Main Progress of Microgravity Sciences and Space Life Sciences Research in China

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Abstract

The progress of the research activities on space material sciences, microgravity fluid physics and combustion, space life sciences and biotechnology research, fundamental Physics in China are briefly summarized in the present paper. The major space missions and experimental results obtained on board the Chinese recoverable/non-recoverable satellites and the Chinese manned spaceship named "Shan-Zhou" are presented summarily. The recent main activities of the ground-based studies in China are introduced in brief.

1. Introduction

From recent decade, the foundation of the space technology such as the rocket, satellite and manned spacecraft technologies in China have made successfully the bases for the development of the space science, including the microgravity sciences and space life sciences and biotechnology. The Chinese satellite is a useful tool and was used for space experiments of microgravity research and space life sciences research since the 1987. Many microgravity experiments of the materials sciences, microgravity fluid physics and biotechnology have been performed on board the recoverable satellites, and the programs will be continued in the next years[1-3].

Since 1992, the manned spaceflight plan "Shen-Zhou" (SZ) was initiated in China, and the space experiments related to the microgravity science and life sciences have been completed successfully in three unmanned missions on board the "SZ-2", "SZ-3" and "SZ-4", respectively. Since 1999, the relative advanced experimental facilities of microgravity sciences and life sciences were developed as follows:

(1) Furnace of multi-function of materials research with 6 samples inserted one by another.
(2) Facility of fluid physics for multi-purposes to study the Marangoni migration.
(3) Space facility on growth kinetics study of high temperature oxide melt.
(4) Facility of protein crystal growth involving 60 samples.
(5) Space bioreactor for cell/tissue culture.
(6) Facility of cell fusion study.
(7) Facility of space electrophoresis.
(8) Tri-axial acceleration measurement system.

Fruitful results of these space experiments on board the Chinese spaceship have been obtained and will be presented mainly in this paper.

In addition to the space experiment on board the Chinese spaceship, several microgravity experiments will be performed in the Russia model of the International Space Station and on board the Russia FOTON satellite in the near future, respectively.

2. Space Material Sciences

The primary purpose of studying on space material science is to understand and develop application of materials to be produced in microgravity and to improve material processing either on the ground or in space. In recent years, the main research subjects were: space crystal growth, solidification of alloys, real time observation of crystal growth process in space and the development of space experimental hardware. Here are the main activities and results during recent years.

2.1 Space experimental hardware

a) Multi-samples crystal growth furnace[4] (shown partly in **Fig. 1**)

This furnace was prepared for "SZ-2" and "SZ-3" spaceship in the early of this century. In general speaking, it worked well on space. The main parameters of this furnace are as follow:

Max. of sample's number:	6
Max. of sample's diameter:	22 mm
Max. of sample's temperature:	950 C
Accuracy of temperature control:	less then 1 C
Gradient of temperature:	70 C/cm
Moving speed:	3-60 mm/hour
Total mass:	27.5 Kg
Size:	$\Phi 270\times 580$ mm
Power in average:	75 W

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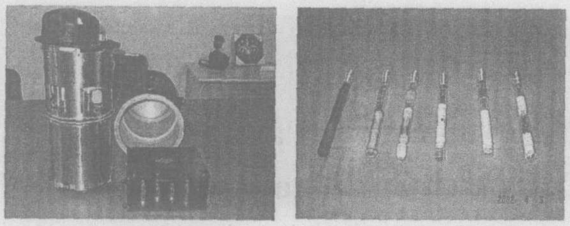

Fig. 1 Photographs of the multi-samples crystal growth furnace and the samples.

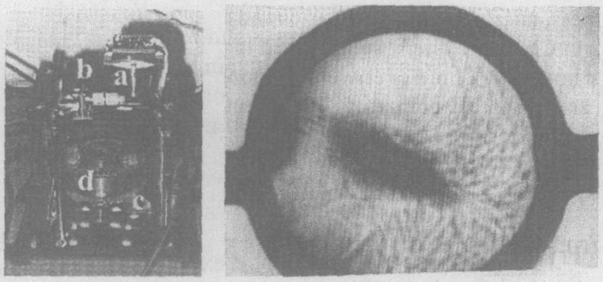

Fig. 2 Photograph of the main part of the observation facility and a pattern got on space.

This furnace can be used for different kind of materials. When the spaceship could communicate with a station, the operation parameters of the furnace (temperature, sample's position and so on) can be transmitted to earth and to the furnace engineers and materials scientists. This furnace was designed and manufactured by the Shanghai Institute of Ceramics, CAS, the Center of Space Science & Application, CAS, and the Lanzhou Institute No: 510, Chinese Academy of Space & Technology.

b) Observation facility for the process of crystal growth

This facility shown in **Fig. 2** was designed for "SZ-2" spaceship. It has been used for "SZ-2" spaceship and a recoverable satellite. Here are its main parameters:

Max. of samples number:	4
Sample's size:	Φ2 mm
Max. of samples temperature:	1100 C
Accuracy of temperature control:	less then 2 C
Pattern recording system: black & white CCD camera with automatic focus system	
Total mass:	14.3 Kg
Size:	250×155×230 mm (observation facility) 260×130×200 mm (record system)
Power in average:	22 W
Peak power:	<50 W

The patterns can be transmitted to earth when the spaceship or satellite could communicate with a station. This facility was designed and manufactured by the Shanghai Institute of Ceramics, CAS, and the Shanghai Institute of Technical Physics, CAS.

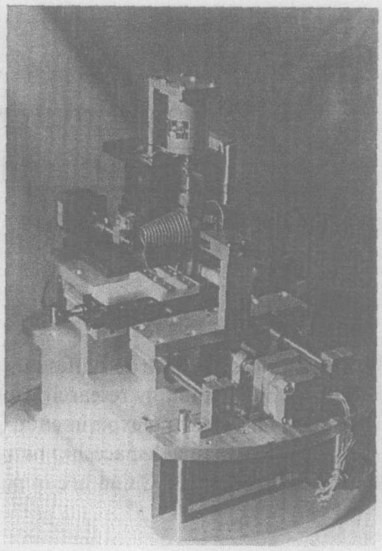

Fig. 3 Photograph of the main part of the electromagnetic levitation furnace.

c) Ground test of a space electromagnetic levitation furnace

An engineering model of an electromagnetic levitation furnace has been manufactured and tested on ground. The main parameter of this furnace shown in **Fig. 3** are as follow:

Max. of sample's number:	10
Size of sample:	Φ3–6 mm
Max. of sample's temperature:	1500 C
Accuracy of sample's position:	less then 1 mm
Vacuum:	0.001 Pa

The measurement of levitation force, the efficiency of the laser heating and the simulation of nucleation of the trigger system have been carried out. This furnace was designed and tested by the Institute of Physics, CAS.

d) New facility for space crystal growth from solution

The main objective of this facility shown in **Fig. 4** was that (1) to develop multi-function experiments in one facility; (2) to optimize the crystal growth parameters and (3) to perform long duration experiment and growing larger crystal in space. The engineering model of this facility has been constructed and has been used to diagnose the fluid flow and solution concentration field near the solid/liquid interface[5]. By use of this facility, $NaClO_3$, α-$LiIO_3$, $Ba(NO_3)_2$ and $Sr(NO_3)_2$ crystals have been grown in ground[6]. This work was done by the Institute of Physics, CAS. The specification of this facility is listed below:

Item	Specification
Volume of cell:	1200 m*l*
Temperature range:	0–99°C
Temperature precision:	0.05°C

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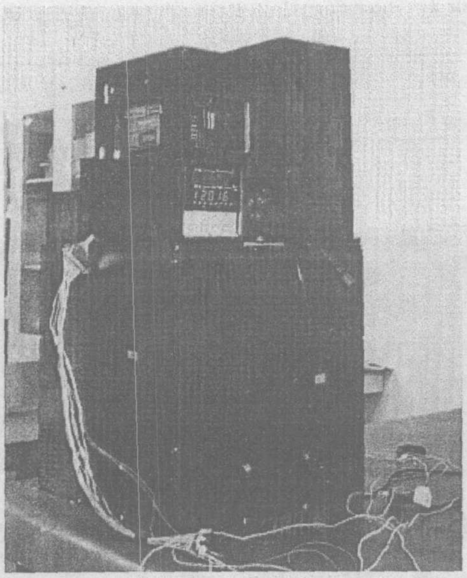

Fig. 4 Photograph of the new facility for space crystal growth from solution.

Fig. 5 Photograph of BSO crystals grown in space and on the earth.

Table 1 The difference (Δd) between the maximal diameter and the minimal diameter of the sample

Sample solidified in space	$d_{max.}$(mm)	$d_{min.}$(mm)	Δd(mm)
SZ3-1	1.570	1.560	0.010
SZ3-2	1.025	1.015	0.010
Sample solidified on ground	$d_{max.}$(mm)	$d_{min.}$(mm)	Δd(mm)
DM-1	1.485	1.185	0.300
DM-2	1.365	1.250	0.115

Amplitude Modulation: ×0.8; ×100
Image resolution: <2 μm
Power: <40 W
Weight: 10 kg

In order to fit the requirements of the second stage of Chinese Manned Spaceflight and the National Spaceflight Plan in the 11^{th} "five years" (2006-2010), the scientists and engineers are designing new generation of the space materials research facilities.

2.2 Orbital experiments on crystal growth and alloy solidification

a) Crystal growth of $Ce:Bi_{12}SiO_{20}$ (BSO) in "SZ-3" spaceship

This experiment was done in the multi-samples crystal growth furnace in March 2002. A crystal with size of $\Phi 10\times 40$ mm shown in **Fig. 5** was grown by Bridgman technique. The morphology of this crystal is different from that grown on the earth. The physical and chemical properties of crystal were characterized by different methods. The measured results indicate that the crystal quality grown in space is more perfect compared with that grown in the earth[4]. This work was done by Dr. Y. F. Zhou and her colleagues in Shanghai Institute of Ceramics, CAS.

b) Solidification of $Pd_{40}Ni_{10}Cu_{30}P_{20}$ alloy in "SZ-3" spaceship

The solidification experiment of $Pd_{40}Ni_{10}Cu_{30}P_{20}$ alloy was made in the multi-samples crystal growth furnace. The sizes of the samples are from 1.02 mm to 3.04 mm in diameter. All the samples solidified in space present smooth surface and standard regular spherical shape. The X-ray diffraction patterns of these spheres are only composed by a broad halo without any sharp peak indicating that the samples solidified in space consist of a single amorphous phase. The results of scanning electron microscopy and electron diffraction are completely in agreement with that of the X-ray diffraction.

The shapes of the corresponding samples solidified on ground are ellipsoid. **Table 1** indicates the difference (Δd) between the maximal diameter and the minimal diameter of the sample. It can be seen that the Δd of the sample solidified on ground is more then ten times as big as that of the corresponding sample solidified in space.

However, the results of the X-ray diffraction of the samples solidified on ground indicate that these samples consist of the crystal phases. It means that the samples solidified in space have got a much greater undercooling than that samples solidified on ground[4].

c) Wettability and interface reaction research of Ag-Sn, Cu-Sn liquid alloys with Ni & Fe substrates in "SZ-3" spaceship

It is important to understand the wettability and interface reaction of liquid alloys with crucible for materials process. By use of the multi-samples crystal growth furnace, four samples have been tested in space. The samples have been characterized by the physical & chemical methods and compared with the samples got on the earth in same condition. It shows that there are obvious differences shown in **Fig. 6** be-

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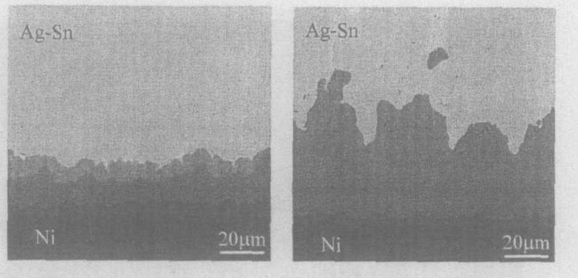

Fig. 6 The comparison of the shape and thickness of the liquid/solid interface reaction layers between the samples got in space (left) and on the earth (right).

tween two kinds of samples: in shape, thickness and composition of the reaction layers of the liquid/solid interface. For the samples got in space, the shape of the layers looks smooth. The thickness of the reaction layers is thin and the composition change is not obvious.

For the samples got on the earth, the shape of layers looks like waves. The thickness of the reaction layers is twice of that got in space. The composition change is larger. The results indicate that on the earth, the liquid/solid interface reaction is stronger then that in space. The reason may be come from the convection driven by gravity and hydrostatic pressure on the earth. In space there is no those effects, the interface reaction is driven mainly by atomic diffusion process[4]. This work was done by Prof. B. Z. Ding, H. F. Zhang, Z. H. Mai and their colleagues in the Institute of Metal Research, CAS and the Institute of Physics, CAS.

2.3 Post-research on space grown crystal α-$LiIO_3$

The experimental results in space grown crystal α-$LiIO_3$ indicate that the relationship among the pH of a supersaturated solution, the growth rate and the crystal morphology under microgravity condition is different from that one on the earth. In particular the critical pHc is increased under microgravity. **Table 2** shows the influence of pH on the growth rate of α-$LiIO_3$ crystal growth in space. It could be seen that at pH = 4.02. The growth rates along both directions are equal, that means pHc is increased under microgravity in comparing with the case on the earth[7].

In order to explain the space experimental phenomena on α-$LiIO_3$ crystal growth and understand the effect of gravity on crystal growth, the crystal growth processes of α-$LiIO_3$ have been observed by Mach-Zehnder interferometric technology. The boundary layer characteristic and the concentration distribution close to the liquid/solid interface were studied. The crystal growth rate of α-$LiIO_3$ was measured and calculated. The experimental findings show that the growth rate and the boundary layer characteristics are influenced by the convection. The concentration distribution along [0001] and $[000\bar{1}]$ directions are different. This finding could be useful to understand the space experimental results on α-$LiIO_3$ crystal growth. This

Table 2 The influence of pH on the growth rate of α-$LiIO_3$ crystal grown in space

pH	3.60	4.02	7.54	8.10	8.79	9.28
$R_{[0001]}/R_{[000\bar{1}]}$	<1.0	~1.0	~30	~35	~40	>40

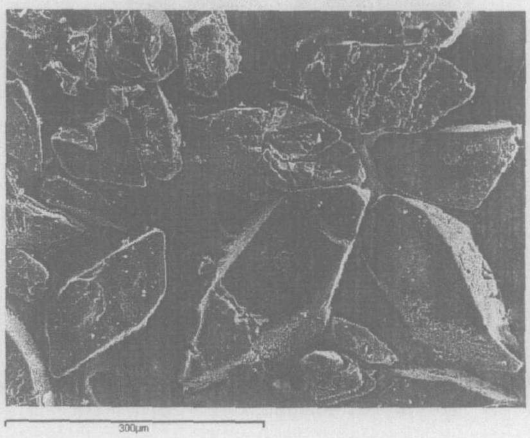

Fig. 7 SEM photograph of the double pyramid $AlPO_4 \cdot H_2O$ synthesized from solution.

work was done by Prof. W. C. Chen and his colleagues in the Institute of Physics, CAS.

2.4 Ground-based studies on crystal growth and alloy

a) Hydrothermal synthesis of $AlPO_4 \cdot H_2O$

In order to investigate the fundamental problems of crystal growth on the earth and in space, the synthesis related aluminum phosphate system has been studied. A new crystal of $AlPO_4 \cdot H_2O$ was synthesized from aqueous solution under hydrothermal condition (see in **Fig. 7**). The experimental results indicated that there are two different nucleation and growth processes: single crystal growth and aggregation solidification. Several analytical techniques have been used to identify the crystalline phases. The crystal morphologies were observed by SEM. Five types of crystal morphology were discovered which not seen before. This work was done by Prof. W. C. Chen and his colleagues.

b) Amorphous metallic plastic

A kind of cerium-based bulk metallic glasses with an exceptionally low glass transition temperature Tg has been found[8] (see in **Fig. 8**). The Tg of this alloy is similar to or lower than that of many polymers. In near-boiling water there materials can be repeatedly shaped and can thus be regarded as metallic plastics. There resistance to crystallization permits extended forming time above Tg and ensures an adequate lifetime at room temperature. Such materials are highly unusual for metallic alloys and have great potential in application and can also facilitate studies of the supercooled liquid state. This work was done by Prof. W. H. Wang, M. X. Pan and their colleagues in the Institute

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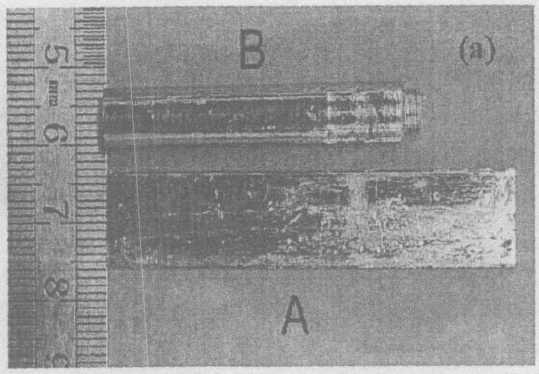

Fig. 8 Photograph of the cerium-based amorphous alloy.

of Physics, CAS.

3. Microgravity Fluid Physics and Space Combustion

After the previous microgravity experiments of materials science, biology and biotechnology performed on board the Chinese recoverable satellites, the first Chinese microgravity experiment of fluid physics was carried out successfully on board the scientific satellite SJ-5 in1999 by using the tele-operation technique. Recently, the Chinese spacecraft "Shen-Zhou" was launched and recovered successfully with on board an astronaut, and it open a new era of the manned space mission and the microgravity research in China. An important fluid experiment in space on the investigation of the phenomena of migration of liquid drop has been performed on board it[3].

3.1 Space experiment on board the Chinese Satellite SJ-5

The space experiments of the Marangoni convection and the thermocapillary convection in a system of two immiscible liquid layers on board the scientific satellite SJ-5 were completed in the May of 1999. Special two-layer liquids such as FC-70 liquid and paraffin were used successfully in space. This work was done by Prof. Q. S. Liu, W. R. Hu and their colleagues in the National Microgravity Laboratory of CAS, Institute of Mechanics.

The experimental set-up contains two fluid tanks with applied temperature difference perpendicular and parallel to the interface of two layer, the optical diagnostic system, the control system of temperature, and the system of data acquisition (see **Fig. 9**). The flow visualization makes use of PIV method. The images of flow pattern are recorded using a CCD camera and transmitted to the ground laboratory in real time. This facility was designed for a non-recoverable satellite[9]. Here are its main parameters:

Test cell number: 2

Test cell's size:

$35 \times 32 \times 20$ mm^3 (TC *A*); $35 \times 32 \times 20$ mm^3 (TC-*B*)

Temperature variation: $+5$°C—$+85$°C

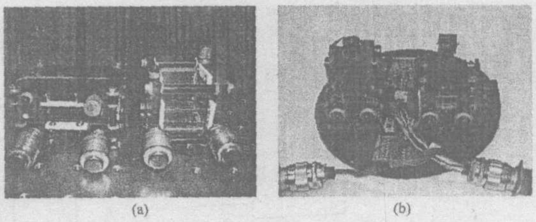

Fig. 9 Space experimental facility. (a) before assemble: Test-cell *A* (left) and Test-cell *B* (right); (b) integration of the set-up.

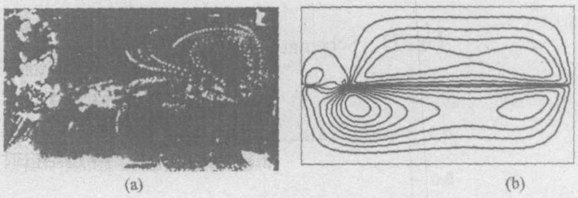

Fig. 10 Thermocapillary convection in Test-Cell *B* heated from the right side: (a) Image of streamlines of space experiment; (b) Simulating streamlines with the effect of gas bubble.

Accuracy of temperature control: ± 0.1°C

Pattern recording system:

CCD camera with $512 \times 512 \times 8$ bit

Flow visualization:

PIV method with 100 μm tracer particles in diameter,

Total mass: 22.76 Kg $\pm$ 0.5 Kg

Size: $372 \times 416 \times 340$ mm^3

Power in average: 20 W

Peak power: <40 W

The experiments were completed by the method of tele-science, and the temperature distribution and the flow field were obtained clearly. The Marangoni convection and thermocapillary convection in the system of two-layer liquids were observed in two different test-cells subjected a temperature gradient perpendicular to or parallel to the interface. A reasonable agreement between the theoretical analyses and the experimental results has been obtained and the theoretical model on the thermal interface-tension driven convective flow is confirmed by space experiments. A new model system of two-layer liquids with the effect of the bubble observed in the space experiment is suggested for considering the effect of gas bubble on the Marangoni convection and thermocapillary convection[9].

Fig. 10 shows, in the case of the applied external temperature gradient parallel to the Paraffin-FC70 interface, the thermocapillary convection observed in space was steady. The typical thermocapillary convection in microgravity observed in space has the same profile in comparison with the numerical result.

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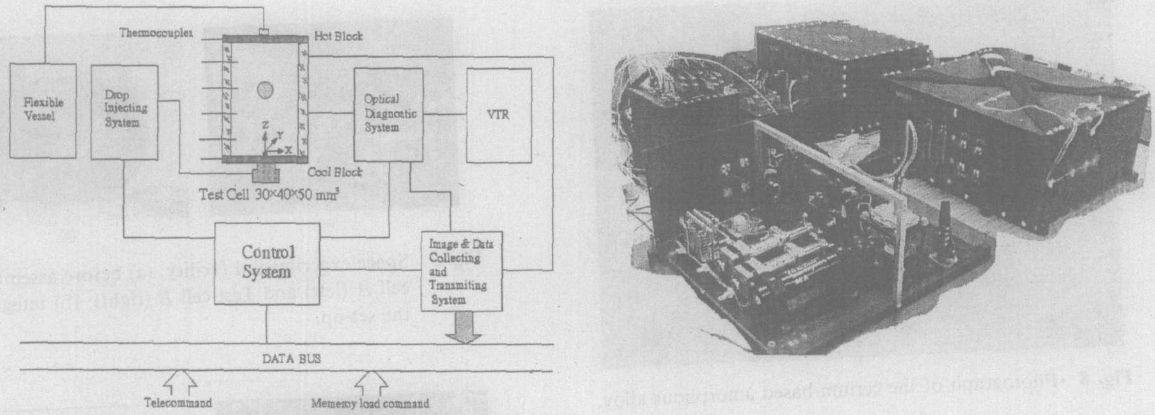

Fig. 11 Schematic diagram of the apparatus and space experiment apparatus Mounted in the recoverable capsule.

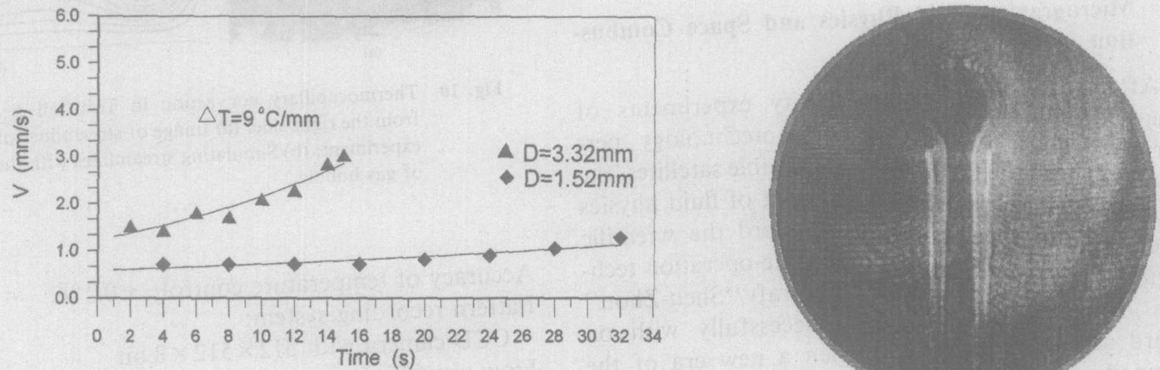

Fig. 12 Drop migration velocity in the function of real time (left) and interferometry image of the temperature field around a moving drop (right).

3.2 Space Experiment on thermocapillary drop migration on board the Chinese spacecraft Shen-Zhou-4

At the end of 2002, the experiment of drop migration was arranged and flown aboard China's spacecraft "SZ-4". The purpose of the space experiment is to expand the knowledge about the behaviors of drop migration at larger Marangoni numbers. Fluorinert liquid FC-75 and 5 cst silicone oil were adopted as drop liquid and matrix phase, respectively, in this experiment[10]. The experimental system mainly consists of (see in **Fig. 11**):

- Test cell: $30 \times 40 \times 50$ mm^3,
- Drop injecting system,
- Optical diagnostic system,
- Controlling system,
- Data and image recording system.

In the experiment, isolated drops of Fluorinert liquid moved in a matrix liquid of 5 cst silicone oil at values of the Marangoni numbers (Ma) ranging up to 5500 (see **Table 3**) and the interferometry images showed the temperature distribution inside the test cell. The drop migration velocity was measured. The experimental results show that the scaled drop migration velocity V/VYGB obviously decreases with Ma increasing the values up to 5500. The space experimental results are also compared with those from our early experiments, other space experiments, and some theoretical predictions. During the space experiment, not only was the telescience available, but also some patent technologies were successfully utilized. All the corresponding interferometry images of drop migration were recorded in real time by using a VTR. **Fig. 12.** gives an original interferometry image showing the temperature field around a moving drop.

Table 3 Parameter range of experimental data

Temperature gradient (°C/cm)	Radium range (mm)	Reynolds number	Marangoni number
9	0.76～4.0	3.2～89.8	148～4103
12	0.57～3.52	4.5～302.6	145～5525

The space experimental investigation indicates that the drop thermocapillary migration at large Marangoni numbers showed rather complex behavior and, fur-

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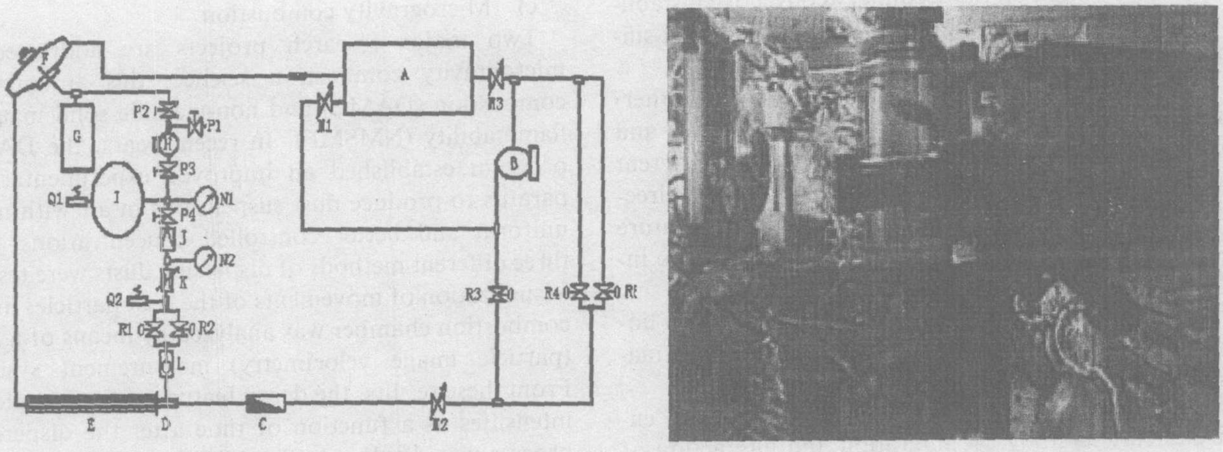

Fig. 13 Schematic (left) and photography (right) of the experimental facility aboard the Mir Space Station. (A) Liquid storage vessel, (B) pump, (C) turbine flowmeter, (D) mixer, (E) test tube, (F)separator, (I) gas storage tank.

ther studies are still needed. This work was done by Prof. J. C. Xie, W. R. Hu and their colleagues in the National Microgravity Laboratory of CAS, Institute of Mechanics.

3.3 Space experimental studies on two-phase flow patterns aboard the Mir spaces station

In the August of 1999, a series of two-phase flow experiments were performed on board the Russian MIR Space Station. The main goal of the space experiments is to observer different possible kinds of two phase gas-liquid flow patterns at the microgravity environment and to analyze the basic mechanism of the flow pattern transitions[12]. This work was done by Prof. J. C. Xie, J. F. Zhao and W. R. Hu in the National Microgravity Laboratory of CAS, Institute of Mechanics.

The experimental facility shown in **Fig. 13** schematically was mounted in the "Volna-2A" stand aboard the Mir Space Station. The test tube with a 16×16 mm^2 square cross-section is 356 mm in the length and is parallelized at a distance 620 mm from the rotary axis of the Volna-2A stand. The experiments were performed both at the long-term, steady microgravity condition less than 10^{-5} g aboard the Mir Space Station and at the low gravity conditions 0.1 g and 0.014 g provided by the rotation of the Volna-2A stand in the space experiments. Air is used as the gas phase, and the Carbogal liquid with a small contact angle (0°–7°) with the test tube is used as the liquid phase. In the space experimental, the gas and liquid superficial velocities were varied in the range of 0.09–63. and 0.04–0.81 m/s, respectively.

In the space microgravity condition, five kinds of gas-liquid flow patterns, such as dispersed bubble flow, bubble flow, slug flow, slug-annular transitional flow and annular flow were observed (see **Fig. 14**). Due to the small length-to-diameter ratio of the test tube used in this space experiment, the observed flow patterns should be considered to be developing ones. The experimental results were compared with the model

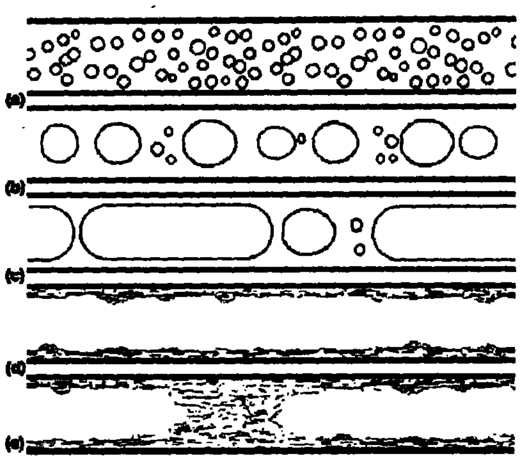

Fig. 14 Two-phase flow patterns observed in the experiments aboard the MIR Space Station.

proposed previously which accounts for the entrance effects on the flow pattern transitions, and a good agreement between the predictions and these results were obtained[11].

3.4 Ground-based studies on microgravity fluid physics and combustion in NML/CAS

a) Surface-tension driven convection and multiphase flow

The influences of evaporation on the Marangoni-Bénard convective instability for both non-deformable and deformable perturbed vapor-liquid interface have been studied theoretically and experimentally. A systematic model of two-layer system consisting of the evaporating liquid layer and vapor-phase layer heated from below was analyzed and a corresponding space experimental investigation for future program on board a Chinese scientific satellite has been proposed. The study on the oscillatory instabilities of two-layer Rayleigh-Marangoni-Benard Convection was performed by both linear instability analysis and 2D numerical simulation. Nonlinear instability such as a

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Hopf bifurcation on the secondary convective instability has been found in the real two-layer system of silicon oil over water[12].

Surface deformation and surface wave of the thermocapillary convection are studied theoretically and experimentally in a rectangular cavity with different heating sidewalls. Surface deformation and the direction of deformation are related with temperature gradient and liquid thickness. Using the Michelson interferometer, the present experiment proves that surface wave of thermocapillary convection exists on liquid free surface, and it is wrapped in surface deformation.

Experiments were performed, in a terrestrial environment, to study the migration and interaction of two drops with different diameters in matrix liquid under temperature gradient field. The oscillation of migration velocities of both drops was observed as they were approaching. For a short period the smaller drop even moved backwardly at the moment when it became side by side with the larger one during the migration. Although the present experimental results on the behavior of two drops are basically consistent with the theoretical predictions, there are also apparent differences appeared.

A TCPB (Temperature-Controlled Pool Boiling) device was developed to conduct experiments of pool boiling heat transfer both on the ground and aboard the 22^{nd} Chinese recovery satellite. Preliminary ground experiments and several experimental runs in microgravity in the drop tower Beijing (NMLC) were conducted in this year.

b) Complex fluid physics

A novel approach to the investigation of colloidal aggregation in experiments performed at microscopic particle levels by means of artificially induced particle collisions with the aid of optical tweezers is proposed. A physical model describing the artificially induced collisions was suggested. The stability ratios for different electrolyte concentrations (NaCl) are estimated by dividing the total number of particle collisions by the number of collisions leading to permanent doublets. The experimental results under different electrolyte concentrations are compared with Zeta potentials and turbidity measurements.

The lysozyme crystals were growth by batch crystallization method. The aggregative behavior in solution during the period of lysozyme crystal growth was investigated using Dynamic Light Scattering (DLS) and Atomic Force Microscopy (AFM), and the vector plots of flow in solution were observed by Particle Imaging velocimetry (PIV) technology. The experiments showed that the growth rate of (110) face wasn't influenced by sedimentation movement, it was thought that transport process wasn't the slowest process when the growth unit came into protein crystal from solution.

c) Microgravity combustion

Two major research projects are addressed in microgravity combustion science, dust-air mixture combustion (DAMC) and non-metallic solid material flammability (NMSMF). In recent years, the DAMC program established an improved experimental apparatus to produce dust suspensions in air with more uniform and better controlled concentrations, and three different methods of dispersing dusts were tested. Visualization of movements of the dust particles in the combustion chamber was analyzed by means of a PIV (particle image velocimetry) measurement system. From these results, the decay feature of the turbulence intensities as a function of time after the dispersion process was displayed. The NMSMF program set up narrow channel equipment for solid material flammability experiments, and took a successful first step towards developing the ground functional simulation of non-metallic solid material flammability in microgravity. Dust-air mixture combustion (DAMC) has been studied by using the 3.5 s drop tower at the National Microgravity Laboratory/CAS.

4. Space Life Sciences and Biotechnology Research

Space life sciences and biotechnology research in China started later than some other countries. It underwent a slow developmental stage. Since 1992, the men-aboard spaceflight plan was initiated in China, space life sciences and biotechnology research has had a more fast development. In series of Shen-Zhou missions, several life sciences experiments were performed, which included protein crystal growth, cell cultivation from animal and plant, animal or plant cell electro-fusion, protein electrophoresis separation, some small animals, algae, plant young seedling and so on. All of the hardware for space flight was made by Shanghai Institute of Technology Physics and Center for Space Science & Applied Research, Chinese Academy of Sciences. After a 7-day flight in space, the results were exciting, which revealed that the crystals grown in space could provide more structural Information than the crystals on the ground; the NK92 cells, a human activated immune cell line proliferated more faster in space than ground control (60:4.8); the production of McAb by TE-1 hybridoma cells was increased about 8-10% after space flight; in total 8465 gene, 456 gene expression were changed analysed by micro array, among them, 224 gene expression were increase and 232 gene expression were down regulated, 22 genes were related to protein synthesize; the A3-2 CFFE device worked very well in the space, hemoglobin and cytochrome C were clearly separated, and the positions and widths of the two peaks were different. Using self-made rotating equipment or rotating-wall vessel (RWV) designed by NASA, many experiments for simulating microgravity effects were performed and obtained some significant results. Re-

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cently, a recoverable satellite platform plan is going on, which will provide more chance for future life sciences research in space.

4.1 Protein crystal growth in space

Year	Spacecraft	Hardware	Proteins	Samples	Rate	Better crystals
1988	FWZ sat.	COSI	1	2	2/2	
1992	FWZ sat.	TVDA*	10	48	25/48	1
1994	FWZ sat.	TVDA	10	48	33/48	3
1995	US shuttle	MDA	3	6	6/6	0
2002	SZ3 Spaceship	PCGA	16	60	45/60	5

*The first generation of Chinese flight hardware (see the picture in Fig. 15).
Except the trials with few samples in 1988 & 1995, the result is getting better once by once.
Canadian protein samples were involved in the 1994's & 2002's missions.

The main achievements include: (1) Two generations of flight hardware shown in **Fig. 15** were developed. (2) The success rate of the protein crystal growth aboard on the SZ-3 spaceship has reached the highest level in the world. (3) The structural comparative studies revealed for the first time that the space grown crystals on the SZ-3 could provide more structural information than the ground crystals. (4) The crystallization by liquid/liquid diffusion method was simulated systemically using numerical studies, and the rules derived were proved by space experiments of mission SZ-3. This work was done by Prof. R. C. Bi and his colleagues in the Institute of Biophysics, CAS.

Results of mission SZ-3:

- More than 5 proteins produced larger crystals in space, including anaerobic mutated MoFe protein.
- Three kinds of space-grown protein crystals could diffract X-ray to the highest resolutions reported so far for the same kinds of crystals.
- Most space crystals have improved resolutions, signal/noise ratio and Rmeg factors.
- Comparative studies with PCK crystals indicate that the electron density maps calculated with the best space crystal show more structural details than the ones from the best ground counterpart, shown in **Fig. 16**.

L/LD rules and apparent effects of gelled protein solution have been displayed by lysozyme crystallization in space.

4.2 Space cell cultivation and cell science research

In order to understand the effects of microgravity condition on immune cell growth, proliferation, structure and function, the NK92 cells were cultured in a bioreactor shown in **Fig. 17** which was loaded on "SZ-3" spaceship for a seven-day flight. This work was performed by Prof. Meifu Feng and her colleagues in the Institute of Zoology, CAS.

The results in **Table 4** indicate that the NK92 cells could grow and survive very well under microgravity condition. The rate of their proliferation was about 12 fold higher than that of the ground control.

Total 22 genes were related with protein synthesize giving in the **Table 5**.

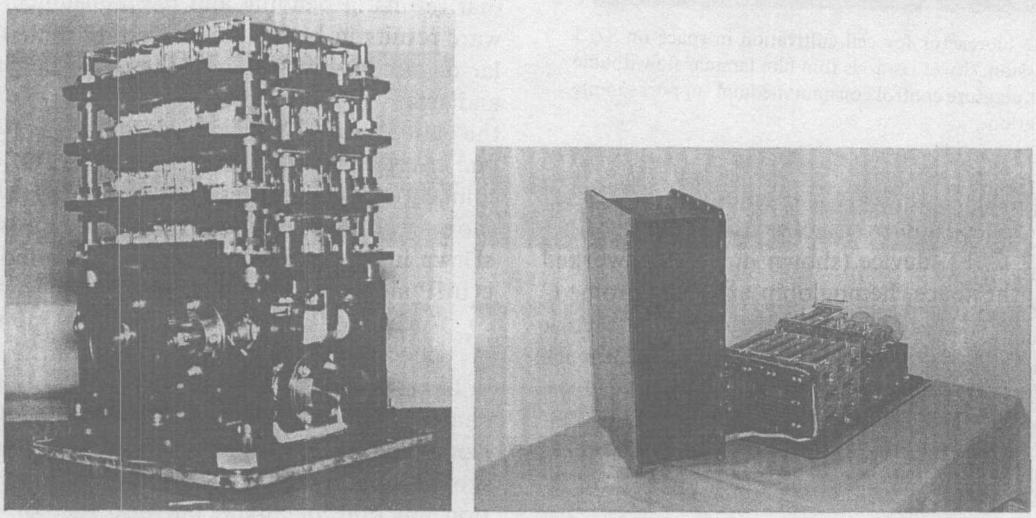

Fig. 15 Chinese flight hardware. (a) The first generation; (b) the second generation of used on mission SZ-3 for Protein crystal growth.

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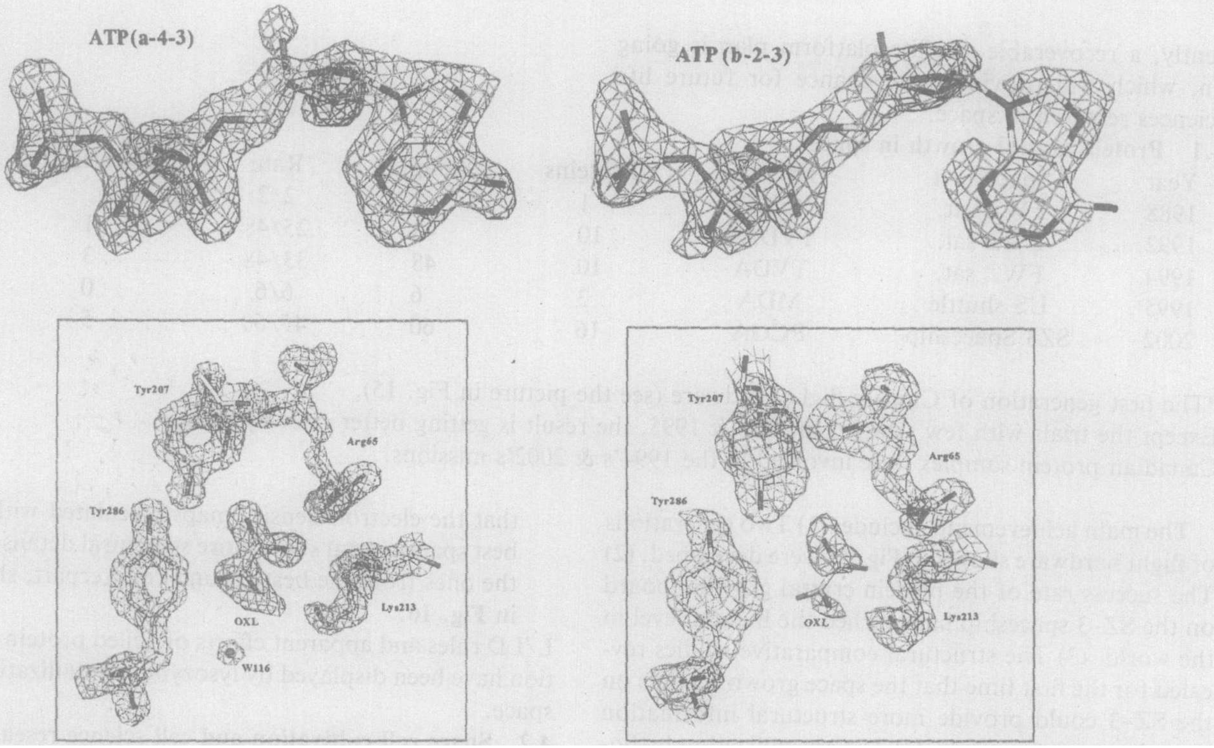

Fig. 16 Electron density maps calculated with the best space PCK crystal (left) are much better than those from the best ground counterpart (right).

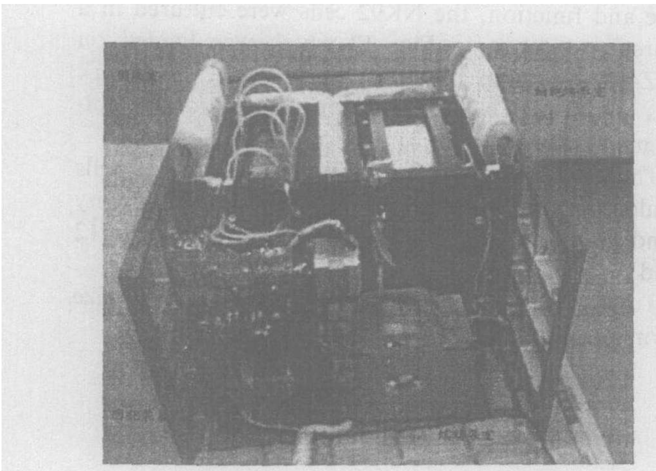

Fig. 17 The bioreactor for cell cultivation in space on SZ 3 mission. Style: vis-à-vis thin film laminar flow double temperature control constant medium support sample fixation.

4.3 Protein electrophoresis separation in space

The A3-2 CFFE device (shown in **Fig. 18**) worked very well in the space, hemoglobin and cytochrome C were clearly separated, and the positions and widths of the two peaks were different (see in **Fig. 19**). This work was done by Prof. Hanji Wu and his colleagues in the Center for Space Science and Applied Research, CAS.

Table 4 The rate of proliferation

	Seeded No	After flight	Survival rate	Proliferation
Flight	2×10^5	1.2×10^7	77.8%	60 fold
Ground	2×10^5	9.5×10^5	78.9%	4.8 fold

4.4 Plant gravitropism and biological effect of microgravity

a) Nitric Oxide Mediates Gravitropic Bending in Soybean Roots

Plant roots are gravitropic, detecting and responding to changes in orientation via differential growth that results in bending and reestablishment of downward growth, but little is known regarding the molecular details of such effects. Here, we investigate auxin and gravity signal transduction by demonstrating that the endogenous signaling molecules nitric oxide (NO) and cGMP mediate responses to gravistimulation in primary roots of soybean (*Glycine max*). The results shown in **Fig. 20** indicate that auxin-induced NO and cGMP mediate gravitropic curvature in soybean roots.

b) Gibberellin-regulated *XET* is differentially induced by auxin in rice leaf sheath bases during gravitropic bending

The asymmetric distribution of auxin plays a fundamental role in plant gravitropism, yet little is understood about how its lateral distribution stimulates growth. In the present work, the asymmetric distribution not only of auxin, but also that of gibberellins

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(GAs), was observed in rice leaf sheath bases following gravistimulation. The results suggest that the asymmetric distribution of auxin effected by gravistimulation induced a gradient of GAs via asymmetric expression of *OsGA3ox1* in rice leaf sheath bases, and hence

Table 5 The results obtained in the bioreactor NK92 cells on SZ 3 mission

Cluster	Gene	Spaceflight/ground-based	Function
Ribosome generation	RNA cyclase homolog	8.96	pre-rRNA processing
	Fibrillarin	2.51	nearly all major posttranscriptional activities in ribosome synthesis
	Mrps14	4.41	mitochondrial ribosomal protein
mRNA splicing and export	PSF	6.98	pre-mRNA splicing
	JKTBP	4.96	mRNA biogenesis and metabolism
	DDX-15	4.04	pre-mRNA and pre-rRNA splicing
	MAGOH	2.93	pre-mRNA splicing and export
	SRp20	2.83	mRNA splicing and export
	U2 snRNP-A	2.75	early events in mRNA processing
	$U2af^{35}$	2.62	RNA splicing
	$SF3a^{60}$	2.60	subunit of splicing factor 3
	zfp162	2.50	pre-mRNA splicing
Translation	eIF2gamma	6.74	assembly of translation initiation complex
	eIF4G2	4.37	assembly of translation initiation complex
	eEF1 epsilon 1	3.12	elongation of translation
	eRF1	3.01	release of new peptide

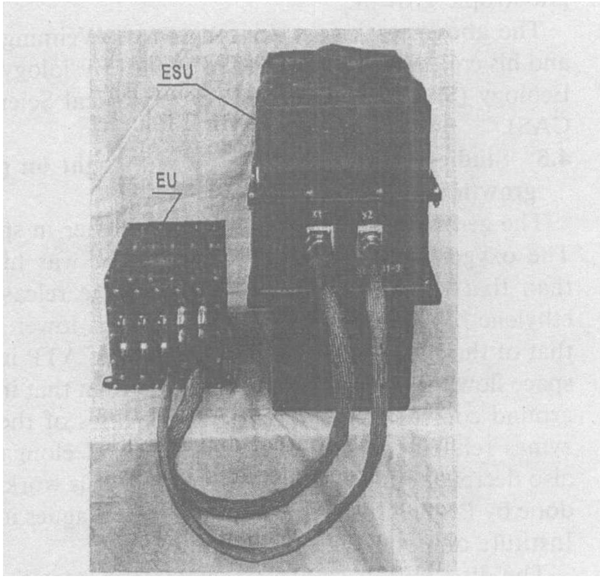

Fig. 18 The Continue flow free electrophoresis device (CFFE A3-2).

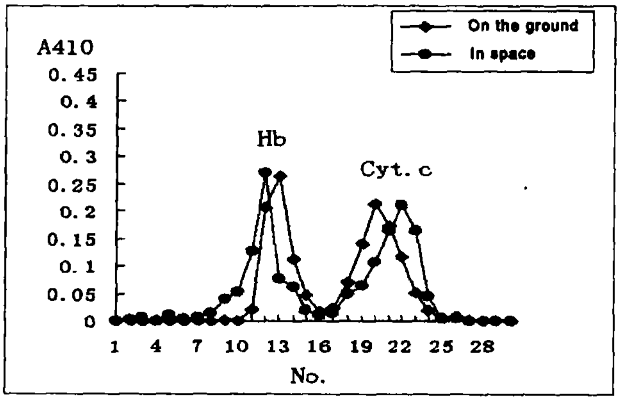

Fig. 19 The separating curves.

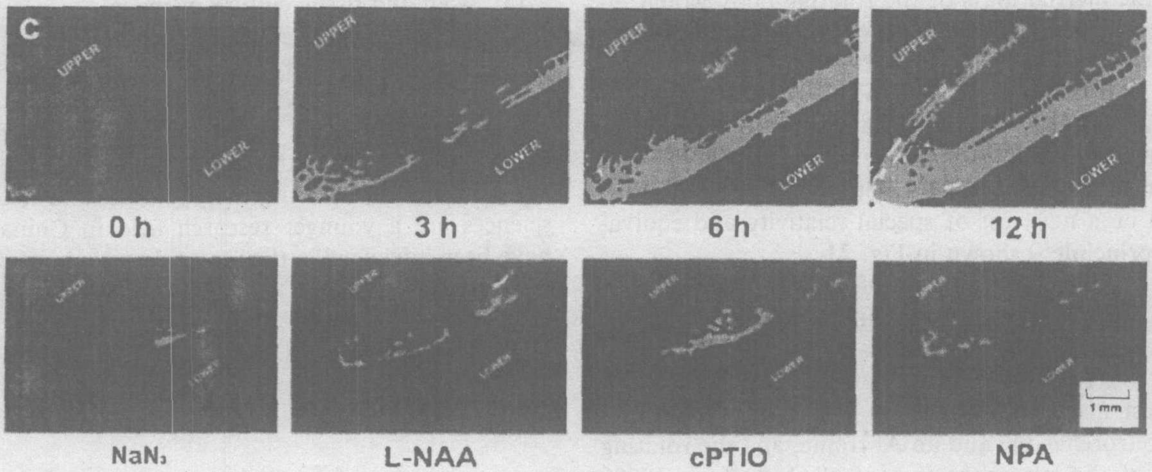

Fig. 20

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caused the asymmetric expression of *XET*. Cell wall loosening in the curvature site of the leaf sheath triggered by the expression of *XET* would contribute to gravitropic growth.

The above work was done by Prof. Weiming Cai and his colleagues in Institute of Plant Physiology and Ecology (Shanghai Institutes for Biological Sciences, CAS).

4.5 Studies on the influence of spaceflight on plant growth and development

The germination rate of seeds was higher in space. The oxygen consumption of space flight was higher than that of the ground control, but the release of ethylene of the space flown seedlings was lower than that of the ground control. The content of ATP in the space flown plant was obviously lower than that in the ground control. The content and activities of the enzymes related to senescence and cell wall elongation also decreased in the space flown plant. This work was done by Prof. Xiaogang Wen and his colleagues in the Institute of Botany, CAS.

The distribution of Ca^{2+} sediments in root tip tissues and cells of Asparagus officinalis seedlings after 15 days spaceflight was studied. It was shown that the Ca^{2+} distribution within cell of the spaceflight samples was notably different from the ground control. In the control cells, Ca^{2+} concentrated to vacuole and was less in other cellular organdies. But, in the spaceflight samples, Ca^{2+} was concentrated to the vacuole membrane with a linear pattern, less Ca^{2+} was in the vacuoles. Ca^{2+} increased remarkably in cytoplasm and inner lateral of vacuole membrane. Ca^{2+} in cell walls notably increased than in control. The results showed that Ca^{2+} sediments were forced to move out from vacuole, and concentrated to the cell membrane, the organelle membrane and the cytoplasm.

5. Fundamental Physics in Microgravity

An effect of gravitational field on rotating extended bodies has been studied. This effect comes from a rotation body in an external gravitational field. In this case, the inertial mass of the rotating body would increase according to the mass-velocity relation in special relativity, and the same time the passive gravitational mass of the body should get a corresponding gain. In order to test the equivalence between the extra masses one could compare free-fall acceleration of a rotating body to that of a not rotating body, which would be a new test of special relativity and equivalence principle[13] shown in **Fig. 21**.

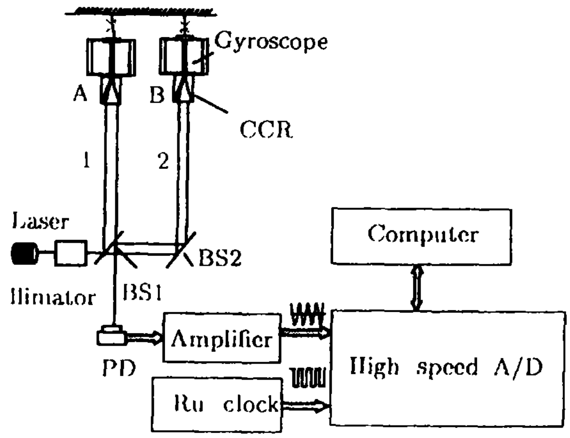

Fig. 21 Schematic diagram of the new equivalence principle test with free-fall interferometer.

An experiment using free-fall interferometer has been carried out in the Huazhong University of Science sand Technology. This is the first experiment to test the equivalence of the extended rotation body. The test mass is consisted of a gyroscope, a corner cube retroreflector, and an Al frame, and the rotating speed of the gyroscope is controlled at about 18000 rpm. 10 m-dropping-length experimental results showed that a new upper limit for the violation of the equivalence principle is obtained at the level of 1.6×10^{-7}. This means that the spin-gravity interaction between the extended bodies has not been observed at this level[14].

6. Conclusion

In the present paper, the main missions of the microgravity research and the space experiments on space material sciences, microgravity fluid physics and combustion, space life sciences and biotechnology research, fundamental Physics in China are summarized. A recoverable satellite was recently launched successfully in the August of 2005. On board the satellite, the following space experiments have been performed:

(1) Influence of space environment on the bio-samples.
(2) Space experiments on the boiling heat transfer.
(3) Interaction of two bubbles in microgravity.
(4) Contact angle measurement of melt alloy drop suspended on a plane.
(5) Cell and tissue culture in space

As a developing country, China has limited capability in the microgravity research, especially to the space experiments. However, the government and the researchers paid great efforts, and the progress of microgravity research, including the space experiments, are obvious in China. The microgravity sciences and space life sciences are a younger research field in China, and have been advanced in the recent decade. Looking for the future, more contributions of the microgravity research, including space experiments in the space mission of next Chinese scientific satellites and the second stage of Chinese Manned Spaceflight, will be given by the Chinese scientists.

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