Microgravity experiments in the field of physical chemistry in Japan

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Abstract. Japan has been operating ‘KIBO’ (‘hope’ in Japanese) as a Japanese experimental module on ISS (International Space Station) to perform researches on physical, life, medical, space sciences in space. Several research racks and facilities have already been accommodated in the pressurized module of ‘KIBO’ and some researches have already been carried out. Japan currently has 17 ISS flight projects (including 4 candidates) in the field of physical sciences and also incubates new projects through a research support program named as ‘research WG (Working Group)’, where 25 research WGs are active in the field of physical chemistry. The article introduces those to promote international collaborations.
1. Current status on microgravity experiments in Japan

Japan has been operating ‘KIBO’ as Japanese experimental module on ISS to perform researches on physical, life, medical, space sciences in space. Several research racks and facilities have been accommodated in the pressurized module of ‘KIBO’ (see figure 1) and researches on Marangoni convection, ice crystals have already been carried out.

Japan currently has 17 ISS flight projects (including 4 candidates) and 25 research WGs in the field of physical sciences. A research aiming at ISS/KIBO experiment has to follow a process step by step (see figure 2). Activities in research WGs annually solicited are the first step of the process. A research WG discusses new ideas and develops a flight proposal to submit it to a future flight AO (Announcement of Opportunity) to be released on biannual basis. Some research WGs might try BBM (Bread Board Model) tests including parabolic flight experiments to assess feasibilities of their observations and operations and verify the validities of their science requirements, if necessary. A research, after passing a flight AO, will try science definitions as a flight candidate for a couple of years and has to pass the project definition review to step up to a flight project.

![Figure 1. Racks and facilities accommodated in KIBO pressurized module.](image)

The acronyms of the facilities are as follows; CB Clean Bench, CBEF Cell Biology Experiment Facility, GHF Gradient Heating Furnace, FPEF Fluid Physics Experiment Facility, IPU Image Processing Unit, SCOF Solution Crystallization Observation Facility, PCRF Protein Crystallization Research Facility, ELF Electrostatic Levitation Furnace. (c) JAXA.
Figure 2. Japanese implementation process of ISS experiments. The acronyms in the figure are as follows; EM engineering model, FM flight model, BBM bread board model, AO announcement of opportunity.

2. **Current status on researches in physical chemistry in Japan**

There are 1 flight candidate and 4 research WGs (2 WGs + 2 RTs) in the field of physical chemistry. Current status on those will be described in this section.

2.1. **Flight projects**

A research proposal on colloid physics was selected as a candidate of KIBO experiments in 2010 and has been doing phaseA studies.

2.1.1. **Structure analysis on colloid crystals with a laser diffractometer and researches on particle interactions.** The research team organized by Ikuo Sogami is interested in interactions in charged colloid dispersions. Crystal formations in those dispersions which occur when the salt concentrations are decreased were normally explained by DLVO (Derjaguin and Landau, Verwey and Overbeek) theory, but some observations like measurements of lattice spacing of the crystals [1][2], observation of gas-liquid coexistence state in colloid dispersions [3][4], and observation of void formations in colloid dispersions [5]-[7] can not be explained by DLVO theory and suggest existence of long range attractive interaction. The research team has been developing ISS research facility to be accommodated in Multi-purpose small payload rack (see figure 1). CCD (Charge Coupled Device) camera of the facility, having several objective lenses, can observe void formation and its dynamics as well as whole image of a cell. The key element of the facility is ‘Kikuchi-Kossel’ laser diffractometer developed by the team [8][9]. Although this is simpler and more compact than small angle X-ray diffractometer, it can precisely measure crystal structures and lattice spacing (see figure 3). This will be only one facility that enables such precise measurements of crystal structures on colloids on ISS. The members of the project are Ikuo Sogami (Kyoto Sangyo University), Masayuki Tanigawa (Kyoto Sangyo University), Yuji Ikeda (Kyoto Sangyo University), Tadatomi Shinohara (Kyoto Sangyo University), Junpei Yamanaka (Nagoya City University), Hideo Oka (Tayca Corporation), Mitsuhiro Matsumoto (Kyoto University), B. V. R. Tata (Indira Gandhi Centre for Atomic Research), and Naokiyo Koshikawa (JAXA).
Figure 3. ‘Kikuchi-Kossel’ diffraction pattern taken by BBM. The left is an actual picture and the right indicates Miller indexes for the individual lines shown in the left picture.

2.2. Research WGs
The research WGs are categorized into RTs (Research Teams) and WGs (see figure 2). The former is one for new comers to discuss their preliminary ideas and the latter is one for more experienced members to define experimental requirements and research plans. In addition to team meetings, WGs carry out BBM tests to clarify the validity of their experiment techniques and requirements. Some WGs might perform parabolic flight experiments, if necessary. 2 WGs and 2 RTs are currently active in the field of physical chemistry.

2.2.1. Mesoscopic chemistry under microgravity WG. The WG coordinated by Kaoru Tsujii is aiming at incubating new ideas associated with chemistry and various ideas proposed by various members have been discussed.

(1) Honey comb film formation under microgravity. A member of the WG, Masatsugu Shimomura, found that dissipative structures where pores having a uniform diameter are regularly ordered can be obtained if steam is added to casted polymer solutions [10][11]. Although the protocol is very simple, the uniformity and ordering of the pores are quite well (see figure 4). Medical applications have been investigated and larger films are desired for the applications, but a kind of domain formation like a grain boundary for a polycrystalline is observed in some cases. The members speculated that this might arise from natural convections due to gravity and carried out hyper gravity experiments with a centrifuge [12] and has tried low gravity experiments with parabolic flights. The members of the group are Kaoru Tsujii (Hokkaido University (retired)), Masamichi Ishikawa (RIKEN), Masato Sano (Yamagata University), Masatsugu Shimomura (Tohoku University), Hiroshi Yabu (Tohoku University), Yuji Hirai (Tohoku University), Kenichi Yoshikawa (Kyoto University), Nobuyuki Magome (Kyoto University), Takashi Mashiko (Shizuoka University), and Makoto Natsuisaka (JAXA).

Figure 4. A fine structure of a ‘honey comb film’.
2.2.2. Chemical processes in critical density fluctuation WG. The WG organized by Shigeru Deguchi has been discussing two major topics described below. The systems and phenomena on the both topics are fully different, but the WG is considering that density fluctuations in vicinity of critical points play an important role on the both phenomena. The members of the group are Shigeru Deguchi (JAMSTEC), Masamichi Ishikawa (RIKEN), Yoshihisa Inoue (Osaka University), Kaoru Tsujii (Hokkaido University (retired)), Makoto Natsuisaka (JAXA), Keiko Nishiyama (Chiba University), Yasuhiro Nishiyama (NAIST), Toru Maekawa (Toyo University), Takeshi Morita (Chiba University), Sadaatsu Mukai (Kyushu University), and Takehiko Wada (Tohoku University).

(1) Colloid dynamics in the vicinity of critical points. Shigeru Deguchi etc. found that silica particles dispersed in super critical water take a distance longer than Coulomb's interaction predicts. Since the observation was made on ground, the particles were precipitated onto the base plate and the phenomena were restricted in two dimension. The team has proposed microgravity experiments to be free from such constraint and enable more precise observations.

(2) Chiral chemical reactions in near- and super-critical CO\textsubscript{2}. A member of the WG, Yoshihisa Inoue, revealed that photosensitized enantiodifferentiations (see figure 5) would occur in various systems and under various conditions. In particular, he found that it would be enhanced if the reactions were given in super critical carbon dioxide (see figure 6) [13]. The research team expects that this might be more emphasized under microgravity and has proposed microgravity experiments. The team has tried parabolic flight experiments by developing a very compact and automatic super critical reaction chambers.

![Figure 5. Target reactions - photosensitized enantiodifferentiating isomerization.](image-url)
2.2.3. **Exploration of emulsion stability under microgravity RT.** The RT organized by Kazutami Sakamoto is aiming at observation of emulsion formation and its stability under microgravity. This would promisingly help understand the basic mechanisms of emulsification and stabilization. The outcome of this trial would bring better designing and quality assurance of emulsion products as dispersed colloidal system, which are indispensable for household and institutional applications. The team found a long-term stable emulsion system with new amphiphilic material through a basic research [14] and believes that this could contribute to researches in the field. The team has started to communicate with one of the European topical teams, PASTA (Particle Stabilized Emulsions and Foams). The members of the team are Kazutami Sakamoto (Chiba Institute of Science), Hideki Sakai (Tokyo University of Science), Kenichi Sakai (Tokyo University of Science), and Makoto Natsuisaka (JAXA).

2.2.4. **Impressionistic physics of bubbles, drops and foams under microgravity RT.** The RT organized by Ko Okumura studies the dynamics of bubbles, drops and foams under microgravity, via impressionistic physics which is a powerful tool to find out simple laws from complex phenomena. Ko Okumura has started to attract considerable attention in the field through experiments performed with the Hele-Shaw cell (a quasi two-dimensional cell) [15][16] so that he has been invited to join a number of topical teams of ESA; FOAM-C, PolarDrop and DOLFINE. The members of the team are Ko Okumura (Ochanomizu University), Yumiko Yoshitake (Tokyo Denki University), and Makoto Natsuisaka (JAXA).

3. **Conclusions**
There are 1 flight candidate and 3 resea rch WGs in the field of physical chemistry in Japan. They all welcome communication with and/or participation of researchers of international communities.
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