

# Asia and IUPAP

**Judy Franz**

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IUPAP, the International Union of Pure and Applied Physics, just held its 26th General Assembly in Tsukuba, Japan in October, so this is a good time to reflect on the role of Asian physicists in IUPAP and how that role has grown over time. This should be done in the context of IUPAP's goals: "to stimulate and promote international cooperation in physics; to encourage research and education; to sponsor suitable international conferences and assist in their organization; to promote international agreements on the use of symbols, units, nomenclature and standards; and to foster free circulation of scientists."

IUPAP was founded in 1922 with 13 members. One of these was Japan, so Asia has been part of IUPAP from the very beginning. Over time more Asian countries joined IUPAP; China in 1934, India in 1948 and South Korea in 1969. This year Asian membership in IUPAP took a leap forward when Mongolia, Philippines and Singapore became members and helped increase IUPAP membership to 59. There are many more countries in Asia with active physics communities.

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Wouldn't it be good to have physicists in more Asian countries active in IUPAP?

This year Dr. S. Ushioda became President of IUPAP. He is the third Asian physicist to hold this position. In addition, there have been many Asian physicists who served as Vice Presidents, and as

members and officers of IUPAP Commissions. So, many Asian physicists have been involved in the leadership of IUPAP.

IUPAP has 18 Commissions, and they play a very large role. Most of the Commissions represent a special area of physics such as the ones on nuclear physics and low temperature physics. Several others play a more general role like the ones on physics education or physics for development. Many of these Commissions sponsor large international conferences and play a key role in their organization. In addition, they attempt to look after the health of their subfields from an international perspective. More and more of these international conferences are being held in Asia, so it is easier for Asian physicists to participate in these activities.

Along with the Commissions, IUPAP has a growing number of active Working Groups. Several of these are concerned with the international planning of large scale physics facilities. Thus there are Working Groups in accelerator physics, nuclear physics, ultra-high intensity lasers, and the interface of particle, nuclear, and astrophysics. There is a working group on Communications in Physics that brings physicists concerned with publishing issues together from different countries to discuss common concerns and areas of cooperation.

One of the most active Working Groups has been the Working Group on Women in Physics. This Group has sponsored

three large international conferences, one in Paris, one in Rio de Janeiro and a recent one in Seoul. These conferences and their follow up activities have greatly increased the attention given to bringing more women into physics and helping women have successful careers. Physicists in Japan, China, India and Korea have played important roles in these the planning and organization of these conferences. I believe that they have had particularly large influences in Japan and Korea, where the number of women in physics has been quite small in the past. But women in Europe, South American, Africa, and the rest of the world have also profited from these efforts. It is very satisfying to this Working Group and all of us that IUPAP just elected a woman, Cecilia Jarlskog, as its new President Designate, so that in 2011 IUPAP will have its first woman President.

One of IUPAP's long-standing goals has been to foster free circulation of scientists. This is just as important today as it was when IUPAP was founded. For example, we know that Asian scientists can have serious problems obtaining visas to enter the US, and scientists in some countries have had trouble obtaining visas to enter Asian countries. At the recent General Assembly, IUPAP reaffirmed its commitment to free circulation by approving a statement that says, in part, "In pursuing its objectives with respect to the rights and responsibilities of scientists, the International Union of Pure and Applied Physics (IUPAP) actively upholds this [Universality of Science] principle, and, in so doing, opposes any discrimination on the basis of such factors as ethnic origin, religion, citizenship, language, political stance, gender, or age. IUPAP should only sponsor conferences and events at institutions and in countries that uphold this principle."

What else is IUPAP doing? Another major effort has been to reach out and include physicists from developing countries in IUPAP activities. This is done in a number of ways. IUPAP gives travel grants to large IUPAP-sponsored conferences to support the participation of physicists in developing countries. Recently IUPAP has also set up a tiered membership fee system that allows more developing countries to join. Finally IUPAP supports a limited number of regional workshops in developing countries to help foster local scientists.

IUPAP also has a strong interest in fostering the careers of young scientists in all parts of the world and initiated a Young Scientist Prize program in 2005. Each IUPAP Commission can give up to 3 prizes in any three-year period. The prizes consist of a medal, a certificate, and a monetary award that has just been increased from \$1000 to 1000 Euros. So far, about 20 prizes have been awarded to young scientists around the world.

So IUPAP is a very active organization and it is unique: it is the only broad-based international physics organization that is organized and run by the physics community itself. Each member of IUPAP must have a Liaison Committee that acts as an interface between the local physics community and the IUPAP Council. This is a way of making sure that the concerns of physics communities are heard and acted on.

With its growing membership, IUPAP hopes to continue and improve upon its long history of leadership and service. We are very pleased that Asia is playing a large role in all of these efforts, and we hope that many more Asian countries will join IUPAP in the future. **APCTP**

## APCTP NEWS

### India joins the APCTP as a new member country.

India has become the 13th member country of the APCTP. At the 12th meeting of the Board of Trustees, held in consecution with the 11th meeting of the General Council, the India Association for the Cultivation of Science(IACS) joined and signed MOU with APCTP on International Academic Cooperation. India, holding high technologies and human resources of quality especially in pure sciences, is expected to be a significant addition in extending and pursuing the Center's missions. At present the APCTP has memberships from 13 countries over the Asia Pacific region; Australia, Beijing, India, Japan, Korea, Lao DPR, Malaysia, Mongolia, Philippines, Singapore, Taipei, Thailand, and Vietnam. **APCTP**



### Double-Launching of the APCTP-MPG-POSTECH Junior Research Groups

On June 1, 2008 two Junior Research Groups(JRG) were eventually launched according to the Agreement on Scientific Cooperation which had been signed on October 5, 2007 by the APCTP, the Max-Planck-Gesellschaft (MPG) of Germany and POSTECH of Korea. The MPG sponsors the JRG program with an amount of € 300,000 annually for five years, and the program is also co-sponsored by the Korean Ministry of Education, Science and Technology, the provincial governments of Geongsangbuk-do and Pohang city. The JRG program is a representative program of the MPG to cultivate leaders of the next generation and is planned to expand every year in the APCTP. **APCTP**

### Science+Education+Arts+Self-Experiencing = "Science in City Hall"

"Science in City Hall" was promoted twice with a great success. "Science in City Hall" benchmarks the science communication program of the Max Planck Institute for Physics of Complex Systems in Dresden, Germany which introduces the accomplishments of the contemporary science studies toward the public. "Science in City Hall" encloses science, education, arts, and self-experiencing together, introducing a new fashion of public presentation with high-level science contents. The first event in March invited Prof. Y.T. Lee, the Nobel laureate in Chemistry in 1989, who presented a 'Distinguished Lecture' titled as "Awakening Humanity for the 21 century", and also introduced 'Science Magic Show' performed by



Dr. Won-Keun Lee, the Director of the Korean Science Communication Institute. The second event in September was comprised of an invited lecture by Dr. So-Yeon Lee, the first spacewoman of Korea, with a title "From Recruit until Return", and "Copenhagen", the science play acclaimed with three Tony Awards. **APCTP**

## **APCTP achieves the “Center of Excellence” in the Governmental Evaluation for four years in a row**

The APCTP was offered the Best Achievement in the evaluation by the Korean Ministry of Education, Science and Technology which coordinates the Korean Science and Technology Promotion Foundation Project through which the Center is funded. **APCTP**

## **The Crossroads celebrates the third anniversary of its birth.**

It had been three years in the last October since the Crossroads(<http://crossroads.apctp.org>), the webzine of the APCTP, was ever loaded on the web. The Crossroads is published bilingual, in English and Korean, and its monthly issue is composed of various sections: Feature articles, Essays, Columns, Window to Asia, and Scientific Fiction. The purpose of the Crossroads is to show the vision of future science through the diverse science-related writings. The Crossroads is distinctive in that it delivers world-views and future visions envisaged by scientists, instead of heartless scientific knowledge, which is hoped to be more essential for the science communication toward the public. The recent update of the homepage enabled now readers to subscribe for the Newsletter and the RSS on-line, which has led to expansion of the readership into a wider area of the Asia Pacific region. Presently, netizens from more than 60 nations click the Crossroads. **APCTP**

## **The APCTP and the ASEAN COST Agreement**

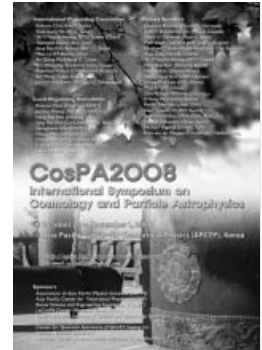
The APCTP and the ASEAN COST(Committee on Science and Technology) co-hosted a workshop in Natrang, Vietnam from September 15 to 21 for the purpose of strengthening cooperation between two institutes. Two institutes agreed on cooperation agenda for co-hosting conferences and cultivating human resources for ‘young scientists’ of the ASEAN nations. **APCTP**

## **Renovation of the APCTP Headquarter Building**

The headquarter of the APCTP located at the Hogil Kim Memorial Building of POSTECH expanded in space and also remodeled. The Center now occupies most space of the floor of the building in present use. This has made the Center enable to provide improved facilities, especially for the ever-growing population in the JRG and YST program. **APCTP**

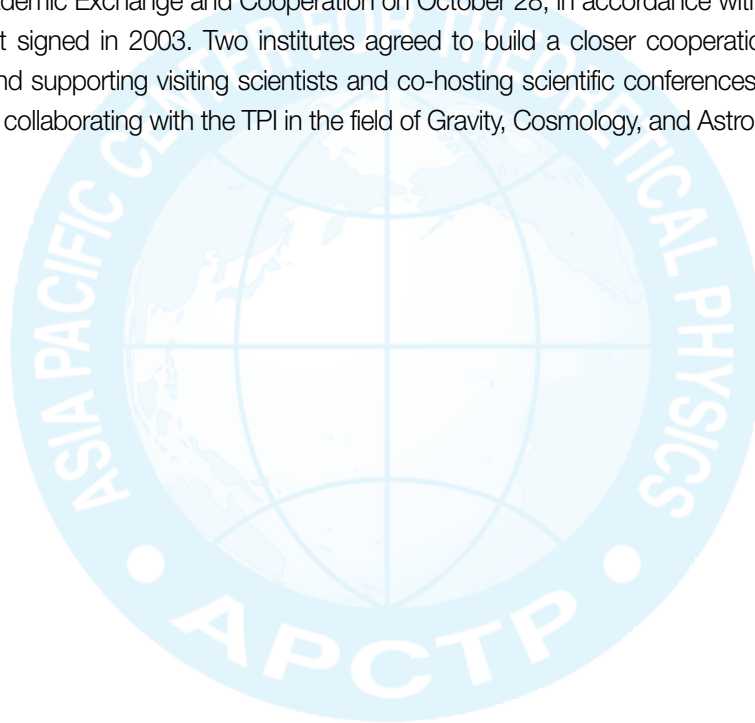
## CosPA2008 held at the Headquarter of APCTP

The CosPA2008, the largest conference in Cosmology and Astrophysics in Asia Pacific region was held at POSTECH for five days from October 28. More than two hundred scientists participated. The main themes of the conference included the novel theories and the recent experimental observations related to the origin and compositions of the universe. The Conference was the first one in this field of science that was organized and held in the Asia Pacific region. **APCTP**



## Renewal of the APCTP and TPI Agreement

The APCTP and the TPI(Theoretical Physics Institute; Director, Prof. Don N. Page) of Alberta University, Canada signed the Agreement on Academic Exchange and Cooperation on October 28, in accordance with the expiration of the preceding first Agreement signed in 2003. Two institutes agreed to build a closer cooperation and to share progress through exchanging and supporting visiting scientists and co-hosting scientific conferences. Since 2004, the APCTP has been continuously collaborating with the TPI in the field of Gravity, Cosmology, and Astrophysics. **APCTP**



# Strong QED

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Maxwell theory of electromagnetism has opened the door for the communication technology of twenty century. Quantum electrodynamics (QED) of electromagnetism and electrons or positrons has proved the correct theory for all phenomena at atomic and photon level and laid the foundation for modern digital technology. QED has also provided the framework for quantum field theory and the paradigm of renormalization, which is absolutely indispensable in subatomic physics and even condensed matter physics. QED has been regarded as a theory that was completed by nineteen fifties and no new physics could be explored. Even the seminal work by Schwinger on the effective action of spinor and scalar QED in a constant electromagnetic field background has almost been forgotten [1]. However, in the past two decades QED has attracted enormous attention not only from the theoretical but also from the experimental view point.

The backdrop for the revival of QED is that some terrestrial experiments may generate strong electromagnetic fields in the near future and astrophysical objects involving extremely strong electromagnetic fields have been found. In the near future X-ray free electron lasers from LCLS (Linac Coherent Light Source) at SLAC and International Linear Collider may attain a strength of electromagnetic field almost comparable to the critical value for electron-positron pair production [2]. Neutron stars have magnetic fields ranging from  $10^8$  G to  $10^{15}$

G and more than one-tenth of them are believed to have magnetic fields stronger than  $10^{14}$  G, the so-called magnetars (for review and references, see [3]), at least one order greater than the critical strength.

Physics of QED in strong electromagnetic field backgrounds (strong QED) differs from the standard QED, the weak-

field limit, whose first few loop diagrams cannot properly describe vacuum polarization and pair production of strong QED, nonperturbative and nonlinear effects. First, vacuum fluctuations due to a strong electromagnetic field background contribute nonlinear terms to the classical Maxwell theory and thus the electromagnetic theory becomes highly nonlinear. At the critical strength of magnetic field the cyclotron energy of an electron equals to the rest mass energy of the electron, leading to  $B_c = m^2 c^3 / e \hbar$  ( $4.4 \times 10^{13}$  G). For magnetic fields greater than the critical value, nonlinear contributions to the Maxwell term make the vacuum polarized by quantum fluctuations and vacuum polarization causes nonlinear effects such as birefringence (propagation of photons in the magnetic vacuum), which may play an important role in the physics of magnetars. In fact, a tiny amount of the light polarization rotation has been measured in the magnetic vacuum generated by an external transverse magnetic field of  $5 \times 10^4$  G [4].

Second, strong electric fields lead to more interesting physics because they make the vacuum unstable and lead to complex effective actions, whose imaginary part determines the decaying rate of the vacuum by creating pairs of charged particles, known as Schwinger pair production. In a strong electric field, virtual pairs of electrons and positrons can gain energy comparable to or greater than the rest mass energy of

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electron or positron. The electric field whose potential energy across the Compton wavelength is the rest mass energy of electron,

$$(eE) \times \frac{[\hbar]}{m[c]} = m[c^2], \quad (1)$$

gives the critical value  $E_c = m^2 c^3 / e \hbar (2.2 \times 10^{15} \text{ V/cm})$ .

Strange stars can emit electron-positron pairs more efficiently than photons. However, in the standard QED magnetic fields are stable up to  $B = 10^{32} \text{ G}$  due to the instability from the self-interaction of an electron and up to the range  $B = 10^{51} - 10^{55} \text{ G}$  due to the instability from magnetic monopole production at the string or Planck scale [5].

Hereafter we shall focus on the field theoretical aspects of strong QED. The success of QED has relied on the perturbation theory in the weak-field limit. However, QED has not been completely understood yet in the other regime of strong electromagnetic fields partly because the full nonperturbative action of QED is not known except for some exactly solved cases. Historically, the effective action of an electron in a constant electromagnetic field was obtained by Heisenberg and Euler, and also by Weisskopf as early as nineteen thirties. Using the proper time method, Schwinger found the exact one-loop effective action of spinor QED for a spin-1/2 fermion with charge  $q$  and mass  $m$  in a constant electromagnetic field

$$\begin{aligned} \mathcal{L}_{\text{eff}} = & -\mathcal{F} - \frac{1}{8\pi^2} \int_0^\infty ds \frac{e^{-m^2 s}}{s^3} \\ & \times \left[ (qs)^2 \mathcal{G} \frac{\text{Re} \cosh(qsX)}{\text{Im} \cosh(qsX)} - 1 - \frac{2}{3} (qs)^2 \mathcal{F} \right], \quad (2) \end{aligned}$$

where

$$X = [2(\mathcal{F} + i\mathcal{G})]^{1/2} = X_r + iX_i. \quad (3)$$

Here,  $\mathcal{F}$  is the negative of the Maxwell term

$$\mathcal{F} = \frac{1}{4} F_{\mu\nu} F^{\mu\nu} = \frac{1}{2} (\mathbf{B}^2 - \mathbf{E}^2), \quad (4)$$

and  $\mathcal{G}$  is another Lorentz invariant tensor

$$\mathcal{G} = \frac{1}{4} F_{\mu\nu} \tilde{F}^{\mu\nu} = \mathbf{E} \cdot \mathbf{B}, \quad (5)$$

where  $\tilde{F}^{\mu\nu} = \epsilon^{\mu\nu\alpha\beta} F_{\alpha\beta}$  is the dual field tensor.

A prominent feature of strong QED is that the effective action has the imaginary part (the vacuum persistence (the rate per unit time and unit volume) being the twice of the imaginary part) given by

$$\text{Im} \mathcal{L}_{\text{eff}} = \frac{2S+1}{2(2\pi)^3} \sum_{n=1}^{\infty} (-1)^{(n+1)(2S+1)} \left( \frac{qE}{n} \right)^2 e^{-\frac{n\pi m^2}{qS}}. \quad (6)$$

Here,  $S$  is the spin multiplicity, being  $S=0$  for scalar particles and  $S=1/2$  for spin-1/2 fermions. The ingoing vacuum decays to the outgoing vacuum by a factor of  $e^{-2(\text{Im} \mathcal{L}_{\text{eff}})}$ , leading to Schwinger pair production. Thus, one way to understand Schwinger pair production is to compute the imaginary part of the effective action. Another way is to find the solution of the field equation and then the Bogoliubov coefficients. Schwinger mechanism may be understood as a quantum tunneling process of virtual pairs from the Dirac sea due to vacuum fluctuations [6–9]. A strong electric field can separate virtual pairs of charged particles over the Compton wavelength and create real pairs, while in a weak electric field virtual pairs recombine due to the Coulomb attraction. The worldline instanton method has been used to calculate the pair-production rate through the tunneling process in inhomogeneous electric fields [10, 11]. Schwinger mechanism is one of the most efficient mechanisms for energy extraction from objects with strong electromagnetic fields.

However, methodologically speaking, finding the effective action is quite a nontrivial task for realistic profiles of electromagnetic fields such as either spatially localized or temporally pulsed. It is hard to practically compute the Schwinger's proper-time integral for such fields. The computational scheme for the pair-production rate based on the recently employed worldline instanton method provides a good approximation for many inhomogeneous fields. But the accuracy of the worldline instanton method for the pair-production rate is not as good as the WKB approximation in many cases. On the other hand, the canonical method based on field equations turns out to be efficient in practically computing the pair-production rate for many configurations of electromagnetic fields. As long as the solutions of field equations are known, one can calculate the pair-production rate through the Bogoliubov transformation between the ingoing and outgoing vacua and, in principle, express the effective action in terms of them.

In canonical quantum field theory, a complex analysis method has been advanced to calculate the pair-production rate via tunneling through the potential barrier of the Dirac sea lowered by electric fields. The idea is simply to find the tunneling and the reflection rates and physically interpret them as vacuum persistence and pair-production rate. For instance, a scalar particle with charge  $e$  ( $e > 0$ ) and mass  $m$  in a constant electric field along the  $x$ -direction satisfies the mode equation of the form [in units with  $\hbar = c = 1$ ]

$$\left[ \frac{\partial^2}{\partial x^2} + q(x) \right] \varphi(x) = 0, \quad q(x) = (\omega + eEx)^2 - (m^2 + \mathbf{k}^2). \quad (7)$$

Then the pair-production rate for a given momentum,  $P(\mathbf{k}) = e^{-\text{Sk}}$ , is determined by the instanton action defined in the complex

x-plane by the contour integral [12–14]

$$S_{\mathbf{k}} = -i \oint_C \sqrt{q(x)} dx = \frac{\pi(m^2 + \mathbf{k}^2)}{eE}, \quad (8)$$

where the integral is along a contour excluding the branch cut connecting two roots. The complex analysis method also works for spinor QED.

Recently a novel method has been introduced to directly find the effective action from the Bogoliubov transformation and coefficients [15]. The essential idea is that the Bogoliubov transformation carries all the information of evolution from the ingoing vacuum to the outgoing vacuum and the effective action is the scattering amplitude between the ingoing and the outgoing vacua. To be concrete, in the presence of a time-dependent electromagnetic field background, the ingoing vacuum is related to the outgoing vacuum through the Bogoliubov transformation as

$$a_{\alpha,\text{out}} = \nu_{\alpha} a_{\alpha,\text{in}} + \nu_{\alpha} b_{\alpha,\text{in}}^{\dagger}. \quad (9)$$

Here,  $\alpha$  denotes all quantum numbers such the momentum, the Landau level in case of a magnetic field and the spin state. The operators  $a_{\alpha}$  and  $b_{\alpha}$  are for particles and antiparticles, respectively, and no mode-mixing is assumed for simplicity. The Bogoliubov coefficients satisfy the relation from the commutator from spin-statistics for scalar particles

$$|\mu_{\alpha}|^2 - |\nu_{\alpha}|^2 = 1, \quad (10)$$

and from the anticommutator for spin-1/2 fermions

$$|\mu_{\alpha}|^2 + |\nu_{\alpha}|^2 = 1. \quad (11)$$

There is a unitary transformation between the ingoing and the outgoing operator for each  $\alpha$

$$a_{\alpha,\text{out}} = U_{\alpha}(A) a_{\alpha,\text{in}} U_{\alpha}^{\dagger}(A), \quad (12)$$

where the evolution operator  $U_{\alpha}$  can be further factored into an overall phase part and a two-mode squeeze operator whose parameters are entirely determined by the Bogoliubov coefficients, in turn by the gauge potential [15].

Using the evolution operator, one can find the vacuum persistence and the mean number of created pairs. Note that equal number of particles and antiparticles can be created from the vacuum due to charge neutrality, whose  $n$ -pair state is compactly denoted as  $|n_{\alpha}, t\rangle = (a_{\alpha}^{\dagger n}(t)(b_{\alpha}^{\dagger n}(t))|0; t\rangle/n!$ . The probability for  $n$ -pairs with  $\alpha$  to be created from the vacuum is

$$P_n(\alpha) = |\langle n_{\alpha}, \text{out} | 0, \text{in} \rangle|^2 = |\langle n_{\alpha}, \text{in} | U_{\alpha}^{\dagger} | 0, \text{in} \rangle|^2. \quad (13)$$

Note that  $P_n = P_0(P_1/P_0)^n$  and  $\sum_{n=0}^{\infty} P_n = 1$  for each  $\alpha$ .

So, in scalar QED the mean number of pairs created from the

vacuum for each quantum number per unit volume is

$$\mathcal{N}_{\alpha}^{\text{sc}} = \sum_{n=0}^{\infty} n P_n(\alpha) = |\nu_{\alpha}|^2. \quad (14)$$

Similarly, the vacuum persistence is

$$|\langle 0, \text{out} | 0, \text{in} \rangle|^2 = \prod_{\alpha} P_0(\alpha) = \prod_{\alpha} \frac{1}{|\mu_{\alpha}|^2}. \quad (15)$$

Alternatively, the vacuum persistence is the probability for the ingoing vacuum to remain the outgoing vacuum

$$|\langle 0, \text{out} | 0, \text{in} \rangle|^2 = \prod_{\alpha} \left[ 1 - \sum_{n=1}^{\infty} P_n(\alpha) \right] = \prod_{\alpha} \frac{1}{|\mu_{\alpha}|^2}. \quad (16)$$

On the other hand, in spinor QED the Pauli blocking allows at most one pair of fermions to be created from the vacuum for each quantum number

$$\mathcal{N}_{\alpha}^{\text{sp}} = |\langle 1_{\alpha}, \text{out} | 0, \text{in} \rangle|^2 = 1 - |\mu_{\alpha}|^2. \quad (17)$$

The advantage of the evolution operator is that the effective action of scalar QED is given by

$$e^{i \int dt d\mathbf{x} \mathcal{L}_{\text{eff}}^{\text{sc}}} = \langle 0, \text{out} | 0, \text{in} \rangle = \prod_n \frac{1}{|\mu_n^*|}, \quad (18)$$

and that of spinor QED by

$$e^{i \int dt d\mathbf{x} \mathcal{L}_{\text{eff}}^{\text{sp}}} = \langle 0, \text{out} | 0, \text{in} \rangle = \prod_n \mu_n^*. \quad (19)$$

Therefore, one finds the effective action per unit volume as

$$\mathcal{L}_{\text{eff}}^{\text{sc/sp}} = \pm i \sum_n \ln(\mu_n^*), \quad (20)$$

where the plus (negative) sign is for scalar (spinor) QED. Further it can be shown that the vacuum persistence and the total mean number of created pairs are related as

$$2(\text{Im} \mathcal{L}_{\text{eff}}) = \pm \sum_n \ln(1 \pm |\mu_n|^2), \quad (21)$$

where the upper (lower) sign is for scalar (spinor) QED. A few comments are in order. First, the effective action in the relation (21) is not renormalized yet, though the total mean number may be finite. Second, the transformation between the ingoing and outgoing vacua is not unitarily equivalent representation of each other because of infinite volume. However, for each quantum number the ingoing and the outgoing operators are related through the unitary transformation as shown above.

We shall use the evolution operator method to find the effective action in two interesting cases: a constant electric field and a Sauter-type electric field. In both cases the renor-

malized one-loop effective action can be obtained from the Bogoliubov coefficients and the relation between the vacuum persistence and total mean number of created pairs holds for the renormalized effective action. In Ref. [15], the gamma function regularization scheme was introduced

$$\ln \Gamma(z) = \int_0^{\infty} \frac{ds}{s} \left[ \frac{e^{-zs}}{1-e^{-s}} + \dots \right]. \quad (22)$$

First, in a constant electric field, the Bogoliubov coefficient  $\mu_\alpha$  involves the gamma function, which depends on the quantum number of momentum and spin states. After eliminating all divergent terms through the vacuum energy renormalization and the charge renormalization, one gets the renormalized exact one-loop effective action per unit volume

$$\begin{aligned} \mathcal{L}_{\text{eff}}^{\text{sc/sp}} &= \mp \frac{2S+1}{16\pi^2} \mathcal{P} \int_0^{\infty} \frac{ds}{s^3} e^{-m^2 s} h(s) \\ &\pm i \frac{(2S+1)qE}{2(2\pi)} \int \frac{d^2 \mathbf{k}_\perp}{(2\pi)^2} \ln(1 \pm \mathcal{N}_{\mathbf{k}}), \end{aligned} \quad (23)$$

where the upper (lower) sign is for scalar (spinor) QED,  $S$  is the spin multiplicity,  $\mathcal{P}$  denotes the principal value,  $\mathcal{N}_{\mathbf{k}} = e^{-\pi(m^2 + \mathbf{k}_\perp^2)/(qE)}$ , and

$$\begin{aligned} h^{\text{sc}}(s) &= \frac{qEs}{\sin(qEs)} - 1 - \frac{(eEs)^2}{6}, \\ h^{\text{sp}}(s) &= (qEs) \cot(qEs) - \frac{1}{s} + \frac{(eEs)^3}{3}. \end{aligned} \quad (24)$$

Second, the exact solutions and thereby the Bogoliubov coefficients can be found for the Sauter-type electric field  $E = E_0 \text{sech}^2(t/\tau)$ , effectively acting for a finite period of time. The Klein-Gordon or Dirac equation has the ingoing and outgoing asymptotic frequencies

$$\begin{aligned} \omega_{\mathbf{k},\text{in}} &= \sqrt{(k_z + qE_0\tau)^2 + \mathbf{k}_\perp^2 + m^2}, \\ \omega_{\mathbf{k},\text{out}} &= \sqrt{(k_z - qE_0\tau)^2 + \mathbf{k}_\perp^2 + m^2}. \end{aligned} \quad (25)$$

Using the gamma function regularization, one obtains the renormalized exact one-loop effective action in both scalar and spinor QED. The real part of the effective action of scalar and spinor QED takes the form

$$\begin{aligned} \text{Re}(\mathcal{L}_{\text{eff}}^{\text{sc/sp}}) &= \pm \frac{2S+1}{2} \int \frac{d^3 \mathbf{k}}{(2\pi)^3} \mathcal{P} \int_0^{\infty} \frac{ds}{s} \\ &\times \left[ (e^{-\Omega_{\mathbf{k}}^{(+)} s} + e^{-\Omega_{\mathbf{k}}^{(-)} s}) f(s) \right. \\ &\left. - (e^{-2\tau\omega_{\mathbf{k},\text{in}} s} + e^{-2\tau\omega_{\mathbf{k},\text{out}} s}) g(s) \right], \end{aligned} \quad (26)$$

where the upper (lower) sign is for scalar (spinor) QED, and

$$\begin{aligned} \Omega_{\mathbf{k}}^{(\pm)} &= \tau\omega_{\mathbf{k},\text{in}} + \tau\omega_{\mathbf{k},\text{out}} \pm 2\lambda^{\text{sc/sp}}, \\ \lambda^{\text{sc/sp}} &= \sqrt{(qE_0\tau)^2 - \frac{(1-2S)}{4}}, \end{aligned} \quad (27)$$

and for scalar QED

$$\begin{aligned} g^{\text{sc}}(s) &= \cot(s) - \frac{1}{s} + \frac{s}{3}, \\ f^{\text{sc}}(s) &= \frac{1}{\sin(s)} - \frac{1}{s} - \frac{s}{6}, \end{aligned} \quad (28)$$

and for spinor QED

$$f^{\text{sp}}(s) = g^{\text{sp}}(s) = \cot(s) - \frac{1}{s} + \frac{s}{3}. \quad (29)$$

Similarly, the imaginary part is given by

$$\begin{aligned} \text{Im}(\mathcal{L}_{\text{eff}}) &= \pm \frac{2S+1}{2} \int \frac{d^3 \mathbf{k}}{(2\pi)^3} \\ &\times \ln \left[ \frac{(1 \pm e^{-\pi\Omega_{\mathbf{k}}^{(+)}})(1 \pm e^{-\pi\Omega_{\mathbf{k}}^{(-)}})}{(1 - e^{-2\pi\tau\omega_{\mathbf{k},\text{in}}})(1 - e^{-2\pi\tau\omega_{\mathbf{k},\text{out}}})} \right], \end{aligned} \quad (30)$$

where the upper (lower) sign is for scalar (spinor) QED. It is further shown that the imaginary part of the renormalized effective action indeed satisfies the general relation, as expected,

$$2(\text{Im}\mathcal{L}_{\text{eff}}^{\text{sc/sp}}) = \pm(2S+1) \int \frac{d^3 \mathbf{k}}{(2\pi)^3} \ln(1 \pm \mathcal{N}_{\mathbf{k}}^{\text{sc/sp}}), \quad (31)$$

where

$$\mathcal{N}_{\mathbf{k}}^{\text{sc/sp}} = \frac{\cosh(2\pi\lambda) \pm \cosh(\pi\tau\omega_{\mathbf{k},\text{out}} - \pi\tau\omega_{\mathbf{k},\text{in}})}{2 \sinh(\pi\tau\omega_{\mathbf{k},\text{in}}) \sinh(\pi\tau\omega_{\mathbf{k},\text{out}})}. \quad (32)$$

In summary, strong QED is a reviving area with real physical applications in terrestrial experiments and celestial observations. Even the seminal paper by Schwinger [1] has been almost neglected for the first two decades but it has begun to attract much attention in the past two decades such that it now surpassed by the number of citations another classical paper that won himself a nobel physics prize. However, the Schwinger's proper-time method has not been used beyond a constant electromagnetic field background or a plane wave partly because of the methodological difficulty for inhomogeneity. The worldline instanton method, a gauge invariant formulation, can work out the pair-production rate for some interesting profiles of electromagnetic fields, though the computational accuracy is not as good as the WKB approximation in many cases. Here in this article we introduced a canonical method based on the field equation. The complex analysis method provides an efficient and accurate method for general configurations of electromagnetic fields. More interestingly, the evolution operator method enabled us to find the renormalized effective action for the Sauter-type electric field. It is

the first exact one-loop calculation for a nontrivial electric field.

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# Fractional quantum Hall effect, composite fermion theory, topological quantum computation, and all that jazz

Kwon Park

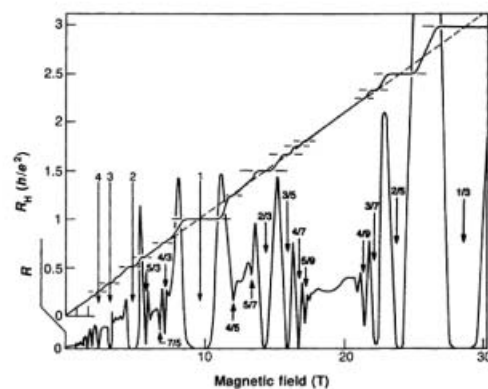
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Challenging problems in nature seem to have a few things in common. It does not matter whether the problem concerns physical or biological science. Not even for social science. More often than not, strong correlation is among such commonalities causing tough challenges. Fortunately, challenges are not just nuisances, but rather open new possibilities that did not exist before. In condensed matter physics, such a new possibility is the fractional quantum Hall effect<sup>[1]</sup>.

The fractional quantum Hall effect is, in a good sense, the limiting situation where electron correlation is pushed to its maximum strength. In general, there are two energy scales in physical systems; the kinetic and potential energy. Due to the presence of the strong magnetic field in fractional quantum Hall systems, the kinetic energy is quantized in

terms of the so-called Landau level so that, within a single Landau level, kinetic energies of all electrons are exactly the same and constant. Therefore, the kinetic energy scale does not influence the dynamics of the system at all. The only remaining energy scale is the electron-electron interaction energy which alone completely determines the nature of the ground state.



ductors of GaAs and AlGaAs) is placed under strong magnetic fields and an electric current is set to flow. Due to the Lorenz force, the electric current is bent and charges are accumulated in the direction perpendicular to the original current. The charge accumulation, of course, does not go on forever, but stops when the Lorenz force is counter-balanced by the electric force exerted by the accumulated charges. The ratio between the steady-state current and the voltage accumulation in the perpendicular direction is the Hall resistance,  $R_H$ . Classically, the Hall resistance is predicted to be simply proportional to the strength of the magnetic field. In a quantum regime, however, it is discovered that the Hall resistance is in fact quantized, showing step-like behaviors as a function of magnetic field. See Fig. 1. Here, the quantum regime signifies low temperature, low impurity density, and high magnetic field.

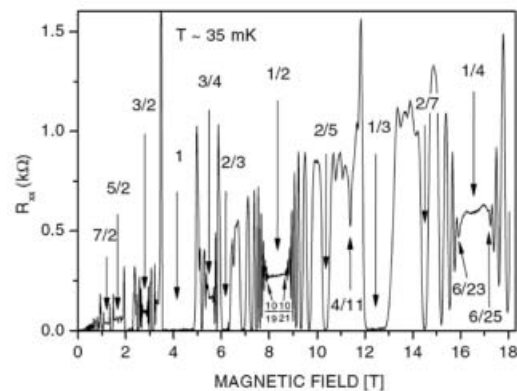
One of the most remarkable aspects of the quantum Hall effect is that the quantization of the Hall resistance is not only extremely precise, but also determined completely by the fundamental constants of nature. That is to say,  $R_H = h/\nu e^2$  where  $h$  is the Planck constant and  $e$  is the charge of electron. Here,  $\nu$  is a pure number, being called the filling factor since it measures how many Landau levels are filled. Without knowing anything, one can see that something is pinning  $\nu$  to specific values for a range of magnetic field and the corresponding quantum Hall state is stable in this range. Then, what is pinning  $\nu$ ?

From the left half of Fig. 1, one can see that  $\nu$  is pinned when it is an integer. This is actually rather natural since there exists an energy gap separating the ground state from excited states when an integer number of Landau levels are filled. This is called the integer quantum Hall effect (IQHE)<sup>[2]</sup>. Puzzling is what happens at the right half of Fig. 1. Why is  $\nu$  pinned even at such fractional numbers as  $1/3$ ,  $2/5$ ,  $3/7$ ,  $4/9$ , and so on?

The quantum Hall effect occurring at fractional filling factors is called the fractional quantum Hall effect (FQHE). This means that there exists an energy gap even when only a fraction of the (lowest) Landau level is filled. As mentioned before, within a single Landau level, the kinetic energy is constant and therefore the only energy scale which can generate the necessary energy gap is the electron-electron interaction. This reasoning is of course correct. What we do not know yet is, however, how this is possible. The answer to this question is given by the composite fermion theory.

## Composite fermion theory

Around the time when the composite fermion theory was put forward by J. K. Jain in 1989<sup>[3]</sup>, there was a widespread, but misleading belief in the condensed matter physics community that the fractional quantum Hall effect was more or less completely explained by the combination of the Laughlin's wave function and the so-called hierarchy theory. The Laughlin's wave function was remarkably successful in explaining the quantum Hall states at  $\nu = 1/(2m+1)$  with  $m$  an integer. Soon after the discovery of the Laughlin's wave function, however, it became clear that the filling factors for the fractional quantum Hall effect were much more diverse than simple  $1/3$ ,  $1/5$ ,  $1/7$ , and so on. Figure 2 shows a relatively more recent experimental data indicating the diversity of the fractional quantum Hall states. Note that the longitudinal resistance should exhibit a deep minimum (and eventually vanish in the limit of zero temperature) when the fractional quantum Hall effect occurs.

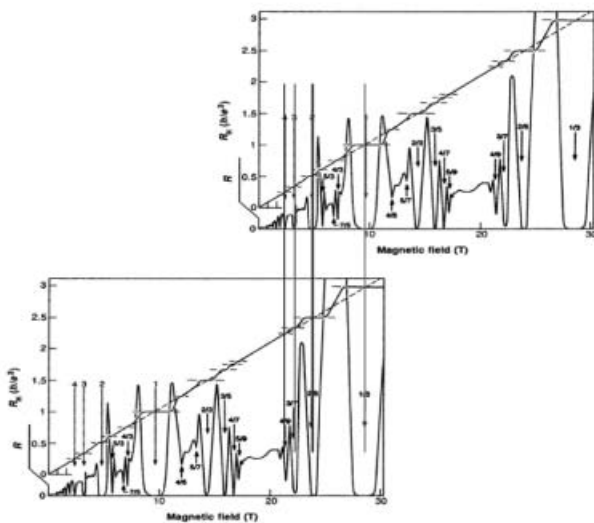


**Figure 2:** Longitudinal resistance data showing the diversity of the fractional quantum Hall states. [Reference: Pan et al., Phys. Rev. Lett. 88, 176802 (2002).]

Naturally, people tried to come up with a theory that can explain other fractions. One theory that attracted much attention was the hierarchy theory<sup>[4]</sup>. The main idea is simple and innovative. Basically, the hierarchy theory tries to make a hierarchical connection between “mother” and subsequent “daughter” fractions, all starting from the Laughlin fraction of  $\nu = 1/(2m+1)$ . For this, fractionally charged quasi-particles in a given “mother” state form a Laughlin-like state to generate a “daughter” state in the next hierarchical level of the fractions.

While this hierarchy scenario was able to successfully

generate the filling fraction sequence of  $1/3, 2/5, 3/7, 4/9,$  and so on, there were a variety of serious inconsistencies compared to experimental facts. One such inconsistency was a relative stability between “daughter” fractions. For example, according to the hierarchy scenario,  $\nu = 5/13$  should be as strong as  $\nu = 3/7$ . However, no FQHE state is observed at  $\nu = 5/13$  while the  $\nu = 3/7$  FQHE is one of the strongest as seen in Fig. 1 and 2. Moreover, even from a theoretical point of view, the hierarchy scenario was unsatisfactory since it lacked a quantitative prediction power. (For more information, see the reference<sup>[5]</sup>.)



**Figure 3:** Comparison between the CF wave function predictions and exact results. Short horizontal lines in the plot indicate eigenenergies obtained from exact diagonalization while dots represent the CF wave function predictions. [Reference: Jain, Physics Today 53, 39 (2000).]

Now enters the composite fermion theory. Instead of focusing on a hierarchical connection between fractions, Jain noticed that there actually existed a close connection between integer and fractional quantum Hall effects. One clue that revealed such underlying connection was that all observed FQHE fractions can be connected to certain IQHE filling factors if the magnetic field is appropriately “shifted”. It is convenient to use actual experimental data to explain this fact. Figure 3 shows two identical experimental data plotting resistance as a function of the magnetic field,  $B$ . It can be seen in this graph that the magnetic field strength of all the  $\nu = n/(2n + 1)$  FQHE states can be aligned with that of the respective  $\nu^* = n$  IQHE states with  $n$  an integer when the magnetic field is shifted by a constant amount. Jain took this fact seriously. As later proven to be correct, this fact could be explained if there exist new qua-

si-particles in the FQHE states, which feel an effective magnetic field,  $B^*$ , that is reduced from the externally applied magnetic field,  $B$ . As a consequence, the new quasi-particles fill  $\nu^*$  effective Landau levels which are generated by  $B^*$ .

A natural question at this stage is how much magnetic field is reduced. Amazingly, the magnetic field reduction turns out to be exactly the same as twice (in general, an even integer times) electron density times magnetic flux quantum,  $\Phi_0 = hc/e$ . This can be interpreted as if each electron captures two magnetic flux quanta. This is the famous flux attachment. In this view, the aforementioned new quasi-particle is nothing but the flux-attached electron which is called the composite fermion (CF).

The composite fermion theory can do much more than just predicting the FQHE fractions. I will show some of the most spectacular consequences of this theory. To this end, it is interesting to notice that many successful theories of strongly correlated electron systems have been formulated in terms of trial wave functions. To name a few, the BCS wave function, the Bijl-Feynman theory of liquid Helium, and the Bethe ansatz wave function are among those. The composite fermion theory is also best represented in terms of the composite fermion trial wave function.

### Trial wave function

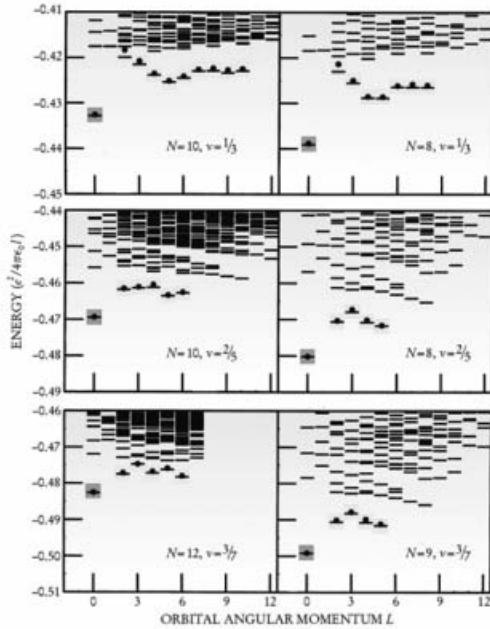
One of the most important elements in constructing the CF wave function is how to represent the flux quantum. Physically, a flux quantum is a vortex around which the phase of the wave function winds by  $2\pi$ . The simplest electronic wave function containing a vortex is  $\prod_j (z - z_j)$  where  $z = x + iy$ . Note that  $z$  and  $z_j$  indicate the positions of the vortex and the  $j$ -th electron, respectively. A natural extension containing a double vortex is then  $\prod_j (z - z_j)^2$ . Now, let us imagine that each electron captures a double vortex. In this case, it is not too difficult to guess that the wave function can be written as  $\prod_{j < k} (z_j - z_k)^2$ .

As mentioned before, the composite fermion captures an even number of magnetic flux quanta and experiences a reduced effective magnetic field. Bearing this physics in mind, one can then arrive at the following form of the CF wave function:

$$\Psi_\nu = P_{LLL} \prod_{j < k} (z_j - z_k)^{2p} \Psi_{\nu^*}^{CF}$$

where  $p$  is an integer and the electron filling factor,  $\nu$ , is

related to the CF filling factor,  $\nu^*$ , via  $\nu = \nu^*/(2p\nu^* + 1)$ . Here,  $P_{LLL}$  is the so-called lowest-Landau-level projection operator which projects out all higher-Landau-level components. Note that we are only interested in the single Landau level physics. While  $P_{LLL}$  is technically important, it is not crucial for the main purpose of this article.



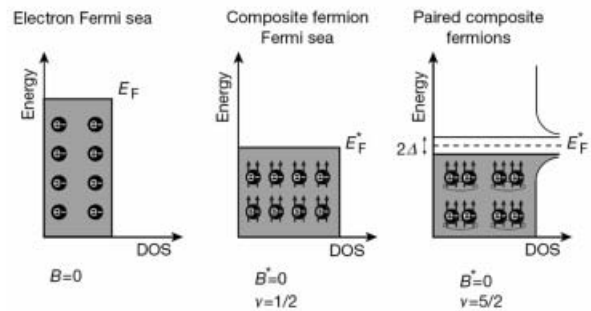
**Figure 4:** Comparison between the CF wave function predictions and exact results. Short horizontal lines in the plot indicate eigenenergies obtained from exact diagonalization while dots represent the CF wave function predictions. [Reference: Jain, Physics Today **53**, 39 (2000).]

Anyone can, of course, propose a trial wave function. The crucial step is, however, to check the validity of the proposed wave function. Figure 4 shows how good the CF wave function predictions are when compared to the exact results. Note that the exact results reported here are computed in the spherical geometry where electrons are placed on the surface of the sphere which contains a magnetic monopole at the center. As one can see, the agreement between exact results and CF predictions is excellent, which is actually quite remarkable considering that the CF wave function is completely free of any variational parameters.

It is important to note that the CF wave function includes the Laughlin's wave function as a natural subset in a particular limit. When  $\nu^* = 1$ ,  $\Psi_{\nu^*=1}^{CF}$  is given by  $\prod_{j < k} (z_j - z_k)$  since this is simply the ground state wave function for a completely-filled (effective) lowest Landau level. Consequently,

the CF wave function for  $\nu = 1/3$  becomes  $\Psi_{1/3} = \prod_{j < k} (z_j - z_k)^3$  which is nothing but the Laughlin's wave function. Now is a high time to discuss why the Laughlin's wave function can be a good state. This also provides an argument why the general CF wave function can be good as well.

The basic scheme is as follows. First, the Laughlin's wave function is shown to be an exact ground state of a short-range potential which imposes an energy cost only when two electrons are closest possible. In the lowest Landau level, this means that there is an energy cost only when the wave function has such component as  $z_j - z_k$  between the  $j$  and  $k$ -th electrons. The functional form of  $\Psi_{1/3}$  tells us that the Laughlin's wave function does not contain this component at all since, for every pair of electrons, the relative component is always  $(z_j - z_k)^3$ . Therefore, the Laughlin's wave function is the exact ground state of this fictitious potential. What is left is to show that the realistic Coulomb interaction is adiabatically connected to this potential. This is proven numerically, for example, by computing the wave function overlap between the exact ground state of the Coulomb interaction and the CF wave function. It has been shown that the wave function overlap is typically higher than 99% for all known cases. For a similar reason, the general CF wave function can provide a good state because it contains the flux attachment factor of  $(z_j - z_k)^2$  which can help void the short-range energy cost very effectively.



**Figure 5:** Schematic diagram for the formation of CF pairing. [Reference: Scarola, Park and Jain, Nature 406, 863 (2000).]

There are a wealth of quantitative predictions that can be obtained from the composite fermion wave function. It is, however, beyond the scope of this article to discuss details of all these predictions. By simply mentioning that all predictions are in excellent agreement with experiment, I would like to focus on two special situations where either the lowest or the second-lowest Landau level is half filled.

Considering that the filling factor is actually the ratio between the number of flux quanta and that of electrons, half filling means that there are exactly two flux quanta per electron. This, in turn, suggests that composite fermions do not feel any effective magnetic field since all external magnetic fields are captured away. What is going to happen when composite fermions become free of magnetic field?

### Composite fermion pairing and topological quantum computation

When fermions become free, they of course form a Fermi sea. One can guess that composite fermions may also form their own Fermi sea in the half-filled Landau levels. This guess actually turns out to be correct in the half-filled lowest Landau level (i. e.  $\nu = 1/2$  ). On the other hand, it is found that, in the half-filled second Landau level, the composite fermi sea is unstable against pairing between composite fermions in a similar way that the usual electron Fermi sea becomes unstable to the formation of Cooper pair<sup>[6]</sup>. A schematic diagram is shown in Fig. 5. An immediate consequence of this difference is that there is no fractional quantum Hall effect at  $\nu = 1/2$  while there is one at  $\nu = 5/2$ ; See Fig. 6. Note that the half-filled second Landau level occurs at  $\nu = 5/2 (= 2 + 1/2)$  since the lowest Landau level is completely filled twice by spin-up and down electrons. In this case, electrons in the filled lowest Landau level become inert and do not participate in the low-energy dynamics.

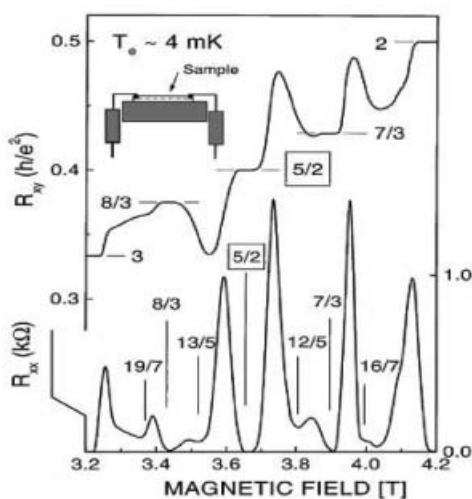


Figure 6: Experiment showing the fractional quantum Hall effect. [Reference: Pan et al., Phys. Rev. Lett. 83, 3530 (1999).]

The  $\nu = 5/2$  fractional quantum Hall effect has attracted so much attention lately that it is among the most active subjects in the research of strongly correlated electron systems. Why is the  $\nu = 5/2$  fractional quantum Hall effect so interesting? For this, there are two reasons. One has something to do with the origin of the state itself. In order to generate pairing between composite fermions, an attractive force is necessary. But, is this possible? The original electron-electron interaction is completely repulsive so that, eventually, attraction between composite fermions must come from electronic repulsion itself. This is mind-boggling.

The other reason is actually much more closely related to the current craze in the  $\nu = 5/2$  FQHE research. As mentioned previously, our current understanding is that composite fermions are paired at  $\nu = 5/2$ . What is peculiar here is that pairing occurs between the same spin composite fermions, which is contrasted to the usual superconductivity where opposite spins are paired. For this reason, the lowest allowed angular-momentum channel for pairing is  $p$ -wave. In fact, according to a leading theory, the pairing symmetry is predicted to be  $p_x + ip_y$ .

The center piece of this theory is a proposition of a trial wave function called the Moore-Read Pfaffian state. The Moore-Read Pfaffian state is in essence the BCS wave function for composite fermions. To see this, let us remind ourselves of how to construct the composite fermion wave function at half filling:

$$\Psi_{\nu=1/2}^{CF} = P_{LLL} \prod_{j < k} (z_j - z_k)^{2p} \Psi_{B^*=0}^{CF}$$

where  $\Psi_{B^*=0}^{CF}$  is a trial wave function when the effective magnetic field,  $B^*$ , becomes zero. In the Moore-Read Pfaffian state,  $\Psi_{B^*=0}^{CF}$  is chosen to be the BCS wave function with  $p_x + ip_y$  pairing symmetry<sup>[7]</sup>.

Here is the place where an extraordinary thing happens. It has been known for some time that superconductors with  $p_x + ip_y$  pairing symmetry may have topologically stable vortex excitations which follow non-Abelian braiding statistics. What attracted people's attention was the fact that this could be in principle used for solid-state implementation of quantum computation. One nice advantage of this scheme over other quantum computation proposals is that the quantum bit (qubit) in this scheme is topologically stable so that it is immune to various decoherence mechanisms which are usually local. Implementing this idea in realistic solid-state systems is one of the most actively pursued goals in the field of quantum computation.

## Conclusion and open question

Since its discovery, the fractional quantum Hall effect has continued to generate a remarkable array of spectacular experiments and brilliant theoretical ideas, that witnessed potent effects of synergy as well as uncommon harmony. The  $\nu = 5/2$  fractional quantum Hall effect is the latest in this array. It is generally believed that this effect is caused by composite fermion pairing. Moreover, a leading current theory predicts that the pairing symmetry is  $p_x + ip_y$ . If this is indeed true, it would open up an exciting possibility of observing non-Abelian statistics in a solid-state environment.

At present, however, there are a number of logical jumps in the theory that are not fully verified. One such problem is associated with the Moore-Read Pfaffian wave function itself. It is known that the Moore-Read Pfaffian wave function has rather low overlaps of 70-80% with the exact ground states of the realistic Coulomb interaction, which are obtained from finite-system-size exact diagonalization studies containing about ten electrons. This is contrasted to the almost unity overlap of the composite fermion wave functions at other filling factors in similar-sized systems. Another related, but somewhat more disturbing problem is that the Moore-Read Pfaffian state is an exact ground state of a fictitious three-body interaction potential (that is not given here due to a lack of space). This is a serious problem since all physical interactions are two-body and it is unclear how relevant the three-body interaction would be. For these reasons, it is very important to investigate the role of the three-body interaction and the validity of the resulting Moore-Read Pfaffian wave function<sup>[8]</sup>.

At the end of the day, all these questions stem from arguably the most fundamental question of all: What is the pairing mechanism of composite fermions in the  $\nu = 5/2$  fractional quantum effect? This is the open question.

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# How to understand molecular motors

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Proteins are macromolecular machines that carry out vital functions in every living organism. The basic building block of a protein is a single polypeptide chain folded into a distinct structure that determines the function of the protein [1]. While protein functions considered to date have been mostly chemical (*i.e.*, proteins regarded as enzymes), developments in single molecule manipulation experiments in less than past two decades have highlighted different classes of *motor proteins*, that can convert chemical energy directly into mechanical work.

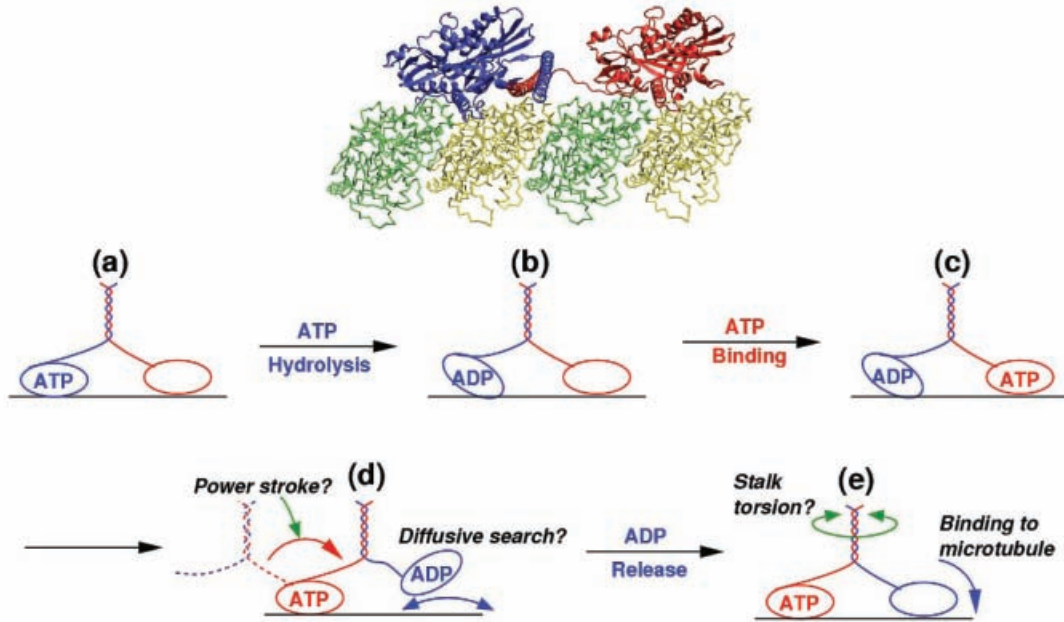
Many motor proteins move on biofilament tracks, for example, myosins walk on actin filament (for muscle contraction and intracellular transport), kinesins walk on microtubule (for intracellular transport and cell division), and a cohort of DNA or RNA-associated motors move along nucleotide chains (for polymerization, gene transcription from DNA to RNA, nucleotide digestion, DNA repair, *etc.*) [2]. On the other hand, the membrane-bound motor  $F_1$ -ATP synthase utilizes proton gradient across the membrane as energy source, to synthesize the energy currency of the cell,

adenosine triphosphate (ATP), with an amazing near 100% efficiency [3]. Note that motor proteins are not thermodynamic engines that couple two heat reservoirs at different temperatures. Instead, they work in the isothermal environment of the cell and convert chemical energy of fuel molecules (such as ATP) directly into mechanical work, which is dictated by the structure of the protein.

For translocating motors that walk along biofilament tracks, single molecule experiments employing optical traps have revealed much about their motile properties [4]. In a typical experimental setup, for kinesin as an example, the motor is linked to a microbead held by an optical trap and is brought near a microtubule filament affixed on the substrate [5]. When kinesin binds to the microtubule, it hydrolyzes ATP supplied from the surrounding solution into adenosine diphosphate (ADP), resulting in one ATP used per one 8-nm step of kinesin [6]. As the motor walks along the microtubule, microbead attached to its tail moves out of the focus of the optical trap, which exerts a restoring force to the bead. Thus, after the motor moves by a certain distance, it eventually stops walking and detaches from the microtubule when the *stall force* is reached. For conventional kinesin, the stall force is 5–7 pN [5]. In contrast to an optical trap, in a *force clamp* setup, a constant force is applied by a fast feedback loop as the motor walks, which allows more flexibility in manipulation and measurements [7].

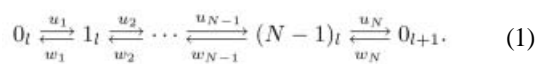
Typical data obtained from experiments are the bead position as a function of time (trajectory), force-velocity relation-

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**FIG. 1:** Model of kinesin motility. **Top:** Structural model of a dimer of conventional kinesin bound to a microtubule protofilament. The coiled-coil neck stalk joining the two motor heads is shown in a truncated form and is actually about 80-nm in length. The underlying microtubule subunits (green and yellow) have a periodicity of 8.3 nm, which determines the step size of kinesin. **Bottom:** Proposed mechanochemical cycle. Captions on the arrows are colored to represent events occurring on the motor head with the corresponding color. (a) The trailing head (blue) has a bound ATP and the leading head (red) is nucleotide-free. (b) Hydrolysis of ATP on the trailing head loosens its binding to the microtubule. (c) ATP binds to the leading head. This leads to the formation of the force-generating element, the cover-neck bundle [9], which generates a power stroke (c→d). (d) After the moving head (blue) moves forward, it searches for its next binding site on the microtubule, a process which is not well-understood. (e) When the moving head lands on the microtubule, ADP is released from it, completing one step. (a) and (e) differ by the colors of the motor heads in the leading and trailing positions. However, rotation of the neck stalk, or other unknown factors might be responsible for the asymmetric stepping behavior of kinesin [10].

ship, and the stall force. Such experiments have generated much interests in explaining the motile behavior on the theoretical side as well. As a background for modeling, the currently proposed mechanochemical cycle of kinesin is shown in Fig. 1. A salient feature of this cycle is the existence of *substeps* during one stepping event. However, substeps have not been observed to date, mainly due to the limited temporal resolution in experiments  $\sim 30 \mu\text{s}$  [11]. Yet, since these substeps involve domain motions to varying degrees, it is expected that some of these substeps will have stronger load-dependence than others, and many phenomenological models have been proposed to describe the mechanochemical cycle as a chemical reaction with multiple transition states [12–14]. Suppose that there are  $N$  sub-states in one mechanochemical cycle [15]:



Here,  $l$  is the step index, and  $\{0_l, 1_l \dots (N-1)_l\}$  are substeps within one stepping event. The forward and reverse transition rates  $u_i, w_i$  ( $1 \leq i \leq N$ ) depend on the energy landscape of the

motor making a step as well as solvent conditions such as the concentration of ATP or ADP. The energy landscape can be distorted by the applied force  $f$ , so  $u_i$  and  $w_i$  are functions of  $f$ .

Probably the simplest model that enjoyed popularity is the two-state ‘Boltzmann model,’ with one load-independent and one irreversible load-dependent transitions [16].



Here, irreversibility of the load-dependent step is an approximation based on the observation that the motor seldom makes backward steps. This is essentially Michaelis-Menten kinetics [17], and the force-velocity ( $f$ - $v$ ) relation is given by [16]

$$v(f) = \frac{v_{max}(1+A)}{1+A\exp(f\delta/k_B T)} \quad (3)$$

where  $v_{max}$  is the unloaded velocity given by  $v_{max} = \Delta / (\tau_1 + \tau_2)$ ,  $\Delta$ : step size,  $\tau_1$  and  $\tau_2$  are the times associated with load-independent (biochemical) and load-dependent (mechanical) transitions at zero load, respectively,  $A = \tau_2/\tau_1$ ,  $\delta$  is the effective distance over which the force acts,  $k_B$  is

Boltzmann's constant, and  $T$  is temperature [18]. Although useful in fitting  $f$ - $v$  curves, this model does not explain additional details about the motility data. For example, Eq. 3 predicts that for  $f < 0$  (assisting load),  $v$  increases. However, assisting load was found not to lead to an increase in velocity [5]. More sophisticated models have been proposed that consider different transition states during the hydrolysis cycle of ATP and their load-dependence [12, 19, 20]. These models better explain the dependence of the stall force or unloaded velocity on ATP concentrations, as well as variations in the shape of the  $f$ - $v$  curve. However, motor proteins continue to present surprises in their motility behavior. Taking kinesin as an example, it was found that kinesin responds anisotropically to sideways loads: a leftward load slows down kinesin more than a rightward load does, and overall, sideways loads are less effective in slowing down the motor compared to the rearward (opposing) load, suggesting that the reaction coordinate is aligned largely with the direction of motion [5]. Furthermore, a number of experiments have shown that kinesin walks with an asymmetric hand-over-hand mode, *i.e.*, even- and odd-numbered steps have different dwell times, suggesting that the motor 'limps' [10, 21]. Note that the motor limps although the conventional kinesin is a homodimer with identical motor domains stepping on the same location of the microtubule. Mechanistic origin for asymmetric walking mode by such a symmetric molecule remains a puzzle.

A key substep in the mechanochemical cycle is the force-producing or movement step where translocation in space actually occurs. In comparison to this 'walking step,' there can be 'biochemical' transitions without a net movement. For example, hydrolysis of an ATP molecule bound to the motor head to adenosine diphosphate (ADP) and a phosphate is a chemical reaction step without the center of mass movement of the motor. There have been two types of movement mechanisms considered, power stroke and Brownian ratchet (Ch. 8 in [2]). A power stroke can be considered as creation of a forward free energy gradient by chemical events such as binding of an ATP to the motor head so that the motor moves forward nearly deterministically. The Brownian ratchet mechanism, on the other hand, works by rectifying rapid thermal fluctuations. It is difficult to formally distinguish between the two mechanisms [22]. Yet, in situations describing actual motor proteins, it is convenient to have the distinction, as a non-robust but practical criterion to distinguish motor mechanisms. For a given motor, both power stroke and Brownian ratchet substeps can exist during the mechanochemical cycle [22].

It should be noted that, all kinetic models proposed so far essentially treat the motor protein as a black box, set up a certain number of transition states based on assumptions about the motor mechanism, and solve the corresponding differential equations. While such approaches have been effective in explaining (or fitting) the trajectory of the motor under various experimental conditions, it is impossible for these models to reveal the physical mechanism by which the motor moves, for example how force is generated. To elucidate the mechanism, it is necessary to study atomistic structures of the motor as shown in Fig. 1 and its conformational dynamics. In this regard, we have recently studied the motor head of kinesin by using molecular dynamics simulations and structural analysis, and we were able to find kinesin's force-generation mechanism [9]. The result was unexpected – rather than switching between well-defined conformations, force in kinesin is generated by dynamic folding of a mechanical element that we named the 'cover-neck bundle.' When kinesin makes a step, it folds the cover-neck bundle to generate a power stroke. If it is indeed the force-generating element, mutations to this domain that alter its folding kinetics and conformational properties will change force-generating capacity of the molecule. This has been recently shown by single-molecule experiments [18]. Such a dynamic nature of motor proteins is probably the reason why their force generation mechanism remains largely a mystery, although crystal structures of these motors are becoming increasingly available. By contrast, rate equation-based models cannot lead to mutant design or predict how the mutants behave. Yet, it would be extremely difficult for structural models to directly explain motility data. In the end, a multitude of approaches will have to be combined.

As structure-based computational analysis has begun to elucidate physical principles underlying the motor function [9], in a not too distant future, it will be possible to construct more robust physical models of motility based on specific structural events rather than driven by assumptions. Once our understanding of a motor protein reaches that level, then the motor might be recognized as a 'regular' protein rather than as a special class. However, since discoveries of previously unknown motility behaviors as well as new types of motor proteins keep adding challenging questions faster than they can be answered, there is a long road ahead for exploring these amazing mechanical systems.

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# Indian Association for the Cultivation of Science, Kolkata

Debashis Mukherjee



The main building of the IACS

Indian Association for the Cultivation of Science, established in 1876, is the oldest research institution in India. It was started as a part of the national freedom movement against the British colonial rule, voicing the expression and aspiration of the Indians to pursue modern science. It was established entirely by the donation of Indians without any patronage or financial help from the ruling British System. Its role in shaping Indian scientific environment is unarguably the most important of any other single institution. It is also unparalleled in any other colonized country in the history. Not only C. V. Raman did his pioneering

## *Professor Debashis Mukherjee*

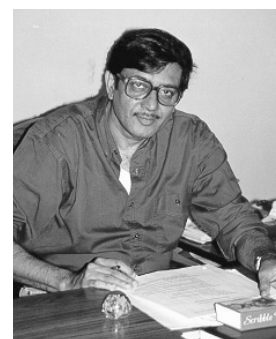
*Professor Debashis Mukherjee is the Chairman of the Raman Center for Atomic, Molecular and Optical Sciences at the Indian Association for the Cultivation of Science, Kolkata, India. He received many honors and accolades: Asutosh Mukherjee Prize, Shantiswarup Bhatnagar Prize, Jagdish Shankar Endowment Lectureship and Sadhan Basu Memorial Lectureship of Indian National Science Academy, and international awards like the Coulson Memorial Lectureship and the Fukui Medal. He is also a Fellow of all the Indian National Academies, and of the International Academy of Quantum Molecular Science, the Academy of Science of the developing World and of the Asia-Pacific Association for Theoretical and Computational Chemists.*

experiments at this institution, making this the only institution in India to have a Nobel Prize winning work in science, all famous physicists of India, such as S.N. Bose, M.N. Saha, Amal Raychaudhuri, Samar Biswas, K S Krishnan, K Banerjee, P C Datta and S R Palit were closely associated with IACS for many years.

Today, 132 years after its inception, IACS continues to adorn the mantle of academic and intellectual excellence in India and abroad and now stands at the crossroad of a critical era. Apart from fundamental researches in the various frontier areas of physics and chemistry, IACS has ventured in a significant way, for the past two decades, into multidisciplinary areas such as non-conventional energy sources, advanced and novel materials, and biology-inspired sciences. The institute consciously strives to consolidate in the fields it has long-established reputations, and at the same time looks forward to embed them to the burgeoning frontiers of the emerging areas.

An important intellectual component of research in IACS is the synergy of theoretical and experimental activity, and the cross-talk between the various areas. The core-competence of IACS includes such diverse fields such as Advanced Materials, Amorphous Silicon Cell Technology, Theoretical Physics, Theoretical Chemistry, Ultrafast Photodynamics, Biochemistry of Cancer Controlling Agents, Synthesis of Natural Products, Novel Inorganic materials, Bio-inorganic Chemistry and Metallo-organic Chemistry, to mention some theme areas.

At present, IACS represents the largest pool of scientific talents within a single research institution under the Department of Science and Technology. With close to 100 faculty members spread over Physics, Chemistry and Biology, it is rated as one of the best research institutions in India.



Prof. Debashis Mukherjee



It boasts the largest number of awards, honours and decorations for its faculty members among all other research institutions of its kind; for example, it has the largest number of members of various scientific academies within India and abroad, and boasts of an unusually high concentration of scientists with high citations and visibility through a higher rate of publications in top-most international journals.

The Institute has a dynamic academic program for training undergraduate to doctoral students and postdoctoral associates and has an attractive Visiting Scientists Scheme for senior researchers. IACS at present has more than 300 Ph.D. students and a large number of postdoctoral fellows. A large number of projects have been supported by different funding agencies such as CSIR, UGC, DAE, DNES, DST, DOS, DSIR, ICMR, INSA, IFCAR, Indo-NSF and Indo-EU.

IACS presently has eight departments (Materials Science, Solid State Physics, Spectroscopy, Theoretical Physics, Biological Chemistry, Inorganic Chemistry, Organic Chemistry and Physical Chemistry) and three Units (Polymer Science Unit, Energy Research Unit and MLS Professor<sup>o</sup>s Unit). To keep pace with demands of time, to diversify research activities and to consolidate its achievements and provide platforms where scientists can interact, exchange ideas and pursue research across formal boundaries of departments and units, three centers, viz. Centre

for Theoretical Sciences, Centre for Advanced Materials and Centre for Renewable Energy Sources were established. The Centre for Advanced Materials, with already a very impressive per-



The first spectroscope used by C.V. Raman.

formance record has largely succeeded in integrating a wide spectrum of research in materials science and condensed matter physics. The Centre for Theoretical Sciences has successfully put in place a vigorous visitors programme fostering interaction with scientists. To venture into the emerging fields of research in atomic, molecular and optical sciences, to intensify the strong and traditional base in the area and to have intense collaboration among different groups in the field, the Raman Center for Atomic Molecular and Optical Sciences has recently been formed at IACS.

Maintaining pace with the changing global scenario, IACS now has adopted a comprehensive technology development policy and is strengthening strategic alliances through industry-institute partnerships. It has started a Mission Programme for Technopreneurship to serve as an outreach organ of the institute in terms of technology development and transfer. It is mandated to inculcate innovation and knowledge-based entrepreneurship amongst the scientists and enable IACS position itself as an effective provider of technology products and techno-entrepreneurial outputs.



The statue of C.V. Raman.

With the vibrant dynamism, commitment to excellence and the drive to reach new heights in the scene of world science in general and in the Asia-Pacific region in particular, IACS is poised to play an even bigger role in contributing to the scientific leadership that epitomizes the charter of APCTP.

# From a Summer School Down Under

**Kyuyong Lee**

*Department of Physics, Pusan National University, Korea*

A Christmas tree and a bikini. It may sound like a strange combination, but probably not as much as complexity and simplicity together. What is it about? That's right: I am talking about a summer school being held (still going on) in Australia near the Christmas season? the 22nd Canberra International Summer School on Complex Physical, Biophysical, and Econophysical Systems. The school is organized and funded by the Australian National University (ANU) Centre for Complex Systems and the ARC Complex Open Systems Research Network (COSNet), and sponsored by APCTP.



As the title suggests, the topics covered in the school are diverse and yet, highly focused, including most complex systems that physicists are currently interested in: "Introduction to Complex Systems and Econophysics, Tomaso Aste (ANU, Australia)", "Fusion, Space and Solar Plasmas as Complex Systems, Richard Dendy (University of Warwick and UKAEA Culham Lab, UK)", "Inverse Problems in Earth Systems Science, Ian Enting (University of Melbourne, Australia)", "Maximum Entropy and Maximum Entropy Production Principles and their Application to Physics and Biology, Roderick Dewar (INRA Bordeaux/ ANU, France/Australia)", "Fractional Diffusion - Theory and Applications, Bruce Henry (University of New South Wales, Australia)", "Jaynes' MaxEnt, Riemannian Metrics and the Principle of

*Dr. Kyuyong Lee graduated from Korea University, Korea with B.S. in Physics in 1993. He earned M.S. in Physics at Louisiana Tech University, USA in 1998, Ph.D. in Physics at University of Maryland, USA in 2004. He was a Postdoctoral Fellow at Iowa State University, USA (2005~2006). Since then, he has been at Pusan National University, Korea as a Postdoctoral Fellow.*

Least Action, Robert Niven (University of New South Wales at Australian Defence Force Academy, Australia)", "Bayesian Data Analysis by Mike Wheatland", "Network Theory, Hawoong Jeong, (KAIST, Korea)", "Introduction to Dynamical Systems, Rowena Ball (ANU, Australia)", "Brain Dynamics, David Liley (Swinburne University of Technology, Australia)", "Chaotic Mixing, Guy Metcalfe (Commonwealth Scientific and Industrial Research Organisation, Australia)",

"Recent Approaches to Understanding Global Gene Expression, Rohan Williams (ANU, Australia)", "Fluid Turbulence, John Finnigan (Commonwealth Scientific and Industrial Research Organisation, Australia)" and "Modeling the 'Human-world' System in the Context of Climate Mitigation and Global Change, John Finnigan (Commonwealth Scientific and Industrial Research Organisation, Australia)".

The program is tight. The morning session consists of four one-hour-long lectures. An hour's lunch is followed by the afternoon session, a three-hour-long-computer-based tutorial on various subjects: "Introduction to the Analysis and Visualisation of Complex Data", "Matrix Decompositions for the Analysis and Visualisation of Complex Data", "Agent-based modeling with Netlogo", "Applications of Entropy Methods to Climate Models", "Dynamical Systems / Modeling and Analysis" and "Network Analysis with Pajek".





Sulleavans Creek in the ANU campus

The school attendees are also diverse in terms of their nationality - Australian, Malaysian, Chinese, Korean, etc. (surely it is an international school!), of their research fields - physics, mathematics, information technology, civil engineering, medical research, etc. (not to mention the various subfields!) and of their professions - undergraduates, graduates, post-docs, professors, etc. Meals and tea are shared under busy banter; a free exchange of ideas among attendees. In one evening, after listening to the public lecture “Exploring the Quantum Effects of Light” by Alain Aspect (CNRS, Institut d’Optique, France), people started to discuss the EPR paradox over the dinner. In another evening, my visit to Darwin Exhibition triggered the discussion on “simultaneous and independent discovery of a new theory”.

All the attendees seem to really enjoy the school. “Informative and stimulating!” exclaims Dandong Zheng from the University of Adelaide, Australia. Yacov Salomon, from the University of Melbourne, Australia, finds it “to the point, great combination of complex system approaches”. “A wide range of interesting topics and I enjoyed the social aspect” says Sacha van Albada from University of Sydney, Australia. “My brain hurts! I’ve never felt so small and stupid in my life!” an exasperated Waiho Wong from the University of Sydney, Australia, says in half-jest. Of course, the search for knowledge requires knowing what we do not yet know.

So far I’ve talked about the complexity based on the topics and the diversity of this school. Then, what is the aspect of simplicity? The simplicity that I envision lies in the environmental setup that the school provides. Canberra, the capital of Australia, is anything but complex. The ANU is in the heart of the city: calm, peaceful, and simple. Ursula Hall, the dormitory building where I stay, is right in front of a creek. A 10

minute walk along the creek leads to a beautiful lake called Lake Burley Griffin. Another 10 minute walk around the lake brings you to the National Museum of Australia. Professor Hyungtae Kook (Kyungwon University, Korea), the representative of APCTP, and I visited the Australian National Botanic Gardens, which is yet another 10 minute walk away toward the Black Mountain. Can you imagine the feeling that I steep myself in while I walk around the lake in a sunset after having myself exposed to the beauty of complexity, a scene worthy of poetry?

The school is only half way through. I may have a chance to write more about the second half if I survive this overwhelming experience. But I’m sure the guy from the University of Sydney will crack before I do.



## Scientific Activities (January ~ December 2008)

### - Conferences & Workshops

1. **The 24th Workshop on Numerical Relativity**  
APCTP Seoul Branch Office, Mar. 29
2. **APCTP Spring Meeting on The Spacetime Structure in General Relativity and Gravitation**  
Int'l Conference Hall, KISTI, Apr. 18 ~ 19
3. **Heavy Ion Meeting 2008-04**  
University of Seoul, Seoul, Apr. 19
4. **Mini-workshop on field theory**  
Academyhouse, Seoul, May 17 ~ 18
5. **Heavy Ion Meeting**  
APCTP Headquarters, Pohang, Nov. 14 ~ 16
6. **The 28th Workshop on Numerical Relativity**  
Inje Univ., Busan, Nov. 21 ~ 22
7. **The 1st for Emergent Material Research**  
APCTP Headquarters, Pohang, May 23~24
8. **The 32nd Johns Hopkins Workshop on Perspectives in String Theory**  
Seoul Nat'l Univ., Seoul, May 28~31
9. **The 25th Workshop on Numerical Relativity**  
APCTP Seoul Branch Office, Jun. 14
10. **Atomic and Molecular Physics workshop(AMP 2008)**  
Muju Resort, Jun. 19~20
11. **Nuclear Physics School 2008**  
Korea Univ., Seoul, Jun. 30~Jul. 4
12. **Heavy Ion Meeting**  
Pusan Nat'l Univ., Pusan, Jul. 11 ~ 12
13. **6th International Symposium on Intrinsic Josephson Effect and Plasma Oscillations in High-Tc Superconductors (Plasma 2008)**  
APCTP Headquarters, Pohang, Jul. 17~19
14. **2008 APCTP-KAIST Summer School for Brain Dynamics**  
KAIST, Daejeon, Jul. 17~18
15. **The 8th Summer Institute for Theoretical Physics**  
KIAS, Seoul, Aug. 4~15
16. **APCTP 2008 LHC Physics Workshop at Korea**  
Konkuk Univ., Seoul, Aug. 19~21



17. **The 30th International Free Electron Laser Conference**  
Hotel Hilton, Gyeongju, Aug. 24~29
18. **The 27th Workshop on Numerical Relativity**  
Daejon Convention Center, Daejon, Sep. 8
19. **Recent Developments in String M Theory**  
Int'l Conference Hall, KIAS, Sep. 22 ~ 26
20. **The Third IUPAP International Conference on Women in Physics**  
Sofitel Ambassador Hotel, Seoul, Oct. 8 ~ 10
21. **4th Asian conference on High pressure research (AHP)**  
Seoul Nat'l Univ., Oct. 14~17
22. **Gwangju String Theory Workshop**  
Hotel Mudeung Park, Gwangju, Oct. 24 ~ 26
23. **CosPA 2008 (International Symposium on Cosmology and Particle Astrophysics)**  
POSCO Int'l Center, POSTECH, Pohang, Oct. 29 ~ Nov.1
24. **The 18th Workshop on Nanoscale and Mesoscopic Systems**  
APCTP Headquarters, Pohang, Dec. 5 ~ 6
25. **1st APCTP WORKSHOP ON MULTIFERROICS**  
APCTP Headquarters, Pohang, Dec. 10 ~ 17
26. **2008 APCTP Astrophysics Winter school**  
Ewha Womans University, Seoul, Dec.15 ~ 16

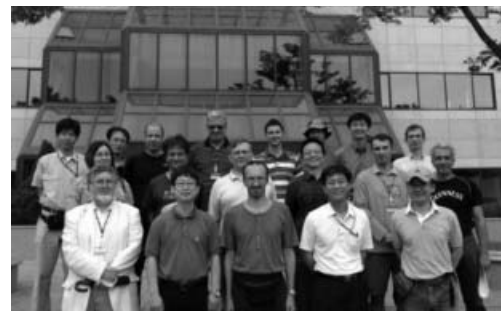
## - Winter Schools

1. **The 12th APCTP Winter Workshop on Strongly Correlated Electron Systems**  
APCTP Headquarters, Pohang, Jan. 20~26
2. **APCTP Winter School on Black Hole Astrophysics 2008**  
KASI, Daejeon / APCTP Headquarters, Pohang, Jan. 24~29
3. **5th APCTP-KIAS Winter School on Statistical Physics**  
Phoenix Park, Gangwondo, Jan. 28~31
4. **APCTP Field Theory Winter School 2008**  
APCTP Headquarters, Pohang, Feb. 18~22
5. **YongPyong Astro-Particle and Conformal Topical Physics (APCTP) 2008**  
YongPyong Ski Resort, Feb. 25~29



## - Focus Programs

1. **Quantum Effects in Non-trivial Background Fields**  
APCTP Headquarters, Pohang, Jan 6~15
2. **Finite-size technology in low dimensional quantum system (IV)**  
APCTP Headquarters, Pohang, Jun. 25~Jul. 15
3. **Unsolved theoretical problems in quantum transport of electrons**  
APCTP Headquarters, Pohang, Aug. 14~27
4. **Molecular Dynamics Simulations on Nano/micro Systems**  
APCTP Headquarters, Pohang, Aug. 4~12



## - External Activities

1. **14th Vietnam School of Physics(VSOP)**  
Quynhon Univ, Quynhon, Vietnam, Jan. 3~16
2. **2008 Taitung International School/Workshop on Cosmology and Gravitation (ISWCG)**  
Nat'l Taitung Univ., Taitung Taiwan, Jan.7~10
3. **21th Spring School on Particles & Fields (SS2008)**  
Hsinchu, Taiwan, Mar. 31~Apr. 3
4. **Fourth Asia Pacific Conference in Quantum Information Science**  
Cairns, Queensland, Australia, Jul. 2~5
5. **Summer Institute 2008**  
Chi-Tou, Taiwan, Aug. 10~17
6. **The 5th International Conference on Nonlinear Science "Dynamics Days Asia Pacific 5" (DDAP5)**  
Nara, Japan, Sep. 9~12
7. **What is Creativity?**  
**Emergent Phenomena in Complex Adaptive Systems**  
Co-op Inn Kyoto, Oct. 20~22
8. **The 11th Asian Workshop on First-Principles Electronic Structure Calculations**  
Nat'l Sun Yat-sen Univ., Taipei, Nov. 3~5
9. **22nd Canberra International Physics Summer School: Complex**  
Australian Nat'l Univ., Canberra, Australia, Dec. 9~18



## - Joint Activities

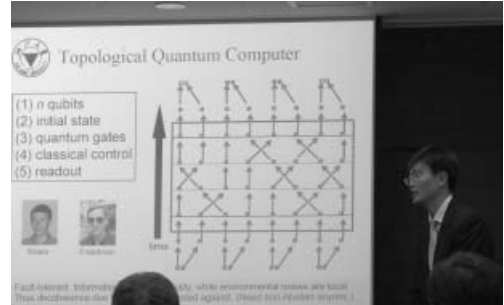
- 1. APCTP-YITP Workshop on “Accretion and Outflow in Astrophysics” and the second Korea-Japan Young Astronomers Meeting (KJYAM)**  
Honnouji Kaikan, Kyoto, Japan, Jan. 8~11
- 2. The 2nd Asian Winter School on String Theory**  
Hotel Village, Kusatsu-Machi, Agatsuma-Gun Gunma, Japan, Jan. 15~25
- 3. APCTP-BLTP JINR Joint Workshop on “Quarks and Mesons in Nuclear Physics”**  
APCTP Headquarters, Pohang, Korea, Apr. 20~24
- 4. Summer School on Particles, Fields and Strings**  
Univ. of British Columbia, Vancouver, Canada, Jul. 22~Aug. 1
- 5. “MPI-PKS and APCTP Int'l Workshop on Time-Resolved X-Ray Dynamics Summer School on Time-Resolved X-Ray Processes in Atoms, Molecules and Solids”**  
MPI-PKS Dresden, Germany, Jul. 28~Aug. 8
- 6. APCTP - ASEAN Workshop on Advanced Materials Science and Nanotechnology**  
Nha Trang, Vietnam, Sep. 15~21
- 7. APCTP-TPI-YITP Joint Workshop on Black Holes: Theoretical, Mathematical and Computational Aspects**  
Banff Int'l Research Station (BIRS), Banff, Alberta, Canada, Nov. 9~14



## Junior Research Group (June ~ December 2008)

### - Workshop

1. Discussion Group on Strongly Correlated Systems  
APCTP Headquarters, POSTECH, Pohang, August 14
2. Discussion Group on Quantum Non-Locality and Topological Quantum Computing  
APCTP Headquarters, POSTECH, Pohang, September 26
3. Discussion Group on Monolayer  
APCTP Headquarters, POSTECH, Pohang, October 16



### - Seminar

1. Molecular Dynamics Simulation of Water  
APCTP Headquarters, POSTECH, Pohang, Jun 9
2. Interferometric experiments on filling fraction  $5/2$  quantum Hall system  
APCTP Headquarters, POSTECH, Pohang, Jul 30
3. The  $5/2$  fractional quantum Hall effect and electron pairing via repulsive interaction  
APCTP Headquarters, POSTECH, Pohang, Oct 2
4. Disorder-induced Length Scales and Faster Scalable Algorithms  
APCTP Headquarters, POSTECH, Pohang, Oct 7
5. Dynamical Structure Factor and Spin-Density Separation for a Weakly Interacting Two-Component Bose Gas  
APCTP Headquarters, POSTECH, Pohang, Oct 9
6. Numerical Renormalization Group Calculations for the Bosonic Single-Impurity Anderson Model  
APCTP Headquarters, POSTECH, Pohang, Oct 17
7. Chiral spin states in the pyrochlore Heisenberg magnet  
APCTP Headquarters, POSTECH, Pohang, Nov 13
8. Interactions of nanoscale ferromagnetic granules in a London superconductor  
APCTP Headquarters, POSTECH, Pohang, Dec 16



## Asia Pacific Scientist Network Activities (January ~ December 2008)

### - Science Communication Forum/Lecture:

A small, intensive forum for communicating multi-disciplinary ideas between science and society at the Center.

1. The 1<sup>st</sup> Science Communication Forum/Lecture: Science Tour  
POSTECH, Pohang, Jan. 23~24
2. The 2<sup>nd</sup> Science Communication Forum/Lecture:  
J. Y. Gong (novelist)  
POSTECH Information Research Laboratories, Pohang, Jun. 13
3. The 3<sup>rd</sup> Science Communication Forum/Lecture: S. S. Choi  
APCTP Headquarters, Pohang, Jun. 25
4. The 4<sup>th</sup> Science Communication Forum/Lecture:  
Helena Norberg-Hodge(ecology scholar)  
APCTP Headquarters, Pohang, Oct. 27
5. The 5<sup>th</sup> Science Communication Forum/Lecture: Priest MAGA  
APCTP Headquarters, Pohang, Nov. 24



### - Science; Speaking through Books:

Popular science writers were invited to interact with readers, in particular, students in domestic library.

1. The 1<sup>st</sup> Science; Speaking through Books: Y. J. Cha  
Changwon Library, Changwon, May. 17
2. The 2<sup>nd</sup> Science; Speaking through Books: E. H. Lee  
Chuncheon Library, Chuncheon, Jun. 7
3. The 3<sup>rd</sup> Science; Speaking through Books: O. K. Kwon  
Pyeongtaek Library, Pyeongtaek, Jul. 12
4. The 4<sup>th</sup> Science; Speaking through Books: U. K. Tae  
Cheonan Library, Cheonan, Jul. 26
5. The 5<sup>th</sup> Science; Speaking through Books: K. M. Park  
Uiwang Library, Uiwang, Sep. 6
6. The 6<sup>th</sup> Science; Speaking through Books: J. M. Lee  
Cheongju Library, Cheongju, Sep. 26
7. The 7<sup>th</sup> Science; Speaking through Books: K. I. Bok  
Gumi Library, Gumi, Oct. 11
8. The 8<sup>th</sup> Science; Speaking through Books: Y. G. Gang  
Mokpo Library, Mokpo, Oct. 24

## - APCTP-POSTECH Distinguished Lectures:

Public lectures by Asia Pacific Scientists on the topics of physics and beyond jointly organized with POSTECH-APCTP.

1. The 1<sup>st</sup> APCTP-POSTECH Distinguished Lectures:  
**J. Michael Kosterlitz**  
 APCTP Headquarters, Pohang, Jun. 16
2. The 2<sup>nd</sup> APCTP-POSTECH Distinguished Lectures:  
**Sadamichi Maekawa**  
 APCTP Headquarters, Pohang, Aug. 25
3. The 3<sup>rd</sup> APCTP-POSTECH Distinguished Lectures: **Don N. Page**  
 APCTP Headquarters, Pohang, Oct. 29



## - Science Communication School:

The university students in science and engineering who had been selected on the applicants were trained as Science Communicators through science writing & debating programs at the Center.

1. Science Communication Winter School  
 APCTP Headquarters, Pohang, Feb. 14~16
2. Science Communication Summer School  
 APCTP Headquarters, Pohang, Aug. 12~14



## - Science in City Hall:

High Quality Science Contents combined with Science, Education, Art, and Experience

1. The 1<sup>st</sup> Science in City Hall: **Y. T. Lee(Nobel Laureate in Chemistry), W. G. Lee(Science Communicator)**  
 Pohang City Hall, Pohang, Mar. 29
2. The 2<sup>nd</sup> Science in City Hall: **S. Y. Lee(astronaut)**  
 Pohang City Hall, Pohang, Sep. 24



## - 'Best Science Book 10' Selected by APCTP:

The best science books were selected and promoted by APCTP for wide readership.

### 1. The Night of APCTP Network ('Best Science Book 10' Selected by APCTP)

Koreana Hotel, Seoul, Dec. 2



## - Other Events:

Promote the science awareness among public

### 1. The 5<sup>th</sup> Pohang Family Science-Festival 'Sanfrancisco Exploratorium in Pohang'

POSTECH Tennis stadium, Pohang, Sep. 19~21

### 2. Local Science Culture Festival:

Sol-bat open-air site, Pohang, Oct. 21



## - Science Book publication

### 1. Published the 2<sup>nd</sup> SF series of Crossroads :

- Title : "Absolute Body", October, 2008
- Author : 12 people

### 2. Published the 1<sup>st</sup> Essay series:

- Title : "The Science calls me", November, 2008
- Author : 30 people

