on us on the first day and we were able see the beautiful city of Geneva. Especially the Jet D'eau, a magnificent 140 meters high water jet, and The Vieille-Ville, the old town with St. Pierre Cathedral, are must-see highlights of city.

We spend the second and third day at CERN. We were all very excited to visit CERN and experience the largest particle accelerator in the world. It was amazing to get off the tram and stand in front of the globe of science and innovation, watching how mountains surround the entire facility. Our guide gave us a warm welcome and told us how physicists and engineers are probing the fundamental structure of the universe. The facilities at CERN extend over large distances and we were transported by bus. Sometimes these trips even involved crossing the French-Swiss border! The Control Centre was divided into four circles, one for each experiment. On the backside of the room, there were a lot of champagne bottles - they must have had a lot to celebrate!

Later that same day, we went to the AMS POOC, an experiment searching for dark matter. The experiment is easier to do in space, according to the people working at AMS, and the detector is located on the International Space Station, where it measures the cosmic radiation. By measuring an excess of particles relative to the predictions of the Standard Model, scientists hope to find the dark matter particle. We had lunch in the cafeteria, where we made up a game called “spot a physicist”. Perhaps we were lucky and had lunch with a Nobel



Prize winner. Afterwards, we went exploring and we ended up walking through old, long corridors with offices. We passed the library where the free materials on experiments carried out at CERN , and especially the poster about the discovery of the Higgs, was a big hit. The rest of the day, the entire group was carrying around Higgs posters.

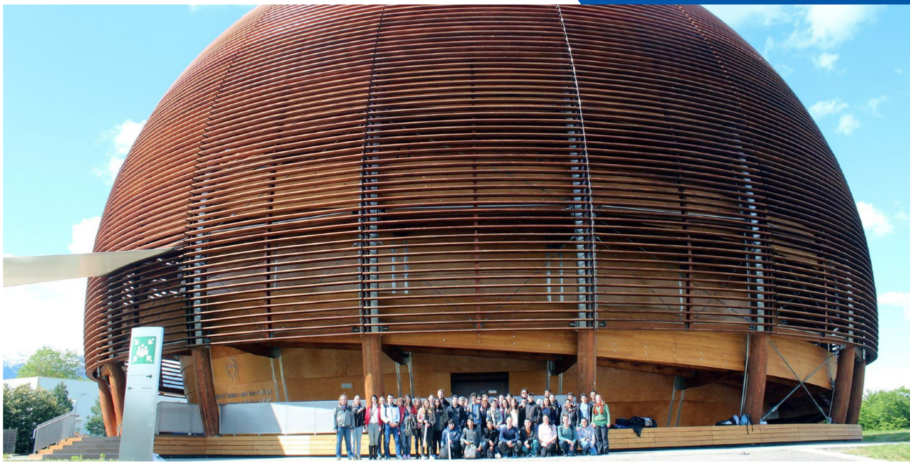
We went to Microcosm, a 500 m2 exhibition dedicated to some of CERN's monumental experiments from another century. In the exhibition, we saw the detector which measured a neutrino for the first time, old accelerators, and bubble chambers. I had a particular interest in the lead tungstate crystals which are one of the materials used in the electromagnetic calorimeter in CMS. It is made primarily of metal and is heavier than stainless steel but, with a touch of oxygen, it is highly transparent and scintillates when electrons and photons pass through it.

Although the day had already offered incredibly many experiences, it was far from over. Our guide introduced us to the laboratory, “The S’Cool Lab”, which he had spent years building and he was - as can be well understood - incredibly proud. We were divided into smaller groups and had the chance to build a cloud chamber. It was pretty awesome and we observed both electrons and muons from the background radiation and alpha particles, which either came from the background radiation a or from the decay of other particles in the chamber. The laboratory was built to motivate and educate high school students. It was a great experience to be able to work with hands-on physics experiments.

Professor Landua gave a lecture in which he spoke about antimatter and the physics, or lack thereof, in the movie, “Angles and Demons”. He brought the antimatter container from the movie and after the lecture we had the opportunity to take pictures with him and the container. Another interesting highlight was the social- and work life at CERN. After the lecture had a question and answers session with three PhD students. A lot of good questions came up , The majority of the questions was about how it feels to work and live at CERN. We learned that there are a lot of social events and an entire CERN community with a kindergarten and everything the scientist might needed. They told us that Geneva is a very expensive city to live in and some rented a room outside the city, where the door didn't quite close and let the cold and snow in. But everything was worth it, when they had their dream job.
On the third day, it was time for the big event on the schedule namely the visit to the CMS detector. The beams

were all around the detector and the experiment cavern was off limits so, instead, we got to visit the underground service cavern. We got our helmets and proceeded to the elevator that would take us 100 meters below the surface. We learned that there was a hierarchy of helmets, namely orange for visitors, blue for VIPs, and white for workers. Equipped with hats and access cards, a lot of selfies were taken, and we acted like a group of children waiting for their presents at the Christmas Eve. A guide took us on a tour and we saw the huge amount of wires connecting the servers that sort the data from the CMS experiment. The wires send the data, which is worth saving for analysis, to super computers all around the world. We arrived to a security point, where only scientists working on the experiment were allowed to enter. A sticky mat was placed on the floor, preventing dirt from shoes to go inside the protected area. The right key would open the first door, where an eye scanner would make sure the second door would only open to the people with access. When we arrived back at the surface, we spend some time at the CMS exhibition. A lot of the technology used in the experiment was at display together with a model of the detector which showed in which layer of the CMS detector different particles are absorbed and detected.

The bus ride from CMS to CERN main reception was nothing like an ordinary bus ride. The view of the amazing mountains, the colourful fields and cute small towns is worth a trip on their own. When we arrived back at the main reception it was time



for a break. We decided that we could explore the area outside and check out all the cool street names. At CERN the streets are named after great scientists. We finally found the A. Einstein Street but at this point we had walked for so long that we were a bit lost. We finally got back just in time to run to the group, which was on the way to the Globe of Science and Innovation across the road. We took a group picture taken in front of the impressive globe, just next to the sculpture, on which all the important equations and discoveries of science were written. Some of the equations were Maxwell's equations, Einstein's Field equations and the Lagrangian for the Standard Model and, at the very end, for the Higgs Boson . Inside the globe, there was an exhibition dedicated to the universe of particles. It contained a live display of LCH collisions, and a section, which demonstrates, how the particles are accelerated and detected. Another section showed how basic research leads to modern technology. In particular, we saw the World Wide Web server.

Along the trip we also learned about the ATLAS detector. ATLAS collaboration is the greatest competitor of CMS collaboration and they are the general-purpose detectors, which in 2012 discovered the Higgs boson. The ATLAS building is painted like the detector on the outside and is a quite a sight. This was the end of our CERN experience. In the evening, we went out for a pizza together and had a great evening. It was great to hang around with people, who have the same scientific interests and we discussed a lot of good and interesting topics. After a long and eventful day, we all had a good night's sleep.

On last day, we had an optional trip to the United Nations, in front of which a a 12 meter high chair with a broken leg is situated. It symbolises the opposition against the land mines and cluster bombs and acts as a reminder to politicians and others visiting Geneva. The UN building was an impressing sight with a lot of flags making the building more beautiful . Later that day I went to the museum of Geneva, displaying the entire history of the city. I found it wonderful that, in Geneva, all the museums are free of charge. It is very easy to get around the city by train that run frequently and a lot of impressing things to see.

I definitely want to come back again and I wish we had an extra day so that we could spend more time with each other. That would have given us the time to visit Mount Blanc which, with its 4810 meters, is the highest mountain in the Alps. IAPS planned an amazing trip with some amazing people. I will never forget the experience I had at CERN.

Sophie Maria Møller is a first year physics student at the University of Southern Denmark.

Going International with Italy

What's more inspiring than the study of neutrino oscillations and the elusive neutrino masses? Maybe the existence of double-beta decays and the incredible ways in which they could be experimentally detected, shielded from cosmic rays? We would bet that most of you would give up their breakfasts to know what on earth is the truth about dark matter.

All the above nonsense could turn on a little light in your mind if you had been at the first edition of the Particle & Astroparticle Physics Programme organised by IAPS and the Italian Association of Physics Students. This event was an enormous success, with 40 international students travelling to the centre of Italy to visit the ENEA labs in Frascati, the Gran Sasso National Laboratory (LNGS) and the Gran Sasso Science Institute (GSSI). If the name "Gran Sasso" doesn't tell you anything, then you might want to Google it: you'll see that it is the name of a 3000 metres high mountain in the Abruzzo region, where the largest underground astroparticle physics laboratory in the world has been hidden from the influence of cosmic rays. Indeed, 1400 metres of solid rock provide an excellent protection from external interferences and provide an opportunity to explore some of the most exciting challenges of modern physics.

In 2016, the Programme is being launched again, this time with the participation of the Frascati National Laboratory (FNL), the largest of its kind in the country. FNL has been active for over 50 years in the fields of particle and astroparticle physics, with key contributions to the international research programme of CERN and a leader at the LNGS facilities. All information on the 2016 edition of the Programme can be seen at www.ai-sf.it/papap.

During this year's edition, the 40 participants will meet in Rome on October 3rd and will be welcomed by local Italian volunteers. The day after, the group will move to FNL for half a day and then travel by coach to the Abruzzo region. During the following evenings, students will be able to visit this ancient city of L'Aquila, which was tragically damaged by an earthquake in 2009. On October 5th, the group will spend the entire day at the Gran Sasso National Laboratory, where they will attend a set of talks presenting the major experiments carried out in the underground lab. An overview of the theory and simulation activities carried out will be also presented during our visit of the Gran Sasso Science Institute on the following day. As in the first edition, students will be able to present a talk or a poster on a research topic of their interest; the best performances will be awarded prizes by the LNGS and the GSSI. Finally, on October 7th we will move back to Rome, where everyone will be able to visit the wonderful city of Rome before leaving.

This year's Particle & Astroparticle Physics Autumn Programme is not the only international event held by the Italian Association of Physics Students (AISF). First of all, everybody knows that AISF will be holding the 32nd International Conference of Physics Students in Turin but not all of you might be aware that already in 2015 we held the first edition of "Lights of Tuscany". This event was born with the wish to contribute to the International Year of Light, by bringing AISF and IAPS students to visit European research facilities in the region of Tuscany. I know that it's shocking the first time that you hear it, but Tuscany is not all about incredible wine, there is also world-leading research being done here, particularly at the European Graviational Observatory EGO-VIRGO and the European Laboratory for Non-Linear Spectroscopy.

During Lights of Tuscany, first held in December 2015, we visited these two facilities in addition to the University of Pisa, the Normal School of Pisa and the Sant'Anna School of Advanced Studies. Students were offered overviews of research on photonics, quantum dynamics and much more. To top it up, we also spent some time in Florence, exploring the Uffizi Gallery and the marvellous story of the city.

The AISF wishes to repeat the event in December 2016. To have a look at last year's programme, have a look at **www.ai-sf.it/lot/**. We hope to open registration for Lights of Tuscany 2016 in Autumn.

We really love organising these international events. We wish that more of the IAPS community did the same, so that more exchanges were possible, with more Italian students travelling to other countries as well as foreign students coming to ours. We understand that challenging Italy in organising scientific events of this sort is pretty scary, but we are confident that som of you could do a good job! We would like to support other NC's and LC's to organise international events. If you would like to collaborate with us, or just ask for advice, please write to our executive committee at esecutivo@ai-sf.it.

Francesco Sciortino will soon start his PhD at MIT. He has organised scientific events in a number of european cities as part of the EC of both IAPS and AISF.

Mexico Has Joined!

On May 2nd, 1986, two curious and passionate minds, Roberto Vazquez and Saul Zavala, created the *Sociedad Científica Juvenil* (SCJ) (English: The Youth Scientific Society) and its first meeting was held at the library of the Astronomy Institute at UNAM in the city of Ensenada, Baja California, Mexico. The mission and vision were raised and continue to be:

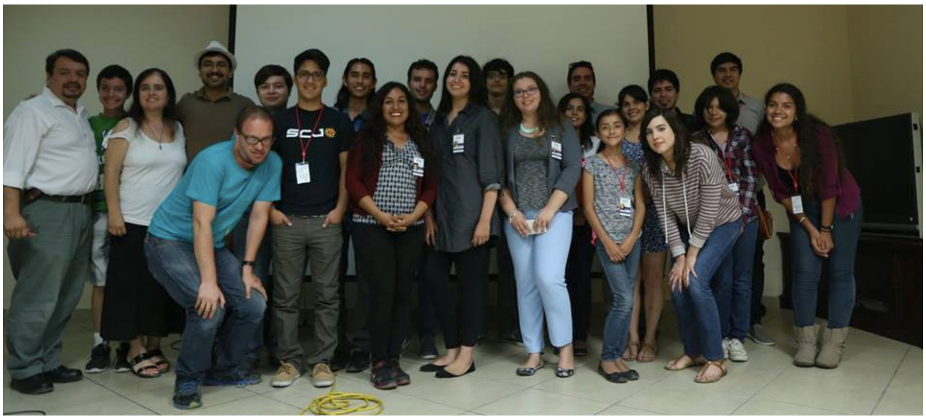
Mission: The dissemination of science and technology; the study of scientific topics and scientific research and technological development.

Vision: Divulging scientific knowledge among young people, thereby creating a critical and analytical objective to achieve full self-realization, with skills and qualities that will be useful for the rest of your life.

A few of the activities still done to this day is that each member can present a scientific topic of interest, organise activities for schools, or work on a personal project. Also, they created a logo consisting of an octagon, in its center are the letters *SCJ* which are crossed by five parallel lines that represent the five basic sciences: Astronomy, Physics, Chemistry, Mathematics and Biology.

Sociedad Científica Juvenil

The SCJ stopped being active in 1994, and renewed its activities on February 24th, 2011. This brand new SCJ is backed up by the original founders through the *Instituto de Estudios Avanzados de Baja California, A.C. (IdEABC)* (Institute of Advanced Studies of Baja California). It has been able to expand and create a greater impact, first in Ensenada and then in different states, consolidating groups in several cities such as Tijuana, Monterrey, Leon, and Mexico City. This resulted in the creation of a new position as national president of the SCJ.



The SCJ has been working with several institutions such as the *Tecnologico de Monterrey, National Autonomous University of Mexico* (UNAM), *University of Guanajuato* (UG), *Autonomous University of Baja California* (UABC), among others. We now have activities such as science fairs, workshops, school visits, multiple participations in an international-wide event known as *Noche de las Estrellas* (Night of the Stars), public talks and conferences, visits to the *National Astronomical Observatory* in San Pedro Martir, NASA and even our very own events such as the SCJ National Congress. All of these activities have managed to increase the number of interested young people in studying sciences and aim to inspire a new generation of scientists and game changers for the benefit of our country and even the world.

SCJ is now the National Committee of Mexico for IAPS which enables international collaborations in diverse topics, enriching each member both culturally and scientifically. It will also help increase the number of Mexican states that are part of the SCJ, making it bigger and stronger so the collaboration between our country and IAPS grows and exceeds its expectations. All in all, this allows the younger generations to get a closer look at science and its international impact.

The IdEABC, as a keeper of SCJ's integrity, cares that the different groups around the country have their own unique identity, without losing what makes it the SCJ. The SCJ is a self-organized and self-learning group, which brings together young people interested in the study and dissemination of scientific knowledge and technological advances, as well as participation in science olympics and friendly academic competition, young people who want to collaborate on projects with a scientist, or even develop their own, and young people who are motivated popularizing science in schools, public events, and everywhere it can be done. The SCJ collaborates with associations, science museums, universities and schools in their various offices.

The SCJ continues fulfilling its main task and making true the watchword: ***"In the youth of today is the science of the future"***.

By **Atalia Navarro** and **Karen Macias**.

Atalia is a graduate student at the University of Guanajuato and the national president of the Sociedad Científica Juvenil. She's interested in cosmology and astrophysics.

Two Closer Unions

Our two countries have a very different structure in providing physics students with their needs, but that doesn't mean we can't work together: since two years, a growing partnership is being built between the Dutch *Studenten Physica in Nederland* (SPIN), a union of study associations, and the German *junge Deutsche Physikalische Gesellschaft* (jDPG), a section of the regular national physics organisation.

WATT, one of the Enschede study associations, invited – as result of first plannings at ICPS in Zagreb – the SPIN and jDPG chapters to the first Dutch-German crossing-border meeting. This invitation following, about 15 students from both countries came together in Enschede to meet with people studying physics just around the border. This day was aimed to present our different associations, to learn from each other and to get new inspirations for own activities. Furthermore we discussed what kind of activities would be possible to extend the exchange across the border and we decided for the beginning to host periodically meetings to deepen our contacts and to collect ideas for larger events.

Therefore we met again in April to refresh the contact and to make new friendships. This time we met in Germany, more precisely in Münster, student city and capital of bicycles. Again 13 people from both countries came together for this one-day trip and talked about the next steps on the way to an formidable exchange and to converge our members. Besides the tour around the historic city centre and its pubs, the discussions of further projects became more and more concrete. We arranged the next meeting in the Nederlands for the new semester – this time in Amsterdam.

After two succesful meetings, it was time to investigate further ways of co-operation. This was one of the points of discussion at the Networking Meeting of the northern sections of the jDPG, at which three representatives of SPIN were present. Also during the two-day event, the group visited the GEO600 detector, with a set-up similar to Caltech's now famous LIGO observatory. Especially the visits to several Hannover bars were successful in building the relations between members, after which a brain storming session about collaboration was all the more fun.

The future is bright for this collaboration between two large and established organisations, with plans for an student exchange in the works. This was the result of the talks in Hannover, and is now being discussed in further detail with the Dutch and German groups. We look forward to this, and meeting each other again in the future.

By **Jan van Staalduinen** and **Matthias Dahlmanns.**

Jan studies Computer Science and Law at Leiden University in The Netherlands. He spent the academic year of 2014-2015 as a board member of the Leiden maths and physics study association “De Leidsche Flesch” (The Leyden Jar) and is now secretary of the Dutch national association for physics students , SP↑N. He loves reading and having long discussions while drinking n+1 beers. He hates that he can't attend ICPS this year.

Vikings from the North

There is a city at the northern part of Germany that was founded centuries ago by vikings, that in the 15th century was accused to give refuge to pirates and where in 1858 birth was given to the man almost every physics issue in Germany is named after. As you may guess it is Max Planck who was born in the city called Kiel (pronounced like kill, but with a long i).
Ten years before young Max first caught sight of the April's sun shining above him, the city was under Danish protection. When he was six years old, the Austrians (!) ruled there together with the Germans and Kiel itself was a city right at the border to Denmark. Several wars later this place is an integral part of the Federal Republic of Germany. But still, there are lots of Danish speaking people living here; a part of our local government is Danish; and children in school can learn Danish before they start learning English.
What I actually want to say is that Europe as it exists today is much more complicated to understand than by just drawing a line and calling it ‚frontier between x and y'.

Today, Kiel has a university where besides many other subjects you can study physics and where you can find physics students eager to learn more about this exiting world. But sometimes besides all this learning about the nature, other small desires awaken. Desires of how this world may look like beyond these university walls filled with books. This desire also awoke in our physics students association which is why we wanted to start something that goes beyond studying physics, something that has this famous international ‚feeling', something that would make our world not necessarily a better place but at least a bit more social.
So we thought in our great Kielian history and remembered in one moment that we are living very close to this kingdom in the north and decided to just invite the physics students of the closest country to visit us. Therefore we made a plan.

The most difficult part of all the plan was „Step 1: Writing a mail". It sounds weird but there is a very high imagined barrier that has to be tunneled through. So we wrote a mail to the students association Aeter in Denmark that must have been very surprised to receive an invitation from strangers in the south just asking whether they might be interested in visiting Kiel, its university and the physics institute. Their answer was basically the following: „Yes".
Afterwards we made a plan on what to show our new friends.
Friday 4.00 pm: arriving
Friday 4.15 pm: talk from our Dean about Astrophysics
Friday 5.00 pm: Lab tour to a 2K laboratory
Friday 7.00 pm: Pizza, Beer, Music, Playing and Conversation

Then there was the problem with accommodation. We didn't want our guests and newly found friends to go alone to a hostel but we decided that each of the Danish should stay in the house of one of the Germans. Here we needed some persuasiveness because naturally, nobody wanted strangers to sleep at his or her place. But at the end we convinced our group and I have to say, it was more than worth it. The Saturday went on as follows:
Saturday 9.30 am: Common Breakfast in a restaurant
Saturday 10.30 am: City tour
Saturday 12.30 pm: Get together, making future plans, evaluating
Saturday 2.00 pm: Good Bye

All together it was an awesome experience.
We as physics students association in Kiel would definitely recommend to every students association to just invite students from other cities to visit you and show them your city. The total cost for each person was only the consumed food (of which 50% was sponsored by German Physics Society). The effort to organise such an event is extremely low (inviting a speaker, talking to someone to make a lab tour, buying pizza, calling the restaurant, finding someone who knows the city). The event in total was less than 24 hours and the outcome are very nice memories, a visit in return and a broader view towards how studying can be somewhere else.

It was definitely worth realising and we are already looking forward to visiting the Danes.

Lukas Deuchler has studied physics in Germany and Argentina. He obtained a MSc in theoretical physics this June and has represented the physics students in numerous university committees.

Trondheim Science Week

The NTNU (Norwegian abbreviation for "Norwegian University of Science and Technology") is arguably the university in Norway with the longest running tradition for student-initiated activities, having numerous student organizations and associations. The (in)famous red building Samfundet, hosting everything from concerts to theme parties for all students in the city. Plenty of opportunities to get in touch with potential future employers and discover different career paths during your studies. This relatively small city in the middle of Norway is host to a thriving student community. The student association Delta is one of the smaller student organizations at campus Gløshaugen in Trondheim. With a student body of approximately 300 members consisting of bachelor, master and one-year study students in the fields of physics and mathematics, it is only in the last couple of years the association has begun to make its mark in the student community.

The idea behind an event similar to Trondheim Science Week (known as Realfagsdagene in Trondheim) had circulated within the student organization for years, and to some extent been tested out on a smaller scale in collaboration with other, larger student associations. It was not until a former leader of Delta put together a small committee of fellow students that the event in its current state began to materialize. When we started out in the early autumn of 2015, we honestly had no idea where to begin. None of us had any prior experience with an event of this size, but it all worked out in the end mainly due to two important factors. First of all, we were fortunate enough to have some of our speakers confirmed for the event early on. Secondly, our speakers did not demand a fee for the lectures, only transportation to and from the event (in addition to food and a hotel stay). This secured early funding from local organizations (acquired through numerous applications),

publicity and some much needed initial momentum. The entire event was organized voluntarily by students from the student organization, which is the norm in the student community.

The event itself was largely based on lectures and talks given by notable speakers. The first confirmed lecturer was the widely known theoretical physicist Prof. Lawrence M. Krauss, and shortly after the acclaimed norwegian lecturer Are Raklev was booked for the event. During the next two months our lineup of speakers began to take form: physicist Alexander Biebricher from The Norwegian Centre of Space-related Education (NAROM), astrochemist Stefanie Milam from NASA and lecturer/author Roger Freedman from UC Santa Barbara said yes to a trip to Trondheim Science Week. Our goal was to settle for around four to six speakers spread over the course of a long weekend, Friday to Sunday. This year's Trondheim Science Week corresponded with another event that was being held in Trondheim this year: the selection of a new head committee for a Norwegian physics interest group called Norsk Fysisk Selskap (NFS). In Norway, if you are studying physics, you are automatically a member of the organization Norske Fysikkstudenters Forening, NoFFo (which translates to Norwegian Physics students Association), and by extension a part of The International Association of Physics Students. All NoFFo and NFS-students were invited to attend the event for free, and many of the attendants got their travel expenses covered by their respective universities. This culminated in a weekend of interesting talks, and a lot of banter between the students.

The event was, in our opinion, a great success. One of the things that surprised us the most was the public interest in the lectures. The talk on gravitational waves with Krauss on Saturday had to be moved to a bigger venue (from a lecture hall to the student melting pot Samfundet), and attenders that were not in designated student organizations or with the NFS/NoFFo-students had to buy a ticket to the event. The tickets were relatively cheap; the most important goal from an economical perspective was to break even. The lecture with Stefanie Milam also required booking in advance if you wanted a seat, but this was free of charge. The other lectures saw good attendance as well. Biebricher held a talk on the connection between mathematics and human fantasy, right before Milams' lecture on her position at NASA as an astrochemist. Are Raklev held a presentation Saturday morning on the CERN-facility, and a couple of hours later Freedman lectured curious attendants on the physics of flight. The talks were filmed by a subcommittee of Delta, and a couple of interviews were conducted with the lecturers that were later posted on the Internet for everybody to see. The attending lecturers were also very open to talking with the students at the event about their fields of work, a gesture we are very grateful for.

This was the first year the event was held, and there are of course a lot of ways to improve upon Trondheim Science Week. In the coming years, we hope to expand with other types of activities and an increased presence of national and international organizations and businesses at the event. However, we feel that the focus on interesting lectures and talks from the great minds of our time in a community characterized by eager students is what could make this happening stand out from other events in Norway. We also hope to add more talks in fields outside physics and mathematics to draw an even more diverse crowd.

We are very grateful for the cooperation, willingness and attendance of most notably the lecturers, but also for all the voluntaries and audience. Plans for the next event are already in the works, and we hope to bring natural science to even bigger crowds in the upcoming years!
Greetings from Norway!

Håkon Pedersen began his physics bachelor in 2014 at the Norwegian University of Science and Technology. He has taken part in several student-driven initiatives, including the student organization in physics and mathematics, and the natural science convention Trondheim Science Week.

Choosing Science Orientation

The AFNEUS (National Federative Association of University Students in Sciences) released on the 9 February 2016 its latest project: Students in Sciences
This is a unique organization that represents students in science as well as members of the FAGE (Federation of General Students Associations) network. The AFNEUS represents at this time forty student's associations, in sciences, mechanics and engineering. It is due to our close workings with these associations that this project "Students in Sciences" started off. It became clear that there are very few tools accessible to young people that help them make the choice of orientation. They are completely abandoned in meandering through all the titles of different bachelor's and master's degrees not to mention the different technology institutes. Properly orienting future as well as young university students is the key to them thriving and succeeding in integrating into the workplace.
The AFNEUS is now developing a gateway "Students in Sciences" which will guide, inform assist young students in their orientation and occupational insertion from high school all the way to their doctorate.
Many different tools will be at their disposal:

- A platform mapping out the technology degrees, the bachelor's and the master's available in France.
- A guide on integrating the workplace that will contain a catalogue of careers and advice of how to integrate these said careers correctly.

AFNEUS
Les étudiant.e.s en sciences

- A digital space that will have all the details necessary for international exchanges.
- A service of information and companionship for future doctoral students.

The aim of this project is to improve the current orientation system by offering an interactive tool that is accessible to everyone and offers information quickly and clearly on the possibilities study-wise.
The portal Etudiants-en-sciences.fr will from now on allow a better visibility on courses in this sector.

This project was created on the principle of active orientation and developed in partnership with the Conference of Directors of the Scientific Faculties, The Minister of Higher Education and Research, the AFNEUS also partnered with Unisciel, the online science university, that offers young people who are interested in studying sciences to write placement tests via the Faq2Sciences website.
The platform is destined to evolve very soon in order to open up to new audiences. The site will be fully operational in 2017 and will keep growing with the aim to offer students all the information they need in order to succeed. This project is a big added value for young students, it favors their comprehension of the university world and gives them the key and vital information to help them to carry out their plans.

This initiative, one of many in the FAGE network, is to contribute towards the same aim: enabling each young person to make an enlightened choice in his or her orientation and fulfill their life plans.

Chelsea Booth is currently active in the AFNEUS as the Vice-President of international affairs.

PHYSICS

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Pendulum with Rotating Pivot

Introduction

One could say that there is nothing new in experimenting with pendulums. Although pendulums have been in the centre of interest of several famous physicists in the past, they are not outdated yet. Nowadays, the research of pendulums is still current, since they can be are varied (simple pendulum, conical pendulum, excited pendulums), and not all combinations of pendulums have been explored. Particularly, there exist various methods of exciting a pendulum.

History of pendulums

The first scientist who studied the behaviour of a pendulum was Galileo Galilei in the late 16th century [1]. He was the first person who realised that the period of a pendulum's swing is independent of its weight, and only depends on the length of the thread. From his experiments he realised that the pendulums are perfect timekeepers. When Galileo Galilei could not continue his inventor works, his son Vincenzio began to build his father's clock according to his notes. Unfortunately, he could not finish the invention completely before his death. The first pendulum clock was built by Christiaan Huygens in 1656, based on Galileo's idea. This was the first practical application of this fantastic invention [2]. Pendulum clocks were used as the best timekeepers for almost three centuries, until the quartz clock was invented in 1927.

In the 1600's Robert Hooke studied the properties of conical pendulums in order to model the orbital motion of the planets. His work was used by Huygens to improve his clock. To regulate the speed of steam engines in the 18th century James Watt also applied a conical pendulum to his centrifugal "flyball" governor [3].

The next significant application of the pendulum was made by a French scientist, Léon Foucault. His invention, a 67 meters long pendulum known as the Foucault pendulum, was presented in Meridian Hall of the Paris Observatory in 1851 [5]. He was the first person who could demonstrate the rotation of the Earth.

A new type of pendulum

Less explored fields of pendulums exist even today; a problem related to excited pendulums even appeared on the list of problems for the International Young Physicist Tournament (IYPT) in 2016 [6]. If we use a simple pendulum (i.e. hang a weight at the end of a strong thread) and rotate its pivot along a horizontal circle with constant angular velocity, it will not be similar to a normal pendulum, we can see a completely different phenomenon. Instead of a periodically repeated motion, we experience that the bob follows a complex, chaotic trajectory after the suspension point starts rotating. However, after some time, the transient components of the motion decrease, and the bob finds a stationary trajectory, starts tracing a circle.

How to do it at home

This experiment is special, as it can be done even at home due to its simplicity. These experiments were mostly made by using a table tennis ball as a bob. By affixing the other end of the thread to a horizontal rod, it becomes easy to rotate the pivot along a circle with constant angular velocity. It is important to use a motor with a very short ramp-up time in order to reach the constant angular velocity as soon as possible. For the measurements it is advised to place a camera under the pendulum, in the axis of rotation. With the recording it becomes possible to not just measure the radius of the circle, but also to determine the 3-dimensional position of the bob.

Possible trajectories

When you first hear about this experiment, the question you ask yourself is – what does the final track of the bob look like? The trivial answer is that the bob must rotate on a larger radius circle around the central axis, on an outer trajectory. On the other hand, it can also find another track, which is a much more surprising situation. Under certain conditions, the orbit of the bob can even have a smaller radius. This is an inner trajectory, since the weight stays under the area of pivot's circle. In this case, the thread intersects the axis of rotation, meaning that they are in opposite phase during the rotation. Since the bob moves along a circle, in both cases the net force points to the centre of the circle (shown in Figure 2).

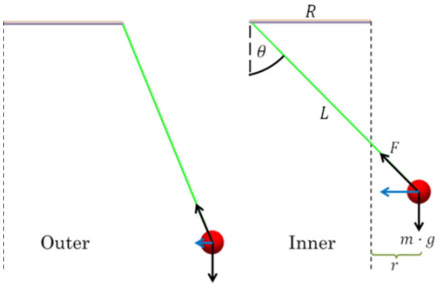

Figure 2: The possible trajectories of the weight and the acting forces.

What does the radius depend on?

In the ideal case the system has three parameters: the length of the thread L, the radius of the pivot's circle R, and the angular velocity of the pivot's rotation ω. Additionally, the gravitational acceleration g can also be counted here. With these parameters, the properties of the bob's final circle can be given.

Parameter space

By expressing the acting forces and using the geometric condition, we can calculate the radius of the orbit of the bob. We can express the dimensionless formula of the equation,

$$\frac{R\omega^2}{g} = \frac{\frac{r}{R}+1}{\frac{r}{R}\sqrt{(\frac{L}{R})^2-(\frac{r}{R}+1)^2}}$$

and draw up a parameter space (Figure 3).

For a given length of thread and radius of pivot, with relatively low angular velocity the equation results only one solution. This represents the outer trajectory, indicated by the red area on the parameter space. It is important to note that this track presents itself at every point of the parameter space, even in the green area. It means that it always exists, independently from these three parameters.

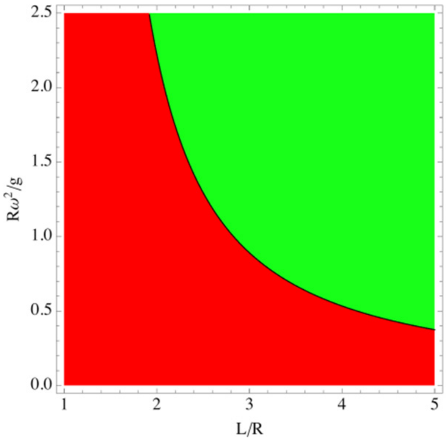

Figure 3: Parameter space

Interestingly, under appropriate circumstances the equation has three solutions. This area is painted green in the figure. The stability testing explained that only two of the three solutions result with stable trajectories, meaning that the third solution must be unstable. These two orbits are the inner and the outer trajectories.

The drag force

As it was mentioned earlier, an important part of the phenomenon is the reduction of transients. At the beginning the bob starts moving randomly, drawing loops instead of a symmetric circle. Because of the drag, these transients decrease by the passage of time, and the phenomenon ends in a stable trajectory.

The Reynolds number provides information about the type and magnitude of the drag force. It can be calculated from the relative velocity and the kinematic viscosity of air [7], and its value was between 10^3 and 10^4 during the measurements. First of all, it means that the drag will be turbulent, which is important as it can increase the chaotic behaviour at the beginning of the rotation. Secondly, the drag coefficient C_D will be approximately constant, according to a study of Faith A. Morrison (2013) [8]. And most importantly, from the Reynolds number we can predict that the drag force will be proportional to v^2 where v is the velocity of the bob. With all these informations, the drag force can be calculated as

$$F_D = \frac{1}{2}\rho C_D A v^2$$

where ρ is the density of air, and A is the cross sectional area of the bob [9].

Interesting facts

Obviously, the net force has to point to the centre of the circle in case of a uniform circular motion. This is true even if the drag force acts on the mass point. But how does the drag force modify the final trajectory of the bob? It is quite clear that the weight's relative position will be different to the suspension point. Suppose that there are no transient components at the beginning, and the bob has already found its final circle. Then if the drag force does not exist (e.g. the experiment is done in a vacuum), the weight

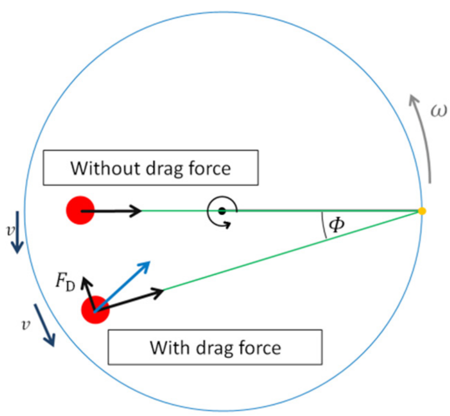

Figure 4: The position of the bob without and with the drag force.

would stay in the vertical plane of the rod. On the other hand, if the drag force acts on the bob, it will leave its original place and move a little bit ahead of it. This phenomenon is explained in Figure 4.

Secondly, we can also find curiosities by examining the radius of the inner trajectories. If we compared the bob's track with the circle of the pivot we would experience that its radius is not always smaller. Under certain conditions, the inner trajectory can also have a bigger radius, although it happens in a very small range of the parameter space. In Figure 5 it is indicated by the black area. It requires a relatively long thread, and low angular velocity. Even under appropriate circumstances it results a very small difference between the radii of the two circles.

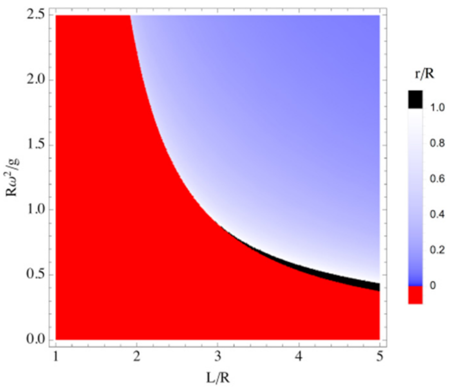

Figure 5: The ratio of the radii.

Conclusion

Pendulums are still an open question in the field of physics due to their diversity. Even a circularly excited pendulum can provide new, exciting phenomena. The pendulum that has been described in this paper, showed two types of motion. At the beginning the bob had a chaotic behaviour. After that, it was deduced that under certain conditions there exist three stationary trajectories depending on three parameters (L, R, ω), although only two of them will be stable. The drag plays an important role in the phenomenon, as it allows damping to end in a stable trajectory, and it also changes the final track of the bob. With all this knowledge it is possible to draw up the 3-dimensional reconstruction of the trajectory of the bob. Our methods applied in this project might help in further similar researches.

Acknowledgment

I would like to thank Péter Boross (PhD student, Eötvös Loránd University) who provided insight and expertise that greatly assisted the research. I also thank Tímea Bánóczki, my partner in the entire project. Special thanks to Tamás Álmos Vámi, who encouraged me to participate in this project.

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Dániel Adorján is currently a senior student at Szent István Grammar School, in Budapest. He was selected to be a team member representing Hungary on the international competition of Austrian Young Physicist Tournament (AYPT) in 2016.

Mnemonic Devices in Physics

Abstract

Mnemonic devices help with remembering data. When studying physics, students are expected to remember a lot of information in the form of defini-tions, formulas and constants. The main topic of this study is to show whether the use of mnemonic devices can help with this memorization. A research to demonstrate the validity of the thesis is conducted. Two groups, one control and one experimental, of school students are questioned, and their results are compared.

Introduction

Our lives cannot be imagined without memory. Our past, the people we have met, and the skills we have acquired, are all saved within our memory, stay with us wherever we go and can be stolen by no one. Our memories make us who we are.

Mnemonic devices have so far been proven to be useful for memory improvement. Research has been done on the different applications of these devices and the various methods of their incorporation in our daily lives. Furthermore, some research of the effectiveness of different types of mnemonics has been investigated (see Sternberg & Sternberg, 2012).

What is different about this research is that it explores the use of mnemonic devices in the field of physics, particularly how they can be included in physics education for high school students. Some research has been done on the field of mathematics (DLlachmutt, 2007), but to my knowledge, nothing on the field of physics. The goal is to determine whether introducing a mnemonic device leads to better scores on tests.

Characteristics of mnemonic devices

Mnemonic devices (or mnemonics) are tools that can be used for memory improvement and data retention. They are organizational and encoding strategies that are used for better and easier recollection of information (Bellezza, 1981). They work on the basis of cognitive cueing, which means that strings of data are connected in such way that remembering the first immediately brings back the second piece of data.

Such recollection of data is useful when the data studied has little or no meaning. This is sometimes the case when studying physics, and even though mnemonics may help with remembering, it is possible that introducing them in teaching and studying physics may cause more misconceptions. However, this is beyond the scope of this study.

Invention of mnemonic devices is a creative process. Each individual can produce a different mnemonic for the same piece of information. This is why students need to be made aware of the existence of mnemonics, if we wish to incorporate them in the curriculum. The best way to achieve that is by introducing examples.

Examples of mnemonic devices in physics

Example 1

An electric current is defined as the flow of electric charge. This can be written as:

$$I = \frac{Q}{t} \Leftrightarrow Q = It$$

We can create an acronym from this. With addition of some letters, we can make a word that sounds similar to the equation. That word is the word ‘Quit’.

Example 2

When current I flows in a wire, and an external magnetic field B is applied across that flow, the wire experiences a force F perpendicular both to that field and to the direction of the current flow. Fleming’s left hand rule shows the direction of the force F. The left hand thumb shows the direction of the force, the index finger shows the direction of the magnetic field, and the middle finger indicates the direction of the current.

This can be remembered as ‘FBI’. If each letter is imagined to be on one finger, as the palm is turned up, ‘FBI’ can be read across the fingers. Now all that’s left is to positon all three fingers perpendicular to each other, and the direction of the force can be easily determined.

Example 3

To express the angular frequency ω in terms of frequency f, the following equation is used:

$$\omega = 2\pi f$$

We introduce a word for each of those symbols as it follows: – OMG – ‘Oh my God’; – ‘two pigeons’; f – ‘flirting’. Then, we form a sentence using these words, and we get: ‘OMG! Two pigeons are flirting!’ This sentence can be supplemented with a picture, as shown in figure 1.

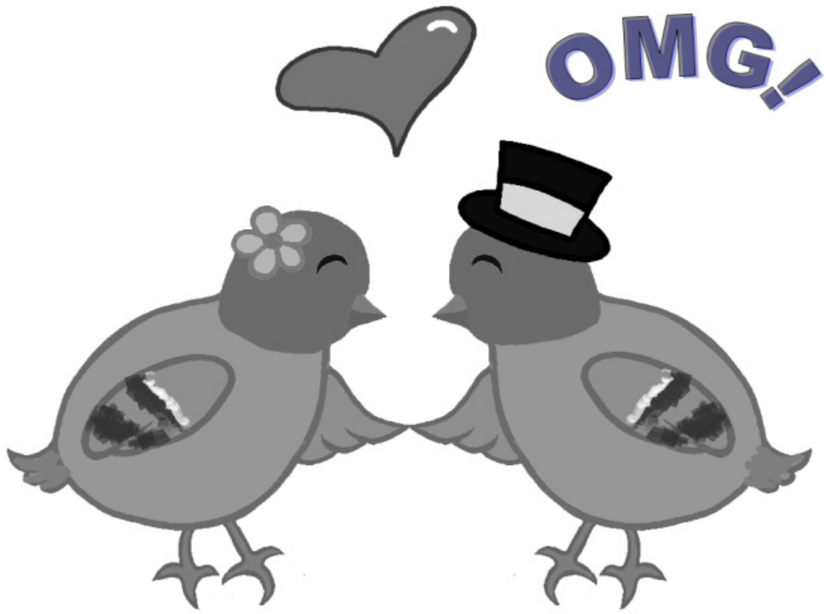

Figure 1: "OMG! Two pigeons are flirting!"

Methodology

The research was conducted twice, once in the second year of high school (students of the ages between 15 and 17), and once in the third year of high school (students of the ages between 16 and 18). Each of these groups consists of two subgroups: an experimental and a control group.

The second year research included 107 students, 62 of which were in the experimental group, and 45 in the control group. The third year group consisted of 55 students, 25 of which were in the experimental group and 30 in the control group. The groups were chosen by their teacher, so that they consisted of students with similar prior physics knowledge. The validity of the choice is confirmed by giving the students questions on the test, which are unrelated to the mnemonic devices.

The effect of the mnemonic devices was measured by a multiple choice test, with three possible answers. The mnemonics were introduced one to two weeks prior to the test. The test was made up from questions that included mnemonics as well as questions unrelated to the mnemonics.

The mnemonics and the test that were given to the students were on topics that were being taught to the students in the regular curriculum. The topic was "Oscillations" for the second year students, and "Nuclear physics" for the third year students. The test was given on May 4, 2016 in the high school 'Georgi Dimitrov' in Skopje, Macedonia.

Results

First, the results of the second year group will be shown. The results are presented as percentages of correct answers. The questions number 1 and 3 can be answered with the help of a mnemonic device, and questions 2 and 4 were unrelated to any mnemonics presented.

Question#	Percentage of correct answers in the experimental group (E)	Percentage of correct answers in the control group (K)
1	90	79
2	85	85
3	90	94
4	34	27

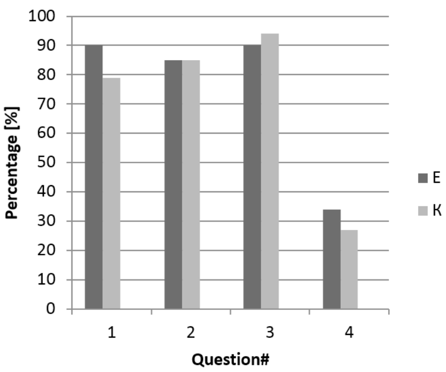

Figure 2: Presentation of the results of the second year group, expressed in percentage of correct answers.

It can be noted that the answers of the questions 2 and 4 are similar, which indicates that the groups were properly selected and can be compared to each other. The first question was answered correctly by 79% of the control group students, and by 90% of the experimental group. This is a considerable difference, and it is possible to conclude that the mnemonic was successful.

The third question was answered correctly by 94% of the control group, compared to 90% of the experimental. Both of these scores are extremely high, and it cannot be expected a mnemonic to make a difference. Possibly the question that was asked was something that students have no trouble remembering. Alternatively, the possible answers that were given did not present a challenge with answering the question.

Question#	Percentage of correct answers in the experimental group (E)	Percentage of correct answers in the control group (K)
1	76	53
2	80	50
3	36	53
4	92	40
5	40	33

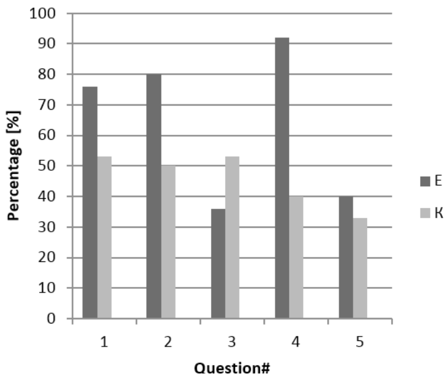

Figure 3: Presentation of the results of the third year group, expressed in percentage of correct answers.

Second, the results of the third year group are to be presented. The difference is quite dramatic in this case. The questions number 1, 2 and 5 can be answered with the help of a mnemonic device, and questions 3 and 5 were unrelated to any mnemonics presented.

The comparison of the answers of the third and fifth question indicates that the groups have once again been chosen appropriately. The first question was answered correctly by 53% of the students in the control group, while this number is 76% for the experimental group.

The second question has a similar situation, 50% in the control group, compared to 80% in the experimental. The fourth question is even more dramatic. Only 40% of the control group answered it correctly but, in the experimental group, 92% of the students gave the correct answer.

Conclusion

This research brings interesting results. The indications that mnemonic devices really do help with studying physics are strong. Their influence on test scores can be seen easily from the results presented. On the other hand, the local character of the research should be taken into account, and these results should not be generalized.

Mnemonic devices still need to be researched, especially their application in school subjects. Further research on this topic should be conducted for students of different ages, starting with the youngest students in kindergarten, and all the way to college students, different ethnic groups, and even students with cognitive disabilities.

The possibilities of mnemonic devices are endless. With a little effort on behalf of the instructor, the student can benefit greatly from mnemonics. I believe every person should find which mnemonics work best for them, and try to improve their learning process by incorporating them in their studies.

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By **Jana Bogdanoska** of the Ss. Cyril and Methodius University of Skopje, Faculty of Natural Sciences and Mathematics, Department of Physics, Arhimedova 3, 1000 Skopje, Republic of Macedonia

Solving Problems in Theoretical Physics

Preamble

How does one solve a problem in theoretical physics? This is a rather dull question, which invites a rather dull answer: using mathematics. No, but how does one solve a problem? What is the thought process of the theoretical physicist, when confronted with an open question? Mathematics as the machinery that takes us from an initial set of equations and conditions, through a series of derivations, and to a final relation or numerical answer is well and good; but, stops short of asking "What is intuition?" What can we do, and what should we do, when coming up with a potential solution to a problem?

The aim of this essay is to pick one such problem, hopefully of interest to the reader concerned with the broad subject of particle physics, and walk through the conceptual construction of its most elegant solution. To do justice to theoretical physics, we will introduce a number of equations; yet, to avoid boring the reader out of their mind, we promise not to bother with their derivations and instead focus on their meaning - and how they serve the greater purpose of developing the solution to our problem.

A brief overview of QCD

Quantum chromodynamics (QCD), developed roughly between the early 1950s and the mid-1970s, is our best theory of strong interactions, giving a precise account of the structure of hadrons and the dynamics of their constituent fundamental particles, the quarks and the gluons. QCD is a quantum field theory, and as such, its dynamics are completely encapsulated by the corresponding Lagrangian density:

$$\mathcal{L}_{QCD} = -\frac{1}{4}G^{c}_{\mu\nu}G^{c\mu\nu} + \bar{\psi}_i\left(i\gamma^{\mu}D_{\mu} - m\delta_{ij}\right)\psi_j \quad (1)$$

Here, the quark fields $\psi_i(x)$ are apparent in the Lagrangian, whereas the gluon fields are somewhat hidden inside $G^{c}_{\mu\nu}$. We call this object the *gluon field strength tensor*: it contains various combinations of space-time derivatives and gluon fields, and carries an index $c = 1,...,8$ that runs over the number of gluons.

Remember that the gluons are the force carriers of the strong interaction (if the reader is familiar with group theory, this is equivalent to saying that gluons are four-vectors lying in the adjoint representation 8 of $SU(3)$, the "colour" gauge group of QCD), so the first term in tells us about the "strength" of the strong interaction. Between brackets, we find the relativistic quantum field theoretic version of a kinetic term for the quarks: a (covariant) derivative and a mass term m.

Global symmetries in QCD

The up and down quarks have very small masses (of the order of 1 MeV) compared to those of the nucleons (~ 938 MeV). Even the lightest meson, the neutral pion, has a mass of around 135 MeV. So it would make sense to simplify our theory a bit, by considering QCD with m(quarks) $\to$ In the massless quark limit, the theory acquires a global chiral symmetry, noted $U(N)_V \times U(N)_A$. This is again group theoretic notation: what $U(N)$ means is simply that we can rotate the quark fields by some complex number and preserve our Lagrangian. The V and A subscripts stand for "vector" and "axial", referring to exactly how the complex numbers act on the fields.

In reality, however, only the up and down quarks have negligible mass; the top quark, with its impressive mass of 173 GeV, is almost as heavy as an atom of tungsten! So we would expect only a $U(2)_V \times U(2)_A$ invariance, for our two light quarks.
We can actually break these down one step further, by writing $U(2) = SU(2) \times U(1)$. Indeed, $U(1)_V$ is an exact symmetry of QCD, corresponding to (vectorial) baryon number, and $SU(2)_V$ is an approximate "isospin" symmetry explaining why the nucleons (proton and neutron) are so similar, and why the pions come in a triplet (π^-, π^0, π^+).

On the other hand, their axial (subscript A) counterparts are not seen in the hadronic spectrum. This is fine for $SU(2)_A$: we say that it is *spontaneously broken* by the QCD vacuum; this mechanism is precisely what gives rise to the three pseudo-Nambu-Goldstone bosons we call the pions. The real problem here is that we don't see any pseudoscalar Nambu-Goldstone candidate for the spontaneous symmetry breaking of $U(1)_A$. It was shown that it should have a mass strictly smaller than $\sqrt{3}m_\pi$, but we know that there is nothing between the $\pi^0(140)$ and the $\eta^-(549)$ in the meson spectrum!
This is the $U(1)_A$ problem.

The Strong CP Problem

Historically, the issue of the missing $U(1)_A$ meson led to a better understanding of the QCD vacuum. In short, we don't see a pseudoscalar Nambu-Goldstone boson associated with this Abelian chiral symmetry, simply because it is *not* a quantum symmetry of QCD. In fact, we say that it is *anomalous*, i.e. broken by quantum effects. Still, this has the consequence that our effective Lagrangian is augmented by an anomalous contribution:

$$\mathcal{L}_{eff} = \mathcal{L}_{QCD} + \theta\frac{g^2}{32\pi}G^{c}_{\mu\nu}\tilde{G}^{c\mu\nu} \quad (2)$$

Here, $G\tilde{G}$ is a combination of the gluon field strength tensor (connected to the chiral anomaly), α_s is a coupling constant and θ is an angle parameter, related to the structure of the QCD vacuum and taking into account additional electroweak effects. This extra term is significant, as it violates **P** (parity) and **T** (time-reversal) symmetries, therefore introducing the possibility for **CP** violation in QCD.

A neat way of looking at QCD-induced **CP** violation, is by measuring the neutron electric dipole moment. The neutron is, of course, made of quarks, but possesses an overall neutral electric charge: we expect the negative and positive charge distributions of the quarks to overlap inside the neutron; any deviation would create localised partial charges, hence a dipole moment. As shown in Figure 1, the (hypothetical) electric and (real) magnetic moments of the neutron are reversed under parity and time-reversal respectively, leading to **P** and **T** violation.
The current experimental bound on

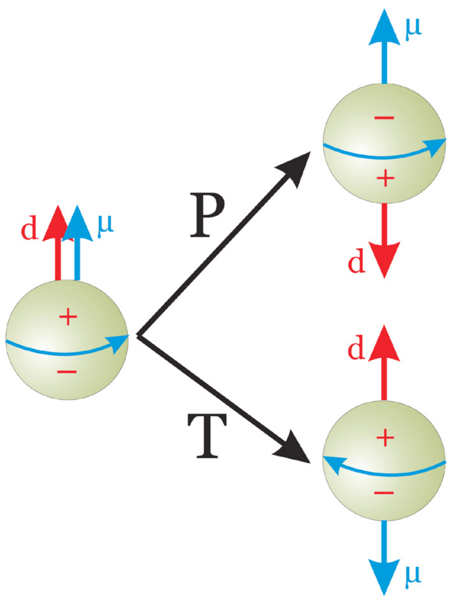

*Figure 1: **P** and **T** violation due to the electric dipole moment of the neutron.*

the neutron electric dipole moment d_n is:

$$|d_n| < 2.9 \times 10^{-26} e \cdot cm \qquad (3)$$

We can also derive a relation between d_n and θ from QCD:

$$d_n \sim \frac{e}{M_n}\left(\frac{m_q}{M_n}\right)\theta \sim 10^{-16}\theta \qquad (4)$$

which in turns means that, to agree with experimental observation, we must have:

$$\theta < 10^{-10} \qquad (5)$$

Why should θ, a free parameter of the theory, presumably of order 1, and containing effects from both strong and weak interactions, be so small? Equivalenty: Why is **CP** (seemingly) conserved in strong interactions? This is the strong **CP** problem.

A number of approaches to solving this problem have been attempted, most notably: unconventional dynamics, spontaneously broken **CP** symmetry, or a massless quark. The former is not really motivated by any deeper theory, and only swaps the strong **CP** problem for another, while the latter two are in disagreement with experiments. Rather, we want to focus on a more elegant solution.

$U(1)_{PQ}$ chiral symmetry

In 1977, Roberto Peccei and Helen Quinn proposed a natural solution to the strong **CP** problem, based on the introduction of a new global, spontaneously broken $U(1)$ chiral symmetry, which we will denote with a PQ subscript. Effectively, we are promoting our troublesome static **CP**-violating angle θ by a **CP**-conserving dynamical object: a scalar field, the *axion*.

$$\theta \to \frac{a(x)}{f_a} \qquad (6)$$

Under the action of $U(1)_{PQ}$, the axion field *a(x)* is simply translated by some multiple of f_a, the scale associated with the breaking of $U(1)_{PQ}$:

$$a(x) \to a(x) + \alpha f_a \qquad (7)$$

This is a brilliant move: we now have a dynamical way of driving the angle θ to 0, through the action of the Peccei-Quinn symmetry. But we've also introduced a new field into the Standard Model; we need to make sure everything else is nice and invariant under $U(1)_{PQ}$. To do so, we add the following terms:

$$\begin{aligned}\mathcal{L}_{total} &= \mathcal{L}_{SM} + \theta\frac{g^2}{32\pi^2}G^c_{\mu\nu}\tilde{G}^{c\mu\nu}\\ &- \frac{1}{2}\partial_\mu a\partial^\mu a + \mathcal{L}_{int}\left[\partial^\mu a/f_a;\Psi\right] \qquad (8)\\ &+ \xi\frac{a}{f_a}\frac{g^2}{32\pi^2}G^c_{\mu\nu}\tilde{G}^{c\mu\nu}\end{aligned}$$

The first line is just what we added before - $\mathcal{L}_{QCD} \subset \mathcal{L}_{SM}$ - and the anomalous **CP**-violating term. The second line is rather straightforward: a kinetic term for the axion field, and some as of yet undetermined interactions between axions and Standard Model particles. Finally, the third line is here to ensure that the $U(1)_{PQ}$ current has indeed a compensating chiral anomaly; this term is an effective potential for the axion field.

The minimum of this effective potential occurs at $\langle a\rangle = -\frac{f_a}{\xi}$. This is of course to make sure that, when the axion field is at the minimum of its potential, the θ-term is nicely cancelled. We can then rewrite our Lagrangian (eq. 8) by replacing a with $a_{phys} = a - \langle a\rangle$, which defines the physical axion; the **CP**-violating term then disappears altogether. The axion mass is obtained, as usual, by expanding the effective potential near its minimum:

$$m_a \simeq 0.6 \text{ eV}\frac{10^7 \text{ GeV}}{f_a} \qquad (9)$$

We still need to get an estimate of our $U(1)_{PQ}$ scale f_a: not only will it give us an idea of the axion mass, but also of the kind of physics it is involved with.

Axion models

Standard: Originally, this scale was thought to coincide with that of electroweak breaking: $f_a \approx 250$ GeV. However, this "standard" or "Peccei-Quinn-Weinberg-Wilczek" axion was excluded after extensive searches. Instead, modern axion models focus on $f_a >> 250$ GeV, dubbed "invisible" axion models.

KSVZ: In the class of models inspired by Kim, Shifman, Vainshtein and Zakharov, new superheavy quarks ($M \sim f_a$) and additional scalar fields carry the $U(1)_{PQ}$ charge, leaving ordinary quarks and leptons without tree-level axion couplings.

DFSZ: In the class of models inspired by Dine, Fischler, Srednicki and Zhitnisky, ordinary quarks and leptons do carry $U(1)_{PQ}$ charges, but one requires at least two Higgs doublets. In both KSVZ and DFSZ models, the axion still couples to photons, as we will see shortly.

SUSY: Supersymmetric models carry the axion as part of a supermultiplet, together with a spin-0 saxion and a spin-1 axino. Their couplings are heavily suppressed by the scale fa, and supersymmetry breaking mechanisms give them a large mass.

Strings: In string theory models, which are usually also supersymmetric, the relevant scale is the GUT (Grand Unified Theory) scale and so fa '1016 GeV. Of course, there is not one, but many string theories and the axion can come about in a number of different ways; the most "natural" or "elegant" are as a fundamental field, or in the process of *moduli stabilization* and string decay. The possible coexistence of (string) axions coexisting at various scales has led to the coinage of the term "axiverse".

Looking for invisible axions

As we've pointed out earlier, there is a term in the Lagrangian (eq. 8) that allows for interactions between axions and other Standard Model particles. However, axions have no electric charge, a very small mass and low interaction cross-sections for the strong and weak forces - in other words, they interact very weakly with ordinary matter. It is therefore almost pointless to look for them in conventional particle experiments and colliders.

This is a recurring problem in modern theoretical physics: we need to go to tremendous levels of energy to try and observe new proposed particles or effects, far beyond the reach of the LHC or any foreseable particle collider. This is where cosmology and astroparticle physics come in: the universe is our largest and most powerful laboratory. We will see shortly how axions fit in cosmology; but first, let's look at an interesting effect, that could help us out even at low energy scales.

Shining light through a wall

In addition to the simple derivative coupling to Standard Model particles, the axion can also have anomalous couplings to electromagnetic fields (and the corresponding particle, the photon). In fact, we have the interaction term

$$\mathcal{L}_{total} \supset \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu} = -g_{a\gamma\gamma} a\vec{E}\cdot\vec{B} \qquad (10)$$

where a is the axion feld, $F_{\mu\nu}$ is the electromagnetic field strength tensor, $\vec{E}$ and $\vec{B}$ are the corresponding electric and magnetic fields and $g_{a\gamma\gamma}$ is the coupling. In the so-called *Primakoff effect*, a high energy photon scattering off a nucleus can transform into an axion, with an amplitude proportional to the axion to 2-photon coupling $g_{a\gamma\gamma}$.

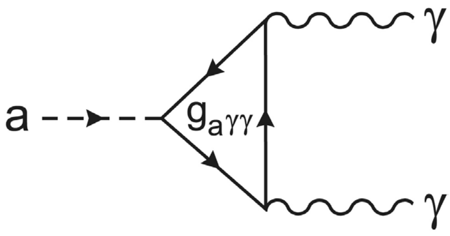

Figure 2: Triangle diagram for the decay of an axion into two photons.

So wherever we have sufficiently high energies and photons, we could theoretically see some funny axion business. There is a caveat to this statement - we do need a strong enough background magnetic field $\vec{B}$ for the Primakoff process (or its reverse) to take place. There are two main astrophysical situations where this could be the case: when looking at galaxies, and at the Sun. The Sun has the advantage of being quite close to us, with strong magnetic fields and, of course, permanent emissions of photons - there is therefore a small probability that a fraction of these photons will convert into axions. Using the reverse process, axions living in halos around galaxies might convert into photons - more about this in the next section.

The CERN Axion Solar Telescope (CAST, see Figure 3) is precisely looking for axions produced in this fashion, using the technology of superconducting magnets inherited from particle accelerators to produce a 9.5 T magnetic field around a telescope tracking the Sun. This should convert any potential solar axion back into X-rays, which can then be detected quite easily. Unfortunately, no definitive evidence has been reported so far. However, this experiment has helped put bounds on both the axion mass and the coupling ga which is related to other parameter in the theory.

Figure 3: CAST. The telescope magnet (blue) pivots about the right hand side, while the yellow gantry on the left of the picture rolls along a circular track in the oor and raises

Another type of experiment, dubbed "shining light through a wall", also exploits the Primakoff effect to do just that - shine light at a wall in the presence of a strong background magnetic field, hoping for $\gamma \to a$ conversion. The axion could then travel through the wall, interacting very weakly with standard matter, then convert back to a photon which could then be detected on the other side of the wall. The main advantage of this setup is that it gets (almost completely) rid of background noise: the detector is in a dark box, so that no outside photon can be registered. As a side-note, this kind of experiment can also look for other Weakly Interacting Massive Particles (WIMPs) and gravitons, for which similar photon conversion effects take place.

A sky full of stars... and axions?

Modern cosmology suggests that matter as we know it (made of elementary particles and interacting via fundamental forces, as described by the Standard Model) only makes up 4.9% of the total mass and energy of the universe. About 68.3% is so-called dark energy: energy, because it plays the role of a cosmological constant in Einstein's equations and powers the observed expansion of the universe; dark, because we have no clue what it might be. The remaining 26.8% correspond to dark matter: again, something "dark", not corresponding to any particle we know. Furthermore, we can only observe this dark matter through its gravitational effects, its localized mass being the reason we call it "matter".

So, what does this have to do with axions? Well, we've shown that axions have a very low mass, and interact extremely weakly with other known particles. It makes sense to propose the axion as a *natural dark matter candidate*: assuming such particles can be produced in large enough quantities, they will happily sit around, subject only to the gravitational effects of regular matter and other axions. In fact, this how we can actually detect and map dark matter: it organizes itself into halos, surrounding galaxies and, because of the non-negligible mass of the halos, cause them to spin faster than they should, based on the quantity of ordinary matter present. We don't observe dark matter, rather we "plug the holes" with it.

It turns out that yes, axions can be produced in abundance in the early universe. After the breakdown of the *PQ* symmetry (as we've seen, possibly at the GUT scale), the axion field relaxes to the minimum of its potential, which is **CP**-conserving, exciting coherent oscillations (axions) that form a condensate of cold dark matter. Moreover, if the *PQ* phase transition happens before ination (an exponentially acceleration period of expansion of the universe), the axion field is subject to quantum fluctations that are greatly amplified, leading to observable isocurvature fluctuations - basically affecting the characteristics of primordial gravitational waves and of the Cosmic Microwave Background (CMB), which we can measure.

Experiment suggests that the PQ symmetry breaking didn't happen until after inflation. Unfortunately, we don't yet have a working model of inflation, so we can only put constraints on the scale f_a. However, it is possible that axions could make up to about 24% of dark matter - the rest could be gravitons, SUSY particles, etc. This is especially interesting for string theoretic models that predict all of these particles.

In summary

The aim of this essay was to show how a theoretical physicist goes about solving a problem, what is involved to reach a consistent solution. We've done so by briey reviewing QCD, using it to explain several important concepts related to particle physics and symmetries, and pointing out the $U(1)_A$ problem. Historically, this led to the discovery of the more fundamental strong **CP** problem, for which we then detailed the most elegant solution: promoting a constant, the anormally small angle θ, to a field, which could be used to dynamically drive θ to zero. We then asked ourselves how to make such a solution consistent with the rest of particle physics: this was answered by modifying the Standard Model Lagrangian, and realizing that there could be many different models of axion physics.

The next step in our reasoning has been to look at immediate consequences of the existence of axion field: Where are the axions? How do they interact? What are their masses? at what energy scale (i.e. when in the history of the universe) are they produced? Could we observe them? And so on. We summarize here the bounds from the experiments we've looked at earlier:

$$10^{-5}\ \text{eV} \leq m_a \leq 1 - 10^{-3}\ \text{eV} \quad (11)$$

$$f_a < 10^{11} - 10^{13}\ \text{GeV} \quad (12)$$

The (possible) solution to a problem in an otherwise very functional theory (QCD) has taken us all the way from particle physics to cosmology, looking at theories such as strings and supersymmetry, experiments pointed at the Sun and the intergalactic medium, but also astroparticle physics, the nature of the elusive dark matter, and the surprising idea of shining light through a wall. The discovery of profound interconnections between the many aspects and scales of the world we live in is what physics is truly all about.

Figure 4: While many particles are named in honour of a physicist - fermion, boson, Higgs, J/ψ - or after a certain property - electron, neutron, neutrino, photon - the axion is the only one named after a brand of detergent!

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Baptiste Ravina recently graduated with a MASt in Theoretical Physics from the University of Cambridge. He will be joining the ATLAS group for his PhD, hunting for the elusive SUSY.

Nanophysics and its frontiers

Nanophysics is halfway between the size scales of quantum mechanics and macroscopic physics governed by the laws of Newton and Einstein. The correct definition of nanophysics is the physics of structures and artefacts with dimensions in the nanometer range or of phenomena occurring in nanoseconds [1].

Modern physical methods whose fundamental are developed in physics laboratories have become critically important in nanoscience. Nanophysics brings together multiple disciplines, using theoretical and experimental methods to determine the physical properties of materials in the nanoscale size range. Interesting properties include the structural, electronic, optical, and thermal behavior of nanomaterials, electrical and thermal conductivity, the forces between nanoscale objects, and the transition between classical and quantum behavior. Nanophysics has now become an independent branch of physics, simultaneously expanding into many new areas and playing a vital role in fields that were once the domain of engineering, chemical, or life sciences [1].

Nanoscience and nanotechnology are all about relating and exploiting phenomena for materials having one, two or three dimensions reduced to the nanoscale. Breakthroughs in nanotechnology require a firm grounding in the principles of nanophysics. It is intended to fulfill a crucial purpose. Nanophysics aims to connect scientists with disparate interests to begin interdisciplinary projects and incorporate the theory and methodology of other fields into their work [2].

Their evolution may be related to three exciting happenings that took place in a short span from the early to mid-1980s with the award of Nobel prizes to each of them [2]. These were: (i) the discovery quantum Hall effect in a two-dimensional electron gas; (ii) the invention of scanning tunnelling microscopy (STM); and (iii) the discovery of fullerene as the new form of carbon. Within a few years, the latter two further led to the remarkable invention of the atomic force microscope (AFM) and, in the early 1990s, the extraordinary discovery of carbon nanotubes (CNT), which soon provided the launch pad for the present-day nanotechnology [2]. The STM and AFM have emerged as the most powerful tools to examine, control and manipulate matter at the atomic, molecular and macromolecular scales – and these functionalities constitute the mainstay of nanotechnology. Interestingly, this exciting possibility of nanolevel tailoring of materials was envisioned way back in 1959 by Richard Feynman in his lecture, “There’s plenty of room at the bottom” [3].

Nanophysics applications

When things get small or cold (or both!), quantum effects start to appear. Nanophysics develops various devices and instruments to reveal and quantify them.

Novel materials, structures and devices are constructed through a variety of fabrication techniques, including e-beam lithography, focused-ion-beam milling, nano-manipulation, and self-assembly [1]. They are then tested at temperatures ranging from ambient down to a few tens of millikelvin using various probes, microscopes and cryostats. Probing the form and function of nano-structure and devices requires and inspires the development of ultra-sensitive detectors, sources (of quanta) and microscopes [1].

Quantum Measurements using Nanomechanical Resonators

The electron has dominated technology, measurement, communications and information processing for around one century, but hard limits may restrict its future dominance. One promising disruptive technology that may grow in future is based on NEMS (nano-scale electromechanical system).

Resonators based on NEMS (so called NMRs) are expected to have a range of applications, from ultra-sensitive sensors for mass, force, charge, spin and chemical specificity, through single-molecule bio-sensing, information storage and processing technologies, to nanoscale refrigerators.

They are sufficiently small that mesoscopic quantum mechanical behaviour is expected to appear, at low temperatures or even at room temperature, with all of the quantum metrology capabilities that have yet to been found in atomic and condensed matter physics.

There is a key requirement to extend quantum metrology to the nanoscale and to achieve measurements that are limited only by counting statistics or, going further, by the Heisenberg uncertainty principle limit.

It focuses on metrological aspects of NMRs as they approach the quantum regime, where the resonator's state is not significantly 'mixed' by thermal noise; in other words, one requires

$$\hbar\omega > k_B T$$

where ω is one of the resonator's fundamental frequencies, T is its effective operating temperature, and $\hbar$ and k_B are fundamental constants.

The ultimate metrological target, towards which it is aiming, is the provision of robust, convenient quantum-NEMS-based devices for the generation and counting of individual phonons. If this can be achieved it will have the mechanical analogue of 'quantum optics' and a whole new area of device engineering.

To avoid the need for ultra-low temperatures an NMR should operate at the highest possible frequency. It should also be capable of fabrication on the smallest possible length scale. A number of nanofabricated structures were researched composed of single-crystal materials such as Si, Si3N4 and particularly carbon nanotubes [4-7].

Nanomaterials and Nanomedicine

Various applications of nanoscale science to the field of medicine have resulted in the ongoing development of the subfield of nanomedicine. Nanomedicine is a relatively new field that is rapidly evolving. Formulation of drugs on the nanoscale imparts many physical and biological advantages. Such advantages can in turn translate into improved therapeutic efficacy and reduced toxicity [8].

Additionally, there is now a broad consensus among medical researchers and practitioners that along with personalized medicine and regenerative medicine, nanomedicine is likely to revolutionize our definitions of what constitutes human disease and its treatment. Nanomaterials are defined as the production of matter with at least one dimension ranging between 1 and 100 nanometers. Due to the very small size and the resulting high surface/volume ratio, nanomaterials have physical-chemical properties that differ from those of macroscopic materials. Nowadays, nanomaterials are often applied in many industrial fields including electronics, optics, textile and many others, including biomedicine [8].

The use of nanoparticles (NPs) in medicine has expanded recently, especially in diagnostic [9]. Actually nanoparticles could be designed as contrast agents, targeted therapies in cancer or nanocarriers able to bind, specifically transport biomolecules and accumulate to the site to treat.

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Enrico Catalano started studying for his BSc in 2015 at the University of Milano Bicocca, Italy. He has previously obtained a PhD in Nanotechnologies and Nanomedicine and started studying physics as a result.

Catalano is currently the president of the Milano Bicocca local group of NC Italy.

Introducing Perovskite Solar Cells

Abstract

One of the greatest challenges the scientific community is facing is to find convenient solutions for the growing global energy demand. The idea of a solar device that will convert the received sunlight into electricity is not new and although a future with solar-powered gadgets cannot yet be predicted, intensive research efforts are devoted to photovoltaics' gradual development. The vast potential of hybrid organic-inorganic solar cells has drawn scientists' attention for almost a decade. Their excellent photovoltaic performance gives rise to great opportunities for practical applications. For this reasons, perovskite solar cells and their properties are reviewed.

Looking at the big picture

We all know the world is growing incredibly fast and there is an end date on fossil fuels. Therefore, constant work is focused on finding renewable energy sources and ways of using it responsibly, without having any impact on the environment.

Ten years ago, the global energy consumption was about 15 TW per day. At present, we consume much more than that and it is predicted that by the year 2050 the total energy consumption will be 30 TW and 50 TW by 2100 [1].

The solar energy flux reaching the Earth's surface is over 100,000 TW. So, how can we use this huge amount of energy? Silicon solar cells were the first to be developed at Bell Laboratories in 1950. However, the traditional silicon technology is too expensive and requires high material usage and complex manufacturing processes. Therefore, new materials are being investigated as candidates for novel solar devices.

What is perovskite?

Technically, perovskite is a calcium titanium oxide mineral ($CaTiO_3$) discovered by Gustav Rose in the Ural Muntains in 1839, and it is named after Russian mineralogist Lev Perovski who characterised its structure. Afterwards, all the materials having the same crystallographic structure as $CaTiO_3$, namely the generic form ABX_3 were termed perovskites [2]. The chemical formula consists of two cations of different sizes (A and B) and an anion (X - typically oxygen, halogens or alkali metals). Oxide-based perovskites (X=O) were most investigated due to their amazing ferroelectric, magnetic and superconductive properties[3].

The key material for the new high-efficiency solar cells is the organometal halide perovskite, used as an absorber. As the name implies, it employs an organic cation (the most commonly used is methylammonium or MA, $CH_3NH_3^+$, placed in the A site), a metal cation (usually B = Pb^{2+}) and an inorganic halide(X = I^-, Cl^- or Br^-). The methylammonium lead halide perovskite is a low-cost material, which is simple to fabricate via various processing techniques.

Miyasaka and colleagues were the first to build a hybrid perovskite solar cell in 2006, realizing an efficiency of 2.2 % [4] Since then, the field of perovskite solar cells has experienced a rapid development. At pesent time, the efficiences of solar devices using perovskite materials have reached 22.1 % [5].

Why are the hybrid halide perovskites so special?

In general, there are two categories of optoelectronic materials, depending on their chemical structure: organic and inorganic. The family of hybrid perovskite materials has illustrated an example for perfectly combining the organic and inorganic worlds. This section summarizes some of the excellent attributes the perovskite materials posses.

Crystal structure

In the ideal case, perovskite has a cubic symmetry (Figure 1). However, several factors contribute to its structural distorsion, one being the size effects. It is easy to imagine that by replacing the A cation with an element having a large ionic radius we induce strain in the crystal lattice. Consequently, the B-X bond, responsible for the electronic properties of the perovskite material, is deteriorated [6-7].

Additionally, X-ray Diffraction (XRD) analysis has revealed that the symmetry of perovskite crystals increases with temperature, undergoing phase transitions form orthorombic to tetragonal, to cubic upon temperature increase [8-9].

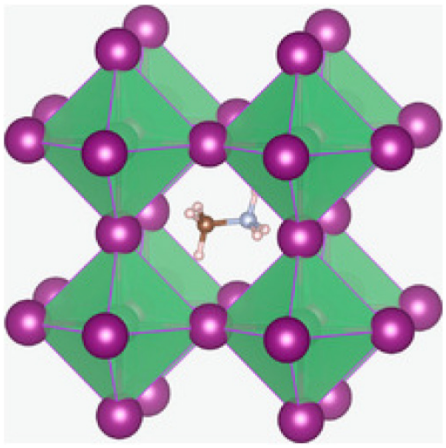

Figure 1: The crystal structure of hybrid halide perovskite. The methylammonium cation (center) is surrounded by PbX_6 octahedra. Source: Wikipedia

Optoelectronic properties

Band gap tuning

A controllable band gap allows for a strong optical absorbance in different ranges of the solar spectrum. Replacing the halide content is one approach to doing this. Thus, it was observed experimentally that a band gap between 1.55 eV and 3.11 eV is obtained for X = I, Br and Cl [10]. Also, the band gap can be tuned in between 1.55 eV and 1.17 eV by varying the ratio of lead to tin [2].

High absorption rate

Hybrid perovskites exhibit high absorption coefficients in the UV and visible range. Moreover, the sharp absorption peaks indicate that the materials have a direct band gap structure [11-12]. Regarding the optical properties, it was reported that lead-based perovskites such as $CH_3NH_3PbI_3$ are superior to their Sn-based analogue [13].

Long diffusion lengths

Interestingly, the carrier diffusion length was estimated over one micron for both holes and electrons via transient photo-luminescence (PL) measurements [14]. A long diffusion length implies that in order to efficiently collect charge carriers, materials of a much reduced thickness are needed.

High carrier mobility

The charge transport in perovskite films is ambivalent. High values for both electrons and holes were reported (≈ 12.5 cm^2/Vs for electrons and ≈ 7.5 cm^2/Vs for holes [15]). This factor may determine the high power conversion effiencies of perovskite solar cells.

The manufacturing ease

The simplicity of processing hybrid perovskite solar cells underlines their major advantage over the traditional silicon solar cells. There are two accessible methods to deposit $CH_3NH_3PbI_3$ on a substrate: the solution-process and the vapor deposition method. Since high crystallinity is required, a comparison between the two of them was made. It was shown that the perovskite films produced by vapor-deposition were more uniform. Also, large grain boundaries are formed, which facilitate the charge separation of excitons [16].

Building a perovskite solar cell

In a typical design, the materials needed to build a solar cell are: an active layer or an absorber material, which is a semiconductor, a carrier transport layer on each side of the absorber material allowing selective passage of either electrons or holes (the electron and the hole transport layers), and finally, two electrodes for charge collection. It is necessary that one electrode is transparent, such that the incident light can reach the absorber material. Perovskites have the ability to adapt to different device architectures. Initially, the perovskite solar cells adopted their structure from dye-sensitized solar cells. At present, the most popular configuration of perovskite solar devices is the mesoporous structure.

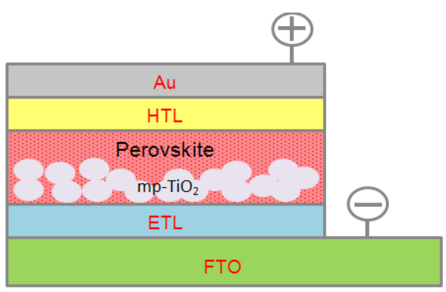

Figure 2: The build-up of a perovskite solar cell. The figure was adapted from https://coursera.org/learn/solar_cells

A common design consists of a fluorine doped tin oxide (FTO) glass substrate on which a compact TiO_2 ETL (≈ 80 nm) is added. The perovskite absorber is infiltrated in a mesoporous TiO_2 scaffold (≈ 350 nm) on top of the compact TiO_2 layer. Then, a HTL is deposited, the most used being the spiro-OMeTad polymer (≈ 200 nm). In the end, the top electrode is deposited, usually as a thin layer of gold (≈ 100 nm) [10].

Planar configurations (having no TiO_2 scaffold) have also been developed in the form of a n-i-p or p-i-n layer structure. This category of architectural design has attracted much interest due to its simplicity and versatility for device optimization.

Working mechanisms

For solar cells to generate electricity by converting a flux of incident photons into a flux of charge carriers there is a cascade of processes happening starting with the light absorption in the active layer, followed by charge separation, charge transport and finally, charge collection.

If an incident photon has an energy equal or greater than the semiconductor's energy band gap then the photon will be absorbed by the material exciting an electron from the valence band into the conduction band. At this point, the advantage of direct band gap semiconductors is emphasized as they facilitate the absorption of photons. Absorption is more complex for indirect band semiconductors because a phonon-assisted mechanism is required.

Moreover, an important parameter to consider is the width of the semiconductor's band gap. To determine the optimum band gap, it is necessary to

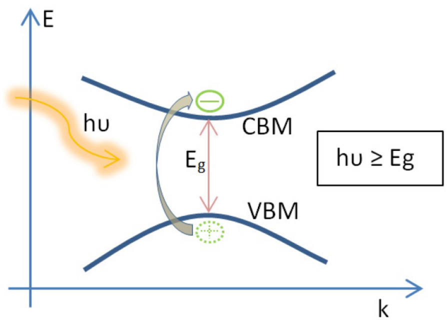

Figure 3: The absorption mechanism in a direct band gap semiconductor. The electron is excited from the maximum of the valence band (VBM) to the minimum of the conduction band (CBM).

estimate the energy of the photons available in the range of interest. This is given by the solar spectrum. Consequently, the advantage of a direct tunable bang gap makes perovskites promising materials. Upon absorption, a hole is created in the valence band exerting electrostatic forces on the neighbouring electrons and alters the initial electronic state distribution. This perturbation cannot be neglected and thus an effective interaction between the electron and hole is introduced. Having this in mind, we can consider the electron-hole pair a single neutral quasi-particle called an exciton. The excitons generated in the hybrid halide perovskite material are called Mott-Wannier excitons and they have a long range of action. In order to create charge carriers the excitons have to dissociate. It is supposed that charge separation occurs in hybrid halide perovskites at grain boundaries, when a potential barrier is encountered. It is presumed that the binding energy of the Mott-Wannier excitons in hybrid halide perovskite materials is very low, permitting the charge separation at room temperature due to its thermal energy [17].

The charge carrier will travel selectively to the electrodes due to the presence of electron and transport layers.

Future challenges

The prospects for practical application and long-term use of hybrid halide perovskite solar cells are hindered by their instability and degradation within a few hours to days in ambient environment [18]. The origins of

perovskite cells unstable nature are still under debate, although ultraviolet light, humidity and temperature have already been identified as major contributors [19]. Nevertheless, to improve the long-term stability, which is an important criterion for their commercialization, a clear explanation for the rapid degradation is needed.
Another issue is that the current-voltage measurements, which are the key to determine the power conversion efficiencies, exhibit hysteretic behaviour, in contrast to other solar cells. This makes parameter analysis difficult. There are some hypotheses for understanding the origin of this hysteresis. One of them indicates the perovskite material has a large dielectric constant suggesting ferroelectric properties and consequently a large charge capacity. Another theory considers the presence of defects that could trap and release electrons when a voltage is applied. Furthermore, a contributing factor to the observed hysteresis may be in the case of $CH_3NH_3PbI_3$ an ion migration. If the iodine element travels through the material and is accumulated near the contacts then a double high capacity electronic layer is formed at the interfaces [20].
Moreover, the toxicity challenge is substantial with the use of the lead element which restrains the commercialization of hybrid halide perovskites. Thus, finding Pb-free light absorbing materials, having the same attributes as the methyl ammonium lead halide perovskite, is currently a topic of intense research.

Conclusions

Hybrid organic-inorganic lead halide perovskite materials, in particular the methyl-ammonium lead halides have been considered prominent candidates for applications in photovoltaics due to their excellent attributes leading to superb power conversion efficiencies steadily rising towards 20 %. However, there are lots of puzzles to unravel in order to better understand the working principles which govern the device operation. Additionally the most important issues such as the perovskite cell instability and Pb toxicity need to be resolved, all with the purpose of continuously improving their performance. The future will tell whether the hybrid organic-inorganic perovskite solar cells will find a way to commercial implementation.

Hopefully, this article has attracted great interest on perovskite solar cells and it should be a source of motivation for young scientists to follow or continue further research in this field of photovoltaics.

Terms and abbreviation

Dye-sensitized solar cell (DSSC): a low-priced solar cell consisting of a semiconductor placed between a photo-sensitized anode and an electrolyte
ETL/HTL: an electron/hole transport layer allowing the selective passage of either electrons or holes
Direct band semiconductor: the maximum of the valence band and the minimum of the conduction band are placed for direct band semiconductors in the same position in the reciprocal space (k-space). Examples of such semiconductors are GaAs, CdS and ZnO.
Indirect band semiconductor: the absorption of photons in indirect band semiconductors (such as C, Si, Ge or TiO_2 is necessarily assisted by lattice vibrations or fonons)
Mott Wannier excitons: long range excitons meaning the distance between the hole and the electron is greater than the materials lattice constant
n-i-p structure: a junction formed an intrinsic undoped semiconductor placed in between a n-type and p-type semiconductor

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Daniela Dogaru studies physics of advanced materials and nanostructures and works as a research assistant at the National Institute of Material Physics in Romania. Her present research interests include organic solar cells and semiconductor materials used as transparent conductors.

Who will be the next editor-in-chief of jIAPS?

For years, jIAPS has spread news of the activities and science performed by fellow students, connecting the IAPS members. But to really grow, we are now looking for someone who can focus on improving jIAPS throughout the year.

You have:
- an enthusiasm for the international IAPS community.
- the vision to think of improvents to jIAPS.
- time to spare throughout the year at an average two hours per week.
- preferably experience with editing in Indesign and/or other software.

You gain experience in:
- editorial and journalistic choices.
- scientific publishing, giving you an advantage in your own potential research career
- international collaborations through contact with IAPS and jIAPS contributors

Send your CV and motivational letter to ec@iaps.info before 1 October 2016.

Run for the Executive Committee!

IAPS is managed by a team of nine motivated members making up the Executive Committee (EC) who maintain and develop all IAPS activities. They are elected each year at the Annual General Meeting (AGM) at the ICPS in August so that they can take over from the past EC on 1 September. Any member of IAPS - also you - can run for one of nine positions, consisting of the President, Treasurer, and Secretary as well as IT, Members & Alumni, Outreach & Education, PR, Events, and General – the General area being special projects and other tasks not already covered.

Though not required, you can send CV and motivational letter beforehand for the AGM participants to read through. Applications and questions are welcome at: ec@iaps.info

The next AGM will be held 14 August 2016 in Malta during the ICPS.

GET INVOLVED

An organisation is only as good as its volunteers. That is why IAPS regularly offers new opportunities. Possible areas of volunteering can be:
- building the IT infrasture we need to grow
- finding funding and making IAPS affordable for all physics students
- making everyone aware of us - a new member today is the ICPS host of tomorrow.

Go to iaps.info/opportunities/volunteering-work an join!

Volunteers at the IYL Closing Ceremony this February in Merida, Mexico.

Image by Berit Watkin