The 53rd *Remote*
IChO 2021
Japan

July 25 ~ August 2, 2021

Report

The 53rd International Chemistry Olympiad (IChO) 2021 Japan
Organizing Committee

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IChO

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The 53rd IChO 2021 Japan

Report

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53rd IChO 2021 JAPAN

Message

Kohei Tamao

President of IChO 2021 Japan Committee
Chair of the 53rd IChO 2021 Japan Organizing Committee

The 53rd International Chemistry Olympiad, IChO 2021 Japan, was held remotely from July 25 to August 2, 2021, under the slogan “Chemistry*!* It’s Cool*!*”.

Originally, we had been preparing to hold IChO 2021 Japan at Kindai University, one of the biggest private universities in Japan, located in the lively and modern commercial city of Osaka in mid-west Japan, also known as the historically important birthplace of chemical research in this country.

However, in light of the ongoing COVID-19 pandemic, we had no choice but to hold IChO 2021 remotely, following the lead of IChO 2020 Turkey last year.

This was the result of giving top priority to the safety of our young talented students and all participants, even at the expense of practical examinations and opportunities for in-person international exchange. I would like to thank all the International Steering Committee members led by Dr. Gábor Magyarfalvi for their enthusiastic discussion and acceptance of our decision.

The purpose of the IChO is not only to provide a venue for a test of students’ chemistry skills, but also to foster communication among students through chemistry and to gain familiarity with the culture of the host country. Despite being a remote competition held under the difficult conditions presented by the COVID-19 pandemic, the question of how to effectively implement these three elements was our biggest challenge.

The key dates were as follows:

July 25 (Sunday): Opening Ceremony
July 28 (Wednesday): Theory Examination
August 2 (Monday): Closing Ceremony

On other days, we offered various initiatives for students to create international friendships and become familiar with Japanese culture, in addition to the challenges of the scientific competition. We also provided a demonstration video of the practical tasks to compensate for the fact that the practical examinations could not be held. Virtual reality avatars for all students were prepared to facilitate remote networking and to give greater realism to virtual participation in the realistic Opening and Closing Ceremonies and virtual visits to sensitive areas such as SPring-8, the world largest synchrotron radiation facility, and the restoration site of an ancient Buddha statue to which access is normally prohibited. The IChO newsletter *Catalyzer*, including these all items, was published every day for a total of 11 editions.

The good news was that we accepted 312 talented students registered from the highest-ever 85 countries and regions of the 89 to which we sent invitations. I would like to express my sincere gratitude and respect for the wonderful efforts of mentors, teachers, and all concerned in each country (in total, 520) to select talented students and set up the examination sites in their own countries.

The theoretical examinations were held on July 28th in each country: the first started at 12:00 JST in New Zealand, the easternmost country, and the last started at 24:00 JST in the USA and Costa Rica, the westernmost countries. The 5-hour examinations ended at 5:00 am JST on July 29. All examination sites were monitored and recorded throughout the examination via Zoom through 100 PC monitors. It is my great pleasure to report that all theoretical examinations were carried out in an atmosphere of justice, fairness, and trust, maintaining the spirit of IChO, and I thank all the invigilators (in total, 183) for their earnest efforts.

In the Closing Ceremony on August 2, a list of medalists was announced: 33 Gold (top 10%), 67 Silver (next 20%), 94 Bronze (next 30%) and 24 honorable mention awardees (top 10% of non-medalists). I would like to congratulate all the awardees on their very best efforts, showcasing the talents and skills they demonstrate every day.

Now I would like to ask all the participating students to keep the following three things in mind as they reflect on this once-in-a-lifetime valuable experience.

First, they were given hope and courage to overcome difficulties through participation in IChO 2021 Japan.

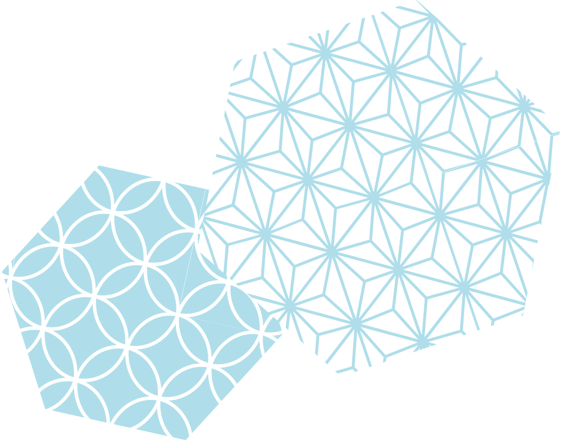
Second, the unprecedented difficulties we are still facing can only be overcome by international friendships and trust.

Third, I want them to remember that chemistry, the central science, is all around us. Chemistry must therefore play a key role in finding solutions for many global challenges, including the energy, environmental, and resource-related challenges that humanity is now facing.

I hope that IChO 2021 Japan helps to foster many talented young people who will go on to play roles as future world leaders. While these talented students did not have the opportunity to meet each other in person this time, I am convinced that one day they may meet each other somewhere in the world when they go to university or graduate school. I sincerely hope that they take the opportunities given to them as participants in IChO 2021 to create strong networks of international friendship, with the slogan “Chemistry*!* It’s Cool*!*” as their watchword.

Finally, I would like to thank IUPAC, the Ministry of Education, Sports, Science and Technology (MEXT Japan) and the Japan Science and Technology Agency (JST) for their meaningful support, and the more than 180 chemical companies and trading companies in Japan as our sponsors for their substantial financial assistance, as well as numerous personal donations.

My special thanks are also due to all the members of the Japan Committee and Organizing Committee for IChO 2021 Japan, as well as our secretariat and KNT Corporate Business Co., Ltd. Without their remarkable support and endeavors, this remote IChO 2021 Japan would not be possible.



Overview

The IChO program is intended to stimulate students' interest in chemistry through solving creative chemical problems that are both practical and theoretical. In a usual IChO, the participating students are tested on their chemistry knowledge and skills in a five-hour laboratory practical examination and a five-hour written theoretical examination. It also aims to promote international contacts in chemistry, friendships between young chemists of different nationalities, cooperation among pupils, and exchange of scientific experiences in chemistry.

At 47th IChO 2015 in Baku, Azerbaijan, Japan was invited to hold the 53rd IChO in 2021. It was originally planned to follow the 2020 Olympic and Paralympic Games in Tokyo. We anticipated that popular interest in chemistry would be enhanced by a scientific Olympiad being held after the excitement of a sporting Olympiad.

When we heard the first reports of COVID-19 early in 2020, it appeared to be a minor concern. Despite the virus being thought of as causing a new kind of cold, we knew that the common cold is inactive in summer when the IChO was to be held. However, shortly after the pandemic spread across the globe, it became evident that COVID-19 was active in summer, too. The 2020 Olympics and Paralympics were postponed for one year, and the 52nd IChO 2020 in Turkey was held remotely, because the university venue could not be used for an in-person event during the period scheduled for the IChO.

The IChO is composed of three key elements:

(1) Examination

Chemistry is an experiment-based science, with every theory coming out of the laboratory. Therefore, both theoretical and practical examinations play important roles in the IChO.

(2) Communication

Talented students from all over the world come together to take part in the IChO. Conversation, cooperation, and communication with each other provide a great opportunity for promising youngsters to enjoy international experiences and to make friends with other participants via their common interest, chemistry.

(3) Culture

The venue chosen for the 53rd IChO 2021 Japan, the Kansai area, is 500 km from Tokyo and was the ancient capital where the first government of Japan was established 2681 years ago (according to Japanese legend). Several places were to be visited, including not only very old temples but also state-of-the-art scientific institutes.

In the middle of January 2021, the Organizing Committee (OC) of the 53rd IChO 2021 Japan met with the Steering Committee (SC) of the IChO via Zoom. We discussed two proposals: for an in-person IChO and a remote IChO. Unfortunately, it was already clear that all the elements of the IChO described above could not be included in an in-person IChO during the COVID-19 pandemic, due to difficulties in immigration control and the need for social distancing.

The first priority of any IChO is, of course, the safety of all participants. After the meeting with the SC, the OC finally decided to hold the 53rd IChO 2021 Japan as a remote event. At the end of February, when we had our second meeting with the SC, the holding of a remote IChO was approved.

In this remote IChO, the competition only involved theoretical problems, and the students attended the examination from their own countries. Most of the elements essential to the IChO would be lost in the remote IChO, which was very disappointing.

Even in a remote format, however, the important features of IChO must be maintained as much as possible. The participating students must have extraordinary experiences. Therefore, the OC incorporated several activities and communication tools into the 53rd IChO 2021 Japan to cover these important features:

(1) Examination

In order to reinforce the importance of laboratory work, the practical tasks prepared for the 53rd IChO 2021 Japan were made open, despite not being officially approved by the International Jury meeting for the 53rd IChO 2021 Japan. The OC prepared videos in which all tasks were demonstrated with explanations and published the videos as one of the activities during the 53rd IChO 2021 Japan.

The OC will be delighted if those who are inspired by the demonstrations prepare and submit their original videos in which they attempt the practical tasks and discussions. Reports on the tasks will also be highly welcome.

(2) Communication

OC prepared a virtual reality (VR) space for communication. When participants accessed the VR space, their avatars were created. Everyone could participate in events and activities via their avatars. In the VR space, there were venues in which avatars could enjoy close conversations, cooperation, and communication with others.

(3) Culture

IChO participants were offered virtual visits to several locations. Some of these had been planned for the in-person IChO: Nara City, Osaka City, Kyoto City, and Himeji Castle. However, the OC added some that are very interesting to experience but not suitable for in-person visits due to hazards, sensitivity, space limitations, or language difficulties. SPring-8, a large synchrotron radiation facility that delivers the most powerful synchrotron radiation currently available, is one of the most interesting places in the Kansai area for the participating students of the IChO in particular. However, it is very difficult to visit SPring-8 as an activity in the IChO due to space limitations inside SPring-8 and the sensitivity of its advanced instruments. A workshop for preserving cultural assets, for example, repairing an image of Buddha, is another interesting place where modern chemistry is applied to very old subjects, although it is again very difficult to physically visit such a workshop because of the sensitive work, space limitations, and language difficulties. In the 53rd remote IChO, the participants virtually visited these highly restricted locations to experience more interesting cultural tours than would otherwise be possible.

The preparation of the problems started at April 24, 2018 in the first meeting of Science Committee of OC. After several intensive discussions and meetings, nine theoretical problems and three practical tasks were selected, and were brushed up to high quality problems. To complement these problems, thirty-one theoretical problems and seven practical tasks were prepared to be issued as the Preparatory Problems at February 1, 2021.

The opening ceremony started at 15:00 JST on July 25, 2021. The participants of the 53rd IChO 2021 Japan could access the ceremony via either the VR space or the usual video streaming. Over 200 participants entered the VR space to enjoy the realistic ceremony.

The first version of the theoretical problems was published at 21:00 JST on July 25. It should be noted that 21:00 JST is the almost the only time window to permit cooperation on that day all over the world: 21:00 JST is 24:00 for the easternmost country, New Zealand, and 9:00 for the westernmost country, Costa Rica. Therefore, most of the programs were scheduled at 21:00 JST during the 53rd IChO 2021 Japan.

The Science Committee of OC sought comments on the problems from mentors, revised the problems according to the comments, then proposed a second version of the problems for finalization to the international Jury meeting, the body that decides matters regarding the IChO that bind both participants and organizers. The Jury meeting started at 21:00 JST on July 26 and finished around 2:00 JST on July 27. The Science Committee of OC revised the problems according to the decisions of the Jury meeting and published the official final version at 9:00 JST on July 27. Next, the mentors started to translate the official English version into the individual local languages for their students. All delegations finished their translations by 9:00 JST on July 28.

It should be noted that 60 hours elapsed from the publication of the first version of the problems to the deadline for translation. Of course, contact between mentors and students after the publication of the problems was clearly prohibited in the competition guidelines. If a mentor wanted to cheat, for example, passing on the problems and solutions to his or her students, we could not prevent it. However, the OC trusted in the professionalism and the pride of mentors. If a mentor had said to their students, “Hey, I’ll tell you the problems and solutions, then you’ll all get gold medals,” they would lose the respect of their students. As expected, there were no suspicious results in the scores obtained by participating students, confirming that the IChO community is strong and ethically healthy.

The translated versions of the problems were made available to the invigilators at 9:00 JST on July 28. The invigilators downloaded and printed out the problems for students by the starting time of the examination. The invigilators are a crucial component of the remote examination. The OC asked country delegations to appoint invigilators who are independent of the mentors, have no relationship with students and have no other activity in the 53rd IChO 2021 Japan. Invigilators were to be socially well-established persons such as school principals and should not be a parent or a relative of a student. For the same reason, the examination location should be a public place such as a school, and the OC requested that each country choose a single location per a country.

Unfortunately, restrictions on movement were very severe in some countries during the period for the 53rd IChO 2021 Japan. Further, some students had to quarantine because their close relatives were infected by COVID-19. In such urgent circumstances, the OC allowed these students to take the examination in their homes, invigilated by their parents. The relevant delegations were asked to guarantee the fairness of the examination, and all delegations worked hard to make the students’ homes suitable as examination locations.

A total of 309 students took the examination, while three students were absent. All examination locations were inspected beforehand via Zoom and were monitored and recorded throughout the examination via Zoom.

The earliest examination started at 12:00 JST on July 28 in New Zealand, the easternmost country, and the last examination started at 24:00 JST in USA and Costa Rica, the westernmost country. The examination time was 5 hours. Participating students were not allowed to use any communication devices or computers during the period 19:00 to 24:00 JST to avoid any ill-intentioned communication via the Internet or social media. All these requirements were controlled by the invigilators.

After the examination, the invigilators sorted the answer sheets by page numbers, scanned them to prepare PDF files for each student, and submitted them to the OC. After all answer sheets were received, the Science Committee of OC started marking at 9:00 JST on July 29. In the same time, a pdf file with the answer and the marking scheme was published to all mentors, and mentors also started marking in their own countries. At 23:00 JST on July 29, we published our marking, and started receiving the request of arbitration from mentors till 20:00 JST on July 30.

The arbitration was carried out from 9:00 JST for easternmost countries to 24:00 JST for westernmost countries on July 31. The final results after reflection of all results of arbitration were sent to each country at 6:00 JST on August 1. It was announced to the mentors that any query for the final results should be sent to the Science Committee of OC within 6 hours, although no argument came to OC. Thus, the scores of all students were fixed and finalized at 12:00 JST on August 1, and the medals were allocated according to the regulation of IChO.

The students were awarded in the closing ceremony at 21:00 JST, on August 2, which was held also in the VR space and later published as a streaming video. Even after the closing ceremony, the participants could still enjoy virtual tours in the VR space.

The 53rd IChO 2021 Japan was financially supported by IUPAC, the American Chemical Society and Chinese Chemical Society in Taipei. Theses supports were used to subsidize participation fees for some countries that were facing economic difficulties. This year, there were several countries experiencing economic difficulties due to the COVID-19 pandemic.

The 53rd IChO 2021 Japan was totally managed by Zoom and Oly-Exam softwares. Zoom was used for the international discussion, e.g., Jury meeting and arbitration, and monitoring the examination. Oly-Exam was used for the preparation and translation of the examination problems and grading. On-time communication with mentors was carried out with mail and Telegram software.

After several events over the period of 11 days, the 53rd IChO 2021 Japan was successfully completed. We wish to congratulate all participating students. Some received medals, and some did not. However, they all tried their best to tackle the same chemical problems. When these youngsters meet again as the leaders in the field of chemistry, they will talk about the days of the 53rd IChO 2021 Japan. We will be deeply honored if the 53rd IChO 2021 Japan becomes one of the career milestones marked by the excellent chemists of the future.

Nobuhiro Kihara
Member of the Steering Committee
Member of the 53rd IChO 2021 Japan Organizing Committee
Vice Chair of Science Committee
Vice Chair of Executive Committee
Kanagawa University, Professor

The 53rd IChO 2021 Japan

Event Period July 25 ～ August 2, 2021

Main host

The 53rd International Chemistry Olympiad (IChO) 2021 Japan Organizing Committee

Co-host

Japan Science and Technology Agency (JST)

Endorsing Institution

Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Ministry of Economy, Trade and Industry (METI)
Osaka Prefecture Board of Education

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Participating countries/regions 79
＋5 Observer countries

Number of participants 709
Students 312
(Number of examinees 309)
Mentors 160
Observers 51
Guest 1
Invigilators 185

Schedule

Date	JST Time (UTC+9)	Student	Mentor/Observers	Invigilator	SC	Organizer
Jul 22, Thu	21:00				Mock exam	
Jul 23, Fri	21:00		Training of Oly-Exam (Zoom)			
Jul 24, Sat	0:00			Training of Oly-Exam (Zoom)		
	21:00				Mock discussion	Mock discussion
Jul 25, Sun	15:00	Opening Ceremony	Opening Ceremony	Opening Ceremony	Opening Ceremony	Opening Ceremony
	21:00		Receipt of the problem for review (Oly-Exam)			Publication of the problem (Oly-Exam)
Jul 26, Mon	9:00		Deadline of feedback (Oly-Exam)			
	21:00		Jury meeting (Zoom)		Jury meeting (Zoom)	Jury meeting (Zoom)
Jul 27, Tue	9:00		Receipt of the authorized problem for translation and submission (Oly-Exam)			Publication of the final version of official problem (Oly-Exam) Information of erratum (Zoom)
Jul 28, Wed	9:00		Deadline of translation	Receipt of the problem to print out (Oly-Exam)		
	14:00 ↓ 29:00	Examination (5 h) Asia → Europe → America		Submission of the solutions (Oly-Exam) within 2 hours after the end of the examination		Observation of every examination (Zoom/video) Receipt of all solutions (Oly-Exam) and reports (mail)
	21:30				SC meeting (Zoom)	
Jul 29, Thu	9:00		Receipt of the answer with grading scheme (Oly-Exam)			Distribution of the answer with grading scheme (Oly-Exam)
	9:00	SPring-8 virtual tour	SPring-8 virtual tour			
	23:00		Receipt of scores from Organizer (Oly-Exam) Request for arbitration (Oly-Exam)			Publication of scores (Oly-Exam)

Date	JST Time (UTC+9)	Student	Mentor/Observers	Invigilator	SC	Organizer
Jul 30, Fri	9:00	Video of Practical Task	Video of Practical Task			
	20:00		Deadline of arbitration request			
	21:00		Jury meeting (Zoom)		Jury meeting (Zoom) SC meeting (Zoom)	Jury meeting (Zoom)
Jul 31, Sat	9:00	Video of preserving cultural assets	Arbitration (Zoom) Asia → Europe → America			Arbitration (Zoom)
Aug 1, Sun	6:00		Receipt of final results (mail)			Report of final points (mail)
	9:00	Virtual visit for Himeji Catle, Osaka, Kyoto	Virtual visit for Himeji Catle, Osaka, Kyoto			
	12:00		Deadline of argument			
Aug 2, Mon	21:00	Closing Ceremony	Closing Ceremony	Closing Ceremony	Closing Ceremony	Closing Ceremony

Profit and loss statement 2019.4～2022.3

income

1 USD → 114 Yen

Account	Dollar
Donation income	1,941,560
Subsidies from the country	1,604,986
Participation fee income	85,865
Interest income	168
Miscellaneous income	414
Total amount	3,632,993

detail

Donation income		Dollar
	Donations from ACS,IUPAC,CSLT	6,217
	Donations from companies	1,915,877
	Donations from individuals	19,465
Total amount		1,941,560

ACS(American Chemical Society)
IUPAC(International Union of Pure and Applied Chemistry)
CSLT(Chemical Society Located in Taipei)

cost

Account	Dollar
labor cost	494,258
Payroll taxes expense	3,786
Welfare expenses	344
Outsourcing cost	2,075,278
Conference expenses	9,548
Traveling expense	88,955
Postage expense	12,163
Supplies expenses	172,710
Office maintenance and management fees	88,272
Member dues	114
Commission paid	2,370
Lease expenses	31,449
Taxes and dues	932
Compensation paid	4,075
Donations expense	3,881
administrative expenses	193,431
Participation fee	17,222
Printing costs	792
Miscellaneous expenses	114
Relocation fee	309
Total amount	3,200,003

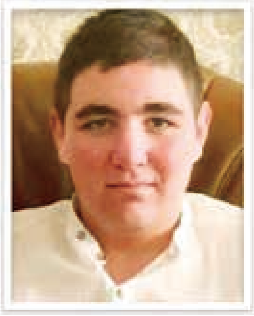
detail

Expenses directly related to the 53rd IChO 2021 Japan 2021.7.25～8.2		Dollar
	VR-AVATER production cost	666,349
	Video production cost	511,650
	labor cost	90,788
	Ceremony production cost	53,070
	accommodation charge	68,068
	Meeting room rental fee	527,904
	cost of a meal	9,491
	Courier fee and others	4,439
	PC rental fee for monitoring, etc.	31,546
	Medals and other souvenirs	95,750
	shipping charges	81,013
	part-time job offer	12,934
Total amount		2,153,002

National Team of Countries

Armenia

Student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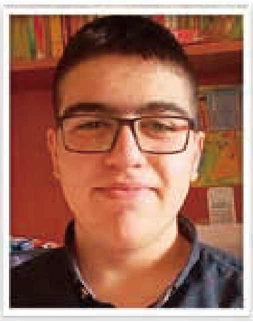
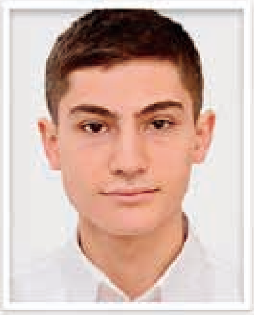

Leonid Asatryan


Tigran Harutyunyan


Sevada Nersisyan

Head Mentor

Andranik Davinyan

Mentor

Armen Galstyan

Invigilator

Artyom Petrosyan

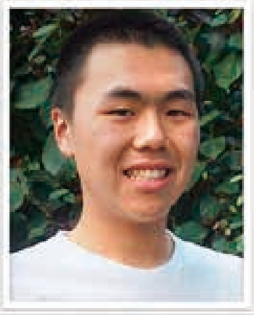
Australia

Student


Oscar Dong


Austin Lin


Vincent Ng


Keith Wong

Head Mentor

Mackenzie Shaw

Mentor

Amy Zhou

Invigilator

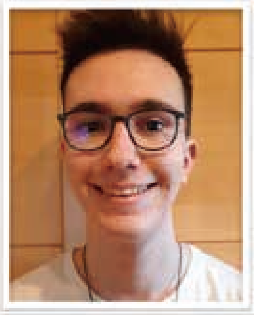
Samuel Alsop / Yao-Hua Helen Chang / Chris Choon Ng / Carol Zhang

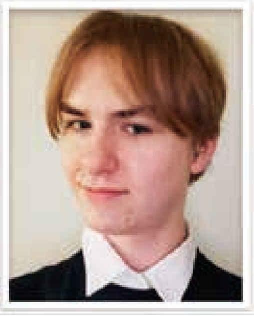
Austria

Student


Paul Johann Dorfer


Lukas Rost


Michael Schembera


Maciej Swiatek

Head Mentor

Georg Schellander

Mentor

Mathias Scherl

Observer

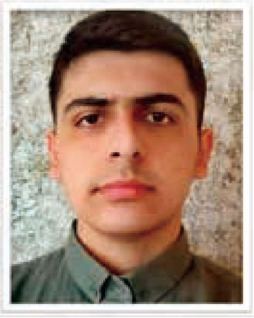
Felix Eder / Florian Kluibenschedl

Invigilator

Wolfgang Faber / Paul Glanzer

Azerbaijan

Student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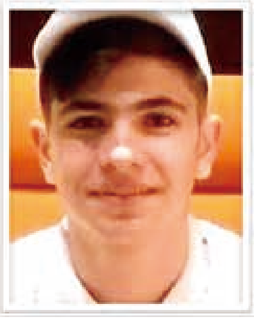
Mahsati Piriyeva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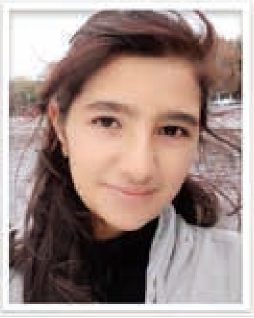

Khanim Yagublu

Head Mentor

Igrar Nazarov

Mentor

Milana Agayeva

Invigilator

Ali Aliyev / Bezlepkina Veronika

Bangladesh

Student


Tawhid Muhammad Mubashwir


Safwan Sakib


Mahin Kamal Sawdager


Khalid Hasan Tuhin

Head Mentor

Md Wahab Khan

Mentor

Mohammad Shoeb

Observer

Md. Abdul Jabbar / Md. Nurnabi

Invigilator

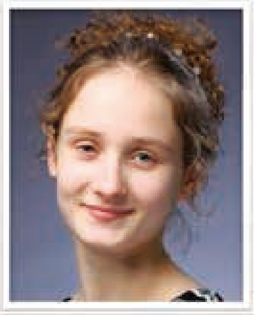
Md. Aminul Haque / N. K. M Akber Hossain / Md. Iqbal Rouf Mamun / Chanchal Kumar Roy

Belarus

Student


Uladzislau Hlatankou


Kiryl Maroz


Angelina Rogatch


Alina Tumashyk

Head Mentor

Viktar N. Khvalyuk

Mentor

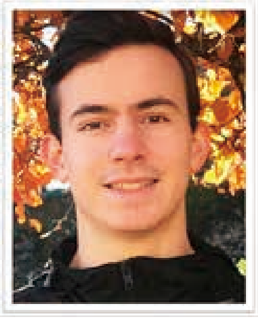
Denis G. Shklyaruck

Invigilator

Natallia Babaryka / Ekaterina Pavlyuchkova

Belgium

Student


Louis Pecheur


Lukas Schieble


Jef H. K. Van Eester


Daan Roger Stan
Vanhaecke

Head Mentor

Hans Vanhoe

Mentor

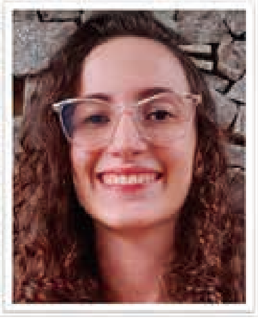
Sylvestre Dammicco

Invigilator

Gilliard Laurane / Cedric Malherbe

Brazil

Student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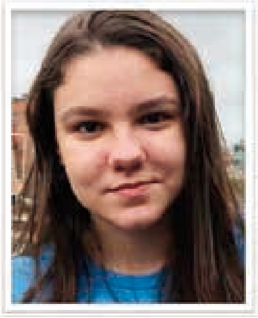
Aguiar da Ponte


Vinicius da Silveira
Lanza Avelar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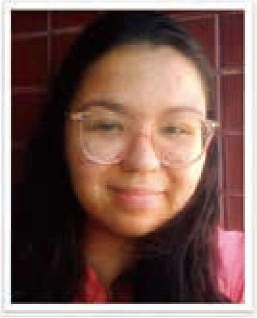

Hana Gabriela
Albuquerque Sousa

Head Mentor

Lucas Carvalho Veloso Rodrigues

Mentor

Joao Paulo Ataide Martins

Observer

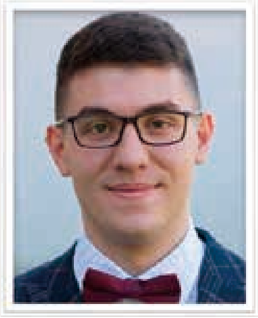
Samuel Anderson Alves Sousa

Invigilator

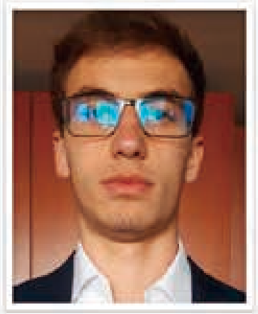
Sergio Maia Melo / Nagila Maria Ponte Silva Ricardo

Bulgaria

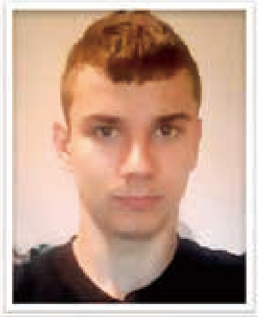
Student



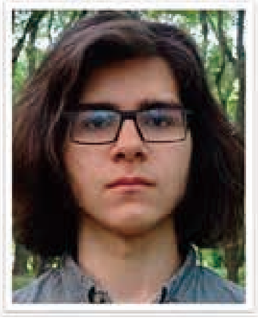
Teodor Svilenov Maslyankov



Georgi Neliyanov Nedyalkov



Pavel Atanasov Nikolov



Samuil Vladimirov Petkov

Head Mentor

Donka Nikolova Tasheva

Mentor

Penka Vasileva Tsanova

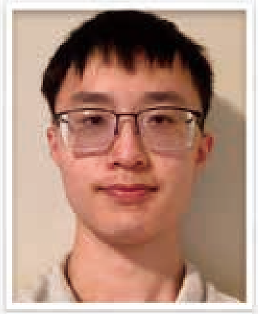
Invigilator

Nikola Tomov Burdzhiev / Plamen Danchev Kolev

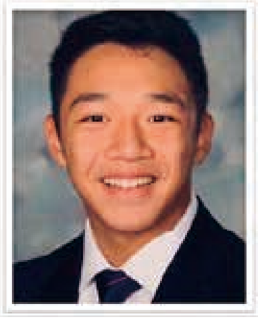
Canada

Student

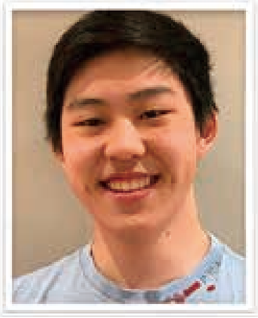
Andrei Banica



Andy Cai



Michael Li



Terry Wang

Head Mentor

Guillaume Bussiere

Mentor

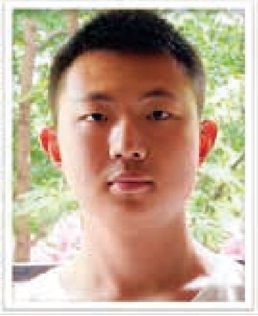
Jennifer Pitt-Lainsbury

Invigilator

Yi (Louise) Lu / Yaoguang Luo / Aleksandra Milicevic / Lisa Stepaniants

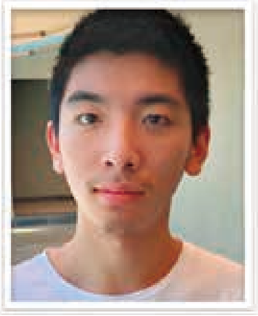
China

Student


Xinyu Cai


Zhangyi Huang


Shu Yang


Bangsen Zhao

Head Mentor

Yingxia Wang

Mentor

Ping Lyu

Observer

Qiaohong He / Zhengjie He / Kai Li / Huaping Xu

Invigilator

Qi Chen / Yinxia Yuan

Chinese Taipei

Student


Bo-An Chen


Hsuan-Ting Lin


Chun-Cheng Ting


Rui-Xi Wang

Head Mentor

Way-Zen Lee

Mentor

Cheng-Huang Lin

Observer

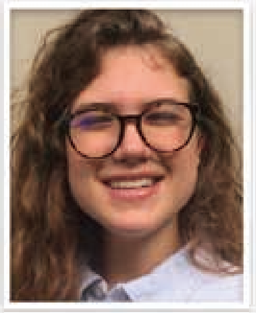
Yu-Tzu Li / Hsiao-Hua Yu

Invigilator

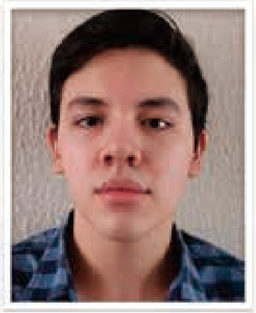
I-Ren Lee / Ming-Kang Tsai

Costa Rica

Student



Olivia Sojourner Dixon



Ignacio Herrera Gamboa

Fanny Mariana Solís González

Head Mentor

José Roberto Vega-Baudrit

Mentor

Wendy Villalobos González

Invigilator

Mario Villalobos Forbes / Andrea Rivera

Croatia

Student

Jasmin Jasarevic

Olga Jerkovic Peric

Fran Miletic

Marko Preocanin

Head Mentor

Branka Zorc

Mentor

Branimir Bertoša

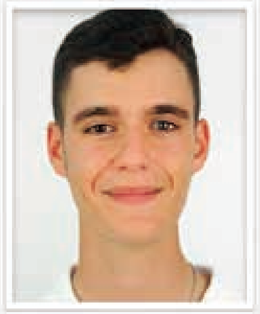
Invigilator

Tin Klacic / Darko Vušak

Cyprus

Student

Christiana Kosta



Giorgos Papachristodoulou

Stylianos Tamasios

Jessica Thackeray

Head Mentor

Stella Ioannou Loucaidou

Mentor

Georgios Miliotis

Invigilator

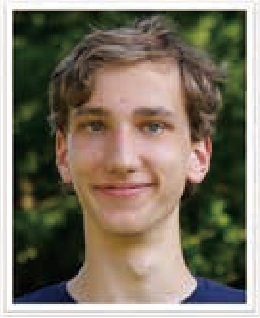
Marios Christodoulou / Georgia Ioannou

Czech Republic

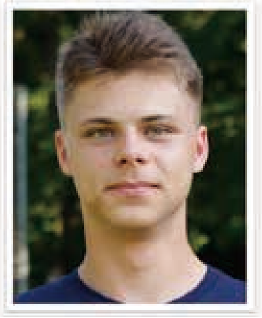
Student

Tomáš Heger

Filip Hůlek



Marek Pavlica



Jakub Sochor

Head Mentor

Petr Holzhauser

Mentor

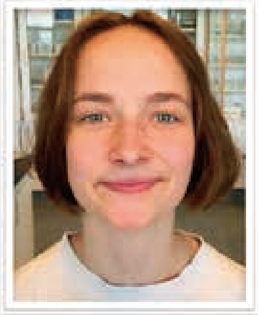
Jiri Ledvinka / Petra Ménová / Lukas Tomanik

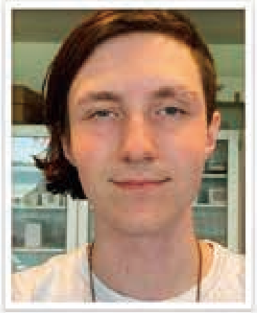
Invigilator

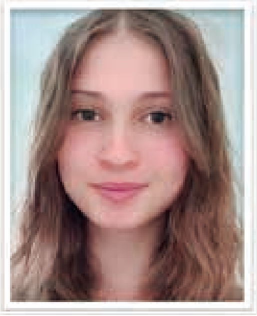
Josef Tomeček

Denmark

Student


Lin Bigom-Eriksen


Michael Estes


Melanie Muntz


Theodor Malte Novrup Redvall

Head Mentor

Kurt Bjoenager Nielsen

Mentor

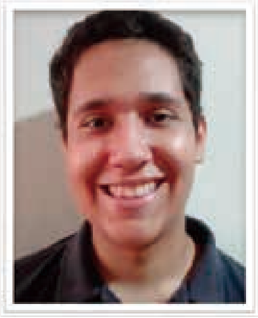
Pia Nielsen

Invigilator

Susanne Lis Mossin / Michael Munck

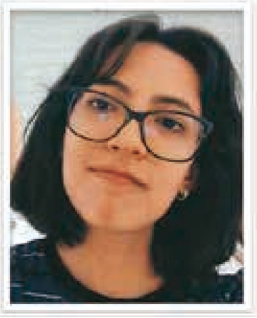
El Salvador

Student


Fredi Manuel Barraza Hernandez


Luis Ronaldo Chavez Escamilla


Emily Alejandra Crespin Guerra


Brenda Nicole Juarez Marroquín

Head Mentor

Johnny Jose Marquez

Mentor

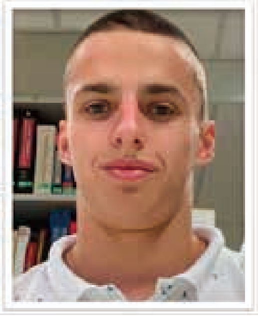
Marvin Alberto Ramirez Alas

Invigilator

Edwin Bladimir Bonilla Ascencio / Rodrigo Ernesto Robles Burgos / Bryan Manuel Salguero Cardoza
Alejandro Adrián Ayala Escamilla

Estonia

Student


Aleksandr Beditski


Andrei Kornijenko


Liis Siigur


Siim Tiivel

Head Mentor

Ida Rahu

Mentor

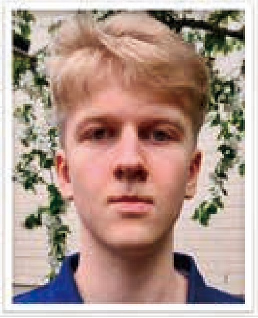
Siim Kaukver

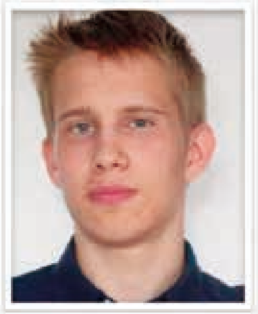
Invigilator

Jörgen Metsik

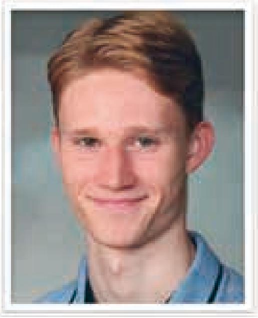
Finland

Student


Aku Hertell


Henri Kärpijoki


Otto Keronen


Samuel Klaver

Head Mentor

Kjell Knapas

Mentor

Miia Mäntymäki

Observer

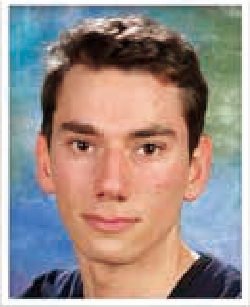
Juulia Talvitie

Invigilator

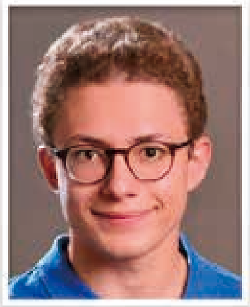
Mikko Kaipio / Leevi Pesonen

France

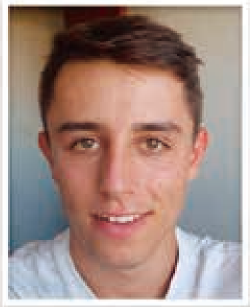
Student



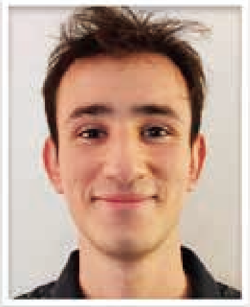
Alexandre Bloquel



Théodore Halley



Théo Mignen



Ruben Tapia

Head Mentor

Clément Guibert

Mentor

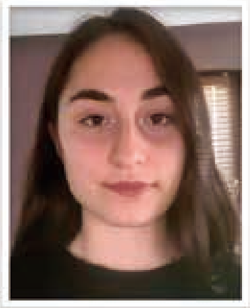
Alix Lenormand

Invigilator

Aurélien Moncomble

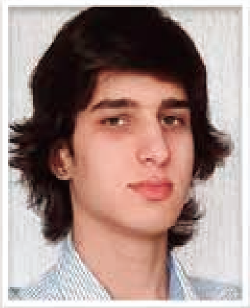
Georgia

Student

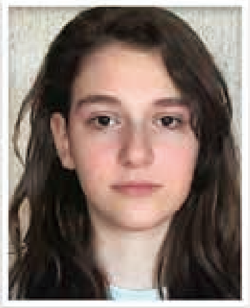


Nino Abesadze

Lizi Darchia



Ioane Kapanadze



Ketevan Peranidze

Head Mentor

Elizbar Elizbarashvili

Mentor

Vakhtang Kurtskhalia

Observer

Tinatin Buthkhuzi / Sophiko Phatsatsia

Invigilator

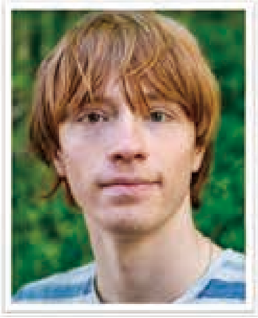
Tamar Bokuchava / Mariam Ghachava / Gia Khatisashvili / Ekaterine Mikautadze

Germany

Student


Johann Sora Blakytny


Tim Bastian Enders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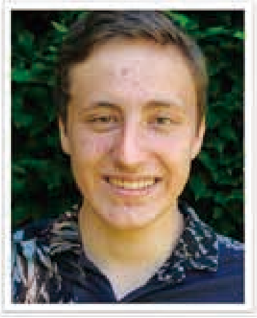

Linus Albert Schwarz

Head Mentor

Frank Witte

Mentor

Felix Strieth-Kalthoff

Observer

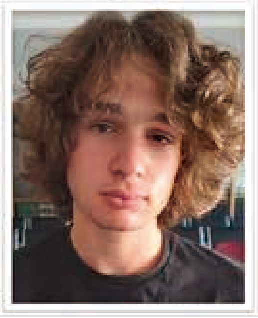
Maximilian Fellert

Invigilator

Jan Hendrik Frenzel / Philipp Gremler / Uta Purgahn

Greece

Student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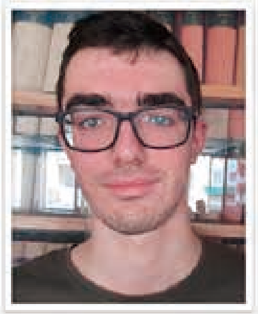
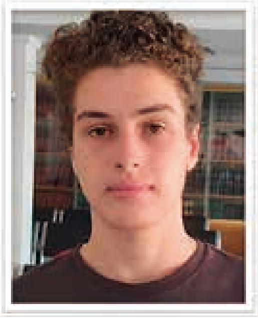

Ioannis Karageorgiou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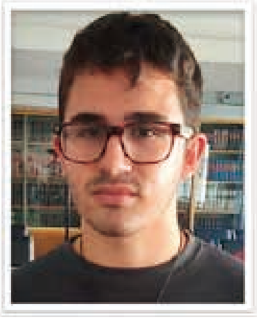

Dimitrios Stylianakis

Head Mentor

Nikolas Psaroudakis

Mentor

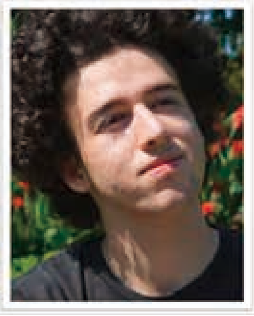
Georgios Melidoneas

Invigilator

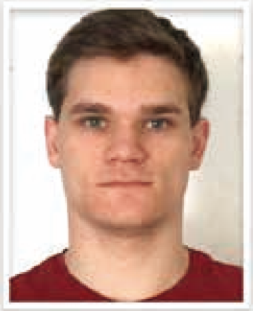
Alexandros Terzopoulos

Hungary

Student



István Babcsányi



Dávid Benkő

Benedek Sajósi

Lucio Saracco

Head Mentor

Gábor Magyarfalvi

Mentor

Szilárd Varga

Observer

Katalin Zih-Perenyi

Invigilator

Gyorgy Koczan

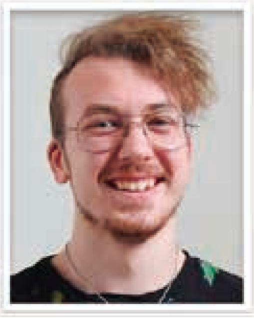
Iceland

Student

Dagur Bjorn Benediktsson

Telma Jeanne Bonthonneau

Isak Hugi Einarsson



Daniel Heidar Jack

Head Mentor

Katrin Lilja Sigurdardottir

Mentor

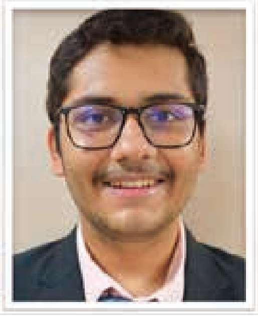
Mar Bjorgvinsson

Invigilator

Rafn Rafnsson

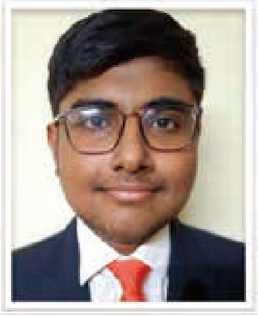
India

Student



Mahit Rajesh Gadhiwala

Adarsh Reddy Madur



Dhananjay Raman

Rishit Singla

Head Mentor

Ankush Gupta

Mentor

Nandita Madhavan

Observer

Dimple Dutta

Invigilator

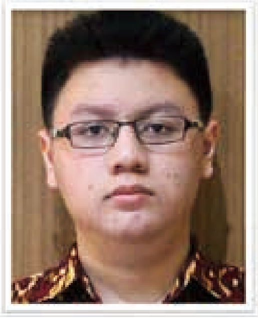
Rajesh Chandrakant Gadhiwala / Rupa Reddy Madur / Swapna Mahesh Narvekar / Praveen Pathak / Shirish Rajan Pathare / Lalitha Raman / Harita Pankajkumar Raval / Indrani Das Sen / Dinesh Kumar Singla

Indonesia

Student

Kevin Lius Bong

Faatih Regind Qashash Roman



Nathanael Reza Putra Widjaja

Hanif Muhammad Zhafran

Head Mentor

Deana Wahyuningrum

Mentor

Fainan Failamani

Observer

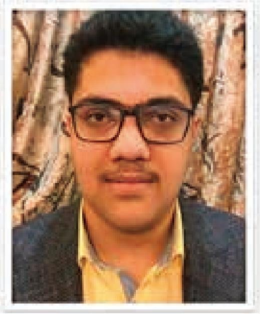
Irma Mulyani

Invigilator

Azis Adharis / Damar Nurwahyu Bima / Arie Hardian / Fatiha Khairunnisa

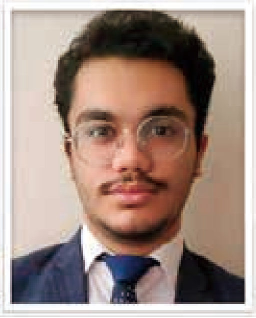
Iran

Student

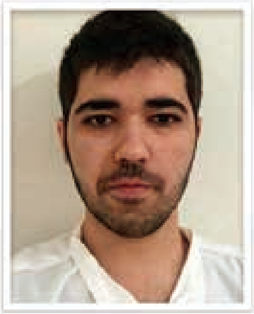


Mahyar Afshinmehr

Mahbod Alian Fini



Seyed Mohammad Hossein Barakati



Ehsan Naderi Donig

Head Mentor

Seifollah Jalili

Mentor

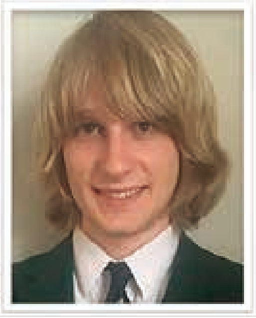
Ebrahim Kianmehr

Invigilator

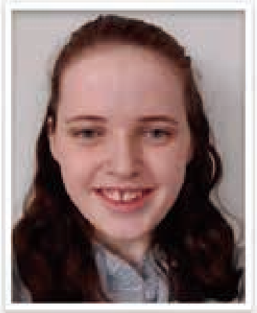
Bahram Madadi / Shahram Seidi

Ireland

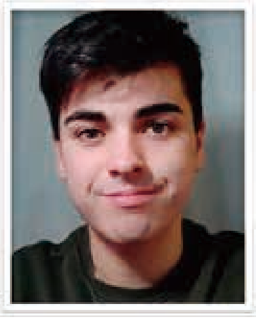
Student



Oscar Eric Moran Despard



Aoife Mary Morris



Oisín Colm Ó Feinneadha

Tong Wu

Head Mentor

Carl Poree

Mentor

Brian Martin Murphy

Observer

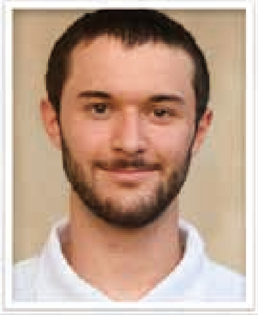
Elizabeth Sarah Gilchrist / John Daniel O'Donoghue

Invigilator

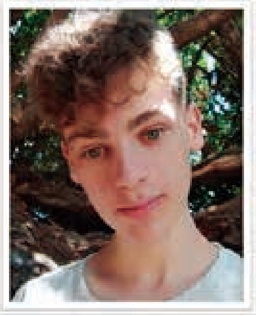
Adrian Sanz Arjona / Susannah Calvert / Aine Coogan / Annie Regan

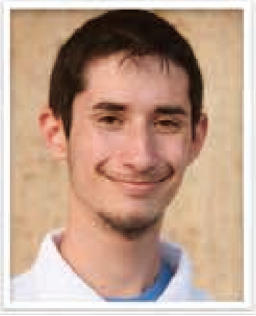
Israel

Student


Nir Cohen


Neta Eiger


Tal Sason


Itamar Steinitz

Head Mentor

Izana Nigel

Mentor

Assaf Mauda

Observer

Zeev Groos

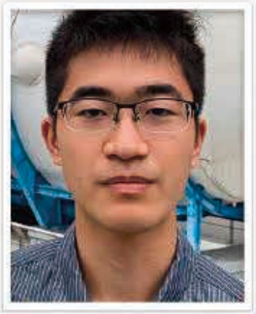
Invigilator

Maria Lavi

Japan

Student


Haruhi Isse


Yuya Koike


Kohei Nishiura


Takahiro Takemoto

Head Mentor

Akira Nagasawa

Mentor

Tsuyoshi Yamaguchi

Observer

Asao Nakamura / Toru Shimada

Guest

Takuji Hirose

Invigilator

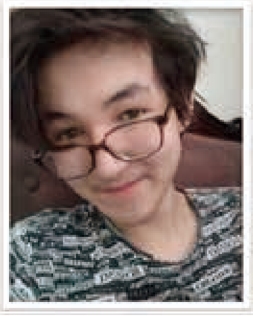
Tomohiro Iwai / Hiroyuki Okura / Noriyuki Yonezawa

Kazakhstan

Student


Sanzhar Bissenali


Khaidar Kairbek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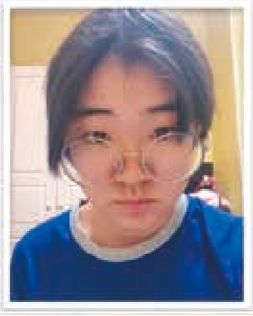

Aigerim Turuspekova

Head Mentor

Yernur Tolep

Mentor

Anton Morgunov

Invigilator

Yerbolat Ablemetov / Zharlagapova Zere

Korea

Student


Seung Jae Kang


Seoyeon Kim


Myeongjin Shin


Hee Seong Yoon

Head Mentor

Bongjin Moon

Mentor

Sung Ik Yang

Observer

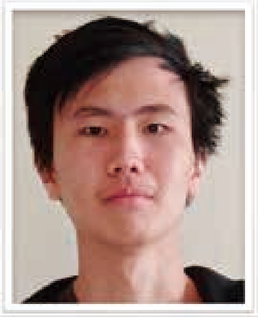
Hyuk Kang / Myung Hwan Park

Invigilator

Myeong-Sook Kim / Yelim Kim

Kyrgyzstan

Student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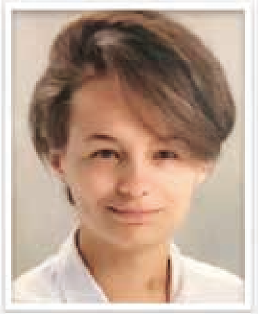
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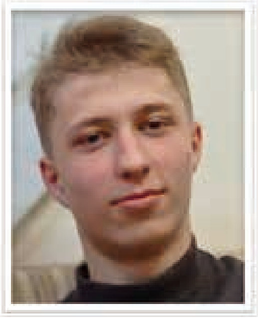

Ivan Reshetnikov


Azamat Salamatov

Head Mentor

Bakut Borkoev

Mentor

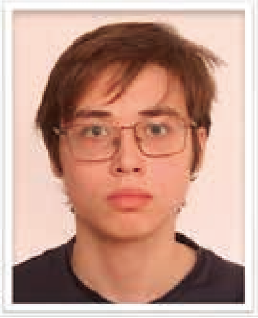
Kalipa Salieva

Invigilator

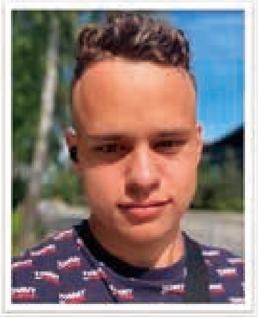
Dooronbek Mametov / Sharshenali Saitkulov

Latvia

Student


Daniils Kargins


Džonatans Miks Melgalvis


Vladislavs Tiščenko


Edvards Jānis Treijs

Head Mentor

Nauris Narvaišs

Mentor

Ritums Cepītis

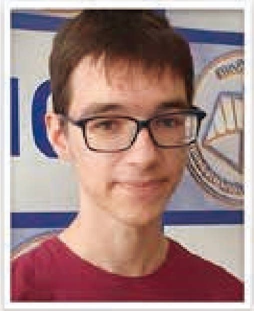
Invigilator

Kristine Zadvinska

Lithuania

Student


Tadas Danilevicius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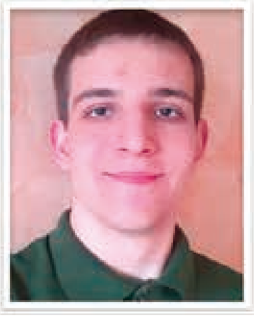
Laimis Jurkenas


Simonas Melaika

Head Mentor

Rimantas Raudonis

Mentor

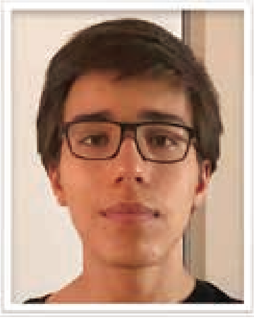
Lukas Steinys

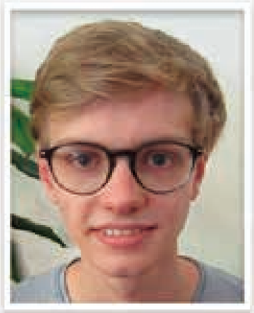
Invigilator

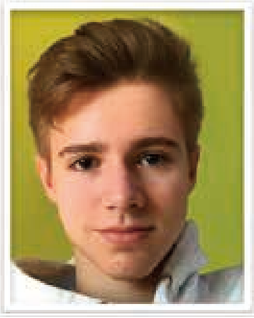
Vytautas Kavaliauskas / Agne Kizalaite

Luxembourg

Student


Laurent Bommertz


Rafael Dux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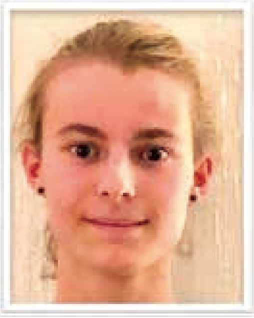

Raphaël Menasce

Head Mentor

Sam Hoffmann

Mentor

Sven Linster

Invigilator

Claude Kiefer

Malaysia

Student


Bernie Lim Wei Yuan


Shawn Vernon Wong Siang Ray


Lim Xu Yao


Wong Yi Yang

Head Mentor

Noorsaadah Abd Rahman

Mentor

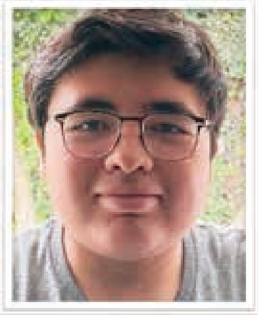
Sharifuddin Md Zain

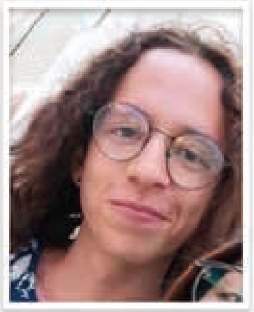
Invigilator

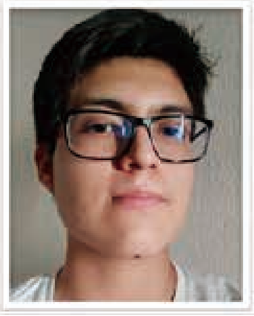
Jahari Jainal / Lee Lay Peng / Goh Boon Swee / Mary Wong

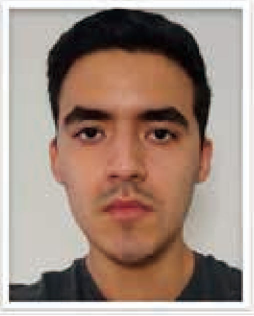
Mexico

Student


Jorge García-Ponce


Gerardo Emiliano Gutierrez-Alvarez


Emmanuel Sotomea-Renova


Emilio Alonso Venegas-Hernandez

Head Mentor

Carlos M Castro-Acuna

Mentor

David Octavio Corona-Martinez

Invigilator

Hector García-Ortega / Gabriel Palacios-Huerta

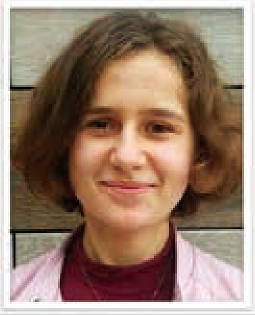
Moldova

Student


Adelina Andrei


Maxim
Cojocari-Goncear


Valerian Mocreac


Tatiana Svirinuc

Head Mentor

Ion Bulimestru

Mentor

Vasile Graur

Invigilator

Stanislav Ciubotaru / Diana Cojocaru

Mongolia

Student


Irmuun Altankhuyag


Gerel Bayarmagnai


Bumchin Dolgormaa


Temujin Orkhon

Head Mentor

Otgondemberel Galaaraidii

Mentor

Nyamgerel Choijilsuren

Observer

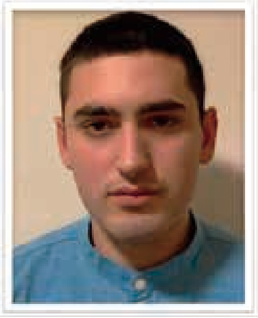
Munkhjargal Burenjargal / Battugs Davaasambuu

Invigilator

Altanzul Altangerel / Saruul Idesh

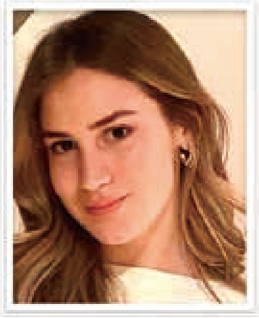
Montenegro

Student


Danijel Aleksic


Iva Djurickovic


Ksenija Tadic


Milica Zizic

Head Mentor

Miljan Bigovic

Mentor

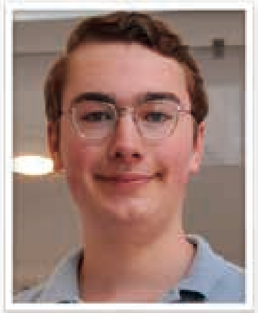
Bojana Ostojic

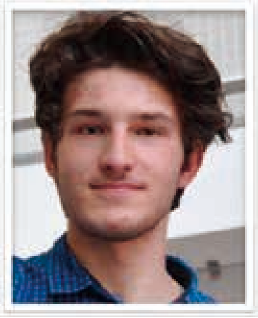
Invigilator

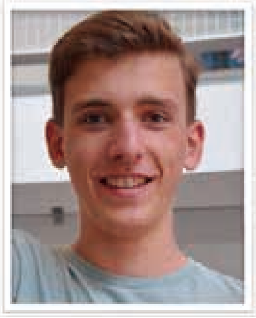
Momir Radulovic / Ivana Vukcevic

Netherlands

Student


Sebastian Jacob Krikke


Mitchell Rikken


Jochem van den Broek


Max Rudolf Antonius
Karel van Hest

Head Mentor

Emiel de Kleijn

Mentor

Kees Beers

Invigilator

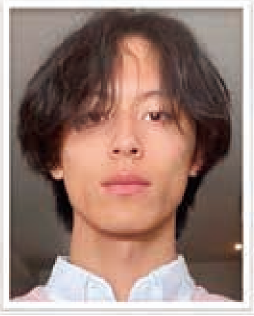
Martin Groeneveld / Dick Hennink / Marijn Jonker

New Zealand

Student

Abhinav Chawla

Daniel Jiyoun Jang



Mason Minghan Liu

Sam Wuji Zhuang

Head Mentor

Duncan J McGillivray

Mentor

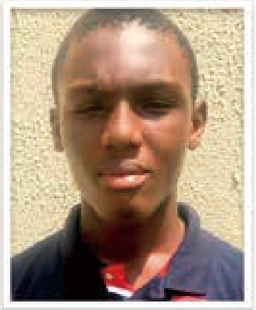
Sheila Woodgate

Invigilator

Jan Giffney / Stephen McCracken / Andrew Rogers

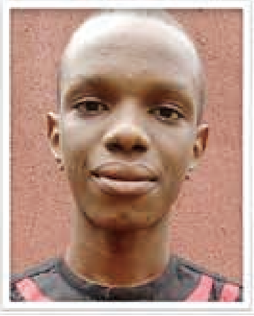
Nigeria

Student



Joseph Eghenevwegba Ikuru

Winston Ukpong



Ifeanyichukwu Valentine Umeanyika

Head Mentor

Chinenye Nna Orji

Mentor

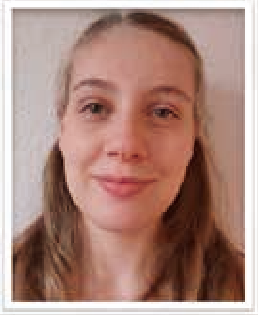
Aishat Yetunde Abdulkareem

Invigilator

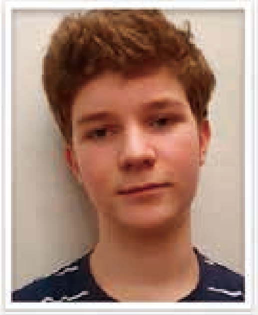
Ugochukwu David Uche

North Macedonia

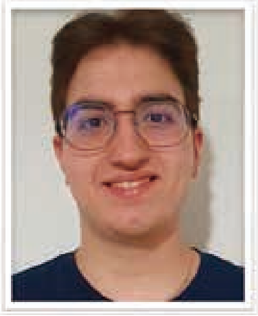
Student



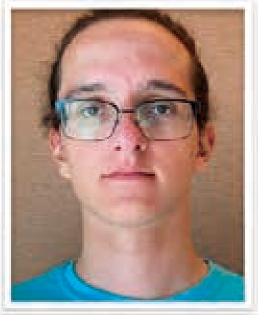
Anja Spasovska



Jan Stojanovski



Darko Stojchev



Mihail Trajkov

Head Mentor

Miha Bukleski

Mentor

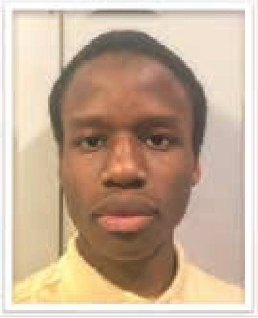
Natasha Ristovska

Invigilator

Leon Stojanov

Norway

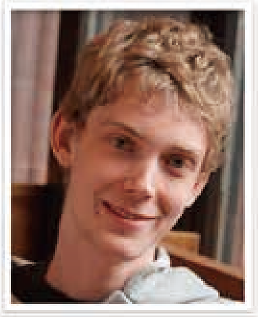
Student



Abdur-Raheem Idowu

Tina Kalleson

Joachim Julian Klaussen



Simen Mannsåker

Head Mentor

Hans-Petter Hersleth

Mentor

Kristian Vestli

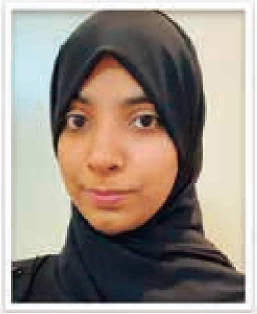
Invigilator

Bjørn Dalhus / Henrik Hovde Sønsteby

Oman

Student


Lujaina Al Badi


Arwa Al Hashimi


Abdullah Al-Azri


Maryam Al-Hatmi

Head Mentor

Mohamed Alnaabi

Mentor

Said Al Ghawi

Invigilator

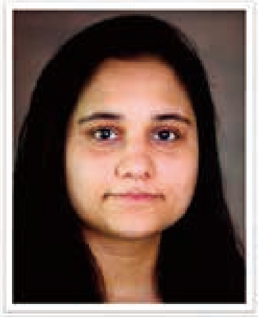
Fatma Al Badi / Nasser Al Mushaifri / Sultan Al Rahbi / Mohsin Al Riyami

Pakistan

Student


Muhammad Ismail


Ayesha Junaid


Rameesha Khursheed


Muhammad Yahya

Head Mentor

Khan M. Khalid

Mentor

Muhammad Raza Shah

Invigilator

Arslan Ali / Muhammad Imran Malik / Syed Muhammad Saad

Philippines

Student

Nathan Wayne F. Ariston

Ron Angelo A. Gelacio

Aames Juriel B. Morales

Kristoff John F. Padilla

Head Mentor

Jose M. Andaya

Mentor

Faith Marie Goli Lagua

Invigilator

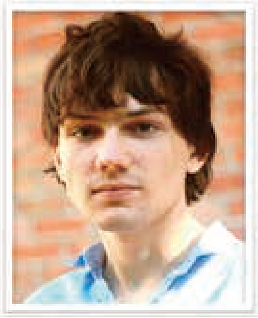
Aimee Fontanilla Ariston / Kenneth Arnyl Diaz / Maria Ana Atienza Gelacio / Merlyn Beladas Morales / Raymond Rosalejos Padilla

Poland

Student

Jakub Krzysztof Kwiatkowski

Michal Piotr Lipiec



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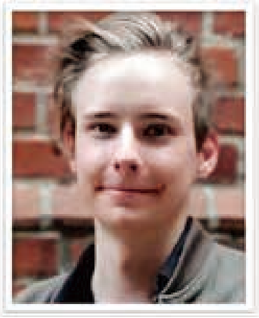


Adam Szymon Sukiennik

Head Mentor

Marek Orlik

Mentor

Aleksandra Misicka-Kesik

Observer

Piotr Kwiatkowski

Invigilator

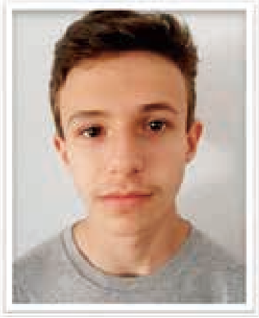
Ewa Pobozy

Portugal

Student

João Pedro Bonito Caldeira

Mariana Vilela Marta Rio Costa



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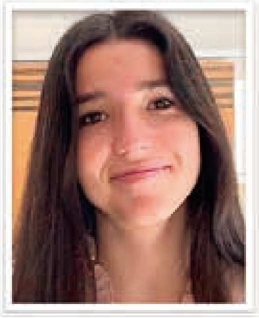


Beatriz Crisóstomo Valério Figueiredo

Head Mentor

Vasco Figueiredo Batista

Mentor

João Miguel Pimenta Pereira

Invigilator

Diana Cláudia Gouveia Alves Pinto / Carlos Fábio Magalhães da Silva

Qatar

Student

Nihit Agarwal

Sara Fahed Al ali Alahmad

Asmahan Abdulaziz Al-Kuwari

Sushanthi Anandaraja

Head Mentor

Lamyah Yousef Al-Hayki

Mentor

Rabab Farouk Awad

Observer

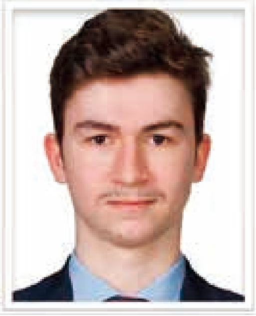
Emad Abdel Rehem Alsaifi / Sherif Abdel Hamid Elhefnawi

Invigilator

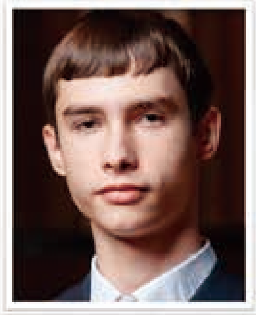
Sahar Mohammed Omar / Wafaa Gafer Othman

Romania

Student


Mircea Raul Bodrogean


Alexandru Catalin Dianu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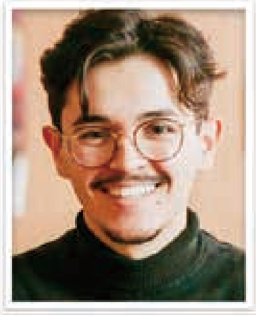

Tudor Lile

Head Mentor

Marius Andruh

Mentor

Mihaela Matache

Invigilator

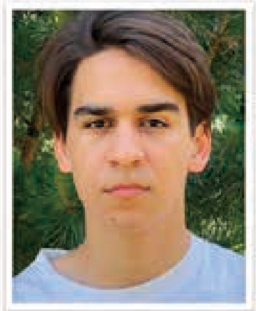
Adrian Apostol / Anca Paun / Codruta Popescu

Russian Federation

Student


Timofey A. Charkin


Aleksandr E. Trofimov


Andrei S. Tyrin


Georgii M. Zhomin

Head Mentor

Vadim V. Eremin

Mentor

Alexander S. Belov

Observer

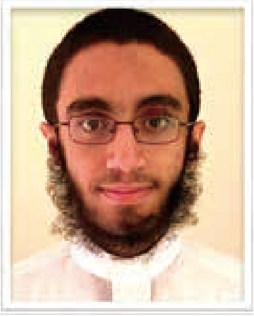
Alexander K. Gladilin / Leonid V. Romashov

Invigilator

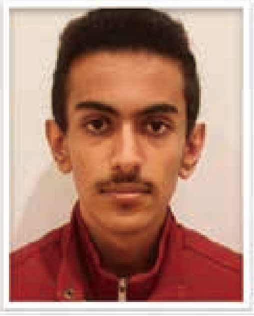
Sergey I. Kargov

Saudi Arabia

Student


Mohammad Solaiman AlHadlaq


Mohammad Rashed AlHudaithi


Abdulaziz Abdulrahman AlJuaid


Saeed Sultan Baghdadi

Head Mentor

Reem Sadeq AlMohammed

Mentor

Abdullah Jassim AlAbdulghani

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Waed Zouhir AlKayali / Bader Mohammed AlMajrathi

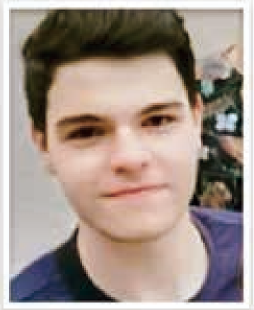
Invigilator

Nasser Abdullah AlObaid

Serbia

Student


Dimitrije Gligorovski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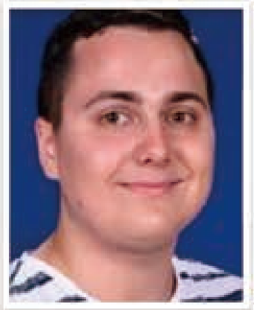

Lazar Savić


Nevena Stojković

Head Mentor

Dušan Sladić

Mentor

Niko Radulović

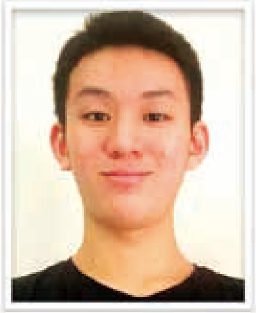
Invigilator

Irena Novaković / Vidak Raičević

Singapore

Student


Cheng Jun, Nicholas Goh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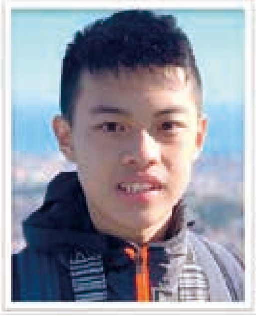

Alphonsus Yu Xiang Neo


Chen Yizhou

Head Mentor

Wee Boon Tan

Mentor

Hoang Truong Giang

Observer

Kailun You

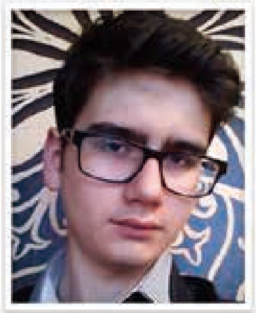
Invigilator

Stephanie Jee / Yih Check Wong

Slovakia

Student


Patrik Fábrik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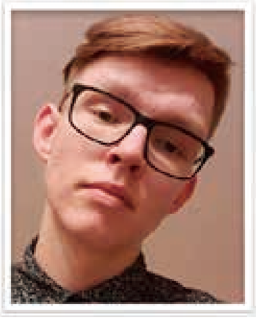
Ján Plachý


Matúš Tomčo

Head Mentor

Martin Putala

Mentor

Jela Nociarová

Invigilator

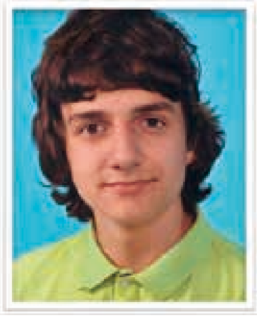
Samuel Andrejčák

Slovenia

Student


Jernej Birk


Simon Bukovšek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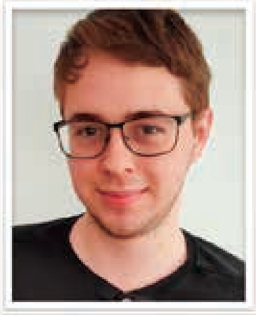

Patrik Žnidaršič

Head Mentor

Andrej Godec

Mentor

Berta Košmrlj

Invigilator

Miha Lukšič / Aljoša Seljak

South Africa

Student


Mohammed Tanweer Alli


Erkam Cihan Caglak


Muhammad Mahdi da Costa


Abdul-Baasit Salie

Head Mentor

Ajay Bissessur

Mentor

Bice Martincigh

Invigilator

Dalaal Abrahams / Ugur Hulusi Patli

Sri Lanka

Student


Achira Hansindu
Kelambi Arachchige


Dinithi Shalika
Madhubhashini


Nadun Naveendra
Rajapaksha


Manujaya Praveen
Wijesinghe

Head Mentor

Chinthaka Nadun Ratnaweera

Mentor

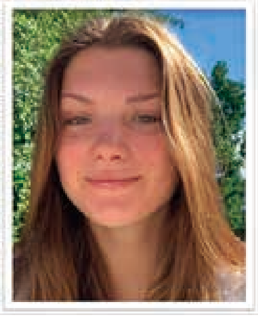
Ireshika Chathurani de Silva

Invigilator

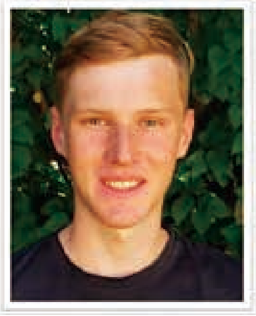
Hasantha Abayrathna / Sameera Ranmal Gunatilaka / Dulshani Kandambi / Upeksha Welikala

Sweden

Student


Elsa Bitzén


Erik Bryland


Leopold Kall


Yangyi Qi

Head Mentor

Johanna Rogvall

Mentor

Erik Sundén

Observer

Cecilia Stenberg

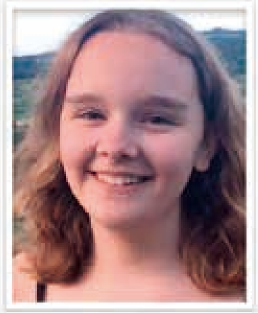
Invigilator

Mona Koder Hamid / Mikael Landgren / Tobias Sparrman

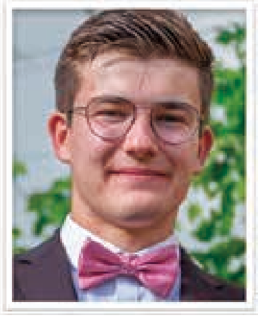
Switzerland

Student

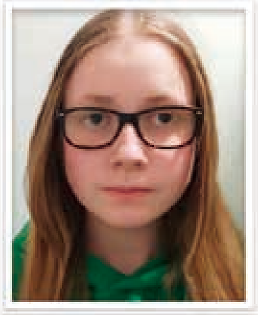
Antoine Robin Chèvre



Jessica Rebekka Kurmann



Sandro Pfammatter



Anastasia Aleksandrovna Sandamirskaya

Head Mentor

Mario Michele Oreste De Capitani

Mentor

Maurice Cosandey

Observer

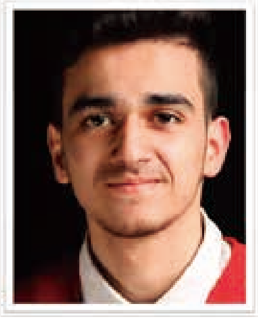
Linda Katharina Sonderegger / Silena Wegmann / Patrik Oliver Willi

Invigilator

Gunnar Jeschke / Richard Walter

Syria

Student



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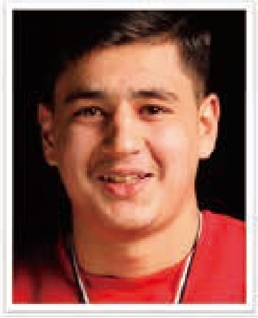
Maha Ali



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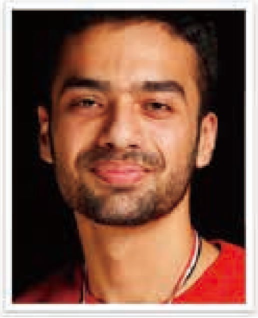


Ali Marouf

Head Mentor

Yomen Sayedsoleman Atassi

Mentor

Mohamad Khaled Al Joumaa

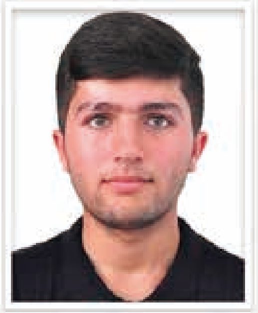
Invigilator

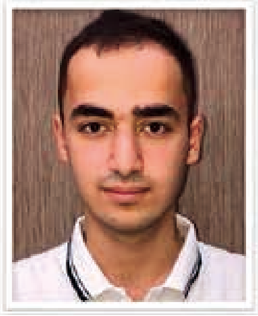
Tamam Hawa / Dima Khalil / Lara Shabea

Tajikistan

Student


Muhammad Barotov


Shahzod Nazirov


Muhammadzhon Otakhonov


Nuriddin Valizoda

Head Mentor

Khushang Sobirov

Mentor

Daler Salimov

Invigilator

Ramazon Ziyoev

Thailand

Student


Sathira Jantarakulchai


Nichawadee Kanjanakosit


Jirapat Rujirayuk


Lita Tantipraphat

Head Mentor

Torsak Luanphaisarnnont

Mentor

Chaiya Prasittichai

Observer

Nattapong Paiboonvorachat / Nisalak Trongsiriwat

Invigilator

Charoensak Mueangkaew / Oratai Rueangsombat / Sakol Warintaraporn

Trinidad and Tobago

Student


Vineeta Bujhawan


Jaasiel Edwards


Alayna Ragbar


Aiden Ramgoolam

Head Mentor

Nigel Kevin Jalsa

Mentor

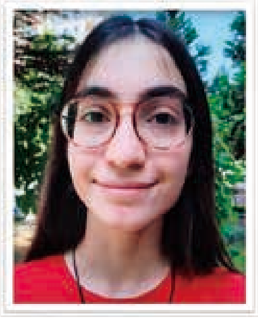
Terry Mohammed

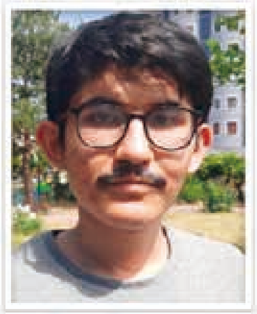
Invigilator

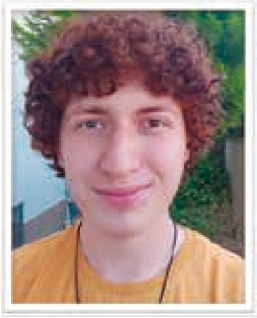
April Koon-Jagassar / Anton Manoo

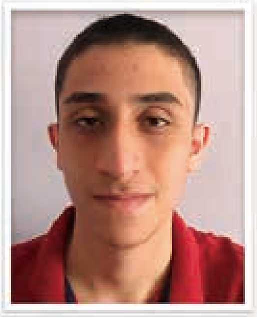
Turkey

Student


Sebnem Gul


Goktug Gulsoy


Deniz Guner


Berkan Tarak

Head Mentor

Arif Dastan

Mentor

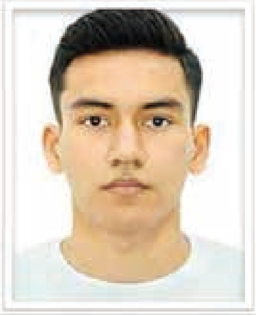
Yunus Emre Turkmen

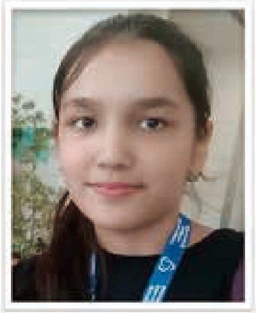
Invigilator

Dilgam Ahmedli / Nurullah Saraçoğlu / Baturalp Yalçın

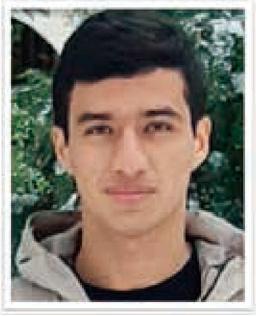
Turkmenistan

Student


Yusup Dovletmyradov


Gozel Dovranova


Davut Muhammetgulyyev


Berdigylych Rejepbayev

Head Mentor

Nazar Mammedov

Mentor

Serdar Begenjov

Invigilator

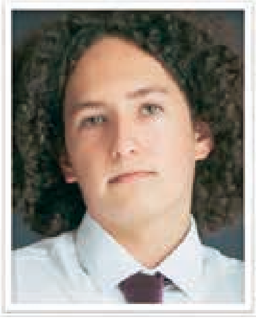
Amangeldi Meretglychov

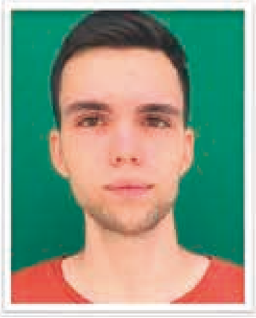
Ukraine

Student


Ihor Kholomieiev


Daria Klymenko


Yurii Okis


Oleksandr Zaporozhets

Head Mentor

Kostiantyn Gavrylenko

Mentor

Dmytro Volochnyuk

Invigilator

Alexander Lyapunov / Makhankova Valeriya

United Arab Emirates

Student


Ahmed Abdulaziz Alsabbagh


Vaidik Rajesh Hurkat


Yasmin Mahmood Abdulla Mohammad Ali


Devavrat Verma

Head Mentor

Abdallah El Marhoune

Mentor

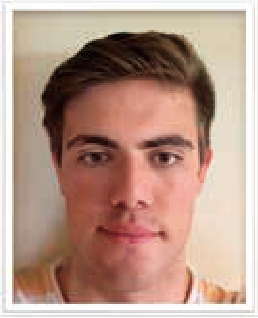
Manish Vijay Chhatre

Invigilator

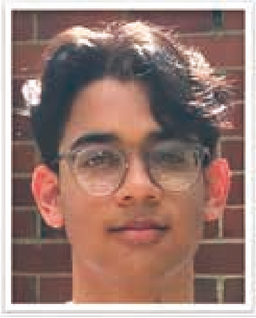
Pooja Badal Debath

United Kingdom

Student


Harry John List


Zachary John McGuire


Rtvik Patel


Alexander Ramsay Thow

Head Mentor

Ben Pilgrim

Mentor

Alex Thom

Observer

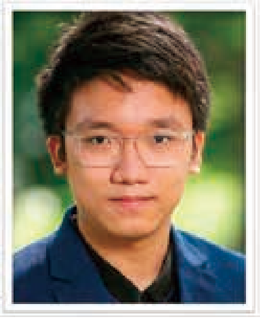
JI Kiappes / Andrew Taylor

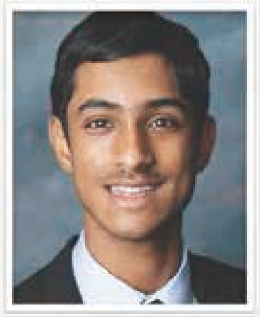
Invigilator

Charlotte Turner

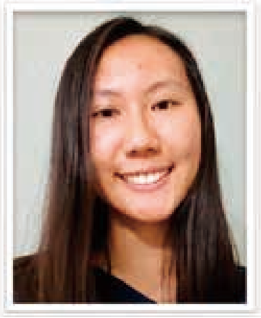
United States of America

Student


Kien Phuong


Nikhil Seshadri


Qiyang Zhou


Yitian Zhu

Head Mentor

Joseph Daniel Houck

Mentor

Esther Hines

Observer

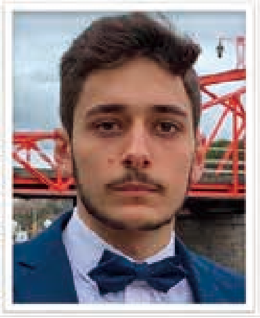
Lily Lambert Raines / Laura Serbulea

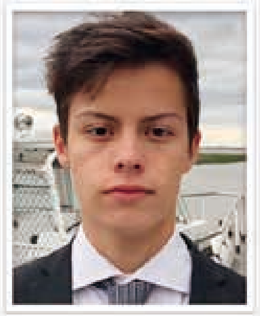
Invigilator

Alvin Collins / David Horwitz / Kelly Love / Malgorzata Thatcher

Uruguay

Student


Agustín Almeida Ahlers


Agustín Corbo Borche


Mariano Díaz Borges


Candela S. Gómez

Head Mentor

Santiago Rostán Talasimov

Mentor

Agustina Vila

Invigilator

Guillermo Bragunde / Laura Posada

Uzbekistan

Student


Sobirjon Amanov


Ikromiddin Boymahammadov


Durdona Muxtarxujayeva


Firdavs Sobirov

Head Mentor

Davron Tukhtaev

Mentor

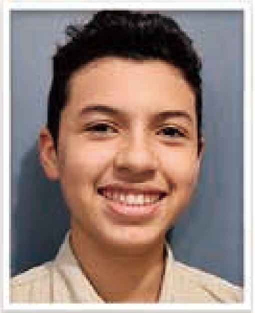
Ortikboy Eshankulov

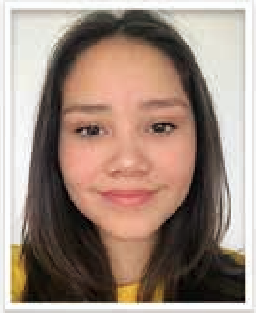
Invigilator

Aziz Khasanov

Venezuela

Student


Alberto Josué Alava Cedeño


Verónica Landaeta Hernández

Head Mentor

Alessandro D. Trigilio

Mentor

Amalia J. Torrealba

Invigilator

Laury Bravo / María P. Hurtado / Carmelina M. Kurilo / Nayleth Yépez

Vietnam

Student

Anh Duy Nguyen

Anh Le Thao Nguyen

Duong Hoang Nguyen

Phuong Duc Nam Pham

Head Mentor

Ha Ngoc Nguyen

Mentor

Phong Van Pham

Observer

Ngan Thi Bich Nguyen

Invigilator

Hai Thi Hong Le / Thuy Thi Thu Luong / Mo Thi Nguyen / Ha Thi Thu Nguyen

Observer

Afghanistan

Rahmkhuda Karimi

Ecuador

Andrea Fernanda Barcia

Kuwait

Essa Menhal Alqallaf

Nepal

Surgeon Bc

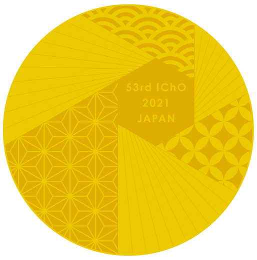
Paraguay

Juan Marcos Serafini Careaga

Country	Student	Mentor	Observer	Guest	Invigilator	Total
Armenia	4	2			1	7
Australia	4	2			4	10
Austria	4	2	2		2	10
Azerbaijan	4	2			2	8
Bangladesh	4	2	2		4	12
Belarus	4	2			2	8
Belgium	4	2			2	8
Brazil	4	2	1		2	9
Bulgaria	4	2			4	10
Canada	4	2			4	10
China	4	2	4		2	12
Chinese Taipei	4	2	2		2	10
Costa Rica	3	2			2	7
Croatia	4	2			2	8
Cyprus	4	2			2	8
Czech Republic	4	4			1	9
Denmark	4	2			2	8
El Salvador	4	2			4	10
Estonia	4	2			1	7
Finland	4	2	1		2	9
France	4	2			1	7
Georgia	4	2	2		4	12
Germany	4	2	1		3	10
Greece	4	2			1	7
Hungary	4	2	1		1	8
Iceland	4	2			1	7
India	4	2	1		9	16
Indonesia	4	2	1		4	11
Iran	4	2			2	8
Ireland	4	2	2		4	12
Israel	4	2	1		1	8
Japan	4	2	2	1	3	12
Kazakhstan	4	2			2	8
Korea	4	2	2		2	10
Kyrgyzstan	4	2			2	8
Latvia	4	2			1	7
Lithuania	4	2			2	8
Luxembourg	4	2			1	7
Malaysia	4	2			4	10
Mexico	4	2			2	8
Moldova	4	2			2	8
Mongolia	4	2	2		2	10
Montenegro	4	2			2	8
Netherlands	4	2			3	9

Country	Student	Mentor	Observer	Guest	Invigilator	Total
New Zealand	4	2			3	9
Nigeria	3	2			1	6
North Macedonia	4	2			1	7
Norway	4	2			2	8
Oman	4	2			4	10
Pakistan	4	2			3	9
Philippines	4	2			5	11
Poland	4	2	1		1	8
Portugal	4	2			2	8
Qatar	4	2	2		2	10
Romania	4	2			3	9
Russian Federation	4	2	2		1	9
Saudi Arabia	4	2	2		1	9
Serbia	4	2			2	8
Singapore	4	2	1		2	9
Slovakia	4	2			1	7
Slovenia	4	2			2	8
South Africa	4	2			2	8
Sri Lanka	4	2			4	10
Sweden	4	2	1		3	10
Switzerland	4	2	3		2	11
Syria	4	2			3	9
Tajikistan	4	2			1	7
Thailand	4	2	2		3	11
Trinidad and Tobago	4	2			2	8
Turkey	4	2			3	9
Turkmenistan	4	2			1	7
Ukraine	4	2			2	8
United Arab Emirates	4	2			1	7
United Kingdom	4	2	2		1	9
United States of America	4	2	2		4	12
Uruguay	4	2			2	8
Uzbekistan	4	2			1	7
Venezuela	2	2			4	8
Vietnam	4	2	1		4	11
Afghanistan			1			1
Ecuador			1			1
Kuwait			1			1
Nepal			1			1
Paraguay			1			1
total	312	160	51	1	185	709

Results



Gold Medal

Rank	Name	Country	Medal	Total
1	Shu Yang	China	Gold	97.57
2	Zhangyi Huang	China	Gold	97.08
3	Xinyu Cai	China	Gold	95.61
4	Bangsen Zhao	China	Gold	94.39
5	Sobirjon Amanov	Uzbekistan	Gold	92.14
6	Mircea Raul Bodrogean	Romania	Gold	90.54
7	Aleksandr E. Trofimov	Russian Federation	Gold	88.67
8	Anh Duy Nguyen	Vietnam	Gold	88.43
9	Bo-An Chen	Chinese Taipei	Gold	88.33
10	Georgii M. Zhomin	Russian Federation	Gold	88.13
11	Chun-Cheng Ting	Chinese Taipei	Gold	87.96
12	Phuong Duc Nam Pham	Vietnam	Gold	86.86
13	Qiyang Zhou	United States of America	Gold	86.83
14	Berkan Tarak	Turkey	Gold	86.20
15	Chen Yizhou	Singapore	Gold	85.35
16	Alexander Ramsay Thow	United Kingdom	Gold	84.33
17	Rui-Xi Wang	Chinese Taipei	Gold	84.05
18	Cheng Jun, Nicholas Goh	Singapore	Gold	83.99
19	Nir Cohen	Israel	Gold	83.71
20	Timofey A. Charkin	Russian Federation	Gold	83.59
21	Tudor Lile	Romania	Gold	82.69
22	Adarsh Reddy Madur	India	Gold	81.99
23	Mahbod Alian Fini	Iran	Gold	81.76
24	Deniz Guner	Turkey	Gold	81.34
25	Andrei S. Tyrin	Russian Federation	Gold	81.31
26	Dhananjay Raman	India	Gold	81.30

Rank	Name	Country	Medal	Total
27	Yitian Zhu	United States of America	Gold	81.03
28	Filip Hůlek	Czech Republic	Gold	80.95
29	Harry John List	United Kingdom	Gold	80.90
30	Anh Le Thao Nguyen	Vietnam	Gold	80.33
31	Mahyar Afshinmehr	Iran	Gold	80.17
32	Myeongjin Shin	Korea	Gold	80.14
33	Alexandru Catalin Dianu	Romania	Gold	79.82

Silver Medal

Rank	Name	Country	Medal	Total
34	Duong Hoang Nguyen	Vietnam	Silver	79.05
35	Stefan Dimitriu	Romania	Silver	78.81
36	Sebnem Gul	Turkey	Silver	78.81
37	Uladzislau Hlatankou	Belarus	Silver	78.74
38	Alphonsus Yu Xiang Neo	Singapore	Silver	77.76
39	Michal Piotr Lipiec	Poland	Silver	77.48
40	Oscar Dong	Australia	Silver	77.22
41	Seung Jae Kang	Korea	Silver	76.88
42	Nikhil Seshadri	United States of America	Silver	76.11
43	Faatih Regind Qashash Roman	Indonesia	Silver	76.06
44	Bernard Tze Wei Kwee	Singapore	Silver	75.83
45	Hsuan-Ting Lin	Chinese Taipei	Silver	74.87
46	Mahit Rajesh Gadhiwala	India	Silver	74.29
47	Seyed Mohammad Hossein Barakati	Iran	Silver	72.82
48	Oisín Colm Ó Feinneadha	Ireland	Silver	72.75
49	Oleksandr Zaporozhets	Ukraine	Silver	71.96
50	Goktug Gulsoy	Turkey	Silver	70.76

Rank	Name	Country	Medal	Total
51	Shahzod Nazirov	Tajikistan	Silver	70.49
52	Hee Seong Yoon	Korea	Silver	69.93
53	Jirapat Rujirayuk	Thailand	Silver	69.79
54	Jovan Marković	Serbia	Silver	69.42
55	Linus Albert Schwarz	Germany	Silver	69.32
56	Muhammad Barotov	Tajikistan	Silver	68.80
57	Vinicius da Silveira Lanza Avelar	Brazil	Silver	68.34
58	Lucio Saracco	Hungary	Silver	67.68
59	Ioannis Karageorgiou	Greece	Silver	67.17
60	Nichawadee Kanjanakosit	Thailand	Silver	67.03
61	Davut Muhammetgulyyev	Turkmenistan	Silver	66.40
62	Takahiro Takemoto	Japan	Silver	65.92
63	Kohei Nishiura	Japan	Silver	65.65
64	Bruno Andrzej Skoczen	Poland	Silver	65.63
65	Khaidar Kairbek	Kazakhstan	Silver	65.20
66	Mohammad Solaiman AlHadlaq	Saudi Arabia	Silver	64.93
67	Marek Pavlica	Czech Republic	Silver	64.38
68	Ehsan Naderi Donig	Iran	Silver	64.21
69	Patrik Žnidaršič	Slovenia	Silver	64.00
70	Seoyeon Kim	Korea	Silver	63.13
71	Gerel Bayarmagnai	Mongolia	Silver	62.88
72	Temujin Orkhon	Mongolia	Silver	62.78
73	Kien Phuong	United States of America	Silver	62.56
74	Tong Wu	Ireland	Silver	61.87
75	Zachary John McGuire	United Kingdom	Silver	61.69
76	Rishit Singla	India	Silver	61.60
77	Andy Cai	Canada	Silver	61.36
78	Lita Tantipraphat	Thailand	Silver	60.66
79	Džonatans Miks Melgalvis	Latvia	Silver	60.60
80	Yuya Koike	Japan	Silver	60.54
81	Mohammad Rashed AlHudaithi	Saudi Arabia	Silver	60.11

Rank	Name	Country	Medal	Total
82	Abdulaziz Abdulrahman AlJuaid	Saudi Arabia	Silver	59.89
83	Matúš Tomčo	Slovakia	Silver	59.85
84	Itamar Steinitz	Israel	Silver	59.60
85	Gozel Dovranova	Turkmenistan	Silver	59.56
86	Ron Angelo A. Gelacio	Philippines	Silver	58.34
87	Simon Bukovšek	Slovenia	Silver	57.50
88	Michael Schembera	Austria	Silver	57.20
89	Sanzhar Bissenali	Kazakhstan	Silver	57.17
90	Tim Bastian Enders	Germany	Silver	57.12
91	Pavel Atanasov Nikolov	Bulgaria	Silver	56.83
92	Berdigylych Rejepbayev	Turkmenistan	Silver	56.72
93	Dávid Benkő	Hungary	Silver	56.28
94	Yusup Dovletmyradov	Turkmenistan	Silver	56.10
95	Madiyar Kassymaly	Kazakhstan	Silver	55.62
96	Povilas Dapsys	Lithuania	Silver	55.52
97	Nathan Wayne F. Ariston	Philippines	Silver	55.36
98	Daniils Kargins	Latvia	Silver	55.21
99	Jakub Krzysztof Kwiatkowski	Poland	Silver	54.81
100	Ihor Kholomieiev	Ukraine	Silver	54.71

Bronze Medal

Rank	Name	Country	Medal	Total
101	Kevin Lius Bong	Indonesia	Bronze	53.77
102	Tadas Danilevicius	Lithuania	Bronze	53.71
103	Khanim Yagublu	Azerbaijan	Bronze	53.59
104	Sathira Jantarakulchai	Thailand	Bronze	53.30
105	Irmuun Altankhuyag	Mongolia	Bronze	53.07

Rank	Name	Country	Medal	Total
106	Kamil Mambetov	Kyrgyzstan	Bronze	52.79
107	Neta Eiger	Israel	Bronze	52.75
108	István Babcsányi	Hungary	Bronze	52.51
109	Samuil Vladimirov Petkov	Bulgaria	Bronze	52.42
110	Durdona Muxtarxujayeva	Uzbekistan	Bronze	52.18
111	Lazar Savić	Serbia	Bronze	52.12
112	Hanif Muhammad Zhafran	Indonesia	Bronze	51.97
113	Darko Stojchev	North Macedonia	Bronze	51.86
114	Vladislavs Tiščenko	Latvia	Bronze	51.06
115	Maciej Swiatek	Austria	Bronze	50.96
116	Keith Wong	Australia	Bronze	50.89
117	Johann Sora Blakytny	Germany	Bronze	50.81
118	Andrei Banica	Canada	Bronze	50.65
119	Firdavs Sobirov	Uzbekistan	Bronze	50.47
120	Ketevan Peranidze	Georgia	Bronze	50.47
121	Abdur-Raheem Idowu	Norway	Bronze	50.24
122	Ruben Tapia	France	Bronze	49.63
123	Austin Lin	Australia	Bronze	49.56
124	Patrik Fábrik	Slovakia	Bronze	49.56
125	Aigerim Turuspekova	Kazakhstan	Bronze	49.45
126	Nathanael Reza Putra Widjaja	Indonesia	Bronze	49.42
127	Edvards Jānis Treijs	Latvia	Bronze	49.41
128	Georgi Neliyanov Nedyalkov	Bulgaria	Bronze	49.28
129	Salman Huseynov	Azerbaijan	Bronze	48.49
130	Cassia Caroline Aguiar da Ponte	Brazil	Bronze	48.22
131	Angelina Rogatch	Belarus	Bronze	48.04
132	Benedek Sajósi	Hungary	Bronze	47.96
133	Alina Tumashyk	Belarus	Bronze	47.73
134	Nariman Shirinli	Azerbaijan	Bronze	47.44
135	Saeed Sultan Baghdadi	Saudi Arabia	Bronze	47.39
136	Ahmad Thaer Ater	Syria	Bronze	47.36

Rank	Name	Country	Medal	Total
137	Maha Ali	Syria	Bronze	47.32
138	Jorge García-Ponce	Mexico	Bronze	46.82
139	Michael Li	Canada	Bronze	46.71
140	Lukas Rost	Austria	Bronze	46.48
141	Teodor Svilenov Maslyankov	Bulgaria	Bronze	46.40
142	Nadun Naveendra Rajapaksha	Sri Lanka	Bronze	46.15
143	Yurii Okis	Ukraine	Bronze	46.09
144	Dimitrije Gligorovski	Serbia	Bronze	45.98
145	Achira Hansindu Kelambi Arachchige	Sri Lanka	Bronze	45.71
146	Marina Malta Nogueira	Brazil	Bronze	45.55
147	Fran Miletic	Croatia	Bronze	45.31
148	Haruhi Isse	Japan	Bronze	45.22
149	Jernej Birk	Slovenia	Bronze	45.05
150	Yangyi Qi	Sweden	Bronze	45.03
151	Aleksandr Beditski	Estonia	Bronze	44.70
152	Vincent Ng	Australia	Bronze	44.41
153	Anas Abbas	Syria	Bronze	44.28
154	Adam Szymon Sukiennik	Poland	Bronze	44.24
155	Tomáš Heger	Czech Republic	Bronze	44.08
156	Ikromiddin Boymahammadov	Uzbekistan	Bronze	43.17
157	Fynn Lasse Noah Kessels	Germany	Bronze	43.07
158	Jakub Sochor	Czech Republic	Bronze	43.03
159	Emilio Alonso Venegas-Hernandez	Mexico	Bronze	42.97
160	Michael Estes	Denmark	Bronze	42.57
161	Liis Siigur	Estonia	Bronze	42.57
162	Jochem van den Broek	Netherlands	Bronze	42.53
163	Nino Abesadze	Georgia	Bronze	42.01
164	Hayk Aghekyan	Armenia	Bronze	41.82
165	Aames Juriel B. Morales	Philippines	Bronze	41.19
166	Théodore Halley	France	Bronze	40.99
167	Valerian Mocreac	Moldova	Bronze	40.56

Rank	Name	Country	Medal	Total
168	Alexandre Bloquel	France	Bronze	40.41
169	Laimis Jurkenas	Lithuania	Bronze	40.39
170	Mahsati Piriyeva	Azerbaijan	Bronze	40.28
171	Daan Roger Stan Vanhaecke	Belgium	Bronze	40.26
172	Simonas Melaika	Lithuania	Bronze	40.10
173	Sandro Pfammatter	Switzerland	Bronze	39.92
174	Ioane Kapanadze	Georgia	Bronze	39.86
175	Fredi Manuel Barraza Hernandez	El Salvador	Bronze	39.45
176	Tatiana Sviriniuc	Moldova	Bronze	39.35
177	Mason Minghan Liu	New Zealand	Bronze	39.27
178	Ján Plachý	Slovakia	Bronze	39.06
179	Oscar Eric Moran Despard	Ireland	Bronze	38.93
180	Leonid Asatryan	Armenia	Bronze	38.91
181	Terry Wang	Canada	Bronze	38.77
182	Hana Gabriela Albuquerque Sousa	Brazil	Bronze	38.75
183	Tal Sason	Israel	Bronze	38.69
184	Tigran Harutyunyan	Armenia	Bronze	38.53
185	Andrei Kornijenko	Estonia	Bronze	38.41
186	Nevena Stojković	Serbia	Bronze	38.31
187	Adelina Andrei	Moldova	Bronze	38.16
188	Samuel Kolesár	Slovakia	Bronze	37.99
189	Sebastian Jacob Krikke	Netherlands	Bronze	37.50
190	Paul Johann Dorfer	Austria	Bronze	37.47
191	Lin Bigom-Eriksen	Denmark	Bronze	37.19
192	Manujaya Praveen Wijesinghe	Sri Lanka	Bronze	36.84
193	Kiryl Maroz	Belarus	Bronze	36.57
194	Maxim Cojocari-Goncear	Moldova	Bronze	36.06

Honorable mention

Rank	Name	Country	Medal	Total
195	Bumchin Dolgormaa	Mongolia	Honorable Mention	35.43
196	Abhinav Chawla	New Zealand	Honorable Mention	35.00
197	Aku Hertell	Finland	Honorable Mention	34.86
198	Daria Klymenko	Ukraine	Honorable Mention	34.83
199	João Pedro Bonito Caldeira	Portugal	Honorable Mention	34.66
200	Théo Mignen	France	Honorable Mention	34.60
201	Ali Marouf	Syria	Honorable Mention	34.56
202	Olga Jerkovic Peric	Croatia	Honorable Mention	34.45
203	Sam Wuji Zhuang	New Zealand	Honorable Mention	34.40
204	Samuel Klaver	Finland	Honorable Mention	34.27
205	Vid Kavčič	Slovenia	Honorable Mention	33.37
206	Jessica Rebekka Kurmann	Switzerland	Honorable Mention	33.21
207	Safwan Sakib	Bangladesh	Honorable Mention	32.87
208	Gerardo Emiliano Gutierrez-Alvarez	Mexico	Honorable Mention	31.69
209	Rafael Dux	Luxembourg	Honorable Mention	31.43
210	Aoife Mary Morris	Ireland	Honorable Mention	31.06
211	Henri Kärpijoki	Finland	Honorable Mention	30.82
212	Dinithi Shalika Madhubhashini	Sri Lanka	Honorable Mention	30.61
213	Daniel Jiyoun Jang	New Zealand	Honorable Mention	30.57
214	Athanasios Feidakis	Greece	Honorable Mention	30.17
215	Jean-Marc Furlano	Luxembourg	Honorable Mention	29.88
216	Vaidik Rajesh Hurkat	United Arab Emirates	Honorable Mention	28.98
217	Mahin Kamal Sawdager	Bangladesh	Honorable Mention	28.76
218	Khalid Hasan Tuhin	Bangladesh	Honorable Mention	28.62

Others

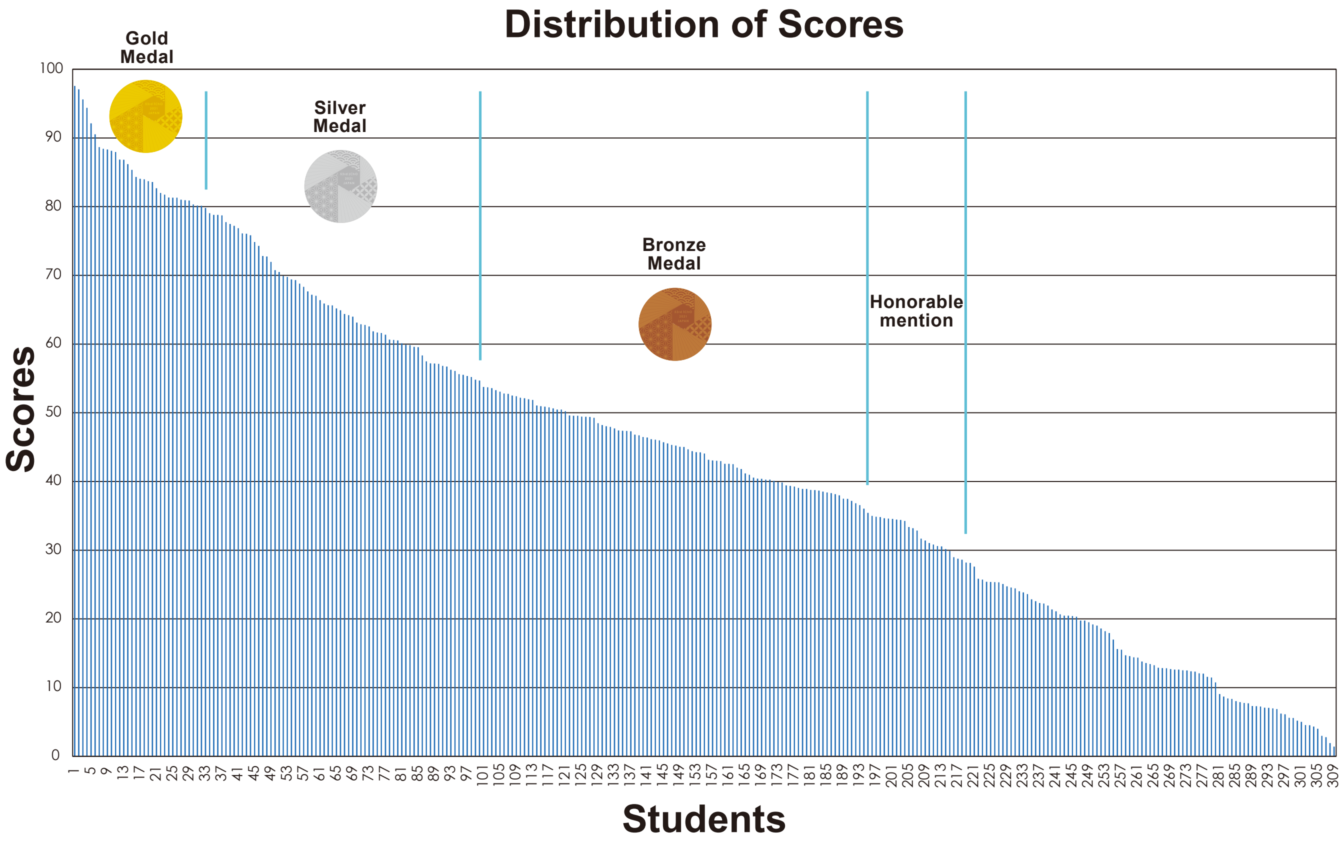
Rank	Name	Country	Total
219	Emmanuel Sotomea-Renova	Mexico	28.20
220	Simen Mannsåker	Norway	28.15
221	Lizi Darchia	Georgia	27.62
222	Joachim Julian Klaussen	Norway	25.84
223	Dimitrios Stylianakis	Greece	25.71
224	Anastasia Aleksandrovna Sandamirskaya	Switzerland	25.41
225	Theodor Malte Novrup Redvall	Denmark	25.37
226	Nadezhda Ondrina	Kyrgyzstan	25.37
227	Nihit Agarwal	Qatar	25.34
228	Anja Spasovska	North Macedonia	25.09
229	Marko Preocanin	Croatia	24.75
230	Joseph Eghenevwegba Ikuru	Nigeria	24.57
231	Mariana Vilela Marta Rio Costa	Portugal	24.45
232	Sevada Nersisyan	Armenia	24.03
233	Jan Stojanovski	North Macedonia	23.86
234	Danijel Aleksic	Montenegro	23.62
235	Devavrat Verma	United Arab Emirates	22.86
236	Azamat Salamatov	Kyrgyzstan	22.58
237	Emily Alejandra Crespin Guerra	El Salvador	22.31
238	Melanie Muntz	Denmark	22.25
239	Ivan Reshetnikov	Kyrgyzstan	21.95
240	Vasileios Papastamopoulos	Greece	21.39
241	Tina Kalleson	Norway	21.12
242	Beatriz Crisóstomo Valério Figueiredo	Portugal	20.68
243	Leopold Kall	Sweden	20.48
244	Tawhid Muhammad Mubashwir	Bangladesh	20.47
245	Mihail Trajkov	North Macedonia	20.42
246	Kristoff John F. Padilla	Philippines	20.34

Rank	Name	Country	Total
247	Jef H. K. Van Eester	Belgium	19.77
248	Lim Xu Yao	Malaysia	19.77
249	Yasmin Mahmood Abdulla Mohammad Ali	United Arab Emirates	19.52
250	Jasmin Jasarevic	Croatia	19.20
251	Agustín Corbo Borche	Uruguay	19.02
252	Ayesha Junaid	Pakistan	18.60
253	Erik Bryland	Sweden	18.22
254	Mitchell Rikken	Netherlands	17.95
255	Nuriddin Valizoda	Tajikistan	16.99
256	Giorgos Papachristodoulou	Cyprus	15.63
257	Tiago Miguel Gomes de Sousa	Portugal	15.53
258	Dagur Bjorn Benediktsson	Iceland	14.71
259	Otto Keronen	Finland	14.59
260	Raphaël Menasce	Luxembourg	14.43
261	Mariano Díaz Borges	Uruguay	14.36
262	Luis Ronaldo Chavez Escamilla	El Salvador	13.81
263	Muhammad Mahdi da Costa	South Africa	13.57
264	Verónica Landaeta Hernández	Venezuela	13.42
265	Agustín Almeida Ahlers	Uruguay	13.25
266	Alberto Josué Alava Cedeño	Venezuela	12.91
267	Antoine Robin Chèvre	Switzerland	12.84
268	Louis Pecheur	Belgium	12.83
269	Lukas Schieble	Belgium	12.69
270	Christiana Kosta	Cyprus	12.62
271	Max Rudolf Antonius Karel van Hest	Netherlands	12.62
272	Arwa Al Hashimi	Oman	12.53
273	Wong Yi Yang	Malaysia	12.49
274	Elsa Bitzén	Sweden	12.38
275	Telma Jeanne Bonthonneau	Iceland	12.34
276	Jessica Thackeray	Cyprus	12.09
277	Bernie Lim Wei Yuan	Malaysia	12.03
278	Muhammad Yahya	Pakistan	11.58
279	Laurent Bommertz	Luxembourg	11.48

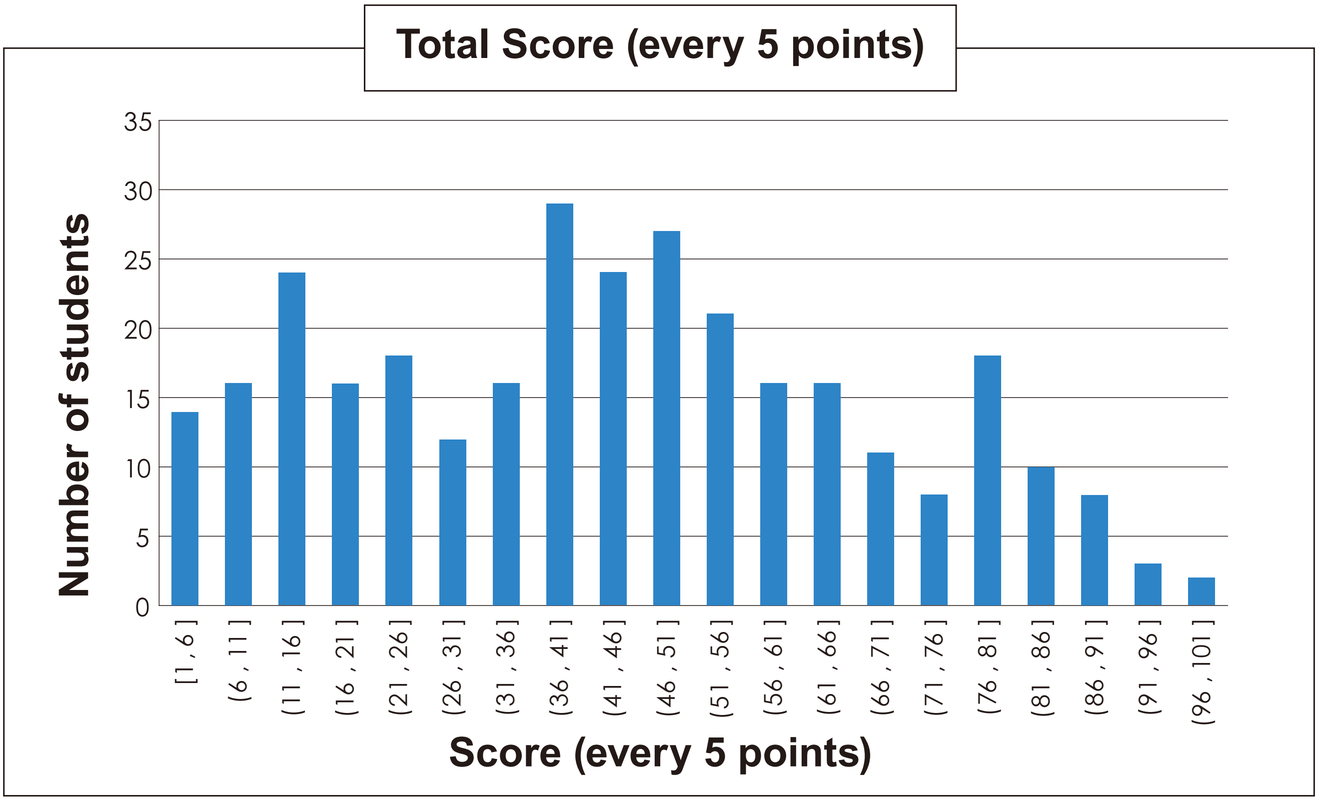
Rank	Name	Country	Total
280	Sushanthi Anandaraja	Qatar	10.75
281	Sara Fahed Al ali Alahmad	Qatar	9.07
282	Muhammad Ismail	Pakistan	8.71
283	Iva Djurickovic	Montenegro	8.42
284	Ahmed Abdulaziz Alsabbagh	United Arab Emirates	8.36
285	Stylianos Tamasios	Cyprus	8.05
286	Daniel Heidar Jack	Iceland	7.88
287	Rameesha Khursheed	Pakistan	7.77
288	Shawn Vernon Wong Siang Ray	Malaysia	7.72
289	Fanny Mariana Solís González	Costa Rica	7.33
290	Olivia Sojourner Dixon	Costa Rica	7.29
291	Maryam Al-Hatmi	Oman	7.25
292	Candela S. Gómez	Uruguay	7.08
293	Muhammadzhon Otakhonov	Tajikistan	7.06
294	Abdullah Al-Azri	Oman	6.99
295	Alayna Ragbar	Trinidad and Tobago	6.89
296	Aiden Ramgoolam	Trinidad and Tobago	6.21
297	Vineeta Bujhawan	Trinidad and Tobago	6.12
298	Lujaina Al Badi	Oman	5.61
299	Isak Hugi Einarsson	Iceland	5.58
300	Ignacio Herrera Gamboa	Costa Rica	5.19
301	Mohammed TanweerAlli	South Africa	5.02
302	Jaasiel Edwards	Trinidad and Tobago	4.55
303	Asmahan Abdulaziz Al-Kuwari	Qatar	4.54
304	Erkam Cihan Caglak	South Africa	4.33
305	Brenda Nicole Juarez Marroquín	El Salvador	4.01
306	Ifeanyichukwu Valentine Umeanyika	Nigeria	2.99
307	Ksenija Tadic	Montenegro	2.79
308	Abdul-Baasit Salie	South Africa	1.92
309	Milica Zizic	Montenegro	1.41
unfortunate absence	Siim Tiivel	Estonia	—
unfortunate absence	Rtvik Patel	United Kingdom	—
unfortunate absence	Winston Ukpong	Nigeria	—

	Total Score
Maximum	97.566
Minimum	1.415
Average	43.913
Standard Deviation	24.259

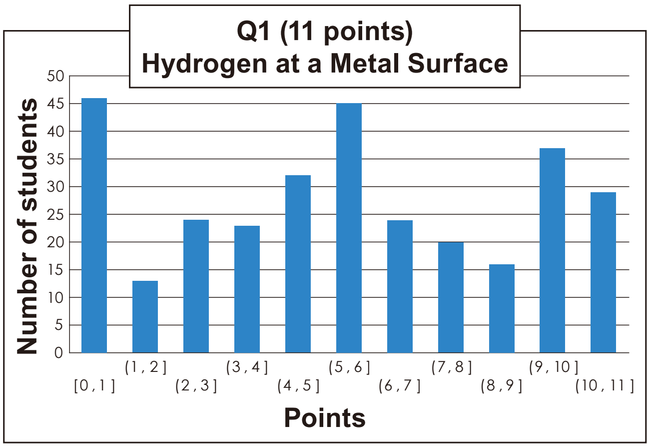
Problem No.	Q1 (11)	Q2 (11)	Q3 (8)	Q4 (11)	Q5 (12)	Q6 (13)	Q7 (13)	Q8 (11)	Q9 (10)
Maximum	11	11	8	11	12	13	13	11	10
Minimum	0	0	0	0	0	0	0	0	0
Average	5.395	3.942	3.422	5.448	5.140	4.743	5.917	4.906	5.001
Standard Deviation	3.289	3.239	2.725	3.781	3.400	3.573	4.308	3.454	3.464



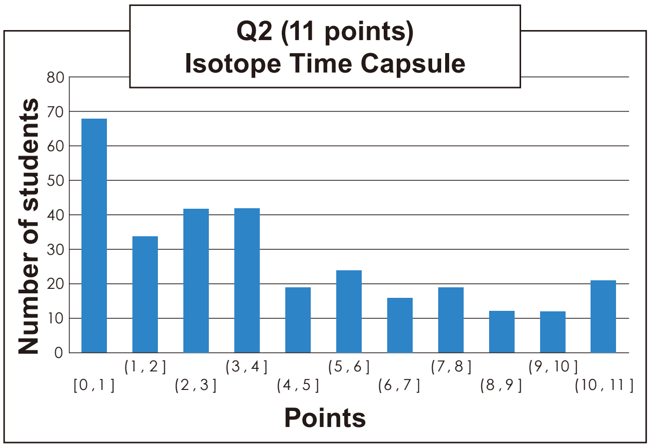
Histogram of Points



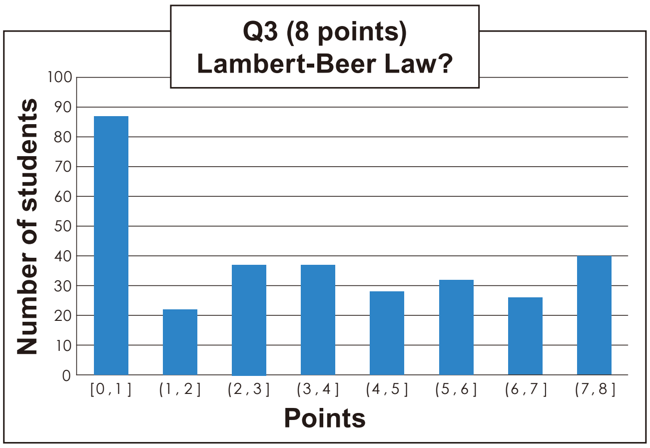
Total Score (every 5 points)



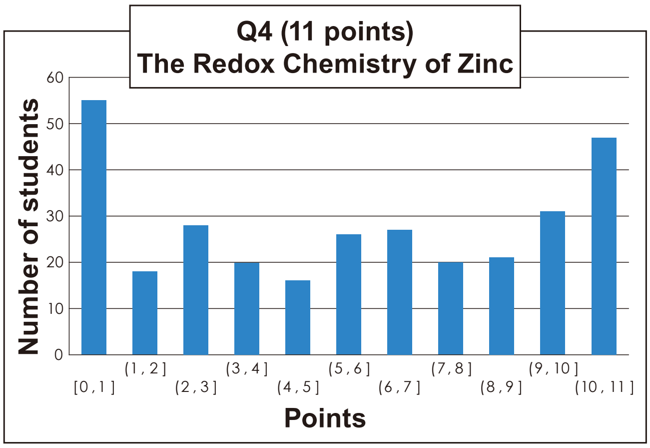
Q1 (11 points)
Hydrogen at a Metal Surface



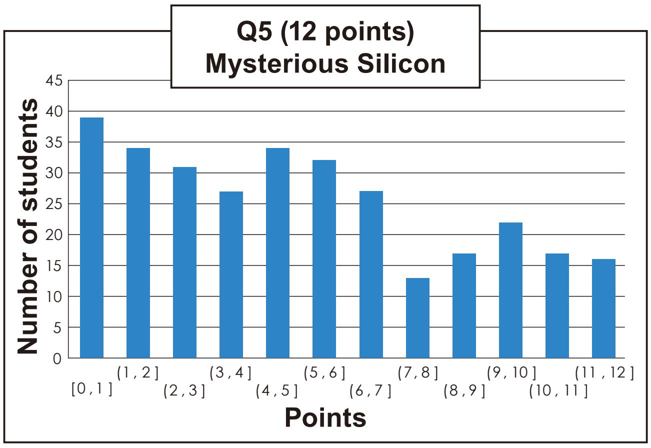
Q2 (11 points)
Isotope Time Capsule

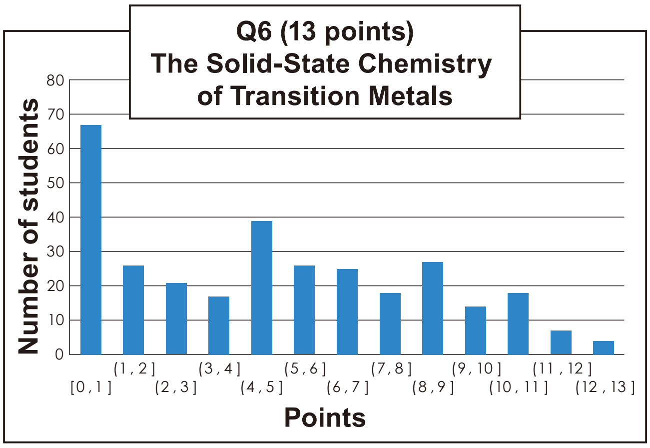


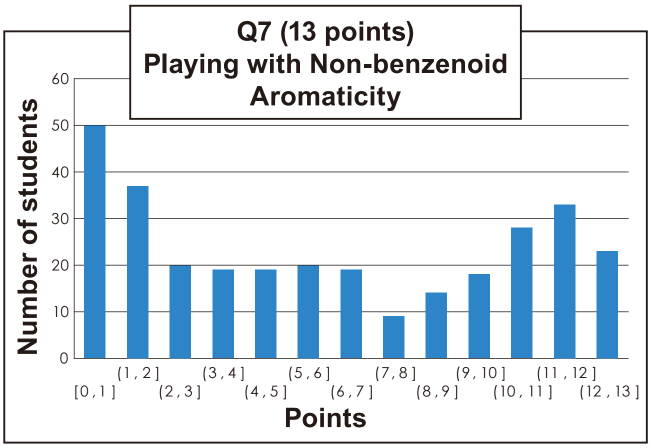
Q3 (8 points)
Lambert-Beer Law?

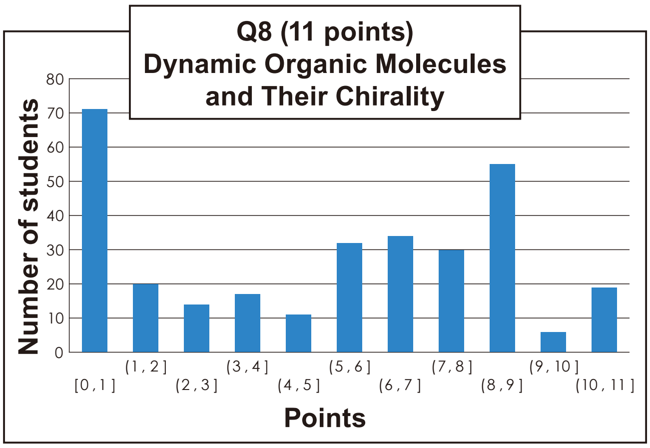


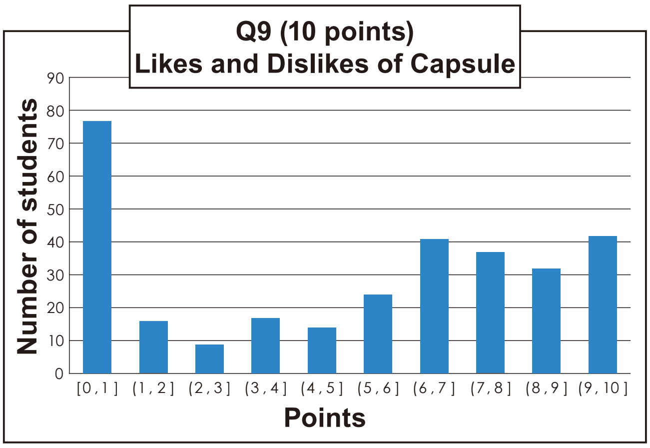
Q4 (11 points)
The Redox Chemistry of Zinc


Q5 (12 points)
Mysterious Silicon


Q6 (13 points)
The Solid-State Chemistry of Transition Metals


Q7 (13 points)
Playing with Non-benzenoid Aromaticity


Q8 (11 points)
Dynamic Organic Molecules and Their Chirality


Q9 (10 points)
Likes and Dislikes of Capsule

Certificate and Medals

Award Certificate

Gold Medal

This is to certify that

Osaka Taro

from

Japan

was awarded a Gold Medal
in the 53rd International Chemistry Olympiad
held in Japan, July 25 – August 2, 2021

玉尾皓平

Dr. Kohei Tamao

President: IChO Japan Committee
Chairman: Organizing Committee for the 53rd IChO2021,Japan

Certificate

Medal Design Concept: "The Chemical Vortex Leading to the Future"

Designer: Sakiko Matsumoto

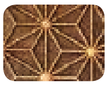
From the center to the edge, the entire medal forms the shape of a vortex, giving the impression of a whirling motion. This movement represents the global impact and upcoming success of young students, originating at IChO2021 Japan. Through the designs found on both sides of the medal, IChO2021 supports the bright future of the contestants.

The obverse side features three kinds of popular auspicious patterns to express aspects of Japanese culture.

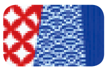
The reverse side contains the logo, which is represented in a simple and emphatic way through an image that spreads across the world.

Seigaiha (青海波) translates to blue ocean waves. The endlessly calm waves are a prayer for long-lasting happiness and a peaceful life.

Shippō Tsunagi (七宝つなぎ) is a pattern of connecting circles, expressing a wish for happiness, harmony, and connection. This connection is as valuable as the Seven Treasures of Buddhism: gold, silver, lapis lazuli, agate, seashell, amber, and coral.



Asanoha (麻の葉) is a pattern representing hemp leaves. Because hemp is resilient, grows vigorously, and requires little care, it is often used as a pattern in the *kimono* of young children in the hope that they grow up big and strong. It is also meant to ward off evil.

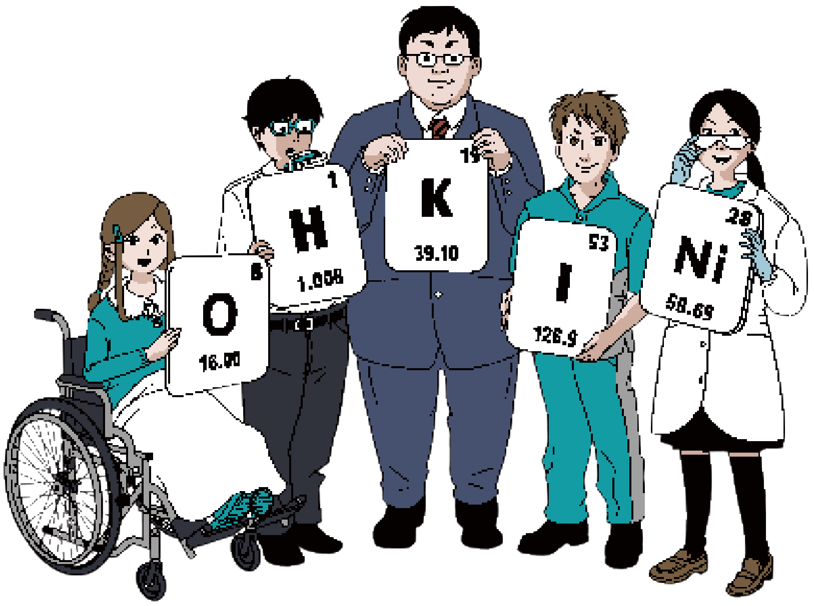


The ribbon represents the image of a whirlpool flowing from the medal in indigo, black, and vermillion, which is the color of Japan. The design also expresses the impact that the students will have in the world.

Obverse side

Reverse side

Chemistry! It's Cool!



Memento and Gifts

Memento and Gifts

Our memento and gifts, presented to all students, mentors and observers, consist of a tin water pot (pewter ware), an “azuma bukuro” and a tote bag with our catch-phrase and characters printed. Some explanations are given below.

【Tin water pot】

A tin water pot has been selected as memento because tin ware is known as one of traditional crafts famous for Osaka, where the 53rd IChO 2021 Japan was originally planned to be held.

Tin has been used since very early in the human history, due to its easy-to-scouring nature and its relatively low melting point (231.9 ℃). Tin water pot made around 1500 B.C. has been discovered in Egypt. Pewter ware, made of 97% tin, was brought to Japan for the first time about 1300 years ago; it seems to have travelled along the Silk Road and arrived via China. Since then in Japan tin had only been used as table ware for ruling class and as tools for Buddist temples and shrines, until a huge tin mine was discovered in the 17th century, after when pewter ware began to be used commonly as utensils for serving and drinking sake and tea.

It is known that a tin processing factory existed in Osaka at the latest in 1679. The production of tin and pewter ware established itself as a major industry in Osaka thanks to its position as a distribution hub. The tin ware made in Osaka was designated Traditional Craft as “Osaka Naniwa Pewterware” in 1983.

【Azuma bukuro】

“Azuma bukuro”, meaning “east bag”, is a traditional Japanese ecofriendly carry and shopping bag made of light and soft cloth. This type of bag was originally made in Edo (old name of Tokyo) during the Edo era (1603~1868), where is located from east (azuma) from Kyoto, old capital of Japan. Kyoto people used it conveniently by calling “Azuma bukuro”. The “Azuma bukuro” should be useful in our modern life.

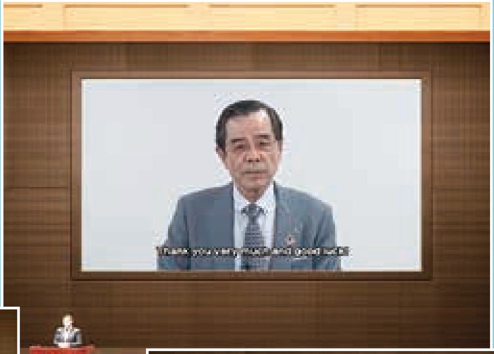
【Tote bag】

The tote bag has our catch phrase “Chemistry! It’s Cool!”, as well as five cards of element symbols O, Mo, Te, Na, Si, carried by our characters: “OMOTENASI” in total means warm hospitality in Japanese. We hope that this will be used for a long time as a commemorative item of the 53rd IChO 2021 Japan.

Memento and Gifts

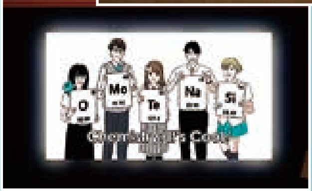
Ceremony


Welcome to the Opening Ceremony of IChO 2021 Japan.

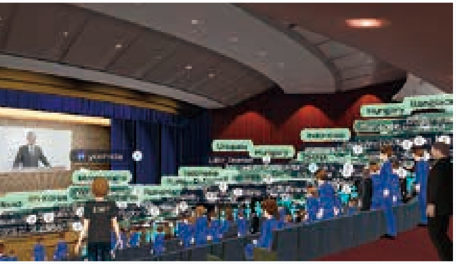

Thank you very much and good luck.

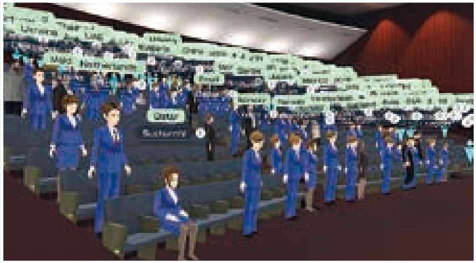

Akira Yoshino
Honorary Fellow, Asahi Kasei Corp.
2019 Nobel Laureate in Chemistry


I hope that you do your best in this chemistry Olympiad
文部科学大臣

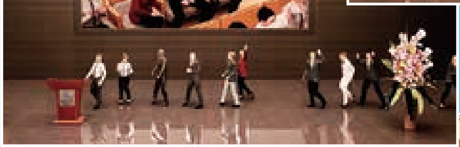

O
Mo
Te
Na
Si
Chemistry Is Cool


This is a high point for the career of your teachers, for your mentors



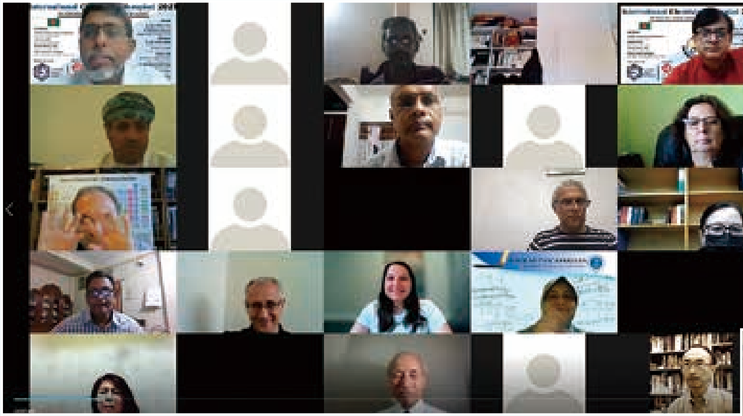


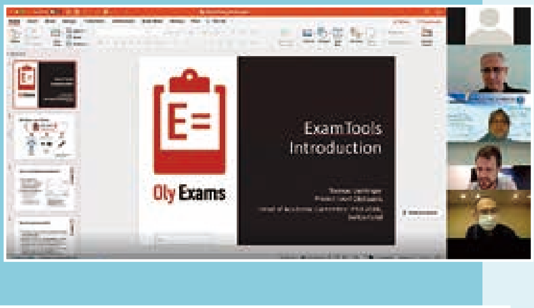

Gold Medal



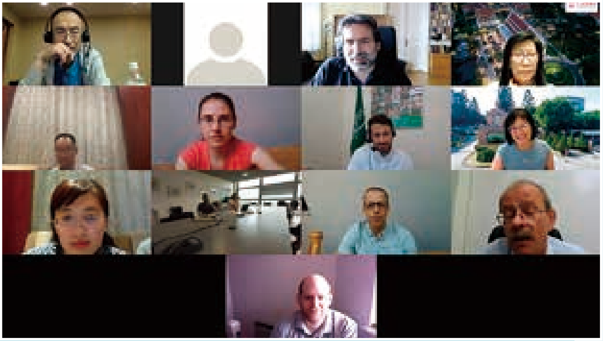
Examination

Meeting





ExamTools
Introduction



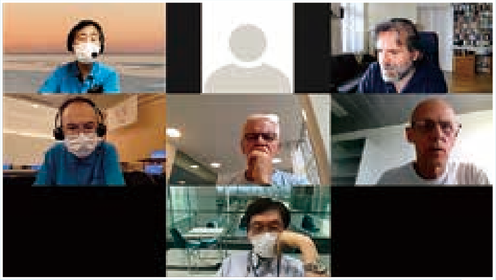
Welcome to Jury Meeting!!

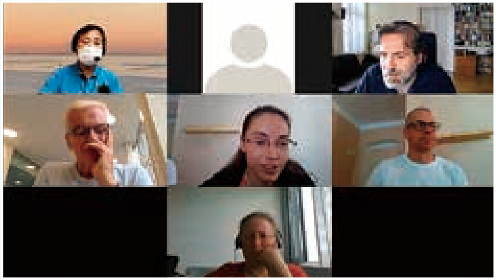
You can find Breakout Room at the bottom.
Please check that your Zoom version is latest.

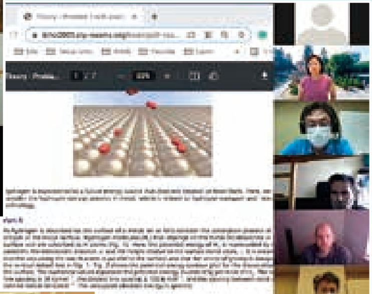
Before moving Breakout Room,

please change your name to be displayed as follows;
AAA-Name
AAA: Three-Letter Country Code

Voters (one for each room)
Please add "@" before Country Code.



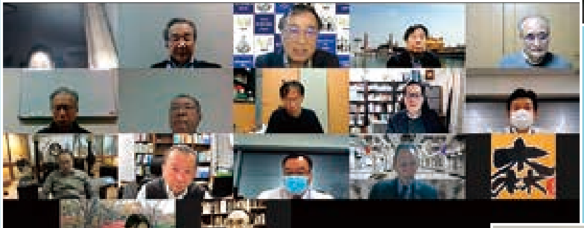


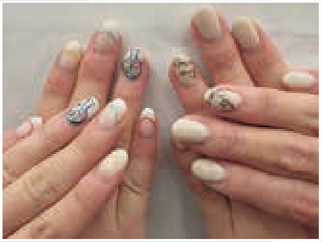


Explainers videos for the practical tasks @Kindai Univ.

Virtual Visit to SPring-8

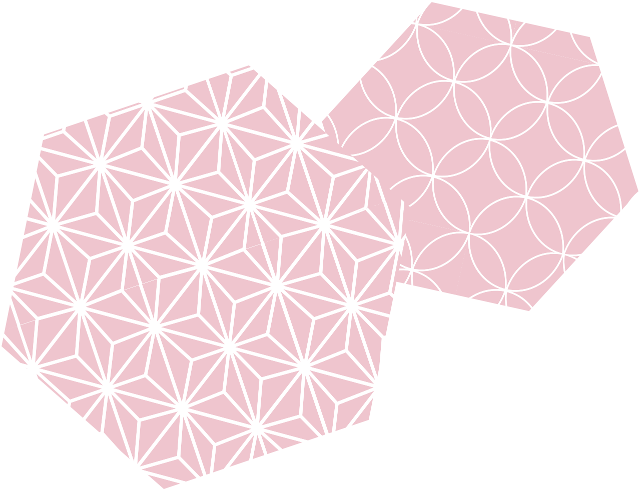
Secretariat





Examination

Examination Guideline



IChO 2021 Japan
Examination Guideline

10 June, 2021
Version 2.2
Organizing Committee of IChO2021 Japan

1. General

1-1. Purpose of This Guideline

Due to the COVID-19 pandemic, IChO2021 Japan will be held remotely. This guideline is published to ensure that the theoretical examination for this remote IChO is conducted appropriately.

This document institutes the rules to be followed. It also provides countries with recommended operational methods to protect their delegations from potential (or false) accusations of cheating. Please read this document carefully.

1-2. Time Zone

All dates and times on this document are based on Japan Standard Time (JST), which is Coordinated Universal Time (UTC) +9 hours. Japan does not use daylight saving time during the summer.

1-3. Future Updates of This Document

This document may be updated in the future. When a modification is made to this document, the IChO2021 Organizing Committee will announce the modification immediately, and send the updated version of the guideline to all country coordinators.

2. Examination Date and Timetable

2-1. Examination Date

The theoretical examination will take place on 28 July, 2021.

2-2. Examination Time

- The duration of the examination is 5 hours.
- The details of the examination (printing time, starting time, ending time, scanning time, times and length of bathroom breaks, and calculator model) must be reported by invigilators. The report form to be completed by invigilators will be provided with the student examination papers.

2-3. Examination Timetable

- The official examination period is 7:00 pm to 12:00 pm JST. If that period is not convenient in the time zone of the participating country, the examination may start up to 5 hours earlier or later. However, in this case, the participating students must observe a total communication ban (blackout) that includes the official examination period. For example, if they start earlier, they must remain secluded until 12:00 pm JST, and if they start later, they must be in isolation from 7:00 pm JST. If the participating country wishes to further change their examination time (for example, further earlier start), they may consult with the Organizer.
- All competitors in each country must have the same examination timetable to avoid ill-intentioned communication among competitors. Countries with multiple time zones must set their timetable on the basis of one specific time zone and conduct the examination accordingly.
- All countries must submit their choices for starting time, location and recording method via the registration site by 30 June.

2-4. Management of the Examination

- The preparation of the examination (discussions, voting, translation, printing) will be conducted using Oly-Exam software. Mentors will read, comment and vote on, and translate the examination text using the Oly-Exam software. Only a browser and internet access are necessary.
- Manuals for the Oly-Exam software can be found at https://demo.oly-exams.org/docs/ In the event of any difficulties, mentors and invigilators should refer to the manual. The Organizing Committee will also provide technical support during IChO2021.
- The mentor and the invigilator for each country will receive individual accounts to access Oly-Exam.
- Online training for Oly-Exam will be held at 9:00 pm JST on 23 July via Zoom. The details of the Zoom meeting will be announced separately. All mentors and invigilators are expected to attend the training. Observer countries are also invited. The training session will be recorded, and the link to the recorded file will be available during IChO2021.

3. Examination Conditions

3-1. Location of Examination

- The examination location must be a calm and quiet room with electricity, PC or smartphone, web camera, microphone, high quality printer, scanner with PDF-conversion software, and stable internet connection. Each location will be checked via Zoom before the examination.
- It is the responsibility of the country to maintain the location in a state suitable for the

examination. No additional time will be given, even if the examination is interrupted as a result of local problems.

- The examination location should not be the home of a student or a student's relative.
- A single location for the full number of 4 students is highly preferred. If legal travel restrictions in the country forbid a single location, multiple locations for one country are acceptable. In this case, all locations must follow the same examination timetable, and must meet all the requirements. All locations must be notified to the IChO2021 Organizer with the names of the invigilators.
- The students in each location are to be supervised by 1 or 2 invigilators during the examination.
- The students must maintain an appropriate distance from each other in the examination room.

3-2. Invigilators

- Invigilators must be independent of the mentors, must have no relationship with students and must have no other activity in IChO2021. Invigilators should be socially well-established persons such as school principals. The names, positions, and affiliations of the invigilators will be open, as well as those of the mentors.
- Invigilators should not be a parent or a relative of a student.
- Each delegation must register all invigilators at the registration site.
- The invigilators need a good command of English.
- Invigilators will receive an individual account to access Oly-Exam. This account only allows them to access the PDF files of the official English version and final translated version of the problems, and to upload the scanned answers.
- Invigilators must complete the downloading and the printing of the English version and the final translated version of the problems for each student before starting the examination. The problems and answer sheets must be printed clearly. The Organizing Committee will not take any responsibility if an unclear print-out results in incorrect answers given by a student.
- Invigilators should clearly announce the examination timetable to the students before the examination.
- Students are not allowed to use any electronic communication devices (e.g., smartphone, computers, smartwatches) during the examination and between 7:00 pm and 12:00 pm JST. Taking account of different examination starting and ending times, the total blackout periods are as follows:

Exam start	Exam end	Total blackout period
2:00 pm JST	7:00 pm JST	2:00 pm - 12:00 pm JST
3:00 pm JST	8:00 pm JST	3:00 pm - 12:00 pm JST
4:00 pm JST	9:00 pm JST	4:00 pm - 12:00 pm JST

5:00 pm JST	10:00 pm JST	5:00 pm - 12:00 pm JST
6:00 pm JST	11:00 pm JST	6:00 pm - 12:00 pm JST
7:00 pm JST	12:00 pm JST	7:00 pm - 12:00 pm JST
8:00 pm JST	1:00 am* JST	7:00 pm - 1:00 am* JST
9:00 pm JST	2:00 am* JST	7:00 pm - 2:00 am* JST
10:00 pm JST	3:00 am* JST	7:00 pm - 3:00 am* JST
11:00 pm JST	4:00 am* JST	7:00 pm - 4:00 am* JST
12:00 pm JST	5:00 am* JST	7:00 pm - 5:00 am* JST

*: 29 July

Students are to give their devices to the invigilators before the blackout period shown above. The invigilators will store them for the total blackout period. If the total blackout period includes mid-night or early morning, the invigilators may store them until the next day or from a day before the examination day. The invigilators must ensure that the students do not use any computers installed in the examination location over the relevant total blackout period.

- Invigilators must not allow the students to open the booklet of problems before the examination starts.
- After the examination, invigilators should scan all answer sheets to prepare one PDF file per student, sorting the sheets in the order of the page numbers. All PDF files should be submitted to the IChO2021 Organizer using Oly-Exam within 2 hour after the end of the examination. The answer sheets must be scanned clearly and properly. The Organizing Committee will not take any responsibility if grading is impossible due to unreadable scanning. Only a PDF format file is acceptable.
- Students are not supposed to ask questions during the exam. Invigilators are not to speak with students other than to issue the instructions to begin and end the examination. Students may view the official English version of the examination only when they request clarification of a problem.
- Invigilators may prepare water and snacks or refreshments for the students outside the examination room.
- It is strongly recommended that recording, printing, scanning and uploading files are tested before the examination.

3-3. Equipment

- Only a non-programmable calculator, good writing pen and a ruler can be used during the examination.
- The calculator should be a scientific electronic calculator by which logarithmic function, using both base 10 and e, exponential function, and root can be calculated. Students must be familiar with how to use the calculator, and can use their own calculator. The brand and the model name or number of the calculator must be notified

from the registration site.
- Students should write their answers only using a pen with dark ink. The invigilators may test the printing and scanning process in advance for readability.

3-4. Recording

Videos of the students must be recorded from the beginning to the end of the examination.

All students (whole body) and their activities need to be visible. The IChO2021 Organizer will send the individual Zoom meeting links to invigilators. Invigilators should click on the link at a reasonable time before the examination to directly enter the Zoom meeting hosted by the IChO2021 Organizer. The recording in the cloud will start automatically. Invigilators should place their PC or web camera at a location where the whole room (four students together) can be seen. All devices must have a stable internet connection and the data-transfer rate must be greater than 2 Mbps.

If a country faces a technical problem regarding a stable internet connection because of local factors, it must report the situation to the IChO2021 Organizer before the examination. In this situation, offline recording of the examination will be approved, and the invigilators must upload the recorded video data after the examination. If recording offline, the video-camera or recording device must be able to record at least 5 hours in an easily shared format (e.g. MP4) with a reasonable file size and quality. The recording can be made in parts without any perceivable time-gaps (e.g. two devices are used alternatively). The recording file must have time-stamps.

Students or their parents must give their written consent for the recording and its sharing with the IChO2021 Organizer.

4. Important Dates

9:00 pm JST, 23 July

Online training for Oly-Exam will be held via Zoom.

9:00 am JST, 25 July

The online opening ceremony will start. The access point for the ceremony will be announced separately. After the opening ceremony, the mentors are not allowed to contact the students.

9:00 pm JST, 25 July

Oly-Exam will be open for access. The first versions of the problems will be provided to mentors, who can submit questions, suggestions, corrections and comments via Oly-Exam. Online discussion will end at 9:00 am JST, 26 July. The Organizing Committee expects mentors to post all discussions on Oly-Exam to keep the Jury meeting short.

9:00 pm JST, 26 July
The first International Jury meeting will be held via Zoom to finalize the problems. The Zoom meeting link and password will be sent to mentors.
The attendees' display names should be their Country Code (three letters) followed by their name (e.g., JPN_Aaa Bbb). The display name can be changed after entering the Zoom meeting.
Only the head mentor can vote in the Jury meeting. When the Jury meeting is split into two parallel sessions, and the head mentor and mentor attend each session separately, mentor can also vote.
Observers can attend the Jury meeting, but guests are not allowed. If the display name does not match the registered name, the host will dismiss this attendee from the Zoom meeting after taking care to ensure that only the appropriate people attend the Jury meeting.

9:00 am JST, 27 July
Translation via Oly-Exam will begin. The official English versions of the problems will be provided to mentors via Oly-Exam. If any revisions have been made, Oly-Exam will show the revised version of the problems along with the previous version. The changes can therefore be readily reflected in the translations by the mentors.
After the translations are completed, the mentors should approve the translated versions of the problems. Once the mentors approve a translation, no more changes are allowed. Therefore, approvals must be done carefully. The translations must be completed by 9:00 am JST, 28 July.

11:00 am JST, 28 July
Invigilators can access Oly-Exam to print out the translated versions of the problems along with the official English version.

2:00 pm to 12:00 pm JST, 28 July
Invigilators instruct the students to start the examination according to the time schedule in each country.

7:00 pm JST, 28 July to 5:00 am JST, 29 July
Invigilators instruct the students to stop the examination at 5 hours after the start time (i.e. from 2:00 pm to 7:00 pm JST in the earliest timetable and from 12:00 pm to 5:00 am JST in the latest timetable). The invigilators collect all answer sheets, sort and scan them, and convert them to PDF files. The PDF files for each student are submitted to Oly-Exam.

9:00 am JST, 29 July
The student answers, solutions, and marking scheme are provided to mentors via Oly-Exam. The Organizer and the mentors begin marking.

9:00 am JST, 30 July
Grading of the students will be announced by the Organizer. The mentors decide the arbitration list and report it via Oly-Exam. The deadline for requests will be 9:00 pm JST, 30 July.

9:00 pm JST, 30 July
The second International Jury meeting will be held via Zoom. This meeting is intended mainly for IChO business. The time slots for arbitration will be also announced. The attendees are requested to follow the Zoom meeting rules noted above.

9:00 am JST, 31 July to 12:00 am JST, 1 August
Arbitration will be conducted via Zoom. The mentors should enter the Zoom meeting for every problem. Mentors are requested to follow the Zoom meeting rules noted above. Arbitration time slots will be arranged according to the local time zones of participating countries.

9:00 am JST, 1 August
The final points scores will be provided to mentors via Oly-Exam.

9:00 pm JST, 2 August
The online closing ceremony will start. Students may attend the ceremony with their avatars. The access point for the ceremony will be announced via email and the website. Medals and certificates will be sent to the participants via surface mail. Certificates can also be sent via email.

5. Contact Us

5-1. Technical Support

During the Olympiad period, technical issues should be reported to support@icho2021.org. The support team will get back to you as soon as possible.

5-2. Instant Communication

Telegram will be used for text-based and instant announcements. Information on how to access Telegram will be provided separately. All mentors and invigilators are expected to download the Telegram application on their mobile device or computer before IChO2021 to avoid missing any instant information from the Organizing Committee. Telegram display names should consist of a Country Code (three letters) followed by the person’s name (e.g., JPN_Aaa Bbb).

Instruction for Invigilators

1. Training of Oly-Exam

There will be a training session of Oly-Exam for Invigilators via Zoom meeting at 0:00 JST, July 24 (15:00 UTC, July 23):
https://zoom.us/j/4189597251?pwd=R3dXQjkremxFNmJaY1BZWFByS0pDdz09
Meeting ID: 418 959 7251
Pass Code: 916970

In this session, following topics will be discussed:
- How to access Oly-Exam
- How to download the examination problems (both the official English version and the translated version) and answer sheets
- How to submit the scanned pdf files after the examination

2. Information for the examination

Access accounts for Oly-Exam, Zoom ID for on-line recording, and student codes will be informed after the training session.

The following information should be checked before the examination:
- Names of students in all locations of your country
- Starting time of the examination in the local time
- Brand name and model name of each calculators

3. Communication ban

Students are not allowed to use any electronic communication devices (e.g., smartphone, computers, smartwatches) during the examination and between 7:00 pm and 12:00 pm JST, 28 July. Invigilators have to control the communication ban.

4. Setting of the Location

The examination location should be a calm and quiet room. Please maintain the location in a state suitable for the examination.

The students must maintain an appropriate distance from each other in the examination room.

Invigilators should prepare water and snacks or refreshments for the students. Basically, they should be outside of the examination room not to disturb other students. However, they can be inside of the room or on the desk if invigilators can manage the examination room adequately.

The location should have:
- Electricity
- PC or smartphone with zoom application
- Web camera (PC-built-in camera can be used)
- Microphone (PC-built-in microphone can be used)
- High quality printer

- Scanner with PDF-conversion software
- Stable internet connection.

No additional time will be given, even if the examination is interrupted as a result of local problems. It is strongly recommended that recording, printing, scanning and uploading files are tested before the examination.

5. Equipment

Students can use only:
- A non-programmable scientific electronic calculator
- Good writing pen with dark ink
- A ruler

Students are allowed to put equipment that is necessary for the examination (e.g., medicine and handkerchief) on their desk.

6. Recording

All students (whole body) and their activities during the examination will be recorded via Zoom application.

Invigilators should enter the Zoom meeting hosted by the organizer at a reasonable time before the examination. The recording in the cloud will start. Invigilators should place their PC or web camera at a location where all students in the location can be viewed.

The location will be inspected by the organizer. Please follow the request of the organizer who controls the Zoom meeting.

Only for the country that registered Off-line recording: If a country registered the off-line recording because of local factors, invigilators have to record the examination as the same manner of on-line recording. The video-camera or recording device used in off-line recording must be able to record at least 5 hours in an easily shared format (e.g., MP4) with a reasonable file size, quality, and time-stamp. The recording can be made in parts without any perceivable time-gaps (e.g., two devices are used alternatively). The URL for upload will be informed separately.

7. Examination

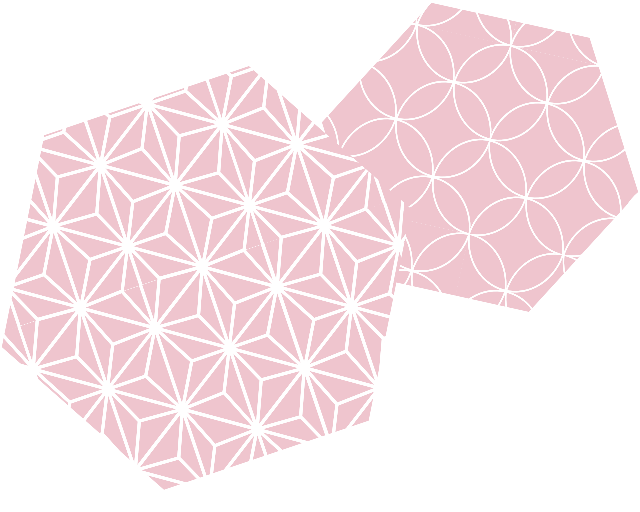
- Invigilators can access Oly-Exam after 9:00 am JST (0:00 am UTC), 28 July to download the problems and answer sheets (both the translated and the official English version). Invigilators must complete the downloading and the printing of the both materials (A4 format) for each student before starting the examination. The problems and answer sheets must be printed clearly on only one side (the back must be blank). Although some problems include color figures, color-printing is not essential. The print-out can be bound separately for each student. Any binding stationary (clip, stapler, binder etc.) can be used.
  Every problem and answer sheets have student codes. If there are more than one examination locations in the country, carefully prepare the only

necessary problems and answer sheets for the location.

- Please also download and print out the report form from the download site of Oly-Exam. The report form will be available also from the Web site: https://www.icho2021.org/problems/icho2021/
- Invigilators may activate Zoom link 30-60 min before the examination to connect the organizer. The organizers will inform a Zoom link for a country. If there are more than one examination locations in the country, use the same link in the country.
- After Zoom connection is established, the organizer will inspect the examination room: Name of invigilators and students, the face of students, the position of camera for recording, distance between students, calculator, etc.
- After the inspection, the organizer will be invisible, although the organizer will be always there. Please do not mute. Please do not stop video. To maintain the examination room calm, the volume can be minimized.
- Invigilators should clearly announce the examination timetable to the students before the examination. Invigilators must not allow the students to open the booklet of problems before the examination starts.
- At least 5 min before the starting time, invigilators allow the students to read the General Instruction at the first page.
- At the exact starting time registered, invigilators have to instruct the students to start the examination. All locations in the country must follow the same examination timetable.
- Students are not supposed to ask questions during the exam. Invigilators are not to speak with students other than to issue the instructions to begin and end the examination. Students may request the break for bathroom, water, and snacks, and may view the official English version of the examination only when they clarification of a problem.
- The details of the examination (printing time, starting time, ending time, scanning time, and times and length of bathroom breaks) must be recorded by invigilators.
- Invigilators announce the warning at 30 min before the end time (4 hours and 30 min after the start time).
- Invigilators instruct the students to stop the examination at 5 hours after the start time. All students have to stop working. If students do not stop writing, warn the nullification of the points.
- After the examination, invigilators collect all answer sheets, sort the sheets in the order of the page numbers, and scan them to prepare **one PDF file per problem and per student**. The PDF files for each student are submitted to organizer using Oly-Exam within 2 hours after the end of the examination. The answer sheets must be scanned clearly and properly. **Even blank answer**

sheets must be uploaded.
All process must be confidential, and invigilator must keep the students away from the answer sheets after the examination.

Problem English Version with Solution



G0-1

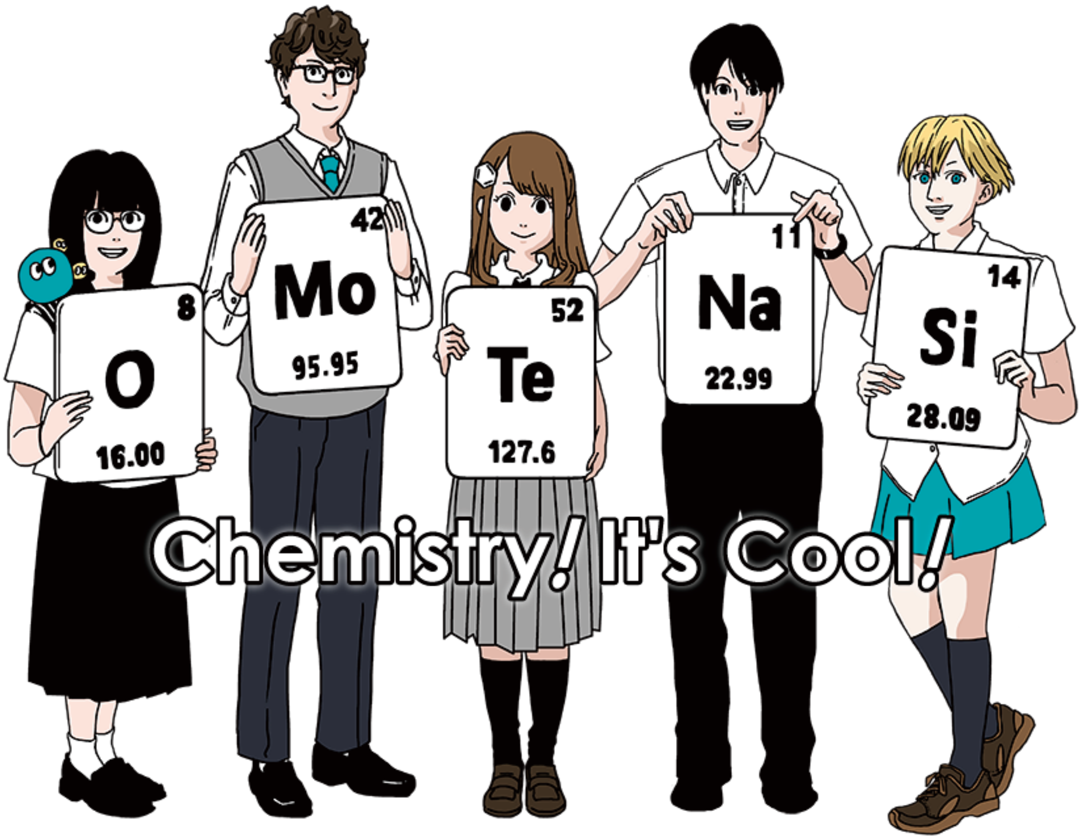
English (Official)

International Chemistry Olympiad 2021 Japan

The 53rd IChO 2021 Japan

25th July - 2nd August, 2021

https://www.icho2021.org



General Instruction

- You are allowed to use only pen to write the answer.
- Your calculator must be non-programmable.
- This examination has **9 problems**.
- You can solve the problems in any order.
- You will have **5 hours** to solve all problems.
- You can **begin** working only after the **START** command is given.
- All results must be written in the appropriate answer boxes with pen on the **answer sheets**. Use the back of the question sheets if you need scratch paper. Remember that answers written outside the answer boxes will not be graded.
- Write relevant calculations in the appropriate boxes when necessary. Full marks will be given for correct answers only when your work is shown.
- The invigilator will announce a **30-minute** warning before the **STOP** command.
- You **must stop** working when the **STOP** command is given. Failure to stop writing will lead to the nullification of your examination.
- The official English version of this examination is available on request only for clarification.
- You are not allowed to leave your working place without permission. If you need any assistance (broken calculator, need to visit a restroom, etc), raise your hand and wait until an invigilator arrives.

GOOD LUCK!

Problems and Grading Information

	Title	Total Score	Percentage
1	Hydrogen at a Metal Surface	24	11
2	Isotope Time Capsule	35	11
3	Lambert–Beer Law?	22	8
4	The Redox Chemistry of Zinc	32	11
5	Mysterious Silicon	60	12
6	The Solid-State Chemistry of Transition Metals	45	13
7	Playing with Non-benzenoid Aromaticity	36	13
8	Dynamic Organic Molecules and Their Chirality	26	11
9	Likes and Dislikes of Capsules	23	10
		Total	**100**

Physical Constants and Equations

Constants

Speed of light in vacuum	$c = 2.99792458 \times 10^{8}$ m s^{-1}
Planck constant	$h = 6.62607015 \times 10^{-34}$ J s
Elementary charge	$e = 1.602176634 \times 10^{-19}$ C
Electron mass	$m_\mathrm{e} = 9.10938370 \times 10^{-31}$ kg
Electric constant (permittivity of vacuum)	$\varepsilon_0 = 8.85418781 \times 10^{-12}$ F m^{-1}
Avogadro constant	$N_\mathrm{A} = 6.02214076 \times 10^{23}$ mol^{-1}
Boltzmann constant	$k_\mathrm{B} = 1.380649 \times 10^{-23}$ J K^{-1}
Faraday constant	$F = N_\mathrm{A} \times e = 9.64853321233100184 \times 10^{4}$ C mol^{-1}
Gas constant	$R = N_\mathrm{A} \times k_\mathrm{B} = 8.31446261815324$ J K^{-1} mol^{-1} $= 8.2057366081 \times 10^{-2}$ L atm K^{-1} mol^{-1}
Unified atomic mass unit	$u = 1$ Da $= 1.66053907 \times 10^{-27}$ kg
Standard pressure	$p = 1$ bar $= 10^{5}$ Pa
Atmospheric pressure	$p_\mathrm{atm} = 1.01325 \times 10^{5}$ Pa
Zero degree Celsius	$0\,^\circ\mathrm{C} = 273.15$ K
Ångstrom	1 Å $= 10^{-10}$ m
Picometer	1 pm $= 10^{-12}$ m
Electronvolt	1 eV $= 1.602176634 \times 10^{-19}$ J
Part-per-million	1 ppm $= 10^{-6}$
Part-per-billion	1 ppb $= 10^{-9}$
Part-per-trillion	1 ppt $= 10^{-12}$
pi	$\pi = 3.141592653589793$
The base of the natural logarithm (Euler's number)	$e = 2.718281828459045$

Equations

The ideal gas law	$PV = nRT$, where P is the pressure, V is the volume, n is the amount of substance, T is the absolute temperature of ideal gas.
Coulomb's law	$F = k_\mathrm{e}\frac{q_1 q_2}{r^2}$, where F is the electrostatic force, $k_\mathrm{e}(\simeq 9.0 \times 10^9\ \mathrm{N\,m^2\,C^{-2}})$ is Coulomb's constant, q_1 and q_2 are the magnitudes of the charges, and r is the distance between the charges.
The first law of thermodynamics	$\Delta U = q + w$, where ΔU is the change in the internal energy, q is the heat supplied, w is the work done.
Enthalpy H	$H = U + PV$
Entropy based on Boltzmann's principle S	$S = k_\mathrm{B} \ln W$, where W is the number of microstates.
The change of entropy ΔS	$\Delta S = \frac{q_\mathrm{rev}}{T}$, where q_rev is the heat for the reversible process.
Gibbs free energy G	$G = H - TS$ $\Delta_\mathrm{r} G^\circ = -RT \ln K = -zFE^\circ$, where K is the equilibrium constant, z is the number of electrons, E° is the standard electrode potential.
Reaction quotient Q	$\Delta_\mathrm{r} G = \Delta_\mathrm{r} G^\circ + RT \ln Q$ For a reaction $a\mathrm{A} + b\mathrm{B} \rightleftharpoons c\mathrm{C} + d\mathrm{D}$ $Q = \frac{[\mathrm{C}]^c[\mathrm{D}]^d}{[\mathrm{A}]^a[\mathrm{B}]^b}$, where [A] is the concentration of A.

Heat change Δq	$\Delta q = nc_\mathrm{m}\Delta T$, where c_m is the temperature-independent molar heat capacity.
Nernst equation for redox reaction	$E = E^\circ + \frac{RT}{zF} \ln \frac{C_\mathrm{ox}}{C_\mathrm{red}}$, where C_ox is the concentration of oxidized substance, C_red is the concentration of reduced substance.
Arrhenius equation	$k = A \exp\left(-\frac{E_a}{RT}\right)$, where k is the rate constant, A is the pre-exponential factor, E_a is the activation energy. $\exp(x) = e^x$
Lambert–Beer equation	$A = \varepsilon l c$, where A is the absorbance, ε is the molar absorption coefficient, l is the optical path length, c is the concentration of the solution.
Henderson–Hasselbalch equation	For an equilibrium $\mathrm{HA} \rightleftharpoons \mathrm{H^+} + \mathrm{A^-}$, where equilibrium constant is K_a, $\mathrm{pH} = \mathrm{p}K_\mathrm{a} + \log\left(\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}\right)$
Energy of a photon	$E = h\nu = h\frac{c}{\lambda}$, where ν is the frequency, λ is the wavelength of the light.
The sum of a geometric series	When $x \neq 1$, $1 + x + x^2 + \cdots + x^n = \sum_{i=0}^{n} x^i = \frac{1 - x^{n+1}}{1 - x}$
Approximation equation that can be used to solve problems	When $x \ll 1$, $\frac{1}{1-x} \simeq 1 + x$

G0-6

English (Official)

Periodic Table

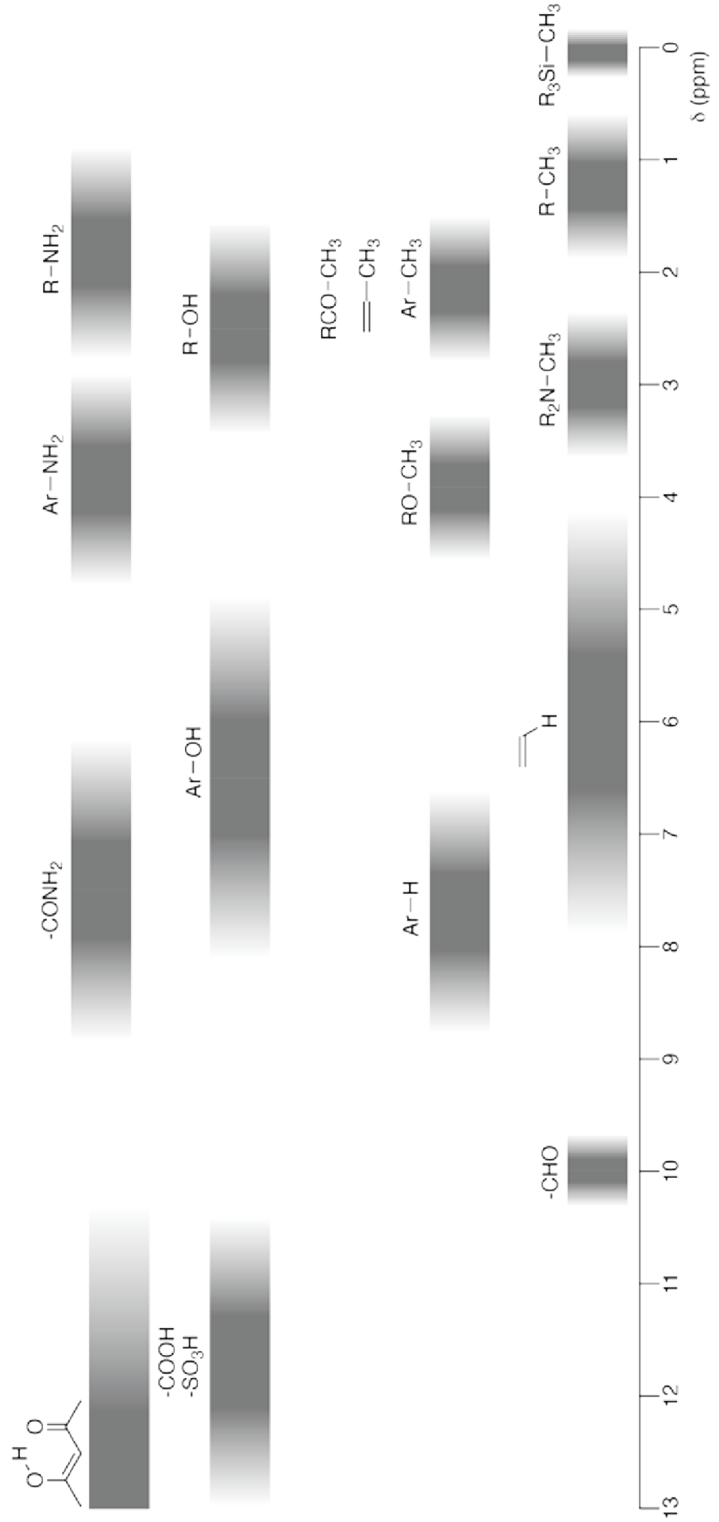
Key:

113 Nh Nihonium [278]	atomic number Symbol name atomic weight [in parenthesis for the radioactive element]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.968	4 Be Beryllium 9.012											5 B Boron 10.814	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.306											13 Al Aluminium 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.068	17 Cl Chlorine 35.452	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium [99]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	47 Ag Silver 107.868	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293
55 Cs Caesium 132.905	56 Ba Barium 137.327	57-71 La-Lu Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.384	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium [210]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Ac-Lr Actinoids	104 Rf Rutherfordium [267]	105 Db Dubnium [268]	106 Sg Seaborgium [271]	107 Bh Bohrium [272]	108 Hs Hassium [277]	109 Mt Meitnerium [276]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [278]	114 Fl Flerovium [289]	115 Mc Moscovium [289]	116 Lv Livermorium [293]	117 Ts Tennessine [293]	118 Og Oganesson [294]

57-71 La-Lu Lanthanoids	57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.967
89-103 Ac-Lr Actinoids	89 Ac Actinium [227]	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium [237]	94 Pu Plutonium [239]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [252]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [259]	103 Lr Lawrencium [262]

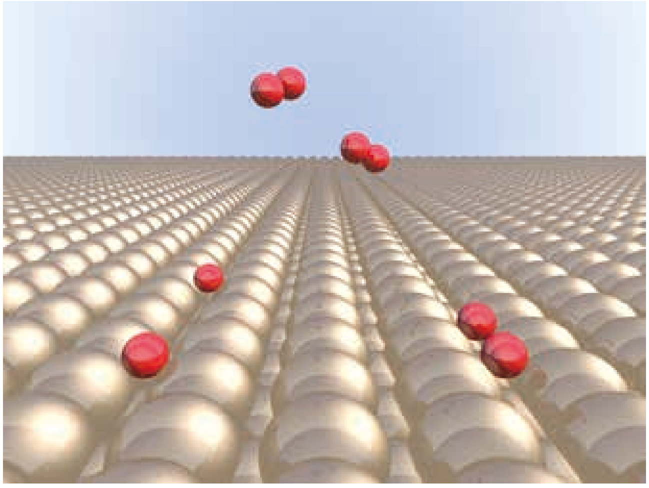
^{1}H NMR Chemical Shifts



Δδ for one alkyl group-substitution: *ca.* +0.4 ppm

Hydrogen at a Metal Surface

11 % of the total							
Question	A.1	A.2	B.1	B.2	B.3	B.4	**Total**
Points	6	4	5	3	3	3	**24**
Score							



Hydrogen is expected to be a future energy source that does not depend on fossil fuels. Here, we will consider the hydrogen-storage process in a metal, which is related to hydrogen-transport and -storage technology.

Part A

As hydrogen is absorbed into the bulk of a metal via its surface, let us first consider the adsorption process of hydrogen at the metal surface, $H_2(g) \rightarrow 2H(ad)$, where the gaseous and adsorbed states of hydrogen are represented as (g) and (ad), respectively. Hydrogen molecules (H_2) that reach the metal surface (M) dissociate at the surface and are adsorbed as H atoms (Fig. 1). Here, the potential energy of H_2 is represented by two variables: the interatomic distance, d, and the height relative to the surface metal atom, z. It is assumed that the axis along the two H atoms is parallel to the surface and that the center of gravity is always on the vertical dotted line in Fig. 1. Fig. 2 shows the potential energy contour plot for the dissociation at the surface. The numerical values represent the potential energy in units of kJ per mole of H_2. The solid line spacing is 20 $kJ\,mol^{-1}$, the dashed line spacing is 100 $kJ\,mol^{-1}$, and the spacing between solid and dashed lines is 80 $kJ\,mol^{-1}$. The zero-point vibration energy is ignored.

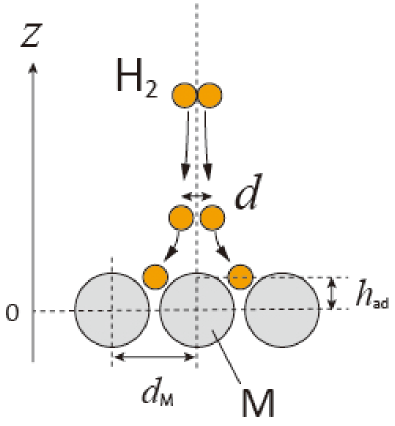


Fig.1 Definition of variables. Drawing is not in scale.

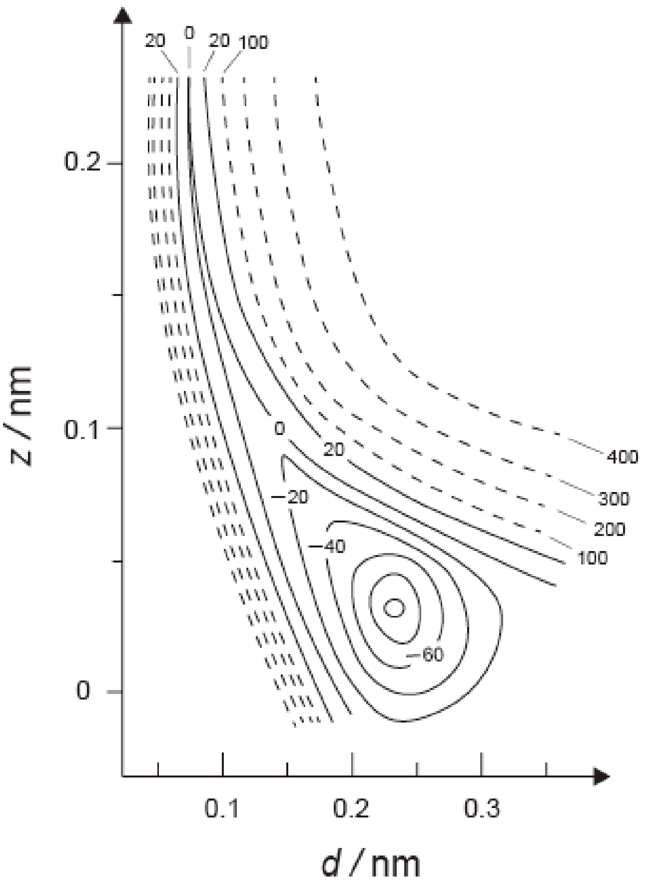


Fig.2

A.1 For each of the following items (i)–(iii), **select** the closest value from A–G. 6pt
(i) The interatomic distance for a gaseous H_2 molecule
(ii) The interatomic distance between metal atoms (d_{M} in Fig. 1)
(iii) The distance of adsorbed H atoms from the surface (h_{ad} in Fig. 1)

A. 0.03 nm	B. 0.07 nm	C. 0.11 nm	D. 0.15 nm
E. 0.19 nm	F. 0.23 nm	G. 0.27 nm	

(i) B (ii) F (iii) A
6 points in total:
2 point for (i), (ii) and (iii)

A.2 For each of the following items (i)–(ii), **select** the closest value from A–H. 4pt
(i) the energy required for the dissociation of gaseous H_2 to gaseous H [$H_2(g) \rightarrow 2H(g)$]
(ii) the energy released during the adsorption of a gaseous H_2 [$H_2(g) \rightarrow 2H(ad)$]

A. 20 $kJ\,mol^{-1}$	B. 40 $kJ\,mol^{-1}$	C. 60 $kJ\,mol^{-1}$	D. 100 $kJ\,mol^{-1}$
E. 150 $kJ\,mol^{-1}$	F. 200 $kJ\,mol^{-1}$	G. 300 $kJ\,mol^{-1}$	H. 400 $kJ\,mol^{-1}$

(i) H (ii) D
4 points in total:
2 points for (i) and (ii)

Part B

The adsorbed hydrogen atoms are then either absorbed into the bulk, or recombine and desorb back into the gas phase, as shown in the reactions (1a) and (1b). H(ab) represents a hydrogen atom absorbed in the bulk.

$$\mathrm{H_2(g)} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \mathrm{2H(ad)} \tag{1a}$$

$$\mathrm{H(ad)} \xrightarrow{k_3} \mathrm{H(ab)} \tag{1b}$$

The reaction rates per surface site for adsorption, desorption, and absorption are $r_1[\mathrm{s}^{-1}], r_2[\mathrm{s}^{-1}]$ and $r_3[\mathrm{s}^{-1}]$, respectively. They are expressed as:

$$r_1 = k_1 P_{H_2}(1-\theta)^2 \tag{2}$$

$$r_2 = k_2\theta^2 \tag{3}$$

$$r_3 = k_3\theta \tag{4}$$

where k_1 [s^{-1} Pa^{-1}], k_2 [s^{-1}] and k_3 [s^{-1}] are the reaction rate constants and P_{H_2} is the pressure of H_2. Among the sites available on the surface, θ ($0 \le \theta \le 1$) is the fraction occupied by H atoms. It is assumed that adsorption and desorption are fast compared to absorption ($r_1, r_2 \gg r_3$) and that θ remains constant.

B.1 r_3 can be expressed as: 5pt

$$r_3 = \frac{k_3}{1+\sqrt{\frac{1}{P_{H_2}C}}} \tag{5}$$

Express C using k_1 and k_2.

From $r_1, r_2 \gg r_3$ and $r_1 = r_2 + r_3$,
$r_1 = r_2$.
Then $k_1 P_{H_2}(1-\theta)^2 = k_2\theta^2$ (1')
Solve for θ:

$$\theta = \frac{1}{1+\sqrt{\frac{k_2}{P_{H_2}k_1}}}$$ (2')

From $r_3 = k_3\theta$:

$$r_3 = \frac{k_3}{1+\sqrt{\frac{k_2}{P_{H_2}k_1}}}$$

Thus, $C = \frac{k_1}{k_2}$

5 points in total:
5 points for the final correct answer.
partial points:
(1') and (2'): 2 points each.

A metal sample with a surface area of $S = 1.0 \times 10^{-3}$ m^2 was placed in a container (1L = 1.0×10^{-3} m^3) with H_2 ($P_{H_2} = 1.0 \times 10^2$ Pa). The density of hydrogen-atom adsorption sites on the surface was $N = 1.3 \times 10^{18}$ m^{-2}. The surface temperature was kept at $T = 400$ K. As the reaction (1) proceeded, P_{H_2} decreased at a constant rate of $v = 4.0 \times 10^{-4}$ Pa s^{-1}. Assume that H_2 is an ideal gas and that the volume of the metal sample is negligible.

B.2 **Calculate** the amount of H atoms in moles absorbed per unit area of the surface per unit time, $A\,[\text{mol s}^{-1}\text{ m}^{-2}]$. 3pt

The change in the amount of hydrogen atoms per unit time in the gas phase is $A \times S$. Thus,

$A \times S = \dfrac{2vV}{RT}$ (1')

$= 2 \times 4.0 \times 10^{-4} \times \dfrac{1.0 \times 10^{-3}}{8.31 \times 400} = 2.4 \times 10^{-10}$ mol s^{-1}

Therefore,

$\underline{A = 2.4 \times 10^{-7} \text{ mol s}^{-1}\text{ m}^{-2}}$

3 points in total:

2 points for (1'), and 1 point for the final answer.

-1 point if $A \times S = \dfrac{vV}{RT}$ (missing the factor 2).

B.3 At $T = 400$ K, C equals 1.0×10^2 Pa^{-1}. **Calculate** the value of k_3 at 400 K. If you did not obtain the answer to **B.2**, use $A = 3.6 \times 10^{-7}$ mol s^{-1} m^{-2}. 3pt

The relationship between r_3 and A is:

$$A = r_3 \times \frac{N}{N_\mathrm{A}}$$

Thus,

$$r_3 = A \times \frac{N_\mathrm{A}}{N} = 1.1 \times 10^{-1}\,\mathrm{s}^{-1}\ (1')$$

Solution 1

$$r_3 = \frac{k_3}{1 + \sqrt{\dfrac{k_2}{P_{\mathrm{H}_2} k_1}}} = \frac{k_3}{1 + \sqrt{\dfrac{1}{10000}}} = \frac{k_3}{1.01}\ (2')$$

Thus,

$$\underline{k_3 = 1.01 \times r_3 = 1.1 \times 10^{-1}\,\mathrm{s}^{-1}}$$

Solution 2

Under the condition $P_{\mathrm{H}_2} C \gg 1,$ it follows that:

$$r_3 = \frac{k_3}{1 + \sqrt{\dfrac{k_2}{P_{\mathrm{H}_2} k_1}}} \approx \frac{k_3}{1} = k_3\ (3')$$

Thus,

$$\underline{k_3 = r_3 = 1.1 \times 10^{-1}\,\mathrm{s}^{-1}}$$

(1.7×10^{-1} s^{-1} with $A = 3.6 \times 10^{-7}$ mol s^{-1} m^{-2})

3 points in total:
2 points for the correct value (1').
(if correct formulation (1'), 1 point).
1 point for the final correct answer.
It does not affect the score whether the approximation of (3') is used or not.

B.4 At a different T, $C = 2.5 \times 10^3$ Pa^{-1} and $k_3 = 4.8 \times 10^{-2}$ s^{-1}are given. For r_3 as a function of P_{H_2}at this temperature, **select** the correct plot from (a)–(h). 3pt

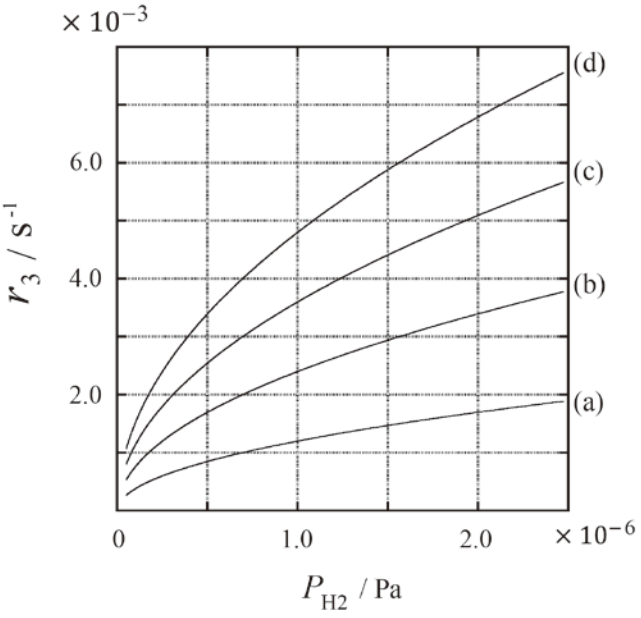
The figures show the region in which $P_{\mathrm{H_2}}C \ll 1$. Therefore,

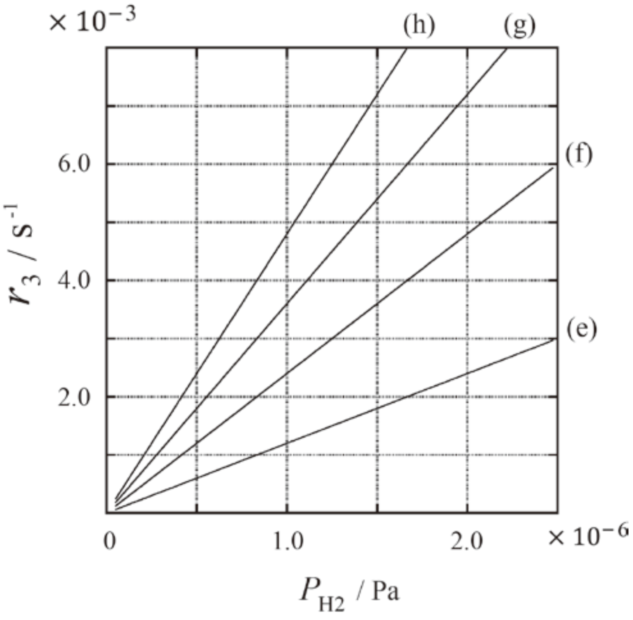
$$r_3 = \frac{k_3}{1 + \sqrt{\dfrac{1}{P_{\mathrm{H_2}}C}}} \quad \text{(1')}$$

$$\approx \frac{k_3}{\sqrt{\dfrac{1}{P_{\mathrm{H_2}}C}}} = k_3\sqrt{P_{\mathrm{H_2}}C} = 2.4\sqrt{P_{\mathrm{H_2}}}$$

Thus, (b)

3 points in total:
3 points for selecting (b).





Isotope Time Capsule

11 % of the total					
Question	A.1	A.2	A.3	A.4	**Total**
Points	8	8	10	9	**35**
Score					

Molecular entities that differ only in isotopic composition, such as CH_4 and CH_3D, are called isotopologues. Isotopologues are considered to have the same chemical characteristics. In nature, however, there exists a slight difference.

Assume that all of the substances shown in this Question are in a gas phase.

Let us consider the following equilibrium:

$$^{12}C^{16}O_2 + ^{12}C^{18}O_2 \rightleftharpoons 2\,^{12}C^{16}O^{18}O \qquad K = \frac{[^{12}C^{16}O^{18}O]^2}{[^{12}C^{16}O_2][^{12}C^{18}O_2]} \tag{1}$$

The entropy, S, increases with increasing the number of possible microscopic states of a system, W:

$$S = k_B \ln W \tag{2}$$

$W = 1$ for $^{12}C^{16}O_2$ and $^{12}C^{18}O_2$. In contrast, $W = 2$ for a $^{12}C^{16}O^{18}O$ molecule because the oxygen atoms are distinguishable in this molecule. As the right-hand side of the equilibrium shown in eq. 1 has two $^{12}C^{16}O^{18}O$ molecules, $W = 2^2 = 4$.

A.1 The enthalpy change, ΔH, of eq. 3 is positive regardless of the temperature. 8pt

$$\mathrm{H_2 + DI \rightleftharpoons HD + HI} \qquad (3)$$

Calculate the equilibrium constants, K, for eq. 3 at very low (think of $T \to 0$) and very high (think of $T \to +\infty$) temperatures. Assume that the reaction remains unchanged at these temperatures and that ΔH converges to a constant value for high temperatures.

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ = -RT \ln K \to \ln K = -\dfrac{\Delta H^\circ}{RT} + \dfrac{\Delta S^\circ}{R}$

$\left(K = \exp\left[-\dfrac{\Delta H^\circ}{RT}\right] \exp\left[\dfrac{\Delta S^\circ}{R}\right]\right)$

$T \to 0$: As $\Delta H^\circ > 0$, $\ln K$ converges to $-\infty$ and therefore $K = 0$.

$T \to +\infty$: $\ln K \to \dfrac{\Delta S^\circ}{R}$

Given that ΔS° per 1 mole is $N_\mathrm{A} k_\mathrm{B} \ln W = R \ln 2$, $K = 2$.

8 points in total:

3 points for the correct answer for $T \to 0$,

5 points for the correct answer for $T \to +\infty$.

Partial points:

If neither the correct answer for $T \to 0$ nor that for $T \to +\infty$ is obtained: 2 points for showing that $\ln K = -\dfrac{\Delta H^\circ}{RT} + \dfrac{\Delta S^\circ}{R}$.

If the correct answer for $T \to +\infty$ is not obtained: 2 points for showing that $W = 2$.

The Δ*H* of the following process can be explained by molecular vibrations.

$$\mathrm{2HD \rightleftharpoons H_2 + D_2} \qquad K = \frac{[\mathrm{H_2}][\mathrm{D_2}]}{[\mathrm{HD}]^2} \qquad (4)$$

At T = 0 K, the vibrational energy of a diatomic molecule whose vibration frequency is ν [s^{-1}] is expressed as:

$$E = \frac{1}{2}h\nu \qquad (5)$$

$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}} \qquad (6)$$

Wherein k is the force constant and μ the reduced mass, which is expressed in terms of the mass of the two atoms in the diatomic molecule, m_1 and m_2, according to:

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \tag{7}$$

A.2 The vibration of H_2 is at 4161.0 cm^{-1} when reported as a wavenumber. **Calculate** the ΔH of the following equation at T = 0 K in units of J mol^{-1}. 8pt

$$2\mathrm{HD} \rightarrow \mathrm{H_2} + \mathrm{D_2} \tag{8}$$

Assume that:

- only the vibrational energy contributes to the ΔH.
- the k values for H_2, HD, and D_2 are identical.
- the mass of H to be 1 Da and the mass of D to be 2 Da.

$\mu_{\mathrm{H_2}} = 1/2\,\mathrm{Da}$, $\mu_{\mathrm{HD}} = 2/3\,\mathrm{Da}$, $\mu_{\mathrm{D_2}} = 1\,\mathrm{Da}$.
Using $\nu = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}}$, $\frac{\nu_{\mathrm{HD}}}{\nu_{\mathrm{H_2}}} = \sqrt{\frac{\mu_{\mathrm{H_2}}}{\mu_{\mathrm{HD}}}}$ and $\frac{\nu_{\mathrm{D_2}}}{\nu_{\mathrm{H_2}}} = \sqrt{\frac{\mu_{\mathrm{H_2}}}{\mu_{\mathrm{D_2}}}}$ are obtained.
The frequency of the H_2 vibration is 4161.0 cm^{-1} in units of wavenumbers.
Therefore, the frequencies of the molecular vibration for HD and D_2 are calculated to be 3603.5 cm^{-1} and 2942.3 cm^{-1}, respectively.
The difference of the zero-point energies of eq. 4 is calculated to be
$(4161.0 + 2942.3)/2 - 3603.5 = -51.9\,\mathrm{cm^{-1}}$.
$E = N_{\mathrm{A}} h\nu = N_{\mathrm{A}} hc\tilde{\nu}$ ($\tilde{\nu}$: frequency in wavenumbers), and therefore $E = \Delta H^\circ = -621\,\mathrm{J\,mol^{-1}}$.

8 points in total:
2 points for the correct vibrational frequency of HD
(1 point for the correct μ value of HD,
1 point for the correct formulation $\left(\frac{\nu_{\mathrm{HD}}}{\nu_{\mathrm{H_2}}} = \sqrt{\frac{\mu_{\mathrm{H_2}}}{\mu_{\mathrm{HD}}}}\right)$ to calculate the vibrational frequency of HD),
2 points for the correct vibrational frequency of D_2
(1 point for the correct μ value of D_2,
1 point for the correct formulation $\left(\frac{\nu_{\mathrm{D_2}}}{\nu_{\mathrm{H_2}}} = \sqrt{\frac{\mu_{\mathrm{H_2}}}{\mu_{\mathrm{D_2}}}}\right)$ to calculate the vibrational frequency of D_2),
2 points for the correct conversion from cm^{-1} to J mol^{-1}
(partial points: 1 point for the correct conversion from cm^{-1} to J (N_{A} is missing)),
2 points for the correct energy difference
(partial points: -1 point when the value is not divided by 2, -1 point when the sign is wrong).

The molar ratio of H_2, HD, and D_2 depends on the temperature in a system in equilibrium. Here, Δ_{D_2} is defined as the change of the molar ratio of D_2.

$$\Delta_{D_2} = \frac{R_{D_2}}{R^*_{D_2}} - 1 \tag{9}$$

Here, R_{D_2} refers to $\frac{[D_2]}{[H_2]}$ in the sample and $R^*_{D_2}$ to $\frac{[D_2]}{[H_2]}$ at $T \rightarrow +\infty$. It should be noted here that the distribution of isotopes becomes random at $T \rightarrow +\infty$.

A.3 **Calculate** Δ_{D_2} with natural D abundance when the isotopic exchange is in equilibrium at the temperature where K in eq. 4 is 0.300. Assume that the natural abundance ratios of D and H are 1.5576×10^{-4} and $1 - 1.5576 \times 10^{-4}$, respectively. 10pt

Let the sum of the concentrations of H_2, HD, and D_2 be C.

Solution 1:

$T \to +\infty\ (K = 1/4)$:
$[H_2]_0 = (1 - 1.5576 \times 10^{-4})^2 C = 9.9969 \times 10^{-1} C$
$[D_2]_0 = (1.5576 \times 10^{-4})^2 C = 2.4261 \times 10^{-8} C$

$K = 0.300$:
Let the amount of change in the molar ratio be x.

$$\frac{[H_2][D_2]}{[HD]^2} = \frac{\left(\frac{[H_2]_0}{C} + x\right)\left(\frac{[D_2]_0}{C} + x\right)}{\left(\frac{[HD]_0}{C} - 2x\right)^2} = K$$

Solve the equation for x when $K = 0.300$:

$$(1 - 4K)x^2 + \left(\frac{[H_2]_0}{C} + \frac{[D_2]_0}{C} + 4K\frac{[HD]_0}{C}\right)x + \left(\frac{[H_2]_0[D_2]_0}{C^2} - K\frac{[HD]_0^2}{C^2}\right) = 0,$$

$x = 4.8504 \times 10^{-9}$.
From this value, we obtain $[H_2] = 9.9969 \times 10^{-1} C$ and $[D_2] = 2.9112 \times 10^{-8} C$.

$$\Delta_{D_2} = \frac{R_{D_2}}{R^*_{D_2}} - 1 = \frac{\frac{2.9112 \times 10^{-8}}{9.9969 \times 10^{-1}}}{\frac{2.4261 \times 10^{-8}}{9.9969 \times 10^{-1}}} - 1 = 0.200$$

Solution 2:

By using an appropriate approximation, we can obtain the answer without calculating the concentration of each species.
Let the increase of $[D_2]$ be δ.

$$K = \frac{[H_2][D_2]}{[HD]^2} = \frac{([H_2]_0 + \delta)([D_2]_0 + \delta)}{([HD]_0 - 2\delta)^2} \simeq \frac{[H_2]_0([D_2]_0 + \delta)}{[HD]_0^2} = \frac{[H_2]_0[D_2]}{[HD]_0^2}$$

$$\Delta_{D_2} = \frac{R_{D_2}}{R^*_{D_2}} - 1 = \frac{\frac{[D_2]}{[H_2]}}{\frac{[D_2]_0}{[H_2]_0}} - 1 \simeq \frac{[D_2]}{[D_2]_0} - 1 = \frac{\frac{[H_2]_0[D_2]}{[HD]_0^2}}{\frac{[H_2]_0[D_2]_0}{[HD]_0^2}} - 1 \simeq \frac{0.300}{0.250} - 1 = 0.200$$

10 points in total:
1 point for the correct $[H_2]_0$,
1 point for the correct $[D_2]_0$,
2 points for the correct formulation for either $[H_2]$ or $[D_2]$,
2 points for the correct $[H_2]$,
2 points for the correct $[D_2]$,
and 2 points for the correct Δ_{D_2}.
Full marks when the correct Δ_{D_2} is shown using an appropriate approximation (without calculating each concentration).
Partial points: 5 points for showing that $[H_2]_0 \simeq [H_2]$.
No deficiency point when the sum of the concentration, C, is assumed to be 1.

In general, the molar ratio of the doubly substituted isotopologue, which contains two heavy isotope atoms in one molecule, increases with decreasing temperature. Let us consider the molar ratio of CO_2 molecules with molecular weights of 44 and 47, which are described as $CO_2[44]$ and $CO_2[47]$ below. The quantity Δ_{47} is defined as:

$$\Delta_{47} = \frac{R_{47}}{R^*_{47}} - 1 \tag{10}$$

R_{47} refers to $\frac{[CO_2[47]]}{[CO_2[44]]}$ in the sample and R^*_{47} to $\frac{[CO_2[47]]}{[CO_2[44]]}$ at $T \to +\infty$. The natural abundances of carbon and oxygen atoms are shown below; ignore isotopes that are not shown here.

	^{12}C	^{13}C
natural abundance	0.988888	0.011112

	^{16}O	^{17}O	^{18}O
natural abundance	0.997621	0.0003790	0.0020000

The temperature dependence of Δ_{47} is determined as follows, where T is given as the absolute temperature in units of K:

$$\Delta_{47} = \frac{36.2}{T^2} + 2.920 \times 10^{-4} \tag{11}$$

A.4 The R_{47} of fossil plankton obtained from the Antarctic seabed was 4.50865×10^{-5}. **Estimate** the temperature using this R_{47}. This temperature is interpreted as the air temperature during the era in which the plankton lived. Consider only the most common isotopologue of $CO_2[47]$ for the calculation. 9pt

The most common isotopologue of $CO_2[47]$ is $^{13}C^{16}O^{18}O$.
The molar ratio of $^{13}C^{16}O^{18}O$ in the case where all the isotopes are distributed randomly is:
$0.011112 \times 0.002000 \times 0.997621 \times 2$ [O is distinguishable] $= 4.43423 \times 10^{-5}$
The molar ratio of $^{12}C^{16}O_2$ ($CO_2[44]$) in the case where all the isotopes are distributed randomly is:
$0.988888 \times 0.997621^2 = 9.84188 \times 10^{-1}$
$$R^*_{47} = \frac{4.43423 \times 10^{-5}}{9.84188 \times 10^{-1}} = 4.50547 \times 10^{-5}$$
$\Delta_{47} = 7.06 \times 10^{-4}$
$T = 296$ K.

9 points in total:
2 points by indicating that the most common isotopologue of $CO_2[47]$ is $^{13}C^{16}O^{18}O$.
3 points for the correct molar ratio of $^{13}C^{16}O^{18}O$ (1 point when $\times 2$ is missing),
2 points for the correct molar ratio of $^{12}C^{16}O_2$,
2 points for the correct T.
(1 deficiency point when the calculated T is a negative value.)

Lambert–Beer Law?

8 % of the total				
Question	A.1	B.1	B.2	**Total**
Points	10	6	6	**22**
Score				

In this problem, ignore the absorption of the cell and the solvent. The temperatures of all solutions and gases are kept constant at 25 °C.

Part A

An aqueous solution **X** was prepared using HA and NaA. The concentrations $[\mathrm{A^-}]$, $[\mathrm{HA}]$, and $[\mathrm{H^+}]$ in solution **X** are 1.00×10^{-2} mol L^{-1}, 1.00×10^{-3} mol L^{-1}, and 1.00×10^{-4} mol L^{-1}, respectively, which are correlated via the following acid-base equilibrium:

$$\mathrm{HA} \rightleftharpoons \mathrm{A^-} + \mathrm{H^+} \qquad\qquad K = \frac{[\mathrm{A^-}][\mathrm{H^+}]}{[\mathrm{HA}]} \tag{1}$$

The optical path length is l in Part A. Ignore the density change upon dilution. Assume that no chemical reactions other than eq 1 occur.

A.1 The absorbance of **X** was A_1 at a wavelength of λ_1. Then, solution **X** was diluted to twice its initial volume using hydrochloric acid with pH = 2.500. After the dilution, the absorbance was still A_1 at λ_1. **Determine** the ratio $\varepsilon_{\text{HA}}/\varepsilon_{\text{A}^-}$, where ε_{HA} and ε_{A^-} represent the absorption coefficients of HA and of A⁻, respectively, at λ_1. 10pt

$$K = \frac{[\text{A}^-][\text{H}^+]}{[\text{HA}]} = \frac{(1.00 \times 10^{-2})(1.00 \times 10^{-4})}{1.00 \times 10^{-3}} = 1.00 \times 10^{-3} \text{ mol L}^{-1}$$

Concentration before the dilution:
$[\text{HA}] = 1.00 \times 10^{-3}$ mol L^{-1}
$[\text{A}^-] = 1.00 \times 10^{-2}$ mol L^{-1}
$[\text{H}^+] = 1.00 \times 10^{-4}$ mol L^{-1}

Concentrations just after the dilution (nominal initial concentrations before the equilibrium):
$[\text{HA}] = 5.00 \times 10^{-4}$ mol L^{-1}
$[\text{A}^-] = 5.00 \times 10^{-3}$ mol L^{-1}
$$[\text{H}^+] = \frac{1.00 \times 10^{-4} + 3.16 \times 10^{-3}}{2} = 1.63 \times 10^{-3} \text{ mol L}^{-1}$$
(pH = 2.500 → $[\text{H}^+] = 3.16 \times 10^{-3}$ mol L^{-1})

Equilibrium after the dilution:
$$\frac{[\text{A}^-][\text{H}^+]}{[\text{HA}]} = \frac{(5.00 \times 10^{-3} - x)(1.63 \times 10^{-3} - x)}{5.00 \times 10^{-4} + x} = 1.00 \times 10^{-3} \text{ mol L}^{-1}$$
Solve the equation for x: $x = 1.19 \times 10^{-3}$ mol L^{-1}
$\rightarrow [\text{A}^-] = 3.81 \times 10^{-3}$ mol L^{-1}, $[\text{HA}] = 1.69 \times 10^{-3}$ mol L^{-1}.
Therefore,
$1.00 \times 10^{-2}\varepsilon_{\text{A}^-} + 1.00 \times 10^{-3}\varepsilon_{\text{HA}} = 3.81 \times 10^{-3}\varepsilon_{\text{A}^-} + 1.69 \times 10^{-3}\varepsilon_{\text{HA}}$
By solving this equation: $\underline{\varepsilon_{\text{HA}}/\varepsilon_{\text{A}^-} = 9.0}$

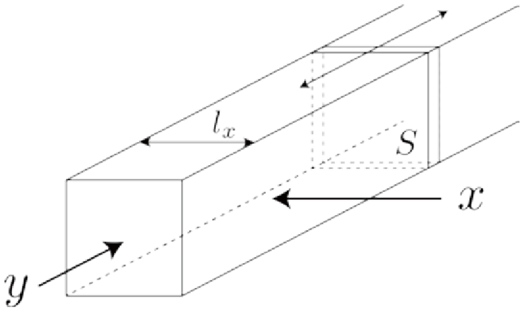
10 points in total:
2 points for the correct K value,
2 points for the formulation to give the correct $[\text{A}^-]$ and $[\text{HA}]$ values after dilution,
2 points for the correct $[\text{A}^-]$ and $[\text{HA}]$ values after dilution (1 point for each),
2 points for the formulation to give the correct relationship between ε_{A^-} and ε_{HA} using $[\text{A}^-]$ and $[\text{HA}]$,
and 2 points for the correct relationship between ε_{A^-} and ε_{HA}.

Part B

Let us consider the following equilibrium in the gas phase.

$$\mathrm{D} \rightleftharpoons 2\mathrm{M} \tag{2}$$

Pure gas D is filled into a cuboid container that has a transparent movable wall with a cross-section of S (see the figure below) at a pressure P, and equilibrium is established while the total pressure is kept at P. The absorbance of the gas is $A = \varepsilon(n/V)l$, where ε, n, V, and l are the absorption coefficient, amount of the gas in moles, volume of the gas, and optical path length, respectively. Assume that all components of the gas mixture behave as ideal gases.



Use the following definitions if necessary.

	Initial state		After equilibrium	
	D	M	D	M
Partial pressure	P	0	p_D	p_M
Amount in moles	n_0	0	n_D	n_M
Volume	V_0		V	

B.1	The absorbance of the gas at λ_{B1} measured from direction x ($l = l_x$) was A_{B1} both at the initial state and after the equilibrium. **Determine** the ratio $\varepsilon_{\mathrm{D}}/\varepsilon_{\mathrm{M}}$ at λ_{B1}, where ε_{D} and ε_{M} represent the absorption coefficients of D and of M, respectively.	6pt

Solution 1:
The absorbance at the initial state is:
$$A_{\mathrm{B1}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_x$$
The absorbance after equilibrium is:
$$A_{\mathrm{B1}} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_x$$

From the ideal gas law, the following relationship is obtained:
$$\frac{n_0}{V_0} = \frac{P}{RT} = \frac{n_{\mathrm{D}} + n_{\mathrm{M}}}{V} \text{ (*1)}$$
From these equations, the following relationship is obtained:
$$A_{\mathrm{B1}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_x = \frac{\varepsilon_{\mathrm{D}}(n_{\mathrm{D}} + n_{\mathrm{M}})}{V} l_x = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_x$$
$$\rightarrow \varepsilon_{\mathrm{D}} n_{\mathrm{M}} = \varepsilon_{\mathrm{M}} n_{\mathrm{M}}$$
$$\rightarrow 0 = (\varepsilon_{\mathrm{M}} - \varepsilon_{\mathrm{D}}) n_{\mathrm{M}}$$
As $n_{\mathrm{M}} > 0$ after the equilibrium, $\underline{\varepsilon_{\mathrm{D}} = \varepsilon_{\mathrm{M}}}$ holds at λ_{B1}.

Solution 2:
Using the ideal gas law, the absorbance at the initial state is expressed as:
$$A_{\mathrm{B1}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_x = \varepsilon_{\mathrm{D}} \frac{P}{RT} l_x \text{ (*2)}$$
The absorbance after equilibrium is:
$$A_{\mathrm{B1}} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_x = \frac{\varepsilon_{\mathrm{D}} p_{\mathrm{D}} + \varepsilon_{\mathrm{M}} p_{\mathrm{M}}}{RT} l_x \text{ (*3)}$$

From these equations, the following relationship is obtained:
$$A_{\mathrm{B1}} = \varepsilon_{\mathrm{D}} \frac{P}{RT} l_x = \frac{\varepsilon_{\mathrm{D}} p_{\mathrm{D}} + \varepsilon_{\mathrm{M}} p_{\mathrm{M}}}{RT} l_x$$

Using the fact that $p_{\mathrm{D}} = P - p_{\mathrm{M}}$,
$$\varepsilon_{\mathrm{D}} P = \varepsilon_{\mathrm{D}}(P - p_{\mathrm{M}}) + \varepsilon_{\mathrm{M}} p_{\mathrm{M}} = \varepsilon_{\mathrm{D}} P + (\varepsilon_{\mathrm{M}} - \varepsilon_{\mathrm{D}}) p_{\mathrm{M}}$$
$$\rightarrow 0 = (\varepsilon_{\mathrm{M}} - \varepsilon_{\mathrm{D}}) p_{\mathrm{M}}$$
As $p_{\mathrm{M}} > 0$ after the equilibrium, $\underline{\varepsilon_{\mathrm{D}}/\varepsilon_{\mathrm{M}} = 1}$ holds at λ_{B1}.

6 points in total:
3 points for showing conversion using ideal gas law (either eq. *1, *2, or *3).
Full marks when the correct relationship between ε_{D} and ε_{M} is shown even without any derivation written.

B.2 The absorbance of the gas at λ_{B2} measured from direction y was A_{B2} both at the initial state ($l = l_{y0}$) and after the equilibrium ($l = l_y$). **Determine** the ratio $\varepsilon_{\mathrm{D}}/\varepsilon_{\mathrm{M}}$ at λ_{B2}. 6pt

Solution 1:

The absorbance at the initial state is:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_{y0}$$

The absorbance after equilibrium is:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_y$$

Using the fact that:

$$l_y = l_{y0}\frac{V}{V_0}$$

The absorbance after equilibrium is expressed as follows:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_y = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V_0} l_{y0}$$

From these equations, the following relationship is obtained:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_{y0} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V_0} l_{y0}$$

Using the fact that:

$n_{\mathrm{M}} = 2(n_0 - n_{\mathrm{D}})$ (*4)

The following relationship is obtained:

$$\varepsilon_{\mathrm{D}} n_0 = \varepsilon_{\mathrm{D}} n_{\mathrm{D}} + 2\varepsilon_{\mathrm{M}}(n_0 - n_{\mathrm{D}}) = 2\varepsilon_{\mathrm{M}} n_0 + (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_{\mathrm{D}}$$

$$\rightarrow (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_0 = (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_{\mathrm{D}}$$

As $n_0 > n_{\mathrm{D}}$ after the equilibrium, $\underline{\varepsilon_{\mathrm{D}} = 2\varepsilon_{\mathrm{M}}}$ holds at λ_{B2}.

Solution 2:

Using the fact that $V_0 = l_{y0} S$, the absorbance at the initial state is expressed as:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_0}{V_0} l_{y0} = \varepsilon_{\mathrm{D}} \frac{n_0}{S}$$

Using the fact that $V = l_y S$, the absorbance after equilibrium is expressed as:

$$A_{\mathrm{B2}} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{V} l_y = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{S}$$

From these equations, the following relationship is obtained:

$$A_{\mathrm{B2}} = \varepsilon_{\mathrm{D}} \frac{n_0}{S} = \frac{\varepsilon_{\mathrm{D}} n_{\mathrm{D}} + \varepsilon_{\mathrm{M}} n_{\mathrm{M}}}{S}$$

Using the fact that:

$n_{\mathrm{M}} = 2(n_0 - n_{\mathrm{D}})$ (*4)

The following relationship is obtained:

$$\varepsilon_{\mathrm{D}} n_0 = \varepsilon_{\mathrm{D}} n_{\mathrm{D}} + 2\varepsilon_{\mathrm{M}}(n_0 - n_{\mathrm{D}}) = 2\varepsilon_{\mathrm{M}} n_0 + (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_{\mathrm{D}}$$

$$\rightarrow (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_0 = (\varepsilon_{\mathrm{D}} - 2\varepsilon_{\mathrm{M}}) n_{\mathrm{D}}$$

As $n_0 > n_{\mathrm{D}}$ after the equilibrium, $\underline{\varepsilon_{\mathrm{D}}/\varepsilon_{\mathrm{M}} = 2}$ holds at λ_{B2}.

6 points in total:

3 points for showing the relationship that n_{M} is twice of $n_0 - n_{\mathrm{D}}$ as in eq.*4.

Full marks when the correct relationship between ε_{D} and ε_{M} is shown even without any derivation written.

The Redox Chemistry of Zinc

11 % of the total							
Question	A.1	A.2	B.1	B.2	B.3	B.4	**Total**
Points	6	5	4	3	5	9	**32**
Score							

Zinc has long been used as alloys for brass and steel materials. The zinc contained in industrial wastewater is separated by precipitation to detoxify the water, and the obtained precipitate is reduced to recover and reuse it as metallic zinc.

Part A

The dissolution equilibrium of zinc hydroxide $Zn(OH)_2(s)$ at 25 °C and the relevant equilibrium constants are given in eq. 1–4.

$$Zn(OH)_2(s) \rightleftharpoons Zn^{2+}(aq) + 2OH^-(aq) \qquad K_{sp} = 1.74 \times 10^{-17} \tag{1}$$

$$Zn(OH)_2(s) \rightleftharpoons Zn(OH)_2(aq) \qquad K_1 = 2.62 \times 10^{-6} \tag{2}$$

$$Zn(OH)_2(s) + 2OH^-(aq) \rightleftharpoons Zn(OH)_4^{2-}(aq) \qquad K_2 = 6.47 \times 10^{-2} \tag{3}$$

$$H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) \qquad K_w = 1.00 \times 10^{-14} \tag{4}$$

The solubility, S, of zinc (concentration of zinc in a saturated aqueous solution) is given in eq. 5.

$$S = [\mathrm{Zn^{2+}(aq)}] + [\mathrm{Zn(OH)_2(aq)}] + [\mathrm{Zn(OH)_4^{2-}(aq)}] \tag{5}$$

A.1 When the equilibria in eq. 1–4 are established, **calculate** the pH range in which $[\mathrm{Zn(OH)_2(aq)}]$ is the greatest among $[\mathrm{Zn^{2+}(aq)}]$, $[\mathrm{Zn(OH)_2(aq)}]$ and $[\mathrm{Zn(OH)_4^{2-}(aq)}]$. 6pt

Solution 1:
From $[\mathrm{Zn(OH)_2(aq)}] > [\mathrm{Zn^{2+}}]$:
$\frac{K_{\mathrm{sp}}}{[\mathrm{OH^-}]^2} < K_1$ (1')
Solve this for $[\mathrm{OH^-}]$:
$\mathrm{pH} > 8.4$
$[\mathrm{Zn(OH)_2(aq)}] > [\mathrm{Zn(OH)_4^{2-}}]$:
$K_1 > K_2[\mathrm{OH^-}]^2$ (2')
Solve this for $[\mathrm{OH^-}]$:
$\mathrm{pH} < 11.8$
Thus,
$\underline{8.4 < \mathrm{pH} < 11.8}$

Solution 2:
From (1):
$\log[\mathrm{Zn^{2+}}][\mathrm{OH^-}]^2 = \log\ \mathrm{K_{sp}}$
$\log[\mathrm{Zn^{2+}}] = \log \mathrm{K_{sp}} - 2\log[\mathrm{OH^-}]$
From (2'):
$\log[\mathrm{Zn(OH)_2(aq)}] = \log \mathrm{K_1}$
$[\mathrm{Zn(OH)_2(aq)}] > [\mathrm{Zn^{2+}}]$:
$\log \mathrm{K_{sp}} - 2\log[\mathrm{OH^-}] < \log \mathrm{K_1}$ (1')
$\log \mathrm{K_{sp}} - 2\,(\mathrm{pH} - 14) < \log \mathrm{K_1}$
From (3'):
$\log([\mathrm{Zn(OH)_4^{2-}}]/[\mathrm{OH^-}]^2) = \log\ \mathrm{K_2}$
$\log[\mathrm{Zn(OH)_4^{2-}}] = 2\log[\mathrm{OH^-}] + \log\ \mathrm{K_2}$
$[\mathrm{Zn(OH)_2(aq)}] > [\mathrm{Zn(OH)_4^{2-}}]$:
$\log \mathrm{K_1} > 2\log[\mathrm{OH^-}] + \log \mathrm{K_2}$ (2')
$\log \mathrm{K_1} > 2\,(\mathrm{pH} - 14) + \log \mathrm{K_2}$
Thus,
$\underline{8.4 < \mathrm{pH} < 11.8}$

6 points in total:
3 points for $8.4 < \mathrm{pH}$
3 points for $\mathrm{pH} < 11.8$.
Partial point:
If correct answers are not obtained;
(1') and (2'): 2 points each.

A.2 A saturated aqueous solution of $\mathrm{Zn(OH)_2(s)}$ with pH = 7.00 was prepared and filtered. NaOH was added to this filtrate to increase its pH to 12.00. **Calculate** the molar percentage of zinc that precipitates when increasing the pH from 7.00 to 12.00. Ignore the volume and temperature changes. 5pt

For pH=12.00:
$\log[\mathrm{Zn(OH)_4^{2-}}] = -29.19 + 2\,\mathrm{pH} = -5.19$
$\log[\mathrm{Zn(OH)_2(aq)}] = -5.58$
$\log[\mathrm{Zn^{2+}}] = 11.24 - 2\,\mathrm{pH} = -12.76$
Thus, $S = 9.0865 \times 10^{-6}\ \mathrm{mol\,L^{-1}}$ (1')
For pH=7.00:
$\log[\mathrm{Zn(OH)_4^{2-}}] = -29.19 + 2\,\mathrm{pH} = -15.19$
$\log[\mathrm{Zn(OH)_2(aq)}] = -5.58$
$\log[\mathrm{Zn^{2+}}] = 11.24 - 2\,\mathrm{pH} = -2.76$
Thus,
$S = 1.7404 \times 10^{-3}\ \mathrm{mol\,L^{-1}}$ (2')
The percentage of zinc precipitated is:

$$\frac{1.7404 \times 10^{-3} - 9.0865 \times 10^{-6}}{1.7404 \times 10^{-3}} = 0.9948 = 99.5\%$$

5 points in total:
2 points for the correct value of (1').
2 points for the correct value of (2').
1 point for the final correct answer. The calculation for the negligible component is not required.

Part B

Next, the recovered zinc hydroxide is heated to obtain zinc oxide according to the reaction below:

$$\mathrm{Zn(OH)_2(s) \rightarrow ZnO(s) + H_2O(l)} \qquad (6)$$

The zinc oxide is then reduced to metallic zinc by reaction with hydrogen:

$$\mathrm{ZnO(s) + H_2(g) \rightarrow Zn(s) + H_2O(g)} \qquad (7)$$

B.1 In order for reaction (7) to proceed at a hydrogen pressure kept at 1 bar, it is necessary to reduce the partial pressure of the generated water vapor. **Calculate** the upper limit for the partial pressure of water vapor to allow reaction (7) to proceed at 300 °C. Here, the Gibbs formation energies of zinc oxide and water vapor at 300 °C and 1 bar for all gaseous species are $\Delta G_{\mathrm{ZnO}}(300^\circ\mathrm{C}) = -2.90 \times 10^2\ \mathrm{kJ\,mol^{-1}}$ and $\Delta G_{\mathrm{H_2O}}(300^\circ\mathrm{C}) = -2.20 \times 10^2\ \mathrm{kJ\,mol^{-1}}$, respectively. 4pt

$Zn + \frac{1}{2}O_2 \rightarrow ZnO,\ \Delta G_{\mathrm{ZnO}}(300^\circ\mathrm{C}) = -2.90 \times 10^2\ \mathrm{kJ\,mol^{-1}}$
$H_2 + \frac{1}{2}O_2 \rightarrow H_2O,\ \Delta G_{\mathrm{H_2O}}(300^\circ\mathrm{C}) = -2.20 \times 10^2\ \mathrm{kJ\,mol^{-1}}$
Thus,
$ZnO + H_2 \rightarrow Zn + H_2O,\ \Delta G = \Delta G_{\mathrm{H_2O}}(300^\circ\mathrm{C}) - \Delta G_{\mathrm{ZnO}}(300^\circ\mathrm{C})$ (1')
$= 7.0 \times 10^1\ \mathrm{kJ\,mol^{-1}}$
$\ln K = \ln\frac{p_{\mathrm{H_2O}}}{p_{\mathrm{H_2}}} = -\frac{\Delta G}{RT}$ (2')
From $T = 573.15\ \mathrm{K}$,
$\underline{p_{\mathrm{H_2O}} = 4.14 \times 10^{-7}\ \mathrm{bar} = 4.1 \times 10^{-7}\ \mathrm{bar}}$

4 points in total:
1 point for the correct formulation of (1').
2 point for the correct formulation of (2').
1 point for the correct final answer.

Metallic zinc is used as a negative electrode (anode) material for metal-air batteries. The electrode consists of Zn and ZnO. It uses the following redox reaction to generate electricity with the electromotive force (e.m.f.) at 25 °C and pressure of 1 bar, E°.

$$Zn(s) + \frac{1}{2}O_2(g) \rightarrow ZnO(s) \qquad E^\circ = 1.65\ \mathrm{V} \tag{8}$$

B.2	A zinc–air battery was discharged at 20 mA for 24 hours. **Calculate** the change in mass of the negative electrode (anode) of the battery.	3pt

The reaction Zn → ZnO occurs at the negative electrode and consumes 2 mol electrons per mol Zn oxidized.
Thus, the weight change is:
$W = \frac{0.02 \times 24 \times 60 \times 60 \times 16}{2F}$ (1')
$\underline{= 0.14\ \mathrm{g}}$

3 points in total;
2 points for the correct formulation (1').
1 point for the correct final answer.

Mt. Fuji

B.3 Consider the change of e.m.f. of a zinc–air battery depending on the environment. **Calculate** the e.m.f. at the summit of Mt. Fuji, where the temperature and altitude are $-38\,^\circ$C (February) and 3776 m, respectively. The atmospheric pressure is represented by 5pt

$$P\,[\text{bar}] = 1.013 \times \left(1 - \frac{0.0065h}{T + 0.0065h + 273.15}\right)^{5.257} \qquad (9)$$

at altitude $h\,[\text{m}]$ and temperature $T\,[^\circ\text{C}]$. The molar ratio of oxygen in the atmosphere is 21%. The Gibbs energy change of reaction (8) is $\Delta G_{\text{ZnO}}(-38^\circ\text{C}) = -3.26 \times 10^2$ kJ mol^{-1} at $-38\,^\circ$C and 1 bar.

Solution 1:
From (9), the air pressure at 3776 m and $T = -38\,^\circ\text{C}$ is
$P = 0.6011$ bar (1')
From the oxygen content of 21% , the partial pressure of oxygen is:
$P_{\text{O}_2} = 0.126$ bar
From the Nernst equation ($T = -38\,^\circ\text{C}$) :
$E(-38\,^\circ\text{C}) - E^\circ(-38\,^\circ\text{C}) = -\frac{RT}{2F}\ln\frac{1}{\sqrt{P_{\text{O}_2}}} = -0.01048\,\text{V} = -0.01\,\text{V}$ (2')
$E^\circ(-38\,^\circ\text{C}) = -\frac{\Delta G^\circ(-38\,^\circ\text{C})}{2F} = \frac{326000}{2F} = 1.6894\,\text{V} = 1.69\,\text{V}$ (3')
From (2') and (3'):
$\underline{E(-38\,^\circ\text{C}) = 1.68\,\text{V}}$

Solution 2:
From (9), the air pressure at 3776 m and $T = -38\,^\circ\text{C}$ is
$P = 0.6011$ bar (1')
From the oxygen content of 21% , the partial pressure of oxygen is:
$P_{\text{O}_2} = 0.126$ bar
$\Delta G(-38\,^\circ\text{C}) = \Delta G^\circ(-38\,^\circ\text{C}) - \frac{1}{2}RT\ln P_{\text{O}_2}$ (2')
$= -3.24 \times 10^2\,\text{kJ mol}^{-1}$
$E(-38\,^\circ\text{C}) = -\frac{\Delta G(-38\,^\circ\text{C})}{2F}$ (3')
$\underline{= 1.68\,\text{V}}$

($^\circ$ is used for 1 bar)

5 points in total:
1 point for the correct value of (1').
2 points for the correct formulation of (2').
1 point for the correct formulation of (3')
1 point for the correct final answer.

B.4 **Calculate** the Gibbs energy change for reaction (6) at $25\,^\circ\text{C}$. Note that the standard reduction potentials, $E^\circ(\text{Zn}^{2+}/\text{Zn})$ and $E^\circ(\text{O}_2/\text{H}_2\text{O})$ at $25\,^\circ\text{C}$ and 1 bar are given as (10) and (11), respectively. 9pt

$$\text{Zn}^{2+} + 2\text{e}^- \rightarrow \text{Zn} \qquad E^\circ(\text{Zn}^{2+}/\text{Zn}) = -0.77\,\text{V} \qquad (10)$$

$$\text{O}_2 + 4\text{H}^+ + 4\text{e}^- \rightarrow 2\text{H}_2\text{O} \qquad E^\circ(\text{O}_2/\text{H}_2\text{O}) = 1.23\,\text{V} \qquad (11)$$

From (10):
$\mathrm{Zn}^{2+} + 2\mathrm{e}^- \rightarrow \mathrm{Zn}, E^\circ = -0.77\,\mathrm{V}$
$\Delta G^\circ = -2F \times -0.77$ (1')
$= 148.59\,\mathrm{kJ\,mol^{-1}}$
From (8):
$\mathrm{Zn} + \frac{1}{2}\mathrm{O}_2 \rightarrow \mathrm{ZnO}, E^\circ = 1.65\,\mathrm{V}$
$\Delta G^\circ = -2F \times 1.65$ (2')
$= -318.40\,\mathrm{kJ\,mol^{-1}}$
From (11):
$\mathrm{O}_2 + 4\mathrm{H}^+ + 4\mathrm{e}^- \rightarrow 2\mathrm{H}_2\mathrm{O}, E^\circ = 1.23\,\mathrm{V}$
$\Delta G^\circ = -4F \times 1.23$ (3')
$= -474.71\,\mathrm{kJ\,mol^{-1}}$
From (1):
$\mathrm{Zn}^{2+} + 2\mathrm{OH}^- \rightarrow \mathrm{Zn(OH)_2(s)}, K_{\mathrm{sp}} = 1.74 \times 10^{-17}$
$\Delta G^\circ = -RT\,\ln K_{\mathrm{sp}}^{-1}$ (4')
$= -95.662\,\mathrm{kJ\,mol^{-1}}$
From (4):
$\mathrm{H}^+ + \mathrm{OH}^- \rightarrow \mathrm{H}_2\mathrm{O}, K_{\mathrm{w}} = 1 \times 10^{-14}$
$\Delta G^\circ = -RT\,\ln K_{\mathrm{w}}^{-1}$ (5')
$= -79.912\,\mathrm{kJ\,mol^{-1}}$
From $\frac{(1')\times2+(2')\times2-(3')-(4')\times2+(5')\times4}{2}$
$\mathrm{Zn(OH)_2} \rightarrow \mathrm{ZnO} + \mathrm{H}_2\mathrm{O}, \Delta G^\circ = 3.0 \sim 3.4 \times 10^3\,\mathrm{J\,mol^{-1}}$
(distributed depending on the handling of figures)

9 points in total:
1 points for correct formulation (1').
1 points for correct formulation (2').
1 points for correct formulation (3').
2 points for correct formulation (4').
2 points for correct formulation (5').
2 point for the correct final answer.

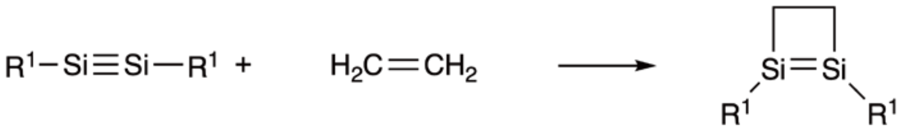
Mysterious Silicon

12 % of the total								
Question	A.1	A.2	A.3	A.4	B.1	B.2	B.3	**Total**
Points	9	7	6	10	5	15	8	**60**
Score								

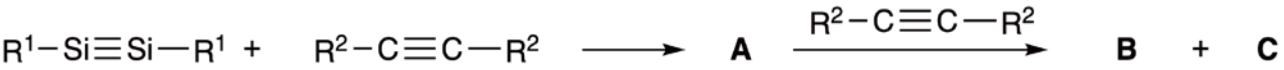
Although silicon is also a group 14 element like carbon, their properties differ significantly.

Part A

Unlike the carbon–carbon triple bond, the silicon–silicon triple bond in a compound formulated as $R^1–Si\equiv Si–R^1$ (R: organic substituent) is extremely reactive. For example, it reacts with ethylene to form a cyclic product that contains a four-membered ring.

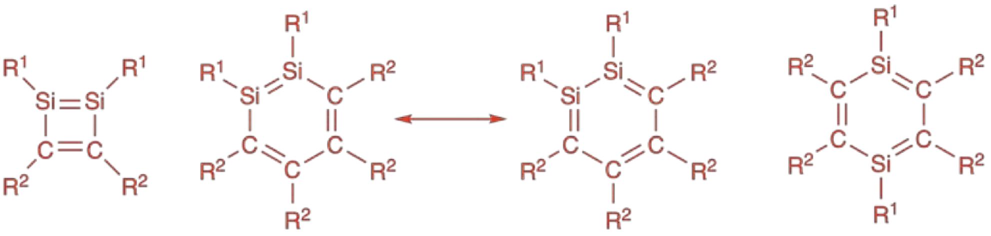


When $R^1–Si\equiv Si–R^1$ is treated with an alkyne ($R^2–C\equiv C–R^2$), the four-membered-ring compound **A** is formed as an initial intermediate. Further reaction of another molecule of $R^2–C\equiv C–R^2$ with **A** affords isomers **B** and **C**, both of which have benzene-like cyclic conjugated structures, so-called ‘disilabenzenes’ that contain a six-membered ring and can be formulated as $(R^1–Si)_2(R^2–C)_4$.



The ^{13}C NMR analysis of the corresponding six-membered ring skeletons Si_2C_4 shows two signals for **B** and one signal for **C**.

A.1	**Draw** the structural formulae of **A**, **B**, and **C** using R^1, R^2, Si, and C, with one of the possible resonance structures.	9pt



A B C

Any resonance structure is acceptable.

9 points in total: 3 points for each correct answer.**A:** 3 points (2 points when the Si=Si–C=C four-membered ring skeleton is drawn correctly.)**B**: 3 points: (2 points when the Si–Si–C–C–C–C six-membered ring skeleton is drawn correctly. 1 point when 1,4- or 1,3-disilabenzene is depicted. 0 points when only the 1,4- or 1,3-disilabenzene is shown and R^1 and R^2 are drawn incorrectly.)**C**: 3 points: (2 points when the Si–C–C–Si–C–C six-membered ring skeleton is drawn correctly. 1 point when 1,2- or 1,3-disilabenzene is depicted. 0 points when only the 1,2- or 1,3-disilabenzene is shown and R^1 and R^2 are drawn incorrectly.)

A.2	**Calculate** the aromatic stabilization energy (ASE) for benzene and **C** (in the case of $R^1 = R^2 = H$) as positive values, considering the enthalpy change in some hydrogenation reactions of unsaturated systems shown below (Fig. 1).	7pt

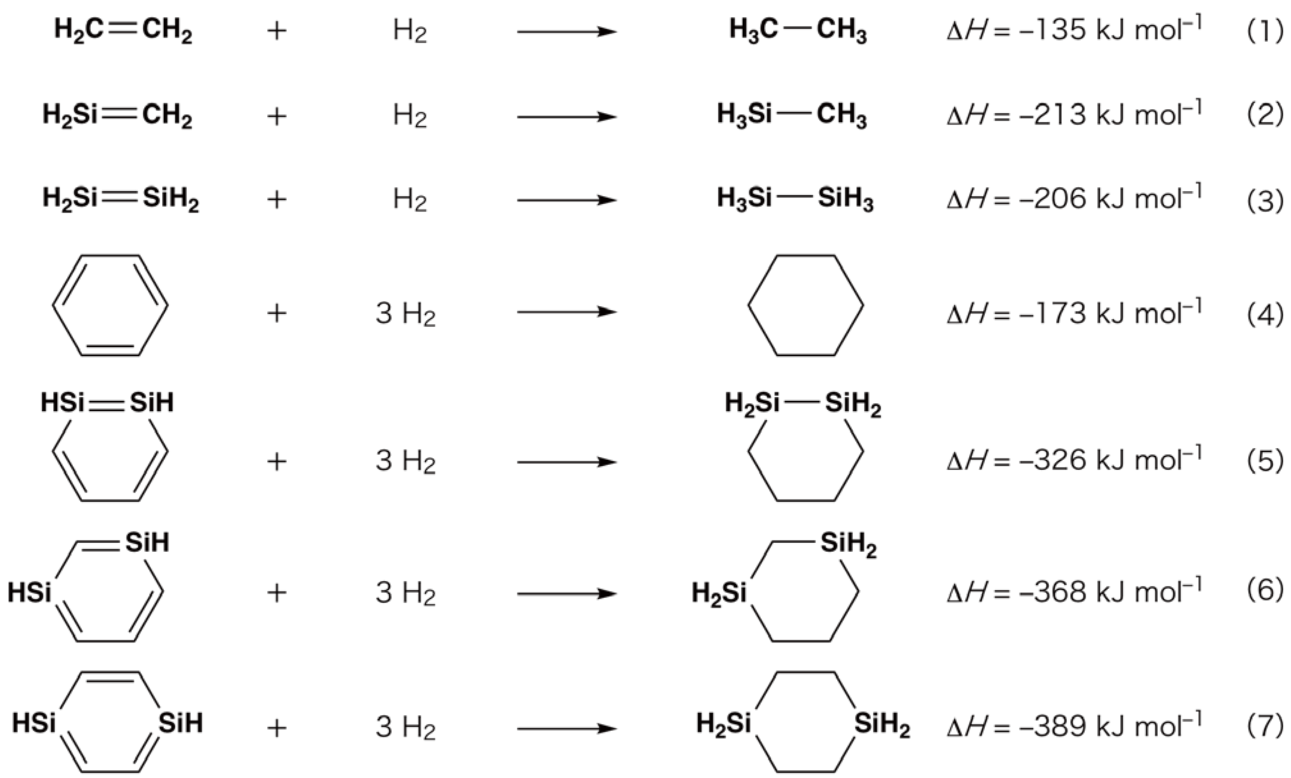


Fig. 1

The aromatic stabilization energy (ASE) can be calculated as the difference of the sum of the heat of hydrogenation of each double bond and the heat of hydrogenation of the aromatic compound.
ASE for benzene: $\underline{135 \times 3 - 173 \ = \ 232\ \mathrm{kJ\,mol^{-1}}}$
ASE for 1,4-disilabenzene (C=C + 2 Si=C): $\underline{(135 + 213 \times 2) - 389 = 172\ \mathrm{kJ\,mol^{-1}}}$

7 points in total: 3 points for ASE for benzene and 4 points for compound **C**.
3 points for the correct ASE value for benzene (2 points when the values have the correct magnitude but are negative.).
4 points for the correct ASE value for compound **C**, 1,4-disilabenzene. (3 points when the values have the correct magnitude but are negative.) (4 points for the ASE value for 1,2-disilabenzene $(206 + 135 \times 2) - 326 = 150\ \mathrm{kJ\,mol^{-1}}$ or $(213 \times 2 + 135) - 326 = 235\ \mathrm{kJ\,mol^{-1}}$ when the 1,2-disilabenzene is written as a structure of **C**. 4 points for the ASE value for 1,3-disilabenzene$(135 + 213 \times 2) - 368 = 193\ \mathrm{kJ\,mol^{-1}}$ when the 1,3-disilabenzene is written as a structure of **C**.)

When a xylene solution of **C** is heated, it undergoes isomerization to give an equilibrium mixture of compounds **D** and **E**. The molar ratio is **D** : **E** = 1 : 40.0 at 50.0 ˚C and **D** : **E** = 1 : 20.0 at 120.0 ˚C.

A.3 **Calculate** ΔH for the transformation of **D** to **E**. Assume that ΔH does not depend on temperature. 6pt

T = 50 ˚C = 323.15 K $\left(\frac{1}{RT} = 0.3722\right)$: $K_{\text{DE}} = 40$

T = 120 ˚C = 393.15 K $\left(\frac{1}{RT} = 0.3095\right)$: $K_{\text{DE}} = 20$

According to ln $K_{\text{DE}} = -\frac{\Delta H}{RT} + \frac{\Delta S}{R}$

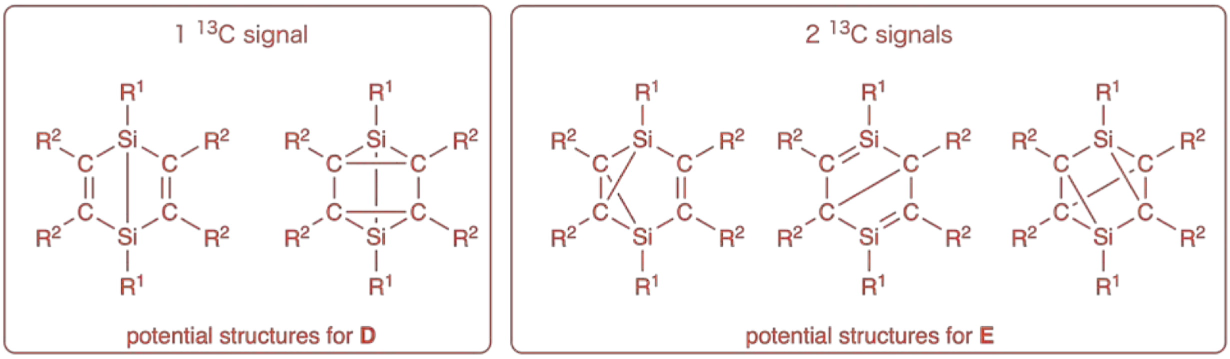
$$\Delta H = -\frac{\ln(K_{\text{DE50}}) - \ln(K_{\text{DE120}})}{\frac{1}{RT_{50}} - \frac{1}{RT_{120}}} = -\frac{\ln 40 - \ln 20}{0.3722 - 0.3059} = -10.5 \text{ kJ mol}^{-1}$$

6 points: (+4 points for the correct equation. -2 points for the positive value.)

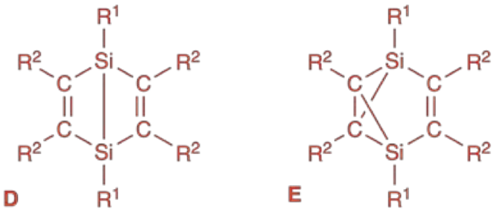
The isomerization from **C** to **D** and to **E** proceeds via transformations of π-bonds into σ-bonds without breaking any σ-bonds. A ^{13}C NMR analysis revealed one signal for the Si_2C_4 skeleton of **D** and two signals for that of **E**. The skeleton of **D** does not contain any three-membered rings, while **E** has two three-membered rings that share an edge.

A.4 **Draw** the structural formulae of **D** and **E** using R^1, R^2, Si, and C. 10pt

Based on the signals observed in the ^{13}C NMR spectra, the following structures could be suggested for **D** and **E**:



In addition, considering that **D** has no three-membered ring in its skeleton while **E** has two three-membered rings that share an edge, the structures of **D** and **E** can be determined to be those shown below:



10 points in total: 5 points for each correct structure.
(4 points for incorrect substituents R^1 or R^2. 3 points for other candidates based on the information from the ^{13}C NMR spectra; 2 points for Si-regioisomers that would satisfy the ^{13}C NMR spectral information; 1 point for Si-regioisomers that would not satisfy the ^{13}C NMR spectral information.)
For **D**: 2 points for other Dewer-benzene structure (because "not contain any three-membered rings"). For **E:** 2 points for other benzvalene structure (because "two three-membered rings that share an edge.").

Part B

Silicon is able to form highly coordinated compounds (> four substituents) with electronegative elements such as fluorine. As metal fluorides are often used as fluorination reagents, highly coordinated silicon fluorides also act as fluorination reagents.

The fluorination reaction of CCl_4 using Na_2SiF_6 was carried out as follows.

- **Standardization of Na_2SiF_6 solution** :

· Preparation

Aqueous solution **F**: 0.855 g of Na_2SiF_6 (188.053 g mol^{-1}) dissolved in water (total volume: 200 mL).

Aqueous solution **G**: 6.86 g of $Ce_2(SO_4)_3$ (568.424 g mol^{-1}) dissolved in water (total volume: 200 mL).

· Procedure

Precipitation titration of a solution **F** (50.0 mL) by dropwise adding solution **G** in the presence of xylenol orange, which coordinates to Ce^{3+}, as an indicator. After adding 18.8 mL of solution **G**, the color of the solution changes from yellow to magenta. The generated precipitate is a binary compound that contains Ce^{3+}, and the only resulting silicon compound is $Si(OH)_4$.

B.1	**Write** the balanced equation for the reaction of Na_2SiF_6 with $Ce_2(SO_4)_3$.	5pt

Na_2SiF_6 = 188.053 g mol^{-1}. The concentration of Na_2SiF_6 in solution **F** is

$$\frac{0.855\ \text{g}}{200\ \text{mL}} = \frac{4.548 \times 10^{-3}\ \text{mol}}{0.2\ \text{L}} = 2.274 \times 10^{-2}\ \text{mol L}^{-1}\ (\mathbf{F})$$

$Ce_2(SO_4)_3$ = 568.424 g mol^{-1}. The concentration of $Ce_2(SO_4)_3$ in solution **G** is

$$\frac{6.860\ \text{g}}{200\ \text{mL}} = \frac{1.207 \times 10^{-2}\ \text{mol}}{0.2\ \text{L}} = 6.034 \times 10^{-2}\ \text{mol L}^{-1}\ (\mathbf{G})$$

The concentration of Ce^{3+} ions in **G** is $6.034 \times 10^{-2} \times 2 = 1.207 \times 10^{-2}$ mol L^{-1}.

In 50.0 mL of solution **F**: $2.274 \times 10^{-2} \times \frac{50.0}{1000} = 1.137 \times 10^{-3}$ mol of Na_2SiF_6 was included.

In 18.8 mL of solution **G**: $6.034 \times 10^{-2} \times \frac{18.8}{1000} = 1.134 \times 10^{-3}$ mol of $Ce_2(SO_4)_3$ was included. Accordingly, Na_2SiF_6 should react with $Ce_2(SO_4)_3$ in a 1:1 ratio.

Ans. $Na_2SiF_6 + Ce_2(SO_4)_3 + 4\,H_2O \longrightarrow 2\,CeF_3 + Si(OH)_4 + Na_2SO_4 + 2\,H_2SO_4$

5 points: (+1 points when "$Na_2SiF_6 + Ce_2(SO_4)_3$" is written on the left side, and +2 points when "CeF_3" is written on the right side of the equation; +1 points when "$Si(OH)_4$" is written on the right side of the equation.) Full mark for showing ionic compounds, which soluble in water as ions/ion pairs such as $NaHSO_4$, Na^+, H^+, and etc. (The calculation procedure is not necessary.)

- **Reaction of CCl_4 with Na_2SiF_6:**

(Substance losses by *e.g.* evaporation are negligible during the following operations.)

Na_2SiF_6(x [g]) was added to CCl_4 (500.0 g) and heated to 300 °C in a sealed pressure-resistant reaction vessel. The unreacted Na_2SiF_6 and generated NaCl were removed by filtration. The filtrate was diluted to a total volume of 1.00 L with CCl_4 (solution **H**). The ^{29}Si and ^{19}F NMR spectra of solution **H** showed SiF_4 as the only silicon compound. In the ^{19}F NMR spectrum, in addition to SiF_4, signals corresponding to $CFCl_3$, CF_2Cl_2, CF_3Cl, and CF_4 were observed (*cf.* Table 1). The integration ratios in the ^{19}F NMR spectrum are proportional to the number of fluorine nuclei.

Table 1

^{19}F NMR data	$CFCl_3$	CF_2Cl_2	CF_3Cl	CF_4
Integration ratio	45.0	65.0	18.0	2.0

SiF_4 is hydrolyzed to form H_2SiF_6 according to the following eq. 8:

$$3SiF_4 + 2H_2O \rightarrow SiO_2 + 2H_2SiF_6 \tag{8}$$

Solution **H** (10 mL) was added to an excess amount of water, which resulted in the complete hydrolysis of SiF_4. After separation, the H_2SiF_6 generated from the hydrolysis in the aqueous solution was neutralized and completely converted to Na_2SiF_6 (aqueous solution **J**).

The precipitate of unreacted Na_2SiF_6 and NaCl, which was removed by filtration in the initial step (underlined), was completely dissolved in water to give an aqueous solution (solution **K**; 10.0 L).

Then, additional precipitation titrations using solution **G** were carried out, and the endpoints of the titrations with **G** were as follows:

·For solution **J** (entire amount): 61.6 mL.

·For 100 mL of solution **K**: 44.4 mL.

It should be noted here that the coexistence of NaCl or SiO_2 has no effect on the precipitation titration.

B.2	**Calculate** the mass of the NaCl produced in the reaction vessel (information underlined), and **calculate** the mass (x [g]) of the Na_2SiF_6 used as a starting material.	15pt

$\underline{3}\,SiF_4 + 2\,H_2O \longrightarrow SiO_2 + \underline{2}\,H_2SiF_6$
The ratio of the consumed SiF_4 and the generated H_2SiF_6 should be 3:2.
As Na_2SiF_6 reacts with $Ce_2(SO_4)_3$ in a 1:1 ratio, the amount of SiF_6^{2-} in the aqueous solution **J** is $(6.034 \times 10^{-2}\ \mathrm{mol\,L^{-1}}) \times (61.6 \times 10^{-3}\ \mathrm{L}) = 3.717 \times 10^{-3}$ mol. Considering the equation shown above, 10 mL of the diluted solution **H** contains $3.717 \times 10^{-3}\ \mathrm{mol} \times \dfrac{3}{2} = 5.576 \times 10^{-3}$ mol of SiF_4. Thus, 1.00 L of diluted solution **H** contains $5.576 \times 10^{-3}\ \mathrm{mol} \times \dfrac{1000}{10} = 5.576 \times 10^{-1}$ mol of SiF_4.
The amount of fluorine atoms that replace the chlorine atoms of CCl_4 should be twice the amount of SiF_4 formed during the reaction. Thus, $2 \times 0.5576 = 1.115$ mol of F^- should replace Cl^- to result in the formation of NaCl. $1.115\ \mathrm{mol} \times 58.44\ \mathrm{g\,mol^{-1}} = 65.17$ g of NaCl was formed.
<u>Ans.: 65.2 g (NaCl)</u>
As Na_2SiF_6 reacts with $Ce_2(SO_4)_3$ in a 1:1 ratio, the amount of SiF_6^{2-} in 100 mL of aqueous solution K is $44.4 \times 10^{-3}\ \mathrm{L} \times (6.034 \times 10^{-2}\ \mathrm{mol\,L^{-1}}) = 2.679 \times 10^{-3}$ mol. Accordingly, the residual amount of Na_2SiF_6 in 10.0 L of aqueous solution **K** is $2.679 \times 10^{-3}\ \mathrm{mol} \times \dfrac{10.0\ \mathrm{L}}{100\ \mathrm{mL}} = 0.2679$ mol. In total, the amount of Na_2SiF_6 used as a starting material is $(0.2679\ \mathrm{mol} + 0.5576\ \mathrm{mol}) \times 188.0\ \mathrm{g\,mol^{-1}} = 155.2$ g
<u>Ans.: 155 g (Na_2SiF_6)</u>

15 points in total:
·10 points for the correct amount of NaCl:
+3 points for the amount of SiF_6^{2-} in solution **J** (3.717×10^{-3}mol)
+2 point for the amount of SiF_4 in 10 mL of the diluted solution **H** (5.576×10^{-3} mol)
+2 point for the amount of SiF_4 in 1.00 L of the solution **H** (5.576×10^{-1} mol)
+2 points for the amount of NaCl in mol (1.115mol)
+1 point when the amount of NaCl is shown in gram.
·5 points for the correct amount of Na_2SiF_6:
+2 points for the amount of SiF_6^{2-} in solution **K** (2.68×10^{-3}mol)
+1 point for the amount of SiF_6^{2-} before dilution to prepare solution **K** (2.68×10^{-1}mol)
+1 point for the addition of the amount of SiF_4 in solution H (8.26×10^{-1}mol)
+1 for answering the initial amount of Na_2SiF_6 in [g].

B.3	77.8% of the CCl_4 used as a starting material was unreacted. **Calculate** the mass of CF_3Cl generated.	8pt

500.0 g = 3.250 mol of CCl_4 was initially used as a starting material. Thus, the amount of the products that contain at least one F atom is 3.250 mol $\times$ 0.222 $=$ 0.721 mol.
The ratio of integrals in the ^{19}F NMR spectrum is $CFCl_3 : CF_2Cl_2 : CF_3Cl : CF_4 = 45.0 : 65.0 : 18.0 : 2.0$. Thus, the mole ratio of these compounds should be $CFCl_3 : CF_2Cl_2 : CF_3Cl : CF_4 = 45.0 : 32.5 : 6.0 : 0.5 = 90 : 65 : 12 : 1$. Accordingly, the amount of CF_3Cl (104.46 g mol^{-1}) is

$$0.721\text{ mol} \times \frac{12}{90+65+12+1} = 0.0515\text{ mol} = 0.0515 \times 104.46\text{ g} = 5.38\text{ g}$$

Ans.: 5.38 g

8 points: (6 points for the answer in [mol]; 4 points for the correct molar ratio of substances $CFCl_3 : CF_2Cl_2 : CF_3Cl : CF_4 = 90 : 65 : 12 : 1$).

The Solid-State Chemistry of Transition Metals

13 % of the total											
Question	A.1	A.2	A.3	B.1	B.2	B.3	B.4	C.1	C.2	C.3	**Total**
Points	6	3	3	6	4	4	4	5	5	5	**45**
Score											

Volcano at Sakurajima island

Part A

Japan is one of the countries with the highest numbers of volcanos worldwide. When silicate minerals crystallize from magma, a part of the transition-metal ions (M^{n+}) in the magma is incorporated into the silicate minerals. The M^{n+} studied in the problem are coordinated by oxide ions (O^{2-}) and adopt a four-coordinate tetrahedral (T_d) geometry in the magma and six-coordinate octahedral (O_h) geometry in the silicate minerals, both of which exhibit a high-spin electron configuration. The distribution coefficient of M^{n+} between the silicate minerals and magma, D, can be expressed by:

$$D = \frac{[\mathrm{M}]_s}{[\mathrm{M}]_l}$$

where $[\mathrm{M}]_s$ and $[\mathrm{M}]_l$ are the concentrations of M^{n+} in the silicate minerals and the magma, respectively. The table below shows the D values of Cr^{2+} and Mn^{2+} as examples.

	Cr^{2+}	Mn^{2+}
D	7.2	1.1

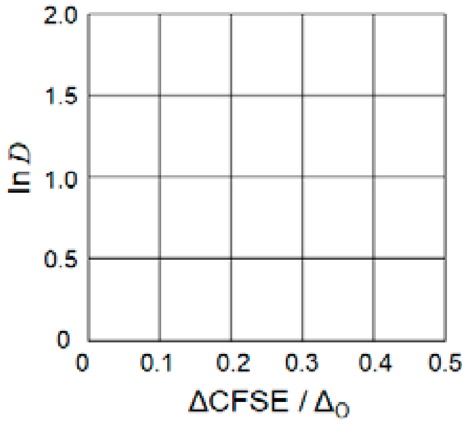
Let Δ_O and CFSE^O be the energy separation of the d-orbitals of M^{n+} and the crystal-field stabilization energy in a O_h field, respectively. Let Δ_T and CFSE^T be those in a T_d field.

A.1 **Calculate** $|\text{CFSE}^O - \text{CFSE}^T| = \Delta\text{CFSE}$ in terms of Δ_O for Cr^{2+}, Mn^{2+}, and Co^{2+}; assume $\Delta_T = 4/9\Delta_O$. 6pt

The d-orbitals of a six-coordinate octahedral complex split into two groups e_g ($d_{x^2-y^2}$, d_{z^2}), and t_{2g} (d_{xy}, d_{yz}, d_{zx}) with an energy separation of Δ_O. The energies of the e_g and t_{2g} orbitals relative to the barycenter are $+0.60\Delta_O$ and $-0.40\Delta_O$, respectively. Likewise, the d-orbitals of a four-coordinate tetrahedral complex split into two groups t_2 (d_{xy}, d_{yz}, d_{zx}) and e ($d_{x^2-y^2}$, d_{z^2}) with an energy separation of Δ_T. The energies of the t_2 and e orbitals relative to the barycenter are $+0.40\Delta_T$ and $-0.60\Delta_T$, respectively. Therefore, in the case of a high-spin electron configuration, CFSE^O and CFSE^T for Cr^{2+} ($3d^4$: ${t_{2g}}^3{e_g}^1$ or $e^2{t_2}^2$) are $-0.60\Delta_O$ and $-0.40\Delta_T$ ($= -0.18\Delta_O$), respectively. CFSE^O and CFSE^T for Mn^{2+} ($3d^5$: ${t_{2g}}^3{e_g}^2$ or $e^2{t_2}^3$) are both zero. CFSE^O and CFSE^T for Co^{2+} ($3d^7$: ${t_{2g}}^4{e_g}^3$ or $e^4{t_2}^3$) are $-0.80\Delta_O$ and $-1.2\Delta_T$ ($= -0.53\Delta_O$), respectively. Accordingly, $|\text{CFSE}^O - \text{CFSE}^T| = \Delta\text{CFSE}$ values for each metal ion are,
Cr^{2+}: $|-0.60\Delta_O - (-0.18\Delta_O)| = \underline{0.42\Delta_O}$, Mn^{2+}: $\underline{0}$, Co^{2+}: $|-0.80\Delta_O - (-0.53\Delta_O)| = \underline{0.27\Delta_O}$

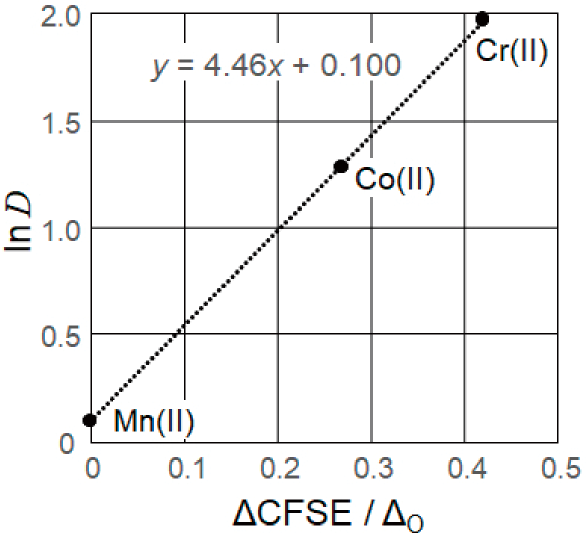
6 points in total: 2 points each for ΔCFSE of the three divalent metal ions.

A.2 A linear relationship is observed by plotting $\ln D$ against $\Delta\text{CFSE} / \Delta_O$ in the Cartesian coordinate system shown below. 3pt
Estimate D for Co^{2+}.



The coordinates of Mn^{2+} and Cr^{2+} are (0, 0.095) and (0.42, 1.97), respectively. The linear regression line calculated from these coordinates would be
$y = 4.46x + 0.100$
ΔCFSE of Co^{2+} is $0.27\Delta_O$
Therefore, $D = \exp(4.46 \times 0.27 + 0.100) = \underline{3.68\ (= 3.7)}$

Whether the graph is drawn does not affect grading.
If the coordinates of Mn^{2+} and Cr^{2+} are correctly plotted and the D is estimated with guide of the graph, full mark is given.



3 points for the calculation of D.
Partial credit of 2 points if the ln$D$ is correctly estimated from the linear regression line or the graph.
If the intercept of the linear regression line is assumed as zero (i.e., Mn^{2+} is at the origin of the coordinate), full mark is given.
In order to avoid double punishment with A.1: If the answers of A.1 were wrong but the coordinates of Mn^{2+} and Cr^{2+} are correctly plotted in the graph (or simultaneous equations are given) according to the answers of A.1, and D of Co^{2+} is correctly estimated from ln$D$ assuming a linear relationship, full mark is given.

Metal oxides MO (M: Ca, Ti, V, Mn, or Co) crystallize in a rock-salt structure wherein the M^{n+} adopts an O_h geometry with a high-spin electron configuration. The lattice enthalpy of these oxides is mainly governed by the Coulomb interactions based on the radius and charge of the ions and some contributions from the CFSE of M^{n+} in the O_h field.

A.3 **Choose** the appropriate set of lattice enthalpies [kJ mol^{-1}] from one of the options (a) to (f). 3pt

	CaO	**TiO**	**VO**	**MnO**	**CoO**
(a)	3460	3878	3913	3810	3916
(b)	3460	3916	3878	3810	3913
(c)	3460	3913	3916	3810	3878
(d)	3810	3878	3913	3460	3916
(e)	3810	3916	3878	3460	3913
(f)	3810	3913	3916	3460	3878

The lattice enthalpy is determined by the Coulomb interactions, which are proportional to the product of the valences of the constituent ions and inversely proportional to the sum of the ionic radii. As the target compounds are oxides of divalent metal ions, we should consider the ionic radii of the metal ions. The radii of divalent metal ions within the same period decrease with increasing atomic number. Let us compare the lattice enthalpies of CaO and MnO with no contribution from the CFSE: The ionic radius of Mn^{2+} is smaller than that of Ca^{2+}, and therefore, the lattice enthalpy is higher for MnO. So, the participants should choose (a), (b), or (c). Then, let us compare the lattice enthalpies of TiO (d^2) and VO (d^3): The ionic radius of V^{2+} is smaller than that of Ti^{2+}, and the CFSE is higher for VO than for TiO. Accordingly, the lattice enthalpy is also higher for VO. Based on these observations, the answer should be (a) or (c). Finally, let us compare the lattice enthalpies of TiO (d^2) and CoO (d^7): The ionic radius of Co^{2+} is smaller than that of Ti^{2+}, while their CFSEs are equal. Thus, the lattice enthalpy is higher for CoO. Thus, the correct answer is (a). Partial credit is given for (b) and (c).

3 points for the correct answer (a). Partial credit of 2 points for (c) and 1 point for (b).

Part B

A mixed oxide **A**, which contains La^{3+} and Cu^{2+}, crystallizes in a tetragonal unit cell shown in Fig.1. In the $[CuO_6]$ octahedron, the Cu–O length along the *z*-axis (l_z) is longer than that of the *x*-axis (l_x), and $[CuO_6]$ is distorted from the regular O_h geometry. This distortion removes the degeneracy of the e_g orbitals ($d_{x^2-y^2}$ and d_{z^2}).

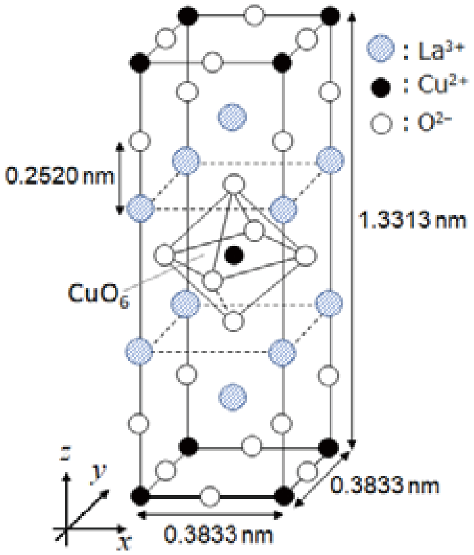


Fig. 1

A can be synthesized by thermal decomposition (pyrolysis) of complex **B**, which is formed by mixing metal chlorides in dilute aqueous ammonia solution containing squaric acid $C_4H_2O_4$, i.e., a diacid. The pyrolysis behavior of **B** in dry air shows a weight loss of 29.1% up to 200 °C due to the loss of crystallization water, followed by another weight loss up to 700 °C due to the release of CO_2. The total weight loss during the formation of **A** from **B** is 63.6%. It should be noted that only water and CO_2 are released in the pyrolysis reaction.

B.1	**Write** the chemical formulae for **A** and **B**.	6pt

The unit cell shown in Fig. 1 contains four La^{3+}, two Cu^{2+}, and eight O^{2-} ions. Therefore, **A**: La_2CuO_4. As the formula weight of La_2CuO_4 is 405.3, that of **B** should be 1113.5 considering the following equation: 405.3 ÷ (1 – 0.636). Given that the weight loss due to crystallization water is 29.1%, the number of molecules of crystallization water is 18.00 considering the following equation: (1113.5 × 0.291) ÷ 18 ($18H_2O$; M = 324). Complex **B** is a trinuclear complex that consists of two La^{3+} and one Cu^{2+} ions. Considering that the synthetic solution is basic, the squaric acid is deprotonated and coordinates to the metal ion as $C_4O_4{}^{2-}$. The number of squaric acid molecules is 4.00 based on the following equation: (1113.5 – 138.9 × 2 – 63.5 – 324) ÷ 112 ($C_4O_4{}^{2-}$; M = 112). B: $La_2Cu(C_4O_4)_4(H_2O)_{18}$ ($La_2CuC_{16}O_{34}H_{36}$)

6 points in total (2 and 4 points for **A** and **B**, respectively). Partial credit of 2 points for the correct number of crystallization water ($La_2Cu(H_2O)_{18}$) for **B**. (full marks are also given for **A**: $La_4Cu_2O_8$ and **B**: $La_4Cu_2(C_4O_4)_8(H_2O)_{36}$ ($La_4Cu_2C_{32}O_{68}H_{72}$), which correspond to the numbers of elements in the unit cell)

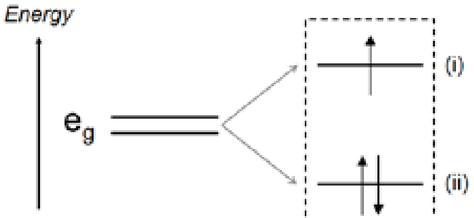
B.2	**Calculate** l_x and l_z using Fig. 1.	4pt

l_x: 0.3833 ÷ 2 = 0.1917 (= 0.192 nm).
l_z: (1.3313 – 0.2520 × 2) ÷ 4 = 0.2068 (= 0.207 nm)

4 points in total (2 points for each correct answer).

B.3 For Cu^{2+} in the distorted $[CuO_6]$ octahedron in **A** of Fig. 1, **write** the names of the split e_g orbitals ($d_{x^2-y^2}$ and d_{z^2}) in (i) and (ii), and **draw** the electron configuration in the dotted box in your answer sheet. 4pt

(i) $d_{x^2-y^2}$, (ii) d_{z^2}



4 points in total: 2 points for the correct names of the orbitals in (i) and (ii), and 2 points for the correct electron configuration in the dotted box. Full mark is given even spin up and down directions of the electrons are not shown (the electrons can be shown in arrows, lines, circles etc.).

A is an insulator. When one La^{3+} is substituted with one Sr^{2+}, one hole is generated in the crystal lattice that can conduct electricity. As a result, the Sr^{2+}-doped **A** shows superconductivity below 38 K. When a substitution reaction took place for **A**, 2.05×10^{27} holes m^{-3} were generated.

B.4 **Calculate** the percentage of Sr^{2+} substituted for La^{3+} based on the mole ratio in the substitution reaction. Note that the valences of the constituent ions and the crystal structure are not altered by the substitution reaction. 4pt

The corresponding reaction equation, where the amount of Sr^{2+} is x%, is:
$La_2CuO_4 + (2x/100)Sr^{2+} \rightarrow [La_{2(1-x/100)}Sr_{(2x/100)}CuO_4]^{(2x/100)-} + (2x/100)La^{3+}$
The charge of $[La_{2(1-x/100)}Sr_{(2x/100)}CuO_4]$ is negative, and the amount of doped holes is $(2x/100)h^+$ per mole. The volume of the unit cell is $0.3833^2 \times 1.3313 = 0.1956$ nm^3. The unit cell contains four La^{3+}, two Cu^{2+}, and eight O^{2-} ions, i.e., the unit contains two La_2CuO_4. Accordingly, the number of holes per unit cell is (4x/100).
Since the concentration of holes is the number of holes divided by the unit cell volume, the following equation is satisfied: $(4x/100)/(0.1956 \times 10^{-27}) = 2.05 \times 10^{-27}$, x = 10%
Alternative answer without giving the substitution reaction; density of La^{3+} in the unit cell $4/(0.3833^2 \times 1.3313) = 20.45$ nm^{-3}
Density of holes in the unit cell is 2.05 nm^{-3}
Therefore, the percentage of substitution is $2.05/20.45 \times 100$ = 10%

4 points for the correct answer; whether the substitution reaction is given does not affect grading; partial credit of 1 point for 20% (forgetting that the unit cell contains two La_2CuO_4).

Part C

$Cu_2(CH_3CO_2)_4$ is composed of four $CH_3CO_2^-$ coordinated to two Cu^{2+} (Fig. 2A). $Cu_2(CH_3CO_2)_4$ exhibits high levels of structural symmetry, with two axes passing through the carbon atoms of the four $CH_3CO_2^-$ and an axis passing through the two Cu^{2+}, all of which are oriented orthogonal relative to each other. When a dicarboxylate ligand is used instead of $CH_3CO_2^-$, a "cage complex" is formed. The cage complex $Cu_4(\mathbf{L1})_4$ is composed of planar dicarboxylate **L1** (Fig. 2B) and Cu^{2+} (Fig. 2C). The angle θ between the coordination directions of the two carboxylates, indicated by the arrows in Fig. 2B, determines the structure of the cage complex. The θ is 0° for **L1**. Note that hydrogen atoms are not shown in Fig. 2.

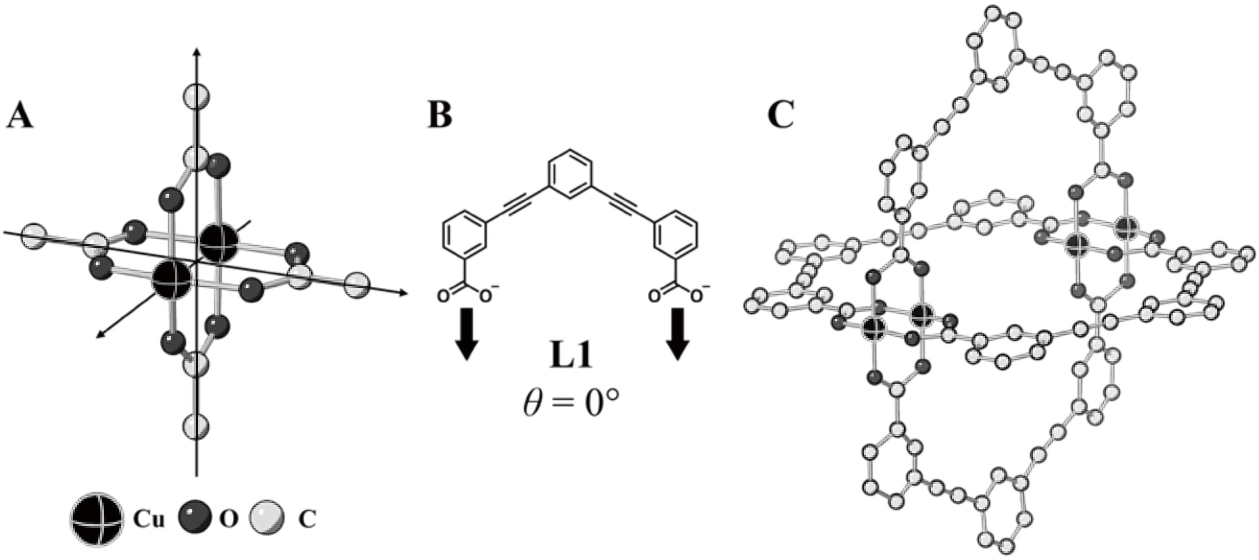
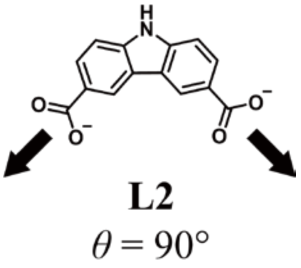
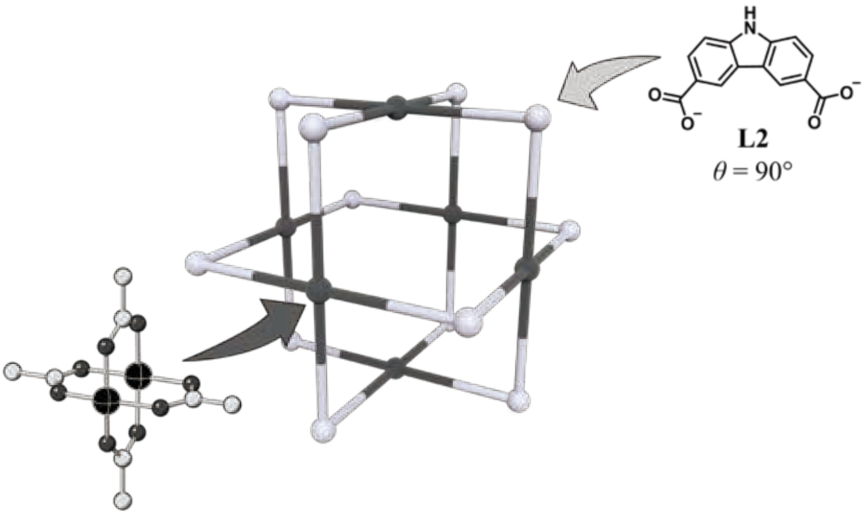


Fig. 2

C.1 The θ of the planar dicarboxylate **L2** below is fixed to 90˚. If the composition of the cage complex formed from **L2** and Cu^{2+} is $Cu_n(\mathbf{L2})_m$, **give** the smallest integer combination of *n* and *m*. Assume that only the CO_2^- groups of **L2** form a coordination bond to Cu^{2+} ions. 5pt



$n = m = 12$



5 points in total. Partial credit of 2 points for all answers with $n : m = 1 : 1$ (charge neutrality is satisfied but Cu^{2+} would not be 4-coordinate) or $n = 6$, $m = 12$ (Cu^{2+} is 4-coordinate but the complex would be an anion).

A zinc complex, $Zn_4O(CH_3CO_2)_6$, contains four tetrahedral Zn^{2+}, six $CH_3CO_2^-$, and one O^{2-} (Fig. 3A). In $Zn_4O(CH_3CO_2)_6$, the O^{2-} is located at the origin, and the three axes passing through the carbon atoms of $CH_3CO_2^-$ are oriented orthogonal relative to each other. When *p*-benzenedicarboxylate (Fig. 3B, **L3**, θ = 180°) is used instead of $CH_3CO_2^-$, the Zn^{2+} clusters are linked to each other to form a crystalline solid (**X**) that is called a "porous coordination polymer" (Fig. 3C). The composition of **X** is $[Zn_4O(\mathbf{L3})_3]_n$, and it has a cubic crystal structure with nano-sized pores. One pore is represented as a sphere in Fig. 3D, and each tetrahedral Zn^{2+} cluster is represented as a dark gray polyhedron in Fig. 3C and 3D. Note that hydrogen atoms are not shown in Fig. 3.

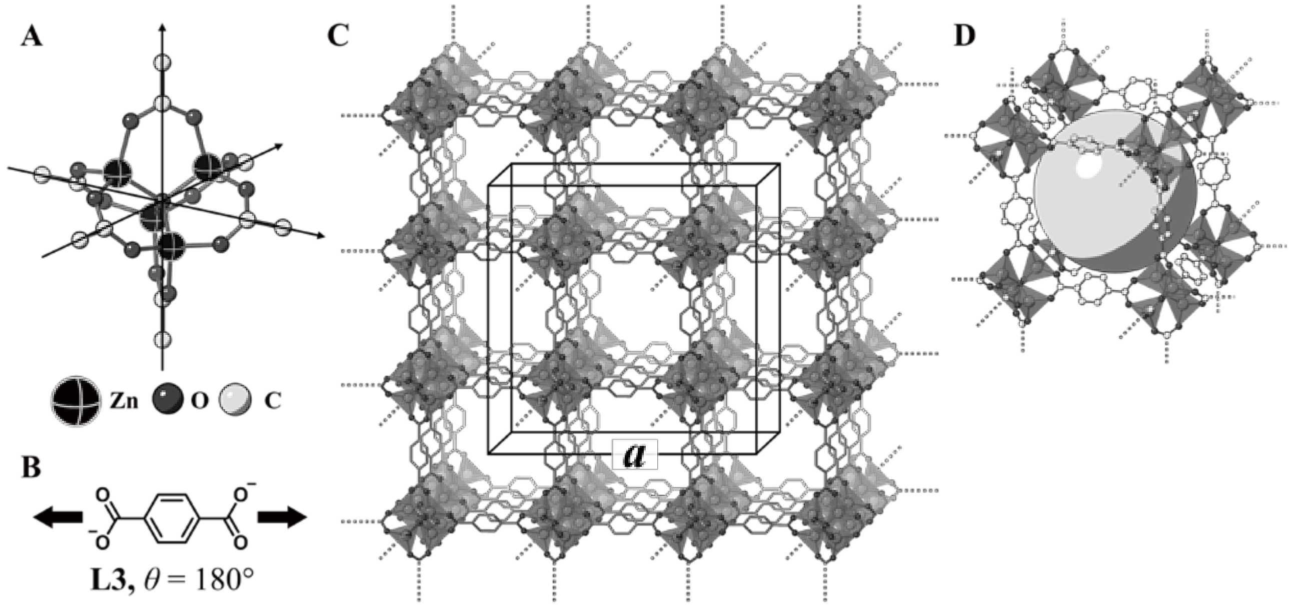


Fig. 3

C.2 **X** has a cubic unit cell with a side length of a (Fig. 3C) and a density of 0.592 g cm^{-3}. **Calculate** a in [cm]. 5pt

The molecular weight of $Zn_4O(\mathbf{L3})_3$ is 770.
According to Figure 3C, there are eight $Zn_4O(\mathbf{L3})_3$ units in the unit cell. Therefore, the molecular weight per unit cell can be calculated as 770 × 8 = 6160.
The weight of the unit cell is $6160 \div N_A = 1.02 \times 10^{-20}$ g
Let the length of the side of the unit cell be a [cm], then, (1.02×10^{-20}) g / a^3 [cm^3] = 0.592 g cm^{-3}.
$a = 2.6 \times 10^{-7}$ cm

5 points in total.
Partial credit of 3 points for the correct formulation to derive the molecular weight of the unit cell; 2 points for the correct value of a.

C.3 **X** contains a considerable number of pores, and 1 g of **X** can accommodate 3.0×10^2 mL of CO_2 gas in the pores at 1 bar and 25 °C. **Calculate** the average number of CO_2 molecules per pore. 5pt

There is one pore per $Zn_4O(\mathbf{L3})_3$ unit.
Number of pores [mol] per 1 [g] of **X**: 1 [g] / 770 = 0.00130.
Based on the ideal gas equation, 3.0×10^2 [mL] of adsorbed CO_2 corresponds to:
(1×10^5 [Pa] × 3.0×10^{-4} [m^3]) / (8.31 × 298 [K]) = 0.0121 [mol] of CO_2.
Therefore, 0.0121 ÷ 0.00130 = 9.3 molecules of CO_2 per pore.

5 points in total.
Partial credit of 3 points for the correct formulation to calculate the number of pores in 1 g; 2 points for the correct calculation of the number of molecules of CO_2 per pore.

Playing with Non-benzenoid Aromaticity

13 % of the total					
Question	A.1	A.2	A.3	B.1	**Total**
Points	5	2	19	10	**36**
Score					

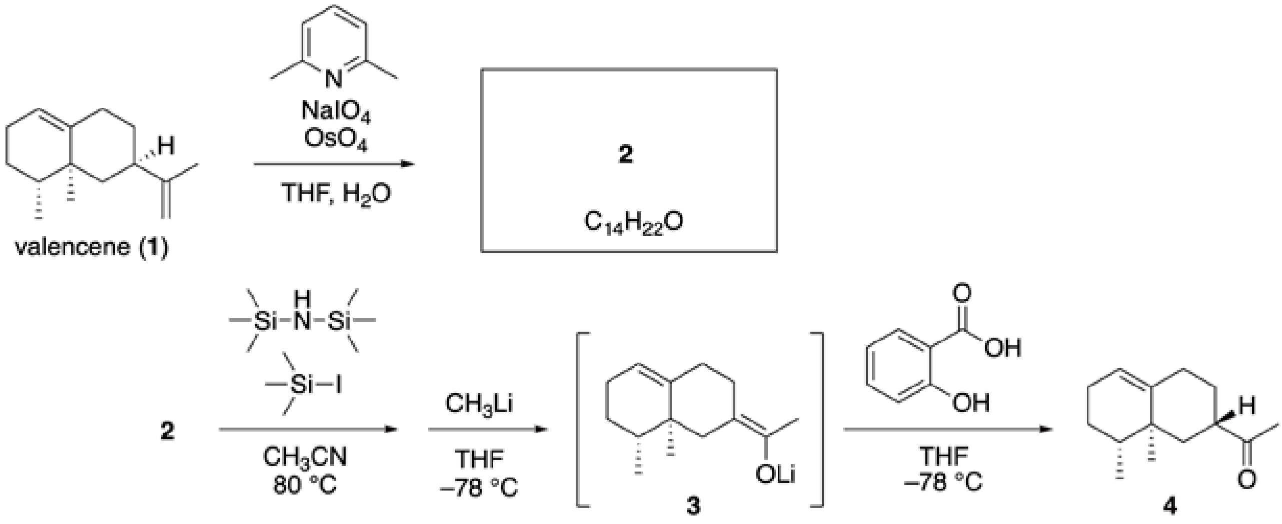
Prof. Nozoe (1902–1996) opened the research field of non-benzenoid aromatic compounds, which are now ubiquitous in organic chemistry.

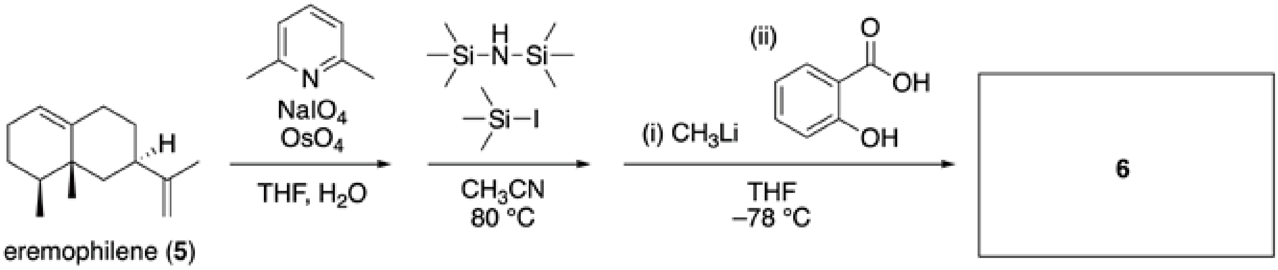
Photo courtesy: Tohoku Univ.

Part A

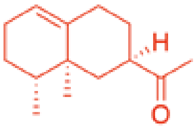
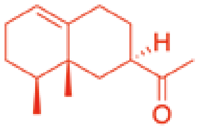
Lineariifolianone is a natural product with a unique structure, which was isolated from *Inula linariifolia*. From valencene (**1**), a one-step conversion yields **2**, before a three-step conversion via **3** yields ketone **4**. Eremophilene (**5**) is converted into **6** by performing the same four-step conversion.

Inula linariifolia





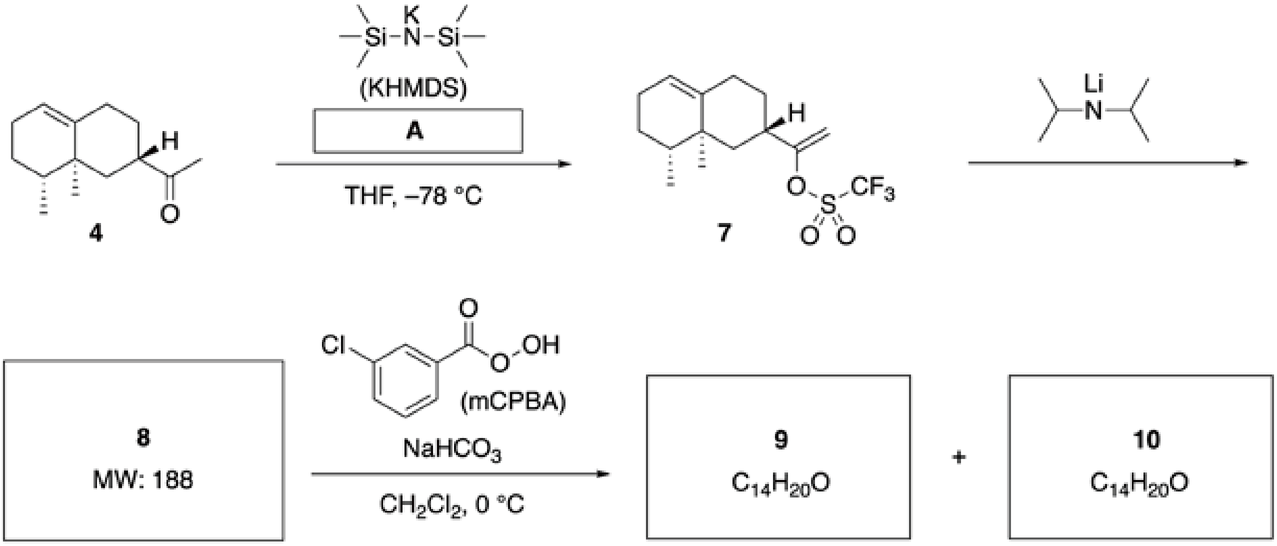
A.1 **Draw** the structures of **2** and **6** and clearly identify the stereochemistry where necessary. 5pt

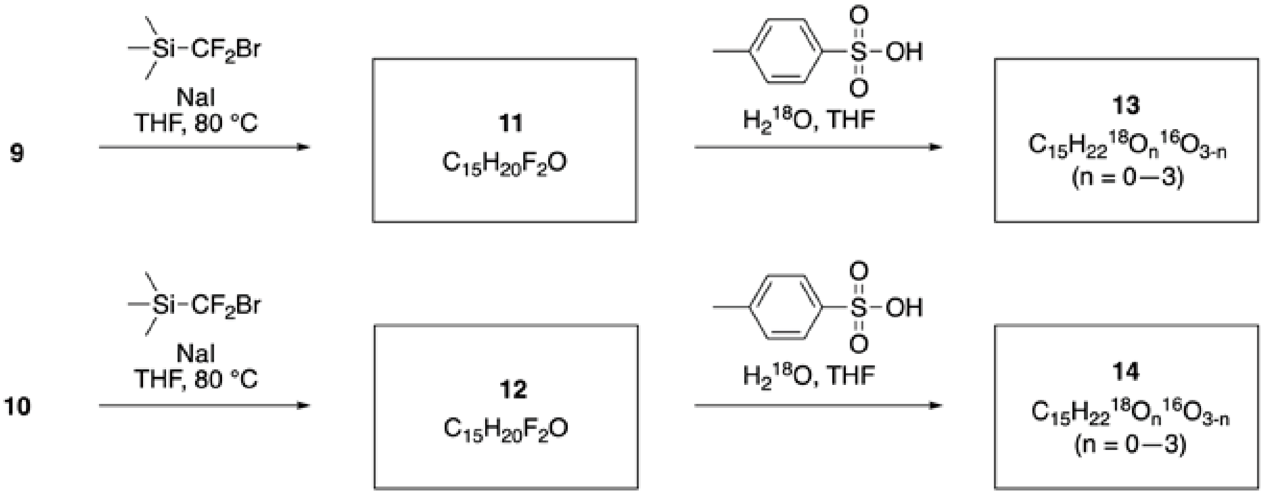
2 (2 pt)	6 (3 pt)
	

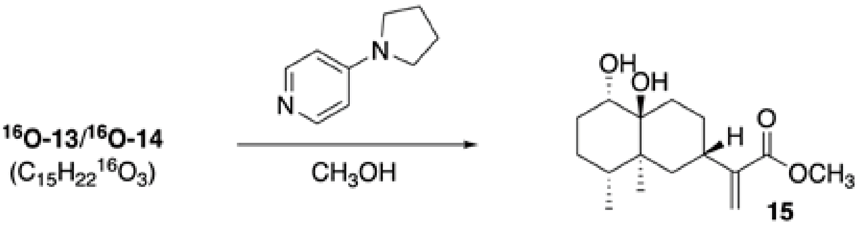
2 (2 pt in total):
–1 pt for missing double bond,
–1 pt for stereochemistry error.

6 (3 pt in total):
–1 pt for missing double bond,
–2 pt for stereochemistry error.

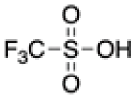
Then, ketone **4** is converted into ester **15**. Compound **8** (molecular weight: 188) retains all the stereocenters in **7**. Compounds **9** and **10** have five stereocenters and no carbon-carbon double bonds. Assume that $H_2{}^{18}O$ is used instead of $H_2{}^{16}O$ for the synthesis of ^{18}O-labelled-weariifolianones **13** and **14** from **11** and **12**, respectively. Compounds **13** and **14** are ^{18}O-labelled isotopomers. Ignoring isotopic labelling, both **13** and **14** provide the same product **15** with identical stereochemistry.


(KHMDS)
A
THF, –78 °C
4
7
8
MW: 188
(mCPBA)
$NaHCO_3$
CH_2Cl_2, 0 °C
9
$C_{14}H_{20}O$
+
10
$C_{14}H_{20}O$

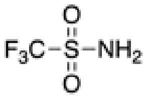

9
NaI
THF, 80 °C
11
$C_{15}H_{20}F_2O$
$H_2{}^{18}O$, THF
13
$C_{15}H_{22}{}^{18}O_n{}^{16}O_{3-n}$
(n = 0—3)
10
NaI
THF, 80 °C
12
$C_{15}H_{20}F_2O$
$H_2{}^{18}O$, THF
14
$C_{15}H_{22}{}^{18}O_n{}^{16}O_{3-n}$
(n = 0—3)


^{16}O-13/^{16}O-14
($C_{15}H_{22}{}^{16}O_3$)
CH_3OH
15

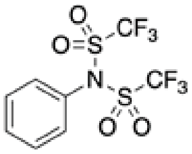
A.2 **Choose** the appropriate structure for **A**. 2pt

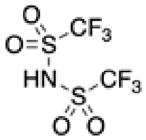
I


$F_3C-S(=O)_2-OH$

II


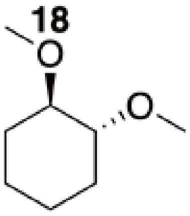
$F_3C-S(=O)_2-NH_2$

III


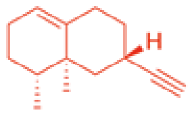
IV


III
A is reacted with the potassium enolate of **4**, thus **I**, **II**, **IV** are inappropriate because these reagents have acidic protons.
2 pt in total
others: 0 pt

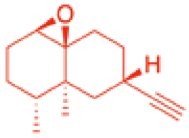
A.3 **Draw** the structures of **8–14** and clearly identify the stereochemistry where necessary. Also, **indicate** the introduced ^{18}O atoms for **13** and **14** as shown in the example below. 19pt



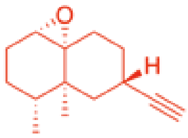
8 (3 pt)



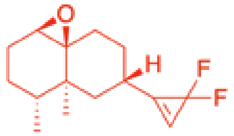
9 (2 pt)



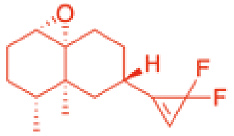
10 (2 pt)



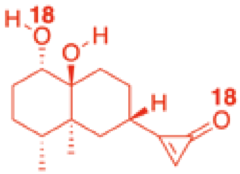
11 (2 pt)



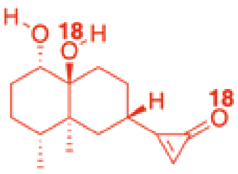
12 (2 pt)



13 (4 pt)



14 (4 pt)



8 (3 pt in total):
–1 pt each for missing one double bond or drawing an allene instead of an alkyne,
0 pt for incorrect planar structure,
-2 pt for an opposite stereochemistry next to the alkyne,
-2 pt for other stereochemistry errors.

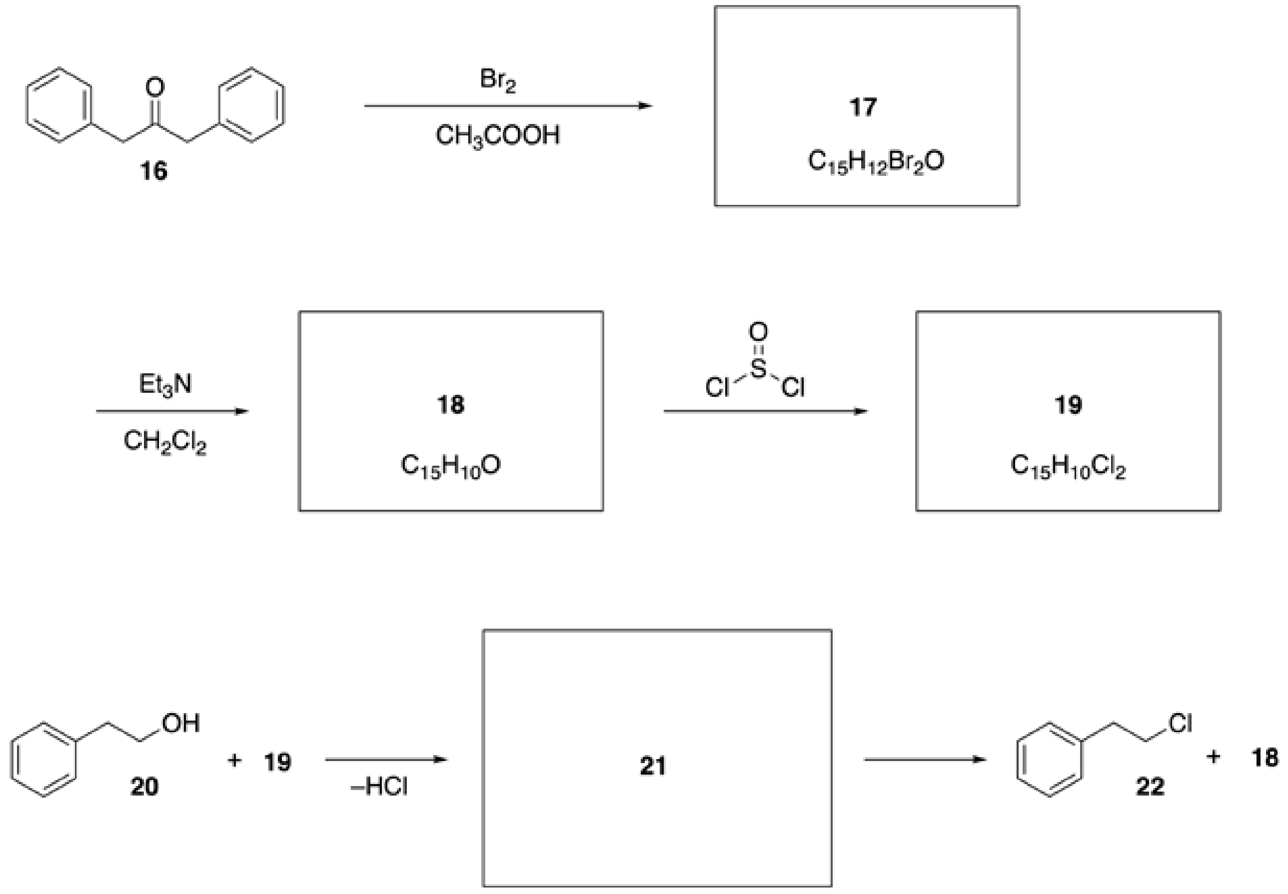
9–12 (2 pt each, 8 pt in total):
–1 pt each for missing atoms (e.g., fluorine atom, oxygen of epoxide),
-1 pt for stereochemistry error,
Two sets of compounds **9**, **11**, **13** and **10**, **12, 14** are interconvertible,

Structures of 13 and 14/^{18}O labelling on hydroxy groups of 13 and 14 (3 pt each, 6 pt in total):
-1 pt each for incorrect or unclear ^{18}O labelling on the diol moiety,
-1 pt each for incomplete transformation (diol only, ketone only),
0 pt for incorrect planar structure other than the above,
-2 pt for stereochemistry error.

^{18}O labelling on carbonyl group of 13 and 14 (1 pt each, 2 pt in total):
0 pt when ^{18}O is incorporated in the carbonyl group of neither **13** nor **14**.

Part B

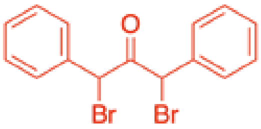
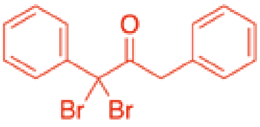
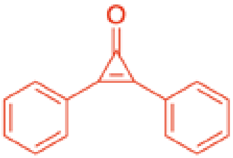
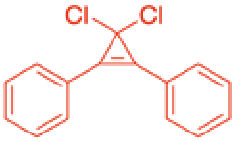
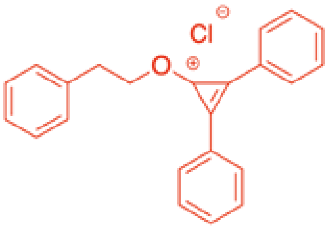
Compound **19** is synthesized as shown below. In relation to non-benzenoid aromaticity, **19** can be used as an activator for alcohols, and **20** was converted to **22** via ion-pair intermediate **21**. Although the formation of **21** was observed by NMR, **21** gradually decomposes to give **18** and **22**.



^{1}H NMR (CD_3CN, ppm) **20**: δ 7.4–7.2 (5H), 3.7 (2H), 2.8 (2H), 2.2 (1H)

21: δ 8.5–7.3 (15H), 5.5 (2H), 3.4 (2H)

B.1 <u>**Draw**</u> the structures of **17–19** and **21**. Identifying the stereochemistry is not necessary. 10pt

17 (2 pt)  or 	**18** (2 pt) 
19 (3 pt) 	**21** (3 pt) 

17 (2 pt in total):
stereochemistry is ignored,
0 pt for bromination on aryl ring.

18 (2 pt in total):

19 (3 pt in total):
Full mark for ionic structure.

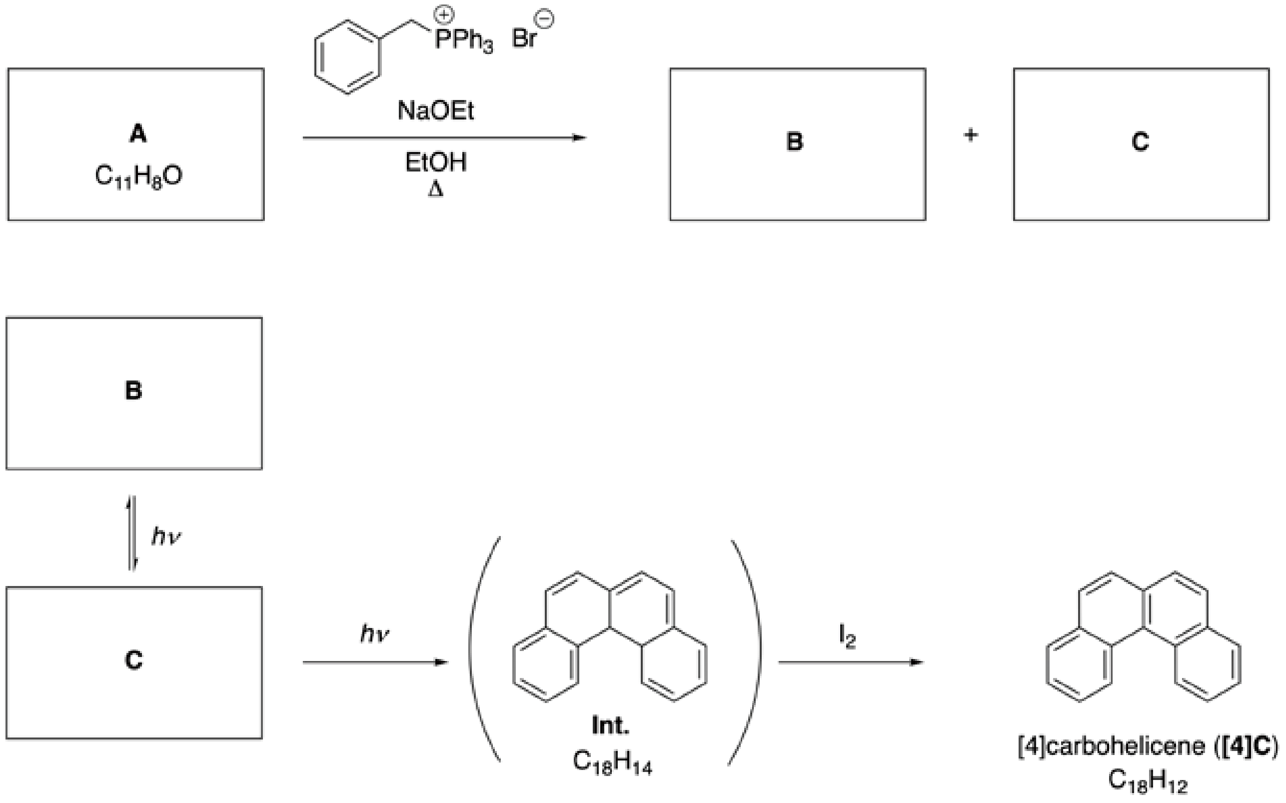
21 (3 pt in total):
–1 pt when Cl^- is omitted,
–1 pt when C–Cl is covalent,
–1 pt each for other errors on connectivity,
–1 pt when the alkoxide and chlorocyclopropenium are given.

Dynamic Organic Molecules and Their Chirality

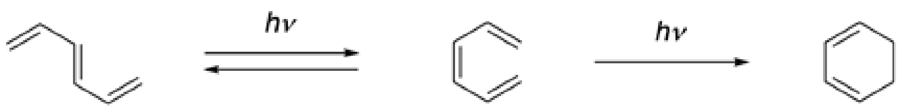
11 % of the total						
Question	A.1	A.2	A.3	B.1	B.2	**Total**
Points	9	3	7	3	4	**26**
Score						

Part A

Polycyclic aromatic hydrocarbons with successive ortho-connections are called [n]carbohelicenes (here, n represents the number of six-membered rings) (see below). [4]Carbohelicene (**[4]C**) is efficiently prepared by a route using a photoreaction as shown below, via an intermediate (**Int.**) that is readily oxidized by iodine.

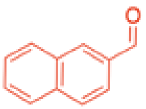
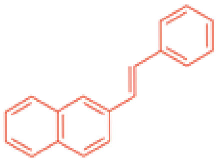
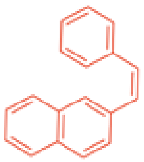


The photoreaction proceeds in a manner similar to the following example.



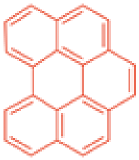
Note: For all of Question 8, please draw alternating single and double bonds in your answers to the problems as depicted in the examples of carbohelicene. Do not use circles for conjugated π systems.

A.1	**Draw** the structures of **A–C**. Stereoisomers should be distinguished.	9pt

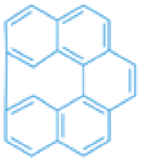
A (3 pt)	**B** (3 pt)	**C** (3 pt)
		

3 points each. When **B** and **C** are reversed, give 1 point each. When missing double bonds in **B** and **C**, -1 point each.
If **B** is blank and **C** is the trans-isomer (i.e. **B**), give 2 points for **C**.
-1 point for each "circled" answer (**this is applied for all the following questions in Q8**)

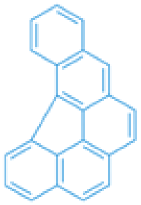
A.2	Attempts to synthesize [5]carbohelicene from the same phosphonium salt and an appropriate starting compound resulted in the formation of only a trace amount of [5]carbohelicene, instead affording product **D** whose molecular weight was 2 Da lower than that of [5]carbohelicene. The ^{1}H NMR chemical shifts of **D** are listed below. **Draw** the structure of **D**. **[D** (δ, ppm in CS_2, r.t.), 8.85 (2H), 8.23 (2H), 8.07 (2H), 8.01 (2H), 7.97 (2H), 7.91 (2H)**]**	3pt



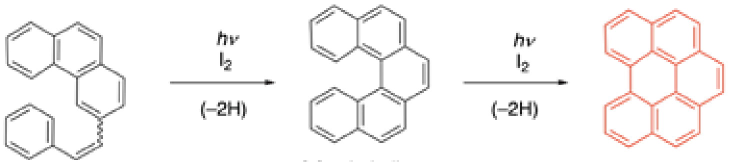
D



D'



D"

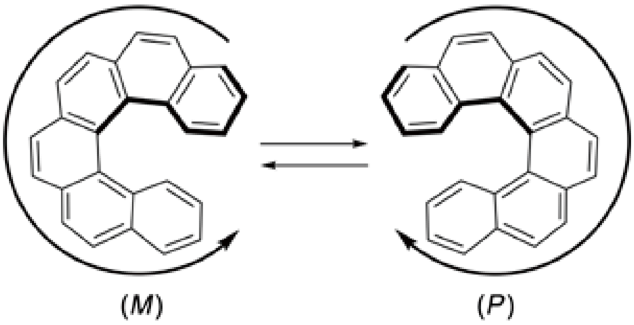


[5]carbohelicene
$C_{22}H_{14}$

D
benzo[*ghi*]perylene
$C_{22}H_{12}$

Structural isomer **D'**: 1 point
Structural isomer **D"**: 1 point
Any careless mistakes such as contamination with sp^3 carbons: -1 point each.

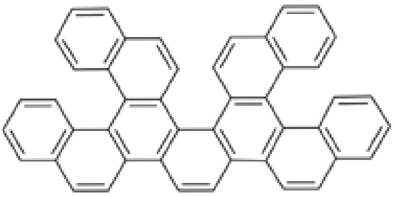
[5]- and larger [n]carbohelicenes have helical chirality and interconversion between enantiomers of these helicenes is significantly slow at room temperature. The chirality of [n]carbohelicenes is defined as (*M*) or (*P*) as shown below.



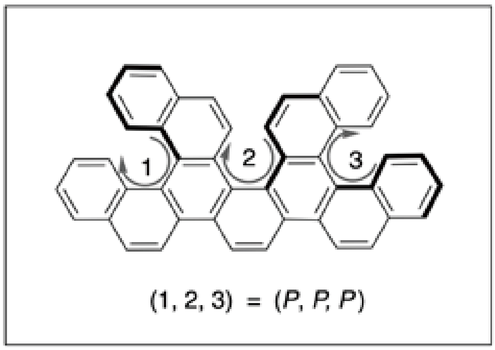
[n]Carbohelicenes with n larger than 4 can be enantiomerically separated by a chiral column chromatography, which was developed by Prof. Yoshio Okamoto.

Photo courtesy: The Japan Prize Foundation

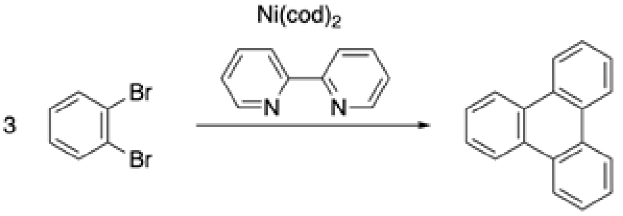
Multiple helicenes are molecules that contain two or more helicene-like structures. If its helical chirality is considered, several stereoisomers exist in a multiple helicene. For example, compound **E** contains three [5]carbohelicene-like moieties in one molecule. One of the stereoisomers is described as (*P*, *P*, *P*) as shown below.

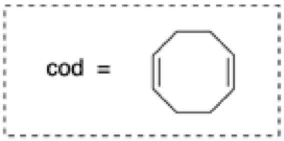


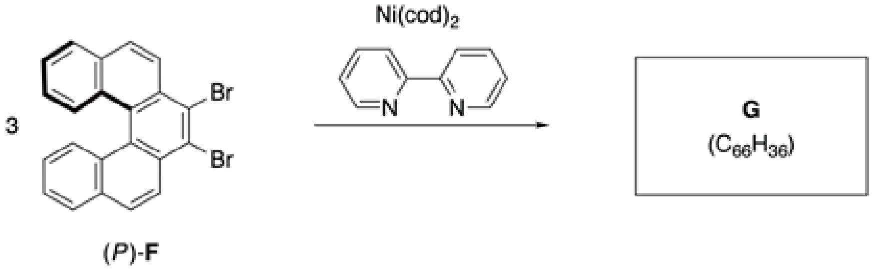
E

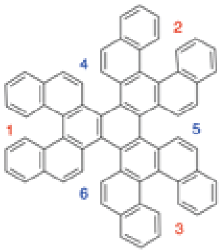


A.3 The nickel-mediated trimerization of 1,2-dibromobenzene generates triphenylene. When the same reaction is applied to an enantiomer of **F**, (*P*)-**F**, multiple helicene **G** ($C_{66}H_{36}$) is obtained. Given that interconversion between stereoisomers does not occur during the reaction, **identify all** the possible stereoisomers of **G** formed in this process, without duplication. As a reference, one isomer should be drawn completely with the chirality defined as in the example above, with numerical labels; the other stereoisomers should be listed with location numbers and *M* and *P* labels according to the same numbering. For instance, the other stereoisomers of **E** should be listed as (1, 2, 3) = (*P*, *M*, *P*), (*P*, *M*, *M*), (*P*, *P*, *M*), (*M*, *M*, *M*), (*M*, *M*, *P*), (*M*, *P*, *P*), and (*M*, *P*, *M*). 7pt

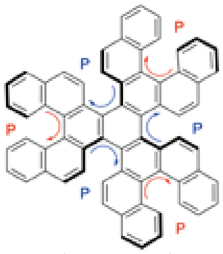






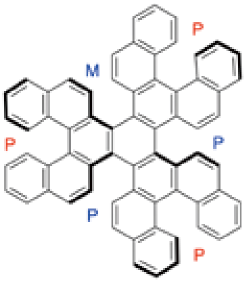


(1, 2, 3, 4, 5, 6)

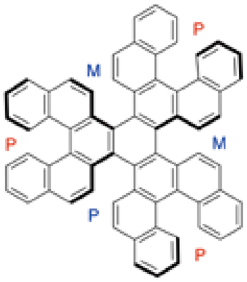


(P, P, P, P, P, P)

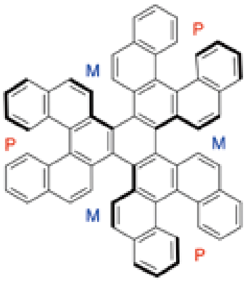
A representative example



(P, P, P, M, P, P)



(P, P, P, M, M, P)

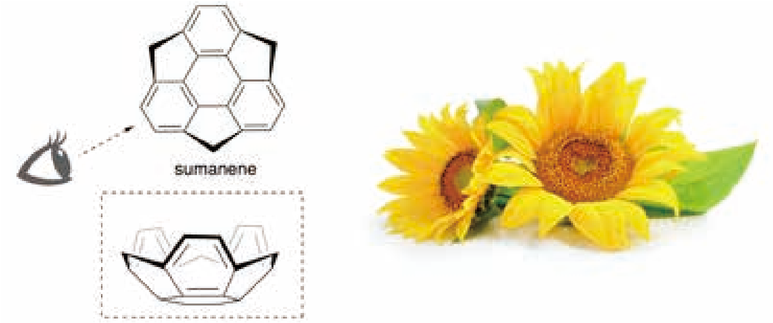


(P, P, P, M, M, M)

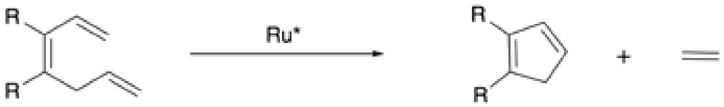
One structure should be drawn fully; chemical structure (2 points) and its stereochemistry (1 point for the original chirality (outside), 1 point for the new chirality (inside))
For the other three isomers (1 point each).
Overcount (answering the same stereochemistry multiple times for an isomer) (-1 point each; this reduction is applied repeatedly up to 4 times).
0 points if no representative structure is drawn.

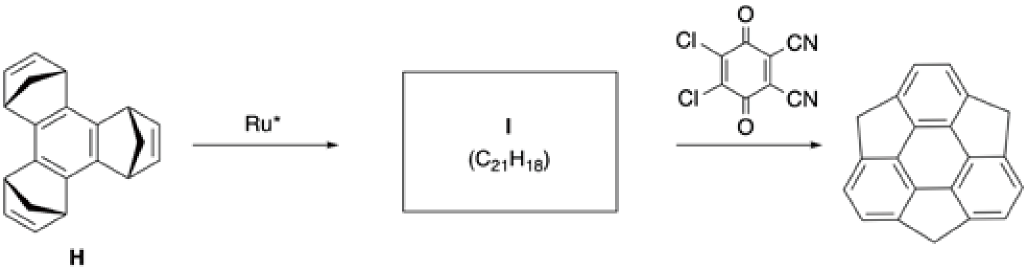
Part B

Sumanene is a bowl-shaped hydrocarbon that was first reported in Japan in 2003. The name "sumanene" derives from a Sanskrit-Hindi word "suman" that means sunflower. The synthesis of sumanene was achieved by a reaction sequence that consists of a ring-opening and a ring-closing metathesis.

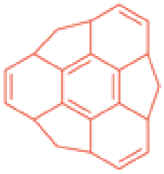


Representative metathesis reactions catalyzed by a ruthenium catalyst (Ru*) are shown below.

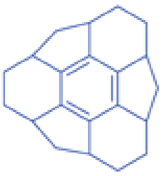




B.1	**Draw** the structure of intermediate **I** (its stereochemistry is not required).	3pt

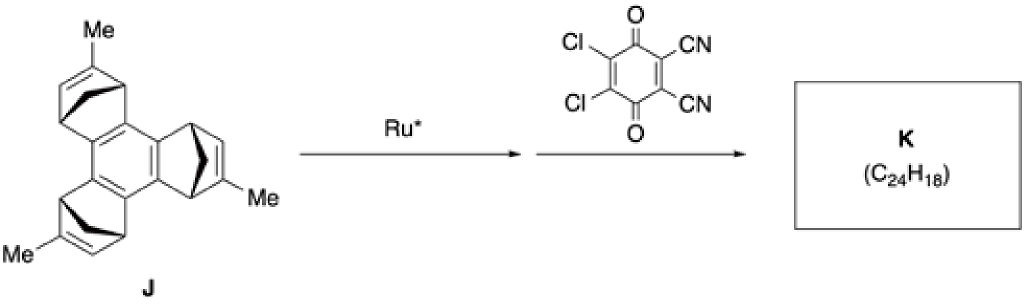


I

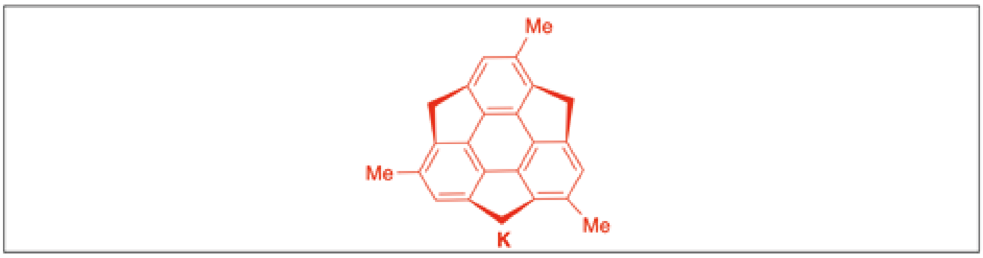


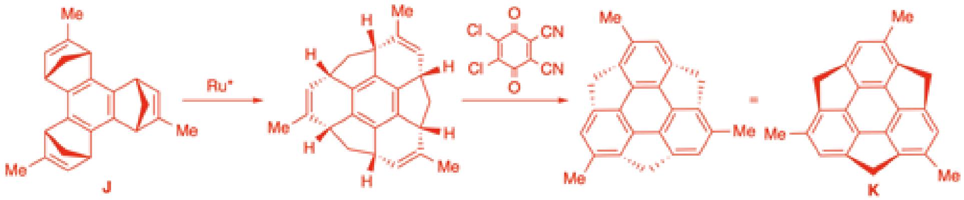
I'

Double bond saturation (such as **I'**): 0 points.
Any careless mistakes such as contamination with wrong sp^2 carbon atoms: -1 point each.
Any different carbon frameworks: 0 points.



B.2	Starting from the optically active precursor **J**, the same reaction sequence gives the optically active sumanene derivative **K**. The stereocenters in **J** suffer no inversion during the metathesis reaction. **Draw** the structure of **K** with the appropriate stereochemistry.	4pt





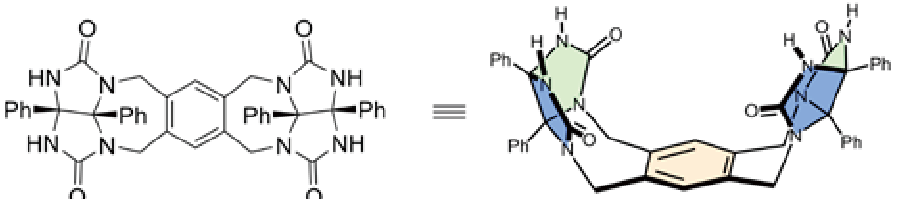
No stereochemistry: 1 point.
The other enantiomer: 2 points.
Lower-symmetry structure (Me at a different position): 0 points.

Likes and Dislikes of Capsule

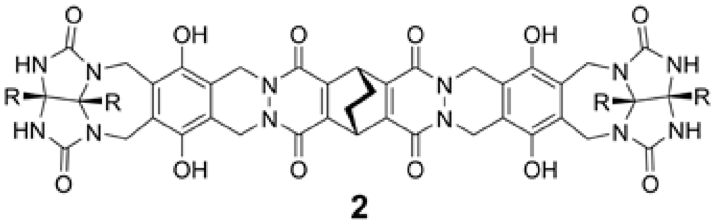
10 % of the total						
Question	A.1	A.2	A.3	A.4	A.5	**Total**
Points	13	2	2	3	3	**23**
Score						

Good kids don't do this, but if you unseam a tennis ball, you can disassemble it into two U-shaped pieces.

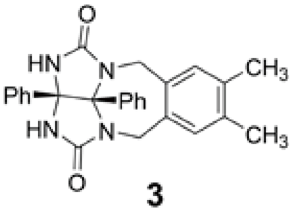
Based on this idea, compounds **1** and **2** were synthesized as U-shaped molecules with different sizes. Compound **3** was prepared as a comparison of **1** and the encapsulation behavior of these compounds was investigated.



1

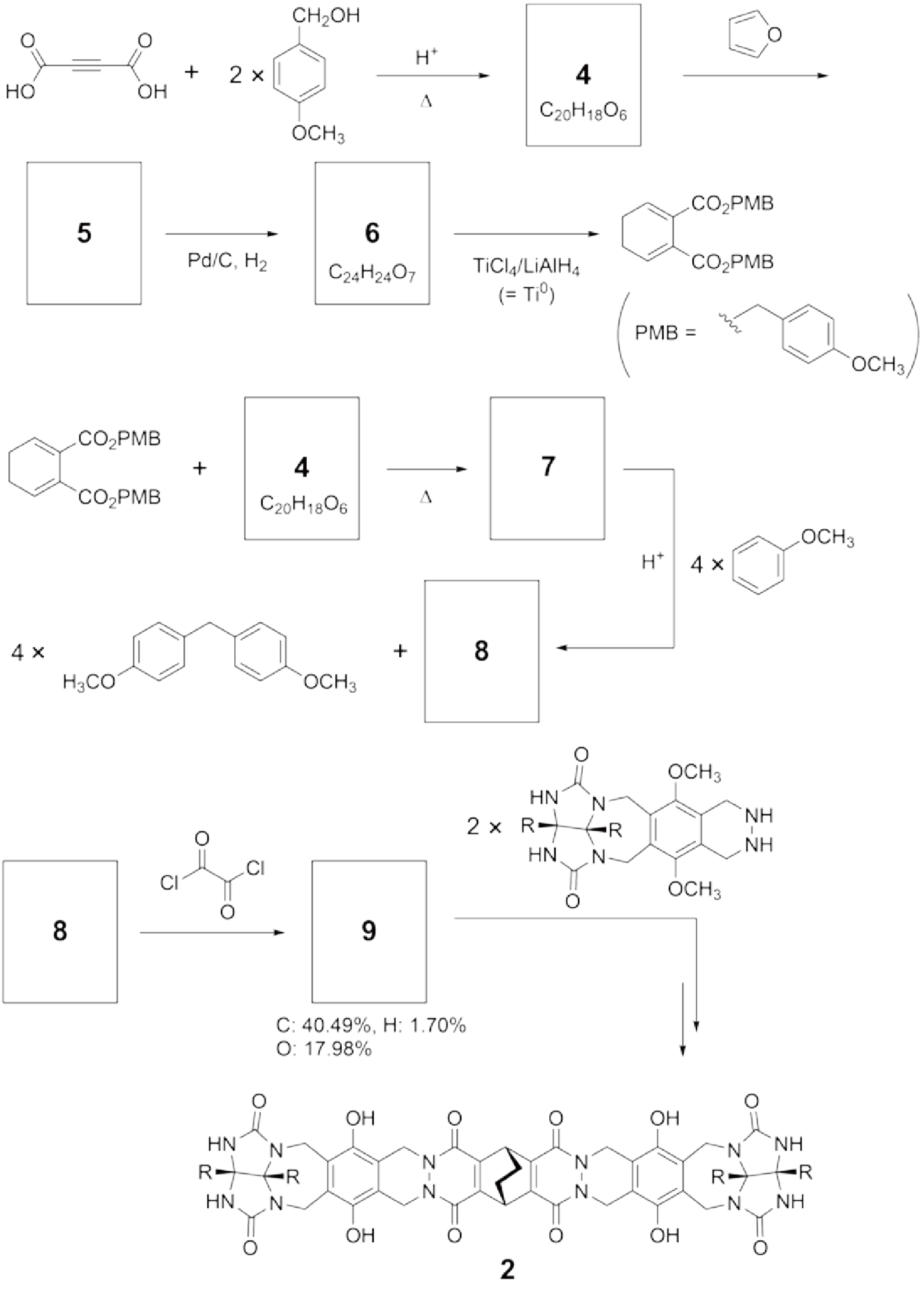


2

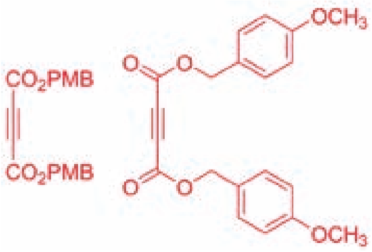
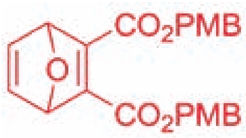
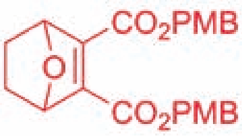
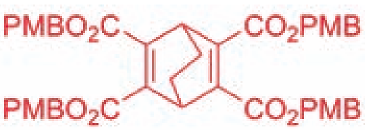
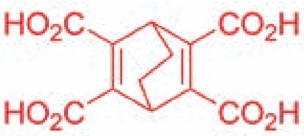
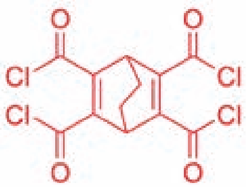


3

The synthetic route to **2** is shown below. The elemental composition of compound **9**: C; 40.49%, H; 1.70%, and O; 17.98% by mass.



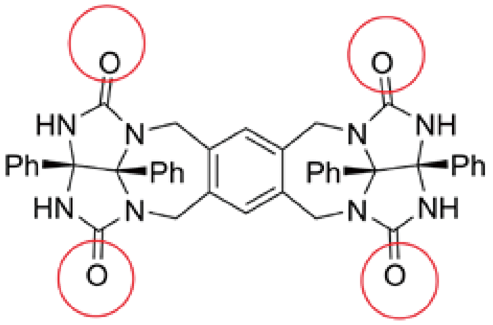
A.1	**Draw** the structures of **4–9**; the stereochemistry can be neglected. Use "PMB" as a substituent instead of drawing the whole structure of *p*-methoxybenzyl group shown in the scheme above.	13pt

4 (2 pt) 	**5** (3 pt) 
6 (2 pt) 	**7** (2 pt) 
8 (2 pt) 	**9** (2 pt) 

·2 points for the correct structures of compounds **4** and **6-9**.
·3 points for the correct structure of compound **5.**
·For compounds **4-9**, any careless mistakes such as the wrong number of carbons or forgetting to write double or triple bonds: -1 point each.
·For compound **6**, 1 point for structures that show the reduced double bond in a different position.
·Full mark will be given if a structure of *p*-methoxybenzyl group is drawn instead of using PMB.
· minimum score: 0 points.

In the mass spectrum of **1**, the ion peak corresponding to its dimer (1_2) was clearly observed, whereas an ion peak for $\mathbf{3}_2$ was not observed in the spectrum of **3**. In the ^{1}H NMR spectra of a solution of $\mathbf{1}_2$, all the NH protons derived from **1** were observed to be chemically equivalent, and their chemical shift was significantly different from that of the NH protons of **3**. These data indicate that hydrogen bonds are formed between the NH moieties of **1** and atoms **X** of another molecule of **1** to form the dimeric capsule.

A.2	**Circle** all the appropriate atom(s) **X** in **1**.	2pt



2 points for the correct answer

A.3	**Give** the number of the hydrogen bonds in the dimeric capsule ($\mathbf{1}_2$).	2pt

8 (because 8 NH protons were observed equally in the ^{1}H NMR spectrum of the dimer.)
2 points for the correct answer.

The dimeric capsule of **1** ($\mathbf{1}_2$) has an internal space wherein an appropriate small molecule Z can be encapsulated. This phenomenon is expressed by the following equation:

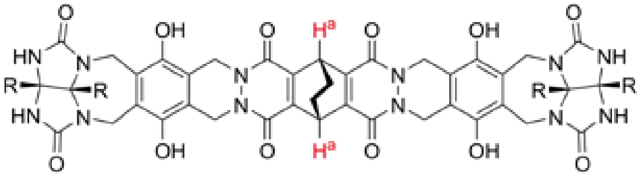
$$\mathrm{Z} + \mathbf{1}_2 \rightarrow \mathrm{Z}@\mathbf{1}_2 \tag{1}$$

The equilibrium constant of the encapsulation of Z into $\mathbf{1}_2$ is given as below:

$$K_\mathrm{a} = \frac{[\mathrm{Z}@\mathbf{1}_2]}{[\mathrm{Z}][\mathbf{1}_2]} \tag{2}$$

Encapsulation of a molecule into a capsule could be monitored by NMR spectroscopy. For example, $\mathbf{1}_2$ in C_6D_6 gave different signals in the ^{1}H NMR spectra before and after addition of CH_4.

Compound **2** also forms a rigid and larger dimeric capsule ($\mathbf{2}_2$). The ^{1}H NMR spectrum of $\mathbf{2}_2$ was measured in C_6D_6, C_6D_5F, and a C_6D_6/C_6D_5F solvent mixture, with all other conditions being kept constant. The chemical shifts for the H^a proton of **2** in the above solvents are summarized below, and no other signals from the H^a in **2**, except for the listed, were observed. Assume that the interior of the capsule is always filled with the largest possible number of solvent molecules and that each signal corresponds to one species of the filled capsule.



2

solvent	δ (ppm) of H^a
C_6D_6	4.60
C_6D_5F	4.71
C_6D_6 / C_6D_5F	4.60, 4.71, 4.82

A.4 **Determine** the number of C_6D_6 and C_6D_5F molecules encapsulated in $\mathbf{2}_2$ giving each H^a signal. 3pt

1 point for the correct number of encapsulated C_6D_6 and C_6D_5F molecules for each NMR signal.

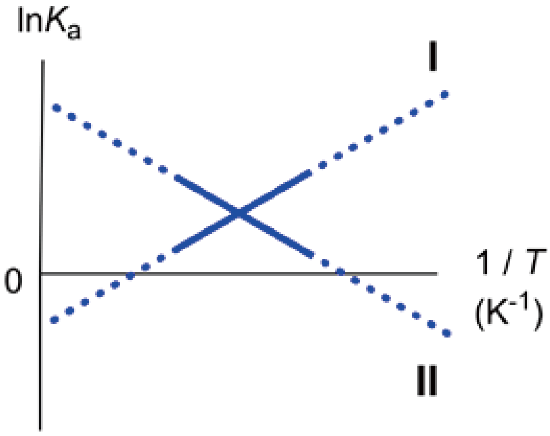
δ (ppm) of H^a	numbers of C_6D_6	numbers of C_6D_5F
4.60 ppm	2	0
4.71 ppm	0	2
4.82 ppm	1	1

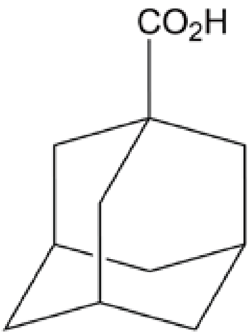
The observation of the third signal in the mixed solvent indicates that two solvent molecules are initially encapsulated in the capsule. Thus, the signal at 4.82 ppm is ascribed to a capsule containing one molecule of C_6D_6 and one molecule of C_6D_5F.

^{1}H NMR measurements in C_6D_6 revealed that $\mathbf{2}_2$ can incorporate one molecule of 1-adamantanecarboxylic acid (AdA), and the association constants (K_a) which are expressed below were determined for various temperatures. [solvent@$\mathbf{2}_2$] denotes a species containing one or more solvent molecules.

$$K_a = \frac{[\mathrm{Z@}\mathbf{2}_2]}{[\mathrm{Z}][\mathrm{solvent@}\mathbf{2}_2]} \tag{3}$$

Similarly, the K_a values of CH_4 and $\mathbf{1}_2$ given as eq (2) at various temperatures in C_6D_6 were also determined by ^{1}H NMR measurements. The plots of the two association constants (as ln K_a vs 1/T) are shown below.





AdA

No C_6D_6 molecule is encapsulated in $\mathbf{1}_2$. In line **II**, the entropy change (ΔS) is (1) and enthalpy change (ΔH) is (2), indicating that the driving force for the encapsulation in line **II** is (3). Therefore, line **I** corresponds to (4), and line **II** corresponds to (5).

A.5 **Choose** the correct options in gaps (1)–(5) in the following paragraph from A and B. 3pt

	A	B
(1)	positive	negative
(2)	positive	negative
(3)	ΔS	ΔH
(4)	$\mathbf{1}_2$ and CH_4	$\mathbf{2}_2$ and AdA
(5)	$\mathbf{1}_2$ and CH_4	$\mathbf{2}_2$ and AdA

(1): A (2): A (3): A
(4): A (5): B

3 points in total
2 points for correct answers for (1)-(3).
1 point for correct answers for (4) and (5).
No points when the former part ((1)-(3)) is incorrect even if the latter part ((4) and (5)) is correct.

Transforming $\Delta G = -RT \ln K_a = \Delta H - T\Delta S$ gives

$$\ln K_a = -\frac{\Delta H}{RT} + \frac{\Delta S}{R}$$

(If ΔH is negative, the slope is positive; if the y-intercept is negative, ΔS is negative.)
The relationship between $\mathbf{1}_2$ and CH_4 is that the entropy change is unfavorable (ΔS < 0) given that the two components become one component. Nevertheless, the encapsulation of CH_4 occurs (ΔG < 0), indicating that the enthalpy change is exothermic and favorable (ΔH < 0). This result indicates a plot with a positive slope and a negative y-intercept for $\mathbf{1}_2$ and CH_4.
Therefore, the plot with a negative slope (ΔH > 0) and positive y-intercept (ΔS > 0) is $\mathbf{2}_2$ and AdA. This is due to the release of the two molecules of C_6D_6 that were initially encapsulated and the encapsulation of one molecule of AdA.

Reference

Practical Tasks

The 53rd International Chemistry Olympiad, IChO 2021 Japan, was held remotely, unfortunately we were not able to do the practical exams.

In order to reinforce the importance of laboratory work, the practical tasks prepared for the 53rd IChO 2021 Japan were made open, despite not being officially approved by the International Jury meeting for the 53rd IChO 2021 Japan.

We prepared videos in which all tasks were demonstrated with explanations and published the videos as one of the activities during the 53rd IChO 2021 Japan.

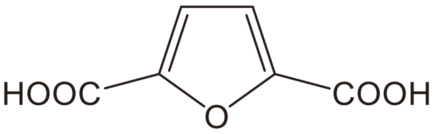
We hope that many of you will take up the challenge of the practical tasks.

Practical Task 1. Partition coefficient of 2,5-furandicarboxylic acid in a 1-octanol/water system

‘Biomass chemistry’ is attracting attention as a strategy to break away from the oil-dependence of human society. Furan derivatives are plant-derived chemicals that can be used as building blocks for new materials. They are made from furfural, which can be easily synthesized from agricultural waste containing sugars. One furan derivative, 2,5-furandicarboxylic acid, has been extensively studied as a raw material for bioplastics.

When using a new material, it is essential to elucidate the effects of the chemical on the human body, animals, and plants. It is known that the accumulation of a chemical in living organisms is related to its hydrophobicity. The 1-octanol/water partition coefficient is one of the best indicators of hydrophobicity/hydrophilicity.

The purpose of this experiment is to calculate the partition coefficient of 2,5-furandicarboxylic acid in a 1-octanol/water system by examining the 2,5-furandicarboxylic acid concentrations in the 1-octanol phase and the aqueous phase and analyzing its aggregation state in 1-octanol.



Chemicals

Substance	**Name**	**State**	**GHS Hazard Statement**
$C_6H_4O_5$	2,5-Furandicarboxylic acid	1-Octanol Solution (0.020 mol L^{-1})	H319
$C_8H_{17}OH$	1-Octanol	Liquid	H319, H412
NaCl	Sodium chloride	Aqueous solution (10%)	NA
NaOH	Sodium hydroxide	Aqueous solution (ca. 0.01 mol L^{-1}) *	H290, H314
$C_{20}H_{14}O_4$	Phenolphthalein	Ethanol solution	H226, H320

*Exact concentration will be shown at the examination.

Glassware and Equipment

- 2 Volumetric flasks, 100 mL
- 2 Pipettes
- 1 Silicone dropper
- 3 Erlenmeyer flasks with stopper, 100 mL
- 4 Volumetric pipettes, 20 mL
- 3 Volumetric pipettes, 10 mL
- 1 Pipettor
- 1 Laboratory stand with burette clamp
- 1 Burette, 25 mL
- 1 Funnel
- 3 Conical beakers, 50 mL
- 1 Magnetic stirrer
- 1 Stirrer bar

For the procedure "*Taking an Aliquot of Aqueous Phase B*"

- 3 Pipettes
- 3 Beakers, 50 mL

Procedure

1. **Transfer** two 20 mL portions of 0.020 mol L^{-1} 2,5-furandicarboxylic acid solution (**Solution A**) to a 100 mL volumetric flask (total volume: 40 mL). **Fill** the flask with 1-octanol using a pipette. **Homogenize** the solution, which is henceforth called **Solution B**.
2. **Transfer** 20 mL of **Solution A** to another 100 mL volumetric flask (total volume: 20 mL). **Fill** the flask and **homogenize** the solution as above. This solution is called **Solution C**.
3. **Transfer** two 20 mL portions of **Solutions A**, **B**, and **C** to 100 mL Erlenmeyer flasks with stoppers (total volume: 40 mL each).
4. **Add** two 20 mL portions of 10% aqueous NaCl solution to each Erlenmeyer flask (total volume of the aqueous solution: 40 mL). **Seal** the Erlenmeyer flasks.
5. **Hold** each Erlenmeyer flask firmly so that the stopper does not come off, **shake** it vertically 30 times, and **let it stand** for 5 minutes. **Shake** the flask and **let it stand** 5 times in total. (In general, the partition coefficient depends on the temperature. However, the partition coefficient does not change in the range of 20-30°C in this system. Therefore, this experiment can be conducted at room temperature without temperature control.)

6. **Transfer** 10 mL of the aqueous phase of **Solution C** to a conical beaker with a 10 mL volumetric pipette (***Refer** to "*Taking an Aliquot of Aqueous Phase A or B*"). **Add** a stirrer bar and 1 drop of phenolphthalein solution. **Titrate** using 0.01 mol L^{-1} aqueous sodium hydroxide solution with stirring. **Repeat** the titration as needed (the titration can be done up to 3 times). Similarly, **titrate Solution B** and **A** in that order.

* "*Taking an Aliquot of Aqueous Phase A*"

a. **Insert** a volumetric pipette into the solution so that the tip is near the center of the aqueous phase.
b. **Blow out** a small amount of air using a pipettor and **push out** the solution at the tip.
c. **Pull up** the aqueous phase so that the none of the oil phase remaining on the bottom and sides of the Erlenmeyer flask is drawn in.
d. **Pull** the volumetric pipette out of the solution and **wipe off** the solution on the outside of the pipette.
e. **Align** the meniscus of the solution and the line marked on the pipette.
f. **Transfer** the aqueous phase to a conical beaker.

* "*Taking an Aliquot of Aqueous Phase B*"

a. **Insert** a pipette into the solution so that the tip is near the center of the aqueous phase.
b. **Blow out** a small amount of air using a silicone dropper and **push out** the solution at the tip.
c. **Pull up** the aqueous phase (more than 10 mL) so that none of the oil phase remaining on the bottom and sides of the Erlenmeyer flask is drawn in.
d. **Pull** the pipette out of the solution and **wipe off** the solution on the outside of the pipette.
e. **Transfer** the aqueous phase to a beaker.
f. **Transfer** the aqueous phase from the beaker to a conical beaker using a volumetric pipette.

Results

Record the titration volume.

No.	Volume for Solution A [mL]	Volume for Solution B [mL]	Volume for Solution C [mL]
1			
2			
3			
Volume determined [mL]			

*It is not necessary to fill in all rows.

Questions

1. **Calculate** the concentration of 2,5-furandicarboxylic acid in the aqueous phase, C_w, and $\log C_w$ from the determined titration volume.

	Solution A	Solution B	Solution C
C_w [mol L^{-1}]			
$\log C_w$			

2. **Calculate** the concentration of 2,5-furandicarboxylic acid in 1-octanol, C_o, and $\log C_o$ using the total amount of 2,5-furandicarboxylic acid.

	Solution A	Solution B	Solution C
C_o [mol L^{-1}]			
$\log C_o$			

3. If 2,5-furandicarboxylic acid is present in water at a concentration of C_w as a single molecule and in 1-octanol at a concentration of C_o as an n-molecule aggregate, the partition coefficient K is calculated using the following equation.

$$\frac{C_o}{{C_w}^n} = K$$

Taking the logarithm of both sides, the equation can be transformed as follows:

$$\log C_o = n \log C_w + \log K$$

Taking points A, B, and C as ($\log C_w$(A), $\log C_o$(A)), ($\log C_w$(B), $\log C_o$(B)), and ($\log C_w$(C), $\log C_o$(C)), respectively, **calculate** n and K from the equations of the straight lines AB, BC, and AC, and **average** them. If necessary, **use** the graph paper on the next page.

	n	K
AB		
BC		
AC		
Average		

4. **Draw** the structure of the aggregated 2,5-furandicarboxylic acid that is expected to be present in 1-octanol from the calculated value of n.

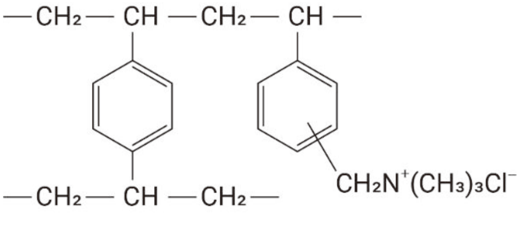
Practical Task 2. Separation and determination of metal ions using anion-exchange resins

Introduction

The separation and quantitative analysis of metal ions is of pivotal importance in the compositional analysis of a variety of materials, such as alloys and metal complexes. In aqueous solution, most metal ions exist as cations (aqua complexes). In hydrochloric acid, on the other hand, some metal ions are in equilibrium with chloride complexes and can be present as anions. The ratio of the cationic and anionic forms in solution depends largely on the chloride concentration, and this mechanism can be used to separate metal ions. In this task, you will separate Co(II) ion impurities from a sample solution containing Fe(III) ions (Sample X) using an anion-exchange resin column and determine the Fe(III) content in Sample X by chelate titration.

Background

The ion-exchange resin is a synthetic polymer with a three-dimensional network structure; the functional substituents responsible for the ion-exchange reaction are introduced on its surface. Resins that perform a cation-exchange reaction, i.e., the adsorption of cations and release of the initially adsorbed cations, typically protons, are called cation-exchange resins, while those that exchange anions are referred to as anion-exchange resins. Various types of ion-exchange resins with different characteristics are commercially available, and an example of the structure of an ion-exchange resin obtained from the copolymerization of divinylbenzene and a styrene derivative that bears a quaternary ammonium group is shown below.



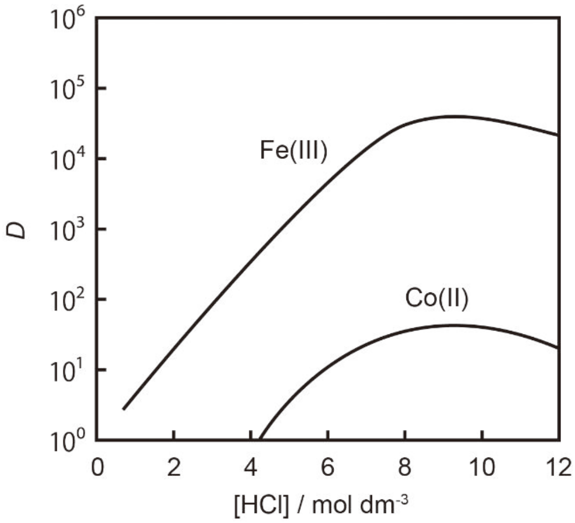
This resin can exchange the anions contained in a solution for the chloride ions associated with the ammonium groups. The adsorption and dissociation of the anions are reversible reactions because they are based on the electrostatic interaction between the ammonium group and the anion. Therefore, specific anions can be retained or eluted by appropriately adjusting the concentration of chloride ions.

In this task, we will use a strongly basic anion-exchange resin manufactured by Dow Chemical Co., Ltd. (DOWEX™ 1×8 100–200 Mesh Cl^- Anion Exchange Resin), which can replace the anions in solution with chloride ions. In our experiment, we use a chromatographic column packed with the resin, and the analyte is passed through the column using hydrochloric acid as the eluent. Assuming that the generation of chloride complexes and their reaction with the resin are in equilibrium, it is possible to elute the desired anions from the column by appropriately adjusting the concentration of the hydrochloric acid.

The partition ratio, D, is defined as the ratio of the total concentration of the substance in the solid phase (mol g^{-1}) to the total concentration of the substance in the liquid phase (mol cm^{-3}).

$$D = \frac{\text{total concentration of the substance in the solid phase (mol g}^{-1}\text{)}}{\text{total concentration of the substance in the liquid phase (mol cm}^{-3}\text{)}}$$

The relationship between D and the concentration of hydrochloric acid, [HCl], for Fe(III) and Co(II) ions is given below. The figure shows that Fe(III) has a large D and is more easily adsorbed on the resin at all [HCl] values. For example, when 4 M HCl is used as the eluent, Fe(III) is about 1000 times more likely to be adsorbed on the resin than Co(II). Therefore, under this condition, Co(II) ions will elute from the column first. By lowering [HCl] after removing the Co(II) ions, the adsorbed Fe(III) can be eluted.



Chemicals

Substance	**Name**	**State**	**GHS Hazard Statement**
HCl (6, 4, 0.5 M)	Hydrochloric acid	Aqueous solution	H290, H301, H314, H318, H332, H334, H370, H372, H400
NH_3 (1 M)	Ammonia	Aqueous solution	H290, H302, H314, H318, H370, H401
VBB indicator	Variamine Blue B	Diluted with KCl	NA
EDTA (0.01 M)	Disodium dihydrogen ethylenediaminetetraacetate	Aqueous solution	NA
Sample X		Acidic solution	NA

Glassware and equipment

1 Column packed with DOWEX™ 1×8 100-200 Mesh Cl^- Anion Exchange Resin (i.d. = 10 mm)
1 Burette, 25 mL
1 Laboratory stand with burette clamp
7 Conical beakers, 100 mL
1 One-mark pipette, 2 mL
1 One-mark pipette, 20 mL
1 Volumetric flask, 100 mL
3 Pipettes
2 Pasteur pipettes
1 Pipetting bulb
1 Glass vial
1 Glass rod
1 Alcohol thermometer
1 Spatula (spoon)
1 Hot plate
\- Congo Red Paper

Procedure

A. Separation of the Co(II) and Fe(III) ions contained in Sample X

1. The column is packed with anion-exchange resin and pre-conditioned with 6 M HCl. **Lower** the liquid level to the cotton on the top of the column, being careful not to let air bubbles enter.
2. **Transfer** 2 mL of Sample X into a sample bottle and then gently **load** the entire volume on the top of the column using a Pasteur pipette so that the sample is charged evenly.
3. **Lower** the liquid level to the cotton. **Rinse** the sample bottle and inner wall of the column with a small amount of 6 M HCl and **load** the washings onto the column in a similar manner. **Repeat** this operation several times to adsorb all the metal ions on the anion-exchange resin.
4. **Elute** the column with 4 M HCl and **collect** the first fraction in a 100 mL conical beaker. You can easily recognize the fraction by color.
5. **Elute** the column with 0.5 M HCl once you observe that all the first fraction has been collected. **Collect** the second fraction in another 100 mL conical beaker until all the second fraction has eluted.
6. **Elute** the column with H_2O to collect the remaining residue adsorbed on the resin.

Note

To repeat the experiment, wash the column with 20 mL of water followed by 10 mL of 6 M HCl before repeating the procedure.

B. Determination of Fe(III) ions

In this experiment, the concentration of Fe(III) ions contained in Sample X is determined using the fraction containing Fe(III) ions obtained in Experiment A.

1. **Dilute** the fraction containing Fe(III) ions separated in Experiment A to 100 mL.
2. **Transfer** 20 mL of the diluted solution to a 100 mL conical beaker.
3. **Adjust** the pH to 2-3 using 1 M aqueous ammonia. In this pH range, the Congo Red test paper turns purple. If a precipitate appears, **add** a small amount of HCl to redissolve all the precipitate.

4. **Warm** the solution to approximately 50 °C using a hot plate.
5. **Add** VBB indicator to the solution until the solution turns dark purple. You do not have to weigh the VBB, but **judge** the appropriate amount by the color of the solution. Approximately 50 mg is required.
6. **Titrate** the sample solution with 0.01 M EDTA quickly so that the solution does not cool.
7. **Determine** and **record** the amount of EDTA added to reach the equivalence point where the sample solution changes from the initial purple color to a pale yellow, and the color does not change further even if additional EDTA solution is added.
8. **Repeat** the titration using the remaining diluted sample solution. Although titration can be performed up to 4 times, it is sufficient to perform it only as many times as you need.

Questions

I. **Draw** the chemical structure of the chemical species that the Fe(III) ion is expected to form in 6 M HCl.

II. **Report** the amount of 0.01 M EDTA solution needed to reach the equivalence point. You only need to report the number of times you titrated.

#	1	2	3	4
Amount of 0.01 M EDTA solution / mL				

III. **Report** the number of Sample X analyzed and **calculate** the molar concentration of Fe(III) ions contained in Sample X.

# of Sample X

Molar concentration of Fe(III) ions in Sample X

mol dm^{-3}

Discussion

What causes the color change of the first fraction before and after elution from the column?

Instructions for mentors

Preparation of Sample X

Dissolve $NH_4Fe(SO_4)_2 \cdot 12H_2O$ ($M = 482.25$) and $CoCl_2 \cdot 6H_2O$ ($M = 237.93$) in 6 M HCl. Concentrations of Fe(III) ions between 0.1–0.2 M are appropriate, while that of Co(II) should be less than 0.1 M.

Note

$FeCl_3 \cdot 6H_2O$ can also be used as the source of Fe(III) ions. However, it may be difficult to know the prepared concentration accurately due to the hygroscopic nature of the salt.

Preparation of VBB indicator diluted with KCl

Mix 1 part VBB with 200 parts KCl in a mortar. Store the mixture in a brown bottle.

Preparation of the anion-exchange resin column

Note

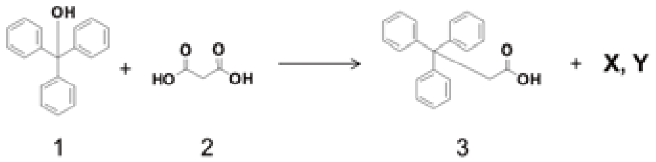
The following procedure can be included in the task if the students have time to spare.

Wash the anion-exchange resin (about 5 g per person) with deionized water (hereafter referred to as water) and let the resin swell in water overnight. Loosely pack absorbent cotton at the bottom of the chromatography column and add water to remove air bubbles. Using a funnel, pour the swollen resin into the column (10 cm in length) and open the cock to drain the excess water. Note that no air bubbles should enter the top of the resin. Place a small amount of absorbent cotton on top of the resin so that its surface is not disturbed and add a small amount of water to remove air bubbles. Check that there is no resin outflow from the column and that the flow rate is around 15 drops/min (typically 10–20 drops/min). If the column is not to be used immediately, add an appropriate amount of water so that the upper part of the column does not dry out. Prior to the experiment, lower the liquid level to the cotton and gently add 10 mL of 6 M HCl to flow through for conditioning.

Practical Task 3. Brevity is the soul of wit in organic synthesis

Introduction

In organic synthesis, C–C-bond-forming reactions to build molecular frameworks are some of the most basic yet also most important reactions. Many C–C-bond-forming reactions require large amounts of organic solvents and complicated procedures for separation and purification of the target compounds and are thus associated with a relatively high environmental load. In this task, a C–C-bond-forming reaction is carried out between triphenylmethanol (**1**) and malonic acid (**2**) to synthesize 3,3,3-triphenylpropionic acid (**3**) as shown in equation (1). This is a well-designed synthetic method in which the reaction proceeds via the simple heating of two solid raw materials, and the target product **3** can be obtained in high purity using only recrystallization without performing complicated separation procedures. The purpose of this task is to consider the reaction mechanism based on the experimental results and understand the well-designed reaction system.



(1)

Chemicals

Substance	Name	State	GHS Codes
$(C_6H_5)_3C–OH$	Triphenylmethanol	Solid	H302
$CH_2(CO_2H)_2$	Malonic acid	Solid	NA
C_2H_5OH	Ethanol	Liquid	H225- H320

Glassware and equipment

- 1 Erlenmeyer flask (30 mL)
- 1 Hot plate with digital temperature display (or a thermometer for the surface temperature)
- 1 Pipette (5 mL)
- 1 Spatula
- 1 Screw-top bottle (20 mL)
- 1 Apparatus for filtration
- 1 Paper for wrapping powdered medicine
- 1 Pair of work gloves

Experimental procedure

Caution

In this task, gases with low toxicity but a strong smell are generated. Perform in an environment where a fume hood or other air exhauster can be used appropriately.

During heating, the hot plate reaches high temperatures. Be careful to avoid burns.

1. **Set** the surface temperature of the hot plate to 170 °C. Control of the surface temperature is essential. If the hot plate does not have a digital temperature display, its surface temperature should be measured using a thermometer (such as a radiation thermometer).
2. **Add** triphenylmethanol (Ph_3C–OH, 1.041 g) and malonic acid (2.082 g) to an Erlenmeyer flask (30 mL) and mix the reactants by gently swirling the flask by hand.
3. **Place** the Erlenmeyer flask on the hot plate at 170 °C.
4. **Heat** the Erlenmeyer flask for 30 min while observing the reaction.
5. Wearing the work gloves, **remove** the Erlenmeyer flask from the hot plate and **place** it on a stack of Kimwipes on the workbench.
6. **Set** the surface temperature of the hot plate to 120 °C.
7. **Allow** the flask to cool for 1 min.
8. **Add** a solution of EtOH:H_2O (5/1, v/v, 1 mL) to the reaction mixture and stir the solution to initiate crystallization.
9. If no crystals form, **rub** the wall with a spatula to induce crystallization.
10. **Add** additional EtOH:H_2O (5/1, v/v, 5 mL).
11. **Place** the Erlenmeyer flask on the hot plate at 120 °C.
12. After complete dissolution, **move** the Erlenmeyer flask onto the Kimwipes on the workbench.
13. **Allow** to cool for ca. 2 h. Caution: even after cooling to room temperature, the crystals continue to grow slowly.
14. **Break** the crystals gently with a spatula.
15. **Collect** the crystals by filtration under reduced pressure.
16. **Place** the crystals into a screw-top bottle (20 mL) and **submit** the sample.

For the evaluation of the purity

1. Melting point

   Pure 3,3,3-triphenylpropionic acid has a melting point of 182 °C.

2. ^{1}H NMR spectroscopy

   The methylene protons and the aromatic protons of pure 3,3,3-triphenylpropionic acid show an integration ratio of 2:15. Use a deuterated solvent other than $CDCl_3$, C_6D_6, or methanol-d_4, because the residual protons in $CDCl_3$ and C_6D_6 overlap with the aromatic protons, while methanol-d_4 causes deuterium exchange of the methylene protons in 3,3,3-triphenylpropionic acid.

3. HPLC

   The main contaminant would be triphenylmethanol, which can be quantified by high-performance liquid chromatography using a reversed-phase column such as an octadecylsilicate column.

Questions

1. **Calculate** the theoretical yield, showing the details of the calculation method. It should be noted that the crystal water and solvent are not included.

2. **Write** the chemical formulae of the products X and Y that are generated by the reaction of triphenylmethanol (**1**) and malonic acid (**2**) in equation (1).

3. **Draw** the chemical structure of the ionic intermediate **A** that is generated from triphenylmethanol (**1**).

4. **Describe** the most important experimental evidence suggesting the formation of the ionic intermediate **A**.

5. In this task, malonic acid plays multiple roles. **Write** the role of malonic acid other than as a stoichiometric reagent and a solvent.

6. This task requires an appropriate air exhauster (such as a fume hood) for removing compound **B** generated during the reaction. **Write** the formula of compound B.

7. The procedure in this task is well designed. If the reaction conditions are changed as described below, **what** will occur?
   (i) using a 1:1 mole ratio of triphenylmethanol and malonic acid to avoid using a large amount of malonic acid.
   (ii) using a solvent for the enhancement of the reaction selectivity.
   (iii) using a Liebig condenser, the generated compound **B** is refluxed to prevent it from leaving the system.
   (iv) the reaction is carried out at 150 °C to implement milder conditions, or at 200 °C to enhance the reaction rate.

To further enhance the efficiency of the reaction (e.g., yield, purity, reduced raw material consumption, reduced energy consumption, reduced waste, simpler procedure), what kind of method might you propose? **Discuss** this with your mentor.

“ The best is not, so long as we can say, ‘This is the best.’” – modified from King Lear.

Catalyzer

Welcome Message

The 53rd International Chemistry Olympiad IChO2021 will be held in Osaka, Japan, from Saturday, July 24 to Monday, August 2, 2021. On behalf of the Organizing Committee, I look forward to welcoming many talented high school students who love chemistry to Japan.

Chemistry is all around us as the central science. Chemistry has a mission to create new materials. Chemistry is the only scientific discipline that can understand and transform the structures and function of materials at the atomic and molecular levels. Chemistry thus must play a key role in finding solutions for many global issues, including energy, environmental, and resource related issues, that humanity is now facing. I hope that IChO2021 Japan contributes to foster many young talents who will be involved in the states of art of such aspects of chemistry.

Osaka, the venue for IChO2021 is surrounded by two old capitals, Nara and Kyoto, as the birthplace of Japan's politics and culture. Osaka is not just a lively, modern commercial city, but also is the birthplace of chemical research in Japan. I really hope that IChO2021 Osaka, Japan serves as a catalyzer for all participants to make many friends through personal communications and cultural exchanges.

However, the situation surrounding us has changed significantly last year, 2020. We have been experiencing a difficult situation due to the COVID-19 global pandemic. The IChO2020 Turkey was forced to be held online. I would like to express my heartfelt appreciation and congratulations to all members of the IChO2020 Turkey Organizing Committee and the Steering Committee for their great efforts to make the IChO2020 so successful with the Online Theory Exam on July 25 and the Online Closing Ceremony on July 30.

I am convinced that the great success of Online IChO2020, as the first attempt in IChO history, should be worthy of note in the following three points: (1) It provided precious opportunity to many talented high school students around the world to enjoy chemistry in their own countries. (2) They were given hope and courage to overcome unprecedented difficulties. (3) International friendships and trust have been strengthened among over 60 participating countries. We have learned a lot from the Online IChO2020.

At the end of the Closing Ceremony, I was invited to hand over the IChO flag through the computer from Professor Hasan Mandal, Chairman of the Organizing Committee for IChO2020 Turkey.

It is finally our turn, but the situation is still uncertain. We have started preparations assuming an Online IChO2021, as well as a real event in Osaka, Japan. In any case, we, organizing committee all together, will concentrate our efforts to lead a successful IChO2021 Japan.

Our final decision will be announced in due course. We ask for the understanding and cooperation of all those involved.

Dr. Kohei Tamao

President, IChO2021 Japan Committee
Chairman, Organizing Committee for the 53rd IChO2021 Osaka, Japan

Japan

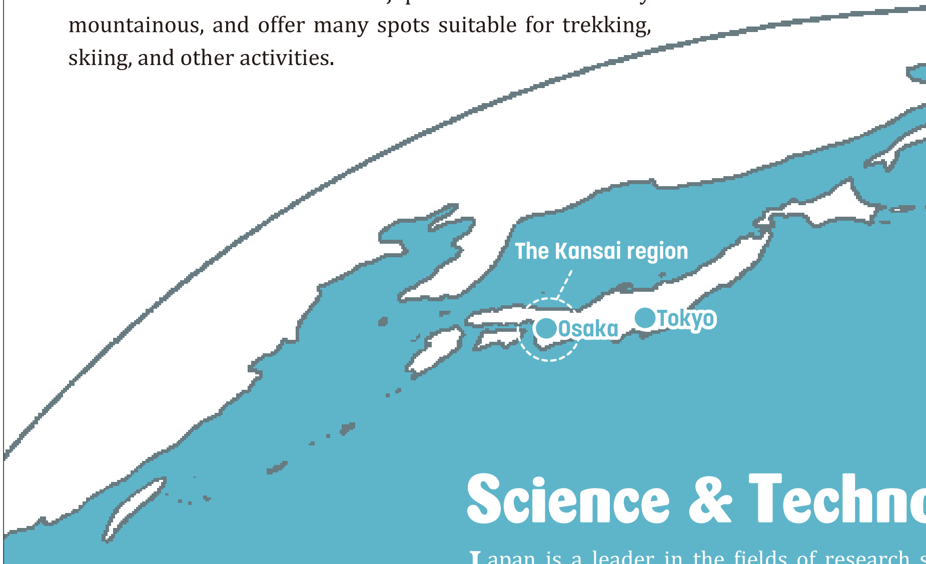
Area: 377,975 km^2 (61st in the world)
Population: 126.86 million (11th in the world in 2019)
Currency: JPY (103 JPY = 1 USD, 05/01/2021)
Language: Japanese (with many dialects)


Mt. Fuji

The 53rd International Chemistry Olympiad (IChO53) 2021 will be held in Osaka, Japan. This is the second time for Japan to host it; the first time (IChO42) was in 2010 in Tokyo. Japan has approximately 6,800 islands, including the four major islands of Hokkaido, Honshu, Shikoku, and Kyushu, and is situated on the Eastern edge of the Eurasia continent. There are mega cities such as Tokyo and Osaka. However as soon as one steps out of such ultra-urban areas, one is greeted by beautiful mountains and streams. Japan is a country whose land stretches from north to south with various climates ranging from subarctic to subtropical, four seasons, and distinctive local regions rich in nature. As the Japanese archipelago is part of circum-Pacific volcanic zone, Japan has several active volcanoes and a countless number of hot springs all around the country. These springs result from volcanic activities and provide a rich resource for bathing. Additionally, Japan has a total of 300,000 kilometers of coastline, and consists of many islands where people can enjoy swimming, fishing, boating, and other marine leisure activities. Japan's islands are mostly mountainous, and offer many spots suitable for trekking, skiing, and other activities.

Along the Pacific coast, major industrial zones were constructed from which various chemical, mechanical, electronic, and automotive products are exported globally. Osaka prefecture, where the 53rd International Chemistry Olympiad (IChO53) will be held, belongs to the Kansai region and is located about 400 kilometers from Tokyo, Japan's capital. It can be reached in only two and a half hours by the Shinkansen bullet train.

Japan's traditional culture has become increasingly popular among international travelers to Japan. This includes not only traditional crafts, *kimono*, and architecture, as seen in its historical shrines and temples. Japanese cuisine and its unique gastronomic culture are also attracting much interest, particularly among those who are health conscious. Japanese animation has become a focus of popular culture and is enjoyed by wide range of generations globally.




SPring-8, photo provided by RIKEN

Science & Technology

Japan is a leader in the fields of research science, technology, machinery, and medicine. There are approximately 700,000 researchers in Japan, and the national R&D budget of $170 billion is the third largest in the world. The Kansai region is home to a number of advanced research facilities including SPring-8, the world's largest third-generation synchrotron radiation facility, Keihanna Science City, and Kobe Biomedical Innovation Cluster, contributing to Japan's leading science and technology. Japan has twenty-four Nobel Prize winners in the natural science fields, the fifth largest number in the world after the United States, the United Kingdom, Germany, and France. Eight are recipients of the Nobel Chemistry Prize, and five of them are from the Kansai region.


Blue LED, photo provided by JST

Osaka and the Kansai region

The Kansai region refers to the area in the mid-western part of the island of Honshu, which is the largest of the four main Japanese islands. This region consists of six prefectures, namely, Osaka, Kyoto, Hyogo, Shiga, Nara, and Wakayama. It is one of the largest economic zones in Japan, second only to the Tokyo area, and has three large cities, Osaka, Kyoto, and Kobe, whose populations exceed one million. Kindai University, the venue of IChO53, is located in Osaka Prefecture, which is a metropolis with a population of 8,800,000.

Historically, this area was once the political, economic, and cultural center of the nation. In the 7th century Japan's first capital and imperial castle were situated in present-day Nara (Asuka Itabukinomiya). The capital was transferred to Osaka (Naniwanomiya) followed by Nara (Heijokyo). It was then relocated to Kyoto (Heiankyo) where it remained for approximately 1,200 years before finally being officially moved to Tokyo in 1868. Given the long history of this area, there are many historical buildings that have been designated as UNESCO World Heritage Sites. Kyoto and Nara are especially well known as Japan's ancient capitals, making them highly popular destinations for domestic and international travelers.

The climate of this area may be divided into the Sea of Japan climate zone, the Pacific climate zone, and the Setouchi climate zone, which is sandwiched between the two. Given these different climate zones, the area is blessed with exquisite natural scenery. The Kii Mountain area that straddles the three prefectures of Wakayama, Nara, and Mie, is famous for its beautiful nature. The sacred sites and pilgrimage routes of the Kii Mountains are registered as World Heritage Sites.

Food

Japanese cuisine is well known worldwide. Among the most popular dishes are sushi, ramen, tempura, and curry and rice. In the Kansai region, Kyoto, which is surrounded by mountains, did not have good access to fresh seafood. Nonetheless, Kyoto is renowned for its cuisine made with unique local vegetables known as *Kyoyasai* and dried foods. Osaka, which is a center for fresh foods, has a rich and varied gastronomic culture that has flourished for centuries. Today it is known for *konamon*, a general term used for savory foods made from flour as well as fresh ingredients. Dishes such as *takoyaki* and *okonomiyaki* have become very popular, even among international visitors, as casual and inexpensive dishes with a savory taste.

Language

Standard Japanese language is used nationwide, but there are also various dialects particular to each region. It is often possible to tell which region a person is from by his or her intonation. Some dialects are distinctive which can make it difficult for someone who is not from that area to understand. The Tokyo dialect is now considered standard Japanese. However, in the Kansai region, there are many distinctive dialects spoken in different areas within the region, forming a group of Kansai dialects or *Kansai-ben*. There are slight differences among the dialects in the region making it possible to distinguish the part of the region from which the speaker comes. Further details regarding the Kansai dialect will be mentioned in Catalyzer No. 1.

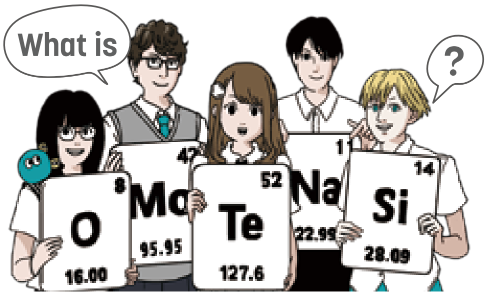
The Venue
Kindai University At a Glance

3-4-1 Kowakae, Higashiosaka City,
Osaka 577-8502, Japan
https://www.kindai.ac.jp/english/

Kindai University was founded in 1925. Now one of Japan's largest universities, it has six campuses in western Japan and boasts research facilities across the nation - from Hokkaido in the north to Kagoshima in the south. Currently, Kindai University comprises 14 faculties with 48 departments, 11 graduate schools, a law school, 18 research facilities, two junior colleges, 18 associated primary and secondary schools, and two teaching hospitals. The university has over 30,000 students and more than 500,000 alumni and has about 500 international students enrolled from all over the world. Kindai University has 250 partner universities in 50 countries and regions, and continues to interact with universities around the world. Kindai University conducts research in a wide range of fields and is making a name for itself as a leader in aquaculture, most notably for its work with bluefin tuna. Dedicated to meeting the needs of today's rapidly changing society, Kindai University will continue expanding its educational programs and facilities.

Useful Japanese Phrases

English		Japanese
Good morning	Ohayou gozaimasu	おはようございます
Good afternoon	Kon'nichiwa	こんにちは
Good evening	Kon'banwa	こんばんは
Good night	Oyasumi nasai	おやすみなさい
Good-bye	Sayounara	さようなら
Excuse me	Sumimasen	すみません
I am sorry	Gomen nasai	ごめんなさい
I don't understand	Wakarimasen	わかりません
Thank you	Arigatou	ありがとう
Yes	Hai	はい
No	Iie	いいえ
Please	Onegai shimasu	おねがいします
Chemistry Olympiad	Kagaku orinpikku	化学オリンピック



These five elements spell "OMoTeNaSi", the Japanese word for hospitality. It means to wholeheartedly take care of guests without expecting anything in return. Attention is paid to even the smallest details in order to bring guests the best experience possible. As you make your way across Japan, you will find *omotenasi* everywhere.

Chemistry! It's Cool!

IChO2021 Catalyzer No. 0

Official Website
https://www.icho2021.org/
icho2021

Weather information
(Average in late July)
Osaka
25 °C/35 °C
Humidity: 75%

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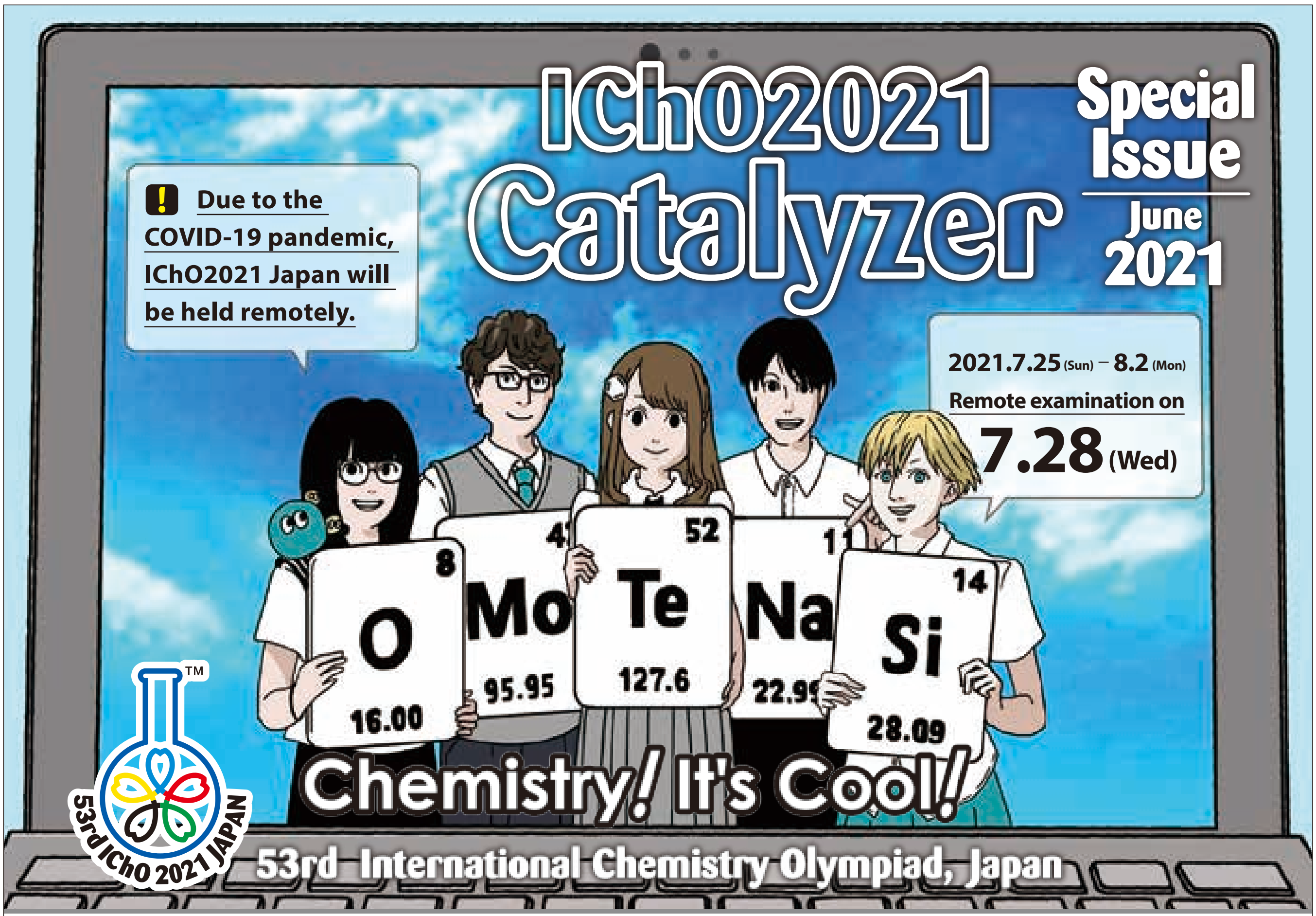


Dear Students, Mentors, Guests, Distinguished Scholars, Observers, SC Members and Colleagues:

Welcome to the IChO2021 Japan 53rd International Chemistry Olympiad. I am delighted to serve as the Chair of the Executive Committee of IChO2021, a very important scientific event especially for students at secondary school level.

This past January, we carefully discussed whether we could hold a real or remote Olympiad in 2021. We eventually decided to hold a remote Olympiad this summer, owing to the ongoing global COVID-19 pandemic. The most important priority was to be able to organize IChO2021 safely and smoothly. Our remote IChO2021 will be held from 25 July to 2 August, 2021. The three key concerns of the Chemistry Olympiad are as follows: (1) The safety of all participants, including secondary school students; (2) Equal opportunity for every student; and (3) International experiences via competition and cooperation, despite the Olympiad being held remotely.

I hope you have already visited our website, https://www.icho2021.org. There you can find our motto for IChO2021, "Chemistry! It's Cool!", as well as our first Catalyzer newsletter. We are sure that you can still enjoy chemistry and experience O-Mo-Te-Na-Si during this remote Olympiad.

The opening ceremony will be held online on our website on 25 July, 2021, and the examination will be conducted in each country on 28 July. Students will be able to take the examination in their home countries. The duration of the examination is five hours. The examination may start at any time between 4:00 pm and 9:00 pm JST, and each country can decide the starting time that suits them.

After grading is complete, an online closing and award ceremony will take place on 2 August. Students may attend the ceremony with their avatars. Medals and the certificates will be sent to participants via surface mail together with commemorative gifts.

Between the opening and closing ceremonies, Olympiad participants can enjoy a series of remote events. These include virtual visits to tourist spots such as Himeji Castle and other famous world-heritage temples and shrines in the Kansai region (Kyoto, Nara, Osaka, and Kobe). Interesting cultural events are also planned, including a visit to a special site at which repair work to an ancient Buddha statue is being carried out. Students can take part in a scientific virtual visit to SPring-8, the world's largest synchrotron radiation facility. Communications among participating students are also important. Virtual reality avatars will be available for all students to enhance their remote communication experiences. We also plan to make the practical examination available to the general public so they can try their own experiments.

We will make every effort to make our remote IChO2021 Japan a resounding success. On behalf of the executive committee, I sincerely hope you all enjoy the Chemistry Olympiad this summer.

Dr. Yoshiki Chujo
Chair of the Executive Committee,
IChO2021 Japan

Remote Examination FAQ

Due to the COVID-19 pandemic, IChO2021 Japan will be held remotely. The safety of every participant is our first priority. Even though we might be far apart, we still aim to provide special experiences to the participants in July.

Several changes to regulations for the examination are listed below. For more details, please see website.

Q What are the time zones for the remote IChO?

A All dates and times on this document are based on Japan Standard Time (JST), which is Coordinated Universal Time (UTC) +9 hours. Japan does not use daylight saving time during the summer.

Q When is the date for the examination?

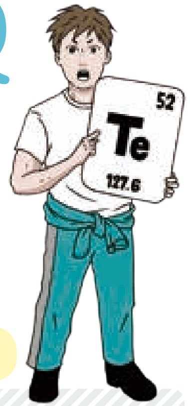
A The theoretical examination will take place on 28 July, 2021.

Q How long is the examination?

A The duration of the examination is 5 hours. The details of the examination must be reported by invigilators. A report form to be completed by invigilators will be provided with the student examination papers.

Q What is the start time of the examination?

A The examination may start at any time between 16:00 and 21:00 JST, and each country can decide its own starting time. However, all competitors in each country must have the same examination timetable to avoid ill-intentioned communication among competitors. Countries with multiple time zones must set their timetable on the basis of one specific time zone and conduct the examination accordingly.



Q How will be the examination conducted remotely?

A The preparation of the examination (discussions, voting, translation, printing) will be done using Oly-Exam software. Mentors will read, comment and vote on, and translate the examination text using the Oly-Exam software.

Q Where should the examination be located?

A The examination location must be a calm and quiet room with electricity, and equipped with a computer or smartphone, web camera, microphone, high quality printer, scanner with PDF-conversion software, and stable internet connection. Each location will be checked via Zoom before the examination.

A single location for the full number of 4 students is highly preferred. If legal travel restrictions in the country forbid a single location, multiple locations for one country are acceptable.

Q What help/tools are allowed for the examination?

A Only a non-programmable calculator, good writing pen and a ruler can be used during the examination. Students should write their answers only using a pen with dark ink.

Q What are the important dates for the IChO2021?

A See the following Table.

Schedule of Remote IChO2021 (Tentative)

J : JST C : CET E : EST

Date	Student	Mentor	
Jul 23, Fri		Training of Oly-Exam	J 21:00 C 14:00 E 8:00
Jul 25, Sun	Opening Ceremony (Start time to be determined)		
		Receive the problem	J 21:00 C 14:00 E 8:00
Jul 26, Mon		Deadline of feedback	J 9:00 C 2:00 E 20:00
	Activity (To be announced)	Jury meeting	J 21:00 C 14:00 E 8:00
Jul 27, Tue	Activity (To be announced)	Receive the authorized problem Translation/submission	J 9:00 C 2:00 E 20:00
Jul 28, Wed	Start remote examination at J 16:00 ▼ 21:00 C 9:00 ▼ 14:00 E 3:00 ▼ 8:00	Deadline of translation	J 9:00 C 2:00 E 20:00
		[Invigilator] Receive and print out the problem	J 14:00 C 7:00 E 1:00
		[Invigilator] Submit the solutions (Within one hour after the end of the examination)	
Jul 29, Thu		Receive the solution and the grading scheme	J 9:00 C 2:00 E 20:00
	Activity (To be announced)		
Jul 30, Fri	Activity (To be announced)	Receive grading (from Organizer, Request arbitration)	J 9:00 C 2:00 E 20:00
		Deadline of request, Jury meeting	J 21:00 C 14:00 E 8:00
Jul 31, Sat		Arbitration America(west) ▶▶▶ Asia ▶▶▶ Europe ▶▶▶ America(east)	J 9:00 C 2:00 E 20:00
Aug 1, Sun		Receive final results	J 9:00 C 2:00 E 20:00
	Activity (To be announced)		
Aug 2, Mon	Closing Ceremony		J 21:00 C 14:00 E 8:00

Seimi-kyoku 舎密局

sei mi kyoku

the Origins of Modern Chemistry in Japan

During the Edo period (1603 to 1868), when the Tokugawa shoguns ruled the country, Japan adopted a policy of seclusion and closed its borders to the outside world for more than 250 years; international trade was allowed only with China (mainly under the Qing dynasty) and the Netherlands. Any information on the natural sciences that emerged in Europe in the early 18th century came only from the Netherlands through *Dejima*, a small artificial island in the bay of Nagasaki on the west end of Japan.

The first systematic chemistry lectures in Japan were given by Johannes Lijdius Catharinus Pompe van Meerdervoort, a physician who came to Japan in 1857. Pompe began teaching Western medicine in Nagasaki, and after he found that the students lacked fundamental knowledge in science, he also started teaching a course in basic science. After Pompe left Japan, Dr Anthonius Franciscus Bauduin was invited to succeed him, and taught chemistry as well as medicine. Following Bauduin, the Dutch chemist Koenraad Wolter Gratama was invited to teach in Japan as a specialist in science and chemistry teaching.

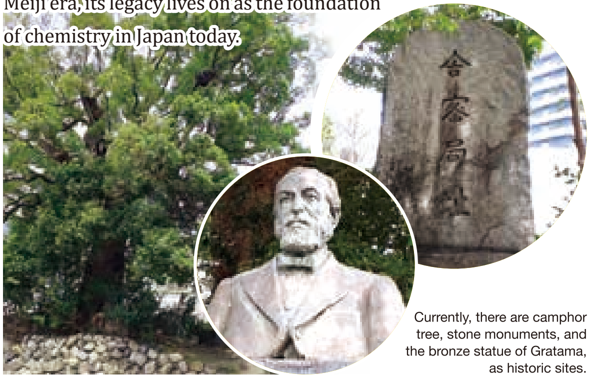
In 1867, Gratama was set to be transferred to the *Kaiseijo*, the shogunate's Western education and research center located in Edo (present-day Tokyo), but this plan was thwarted when the shogunate collapsed during the Meiji Restoration in 1868. The new Meiji government, however, established a college called the *Seimi-kyoku* in Osaka to replace the *Kaiseijo*, and welcomed Gratama as head lecturer there. The word *seimi* was a transliteration of the Dutch word *chemie*, though it is no longer used today. One reason behind the new government's move to establish the *Seimi-kyoku* in Osaka is said to have been their initial intention to move the capital from Kyoto to Osaka, rather than to Tokyo. Ultimately, however, the Emperor moved to Edo Castle where the Tokugawa shogunate was based, after the castle was surrendered bloodlessly to the new government. Eventually, Edo was renamed Tokyo and became the new capital city of Japan.

In 1868, the new *Seimi-kyoku* (also known as the *Osaka Seimi-kyoku*) was completed, and Gratama started teaching physics and chemistry there. Gratama not only taught students, but also initiated training programs for physics and chemistry teachers. The following year, a medical school and hospital were established nearby, where Bauduin also taught. Many students from the medical school also came to attend the lectures at the *Seimi-kyoku*, among them Jokichi Takamine, who later became well-known for his research on adrenaline (Catalyzer, No. 2). Kikunae Ikeda, who discovered the "umami" ingredient *Ajinomoto* (Catalyzer, No. 6), studied chemistry under the tutelage of Jiro Murahashi, Gratama's assistant at the *Seimi-kyoku*. Hiroakira Akashi, who worked at the medical school hospital, deepened his knowledge by listening to Gratama's lectures, and eventually established the *Kyoto Seimi-kyoku* in his home town Kyoto, with the support of the Kyoto prefectural government. Genzo Shimazu, a blacksmith who had been a contractor at the *Kyoto Seimi-kyoku*, was taught by the German teacher there, and later established Shimadzu Corporation, the chemical equipment manufacturer (Catalyzer, No. 5). These are just a few examples of the many students and teachers who received direct or indirect instruction from foreign teachers and who later drove the development of medicine, chemistry, and pharmacy in Japan.

Koenraad Wolter Gratama
(1831-1888)

© Tetsuo Shiba

In 1870, Gratama completed his term of office and returned to the Netherlands the following year. The German chemist Georg Hermann Ritter was invited to replace him. In 1872 however, all the personnel and assets of the *Seimi-kyoku* were transferred to the *Tokyo Kaisei Gakko* school, which later became the University of Tokyo. The *Seimi-kyoku* underwent several organizational and name changes, finally becoming the Third Higher School in 1889, which would later be merged into Kyoto University. At the site of the former *Osaka Seimi-kyoku* near Osaka Castle, there is a large camphor tree in a corner surrounded by a stone wall that appears to block the walkway, and at the base of the tree stands a stone pillar and monument that reads "Site of the Former *Seimi-kyoku*." On the reverse side of the monument is a majestic bust of Gratama. Although the *Seimi-kyoku* disappeared in the turbulent times for Japanese society in the early Meiji era, its legacy lives on as the foundation of chemistry in Japan today.



Currently, there are camphor tree, stone monuments, and the bronze statue of Gratama, as historic sites.

Element
 # 1

Japanese mineral resources
Au, Ag, and Cu

Today, Japan depends mostly on imports of the mineral resources it needs, but in the past it used to produce large amounts of gold, silver, and copper. Marco Polo, the 13th-century merchant and explorer who travelled throughout Asia, introduced Japan to Europe as “Japan, Land of Gold” in his travelogue *The Travels of Marco Polo*, which later became the driving force for adventurous explorers during the Age of Discovery.

Long ago, gold mines such as those on the island of Sado (part of Niigata prefecture today) and in Koshu (Yamanashi prefecture) produced significant amounts of gold. In the Edo era, from the 16th to the 19th centuries, the Tokugawa bakufu (shogunate) established an official gold guild known as the Kin-za, and gold coins called Keicho Koban and Oban were issued.

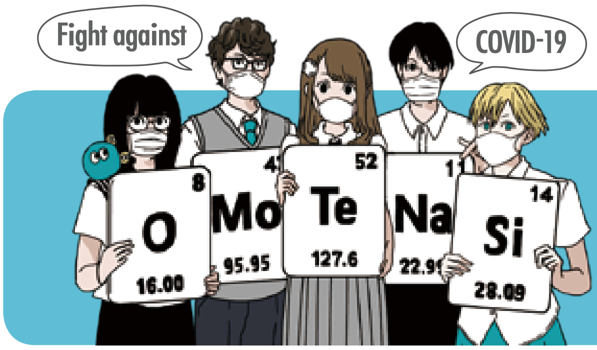
In terms of silver production, one of the major operations was the *Iwami Ginzan* silver mine, where production of silver continued for approximately 400 years from the 16th century. The *Iwami Ginzan* silver mine was located in what is the city of Oda in Shimane Prefecture today, and production reached its peak during the Edo period, when the mine was directly managed by the *bakufu*. Production then gradually decreased until the mine was closed in 1923. The *Iwami Ginzan* silver mine site was registered as a UNESCO World Heritage (Cultural) Site in 2007, listed as the Iwami Ginzan Silver Mine and its Cultural Landscape, with special mention made of its environmentally friendly operation.

Iwami Ginzan Silver Mine

Keicho Oban
© divetobluemarine, CC BY-SA 3.0, via Wikimedia Commons

Minetopia Besshi

The Besshi copper mine located in what is the city of Niihama in Ehime Prefecture, discovered in 1690, produced a total of 700,000 tonnes of copper in 283 years until it was closed in 1973. The former mine site is now the location of Minetopia Besshi, a historical theme park where people can learn how the mine operated in the olden days.



These five elements spell “OMoTeNaSi”, the Japanese word for hospitality. It means to wholeheartedly take care of guests without expecting anything in return. Attention is paid to even the smallest details in order to bring guests the best experience possible. As you make your way across Japan, you will find ***omotenasi*** everywhere.

Chemistry! It’s Cool!

IChO2021 Catalyzer June 2021 Special Issue

Official Website
https://www.icho2021.org/
icho2021

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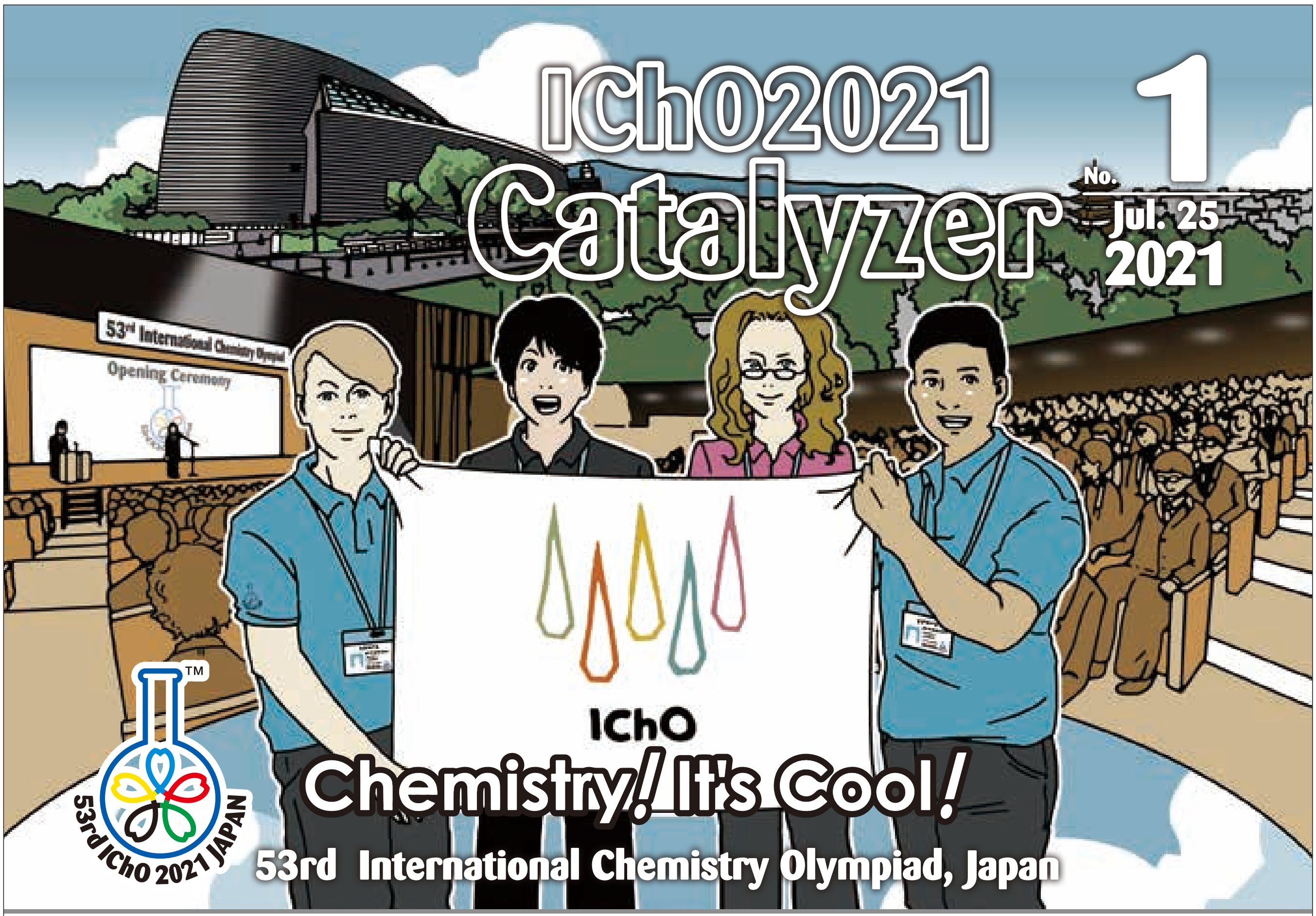


Cover illustration : Opening Celemony

Message

It is our great pleasure to host the 53rd International Chemistry Olympiad (IChO2021), a competition so rich in history since the first one in 1968, and to welcome very talented young students from 79 countries and regions around the world.

As important as it is as an academic subject, chemistry is also the basis for creating materials and substances with a vast range of functions that constantly supports our daily lives.

The COVID-19 pandemic is still plaguing the world. Chemistry is playing a vital role in the fight against COVID-19 by being applied for PCR and antigen testing to detect infection and its history and for the manufacture of COVID-19 treatment drugs.

Moreover, we expect chemistry to greatly contribute to achieving the Sustainable Development Goals, including the stable supply of food, the recycling of waste, and so on.

All the students participating in IChO2021 have the potential to address these various shared problems of the world and to open up a new path for humankind. It is a crucial issue for governments around the world to discover their talents and create an environment to develop fully these capabilities.

The International Science Olympiads, including IChO, have provided various opportunities for talented students to challenge, and contributed to discovering such students and fostering their capabilities. As the host country, Japan will make its utmost efforts to support this mission.

Because of COVID-19, like the previous Olympiad, IChO2021 will be held online. The organizers are planning to make full use of VR technology and avatar technology to provide remote tours to both state-of-the-art and traditional science and technology facilities, which large groups of people cannot usually visit. Unfortunately you will not be able to have direct interaction, however, with the creative use of these technologies, you will be able to overcome the barriers of distance and space to connect with your peers.

We hope that all of you representing your countries at this Olympiad will fully demonstrate your real abilities and the results of your efforts, improve yourselves through competitions, and make lasting friendships with peers.

It is our sincere wish that you all continue your self-improvement and make the most of your experiences to play active roles in leading your countries and the world.

HAGIUDA Koichi

the Minister of Education, Culture, Sports, Science and Technology

IChO2021 Japan Welcome Address at the Opening Ceremony on July 25

I am Kohei Tamao. Thank you for your kind introduction. It is a great pleasure and honor for me to say a few words at the opening ceremony of the 53rd International Chemistry Olympiad, IChO2021 Japan.

Dear talented high school students, mentors, scientific observers, guests, distinguished scholars, invigilators, Steering Committee members, and colleagues from all over the world, welcome to the Opening Ceremony of IChO2021 Japan.

Originally, we had been preparing to hold IChO2021 Japan at Kindai University, one of the biggest private universities in Japan, located in the lively and modern commercial city of Osaka in mid-west Japan, also known as the birthplace of chemical research in this country.

However, in light of the ongoing COVID-19 pandemic, we had no choice but to hold IChO2021 remotely, following the lead of IChO2020 Turkey last year.

This is the result of giving top priority to the safety of our young talented students and all participants, even at the expense of practical examinations and opportunities for in-person international exchange. I would like to thank all the International Steering Committee members led by Dr. Gábor Magyarfalvi for their enthusiastic discussion and acceptance of our decision.

Even under the difficult conditions presented by the COVID-19 pandemic, the good news is that we have accepted registrations from 85 countries and regions of the 89 to which we sent invitations. More than 320 students have been registered. I would like to express my sincere gratitude and respect for the wonderful efforts of mentors, teachers, and all concerned in each country to select talented students and set up the examination sites.

The theoretical examinations will be held on July 28th in each country, and the examination results, including gold, silver and bronze medalists, will be announced in the closing ceremony on August 2nd.

I am confident that the remote examinations on July 28th will be carried out in an atmosphere of justice, fairness, and trust, maintaining the spirit of IChO across space and time. It is my sincere hope that all the participating students will do their very best, showcasing the talents and skills they demonstrate every day.

As we are unable to hold the practical examinations, we have prepared a demonstration video of the practical tasks.

To compensate for the fact that the participants cannot meet in person, we will offer various initiatives for students to create international friendships and become familiar with Japanese culture and the state of art, science, and technology in this country.

For that purpose, VR avatars for all students have been prepared to facilitate remote networking and to give greater realism to virtual visits to sensitive areas such as the restoration site of an ancient Buddha statue and the world's largest synchrotron radiation facility, SPring-8, to which access is normally prohibited.

Dear students, now I would like to ask you to keep the following three things in mind, as you are about to enjoy a once-in-a-lifetime valuable experience.

First, you have been given hope and courage to overcome difficulties through your participation in this remote IChO2021 Japan.

Second, the unprecedented difficulties we have been facing can only be overcome by international friendships and trust. Thus, you should show gratitude and respect to your mentors, teachers, invigilators, and all others who have contributed to make this major international event a reality, despite the obstacles faced.

Third, I want you to remember that chemistry, the central science, is all around us. Chemistry must therefore play a key role in finding solutions for many global challenges, including energy, environmental, and resource-related issues that humanity is now facing.

I hope that IChO2021 Japan helps to foster many talented young people who will go on to play roles as future world leaders. While you do not have the opportunity to meet each other in person this time, I am convinced that one day you may meet each other somewhere in the world when you go to university or graduate school. I sincerely hope that you take the opportunities given to you as participants in this remote IChO2021 to create strong networks of international friendship, with the slogan "Chemistry! It's Cool!" as your watchword.

Finally, I would like to thank the Ministry of Education, Sports, Science and Technology (MEXT Japan) and the Japan Science and Technology Agency (JST) for their meaningful support, and the more than 180 chemical companies and trading companies in Japan as our sponsors for their substantial financial assistance, as well as numerous personal donations.

My special thanks are also due to all the members of the Japan Committee and Organizing Committee for IChO2021 Japan, as well as our secretariat and KNT Corporate Business Company, Ltd., as represented by the Vice President of the Japan Committee and Chair of the Fundraising Committee Dr. Kyohei Takahashi, Chairs of the Finance Committee the late Dr. Tadao Kondo and Dr. Teiji Koge, Chair of the Executive Committee Professor Yoshiki Chujo, Chair of the Scientific Committee Professor Hiroshi Nishihara, and member of the International Steering Committee Professor Nobuhiro Kihara.

Without their remarkable support and endeavors, this remote IChO2021 Japan would not be possible.

Now, it is my great pleasure to officially declare remote IChO2021 Japan open.

Thank you very much for your kind attention.

Dr. Kohei Tamao

President, IChO2021 Japan Committee
Chairman, Organizing Committee
for the 53rd IChO2021, Japan

Schedule of Remote IChO2021

Date	Student	Mentor	
Jul 25, Sun	Opening Ceremony (Virtual Reality Venue)		J 15:00 C 08:00 E 02:00
	VR Closed	Receive the problem	J 21:00 C 14:00 E 08:00
Jul 26, Mon	VR Closed	Deadline of feedback	J 09:00 C 02:00 E 20:00
		Jury meeting	J 21:00 C 14:00 E 08:00
Jul 27, Tue	VR Closed	Receive the authorized problem Translation ▸▸▸ submission	J 09:00 C 02:00 E 20:00
Jul 28, Wed	Examination (5 hours) Start between J 14:00 ▾ 05:00 (Jul 29) C 07:00 ▾ 22:00 E 01:00 ▾ 16:00	Deadline of translation	J 09:00 C 02:00 E 20:00
		[Invigilator] Receive and print out the problem	J 11:00 C 04:00 E 22:00
		[Invigilator] Submit the solutions (Within 2 hours after the end of the examination)	
Jul 29, Thu		Receive the solution and the grading scheme	J 09:00 C 02:00 E 20:00
	Activity (SPring-8 Virtual tour)		
Jul 30, Fri	Video: Practical Examination explanation	Receive grading (from Organizer, Request arbitration)	J 09:00 C 02:00 E 20:00
		Deadline of request, Jury meeting	J 21:00 C 14:00 E 08:00
Jul 31, Sat	Activity Video:History and Culture of Nara	Arbitration America (west) ▸▸▸ Asia ▸▸▸ Europe ▸▸▸ America (east)	J 09:00 C 02:00 E 20:00
Aug 1, Sun	Activity Video:Himeji Castle, Osaka, and Kyoto	Receive final results	J 09:00 C 02:00 E 20:00
		Activity Video:Himeji Castle, Osaka, and Kyoto	
Aug 2, Mon	Closing Ceremony (Virtual Reality Venue)		J 21:00 C 14:00 E 08:00

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time) 00:00 (Brown color letters) : The night before

The VR video programs will be opened at 00:00 JST on each day.

Nobel Prize Research from Japan 01

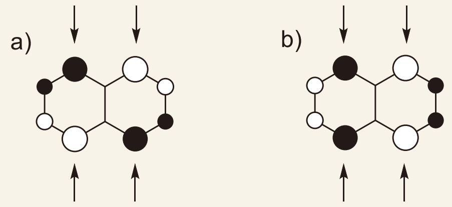
Frontier Orbital Theory

Kenichi Fukui


Photo by Kagaku-Dojin

Dr. Kenichi Fukui
(1918–1998)

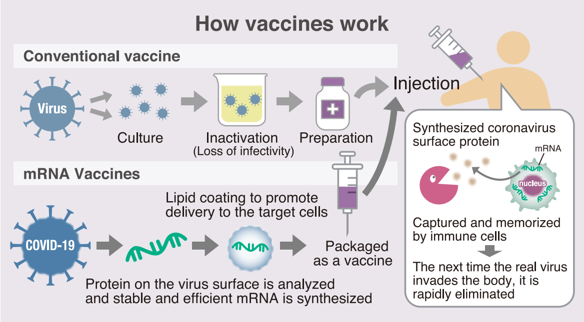
How do chemical reactions occur? For chemistry students, the frontier orbitals called HOMO (Highest Occupied Molecular Orbital) and LUMO (Lowest Unoccupied Molecular Orbital) are extremely important. This concept of frontier orbitals was conceived by Kenichi Fukui, who in 1952 proposed that electrophilic substitution reactions in aromatic hydrocarbons occur at the position with the highest coefficient of HOMO, while nucleophilic reactions are determined by the coefficient of LUMO. This was an epoch-making concept, completely different from the conventional theory of organic electronics, which was based mainly on electron density. In 1964, he further developed this theory by pointing out that the symmetry and phases of the HOMO and LUMO of the reacting molecule play important roles in cycloaddition reactions such as the Diels–Alder reaction. In 1981, he was awarded the Nobel Prize in Chemistry for “the theories concerning the course of chemical reactions,” together with Roald Hoffmann, who separately published the Woodward–Hoffmann rules in 1965. Fukui was the first Japanese chemist and Asian person to be awarded the prize, which had until then been won by researchers from Europe and the United States. Today, the concept of HOMO–LUMO is widely used not only in chemical reactions and physical properties of molecules themselves, but also in molecular electronics, organic electroluminescence, enzymatic reactions, and electron transfer in interactions in biomolecules such as proteins.



Frontier orbitals of naphthalene. a) HOMO. b) LUMO.
The arrows show locations where reactivity is higher.

COVID-19 and mRNA Vaccines

For certain infectious diseases, it is empirically known that once a person is infected they will not contract the disease again. This is due to the function of the immune system, which remembers the disease they have been infected with and can quickly eliminate the pathogen on the second infection. Vaccines make use of this biological function. Less virulent viruses or bacteria, as well as a portion of the pathogen (protein or polysaccharide), can be administered as a vaccine. This allows the immune system to remember the pathogen and prevent infection. Vaccines against COVID-19, a new type of coronavirus, which has had a major impact on our lives since 2020, are being vigorously developed around the world, resulting in the development of mRNA vaccines. Unlike conventional vaccines, mRNA vaccines deliver mRNA, the gene for the pathogen protein, into the human body. Although mRNA vaccines have been studied since the 1990s, they have not been put to practical use due to a number of drawbacks, including the following: 1) mRNA is not stable in vivo, 2) mRNA is not very efficient in the production of proteins, and 3) it is not easy to deliver mRNA into cells. Development of effective mRNA vaccines proceeded by solving these issues one by one. This was done through introducing artificial structures into the mRNA to prevent degradation by metabolism, and optimizing the RNA sequence to increase the efficiency of conversion into protein. Furthermore, by encapsulating the mRNA in lipid nanoparticles, researchers succeeded in efficiently delivering it into the cell. As a result, an extremely effective vaccine against coronaviruses has been developed.


How vaccines work

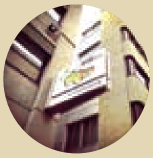
Doshomachi

Kansai Scenes 1

“Medicine Town” and Sukunahikona Shrine

In the era of Toyotomi Hideyoshi (1537 to 1598), drug wholesalers were concentrated in the Doshomachi area of Osaka in accordance with the government’s commercial policy. During the isolationist period of the Tokugawa shogunate (1603 to 1867), exchange with foreign nations was restricted to China and Holland. Drug wholesalers who imported drugs from those two countries established their businesses in Doshomachi, forming an officially approved guild, or *Kabunakama*, called the *Yakushunakagainakama.* In 1721, the Tokugawa government established an agency in Doshomachi for checking the quality of medicinal products made in Japan (*Wayakushu aratame kaisho*). Hence, all medicines commercially traded throughout Japan passed through Doshomachi first. All these historical connections led to Doshomachi being home to many pharmaceutical companies, making it Japan’s first “medicine town,” followed later by Nihonbashi Honcho in Tokyo.

The Doshomachi Pharmaceutical and Historical Museum (*Kusurinomachi Doshomachi Shiryokan*) is a great place to see exhibits of prescription medicines, instruments, equipments, and other related items used by medical wholesalers. The Sukunahikona Shrine, a Shinto shrine that is dedicated to medical deities, can also be found in Doshomachi.



Participating Teams

1 Armenia
2 Australia
3 Austria
4 Azerbaijan
5 Bangladesh
6 Belarus
7 Belgium
8 Brazil
9 Bulgaria
10 Canada
11 China
12 Chinese Taipei
13 Costa Rica
14 Croatia
15 Cyprus
16 Czech Republic
17 Denmark
18 El Salvador
19 Estonia
20 Finland
21 France
22 Georgia
23 Germany
24 Greece
25 Hungary
26 Iceland
27 India
28 Indonesia
29 Iran
30 Ireland
31 Israel
32 Japan
33 Kazakhstan
34 Korea
35 Kyrgyzstan
36 Latvia
37 Lithuania
38 Luxembourg
39 Malaysia
40 Mexico
41 Moldova
42 Mongolia
43 Montenegro
44 Netherlands
45 New Zealand
46 Nigeria
47 North Macedonia
48 Norway
49 Oman
50 Pakistan
51 Philippines
52 Poland
53 Portugal
54 Qatar
55 Romania
56 Russian Federation
57 Saudi Arabia
58 Serbia
59 Singapore
60 Slovakia
61 Slovenia
62 South Africa
63 Sri Lanka
64 Sweden
65 Switzerland
66 Syria
67 Tajikistan
68 Thailand
69 Trinidad and Tobago
70 Turkey
71 Turkmenistan
72 Ukraine
73 United Arab Emirates
74 United Kingdom
75 United States of America
76 Uruguay
77 Uzbekistan
78 Venezuela
79 Vietnam

Observer Teams

- Afghanistan
- Ecuador
- Egypt
- Kuwait
- Nepal
- Paraguay

Early Bird Communication

To Catalyzer

United Arab Emirates

Georgia

Vietnam

Students doing experiments in the lab and standing in front of the chemistry department gate.

Sweden (Sverige)

The Swedish team with the elements. Good luck with the Catalyser!

Kazakhstan

Croatia

Bulgaria

Indonesia

This picture was taken during the IChO training session on July 5 2021.

Nigeria

We are glad to participate in 2021 Remote IChO competition. Regards from Nigeria.

Today's schedule **Jul. 25**

Student

- **Opening Ceremony at VR Venue** J 15:00 C 08:00 E 02:00

Participants of IChO2021 can attend the opening ceremony from VR space.
Non-participants can also watch the opening ceremony from the IChO2021 website.

Mentor

- **Opening Ceremony at VR Venue** J 15:00 C 08:00 E 02:00
- **Receive the problem** (Oly-Exam) J 21:00 C 14:00 E 08:00

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

Short short from Kansai | A Papier-mâché Tiger

In ancient Asia, tigers were considered to be messengers from the Gods, and their bones were used as a medicine and in lucky charms. In 1822, when Osaka was hit by the cholera epidemic that was sweeping the world at the time, an apothecary in Doshomachi, Osaka, created a Japanese herbal medicine containing tiger skulls and distributed it with a tiger-shaped charm made of paper called *Hariko-no-tora*, meaning a papier-mâché tiger. Although the medicine itself became obsolete, *Hariko-no-tora* are still handmade as traditional crafts. They are popular in the Kansai region as lucky charms that protect people from disease and express the wish for healthy growth of children.

Useful Japanese Phrases +α
the Kansai dialect

Following on from the useful Japanese phrases introduced in Catalyzer No. 0, this edition features *Kansai-ben*, a dialect spoken in the Kansai region, where we had originally planned to hold the in-person IChO2021. Let's all try speaking *Kansai-ben!*

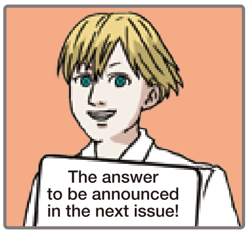
English	Standard Japanese	Kansai Dialect	
Good bye	Sayounara	Sainara	さいなら
I'm sorry.	Gomennasai	Sunmahen	すんまへん
My bad.	Gomen	Suman	すまん
Thank you!	Arigatou	Ohkini	おおきに
Yes	Hai	Soya	そや
No	Iie	Chau	ちゃう
foolish	bakamitai	ahokusa	あほくさ
nonsense	kudaranai	shoumona	しょうもな
strange	okashina	kettaina	けったいな
because	～nanode	～yasakai	～やさかい
tired	tsukareru	shindoi	しんどい
How about?	Dou?	Donai?	どない？
McDonald's	Mac	Makudo	まくど
Father	Tousan	Oton	おとん
Mother	Kasan	Okan	おかん

* These words are just some examples.

ELEMENT QUIZ Q1

A neodymium magnet, known as the world's strongest permanent magnet, is made of three elements. Which of the following is the correct combination?

1. (Nd, Pb, B)
2. (Nd, Pd, Fe)
3. (Nd, Fe, Co)
4. (Nd, Fe, B)



Chemistry! It's Cool!

IChO2021 Catalyzer No. 1

Official Website
https://www.icho2021.org/
icho2021

Jul. 25
1908
Patented!
Production method
of Umami flavor
(AJINOMOTO)

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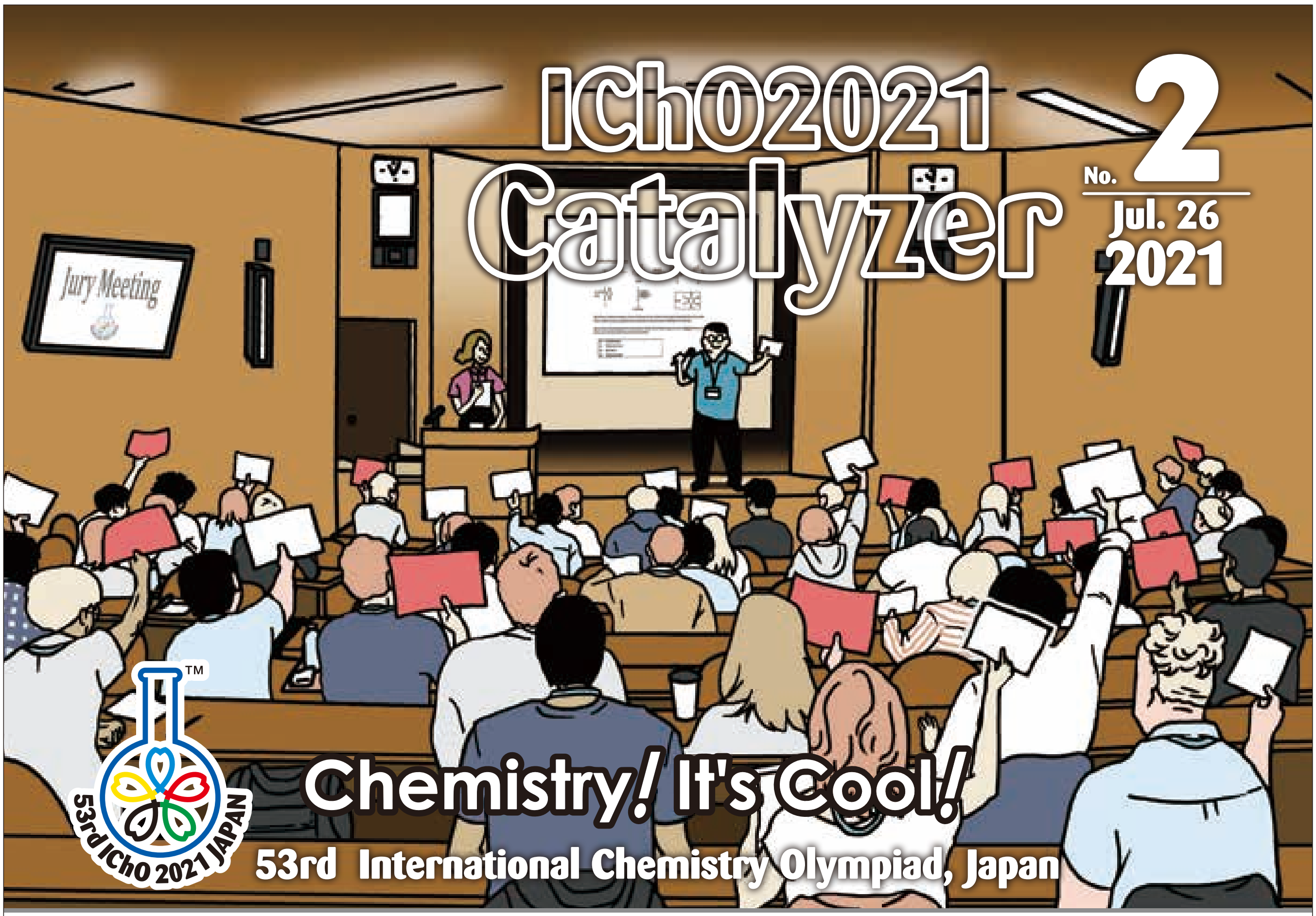
Illustration: Science Manga Studio



Cover illustration : Jury Meeting

Nobel Prize Research from Japan 02

Asymmetric Reactions

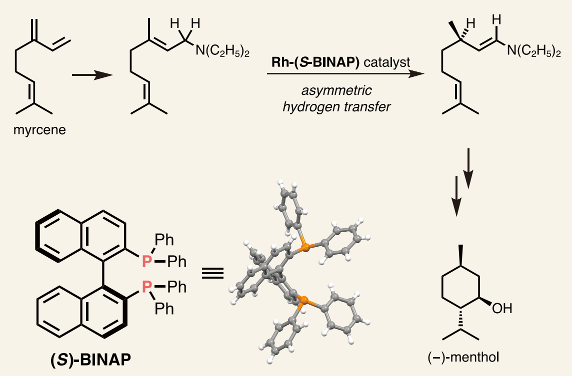
Ryoji Noyori


Photo by Kagaku-Dojin

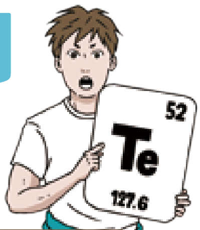
Dr. Ryoji Noyori
(1938–)

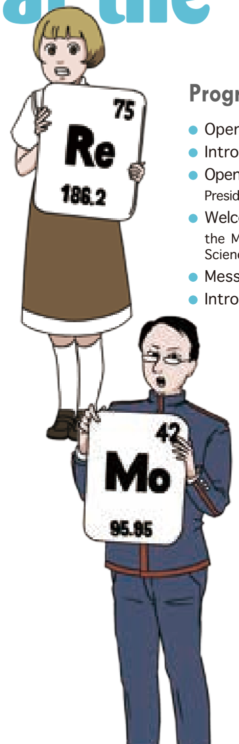
Some organic compounds exist as two stereoisomers that are mirror images of each other (chiral molecules); the relationship resembles that of a person's right hand and left hand. Many chiral molecules are found in nature, typical examples of which are the amino acids that make up proteins in living organisms. Interestingly, proteins in living organisms are composed of only one of the mirror-image isomers (L-type amino acids). Since living organisms distinguish chiral molecules, asymmetric synthesis is extremely important in the development of pharmaceuticals, flavors, and food additives. Ryoji Noyori developed unique chiral phosphorus ligand BINAP as a source of chirality essential for the synthesis of chiral compounds. BINAP has a beautiful structure with C_2 symmetry, and its metal complexes enable various catalytic asymmetric reactions. One of the best known applications of BINAP is the Rh-BINAP-catalyzed asymmetric hydrogen transfer reaction, a key step in the synthesis of (−)-menthol used in flavors and pharmaceuticals. This technology has been commercialized by Takasago International Corporation (Japan), a world leader in the fragrance and flavor industry. For developing such a truly practical method for catalytic asymmetric synthesis, Ryoji Noyori was awarded the Nobel Prize in Chemistry in 2001, together with William S. Knowles and Karl Barry Sharpless.

Industrial synthesis of (−)-menthol



The Opening Ceremony held at the Virtual Reality Venue





Program of Opening Ceremony

- Opening Movie
- Introduction of Sponsors
- Opening Address by Dr. Kohei Tamao
  President, IChO2021 Japan Committee
- Welcome Message from HAGIUDA Koichi
  the Minister of Education, Culture, Sports, Science and Technology
- Message from Dr. Akira Yoshino
- Introduction of Participating Teams

Dr. Kohei Tamao
President, IChO2021 Japan Committee
Chairman, Organizing Committee for the 53rd IChO2021, Japan

HAGIUDA Koichi
the Minister of Education, Culture, Sports, Science and Technology

Dr. Akira Yoshino
Honorary Fellow, Asahi Kasei Corp. 2019 Nobel Laureate in Chemistry

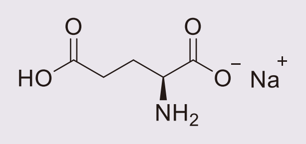
Chemistry! It's Japan!

The Discovery of Umami Component

••• Kikunae Ikeda

Dr. Kikunae Ikeda
(1864–1936)

Our sense of taste includes sweetness, sourness, saltiness, and bitterness as well as umami. The umami component was discovered by Kikunae Ikeda. Back then, the taste was thought to consist of a combination of four tastes: sweet, sour, salty, and bitter. Ikeda believed that dashi or broth made of dried bonito flakes and kelp, contained ingredients that made people feel that a food was delicious. Motivated by this somewhat unique Japanese sensibility, he attempted to identify the source of umami from kelp, and in 1908, determined that monosodium glutamate was indeed the umami component. Although glutamate itself had already been described as a chemical compound, Ikeda was the first to formulate the concept of glutamate as a component of umami. Based on this discovery, the company Ajinomoto was established, which has grown to become one of Japan's leading food companies. Ikeda also discovered the umami component of bonito, and together with his student Shintaro Kodama, discovered inosinic acid as the second umami component. Whether umami is a taste or not has been debated for a long time, but the discovery that the taste buds on the tongue contain sensors (glutamate receptors) that sense umami as well as the other four tastes has scientifically proven that humans can actually sense umami as a taste. The Japanese word umami has now gained currency in English and has become internationally recognized.



Structure of monosodium glutamate

Tenjin Festival and Gion Festival

Kansai Scenes 2

Held throughout the country, many of Japan's festivals are religious events. The Tenjin Festival in Osaka, the Gion Festival in Kyoto, and the Kanda Festival in Tokyo are known as Japan's three top festivals; two of them in the Kansai region of western Japan. The Tenjin Festival is held at the Osaka Tenmangu Shrine, which enshrines Sugawara no Michizane, a 9th century scholar and politician. On the night of July 25, the anniversary of Michizane's death, a boat procession is held on the Okawa River, accompanied by a fireworks display. It is known as the festival of fire and water because of the splendid sight of bonfires, lanterns, and fireworks reflected on the Okawa River. Aside from the festival, the Osaka Tenmangu Shrine also attracts students who come to pray for success in their entrance exams, as Michizane is worshipped as the god of learning. The Gion Festival has been held at Yasaka Shrine since the 9th century. Thirty-two large floats called *Yamahoko* are paraded through the center of Kyoto on July 17 each year.

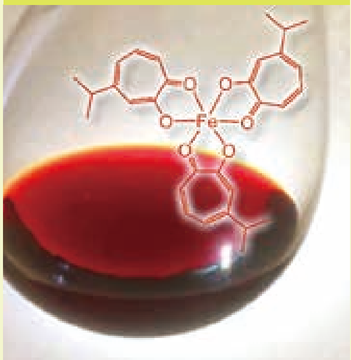
©Osaka Convention & Tourism Bureau

Tenjin Festival

Gion Festival

Tale related to Preparatory Problem

••• Plactical Task 4 •••



Hinokitin : Let a Deep-red Natural Pigment Inspire Your Curiosity

Practical Task 4 of the preparatory problems deals with nonbenzenoid aromatic compounds, a collection of which is designated in Japan as Certified Chemical Heritage No. 036. Reading the related literature, we found an article containing a comment by Tetsuo Nozoe*, looking back on his research into a seven-membered ring compound named hinokitiol, which reads: "I was attracted by the red pigment hinokitin in the wood of the Formosan Hinoki Cypress tree (*Chamaecyparis obtuse var. formosana*) derived by Nenokichi Hirao". Hirao had published a paper on hinokitin in 1926 (*Nihon Kagakukaishi*, vol. 47, pp. 666–671). Nozoe unexpectedly discovered that hinokitin contained iron, and obtained hinokitiol by removing the iron content, leading to the discovery of a new family of chemical compounds, the nonbenzenoid aromatic compounds. Hinokitin is an iron trivalent complex with hinokitiol as a ligand. In Practical Task 4, you are to synthesize hinokitin from hinokitiol and iron (III) nitrate nonahydrate. Watch in awe as the reaction produces a compound with an impressively deep-red color (see photo). I hope that the red color of hinokitin will catalyze the curiosity and passionate spirit of inquiry of young people who will create the future of chemistry.

*Tetsuo Nozoe (1902–1996) : Japanese Chemist, Professor of National Taiwan University (1936–1948) and Tohoku University (1948–1966)

Today's schedule Jul. 26

Student

- VR Closed

Mentor

- **Deadline of The Problem Feedback** (Oly-Exam)
  J 09:00 C 02:00 E 20:00 (Jul. 25)
- **1st Jury meeting** (zoom) J 21:00 C 14:00 E 08:00

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

CHEER UP! Participants!

Welcome to IChO! I hope you are enjoying your virtual stay in Japan and getting ready for the exam. More than anything, however, enjoy your time with participants from other countries. I made many lasting friendships in IChO and I am sure you will too! When you hesitate to talk with someone because they speak a different language or come from a different culture, remember your passion for chemistry will be the bond that connects you together. Have fun!

from **Tomohiro Soejima** (Japan)
University of California, Berkeley
Department of Physics
PhD student

IChO 43rd in Ankara, Turkey Gold medal
IChO 44th in Washington D.C., USA Gold medal

ELEMENT QUIZ Q2

Stainless steel is an alloy made by adding two metals to iron. Which of the following is the correct combination of the two non-iron metal elements?

1 (Co, Mn) 2 (Zn, Ni)
3 (Ca, Mn) 4 (Cr, Ni)

Short short from Kansai

Illumination of Tsutenkaku Tower

As the COVID-19 pandemic continues to rage around the world, Japan too is battling waves of cases and new variants, and has started vaccinating its population in stages. Tsutenkaku Tower, the symbolic tower of Osaka, lights up in different colors to call on the local citizens to help prevent the spread of the disease. In accordance with the model adopted by the Osaka prefectural government in its countermeasures against COVID-19, the color is red during a state of emergency, yellow when an alert is issued, and green when the alert is lifted. The tower has also been illuminated with blue lights to express gratitude to the medical personnel who are struggling on the front lines.

Answer for Q1

4 (Nd, Fe, B)

A neodymium magnet contains iron and boron in addition to neodymium, as shown by the chemical formula $Nd_2Fe_{14}B$.
The iron generates magnetization and the neodymium directs the magnetization in one direction.
The boron keeps the distance between the iron and the neodymium atoms at an optimum level.

Chemistry! It's Cool!

53rd IChO 2021 JAPAN ™

IChO2021 Catalyzer No. 2
Official Website
https://www.icho2021.org/
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Jul. 26
1885
Got married!
Marie &
Pierre Curie

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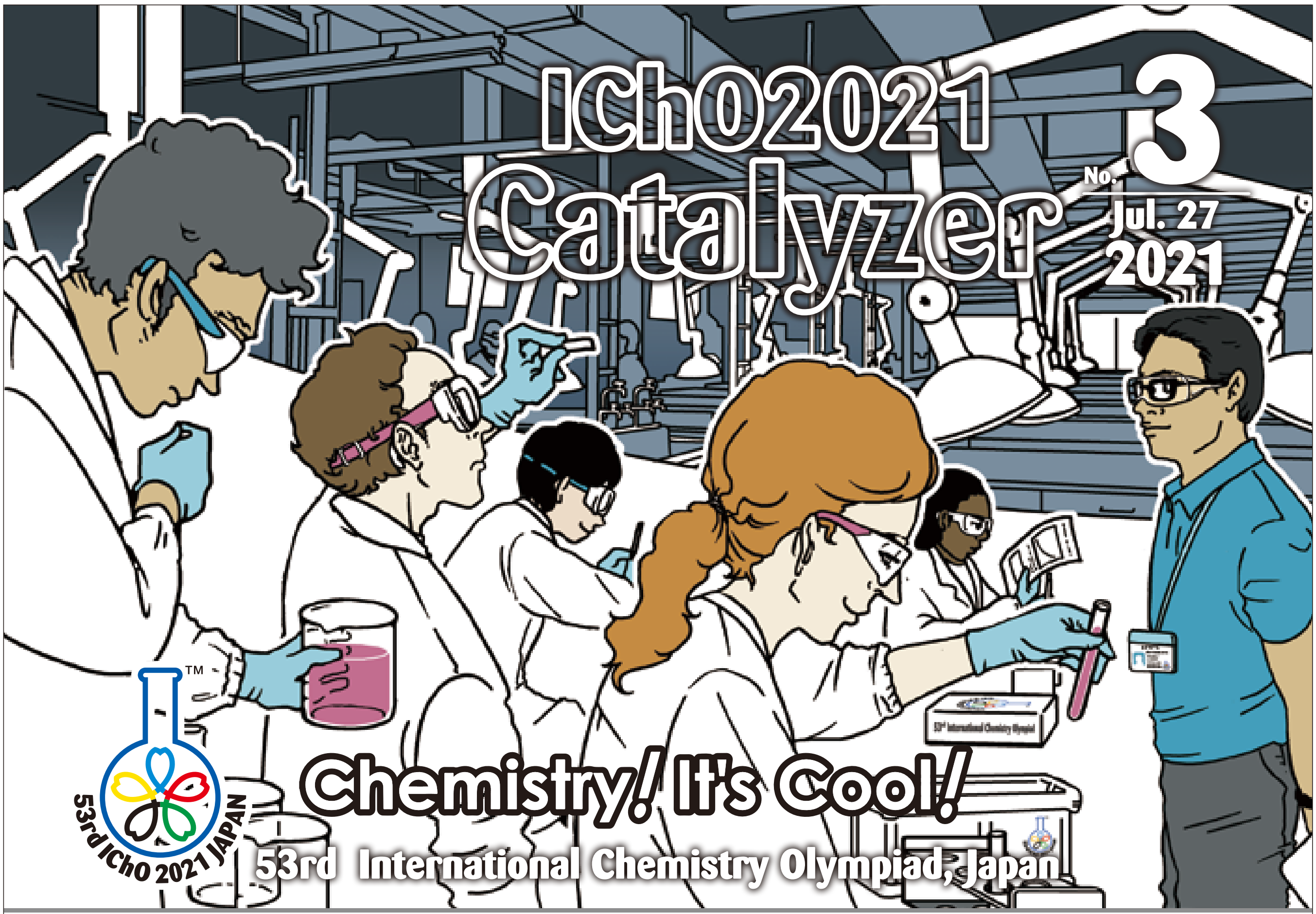


Cover illustration : Practical Exam

Nobel Prize Research from Japan 03

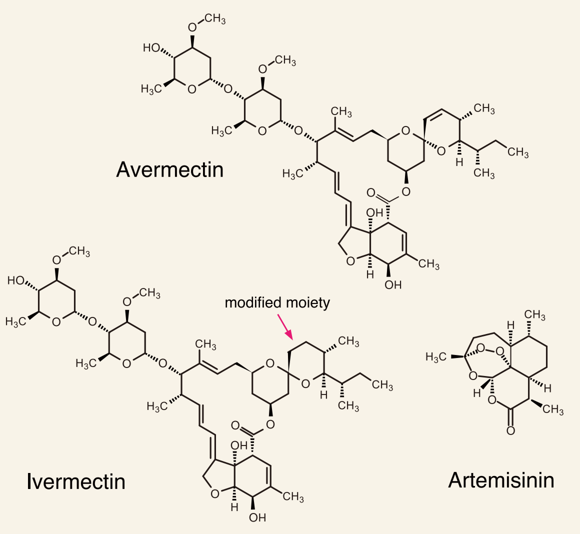
Natural Product Chemistry that Leads to Medicines

Satoshi Ōmura

Nature is host to countless compounds that can be used as medicines and yet remain undiscovered by humans. Satoshi Ōmura has isolated and determined the structures of many useful natural organic compounds produced by microorganisms in soil, many of which have been put to practical use. One such compound is avermectin, a substance produced by the bacterium Actinomycetes that was isolated from the soil of a golf course in Shizuoka Prefecture. Ōmura's research in collaboration with William C. Campbell showed it has strong activity as an anthelmintic, a treatment for parasitic diseases. Subsequently, a structurally modified version of this compound, ivermectin, was developed as an anthelmintic for livestock. Furthermore, ivermectin has been shown to be effective against onchocerciasis, a disease which may lead to loss of sight, caused by filarial nematodes transmitted by mosquitoes in Africa and other tropical regions, and is now widely used as an anthelmintic. The 2015 Nobel Prize in Physiology or Medicine was awarded to Satoshi Ōmura, William C. Campbell, and Youyou Tu for "their discoveries concerning a novel therapy against infections caused by roundworm parasites." Youyou Tu also discovered artemisinin, which is the basis of a group of drugs used to treat malaria.


Photo by Satoshi Ōmura

Dr. Satoshi Ōmura
(1935–)



Chemistry! It's Japan!

Studies on Urushiol

Rikō Majima

Urushi lacquerware is one of Japan's well-known traditional crafts. Urushi, which has a beautiful black luster, is a natural resin obtained from the sap of the lacquer tree and consists mainly of a catechol derivative called urushiol. The structure of urushiol was determined by Rikō Majima, and the research process became the starting point for the development of organic chemistry in Japan. When Majima started his research around 1900, chemistry in Japan was still in its infancy, and there was a serious shortage of skilled chemists to guide experimental research. Majima studied organic chemistry almost entirely on his own and became acutely aware of the gap in ability between Japan and the Western countries; at the same time he came to the conclusion that if he could conduct research on lacquer, which is native to the Orient, he would be able to develop his own original research without being outdone by researchers from other countries.


Urushiol: originally a light-yellow resin, it turned blackish after 100 years

After studying in Germany, Majima began to determine the structure of urushiol in earnest at Tohoku Imperial University. With the latest European methods such as advanced vacuum distillation, ozonolysis, and catalytic reduction, he tried to determine the structure of urushiol. After several steps, he finally determined that urushiol exists as a mixture of the compounds shown in the figure. Majima began to determine the structures of many other natural products found only in the Orient such as indole and aconite alkaloids, in addition to urushiol, and trained many of his students as organic chemists. His students eventually established organic chemistry laboratories at universities around the country and laid the foundation for modern organic chemistry in Japan.

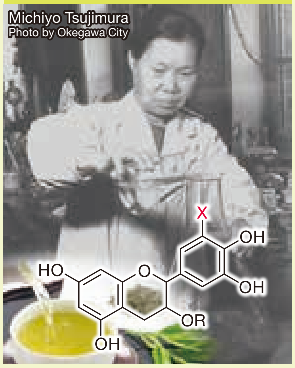

Dr. Rikō Majima
(1874–1962)

Figure: Structure of Urushiol

$$R = \begin{cases} -(CH_2)_{14}CH_3 \\ -(CH_2)_7CH{=}CH(CH_2)_5CH_3 \\ -(CH_2)_7CH{=}CH(CH_2)_4CH{=}CH_2 \\ -(CH_2)_7CH{=}CHCH_2CH{=}CHCH{=}CHCH_3 \\ -(CH_2)_7CH{=}CHCH_2CH{=}CHCH_2CH{=}CH_2 \end{cases}$$

Tale related to Preparatory Problem

••• Theoretical Task 23 •••


Michiyo Tsujimura
Photo by Okegawa City

Green tea, a part of Japanese culture

What would you drink when you are thirsty? Water, juice, soda, or tea? Tea, particularly green tea, is very popular in Japan among other countries. Tea is classified into three major types: green tea (unfermented), black tea (fermented), and the rest such as oolong tea (semi-fermented). As introduced in preparatory problem 23, green-tea culture in Japan started in the early 1200s. The most famous form is the traditional 'tea ceremony', during which *matcha* is prepared and drunk. In addition, green tea is largely consumed as a regular beverage on a daily basis and has been associated with a variety of health benefits. Tea leaves contain several catechins such as epicatechin, epigallocatechin, epicatechin gallate, and epigallocatechin gallate, which are responsible for the characteristic taste (*shibumi*) of green tea. Japan also made significant contributions to green-tea chemistry. For instance, Michiyo Tsujimura, the first Japanese female doctor of agriculture, isolated catechin from green tea for the first time in 1929. Green tea also contains caffeine, which has a bitter taste (nigami), and theanine, which adds a savory (*umami*) flavor. While green tea is produced by suppressing the oxidation of tea leaves, black tea is produced by fermentation of the tea leaves, promoting oxidative dimerization of catechins to give theaflavins, which have a benzotropolone core structure and are characteristic pigments of black tea.

Himeji Castle

Kansai Scenes 3

Himeji Castle (or *Himeji-jo* in Japanese) is an excellent surviving example of a modern Japanese castle. Described as a *Hirayama Jo* in Japanese, meaning a hilltop castle, it is located in the north of present-day Himeji. It is one of the original 12 castle towers (*tenshu*) which were built in the Edo period (1603 to 1868), and is designated as one of the 100 Great Castles in Japan. Himeji Castle was designated as a National Treasure in 1951, and a UNESCO World Heritage Site (Cultural) in 1993; so becoming Japan's first cultural World Heritage Site. The present castle tower was built in 1609 by Ikeda Terumasa, a warlord who married Tokuhime, the second daughter of Tokugawa Ieyasu, the founder of the Edo bakufu (shogunate). The castle is also known fondly as *Shirasagi-jo* (White Egret Castle), as its elegant figure resembles an egret with its wings outstretched. The castle is characterized by brilliant white stucco exterior walls and features a huge *tenshu* (main tower) with five layered roofs and seven stories (one underground and six above ground), which is interconnected with smaller towers (the East, the West, and the Northwest) by *watari-yagura* roofed passages. The *tenshu* was restored to its current beautiful condition after five-and-a-half years of restoration work that stretched from 2009 to 2015.

Early Bird Communication

Saudi Arabia

Mexico

Iceland

Poland

Today's schedule **Jul. 27**

Student

- VR Closed

Mentor

- **Translation ››› submission** J 09:00 C 09:00 E 20:00 (Jul. 26)

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

CHEER UP! Participants!

Not just IChO, but even the months leading up to it, are like a dream come true. Not only are you stimulated intellectually but you get to meet remarkable people at truly amazing places in the world. The knowledge, the drive, and encouragement you take away are unparalleled and stay with you for life.

from **Maaha Ayub** (Pakistan)

IChO 49th in Nakhon Pathom, Thailand
Bronze Medal

Answer for Q2

4 (Cr, Ni)

Stainless steel was developed to strengthen iron's rust resistance, and a number of researchers contributed to its improvement during the 19th and 20th centuries. The metals added to iron are typically chromium and nickel, which form a passive layer on the surface, preventing rust caused by air or water. Today, stainless steel is widely used, for example, in cooking utensils, vehicles, and machine parts.

Element #2

Japanese mineral resources

Iodine

Iodine, with atomic number 53 and an atomic weight of 126.9, is represented by the symbol I. It belongs to Group 17, the halogen group, together with elements such as bromine, chlorine, and fluorine. Although Japan is usually characterized as a country poor in natural resources, it is placed second in the world after Chile in the production of iodine. Eighty percent of iodine is produced from sodium iodide dissolved in ancient seawater in natural gas wells in Chiba Prefecture. Japan even exports iodine to other countries around the world.

Iodine is a dark purple solid at room temperature and ^{127}I is its only stable isotope, with a natural abundance of almost 100%. The isotope ^{131}I is a fission product of uranium and other radioactive elements, and it has a half-life of around 8 days transforming ^{131}Xe with beta and gamma emissions. Therefore, stable ^{127}I can be used to protect people from health hazards caused by a nuclear accident. Iodine as an element has a variety of uses in our lives such as X-ray contrast agents, bactericidal disinfectants, and polarizers used in screens of LCD TVs, PCs, and smartphones.

Since iodine is a component of thyroid hormones, a shortage of iodine in the body may lead to the condition known as hypothyroidism. However, such shortages are rare in Japanese because the country is surrounded by sea and sufficient iodine can be obtained from a diet rich in seaweed and a variety of seafoods. By contrast, many people living in other parts of the world are exposed to the risk of iodine deficiency. Thus, potassium iodide or potassium iodate is added to the table salt to prevent it.

ELEMENT QUIZ Q3

Which element is produced as a result of nuclear fission of uranium-235, apart from krypton?

1 Ba	2 Ra
3 Po	4 Pu

Chemistry! It's Cool!

IChO2021 Catalyzer No. 3

Official Website
https://www.icho2021.org/
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Jul. 27
1921
Succeeded!
Insulin extraction

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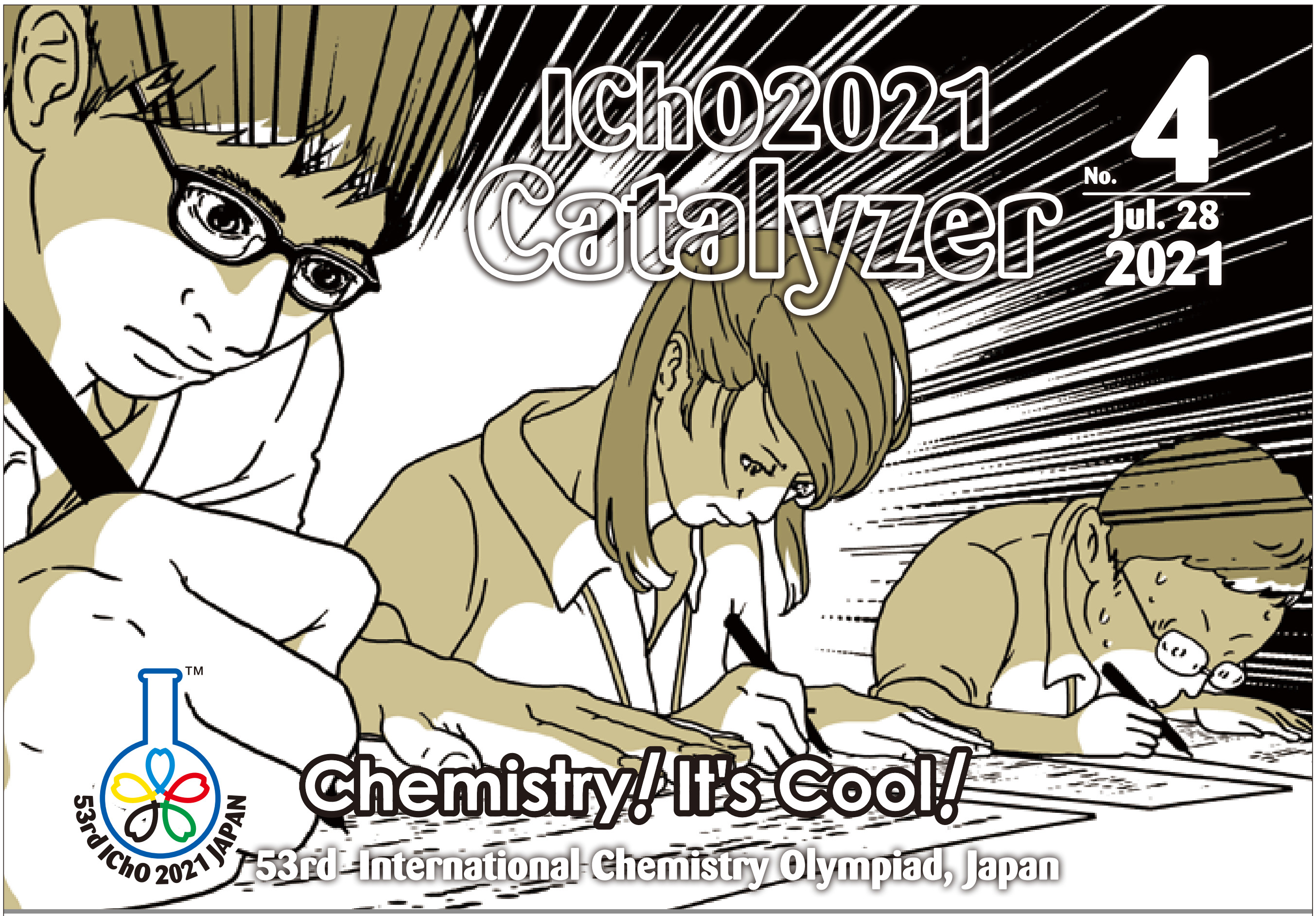
English Editor: Maiko Katayama
Illustration: Science Manga Studio

Catalyzer 4



Cover illustration : Theoretical Exam

Message from Dr. Akira Yoshino

Hello, everyone. This is Akira Yoshino.

Congratulations to all the representatives from all over the world who participated in the 2021 International Chemistry Olympiad in Japan. I congratulate you on your daily interest in chemistry and the fruits of your enthusiastic learning. We would also like to extend our congratulations and respect to the mentors from each country who have nurtured such wonderful athletes.

The International Chemistry Olympiad is an international event in which high school students from all over the world compete for their chemistry skills. Not only that, but it also builds a human resources network for young people through international exchange and deepens their understanding of Japanese culture. It will be of great significance to develop human resources who will be in a leadership position in the future.

Unfortunately, due to the influence of the new coronavirus pandemic, it has become a remote competition, but even in such a difficult situation, it is the relationship of international trust that has been built up so far. I would like to once again recognize with you that it is supported by the depth of friendship, and I would like to express my sincere gratitude to all the people concerned and the executive committees of each country for their efforts.

Chemistry is central science. It plays an important role in creating new substances by making full use of the properties of elements. I received the Nobel Prize in Chemistry in 2019 for developing a lithium-ion secondary battery and leading it to practical use. In this development, after a long basic research based on the properties of lithium, cobalt, carbon, etc., it was put into practical use. In this way, the results of basic research in chemistry have the power to change the social system. Chemistry must play a leading role in solving various problems such as environment, resources, energy, and health that are currently facing on a global scale. And they are entrusted to a younger generation like you.

You are the leaders of each country and the world in the future. Please take pride in participating in the International Chemistry Olympiad, and remind yourself of the importance of these roles in chemistry for further development.

Please do your best in the written test and enjoy the VR videos of various research facilities and cultural activities that are prepared to deepen your exchange. This is my greeting.

Dr. Akira Yoshino

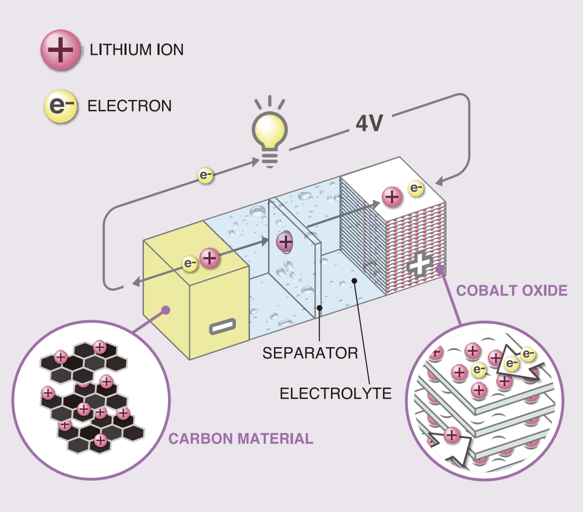
Honorary Fellow, Asahi Kasei Corp.
2019 Nobel Laureate in Chemistry

Nobel Prize Research from Japan 04

Development of Lithium-ion Secondary Batteries

…… Akira Yoshino

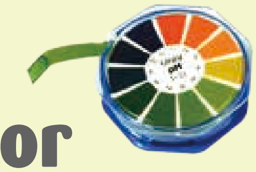
Lithium-ion batteries (Li-ion batteries) are used in all aspects of modern life, from small smartphones and notebook computers to electric vehicles, due to their features such as light weight, rechargeability, and high capacity. It would not be an exaggeration to say that Li-ion batteries enable us to freely carry electricity around. It all started in 1976 when Stanley Whittingham developed a revolutionary rechargeable battery using metallic lithium for the anode and titanium disulfide for the cathode, which intercalates lithium ions. Later, John B. Goodenough developed a battery using lithium-cobalt oxide ($LiCoO_2$) as the cathode, but the practicality of this battery was challenged by the fact that it used metallic lithium as the anode, which posed the risk of explosion and ignition. Akira Yoshino(photo: previous page) overcame these safety and stability issues by using carbon materials for the anode, and laid the foundation for practical Li-ion batteries. For these achievements, Akira Yoshino, John Goodenough, and Stanley Whittingham were awarded the Nobel Prize in Chemistry in 2019. Akira Yoshino was born and raised in Osaka, where IChO2021 was to be held. He says he was inspired to pursue chemistry by the book "THE CHEMICAL HISTORY OF A CANDLE", written by Michael Faraday, which his homeroom teacher in elementary school recommended he read.



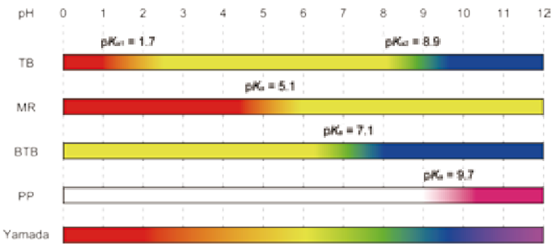
Tale related to Preparatory Problem

Theoretical Task 10

How to make rainbow indicator



Universal indicators are widely used to check the pH values of aqueous solutions. Nowadays, the most popular universal indicator shows red in acidic conditions and blue in basic conditions, the same color variation as that of the rainbow and therefore easy to remember. Is there a suitable molecule that will show such a drastic color change alone? The answer is no: universal indicator is a mixture of several indicators. The original recipe was proposed by a Japanese researcher, Shinobu Yamada, in 1933. Let's see how he cleverly mixed the individual indicators to achieve a rainbow of colors. Thymol blue (TB) changes from red to blue via yellow. To generate the color orange, methyl red (MR) is added. Because of the pKa gap between TB and MR, we can generate an orange color, which is the mixture of red (MR) and yellow (TB), around a pH of 3 to 4. Bromothymol blue (BTB) is used to generate a green color. Using the pKa gap between TB and BTB, we can generate green, which is a mixture of yellow (BTB) and blue (TB), around a pH of 7 to 8. Note that MR in basic conditions and BTB in acidic conditions are yellow. Therefore, too much MR makes the solution green in basic conditions, and too much BTB makes the solution orange in acidic conditions. Fortunately, phenolphthalein (PP) is colorless in acidic and neutral conditions, and therefore the purple color in basic conditions can be adjusted relatively easily. The appropriate constituent ratio is determined by human eyes with a trial-and-error process. We are thankful for Yamada's keen eyes that gave us this universal indicator today.



Color chart of indicators used for Yamada universal indicator (note that the colors and their variations are qualitative).

Chemistry! It's Japan!

Spectrochemical Series

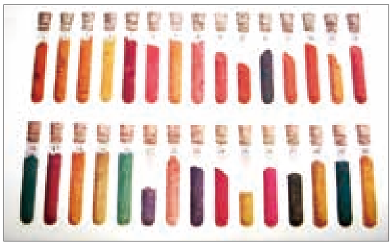
••• Ryutaro Tsuchida

Gems and pigments have attracted human beings with their beautiful colors since ancient times. Such colors are mainly caused by transition metal ions: the colors depend on not only types of metal, but also the ligands attached to the metal, and the coordination structures. However, the colors we see are mere sensory expression, which differs from individual to individual. Thus, quantifying the colors derived from inorganic compounds as energy and understanding the causes of these colors has been a major challenge for complex chemistry.

Complex chemistry was first brought to Japan by Yuji Shibata (1882–1980), who learned from Alfred Werner, the founding father of modern complex chemistry, and later taught at Tokyo Imperial University and Nagoya Imperial University as a Professor. His student Ryutaro Tsuchida, who later taught as professor at Osaka Imperial University, became interested in the relationship between color and ligands in metal complexes. After conducting measurement of the electronic absorption spectra of a numerous kind of metal complexes, he discovered a quantitative relationship between the wavelength of the absorption band and the ligand. Based on this finding, he proposed the spectrochemical series (1938), in which ligands and metal ions are arranged in the order of the energy difference of the d-d transition of octahedral metal complexes. Later, it was theoretically supported by ligand field theory, which considers the covalent nature of the metal–ligand bond, and it became clear that the spectrochemical series is an order of ligand field splitting energies. In addition to colors, Tsuchida was also strongly interested in the steric structure. He assumed the coordination bonds in complexes to be in the same bonding state as the covalent bonds in organic compounds, and the most stable molecular structure is the one that minimizes the repulsion between all electron pairs. This model that Tsuchida conceived was actually almost the same as the model known as the VSEPR rule today; however, this would not be known globally, since Japan was at midst of war. This achievement is very typical of Tsuchida, we may say, who was always conscious of correlations between "structure and properties" of complexes.

Dr. Ryutaro Tsuchida
(1903–1962)

In addition to his chemical research, Tsuchida also devoted himself to the expansion of chemical education as well as his own research. He was involved in producing teaching guidelines for high school chemistry and handbooks to chemical experiments, and he was also involved in launching and publishing chemical magazines for general public. In particular, he was a long-time member of the editorial board of the monthly magazine "*Kagaku* (Chemistry)" (first published in 1951) : this periodical is still published today, and the logo he designed for the magazine is still used as company logo of Kagaku-Dojin.



Complexes synthesized and organized by Tsuchida in the order of the spectrochemical series. Source: *Kinzoku Sakutaino Iro To Kozo* (*The color and structure of metal complexes*), 1944, Zoshinsha.

Company logo of Kagaku-Dojin.

Kansai Scenes 4

Fushimi Inari Taisha Shrine

Fushimi Inari Taisha, also known as *Oinari-san*, is the most important of the *Inari* shrines that are dotted throughout Japan, and is located in Fushimi-ku, Kyoto. Since the shrine was established in 711, it has been worshipped as a god of good harvest, prosperous business, safety in the home, and fulfillment of wishes. The foxes that serve as messengers of the shrine are also cherished by the people. From the first *torii* gate on the main approach to the shrine, the outer hall of worship (*maiden*), inner hall of worship, and main hall of worship are arranged in a straight line. It is said that there are about 10,000 *torii* contributed by followers, including the beautiful vermilion *senbon torii* (one thousand gates) that line the mountain. *Fushimi Inari Taisha* is one of the most popular tourist spots among people visiting Japan.

Early Bird Communication

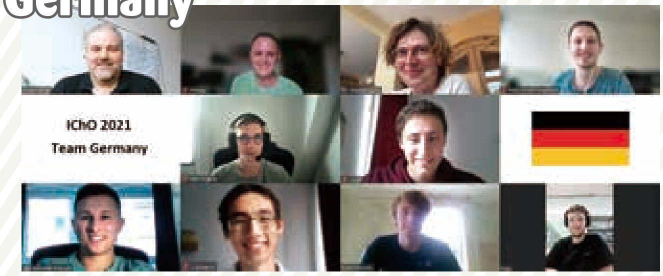
Slovenia

We printed the T-shirts ourselves!

Turkey

One of the pictures belongs to selection exam of Turkish team. Others belong to remote education lessons of team.

Germany



The screenshot is from the conclusion of our virtual study camp on June 11 with selected student representatives for the USA as well as mentors.

Azerbaijan

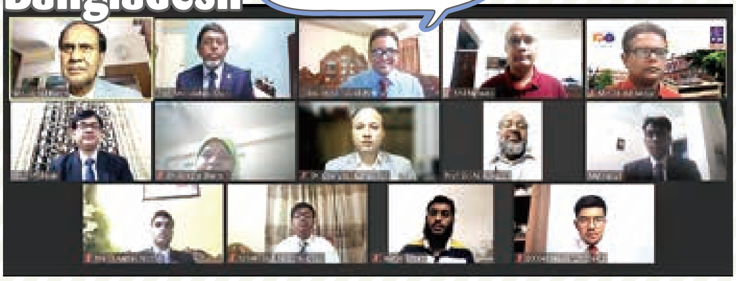
United States of America

Pakistan

Pics of Team Members for Catalyzer.

Bangladesh

Wish great success of 53rd IChO.



Today's schedule Jul. 28

Student

- **Examination** (5 h) Start between J 14:00 ▸ 05:00 (Jul. 27) C 07:00 ▸ 22:00 E 01:00 ▸ 16:00

Mentor

- **Deadline of translation** J 09:00 C 02:00 E 20:00 (Jul. 27)

Invigilator

- **Receive and print out the problem** J 11:00 C 04:00 E 22:00 (Jul. 27)
- **Submit the solutions** (Within 2 hours after the end of the examination)

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

CHEER UP! Participants!

Hello, dear Olympians! My name is Edith Leal and I represented the mexican delegation in the 45th and 46th IChO and now I'm studying my PhD in Chemistry. Looking back from the future, the best advice I can give to you is to give your personal best. Meeting so many young people, who are very intelligent and who seem better prepared for the tasks than you can be very overwhelming, however, remember that just by being here, you have already won a lot of knowledge, from the fundamentals of Chemistry, beyond your usual high school program, to the very specialized Preparatory Problems, which some of them are so specialized, they can be difficult to encounter, even as an undergraduate Chemist. So, stop worrying about anything else and focus into putting everything you know on the questions in the exam, so that when you finish, you feel satisfied and happy with yourself.

Greetings and my very best wishes!

from **Edith Leal** (Mexico)

IChO 45th in Moscow, Russian Federation
Participant

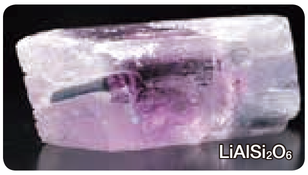
IChO 46th in Hanoi, Vietnam
Bronze medal

Element # 3 Japanese mineral resources Lithium

Basic Information

Origin of the name: Greek word *lithos* (stone)
Discovered by: J. A. Arfvedson (Sweden) [1817].
Global reserves: 21 million tons
Major reserve countries: Chile, Australia, Argentina
Global production: 82,000 tons
Major producers: Australia, Chile, China

Lithium-ion batteries are widely used in smartphones and notebook computers today. The applications of these light-weight and high-performance secondary batteries in electric vehicles have grown, in part due to a shift towards a decarbonized society. Akira Yoshino, a Nobel laureate in chemistry in 2019, developed a new battery using a lithium oxide compound as the cathode and a carbon material as the anode (See page 2 of this issue).


$LiAlSi_2O_6$

© The Courtyard of our Minerals

Answer for Q3

1 Ba

In 1938, German Chemists Otto Hahn and Fritz Strassmann discovered that when uranium-235 is bombarded with neutrons, radioactive barium, krypton, neutrons, and an enormous amount of energy are released. This discovery led to the development of nuclear energy.

ELEMENT QUIZ Q4

Assume you have the same volume of gold, silver, copper, and mercury, and they are all at the same temperature. Which of these metals is the heaviest among them?

1 Gold 2 Silver 3 Copper 4 Mercury

Chemistry! It's Cool!

53rd IChO 2021 JAPAN ™

IChO2021 Catalyzer No. 4

Official Website
https://www.icho2021.org/
icho2021

Jul. 28
1919
Succeeded!
Transatlantic
by R34 airship

Contact Information

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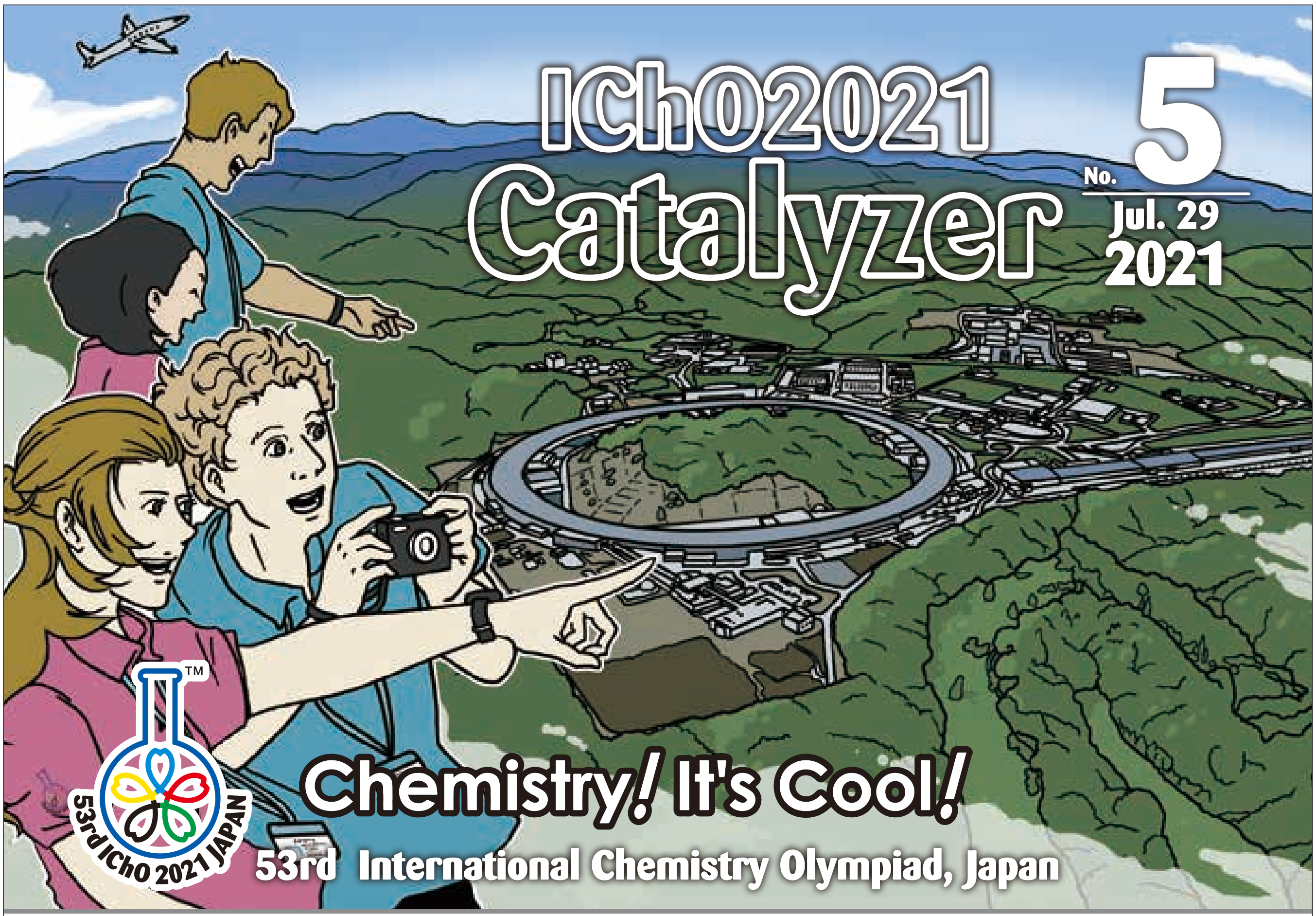
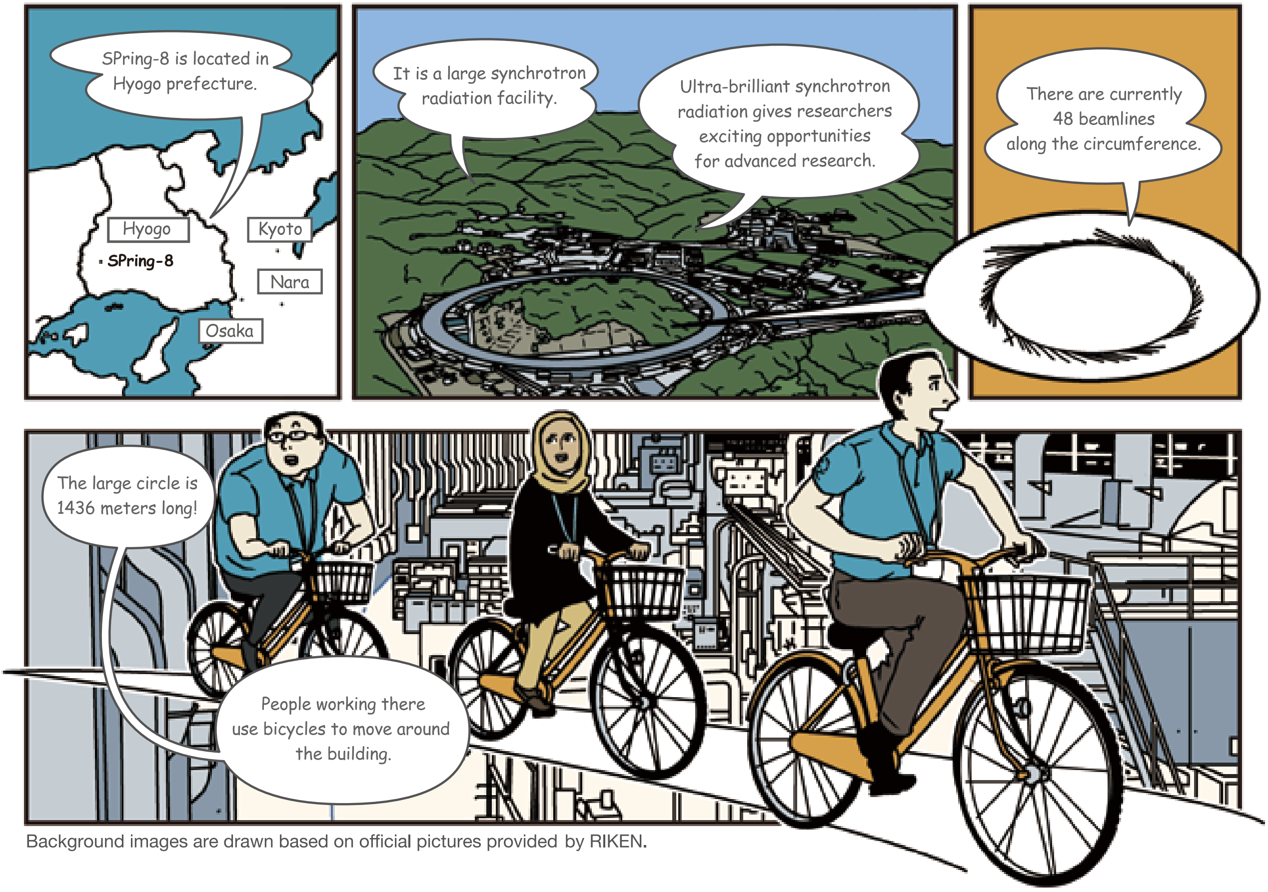
E-mail: contact@icho2021.org
Edited by the Team Catalyzer IChO2021
English Editor: Maiko Katayama
Illustration: Science Manga Studio

Catalyzer 5



Cover illustration : Scientific Program (SPring-8)



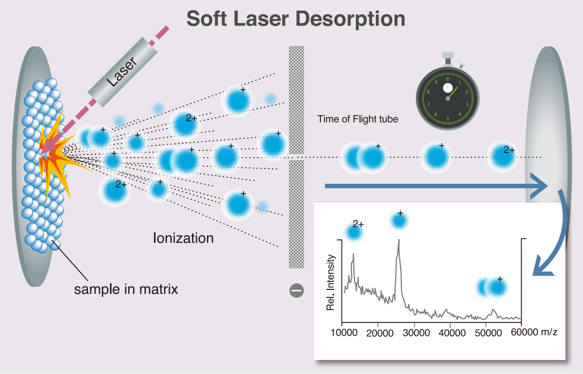
Background images are drawn based on official pictures provided by RIKEN.

Nobel Prize Research from Japan 05

Soft Laser Desorption for Mass Spectrometry

Koichi Tanaka

Recent years have seen a growing need for methods to determine the structure of biomolecules such as proteins, carbohydrates, and lipids. Koichi Tanaka, an engineer at Shimadzu Corporation, has developed an innovative method to enable mass spectrometry of such large biomolecules. Mass spectrometry (MS) is an analytical method for measuring the mass of a material in its ionic state, based on its mass-to-charge ratio, and to do this, the sample (analyte) must first be ionized. Previously, electron ionization (EI), in which the sample is irradiated with thermal electrons, was mainly used for this process, but this did not provide useful information on the mass of biological macromolecules with high molecular weights such as proteins, because they are hard to volatilize and are easily decomposed by heat. On the other hand, in the soft laser ionization method such as the matrix-assisted laser desorption/ionization (MALDI) method, the analyte is mixed with a viscous liquid known as a matrix and irradiated with an ultraviolet laser beam, which causes rapid heating and ablation of the matrix as well as vaporization and ionization of the sample, enabling a soft ionization of the analyte. It is said that this method was conceived when a sample was mistakenly prepared using glycerin instead of acetone, and the sample was analyzed so as not to waste it. This method becomes a particularly powerful tool when analyzing compounds with large molecular weights, making it possible to measure compounds with molecular weights of 100,000 or more. MALDI, and another method known as electrospray ionization (ESI), developed by John B. Fenn, are currently the main methods used for ionizing organic compounds for mass spectrometry. The 2002 Nobel Prize in Chemistry was awarded “for the development of methods for identification and structure analyses of biological macromolecules” to Koichi Tanaka, John B. Fenn, and Kurt Wüthrich for their achievements in protein structure analysis. This particular year’s Nobel Prize in Chemistry was unique in that it was awarded for the development of fundamental technologies that support advanced research.



Dr. Koichi Tanaka
(1959–)

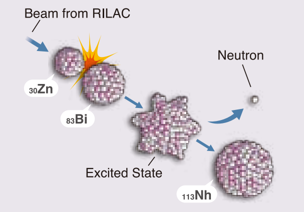
Remote Examination on Jul. 28

Chemistry! It's Japan!

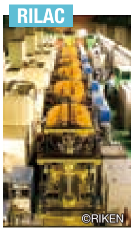
New Nomination to Periodic Table

Nihonium is the 113th element (symbol: Nh) of the periodic table. This element was first discovered in July 2004 by Kosuke Morita and his group at RIKEN, Japan's largest multidisciplinary research institution. After two successful follow-up tests and certification of the element's discovery at the end of December 2015, the name nihonium and the symbol Nh were officially ratified in November 2016. This became the first element to be named in the Asian region, as all the elements identified until then had been found in Western countries. Nihonium (^{278}Nh), was artificially synthesized by fusing two types of nuclei: a thin film of bismuth (^{209}Bi) with atomic number 83 and mass number 209 was irradiated with a beam of zinc (^{70}Zn) with atomic number 30 and mass number 70 that had been accelerated to about 10% of the speed of light. In this experiment, a large linear accelerator (RILAC) with the world's highest beam intensity and a gas-filled recoil separator (GARIS), which extracts only the 113th element from the countless particles produced by irradiation, played a major role. The probability of nuclei fusing is extremely small, and only three atoms of nihonium were obtained after 400 trillion collisions. It was also revealed that the lifetime of nihonium is only 344 microseconds.

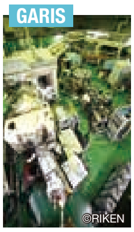
Elements up to the 118th, oganesson (Og), have now been reported, completing the 7th period of the periodic table.



RILAC



GARIS



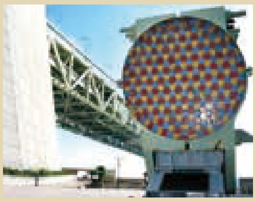
Akashi Kaikyo Bridge

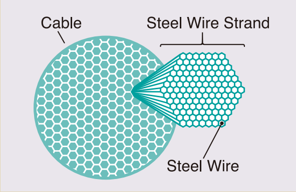
Kansai Scenes 5

the longest suspension bridge in the world

The Akashi Kaikyo Bridge is one of the world's longest bridges. It crosses the Akashi Strait (or Akashi Kaikyo in Japanese), linking Kobe on the mainland of Honshu with Iwaya on Awaji Island, and has a total length of 3,911 meters and central span of 1,991 meters. Awaji is then linked with the island of Shikoku by another suspension bridge called the Onaruto Bridge that crosses the Naruto Strait, well-known for the massive Naruto Whirlpools. Together, these two great bridges provide a seamless route for people travelling between the islands of Honshu and Shikoku.

The suspension cables of the Akashi Kaikyo Bridge are supported by two main towers, which rise 288.3 meters above the sea. The main cables of the supporting towers consist of 290 strands (wire bundles with regular hexagonal cross sections), each of which is made of 127 high-tensile galvanized steel wires. Each cable has a diameter of 112.2 centimeters and can support a load of up to 60,000 tonnes. To protect the wires from wind and rain and to prevent corrosion, their surfaces are coated with rubber, and the cable interiors are protected with desalted and dehumidified air, maintaining the strength and durability of this marvelous suspension bridge.

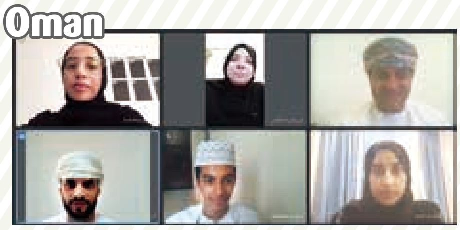




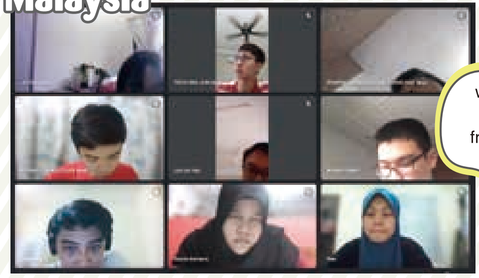
Early Bird Communication

Montenegro

Oman



Malaysia



This is the picture of the final selection test which was conducted online. The best four candidates from this test are representing Malaysia for IChO 2021.

Today's schedule **Jul. 29**

Student

- Activity (SPring-8 Virtual tour)

Mentor

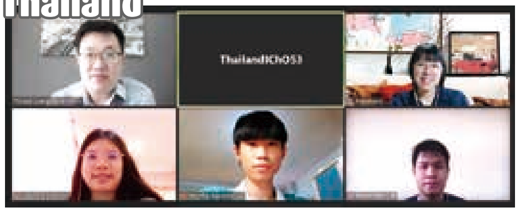
- Receive the solution and the grading scheme

J 09:00 C 09:00 E 20:00 (Jul. 28)

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

Early Bird Communication

Thailand



Philippines

ELEMENT QUIZ

Q5

Which chemist discovered the most elements from nature in history?

1. Marie Curie
2. Davy
3. Lavoisier
4. Humboldt

Element # 4

Japanese mineral resources

Rhenium

Basic Information

Origin of the name: the Latin name of the River Rhine, *Rhenus*
Discovered by: W. Nodak, I. Tacke, and O. Berke (Germany) [1925]
Global reserves: 2,400 tons
Major reserve countries: Chile, the USA, Russia
Global production: 53 tons
Major producers: Chile, Poland, the USA

In 1908, Masataka Ogawa, who was studying at the University of London at the time, reported his discovery of element 43, which he named nipponium (Np), in the mineral trianite produced in Sri Lanka (then Ceylon). Unfortunately, his analysis was later found to be inaccurate, and the element Ogawa had discovered was actually element 75, rhenium, which is one row down on the periodic table. If his analysis had been accurate, there might have been an element named after Japan more than 100 years before nihonium (Nh).

© Crystal Museum

Answer for Q4

1 Gold

Density (weight per cubic centimeter = g/cm^3) is used to compare the weights of substances. The density of water is defined as 1.0 g/cm^3. The densities of the four metals are 19.3, 10.5, 8.96, and 13.6 g/cm^3 for gold, silver, copper, and mercury, respectively; thus, gold is the heaviest of the four. The heaviest of all known metals is osmium, with a density of 22.6 g/cm^3.

Chemistry! It's Cool!

IChO2021 Catalyzer No. 5
Official Website
https://www.icho2021.org/
icho2021

Jul. 29
1836
Completed!
Triumphal arch in Paris

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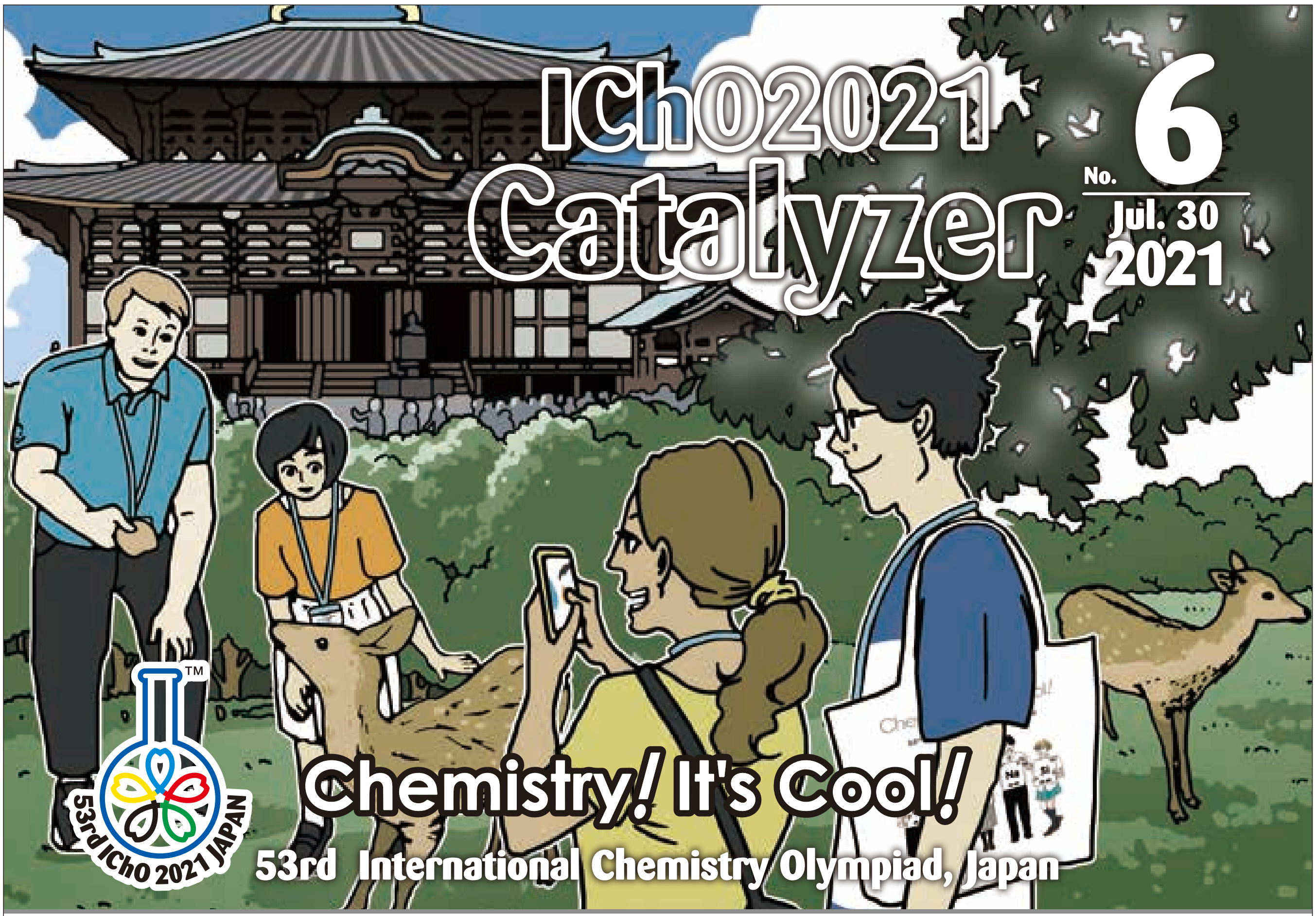
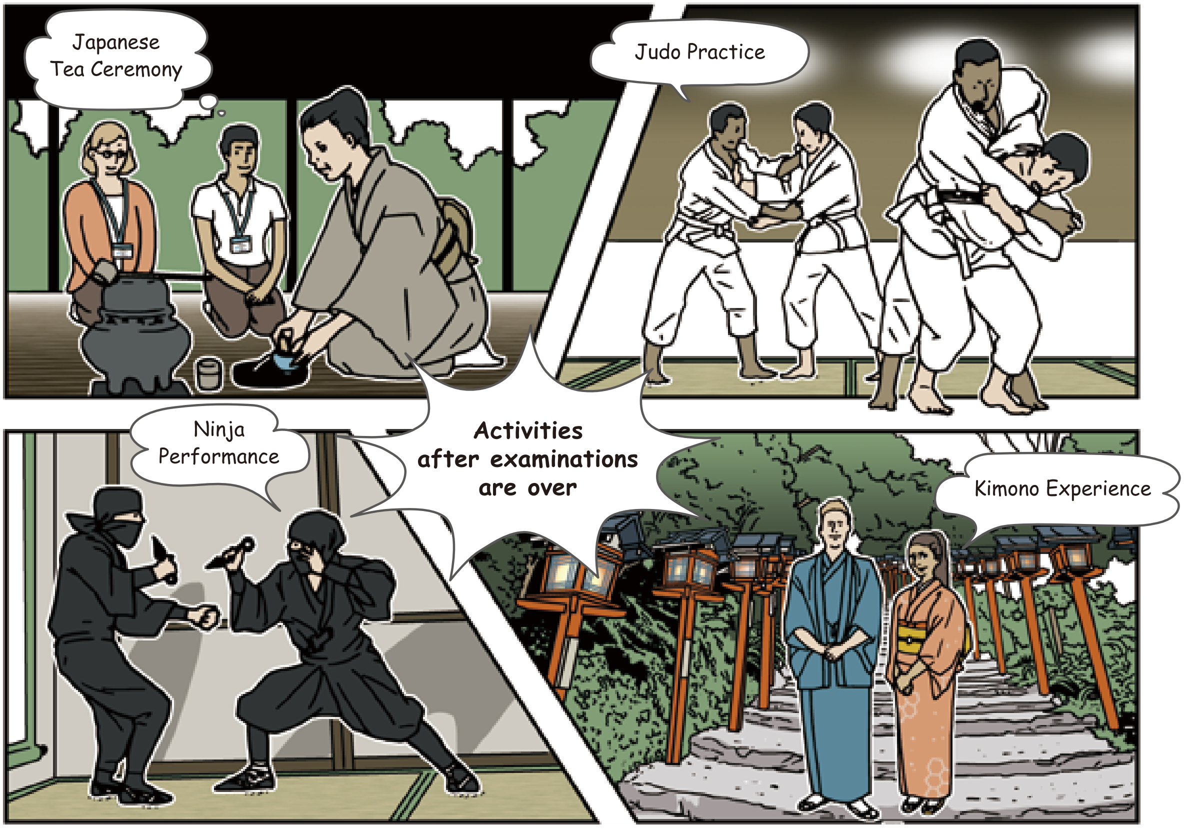
English Editor: Maiko Katayama
Illustration: Science Manga Studio

Catalyzer 6



Cover illustration : Excursion to Nara



Nobel Prize Research from Japan 06

Development of Palladium-Catalyzed Cross Coupling

..... Akira Suzuki / Ei-ichi Negishi

Many of the functional materials and pharmaceuticals that are indispensable to modern life are created by organic synthetic reactions. In order to synthesize such useful materials, carbon–carbon bond formation reactions are indispensable to link the carbon atoms of organic molecules. A typical example of such a cross-coupling reaction is the chemical transformation of benzene rings. This reaction is difficult to achieve by traditional methods using carbocations and carbanions, but was found to be more easily accomplished by using transition-metal catalysts. It is no exaggeration to say that the field of cross-coupling reactions has been led by Japanese researchers, and in particular, the palladium-catalyzed cross-coupling reactions of aryl halides with arylmetal (boron or zinc) reagents developed by Akira Suzuki and Ei-ichi Negishi in the 1970s are extremely versatile. They have a wide range of applications, and are currently being used in the synthesis of numerous pharmaceuticals and organic electroluminescent materials. In 2010, Akira Suzuki and Ei-ichi Negishi were awarded the Nobel Prize in Chemistry, together with Richard F. Heck, for the development of such a truly practical synthetic reaction.

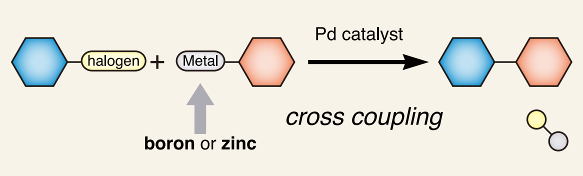



Photo by Hokkaido University

Dr. Akira Suzuki
(1930–)

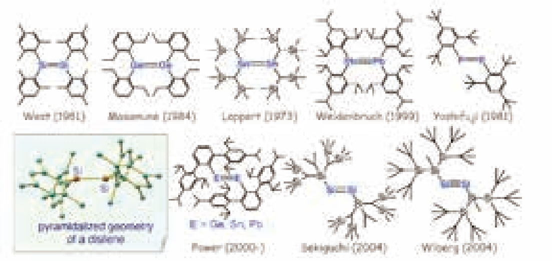
Dr. Ei-ichi Negishi
(1935–2021)

••• IChO2021 Problem Q5 •••

Unsaturated bonds between heavier main-group elements

In the late 1800s, the periodicity of the properties of elements was discovered; this concept suggests that elements that exhibit similar properties appear in a periodic order when arranged according to their atomic numbers. Ultimately, the stringent application of this principle resulted in the creation of the periodic table of elements by Mendeleev in 1869. In general, elements in the same group, *i.e.*, those located in the same column in the periodic table, are thus expected to exhibit similar properties. *What do you think about this statement? Is this true for all the elements in the same group?*

Silicon is the heavier homologue closest to carbon in the periodic table, and the analogies between carbon and silicon have been discussed controversially for a long time. For example, while the chemistry of unsaturated compounds of the main-group elements of the second row such as olefins ($R_2C{=}CR_2$) is plentiful, that of the heavier-element homologues of these multiple-bond compounds has remained underdeveloped in comparison, which is predominantly due to their extremely high reactivity and inherent instability under ambient conditions. Prior to the 1970s, all attempts to synthesize compounds with multiple bonds between heavier main-group elements were unsuccessful, and only cyclic oligomers or polymers with single covalent bonds between the main-group elements were obtained. Accordingly, the scientific consensus at the time was that such heavier main-group elements are probably not able to form π-bonds ('double-bond rule'). However, ambitious chemists were ultimately able to isolate and characterize several kinds of such compounds with unsaturated bonds between heavier main-group elements using bulky substituents for steric protection ('kinetic stabilization'). For example, the first distannene ($R_2Sn{=}SnR_2$, Lappert 1973), diphosphene (RP=PR, Yoshifuji 1981), disilene ($R_2Si{=}SiR_2$, West 1981), and disilynes ($RSi{\equiv}SiR$, Wiberg and Sekiguchi 2004) have been synthesized as stable compounds by using sterically demanding substituents, which disproved the double-bond rule. Since then, the unique features of unsaturated compounds of heavier main-group elements have been investigated in detail, attracting much attention to the area of main-group-element chemistry. For example, it has been reported that disilenes ($R_2Si{=}SiR_2$) and disilynes ($RSi{\equiv}SiR$) exhibit pyramidalized and bent geometries, respectively, which stands in sharp contrast to the planar geometry of ethylene and the linear structure of acetylene. These different structural features should in turn cause different reactivity and properties, and thus, the chemistry of unsaturated silicon compounds can be expected to be characterized by unprecedented functions and chemistry that is different from that of carbon. Thus, it should be noted here that the structure and chemistry of the second-row elements is considerably different in from those of the heavier main-group elements, as exemplified by the case of H_2O (bp: 100 °C; $\measuredangle$HOH ≈ 104.5°) vs. H_2S (bp: –60 °C; $\measuredangle$HSH ≈ 92°).



Chemistry! It's Japan!

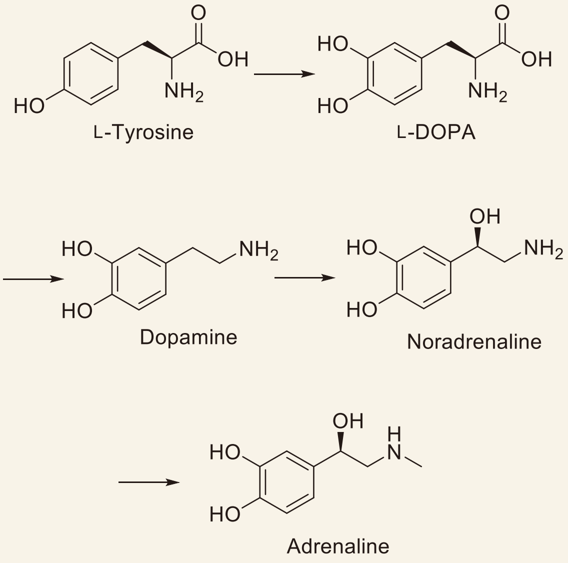
Discovery of Adrenaline

••• Jokichi Takamine / Keizo Uenaka

When one feels anxious, excited, or nervous, such as during important exams, public presentations, cheering on sports teams, muscle training, or when in love, our blood pressure rises and our heart rate increases. A hormone called adrenaline is secreted by the adrenal medulla when the sympathetic nervous system becomes dominant. Adrenaline was the first hormone to be isolated by scientists, in the year 1900. Jokichi Takamine and Keizo Uenaka (1876–1960) played key roles in this discovery. They succeeded in obtaining 7 grams of adrenaline crystals from 9 kilograms of bovine and sheep adrenal tissue by repeated acid and base extraction. Only after the first successful isolation did the hormone become commercialized as adrenaline preparation. Since then, it has become an indispensable agent for raising blood pressure in surgery, ophthalmology, and internal medicine. The number of lives adrenaline has saved to date is testament to the importance of this achievement for humanity.

Dr. Jokichi Takamine
(1854–1922)

In vivo, adrenaline is biosynthesized via L-tyrosine, L-dopa, dopamine, and noradrenaline.



Kansai Scenes 6

Daibutsuden

The world's largest wooden structure

Construction of the Great Buddha of Nara started in the year 745, after Emperor Shomu decided to build a huge statue of Buddha to placate social disturbances in the wake of multiple coups and rebellions. The Buddha statue was completed in 752. The current Buddha is approximately 14.7 meters tall, and the circumferences of the platform, the head, and the palm are 70 meters, 2.6 meters, and 2.6 meters respectively. The head was restored in the Edo (Tokugawa) period (1603 to 1868), and most of the body was restored during the Kamakura period (1185 to 1333), but parts of the original statue still remain. The amount of copper used for building the Buddha varies slightly, depending on the historical record, but it is estimated to be 500 tons. Mercury used as a solvent in the plating process and arsenic contained in copper are said to have caused poisoning of nearby residents, and a medical center was established to treat these patients. The Hall where the Great Buddha (*Daibutsuden*) is enshrined today is 57.5 meters wide in the east-west direction, 50.5 meters deep, and 49.1 meters high to the ridge of the roof. It is the largest wooden frame building in the world, and was designated by the Japanese government as a National Treasure in 1952.

Today's schedule Jul. 30

Student

- **Video: Practical Examination explanation**

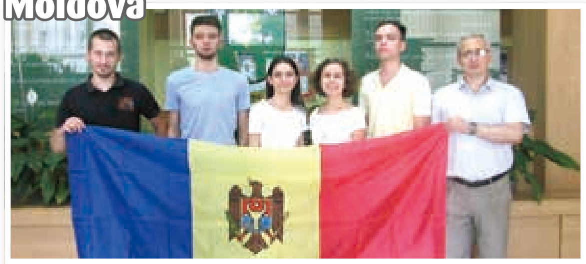
Mentor

- **Receive grading** (from Organizer, Request arbitration)
  J 09:00 C 02:00 E 20:00 (Jul. 29)
- **Deadline of request, Jury meeting**
  J 21:00 C 14:00 E 08:00

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

Early Bird Communication

Moldova



Cyprus

Answer for Q5

2 Davy

Humphrey Davy discovered as many as six elements from nature in his lifetime by electrolyzing a huge number of substances using Volta batteries.

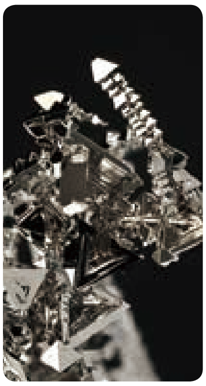
Element # 5

Japanese mineral resources
Palladium

Basic Information

Origin of the name: Named after the asteroid Pallas
Discovered by: W. H. Wollaston (the UK) [1803]
Global production: 210 tons
Major producers: Russia, South Africa, Canada

Palladium catalysts are vital to the efficient formation of carbon–carbon bonds. The compounds produced by cross-coupling reactions with these catalysts are indispensable to industry, from pharmaceuticals and agricultural chemicals to liquid crystals and organic light-emitting diodes. About 60% of palladium production is used in catalysts (three-way catalysts) for the removal of incomplete combustion products and unburned gasoline in automobile exhaust.



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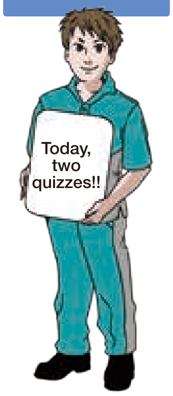
ELEMENT QUIZ Q6



① The 2001 Nobel Prize in Chemistry was awarded “for the development of catalytic asymmetric reactions”. Which catalytic metal was NOT used in the chemical reactions for which the prize was awarded?

1 Osmium 2 Palladium
3 Ruthenium 4 Rhodium

② Which of the following halogen elements is contained in vancomycin, a chemical widely known as an antibiotic?

1 Fluorine 2 Chlorine
3 Bromine 4 Iodine

Chemistry! It's Cool!

IChO2021 Catalyzer No. 6

Official Website
https://www.icho2021.org/
icho2021

Jul. 30
1905
Published!
Special relativity by Albert Einstein

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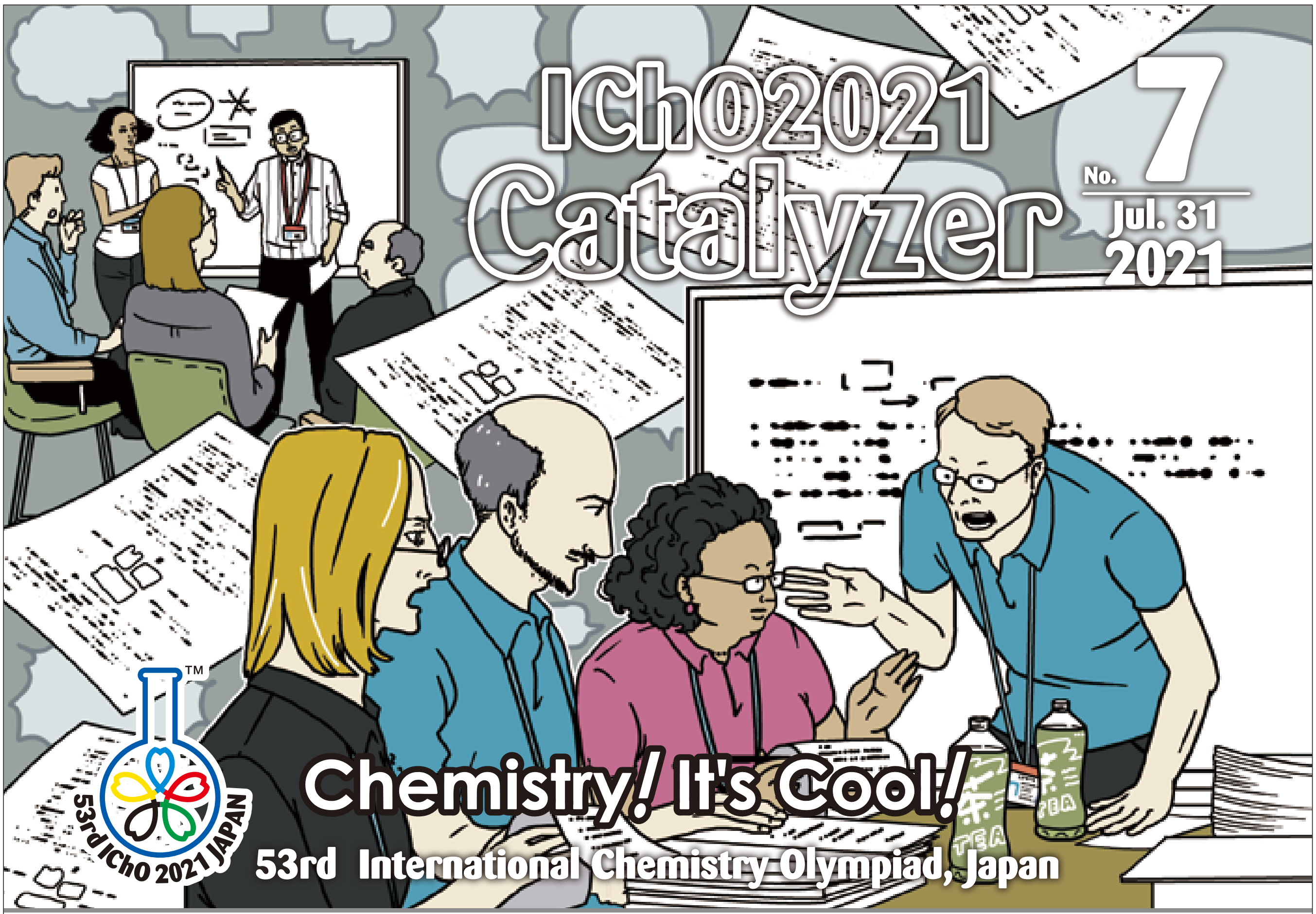


Cover illustration : Grading & Arbitration

Nobel Prize Research from Japan 07

Green Fluorescent Protein

Osamu Shimomura

Osamu Shimomura became interested in how the bioluminescent jellyfish *Aequorea victoria* glows in the dark, and went to Friday Harbor in the U.S. state of Washington with his family every summer to solve the mystery. They collected as many as 850,000 jellyfish and investigated the nature of the substance that made them glow. He isolated the substance in question, a kind of protein called green fluorescent protein (GFP). This protein undergoes a structural transformation to become a chromophore and emits fluorescence; specifically, via cyclization and oxidation of three amino acid residues, Ser65-Tyr66-Gly67. In the jellyfish body, the calcium-responsive protein aequorin absorbs light, and then emits blue fluorescence; in turn, GFP absorbs this blue light and glows green. However, GFP can also glow on its own, so Martin Chalfie and Roger Y. Tsien used genetic engineering to develop a method of attaching GFP to other proteins and making them glow. This tool enabled the analysis of various biological phenomena in cells to reveal the subcellular localization of proteins (GFP tags), and advanced research in a wide range of fields including cell and molecular biology, developmental biology, and medicine. The 2008 Nobel Prize in Chemistry was awarded to Osamu Shimomura, Martin Chalfie, and Roger Y. Tsien for “the discovery and development of the green fluorescent protein, GFP.” Today, artificial fluorescent proteins that glow in a variety of colors are being produced.

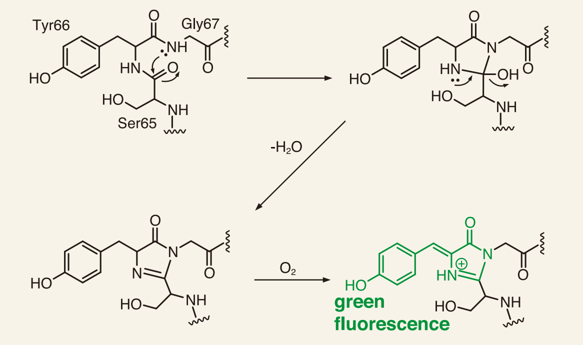



Photo by Nagasaki University

Dr. Osamu Shimomura
(1928–2018)

••• IChO2021 Problem Q6 •••

Coordination polymers: found in minerals - promising storage materials for small molecules

An enormous variety of minerals exist in nature. Most of these are inorganic compounds, while some are known as organic minerals. For example, there are currently 23 known organic minerals that contain carboxylic acids such as formic acid, oxalic acid, or acetic acid. In oxalate minerals, the two carboxylate groups (-COO$^-$) of oxalic acid are linked to various metal ions by coordination bonds to form network crystal structures (Fig. 1). Although not an organic mineral, Prussian blue, which was accidentally discovered in Germany in the early 17th century and has ever since been valued as a blue dye, adopts a crystal structure in which iron cations and cyanide anions (CN$^-$) are linked by coordination bonds (Fig. 2). Prussian blue was also used in Katsushika Hokusai’s famous woodblock print “*Under the Wave off Kanagawa*” (ca. 1831; Fig. 2). Such crystalline network structures, which arise from coordination bonds between metal ions and bridging ligands, are called ‘coordination polymers’.

In the middle of the 19th century, in parallel to the development of X-ray crystallography, chemists began to synthesize new coordination polymers using organic ligands that do not necessarily exist in nature. The crystal structure of an organic ligand-bridged coordination polymer that consists of adiponitrile and copper ions was firstly reported by Yoshihiko Saito et al. in 1959 (Fig. 3; left). We can only wonder how amazed these scientists must have been at the time by the complexity of the “reticular” networks of these crystal structures. After that, various other crystal structures were reported and chemists started to think about useful applications for these characteristic crystal structures.

In 1997, Susumu Kitagawa of Kyoto University discovered that the nanometer-sized small pores formed inside coordination polymers that consist of cobalt ions and bipyridine could be used as a gas-storage material (Fig. 3; right). Such “porous coordination polymers” can store large amounts of gas inside the crystals and are now being put to practical use. The applications of these materials can be expected to continue to expand in the future and probable applications include storing H_2 to power fuel cells, capturing CO_2 to ameliorate global warming, and storing H_2O to water the desert.

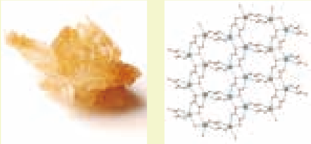


Fig. 1. (left) Photo of a macroscopic crystal of calcium oxalate and (right) its microscopic crystal structure determined by single-crystal X-ray diffraction analysis.

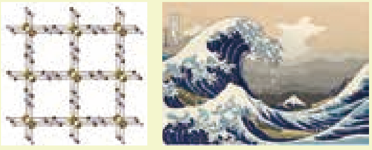


Fig. 2. (left) Microscopic crystal structure of Prussian blue. (right) Katsushika Hokusai’s “*Under the Wave off Kanagawa*”.

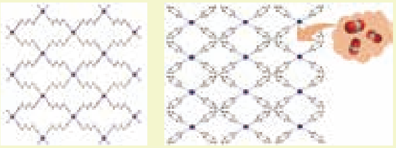
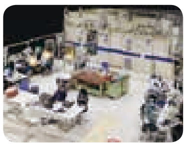
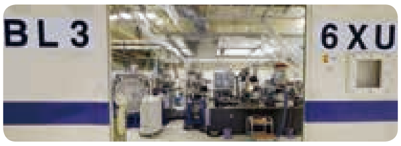


Fig. 3. (left) Crystal structure of a coordination polymer that consists of copper ions and adiponitrile ligands. (right) A representative porous coordination polymer that is able to store gas molecules inside its small pores.

VR TOUR SPring-8

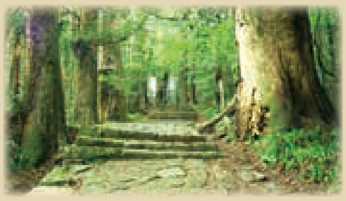




Kumano Kodo

Kansai Scenes 7

Kumano Kodo (literally means the old ways of Kumano) is a general term for the network of pilgrimage routes that lead to the three main Kumano Shrines: *Kumano Hayatama Taisha*, *Kumano Hongu Taisha*, and *Kumano Nachi Taisha*. Located in the southwestern part of the Kii Peninsula and starting eastwards from the city of Tanabe, the network spans Mie, Nara, Wakayama, and Osaka Prefectures. It was registered as a UNESCO World Cultural Heritage Site in 2004. Kumano is regarded by the Japanese people as a sacred place for mountain worship, a practice that originates from the worship of nature in which the gods dwell in rivers, waterfalls, and huge rocks. The *Kumano Kodo* is also mentioned in the ancient history book *Nihon Shoki*, written during the Nara period (710 to 794). People walking the routes today can see the same scenery as the pilgrims who visited Kumano to gain enlightenment in the old days, including such joys of nature as the large cypress trees that are more than 800 years old, and the smooth cobblestones on the paths.



Other Local Dialects in the Kansai Region

In Catalyzer No. 0, we presented a list of useful Japanese phrases, and in Catalyzer No. 1, a comparison of everyday phrases in Standard Japanese and *Kansai-ben*, a dialect spoken in the Kansai region. There are several sub-regional dialects too, each with distinctive expressions, spoken in various parts of Kansai. When a Kansai person speaks, we can often tell which part in the region they come from. The English phrase "Very Good!", for example, is Totemo Iine! in standard Japanese, *Meccha Eeyan!* in Osaka; *Erai Yoroshiyan!* in Kyoto; *Erai Eegai!* in Hyogo; *Erai Eenaa!* in Shiga; *Gottsu Eena!* in Nara; and *Yanikoo Eewaisho!* in Wakayama. Look at some of the other differences in the table below.

English	Standard Japanese	Osaka	Hyogo	Kyoto	Shiga	Nara	Wakayama
I agree.	Sou-dane.	Seya-na.	Seya-na.	Soya-na.	Hoya-na.	Seya-na.	Soya-ne.
No, you can't!	Dame-dayo!	Akan-de!	Akkai-ya!	Akan-shi!	Akasen!	Akan-de!	Akanaa!
Lots	Takusan	Gyousan	Jousan	Tanto	Yokke	Youke	Yousan
No problem.	Kamaimasen.	Kamahen.	Becchonai.	Dannai.	Dannai.	Kamahin.	Kitsukainai.
I can't.	Dekinai.	Dekehen.	Dekihin.	Yousimahen.	Dekihin.	Dekiyan.	Yousen.
Bottom	Saikai	Dobe	Getta	Bebetako	Gebeccha	Bebeta	Betta
Do not come	Konai	Kēhen	Kōhen	Kīhin	Kiyahen	Kyahen	Kēhen

* These words are just some examples.

Practical Examination

A message from the student narrators of the practical examination video

We are fortunate to be given this opportunity to help the International Chemistry Olympics in this way. We are students who like both English and chemistry. We believed challenging ourselves to try new things would give us new perspectives, and we thought taking this opportunity would give us new discoveries and experiences. Being able to participate in this event with friends was another incentive as well.

Although it wasn't an easy task to pronounce the long names of chemical substances or highly technical chemistry terms properly, we enjoyed dealing with it.

Most of us hope to work in a science field such as medicine, biology, or space aeronautics. Some of us would like to deal with environmental problems in the future as well. We are sure we need to use English to work in this field with the global scene. We will make good use of this experience that has given us a chance to get to know what practical English is like. Thank you.

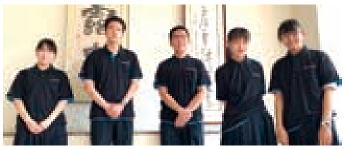

Kyoto Prefectural Sagano Senior High School

PHOTO SELECTION

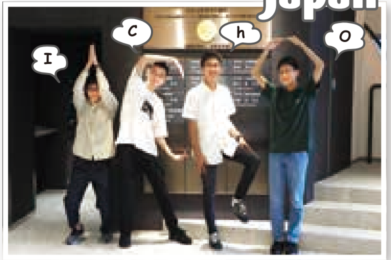
from VR Venue

during IChO2021

Turkey

Bangladesh

Japan



Short short from Editors

The book to take you to the world of Chemistry

Do you remember what made you fell in love with Chemistry? In Japan, there are illustrated books that introduce chemistry to children and fascinates chemists at the same time. Kako is also a scientist himself and has written many Chemistry stories for children. One of them is “Nakayoshi Ijiwaru Genso no Gakkou.” It means “School of ELEMENTS with good friends and mean friends.” This book introduces the process of creating the periodic table by comparing the properties of elements to the personalities of human classmates.


Little Daruma series

Today's schedule Jul. 31

Student

- **Activity** Video: History and Culture of Nara

Mentor

- **Arbitration** (America (west) ›› Asia ›› Europe ›› America (east))
  J 09:00 C 09:00 E 20:00 (Jul. 30)
- **Activity** Video: History and Culture of Nara

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

Early Bird Communication

China

Uruguay

We could not take a group photo since the COVID-19 situation in Uruguay would not allow it. Even when the situation is getting better and the students will perform the test at the same classroom, asking them to travel to the main city, Montevideo, just to take a photo, could not be the best choice.

Sri Lanka

Sri Lankan team meeting with mentors

Element #6

Japanese mineral resources

Indium

Basic Information

Origin of the name: Latin word *indicum* (indigo)
Discovered by: H. T. Richter and F. Reich (Germany) [1863]
Global production: 900 tons
Major producers: China, South Korea, Japan

Indium is an essential material for liquid crystal displays (LCDs), which are widely used for flat-screen TVs and notebook computers. Indium tin oxide (ITO) is used for electrodes in LCD panels because it is both transparent and conductive. Most of the world's indium is now produced in China, but in the past, the Toyoha Mine in Sapporo on the Japanese island of Hokkaido was the world's largest producing mine of indium. However, the mine was closed in 2006 because of its low profitability and the depletion of the resource.

© Crystal Museum

ELEMENT QUIZ Q7

A shape memory alloys is made by mixing two metals in a 1:1 ratio. Which of the following is the correct combination of two metals?

1 (Zn, Cu)
2 (Al, Cu)
3 (Ni, Ti)
4 (Ni, Fe)

Answer for Q6

① 2 Palladium

Osmium was used in the oxidation by Dr. Sharpless, and ruthenium and rhodium were used in the hydrogenation by Dr. Noyori and Dr. Knowles. Palladium was not used in either of these reactions.

② 2 Chlorine

Vancomycin is an antibiotic that belongs to the family of glycopeptides, which contain chlorine.

Chemistry! It's Cool!

53rd IChO 2021 JAPAN
IChO2021 Catalyzer No. 7
Official Website
https://www.icho2021.org/
icho2021

Jul. 31
1800
Birthday
Friedrich Wöhler, Father of Organic Chemistry

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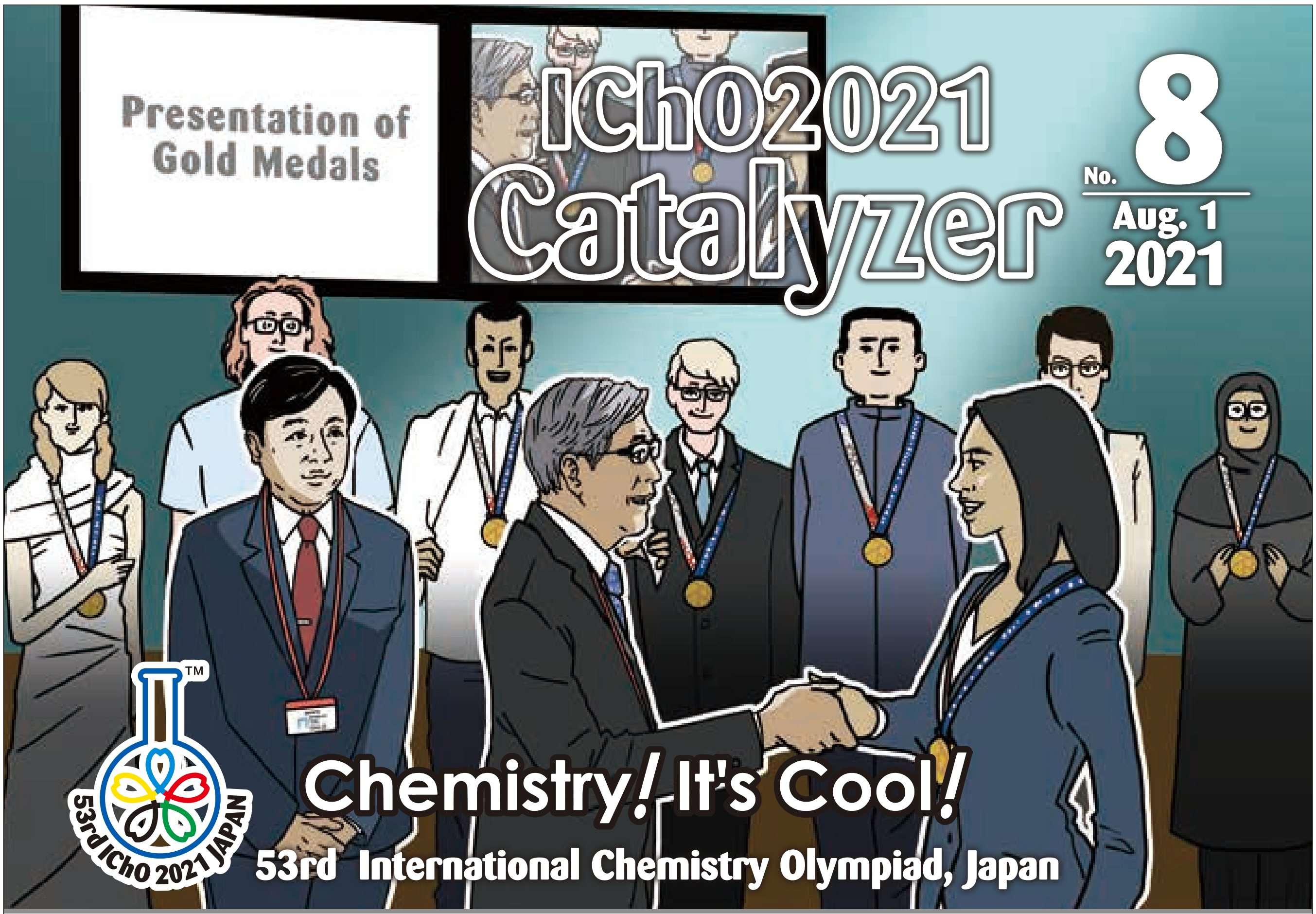
Edited by the Team Catalyzer IChO2021
English Editor: Maiko Katayama
Illustration: Science Manga Studio



Cover illustration : Award Ceremony

Medal Design Concept: “The Chemical Vortex Leading to the Future”

Designer: Sakiko Matsumoto

From the center to the edge, the entire medal forms the shape of a vortex, giving the impression of a whirling motion. This movement represents the global impact and upcoming success of young students, originating at IChO2021 Japan. Through the designs found on both sides of the medal, IChO2021 supports the bright future of the contestants.

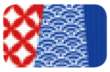
The obverse side features three kinds of popular auspicious patterns to express aspects of Japanese culture.

The reverse side contains the logo, which is represented in a simple and emphatic way through an image that spreads across the world.

Seigaiha (青海波) translates to blue ocean waves. The endlessly calm waves are a prayer for long-lasting happiness and a peaceful life.

Shippō Tsunagi (七宝つなぎ) is a pattern of connecting circles, expressing a wish for happiness, harmony, and connection. This connection is as valuable as the Seven Treasures of Buddhism: gold, silver, lapis lazuli, agate, seashell, amber, and coral.

Asanoha (麻の葉) is a pattern representing hemp leaves. Because hemp is resilient, grows vigorously, and requires little care, it is often used as a pattern in the *kimono* of young children in the hope that they grow up big and strong. It is also meant to ward off evil.



The ribbon represents the image of a whirlpool flowing from the medal in indigo, black, and vermillion, which is the color of Japan. The design also expresses the impact that the students will have in the world.

Nobel Prize Research from Japan 08

Discovery and Development of Conductive Polymers …. Hideki Shirakawa

Plastics (polymers) are used in all aspects of our daily living and enrich our lives with their low cost, light weight, and flexible formability. Initially, plastics were thought not to conduct electricity and were used as insulators. However, various conductive polymers have now been developed and boast a wide range of applications, including touch panels for smartphones and electrodes for lithium-ion batteries. The development of conductive polymers that led to innovation in the world of plastics was triggered by a serendipitous (unexpected) discovery by Hideki Shirakawa. When a student in his laboratory accidentally used one thousand times the required amount of catalyst to synthesize polyacetylene, he obtained a shiny, film-like material that was completely different from the conventional black powdery polyacetylene. Although polyacetylene has many π-electrons, they cannot move freely, and the film-like polyacetylene did not show sufficient conductivity in its original state. However, through trial and error, they came up with a method to dope carriers that act as electron acceptors, and when they added a small amount of bromine or iodine, the conductivity surged 10 million times. This discovery led to a dramatic development in research on conductive polymers. For this series of achievements in laying the foundation for the development of conductive polymers, which became indispensable to modern society, Hideki Shirakawa was awarded the Nobel Prize in Chemistry in 2000, together with Alan Jay Heeger and Alan Graham MacDiarmid.

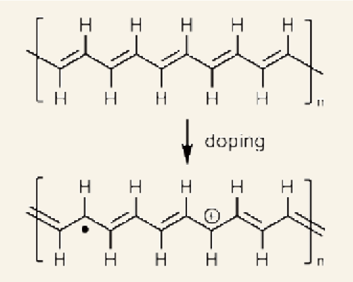



Photo by Kazuhiko Sugano

Dr. Hideki Shirakawa
(1936–)

Japan is a "fermentation powerhouse"

Japan, with its warm and moist climate, is a "fermentation powerhouse" where microorganisms are very efficacious. Fermented foods such as soy sauce, *natto* (fermented soybeans), and *katsuobushi* (dried bonito flakes), which are made by growing mold on fish to remove moisture, are world-famous.


Soy sauce


Natto


Katsuobushi

Kansai is also home to many fermented foods rooted in the local climate. In Wakayama, facing the Pacific Ocean, "*Nare-zushi*", salted fish wrapped in plant leaves with rice and then lacto-fermented, is served on celebratory occasions. "*Funa-zushi*", a kind of *Nare-zushi*, is made along the shoreline of Lake Biwa. *Funa-zushi* is made by marinating spawning crucian carp in salt and fermenting it with rice for one to three years. The lactic fermentation gives it a novel cheese-like flavor and sourness, and the acidity increases its shelf life. There are two types of pickles in Japan: those made of lacto-fermented vegetables, and those made by soaking veges in *koji* (rice malt) or sake lees to add to their flavors. For example, "*Suguki-zuke*" is a lacto-fermented turnip and "*Nara-zuke*" is a type of cucumber or squash pickle that has been pickled in sake lees for years.

Nare-zushi


Funa-zushi


Suguki-zuke


Nara-zuke

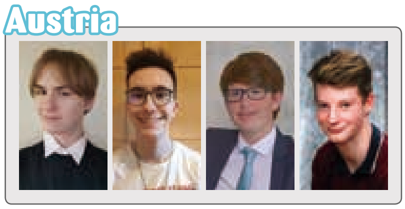
Koji and yeast are crucial for making sake and basic seasonings such as soy sauce, miso, mirin, and vinegar. Jokichi Takamine who succeeded in crystallizing adrenaline (Catalyzer No. 6), devised a method to extract a type of diastase (digestive agent), named Takadiastase later, during the process of growing *koji*. *Koji* is deeply connected to the history of biochemical research in Japan. Against this background, *Aspergillus oryzae*, the main body of *koji* that supports Japanese food culture, was designated as Japan's national fungus in 2006 by the Brewing Society of Japan.

IChO2021 Participating Teams

Armenia

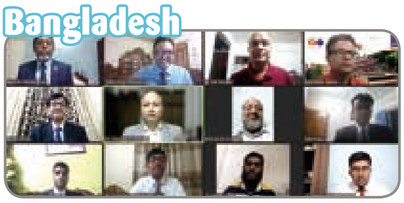
Australia

Austria



Azerbaijan

Bangladesh



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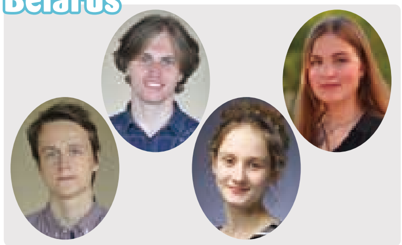

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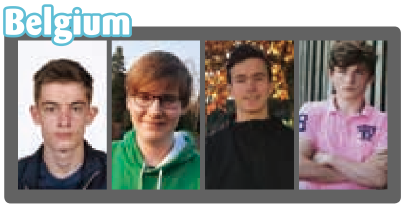

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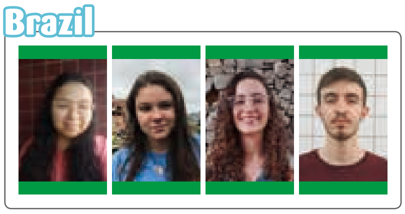

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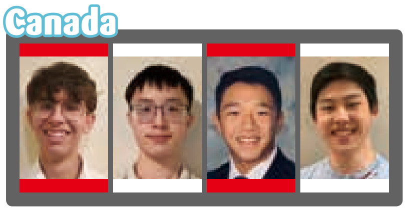

China

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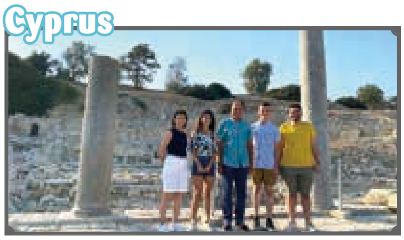
Costa Rica

Croatia

Cyprus



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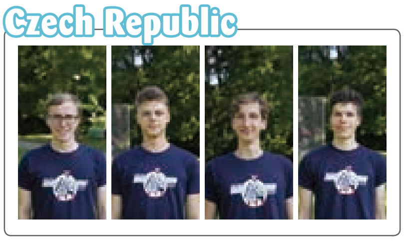

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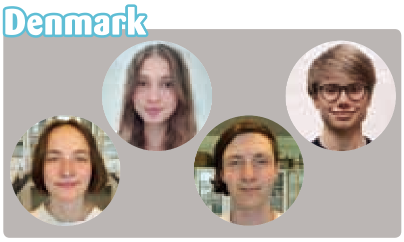

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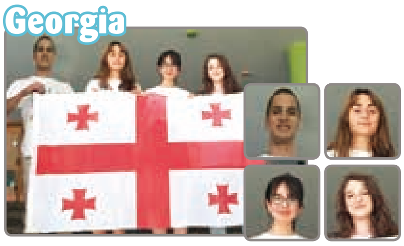
Estonia

Finland

France

Georgia



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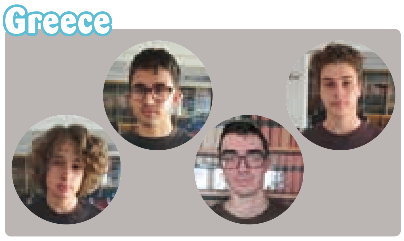

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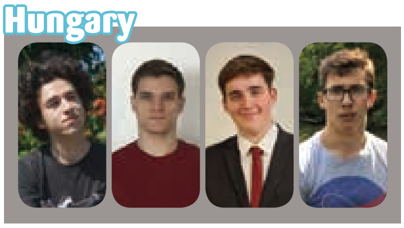

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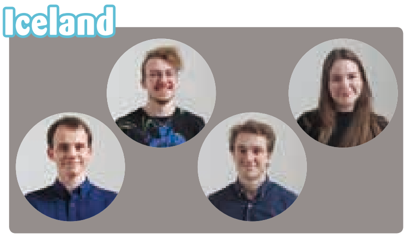

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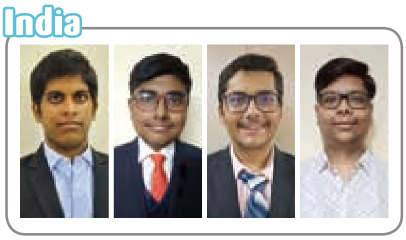

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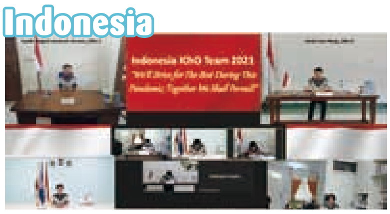

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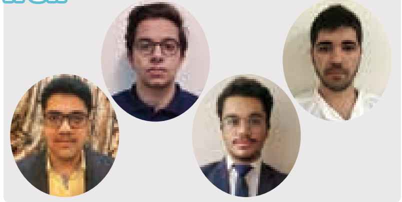

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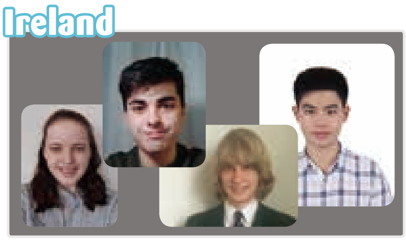

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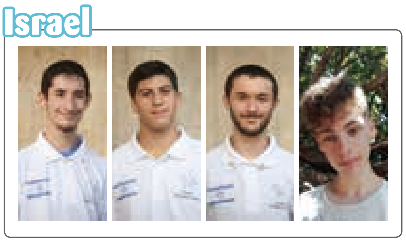

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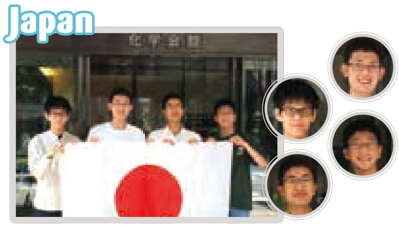
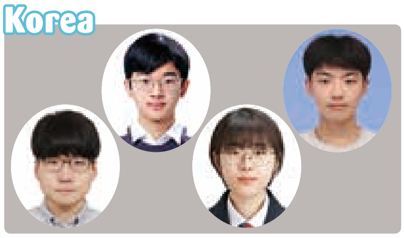


Kazakhstan

Korea



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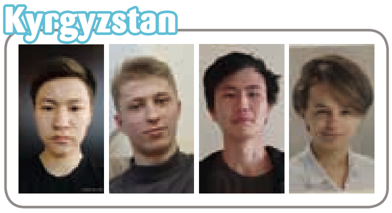

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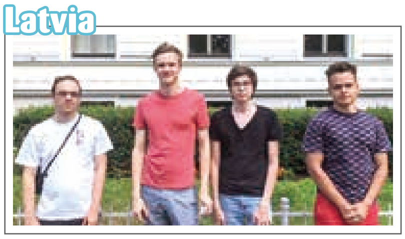
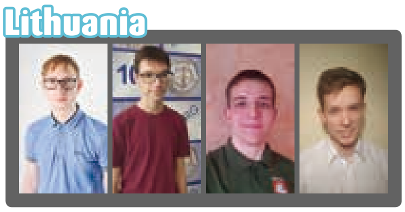
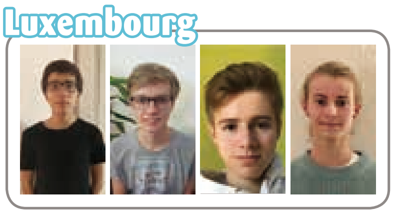


Lithuania



Luxembourg



Malaysia

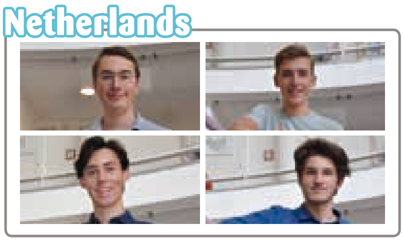
Mexico

Moldova

Mongolia

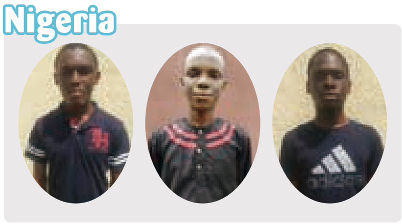
Montenegro

Netherlands



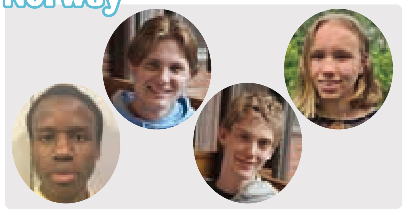
New Zealand

Nigeria



North Macedonia

Norway



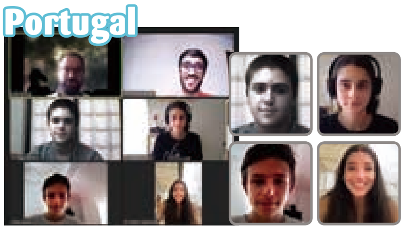
Oman

Pakistan

Philippines

Poland

Portugal



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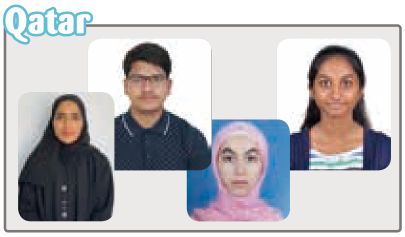
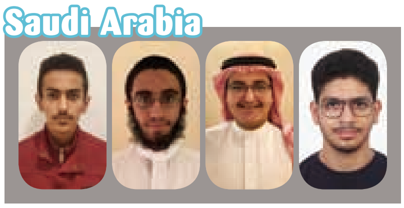


Romania

Russian Federation

Saudi Arabia



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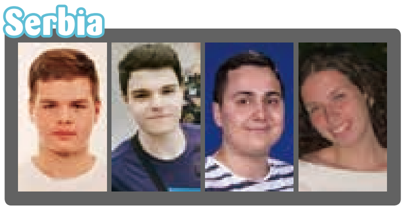


Singapore

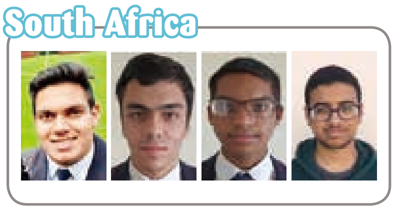
Slovakia

Slovenia

Thailand

United States of America

South Africa



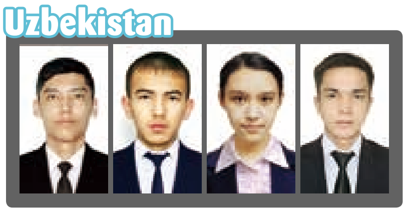
Trinidad and Tobago

Uruguay

Sri Lanka

Turkey

Uzbekistan



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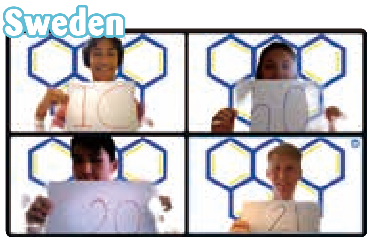

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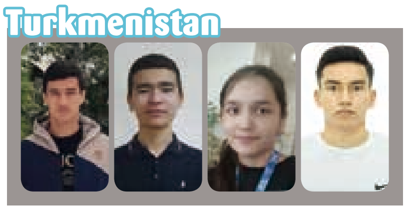
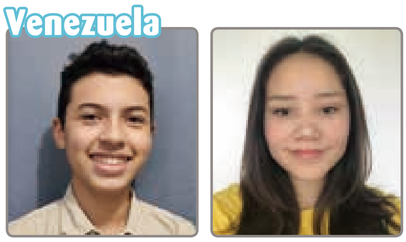
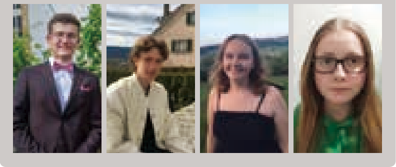


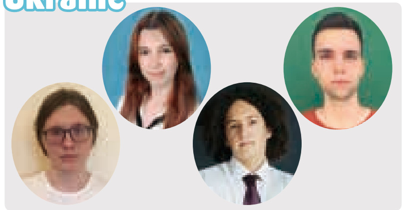
Venezuela



Switzerland

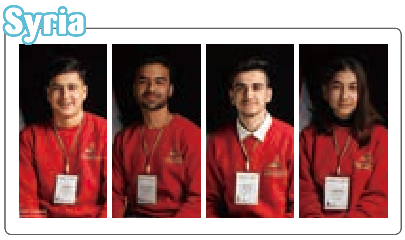


Ukraine



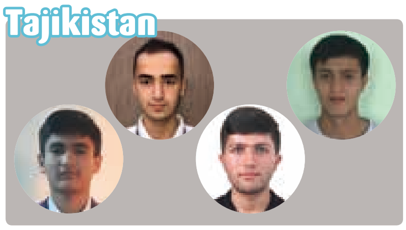
Vietnam

Syria



United Arab Emirates

Tajikistan



United Kingdom

Remote IChO2021 Japan

Looking Back Remote IChO2021

Nobuhiro Kihara

Vice-chair of Executive Committee,
Vice-chair of Science Committee
for the 53rd IChO2021, Japan

The 53rd International Chemistry Olympiad (IChO) 2021 Japan was originally planned to follow the 2020 Olympic and Paralympic Games in Tokyo, Japan. The interest to chemistry from the people was expected to be enhanced when a scientific Olympiad would be held after the excitement of a sporting Olympiad.

When we heard the first reports of COVID-19 early in 2020, it appeared to be a minor concern. Despite the virus being thought of as causing a new kind of cold, we knew that the common cold is inactive in summer, when the IChO was to be held. However, shortly after the pandemic spread across the globe, it became evident that COVID-19 was active in summer, too. The 2020 Olympics and Paralympics were postponed, and the 52nd IChO2020 in Turkey was held remotely, because the University venue could not be used for an in-person event in the period of IChO.

The IChO is composed of three key elements:

(1) Examination

Chemistry is an experiment-based science, with every theory coming out of the laboratory. Therefore, both theoretical and practical examinations play important roles in the IChO.

(2) Communication

Talented students from all over the world come together to take part in the IChO. Conversation, cooperation, and communication with each other provide a great opportunity for promising youngsters to enjoy international experiences and to make friends with other participants via their common interest, chemistry.

(3) Culture

The venue chosen for IChO2021 Japan was the ancient capital of Japan, where the first government of Japan was established 2681 years ago (according to Japanese legend). Several places were to be visited, including not only very old temples but also state-of-the-art scientific institutes.

In the middle of January 2021, the Organizing Committee of IChO2021 Japan met with the Steering Committee (SC) of the IChO. We discussed two proposals; for an in-person IChO and a remote IChO. Unfortunately, it was already clear that all the elements of the IChO described above could not be included in an in-person IChO during the COVID-19 pandemic, due to difficulties in immigration control and of the need for social distancing.

The first priority of IChO is, of course, the safety of all participants. After our meeting with the SC, we finally decided to hold IChO2021 Japan as a remote event. At the end of February, when we had a second meeting with SC, the holding of a remote IChO was approved.

Even in a remote format, all elements essential to the IChO had to be maintained as much as possible:

(1) Examination

The competition involves theoretical problems, and was strictly monitored to avoid cheating. However, in order to reinforce the importance of laboratory work, an activity was developed in which the practical tasks prepared for IChO2021 Japan were demonstrated. We are delighted if those who are inspired by the demonstration can prepare and submit original videos in which they attempt the practical tasks and discussions. Reports on the tasks will also be highly welcome.

(2) Communication

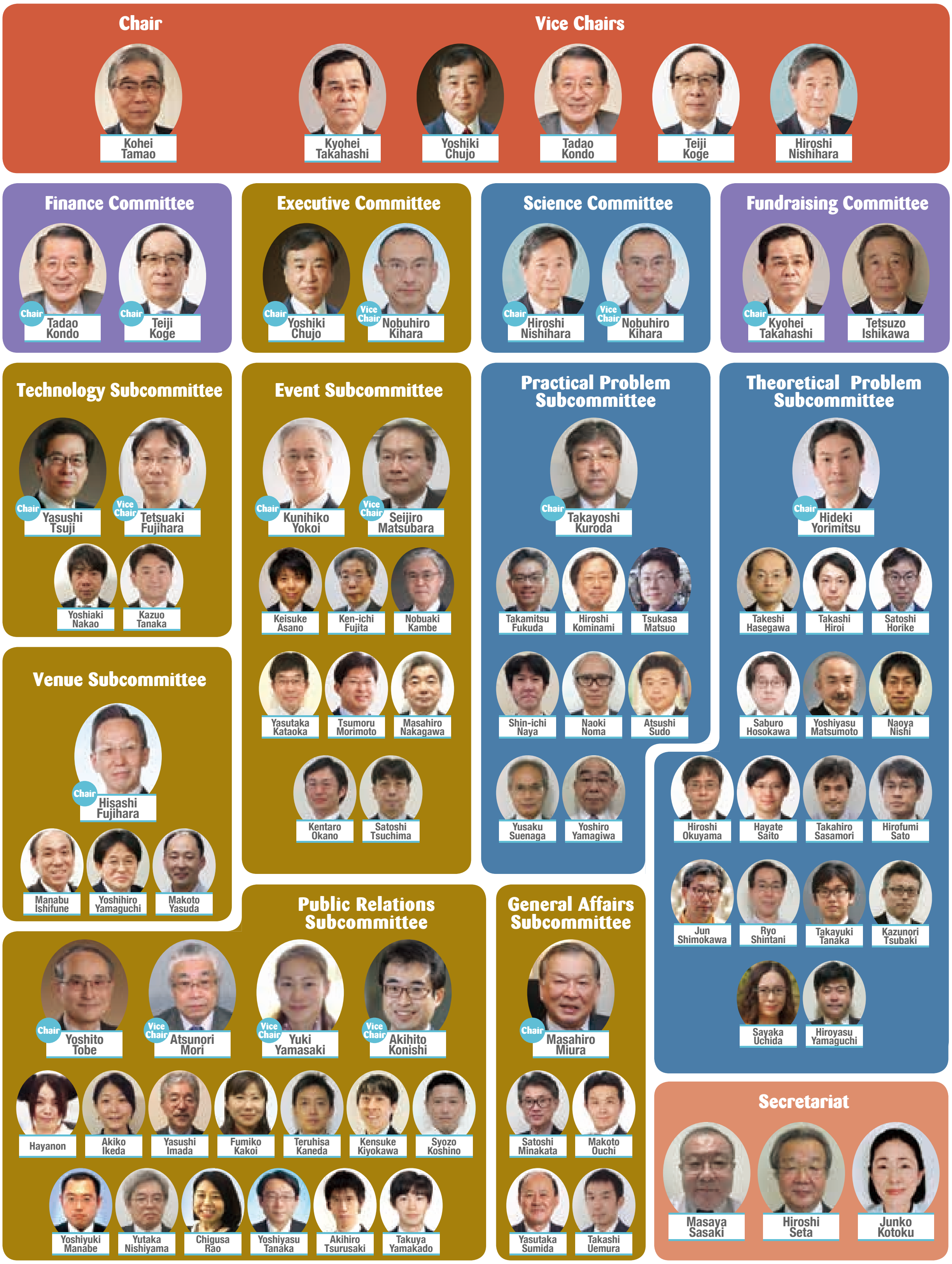
We prepared avatars for all participants. Everyone participated in events and activities via their avatars. We also prepared virtual venues in which avatars can enjoy close conversation, cooperation, and communication with others. Some events also took place in such virtual venues.

(3) Culture

IChO participants were offered the opportunity for virtual visits to several locations. As well as those locations that had been planned for the in-person IChO, we have added several that are very interesting to experience but not suitable for in-person visits due to hazards, sensitivity, space limitations, or language difficulties. However, the participants' avatars can readily visit such restricted locations. The menu of cultural tours for our remote IChO holds more interest than would otherwise be possible.

This remote IChO has given us the chance to make the latest technology to provide great opportunities and special experiences to all participants.

Organizing Committee



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Kohei Tamao

Vice Chairs

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Yoshiki Chujo
Tadao Kondo
Teiji Koge
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Secretariat

Masaya Sasaki
Hiroshi Seta
Junko Kotoku

Today's schedule **Aug. 1**

Student

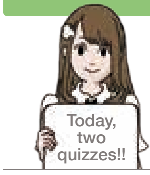
- **Activity　Video: Himeji Castle, Osaka, and Kyoto**

Mentor

- **Receive final results** J 09:00 C 02:00 E 20:00 (Jul. 31)
- **Activity　Video: Himeji Castle, Osaka, and Kyoto**

J : JST = UTC + 9 C : CET = UTC + 2 (summer time) E : EST = UTC - 4 (summer time)

ELEMENT QUIZ Q8



① The term "atom" is said to have been derived from a Greek word "atomos", which literally means "something that cannot be divided". What is the origin of the term "electron"?

1 amber
2 something that shines
3 musical instrument
4 something like water

② Which country is the largest producer of selenium in the world?

1 USA　2 Japan　3 Mexico　4 China

Answer for Q7

3 (Ni, Ti)

Zinc-copper alloy is brass, aluminum-copper alloy is duralumin, and nickel-iron alloy is called permalloy. A nickel-titanium alloy that consists of same ratio of the two metals is called a shape-memory alloy because it has the property of returning to its original shape when heated above a certain temperature, even after deformation.

Element # 7

Japanese mineral resources
Silicon

Basic Information

Origin of the name: Latin word *silex* (hard stone, flint)
Discovered by: J. J. Berzelius (Sweden) [1823]
Global production: 8 million tons
Major producers: China, Russia, Brazil

Silicon does not exist in its pure metal form in nature; however, massive amounts of silicon can be found in soil, stones, and minerals in oxide forms, typically SiO_2, a major constituent of sand. Yamanashi Prefecture in Japan is famous for its natural quartz crystal. Silicon metal is a very important material for industry today, used widely in semiconductors, microchips, and photovoltaic panels.

© The Courtyard of our Minerals

Daisenryo Kofun

Kansai Scenes 8

The *Daisenryo Kofun*, located in the city of Sakai in Osaka Prefecture, was built in the early to mid-5th century and is considered to be Japan's largest *kofun* (Emperor's tomb). It is one of the more than 200 burial mounds that make up the Mozu Tumulus Group, which were built between the late 4th and early 6th centuries. The three-tiered, keyhole-shaped tomb is 486 meters in length and 654 meters at its widest, and is surrounded by a three-tiered moat. Although the actual identity of the Emperor buried there is unknown, the *Daisenryo Kofun* was recorded as the tomb of Emperor Nintoku in a collection of laws compiled by the Imperial Household Agency in the early 10th century. The *Daisenryo Kofun* is one of the three largest tombs in the world, together with the pyramid of King Khufu in Egypt and the tomb of Qin Shi Huang in China. It was designated as a UNESCO World Heritage Site in 2019.

Chemistry! It's Cool!

IChO2021 Catalyzer No. 8

Official Website
https://www.icho2021.org/
icho2021

Aug. 1
1774
Discovered!
Oxygen
by Joseph Priestley

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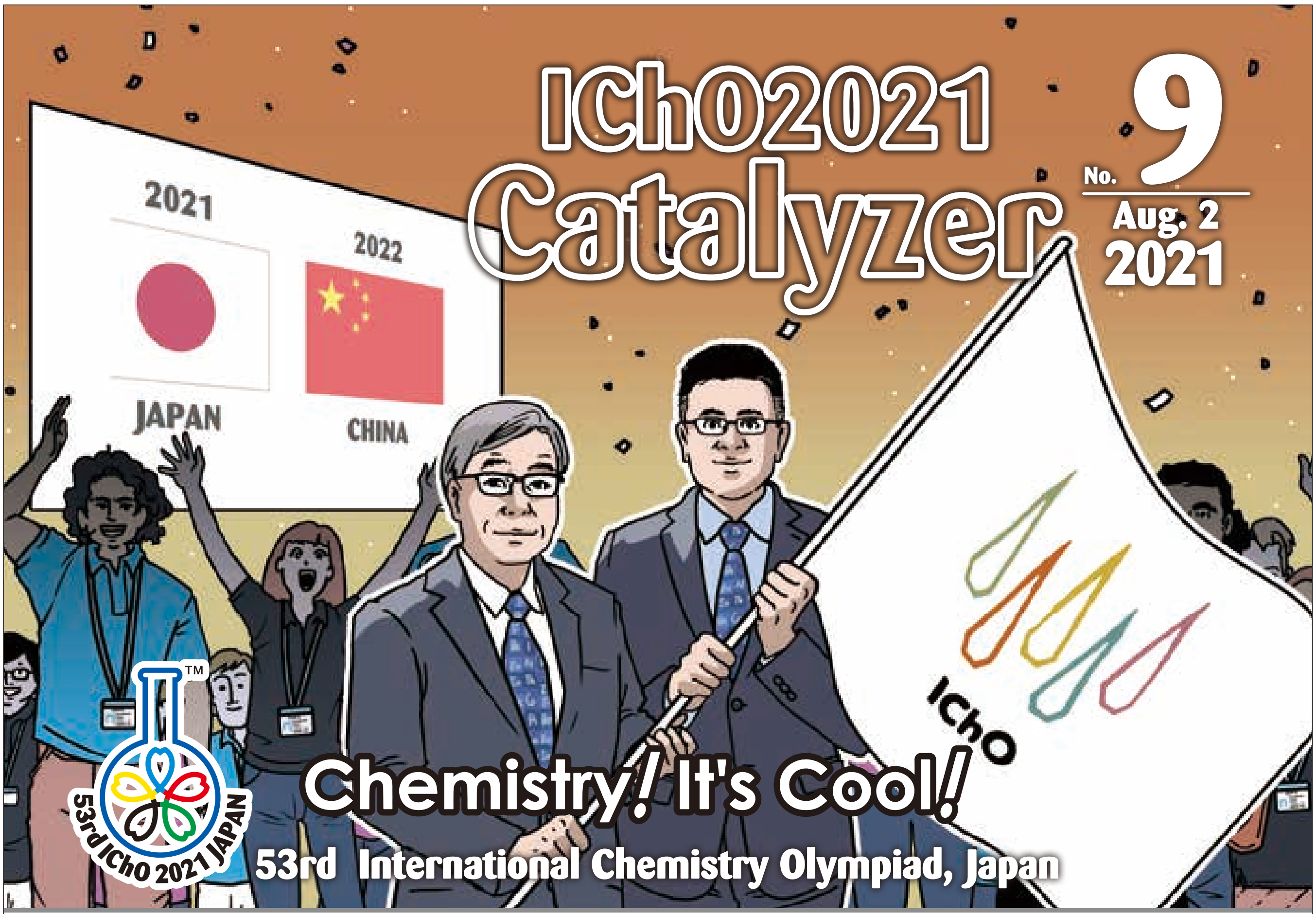
English Editor: Maiko Katayama
Illustration: Science Manga Studio



Cover illustration : IChO flag Ceremony

Welcome Message from China ··· IChO2022

We are looking forward to welcoming you from all over the world to participate in the 54th Chemistry Olympiad in 2022, at Nankai University, in Tianjin city. Tianjin, a meaning of the 'emperor's docks,' resides in Northern China, the key junction of transportation and communication for China and its connection with the world.

As the Vice-Chancellor of Nankai University, it is my greatest pleasure to introduce Nankai University as the 54th IChO host. Founded in 1919, Nankai University has played a vital role in Chinese education over the last 100 years. Today, Nankai has grown to three modern university campuses, plus a full range of educational institutions. Nankai University is a leading multidisciplinary and research-oriented state university, consisting of 26 colleges, covering areas from natural science to humanities, at all levels. As a member of the Global University Leaders Forum, Nankai University strives continuously to deepen its internationalization and globalization process, both in education and research. Not only does Nankai offer opportunities for students to study abroad, but it also provides a growing number of well-supported international studentships and scholar bursary programs each year. These broaden our academic horizons and contribute to building a worldwide academic community and a shared future for humankind.

As a chemist, I have found that Chemistry can start from simple concepts and extend to understand the complexities of the world. Here at Nankai, one is always encouraged to develop social responsibility, practical capabilities, and a creative spirit. This spirit is coincidently shared with the IChO, so we are genuinely looking forward to welcoming the young Olympians to Nankai University, bringing sparks of inspiration and ideas, scientific talent, and starting friendships. Right now, we are working as hard as possible to ensure you will have a safe, and a special IChO in China. We sincerely hope that the pandemic will be over and the world will go back to normal quickly.

Finally, we are looking forward to welcoming you to Tianjin, in 2022!

Prof. Jun Chen

The Chair of the Organizing Committee of
IChO2022
The Vice-Chancellor of Nakai University

IChO2021 Japan Closing Remarks by Vice President of IChO2021

Thank you for kind introduction. My name is Kyohei Takahashi, and I'm originally from a Japanese chemical company, and also ex-Chairman of Japan Chemical Industry Association, an association of all Japanese chemical companies. In Japan, academic society and industry association jointly continue to contribute to overall chemical society, and it is my honor to work as a representative from the chemical industry in this International Chemistry Olympiad Japan Committee.

The 53rd International Chemistry Olympiad in Japan, or IChO2021 Japan, will be closed today after the fruitful session of 9 days. Although due to the ongoing COVID-19 pandemic, we had to have the meetings by WEB system, we had participants from 85 countries and regions. This is the largest number IChO has ever had.

This was made possible by the devoted efforts of the Steering Committee and Chairman Dr. Gábor Magyarfalvi, all national contacts of each country and region, and those who conducted selection of student representatives. I would like to express our sincere thanks to all of you. In addition, thanks to the grate efforts of all mentors, science observers, and invigilators, examinations in all countries and regions were fairly conducted. I really appreciate your efforts and cooperation.

In the host country Japan, sponsorship was provided for us by many governmental agencies including Ministry of Education, Culture, Sports, Science and Technology, Ministry of Economy, Trade and Industry, Japan Science and Technology Agency, and more than 180 chemical companies and associated companies. Here I would like to report that this IChO has been operated under the partnership of All-Japan. Let me express my heartfelt thanks to all organizations and persons who supported us.

Now all of more than 300 students from all over the world taking part in IChO2021 Japan, thank you for your on-line participation despite this difficult situation! Did you demonstrate your ability and results of your daily efforts to the full? I believe all of you did! Properly speaking, you should come to Japan, become good friends with other students, and directly feel Japanese science, technology, society, and culture. However, we could not invite you to Japan due to the pandemic. Nevertheless, we provided you with many extraordinary programs and events only an on-line would be capable of. We provided you with virtual-tour of SPring-8, which is the world's largest radiation facility, and on-line visit to Buddhist temples, Himeji Castle, Kyoto, and Osaka. I am sure you enjoyed these virtual tours! We also hope you enjoyed communication with many new friends from all over the world in the virtual space.

For all of you who gloried as gold, silver, and bronze medal winners, congratulations! Your past effort comes into full bloom now! Also, let me congratulate all other students participated, because taking part in the IChO as representatives from your country or region is an honor you should be proud of. Your experience of this time will let you gain great self-confidence and support in your future.

Chemistry has infinite potential. The chemical industry is the only industry which has a name of science in its name, while other industries, such as the automobile industry and the steel industry, are called with names of products. This is because the chemical industry is based on chemical technology. Our industry manufactures various products, and chemistry is utilized in every possible scene of our life. Therefore, we can say that the chemical industry is the blood for all other industries.

Today we are facing global-scale problems such as global environmental issues, natural resource problems, and energy problems. These problems may jolt the future of human beings. As you know, the UN Sustainable Development Summit held in September 2015 adopted a set of international development goals called "Sustainable Development Goals" known as SDGs and most of such 17 goals requires innovations by chemistry. We believe and hope young people like you, who have rich knowledge and capability about chemistry, will lead the achievement of such goals. My dear students, this time you represented your home countries. But in the future, you must lead chemistry in the world, you must work together with other participants in this IChO, and you must make great contribution to the solution of difficult global problems. My young friends, please have high aims, and attempt new challenges!

At the end of my closing address, I wish you great success in your bright future. Thank you very much and good luck!

Kyohei Takahashi

Vice President, IChO2021 Japan Committee
Vice Chair, Organizing Committee
for the 53rd IChO2021, Japan

Awards and Closing Ceremony

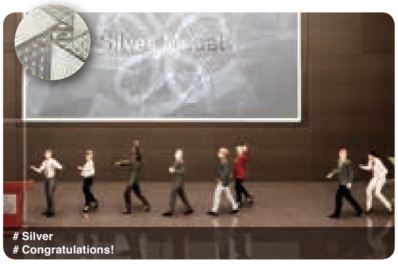
Program

- Opening Movie
- Introduction of Sponsors
- Explanation of Examination by Prof. Hiroshi Nishihara
  Chair of the Science Committee
- Awards Ceremony
- Message from Prof. Gábor Magyarfalvi
  Chair of the Steering Committee
- Closing Remarks by Kyohei Takahashi
  Vice President of IChO2021 Japan Committee
  Vice Chair of IChO2021 Organizing Committee
- Introduction of Organizing Committee Members
- IChO Flag Handover Ceremony
- Welcome Message from Prof. Jun Chen
  Chair of the Organizing Committee of IChO2022
  Vice-Chancellor of Nankai University
- Closing Movie

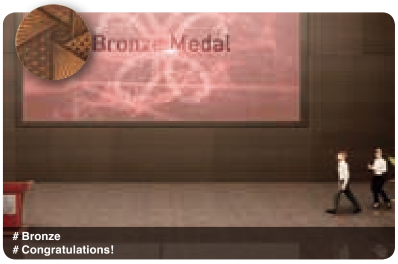

Closing Ceremony # Awards
Aug. 2, 2021

Top 3 of Gold Medalists # 1st, Shu Yang # 2nd, Zhangyi Huang # 3rd, Xinyu Cai
Congratulations! # 3 avatars with reflecting winner's faces

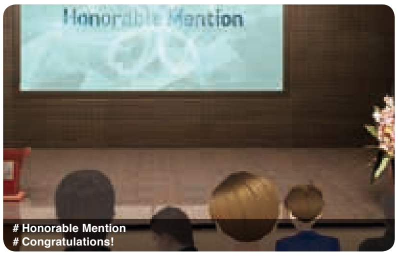
Gold
Congratulations!



Silver
Congratulations!



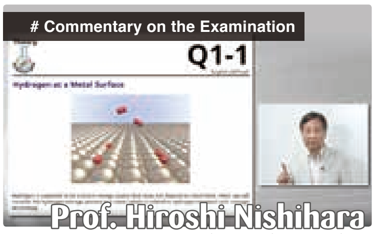
Bronze
Congratulations!



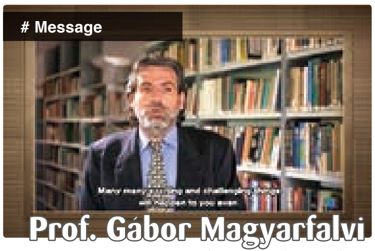
Honorable Mention
Congratulations!


Avatars attended
Remote # Virtual venue


Participants communicated using avatars.
The space is virtual, but your new friendship is real!


Commentary on the Examination

Prof. Hiroshi Nishihara
Chair of the Science Committee


Message
Prof. Gábor Magyarfalvi
Chair of the Steering Committee


Closing Remarks
Kyohei Takahashi
Vice President of IChO2021 Japan Committee


Welcome IChO2022
Prof. Jun Chen
Chair of Organizing the Committee of IChO2022
Vice-Chancellor of Nankai University

Congratulations!!

IChO2021 Japan

Jul. 25 (Sun.) – Aug. 2 (Mon.) 2021

Remote Examination

Jul. 28 (Wed.)

Participants (85 Teams)

521 Total Participants
312 Students
157 Mentors
52 Observers and Guests
183 Invigilators

Awards

Gold Medal : 33
Silver Medal : 67
Bronze Medal : 94
Honorable Mention : 24

Best of IChO2021

1 **Shu Yang**	China
2 **Zhangyi Huang**	China
3 **Xinyu Cai**	China

Gold

Shu Yang	China
Zhangyi Huang	China
Xinyu Cai	China
Bangsen Zhao	China
Sobirjon Amanov	Uzbekistan
Mircea Raul Bodrogean	Romania
Aleksandr E. Trofimov	Russian Federation
Anh Duy Nguyen	Vietnam
Bo-An Chen	Chinese Taipei
Georgii M. Zhomin	Russian Federation
Chun-Cheng Ting	Chinese Taipei
Phuong Duc Nam Pham	Vietnam
Qiyang Zhou	United States of America
Berkan Tarak	Turkey
Chen Yizhou	Singapore
Alexander Ramsay Thow	United Kingdom
Rui-Xi Wang	Chinese Taipei
Cheng Jun Nicholas Goh	Singapore
Nir Cohen	Israel
Timofey A. Charkin	Russian Federation
Tudor Lile	Romania
Adarsh Reddy Madur	India
Mahbod Alian Fini	Iran
Deniz Guner	Turkey
Andrei S. Tyrin	Russian Federation
Dhananjay Raman	India
Yitian Zhu	United States of America
Filip Hůlek	Czech Republic
Harry John List	United Kingdom
Anh Le Thao Nguyen	Vietnam
Mahyar Afshinmehr	Iran
Myeongjin Shin	Korea
Alexandru Catalin Dianu	Romania

Silver

Duong Hoang Nguyen	Vietnam
Stefan Dimitriu	Romania
Sebnem Gul	Turkey
Uladzislau Hlatankou	Belarus
Alphonsus Yu Xiang Neo	Singapore
Michal Piotr Lipiec	Poland
Oscar Dong	Australia
Seung Jae Kang	Korea
Nikhil Seshadri	United States of America
Faatih Regind Qashash Roman	Indonesia
Bernard Tze Wei Kwee	Singapore
Hsuan-Ting Lin	Chinese Taipei
Mahit Rajesh Gadhiwala	India
Seyed Mohammad Hossein Barakati	Iran
Oisín Colm Ó Feinneadha	Ireland
Oleksandr Zaporozhets	Ukraine
Goktug Gulsoy	Turkey
Shahzod Nazirov	Tajikistan
Hee Seong Yoon	Korea
Jirapat Rujirayuk	Thailand
Jovan Marković	Serbia
Linus Albert Schwarz	Germany
Muhammad Barotov	Tajikistan
Vinicius da Silveira Lanza Avelar	Brazil
Lucio Saracco	Hungary
Ioannis Karageorgiou	Greece
Nichawadee Kanjanakosit	Thailand
Davut Muhammetgulyyev	Turkmenistan
Takahiro Takemoto	Japan
Kohei Nishiura	Japan
Bruno Andrzej Skoczen	Poland
Khaidar Kairbek	Kazakhstan
Mohammad Solaiman AlHadlaq	Saudi Arabia
Marek Pavlica	Czech Republic
Ehsan Naderi Donig	Iran
Patrik Žnidaršič	Slovenia
Seoyeon Kim	Korea
Gerel Bayarmagnai	Mongolia
Temujin Orkhon	Mongolia
Kien Phuong	United States of America
Tong Wu	Ireland
Zachary John McGuire	United Kingdom
Rishit Singla	India
Andy Cai	Canada
Lita Tantipraphat	Thailand
Džonatans Miks Melgalvis	Latvia
Yuya Koike	Japan
Mohammad Rashed AlHudaithi	Saudi Arabia
Abdulaziz Abdulrahman AlJuaid	Saudi Arabia
Matúš Tomčo	Slovakia
Itamar Steinitz	Israel
Gozel Dovranova	Turkmenistan
Ron Angelo A. Gelacio	Philippines
Simon Bukovšek	Slovenia
Michael Schembera	Austria
Sanzhar Bissenali	Kazakhstan
Tim Bastian Enders	Germany
Pavel Atanasov Nikolov	Bulgaria
Berdigylych Rejepbayev	Turkmenistan
Dávid Benkő	Hungary
Yusup Dovletmyradov	Turkmenistan
Madiyar Kassymaly	Kazakhstan
Povilas Dapsys	Lithuania
Nathan Wayne F. Ariston	Philippines
Daniils Kargins	Latvia
Jakub Krzysztof Kwiatkowski	Poland
Ihor Kholomieiev	Ukraine

Bronze

Kevin Lius Bong	Indonesia
Tadas Danilevicius	Lithuania
Khanim Yagublu	Azerbaijan
Sathira Jantarakulchai	Thailand
Irmuun Altankhuyag	Mongolia
Kamil Mambetov	Kyrgyzstan
Neta Eiger	Israel
István Babcsányi	Hungary
Samuil Vladimirov Petkov	Bulgaria
Durdona Muxtarxujayeva	Uzbekistan
Lazar Savić	Serbia
Hanif Muhammad Zhafran	Indonesia
Darko Stojchev	North Macedonia
Vladislavs Tiščenko	Latvia
Maciej Swiatek	Austria
Keith Wong	Australia
Johann Sora Blakytny	Germany
Andrei Banica	Canada
Firdavs Sobirov	Uzbekistan
Ketevan Peranidze	Georgia
Abdur-Raheem Idowu	Norway
Ruben Tapia	France
Austin Lin	Australia
Patrik Fábrik	Slovakia
Aigerim Turuspekova	Kazakhstan
Nathanael Reza Putra Widjaja	Indonesia
Edvards Jānis Treijs	Latvia
Georgi Neliyanov Nedyalkov	Bulgaria
Salman Huseynov	Azerbaijan
Cassia Caroline Aguiar da Ponte	Brazil
Angelina Rogatch	Belarus
Benedek Sajósi	Hungary
Alina Tumashyk	Belarus
Nariman Shirinli	Azerbaijan
Saeed Sultan Baghdadi	Saudi Arabia
Ahmad Thaer Ater	Syria
Maha Ali	Syria
Jorge García-Ponce	Mexico
Michael Li	Canada
Lukas Rost	Austria
Teodor Svilenov Maslyankov	Bulgaria
Nadun Naveendra Rajapaksha	Sri Lanka
Yurii Okis	Ukraine
Dimitrije Gligorovski	Serbia
Achira Hansindu Kelambi Arachchige	Sri Lanka
Marina Malta Nogueira	Brazil
Fran Miletic	Croatia
Haruhi Isse	Japan
Jernej Birk	Slovenia
Yangyi Qi	Sweden
Aleksandr Beditski	Estonia
Vincent Ng	Australia
Anas Abbas	Syria
Adam Szymon Sukiennik	Poland
Tomáš Heger	Czech Republic
Ikromiddin Boymahammadov	Uzbekistan
Fynn Lasse Noah Kessels	Germany
Jakub Sochor	Czech Republic
Emilio Alonso Venegas-Hernandez	Mexico
Michael Estes	Denmark
Liis Siigur	Estonia
Jochem van den Broek	Netherlands
Nino Abesadze	Georgia
Hayk Aghekyan	Armenia
Aames Juriel B. Morales	Philippines
Théodore Halley	France
Valerian Mocreac	Moldova
Alexandre Bloquel	France

Laimis Jurkenas	Lithuania
Mahsati Piriyeva	Azerbaijan
Daan Roger Stan Vanhaecke	Belgium
Simonas Melaika	Lithuania
Sandro Pfammatter	Switzerland
Ioane Kapanadze	Georgia
Fredi Manuel Barraza Hernandez	El Salvador
Tatiana Sviriniuc	Moldova
Mason Minghan Liu	New Zealand
Ján Plachý	Slovakia
Oscar Eric Moran Despard	Ireland
Leonid Asatryan	Armenia
Terry Wang	Canada

Hana Gabriela Albuquerque Sousa	Brazil
Tal Sason	Israel
Tigran Harutyunyan	Armenia
Andrei Kornijenko	Estonia
Nevena Stojković	Serbia
Adelina Andrei	Moldova
Samuel Kolesár	Slovakia
Sebastian Jacob Krikke	Netherlands
Paul Johann Dorfer	Austria
Lin Bigom-Eriksen	Denmark
Manujaya Praveen Wijesinghe	Sri Lanka
Kiryl Maroz	Belarus
Maxim Cojocari-Goncear	Moldova

Honorable Mention

Bumchin Dolgormaa	Mongolia
Abhinav Chawla	New Zealand
Aku Hertell	Finland
Daria Klymenko	Ukraine
João Pedro Bonito Caldeira	Portugal
Théo Mignen	France
Ali Marouf	Syria
Olga Jerkovic Peric	Croatia
Sam Wuji Zhuang	New Zealand
Samuel Klaver	Finland
Vid Kavčič	Slovenia
Jessica Rebekka Kurmann	Switzerland

Safwan Sakib	Bangladesh
Gerardo Emiliano Gutierrez-Alvarez	Mexico
Rafael Dux	Luxembourg
Aoife Mary Morris	Ireland
Henri Kärpijoki	Finland
Dinithi Shalika Madhubhashini	Sri Lanka
Daniel Jiyoun Jang	New Zealand
Athanasios Feidakis	Greece
Jean-Marc Furlano	Luxembourg
Vaidik Rajesh Hurkat	United Arab Emirates
Mahin Kamal Sawdager	Bangladesh
Khalid Hasan Tuhin	Bangladesh

out of 309 students

Element
 # 8

Japanese mineral resources

Antimony

Basic Information

Origin of the name: Greek word *anti-monos* (not alone)
Discovered by: known since early history
Global reserves: 1.9 million tons
Major reserve countries: China, Russia, Bolivia
Global production: 153,000 tons
Major producers: China, Russia, Tajikistan

Pyroxene is a mineral composed mainly of antimony sulfide (Sb_2S_3). In Japan, the Ichinokawa mine in Ehime Prefecture on the island of Shikoku used to produce large and beautiful pyroxene specimens. A simple substance of antimony can be obtained by reducing pyroxene with iron, or oxidizing it by combustion first then reducing with carbon. Antimony is still used as an electrode material and as a wear-resistant material for secondary batteries, as well as for flame retardants, type metals, and semiconductors.

© The Courtyard of our Minerals

Answer for Q8

① **1** amber

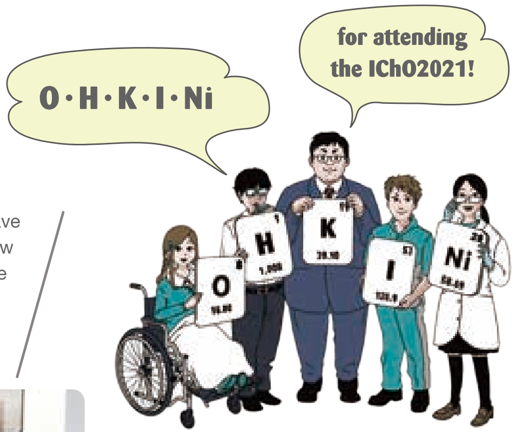
When J. J. Thomson (1856–1940) discovered that cathode ray was actually a stream of particles, G. J. Stoney (1826–1911) named it “electron” after the Greek word *aelectron*, which means amber. It was given the name because the particles were produced by rubbing an amber rod.

② **2** Japan

Japan produces 28% of the world’s selenium (770 tons; 2019 data). Selenium has a range of industrial uses; it is found in applications from electronic devices to pigments, beauty products, and other daily items.

We deeply regret that editing of Catalyzer has mostly been done by remote. We have had little chance to meet and discuss face-to-face upon editing. The photo below is the immersive view in the Zoom meeting of the Team Catalyzer. We hope that human overcomes COVID-19 pandemic soon and the next Chemistry Olympiad the 54th IChO2022 will be held as the really REAL mode.

The Team Catalyzer IChO2021



This popular word has the meaning of “thank you”. Many people in the Kansai area say “Ohkini” at the end of conversation to smooth relations with the person. Ohkini was originally an adverb that indicated large quantities. Therefore, “Ohkini Arigato” is the equivalent of “Thank you very much.” Over the years, this was abbreviated to just “Ohkini.”

Chemistry! It’s Cool!

IChO2021 Catalyzer No. 9
Official Website
https://www.icho2021.org/
icho2021

Aug. 2 1932
Discovered!
Positron
by Carl David Anderson

Contact Information
IChO2021 Office
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Tokyo 101-0062, Japan
E-mail: contact@icho2021.org
Edited by the Team Catalyzer IChO2021
English Editor: Maiko Katayama
Illustration: Science Manga Studio

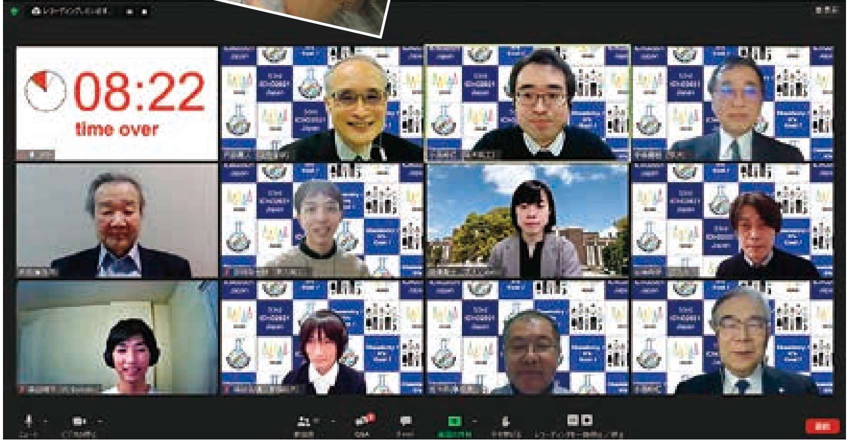
Chemistry! It's cool!

The 53rd IChO 2021 Japan Public Relations Subcommittee organised three pre-events to inform junior high and high school students about the IChO and to show them the fun of chemistry.

The first event was held at Kyoto University during Chemistry Week in October 2019, with lectures and hands-on experiments. A large number of junior and senior high school students attended the event, where they heard about the latest research results and the experiences of the former head of IChO 2021 Japan, and also had the opportunity to try out the precision analysis equipment.

In 2021, due to the pandemic of COVID-19, the events were held online twice, with more than 300 junior high school students, high school students and members of the general public, including those from overseas.

These students must have thought that "chemistry is cool", "chemistry is fun" and "I will challenge the International Chemistry Olympiad".



Pre-event Lectures

Event planner and Facilitator

Akihito Konishi	Osaka Univ.

10/19/2019

Atsushi Wakamiya	Kyoto Univ.
Hayate Saito	Kyoto Univ.
Takuya Yamakado	Kyoto Univ.
Kohei Tamao	IChO 2021 Japan Committee
SHIMADZU CORPORATION	
JEOL Ltd.	
HORIBA, Ltd.	
KOMYO RIKAGAKU KOGYO K.K.	
Toyota Physical and Chemical Research Institute	

3/13/2021

Hiroki Uratani	Waseda Univ.
Shunpei Morita	U.C. Berkeley
Koichiro Masada	UTokyo
Michiya Matsusaki	Osaka Univ.
Aiko Fukazawa	Kyoto Univ.
Kohei Tamao	IChO 2021 Japan Committee
Yoshiki Chujo	IChO 2021 Japan Committee
Yoshito Tobe	IChO 2021 Japan Committee

7/10/2021

Makoto Yamashita	Nagoya Univ.
Aya Eizawa	Air Liquide Laboratories
Kenichi Endo	Kyoto Univ.
Shinsuke Sando	UTokyo
Aoi Takeuchi	UTokyo
Yoshiki Chujo	IChO 2021 Japan Committee
Yoshito Tobe	IChO 2021 Japan Committee
Japan Analytical Instruments Manufacturers' Association	

第 53 回 国際化学オリンピック日本大会 2021
国際化学オリンピックプレイベント 講演会

参加無料
オンライン開催
事前申込制

化学との出会い
未来を拓く君たちへ

日程 2021年3月13日 ㊏ 13:00～15:40

対象 中学生・高校生・一般

申込先
国際化学オリンピック日本委員会ホームページ
https://www.icho2021.org
下記 QR コードからも、お申込できます。

申込締切：定員になり次第

プログラム
13:00 開会の挨拶
中條善樹（国際化学オリンピック日本大会実行委員長）
13:05 基調講演
「一家に 1 枚周期表」から楽しく学ぶわが国の化学技術の底力
玉尾皓平
（国際化学オリンピック日本委員会理事長・組織委員会委員長・公益財団法人 豊田理化学研究所所長）
13:55 研究講演 1
オリジナル分子をデザインし、創り、光・電子機能を拓く
深澤愛子（京都大学 高等研究院 物質－細胞統合システム拠点 (iCeMS) 教授）
14:25 国際化学オリンピック元日本代表経験談
正田浩一朗さん（東京大学 修士課程 2 年）
森田峻平さん（カリフォルニア大学バークレー校 博士課程 2 年）
浦谷浩輝さん（早稲田大学 博士課程 3 年）
15:05 研究講演 2
化学で未来の医療を変える！
松﨑典弥（大阪大学 大学院工学研究科 教授）
15:35 閉会の挨拶
戸部義人（国際化学オリンピック日本大会広報委員長）

問合せ
国際化学オリンピック日本委員会
担 当：古徳、瀬田
mail：info@icho2021.org

主催：国際化学オリンピック日本大会実行委員会／共催：日本化学会・日本分析機器工業会

第 53 回 国際化学オリンピック日本大会 2021
国際化学オリンピックプレイベント 講演会

Part2

化学との出会い
未来を拓く君たちへ

日程 2021年7月10日 ㊏ 13:00～15:50

対象 中学生・高校生・一般

申込先
国際化学オリンピック日本委員会ホームページ
https://www.icho2021.org/jp/
下記 QR コードからも、お申込できます。

申込締切：定員になり次第

プログラム
13:00 開会の挨拶・基調講演
化学で未来を元気に Chemistry! It's Cool!
中條善樹（国際化学オリンピック日本大会実行委員長／京都大学 名誉教授）
13:50 研究講演 1
新奇な結合から究極の触媒まで：分子は「設計」できる！
山下 誠（名古屋大学 大学院工学研究科 教授）
14:20 国際化学オリンピック元日本代表経験談
永澤 彩さん（株式会社エア・リキード・ラボラトリーズ 研究員）
遠藤健一さん（京都大学 博士研究員）
竹内 碧さん（東京大学 修士課程 2 年）
15:00 分析機器の紹介
日本分析機器工業会
15:20 研究講演 2
ケミカルバイオロジー：
分子デザインが実現する創薬
山東信介（東京大学 大学院工学系研究科 教授）
15:50 閉会の挨拶
戸部義人
（国際化学オリンピック日本大会広報委員長／大阪大学 名誉教授）

参加費無料
オンライン開催
事前申込制

問合せ
国際化学オリンピック日本委員会
担 当：古徳、瀬田
mail：info@icho2021.org

主催：国際化学オリンピック日本大会実行委員会／共催：日本化学会・日本分析機器工業会

化学との出会い 未来を拓く君たちへ PART2

国際化学オリンピック元日本代表経験談

えいざわ あや
永澤 彩さん
株式会社エア・リキード・ラボラトリーズ 研究員

えんどう けんいち
遠藤 健一さん
京都大学
化学研究所 博士研究員

たけうち あおい
竹内 碧さん
東京大学大学院薬学系研究科
薬科学専攻 修士課程2年

授賞式後のfarewell partyで

Q. 印象に残っていること

世界には優秀な人がたくさんいる(永澤)
他国の参加者の英語力の高さ(永澤)

高校の課程を超えた化学を「つまみ食い」するのではなく、フルコースで学ぶことができたので、一気に視界が開けた(遠藤)

言語や背景が異なっていてもうれしい、楽しいといった感情を共有できることを実感し、おおいに感動した(竹内)

IChO 2021 Japan Committee

President of IChO 2021 Japan Committee

Kohei Tamao
RIKEN, TOYOTA Physical & Chemical Research Institute, Kyoto Univ.

Vice President of IChO 2021 Japan Committee

Kyohei Takahashi
Showa Denko K.K.

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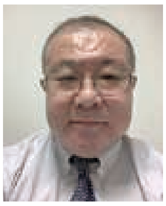

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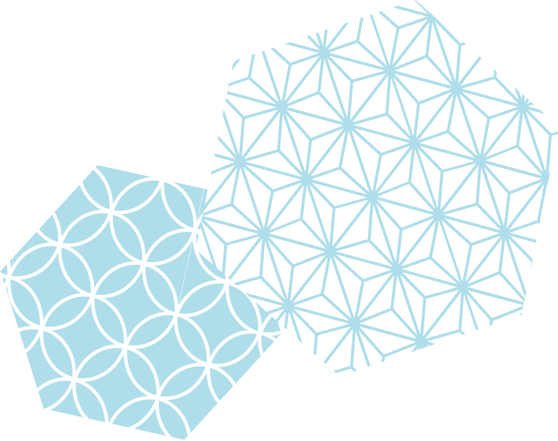

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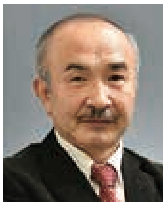

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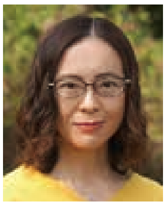

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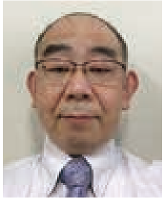

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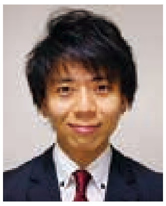

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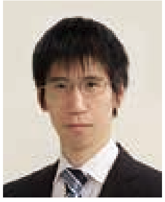

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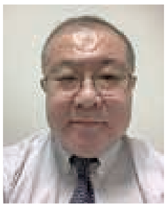

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in China

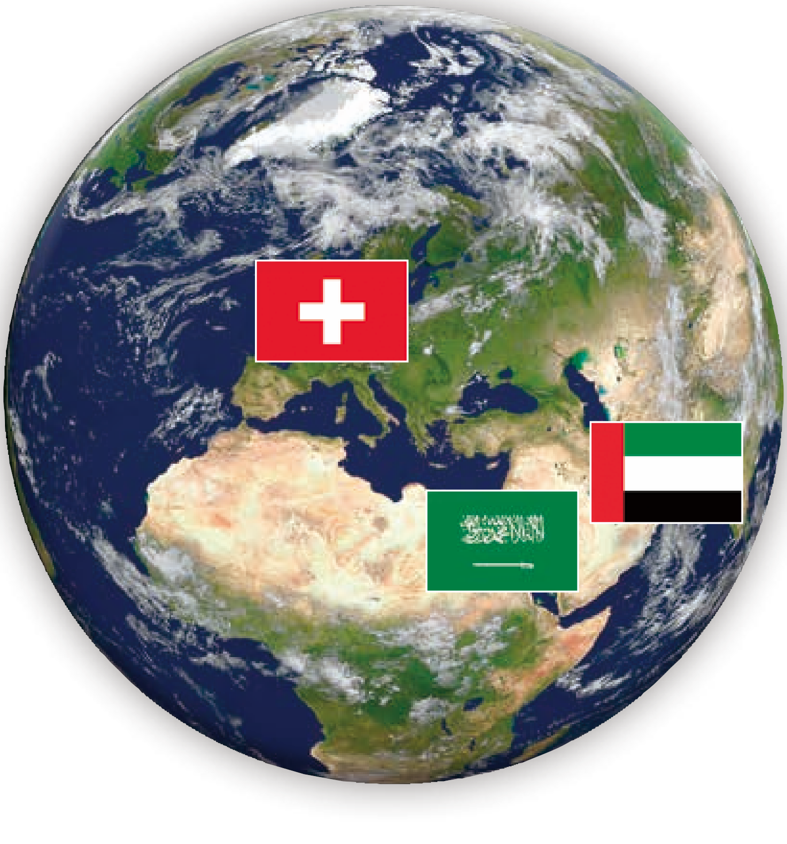
July 10 ~ 18, 2022 (Remote)

See you also in the future host countries

2023 Zurich, Switzerland
July 16~25

2024 Riyadh, Saudi Arabia

2025 Dubai, United Arab Emirates

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