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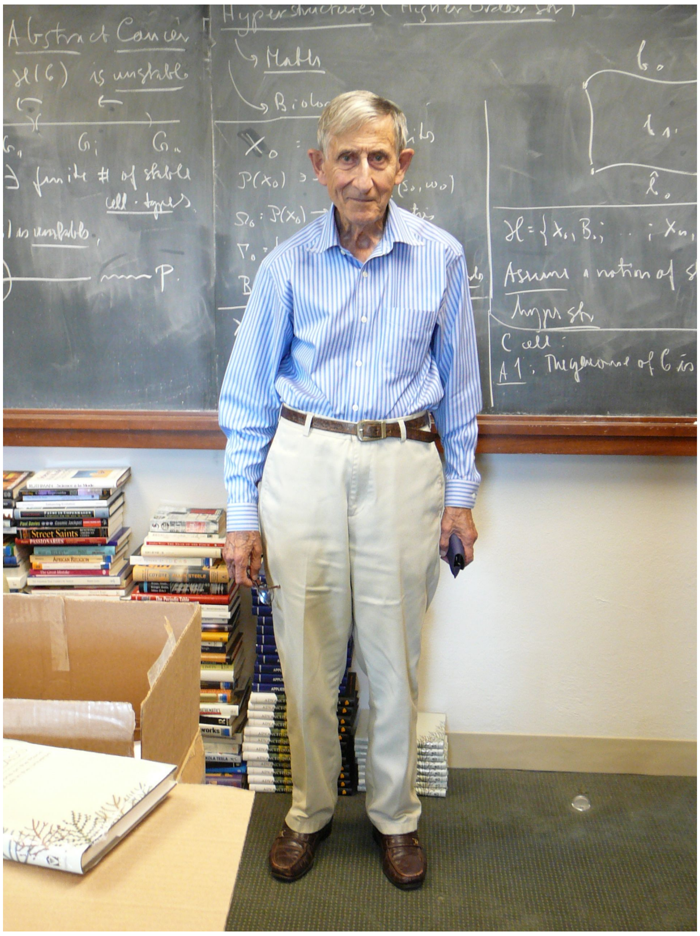

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Cover picture: Freeman Dyson

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From the Chief Editor

In this issue of IAMP News Bulletin we celebrate the 90th birthday of our colleague and tutor, a giant figure and elder of our community, *Freeman John Dyson*. His impact on the creation of Mathematical Physics as a discipline and his various outstanding achievements in this field have been an inspiration for generations of scientists.

To describe Freeman Dyson's personality and achievements, we publish below the Laudatio that Jürg Fröhlich presented on the occasion of awarding Freeman Dyson the Henri Poincaré Prize at the XVIIth International Congress on Mathematical Physics, Aalborg, 2012.

We also reproduce here (courtesy of the World Scientific) the lecture given by Freeman Dyson at the Conference in Honour of his 90th Birthday in Nanyang Technological University, Singapore 2013.

Valentin Zagrebnov (Chief Editor, IAMP News Bulletin)

Tribute to Freeman J. Dyson

Ladies and Gentlemen, colleagues and friends, dear Freeman,

when I was asked to prepare an appraisal of Freeman Dyson's scientific work for today's Prize ceremony my first reaction was to propose some colleagues who are more distinguished and more highly qualified for this job than I am. Unfortunately my proposals could not be accepted. My second reaction was one of considerable anxiety. *Who am I to dare appraise Dyson's work?* He is *the* leading mathematical physicist of the second half of the 20th Century. Back in the late sixties, when I was a student, my teachers Klaus Hepp and Res Jost admired him. Ever since, he has been a model not just for me, but for most of us in the mathematical physics community.

Finally I told myself that Dyson's outstanding accomplishments are so exceedingly well known, and that it is so obvious that he should receive – actually, should *have* received – this particular prize that my appraisal is essentially superfluous, and that it will not be a catastrophe if some small lapses may sneak into my presentation.

When I just started to enjoy studying somewhat voluminous sources of information on Freeman's life and work and had prepared the first thirty minutes of my speech, I was told that I actually had only *five* minutes to talk – at which point I developed acute feelings of panic.

I turned to "Google" for help, where I found out[1] that Freeman Dyson – and I quote – "is best known for his speculative work on the possibility of extraterrestrial civilizations," or "for his speculations on the philosophical implications of science and its political uses,"

[1] in addition to advertisements for the 'Dyson vacuum cleaner' and the 'Dyson airblade'

or that "he is not an unqualified believer in the predictions being made by the believers in global warming," or that he "has suggested a kind of metaphysics of mind" on three levels. Well, all this actually points to different compartments of Freeman's mind and thinking. But, today, we are most interested in the compartment of his creative thinking that relates to mathematical physics!

Let me recall a few basic biographical dates and facts.

Freeman John Dyson was born in Crowthorne, Berkshire, in the United Kingdom, on December 15, 1923. His father was the musician and composer Sir George Dyson, his mother, Mildred Lucy Atkey, was a lawyer and social worker. According to Dyson's own testimony, he became interested in mathematics and astronomy at the age of six. At the age of twelve, he won first place in a scholarship examination to Winchester College, an early indication of his extraordinary talent. In an after-dinner speech, Freeman once described his early education at Winchester. He said that the scope of the official curriculum at the College was limited to imparting basic skills in languages and mathematics; everything else was in the responsibility of the students. He took that responsibility seriously and went ahead to learn whatever he found interesting and important, including, for example, Russian, in order to be able to understand Vinogradov's '*Introduction to the Theory of Numbers*'. In 1941, Dyson won a scholarship to Trinity College in Cambridge. He studied physics with Dirac and Eddington and mathematics with Hardy, Littlewood and Besicovitch, the latter apparently having the strongest influence on his early development and scientific style. He published several excellent papers on problems in number theory, analysis and algebraic topology.

After finishing his undergraduate studies in mathematics, in 1945, and reading Heitler's '*Quantum Theory of Radiation*' and the Smyth Report on the Manhattan Project, Dyson came to the conclusion that – and I quote him – "physics would be a major stream of scientific progress, during the next 25 years," and he decided to trade pure mathematics for theoretical physics.

After having won a Commonwealth Fund Fellowship in 1947, Dyson applied to become a Ph.D. student of Hans Bethe at Cornell. It may be appropriate to ask why he decided to leave Cambridge, the place where the incomparable Dirac and where Eddington and Kemmer taught, and to move to America.

In an article entitled "*The Future of Science*", Dyson writes, and I quote: "Scientists come in two varieties, which Isaiah Berlin[2], [...], called 'foxes' and 'hedgehogs'. Foxes know many tricks, hedgehogs only one. Foxes are broad, while hedgehogs are deep. Foxes are interested in everything and move easily from one problem to another. Hedgehogs are interested in just a few problems that they consider fundamental and stick with the same problems for years or decades. [...] Some periods in the history of science are good times for hedgehogs, while other periods are good times for foxes. The beginning of the twentieth century was good for hedgehogs. [...] in the middle of the century, the foundations were firm and the universe was wide open for foxes to explore." Obviously,

[2]Incidentally, in his book, Berlin tells us many interesting things about Tolstoy's views of history that are surprisingly topical and worth thinking about.

Freeman Dyson is the archetypal 'fox', and the period in physics when he started to do research and scored his first great successes was *exactly right for foxes.* Freeman is so much a fox that he never got around completing his Ph.D.

At the time Dyson started his research career in theoretical physics, the foundations of quantum theory had been laid, but relativistic quantum field theory was in a messy state. The hedgehogs, notably Dirac and Heisenberg, who had created quantum theory, thought that yet another revolution was necessary to have quantum field theory superseded by a better theory. But Dyson, the fox, understood that what was necessary was to better understand the intricacies of the already existing theory and to proceed to doing concrete calculations explaining experimental data. He had learnt some quantum field theory from his friend Nicholas Kemmer and from Wentzel's book, entitled "Quantentheorie der Wellenfelder". Dyson writes: "It was my luck that I arrived with this gift from Europe just at the moment when the new precise experiments of Lamb and others ... required quantum field theory for their correct interpretation. When I used quantum field theory to calculate an experimental number, the Lamb shift [...], Bethe was impressed." Not only did Dyson play a seminal role in making quantum field theory useful for the theoretical interpretation of experimental facts, but he also distilled the right general concepts, in particular the *renormalization method*, that made it more than a miraculous machine spitting out numbers. Dyson's understanding of the relationship between Feynman's and Schwinger's approaches to QED and the general concepts he introduced made quantum field theory a systematic, even if mathematically incomplete, theory that keeps theorists busy till this day. Dyson was first in understanding the importance of scale separation in analyzing quantum field theoretic problems, an idea that later gave rise to the renormalization group. It is an early manifestation of Dyson's great intellectual generosity to have shared his understanding of quantum field theory with Bethe and Feynman and to have played a crucial role in explaining Feynman's approach to people like Oppenheimer and convincing them that it was useful, before it was published. Actually, Dyson went on to give further demonstrations of his generosity with his important input into the beginnings of general or axiomatic field theory.

Since Dyson is a 'fox', it is unimaginable that he would work in the same field for more than a year or so at a time. Indeed, right after his initial successes with QED (and with meson theory [3]), he moved on to work on problems in statistical mechanics and solid-state physics. Many of his contributions are, others ought to be, well known. Let me mention his work on disordered chains that set the stage for Anderson's discovery of localization, his "Citation Classic" on interacting spin waves, his incredibly original analysis of the ground-state energy of the hard sphere Bose gas, and his seminal work on one-dimensional long-range Ising ferromagnets, which played an important role in the development of the mathematics of renormalization group methods – besides playing some role in the scientific trajectories of Tom Spencer and myself.

In a Foreword to Freeman Dyson's '*Selected Papers*', Elliott Lieb writes, and I quote: "In the sixties, and even into the early seventies statistical mechanics was considered by the majority of physicists to be an uninteresting backwater. The situation today is quite

[3] Applications of the Tamm-Dankoff method

different, [...]. One of the people who changed all that was Freeman [...]. The beauty of [his] papers cannot be easily described without going into details but one can say that a paper by Dyson will contain the final word, arrived at in the most direct and elegant way. [...] Sometimes "final" means "two or three decades", which is the time scale needed to make a substantial improvement on a Dyson paper." Elliott then mentions the celebrated work by Dyson and Lenard on "*Stability of Matter*". He refers to Dyson's $N^{7/5}$ Law for bosons, which was proven only 21 years after Dyson had conjectured it.

Dyson has made numerous further contributions to mathematical and general theoretical physics, and to engineering. I want to mention his seminal work on "*Random Matrix Theory*", which – to show that Elliott has been too optimistic – has seen a strong renaissance, not twenty, but only *forty* years after it had been carried out by Dyson, and after he complained that it had little impact. (Of course, it had had impact, e.g., in number-theory, in the work of Montgomery on the zeros of the Riemann zeta function.) His works on "*The Search for Extraterrestrial Technology*" and on "*Artificial Stellar Sources of Infrared Radiation*" deserve to be mentioned, which – if we believe "Google" – are representative for what Freeman is most famous for. I should like to also draw attention to Dyson's work on more applied problems in science, e.g., concerning noise in active optical systems, interstellar communication, or biological problems, etc. Dyson is a 'fox'. He has not discovered a new physical theory. That is a job for hedgehogs. Let me quote Freeman himself to describe what *his job* in physics has been: "I define a pure mathematician to be somebody who creates mathematical ideas, and I define an applied mathematician to be somebody who uses existing mathematical ideas to solve problems. According to this definition, I was always an applied mathematician, whether I was solving problems in number-theory or in physics." I would like to add that Freeman is *the prime* model of a successful mathematical physicist; namely of somebody who knows the existing theories of physics and, with an unfailing instinct for the most important open questions and the most pressing concrete problems, goes ahead and elucidates them mathematically. He is a model in other respects, too: He never published every idea that crossed his mind; he has been generous to his colleagues; he has fought against trends converting the world of science into a jungle and has adhered to noble principles of intellectual honesty and integrity.

It is well known that Dyson has engaged in many other activities. One might mention his involvement with "General Atomic" (design of the TRIGA reactor, Project Orion), or his writing of books directed at a general readership. Who has never heard of "Disturbing the Universe", or of "Weapons and Hope", or of "Origins of Life", or of "Infinite in All Directions"? I am not closely familiar with these books, except for "Disturbing the Universe". But I believe they convey a strong impression of Freeman's infinite and infinitely charming intellectual curiosity.

I could easily spend the next 15 minutes reading a list of Prizes and honors Freeman has been awarded. Let me just mention a few:

- Dannie-Heineman Prize 1965
- Max-Planck Medal 1969
- Wolf Prize 1981
- National Books Critics Circle Award for Non-Fiction 1984
- Oersted Medal 1991
- Enrico Fermi Award
- Antonio Feltrinelli International Prize 1996
- Templeton Prize 2000

Etc. He has more than twenty honorary degrees, including one from ETH Zurich, and is a member of numerous learned societies and academies.

One of Freeman's predilections appears to be to think about the future of the planet and of mankind and to imagine all the new possibilities that may appear on the horizon. He is upholding a strong belief in the survival of our species and an infectious optimism in its potential, which I do not entirely share. My guess is that we will only save the future of the planet and of our species by not losing our past! For me, Freeman Dyson represents a better past in theoretical science, a scientific tradition that we are in some danger of losing. We should preserve and cherish it if we want theoretical science and, in particular, mathematical physics to survive!

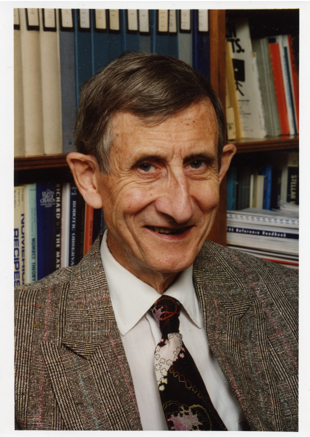
One might say that, today, the IAMP is honoring itself by bestowing this prize upon Freeman Dyson. It is my privilege and pleasure to congratulate him wholeheartedly in the name of the entire mathematical physics community and to wish him good health and continued pleasure and many further surprises in science.

THANK YOU!

Jürg Fröhlich (ETH Zürich)

Is A Graviton Detectable?

by Freeman Dyson (IAS, Princeton)



1 Introduction

I am enormously grateful to Dr. K. K. Phua, and to everyone else who had a hand in organizing this conference, for inviting me to visit Singapore. I am also grateful to my old and new friends who came to Singapore to help me celebrate my birthday. As a former Brit, I am delighted to see this sparkling new country, which has prospered by giving free play to Chinese enterprise while still driving on the left side of the road.

Now I come to the technical substance of my talk. It is generally agreed that a gravitational field exists, satisfying Einstein's equations of general relativity, and that gravitational waves traveling at the speed of light also exist. The observed orbital shrinkage of the double pulsar [1] provides direct evidence that the pulsar is emitting gravitational waves at the rate predicted by the theory. The LIGO experiment now in operation is designed to detect kilohertz gravitational waves from astronomical sources. Nobody doubts that gravitational waves are in principle detectable.

This talk is concerned with a different question, whether it is in principle possible to detect individual gravitons, or in other words, whether it is possible to detect the quantization of the gravitational field. The words "in principle" are ambiguous. The meaning of "in principle" depends on the rules of the game that we are playing. If we assert that detection of a graviton is in principle impossible, this may have three meanings. Meaning (a): We can prove a theorem asserting that detection of a graviton would contradict the laws of physics. Meaning (b): We have examined a class of possible graviton detectors and demonstrated that they cannot work. Meaning (c): We have examined a class of graviton detectors and demonstrated that they cannot work in the environment provided by the real universe. We do not claim to have answered the question of "in principle" detectability according to meaning (a). In Sec. 3 we look at detectors with the LIGO design, detecting gravitational waves by measuring their effects on the geometry of space–time, and conclude that they cannot detect gravitons according to meaning (b). In Secs. 4 and 5 we look at a different class of detectors, observing the interactions of gravitons with individual atoms, and conclude that they cannot detect gravitons according to meaning (c). In Secs. 6 and 7 we look at a third class of detectors, observing the coherent transitions between graviton and photon states induced by an extended classical magnetic field, and find that they also fail according to meaning (c).

In Sec. 2 we look at a historic argument used by Niels Bohr and Leon Rosenfeld to demonstrate the quantum behavior of the electromagnetic field, and explain why this argument does not apply to the gravitational field. In Sec. 8 we briefly examine the possibility of observing primordial gravitons at the beginning of the universe by measuring the polarization of the cosmic background radiation today. No definite conclusions are reached. This talk is a report of work in progress, not a finished product. It raises the question of the observability of gravitons but does not answer it. There is much work still to do.

2 The Bohr-Rosenfeld Argument

Before looking in detail at graviton detectors, I want to discuss a general theoretical question. In 1933 a famous paper by Niels Bohr and Leon Rosenfeld, [2] was published in the proceedings of the Danish Academy of Sciences with the title, “On the Question of the Measurability of the Electromagnetic Field Strengths.” An English translation by Bryce de Witt, dated 1960, is in the Institute library in Princeton, bound in an elegant hard cover. This paper was a historic display of Bohr’s way of thinking, expounded in long and convoluted German sentences. Rosenfeld was almost driven crazy, writing and rewriting 14 drafts before Bohr was finally satisfied with it. The paper demonstrates, by a careful and detailed study of imaginary experiments, that the electric and magnetic fields must be quantum fields with the commutation relations dictated by the theory of quantum electrodynamics. The field-strengths are assumed to be measured by observing the motion of massive objects carrying charges and currents with which the fields interact. The massive objects are subject to the rules of ordinary quantum mechanics which set limits to the accuracy of simultaneous measurement of positions and velocities of the objects. Bohr and Rosenfeld show that the quantum-mechanical limitation of measurement of the motion of the masses implies precisely the limitation of measurement of the field-strengths imposed by quantum electrodynamics. In other words, it is mathematically inconsistent to have a classical electromagnetic field interacting with a quantum-mechanical measuring apparatus.

A typical result of the Bohr–Rosenfeld analysis is their equation (58),

$$\Delta E_x(1)\Delta E_x(2) \sim \hbar|A(1,2) - A(2,1)|\,. \tag{1}$$

Here the left side is the product of the uncertainties of measurement of two averages of the x-component of the electric field, averaged over two space–time regions (1) and (2). On the right side, $A(1,2)$ is the double average over regions (1) and (2) of the retarded electric field produced in (2) by a unit dipole charge in (1). They deduce (1) from the standard Heisenberg uncertainty relation obeyed by the measuring apparatus. The result (1) is precisely the uncertainty relation implied by the commutation rules of quantum electrodynamics. Similar results are found for other components of the electric and magnetic fields.

The question that I am asking is whether the argument of Bohr and Rosenfeld applies also to the gravitational field. If the same argument applies, then the gravitational field must be a quantum field and its quantum nature is in principle observable. However, a close inspection of the Bohr–Rosenfeld argument reveals a crucial feature of their measurement apparatus that makes it inapplicable to gravitational fields. In the last paragraph of

Sec. 3 of the Bohr–Rosenfeld paper, they write: “In order to disturb the electromagnetic field to be measured as little as possible during the presence of the test body system, we shall imagine placed beside each electric or magnetic component particle another exactly oppositely charged neutralizing particle.” The neutralizing particles have the following function. Suppose we have a mass carrying a charge or current J whose movement is observed in order to measure the local electric or magnetic field. The movement of the charge or current J produces an additional electromagnetic field that interferes with the field that we are trying to measure. So we must compensate the additional field by adding a second mass, carrying the charge or current $-J$ and occupying the same volume as the first mass. The second mass is constrained by a system of mechanical linkages and springs to follow the movement of the first mass and cancels the fields generated by the first mass. This cancellation is an essential part of the Bohr–Rosenfeld strategy. It is then immediately obvious that the strategy fails for measurement of the gravitational field. The test-objects for measuring the gravitational field are masses rather than charges, and there exist no negative masses that could compensate the fields produced by positive masses.

The conclusion of this argument is that the Bohr–Rosenfeld analysis does not apply to the gravitational field. This does not mean that the gravitational field cannot be quantized. It means only that the quantization of the gravitational field is not a logical consequence of the quantum behavior of the measuring apparatus. The fact that the electromagnetic field must be quantized does not imply that the gravitational field must be quantized.

3 Can LIGO Detect a Graviton?

In the LIGO experiment, if it is successful, we shall detect a classical gravitational wave, not an individual quantum of gravity. A classical wave may be considered to be a coherent superposition of a large number of gravitons. LIGO is supposed to detect a wave with a strain amplitude f of the order of 10^{-21}. According to Landau and Lifshitz [3], page 370, the energy density of this wave is

$$E = \left(\frac{c^2}{32\pi G}\right)\omega^2 f^2 \,, \tag{2}$$

where G is Newton's constant of gravitation and ω is the angular frequency. For a wave with angular frequency 1 Kilohertz and amplitude 10^{-21}, Eq. (2) gives an energy density of roughly 10^{-10} ergs per cubic centimeter. A single graviton of a given angular frequency ω cannot be confined within a region with linear dimension smaller than the reduced wave-length (c/ω). Therefore the energy density of a single graviton of this frequency is at most equal to the energy of the graviton divided by the cube of its reduced wave-length, namely

$$E_s = \left(\frac{\hbar\omega^4}{c^3}\right). \tag{3}$$

For an angular frequency of 1 Kilohertz, the single graviton energy density is at most 3×10^{-47} ergs per cubic centimeter. So any gravitational wave detectable by LIGO must contain at least 3×10^{37} gravitons. This wave would be barely detectable by the existing LIGO. For a LIGO apparatus to detect a single graviton, its sensitivity would have to be improved by a factor of the order of 3×10^{37}. Even this vast improvement of sensitivity would probably not be sufficient, because the detection of weak signals is usually limited not only by the sensitivity of the apparatus but also by the presence of background noise. But to see whether detection of single gravitons is possible in principle, we disregard the problem of background noise and analyze the structure and operation of a super-sensitive LIGO detector.

For a rough estimate of the sensitivity of a LIGO apparatus required to detect a single graviton, we equate (2) with (3). This gives the strain f to be detected by the apparatus,

$$f = (32\pi)^{1/2}\left(\frac{L_p\omega}{c}\right), \tag{4}$$

where L_p is the Planck length

$$L_p = \left(\frac{G\hbar}{c^3}\right)^{1/2} = 1.4 \times 10^{-33}\ \mathrm{cm}\,. \tag{5}$$

The strain is derived from a measurement of the variation of distance between two mirrors separated by a distance D. The variation of the measured distance is equal to fD, so long as D does not exceed the reduced wave-length (c/ω) of the graviton. For optimum detectability we take D equal to (c/ω). Then the variation of distance is by (4)

$$\delta = (32\pi)^{1/2} L_p\,. \tag{6}$$

Up to a factor of order unity, the required precision of measurement of the separation between the two mirrors is equal to the Planck length, and is independent of the frequency of the graviton.

Is it possible in principle for a LIGO apparatus to measure distances between macroscopic objects to Planck-length accuracy? The following simple arguments give a negative answer to this question. First consider the case in which the objects are floating freely in space. The Heisenberg uncertainty relation between position and momentum of freely floating objects gives the lower bound

$$M\delta^2 \geq \hbar T \tag{7}$$

for the variation of distance δ, where M is the mass of each object and T is the duration of the measurement. Now T must be greater than the time (D/c) required to communicate between the two mirrors. If δ is equal to the Planck length, (5) and (7) imply

$$D \leq \left(\frac{GM}{c^2}\right). \tag{8}$$

So the separation between the two mirrors is less than the Schwarzschild radius of each of them, the negative gravitational potential pulling them together is greater than Mc^2, and they are bound to collapse into a black hole before the measurement can be completed.

We next consider the situation that arises when the two mirrors are clamped in position by a rigid structure. In this case the precision of measurement of the distance between the two mirrors is limited by quantum fluctuations of the rigid structure. We use a simple dimensional argument to estimate the magnitude of the fluctuations. Let s be the velocity of sound in the structure, let D be the separation between the mirrors, and let M be the mass of the structure. There will be at least one mode of sound-vibration of the structure which gives a displacement affecting the measurement of D. The mean-square quantum fluctuation amplitude of the displacement in this mode will then be, up to a factor of order unity, at least as large as the zero-point fluctuation,

$$\delta^2 \geq \left(\frac{\hbar D}{Ms}\right). \tag{9}$$

The duration of the measurement must be of the order of (D/c), the time it takes the graviton to travel through the apparatus. This duration is shorter than the period (D/s) of the sound-vibration, since s cannot exceed c. Therefore the uncertainty of the measurement is at least equal to the instantaneous vibration-amplitude δ. If the uncertainty is as small as the Planck length (5), then (9) implies

$$\left(\frac{GM}{c^2}\right) \geq \left(\frac{c}{s}\right) D > D\,. \tag{10}$$

Again we see that the separation between the two mirrors is smaller than the Schwarzschild radius of the apparatus, so that the negative gravitational potential of the apparatus is greater than Mc^2 and it will again collapse into a black hole. It appears that Nature conspires to forbid any measurement of distance with error smaller than the Planck length. And this prohibition implies that detection of single gravitons with an apparatus resembling LIGO is impossible.

It is clear from Eq. (3) that we have a better chance of detecting a single graviton if we raise the frequency into the optical range and use a different kind of detector. When the frequency is of the order of 10^{15} Hertz or higher, a single graviton can kick an electron out of an atom, and the electron can be detected by standard methods of atomic or particle physics. We are then dealing with the gravitoelectric effect, the gravitational analog of the photoelectric effect which Einstein used in 1905, [4] to infer the existence of quanta of the electromagnetic field, the quanta which were later called photons. The possibility of detecting individual gravitons in this way depends on two quantities, (a) the cross-section for interaction of a graviton with an atom, and (b) the intensity of possible natural or artificial sources of high-frequency gravitons. Most of this talk will be concerned with estimating these two quantities.

4 Graviton Detectors

The simplest kind of graviton detector is an electron in an atom, which we may approximate by considering the electron to be bound in a fixed potential. We choose coordinate axes so that the z-axis is the direction of propagation of a graviton. There are then two orthogonal modes of linear polarization for the graviton, one with the wave-amplitude proportional to xy, and the other with the amplitude proportional to $(x^2 - y^2)$. We choose the x and y-axes so that they make angles of 45 degrees to the plane of polarization of the graviton. Then the matrix element for the electron to absorb the graviton and move from its ground state a to another state b is proportional to the mass-quadrupole component,

$$D_{ab} = m \int \psi_b^* xy \psi_a \, d\tau \,, \tag{11}$$

where m is the electron mass. Equation (11) is the quadrupole approximation, which is valid so long as the wave-length of the graviton is large compared with the size of the atom. The total cross-section for absorption of the graviton by the electron is

$$\sigma(\omega) = \left(\frac{4\pi^2 G \omega^3}{c^3} \right) \sum_b |D_{ab}|^2 \delta(E_b - E_a - h\omega) \,, \tag{12}$$

where E_a and E_b are the energies of the initial and final states. It is convenient to consider a logarithmic average of the cross-section over all frequencies ω,

$$S_a = \int \sigma(\omega) d\omega / \omega \,. \tag{13}$$

Integration of (12) gives the sum-rule

$$S_a = 4\pi^2 L_p^2 Q \,, \tag{14}$$

where the Planck length L_p is given by (4), and

$$Q = \int \left| \left(\frac{x\partial}{\partial y} + \frac{y\partial}{\partial x} \right) \psi_a \right|^2 d\tau \tag{15}$$

is a numerical factor of order unity. It is remarkable that the average cross-section (14) is independent of the electron mass and of the nuclear charge. The same formula (14) holds for the absorption of a graviton by a neutron or proton bound in a nuclear potential.

For simplicity we assume that the electron is in a state with zero component of angular momentum about the z-axis, with a wave-function $f(s, z)$, where s is the distance from the z-axis. Then (15) becomes

$$Q = \left(\int s^3 [f']^2 ds \, dz \right) \Big/ \left(2 \int s [f]^2 ds \, dz \right) , \tag{16}$$

where f' means the partial derivative of f with respect to s. The inequality

$$\int s^3 \left[f' - \left(\frac{f}{s} \right) \right]^2 ds \, dz > 0 \tag{17}$$

implies that for any $f(s, z)$

$$Q > \frac{1}{2}\,. \tag{18}$$

On the other hand, if the electron is in an s-state

$$f(r) = r^{-n} \exp\left(-\frac{r}{R}\right), \tag{19}$$

where r is distance from the origin, then

$$Q = \left(\frac{4}{5}\right)\left[1 - \left(\frac{n}{6}\right)\right]. \tag{20}$$

From (18) and (20) it appears that for any tightly-bound s-state Q will be close to unity. The cross-section for absorption of a graviton by any kind of particle will be of the same magnitude

$$4\pi^2 L_p^2 = \frac{4\pi^2 G\hbar}{c^3} = 8 \times 10^{-65}\ \mathrm{cm}^2\,, \tag{21}$$

spread over a range of graviton energies extending from the binding-energy of the particle to a few times the binding-energy. For any macroscopic detector composed of ordinary matter, the absorption cross-section will be of the order of 10^{-41} square centimeters per gram.

5 Thermal Graviton Generators

We have a splendid natural generator of thermal gravitons with energies in the kilovolt range, producing far more gravitons than any artificial source. It is called the sun. Stephen Weinberg long ago calculated [5] the graviton luminosity of the sun, caused by gravitational bremsstrahlung in collisions of electrons and ions in the sun's core. A later calculation [6] corrected a mistake in Weinberg's paper but does not substantially change the result. For an electron–ion collision with energy E, the differential cross-section $p(\omega)$ for producing a graviton of energy $\hbar\omega$ is divergent at low energies, so that the total cross-section has no meaning. The physically meaningful quantity is the integral of the differential cross-section multiplied by the energy of the graviton,

$$\int p(\omega)\hbar\omega\, d\omega = \left(\frac{320}{9}\right) Z^2 \alpha^2 L_p^2 E\,, \tag{22}$$

where α is the electromagnetic fine-structure constant and Z is the charge of the ion. Including a similar contribution from electron–electron collisions, (22) gives a total graviton luminosity of the sun

$$L_g = 79\ \text{Megawatts}\,, \tag{23}$$

or about 10^{24} gravitons per second with energy in the kilovolt range. This gives a flux at the earth of

$$F_g = 4 \times 10^{-4} \text{ gravitons per cm}^2 \text{ per second}. \tag{24}$$

If we imagine the whole mass of the earth to be available as raw material for the manufacture of graviton detectors, with the cross-section (21) per electron and the flux (24), the counting-rate is 2.4×10^{-17} per second. If the experiment continues for the lifetime of the sun, which is 5 billion years, the expected total number of gravitons detected will be 4. The experiment barely succeeds, but in principle it can detect gravitons.

According to Gould, [6] there exist in the universe sources of thermal gravitons which are stronger than the sun, namely hot white dwarfs at the beginning of their lives, and hot neutron stars. Gould estimates the graviton luminosities of a typical white dwarf and a typical neutron star to be respectively 10^4 and 10^{10} times solar. Their luminosities are roughly proportional to their central densities. But the lifetimes during which the stars remain hot are shorter than the lifetime of the sun, being of the order of tens of millions of years for the white dwarf and tens of thousands of years for the neutron star. The lifetime output of gravitons will therefore be respectively 100 and 10^5 times solar. To stretch the theoretical possibilities of detection to the limit, we may suppose the detector to have mass equal to the sun and to be orbiting around the source of gravitons at a distance of 0.01 astronomical unit with an orbital period of 8 hours. Then the expected number of gravitons detected will be of the order of 10^{13} for the white dwarf and 10^{16} for the neutron star. The detection rate is roughly one per minute for the white dwarf and 3×10^4 per second for the neutron star. The conclusion of this calculation is that graviton detection is in principle possible, if we disregard the problem of discriminating the graviton signal from background noise.

The most important source of background noise is probably the neutrinos emitted by the sun or the white dwarf or the neutron star as the case may be. These neutrinos can mimic graviton absorption events by ejecting electrons from atoms as a result of neutrino–electron scattering. The neutrinos have higher energy than the gravitons, but only a small fraction of the neutrino energy may be transferred to the electron. From the sun, about 10^{14} neutrinos are emitted for each graviton, and the cross-section for neutrino–electron scattering is about 10^{20} times the cross-section for graviton absorption (see Ref. [7]). Therefore there will be about 10^{34} neutrino background events for each graviton absorption event.

For white-dwarfs and neutron-stars the ratio of background to signal is even larger, since neutrino production and scattering cross-sections increase with temperature more rapidly than graviton production and absorption cross-sections. Without performing detailed calculations, we can assert that for all thermal sources of gravitons the ratio of neutrino background to graviton signal will be of the order of 10^{34} or greater. In all cases, the total number of detected graviton events is vastly smaller than the square-root of the number of background events. The graviton signal will be swamped by the statistical scatter of the background noise.

Before jumping to conclusions about the detectability of gravitons, we must explore possible ways in which the neutrino background events might be excluded. The first possible way is to surround the detector with a shield thick enough to stop neutrinos but let gravitons pass. If the shield is made of matter of ordinary density, its thickness must be of the order 10^{10} kilometers, and its mass is so large that it will collapse into a black hole. The second possible way is to surround the graviton detector with neutrino detectors in anticoincidence, to catch the outgoing neutrino after each scattering event. This way fails for the same reason as the shield. The neutrino detectors would need to be at least as massive as the shield. The third possible way is to build a shield or a set of anticoincidence detectors out of some mythical material with superhigh density. The known laws of physics give us no clue as to how this might be done. We conclude that, if we are using known materials and known physical processes in a noisy universe, detection of thermal gravitons appears to be impossible.

6 Nonthermal Gravitons

It is possible to imagine various ways in which energetic objects such as pulsars may emit nonthermal gravitons of high energy. One such way is a process first identified by Gertsenshtein[8], the coherent mixing of photon and graviton states in the presence of an extended classical magnetic field. The graviton emission from various celestial objects resulting from the Gertsenshtein process was calculated by Papini and Valluri [9]. Some interestingly high graviton luminosities were predicted.

The Gertsenshtein process results from the interaction energy

$$\left(\frac{8\pi G}{c^4}\right) h_{ij} T_{ij} \, , \tag{25}$$

between the gravitational field h_{ij} and the energy–momentum tensor T_{ij} of the electromagnetic field. This interaction expresses the fact that electromagnetic fields have weight, just like other forms of energy. Now suppose that h_{ij} is the field of a graviton traveling in the z direction and

$$T_{ij} = \left(\frac{1}{4\pi}\right)(B_i + b_i)(B_j + b_j) \tag{26}$$

is the energy–momentum of the photon magnetic field b_i superimposed on a fixed classical magnetic field B_i. Then the interaction (25) contains the term

$$I = \left(\frac{4G}{c^4}\right) h_{xy} B_x b_y \, , \tag{27}$$

bilinear in the graviton and photon fields. The effect of this bilinear term is to mix the photon and graviton fields, so that a particle that is created as a photon may be transformed into a graviton and vice versa. There is an oscillation between graviton and photon states, just like the oscillation between neutrino states that causes neutrinos to change their flavors while traveling between the sun and the earth. If a photon travels a distance D though a uniform transverse magnetic field B, it will emerge as a graviton with probability

$$P = \sin^2\left(\frac{G^{1/2}BD}{2c^2}\right) = \sin^2\left(\frac{D}{L}\right), \tag{28}$$

with the mixing-length

$$L = \left(\frac{2c^2}{G^{1/2}B}\right) \tag{29}$$

independent of wave-length. In all practical situations, D will be small compared with L, so that

$$P = \left(\frac{GB^2D^2}{4c^4}\right). \tag{30}$$

The quadratic dependence of P on D makes this process interesting as a possible astrophysical source of gravitons. The numerical value of L according to (29) is roughly

$$L = \left(\frac{10^{25}}{B}\right), \tag{31}$$

when L is measured in centimeters and B in Gauss.

We may also consider the Gertsenshtein process as the basis of a graviton detector consisting of a hollow pipe of length D filled with a transverse magnetic field B. The tube must be accurately pointed at a putative source of gravitons in the sky. At the far end of the tube is a shield to block incident photons, and at the near end is a detector of photons resulting from the conversion of gravitons on their way through the tube. If D is one astronomical unit (10^{13} cm), then (30) gives

$$P = 10^{-24}B^2. \tag{32}$$

The field B must be very strong to obtain a reasonable rate of conversion of gravitons to photons. A detector with the same design has been used in a real experiment to detect axions that might be created by thermal processes in the core of the sun [10]. The axion field is supposed to interact with the electromagnetic field with an interaction energy similar to (27), but with a much larger coupling constant. The experimenters at CERN in Switzerland are using a surplus magnet from the Large Hadron Collider project as an axion-detector, pointing it at the sun and looking for kilovolt photons resulting from conversion of axions into photons. The length of the magnet is 9 meters and the magnetic field is 9×10^4 Gauss. They have not yet detected any axions.

The Gertsenshtein process does not require the classical magnetic field to be uniform. For a nonuniform field, the conversion of photons to gravitons still occurs with probability given by (28), if we replace the product BD by the integral of the transverse component of B along the trajectory of the photons. Likewise, the conversion will not be disturbed by a background gravitational field, even when the field is strong enough to curve the photon trajectory, because the gravitational field acts in the same way on photons and gravitons. In a curved space–time, the photons and the gravitons follow the same geodesic paths, and the photon and graviton waves remain coherent.

7 Nonlinear Electrodynamics

However, there is an important disturbing factor which was neglected in previous discussions of the Gertsenshtein process. The disturbing factor is the nonlinearity of the electromagnetic field caused by quantum fluctuations of electron–positron pairs in the vacuum [11, 12]. The fourth-order term in the electromagnetic field energy density is (Ref. [12], page 190),

$$\left(\frac{\alpha}{360\pi^2 H_c^2}\right)\left[(E^2 - H^2)^2 + 7(E \cdot H)^2\right], \tag{33}$$

where α is the fine-structure constant and

$$H_c = \left(\frac{m^2 c^3}{e\hbar}\right) = 5 \times 10^{13} \text{ Gauss} \tag{34}$$

is the critical magnetic field at which electron–positron pair fluctuations become noticeable.

When the field in (33) is divided into classical and photon components as in (26), there is a term quadratic in both the classical and photon fields,

$$\left(\frac{\alpha}{360\pi^2 H_c^2}\right)(4(B \cdot b)^2 + 7(B \cdot e)^2), \tag{35}$$

where b and e are the magnetic and electric fields of the photon. From (35) it follows that the photon velocity v is not equal to c but is reduced by a fraction

$$g = 1 - \left(\frac{v}{c}\right) = \left(\frac{k\alpha B^2}{360\pi^2 H_c^2}\right). \tag{36}$$

The coefficient k is equal to 4 or 7 for a photon polarized with its magnetic field or its electric field parallel to B. We consider the case $k = 4$, since that case is more favorable to the Gertsenshtein process. Since the graviton field is not affected by the nonlinear electromagnetic interaction (33), the graviton velocity is precisely c, and the photon and graviton waves will lose coherence after traveling for a distance

$$L_c = \left(\frac{c}{g\omega}\right) = \left(\frac{90\pi^2 c H_c^2}{\alpha B^2 \omega}\right) = \left(\frac{10^{43}}{B^2\omega}\right). \tag{37}$$

If the propagation distance D is larger than L_c, the Gertsenshtein process fails and the formula (30) for the photon–graviton conversion probability is incorrect. A necessary condition for the Gertsenshtein process to operate is

$$DB^2\omega \leq 10^{43}. \tag{38}$$

Furthermore, even when the Gertsenshtein process is operating, the probability of photon–graviton conversion according to (30) and (38) is

$$P \leq \left(\frac{10^{36}}{B^2\omega^2}\right). \tag{39}$$

We are interested in detecting astrophysical sources of gravitons with energies up to 100 kilovolts, which means frequencies up to 10^{20}. With $\omega = 10^{20}$, (38) and (39) become

$$D \leq \left(\frac{10^{23}}{B^2}\right), \quad P \leq \left(\frac{10^{-4}}{B^2}\right). \tag{40}$$

We consider two situations in which (40) has important consequences. First, with typical values for the magnetic field and linear dimension of a pulsar, $B = 10^{12}$ and $D = 10^6$, (40) shows that the Gertsenshtein process fails by a wide margin. The calculations of the graviton luminosity of pulsars in Ref. [9] assume that the Gertsenshtein process is producing high-energy gravitons. These calculations, and the high luminosities that they predict, are therefore incorrect. Second, in the hollow pipe graviton detector which we considered earlier, (40) shows that the Gertsenshtein process can operate with a modest field, $B = 10^5$ Gauss, and a pipe length $D = 10^{13}$ cm, but the probability of detection of each graviton traveling through the pipe is only 10^{-14}. If the field is made stronger, the length of the pipe must be shorter according to (40), and the probability of detecting a graviton becomes even smaller. The detector can work in principle, but fails for practical reasons in the real universe.

8 Conclusions

We have examined three possible kinds of graviton detector with increasingly uncertain results. First, the LIGO detector for low-energy gravitons, which we prove ineffective as a consequence of the laws of physics. Second, the gravitoelectric detector for kilovolt gravitons, which we prove ineffective as a consequence of the background noise caused by neutrino processes in the real universe. Third, the coherent graviton-conversion detector for high-energy gravitons, is ineffective only because of practical limits to the size of magnetic detectors. In addition to these three kinds of detector, there is a fourth kind which actually exists, the Planck space telescope, detecting polarization of the microwave background radiation. According to Alan Guth [13], the polarization of the background radiation in an inflationary universe could provide direct evidence of the existence of single gravitons in the primordial universe before inflation. The results of the Planck polarization measurements are not yet published, and it remains to be seen whether the observations are able to distinguish between primordial gravitons and other gravitational effects of primordial matter. The question, whether a detector of present-day microwave radiation is in principle able to detect primordial gravitons, remains open.

Many papers have been published, for example Eppley and Hannah [14] and Page and Geilker[15], claiming to demonstrate that the gravitational field must be quantized. What these papers demonstrate is that a particular theory with a classical gravitational field interacting with quantum-mechanical matter is inconsistent. Page and Geilker assume that the classical gravitational field is generated by the expectation value of the energy–momentum tensor of the matter in whichever quantum state the matter happens to be. They performed an ingenious experiment to verify that this assumption gives the wrong answer for a measurement of the gravitational field in a real situation.

In this talk I am not advocating any particular theory of a classical gravitational field existing in an otherwise quantum-mechanical world. I am raising three separate questions. I am asking whether either one of three theoretical hypotheses may be experimentally testable. One hypothesis is that gravity is a quantum field and gravitons exist as free particles. A second hypothesis is that gravity is a quantum field but gravitons exist only as confined particles, like quarks, hidden inside composite structures which we observe as classical gravitational fields. The third hypothesis is that gravity is a statistical concept like entropy or temperature, only defined for gravitational effects of matter in bulk and not for effects of individual elementary particles. If the third hypothesis is true, then the gravitational field is not a local field like the electromagnetic field. The third hypothesis implies that the gravitational field at a point in space–time does not exist, either as a classical or as a quantum field.

I conclude that the first hypothesis may be experimentally testable, but the second and third may not. Analysis of the properties of graviton-detectors, following the methods of this paper, cannot distinguish between the second and third hypotheses. Three outcomes are logically possible. If a graviton detector is possible and succeeds in detecting gravitons, then the first hypothesis is true. If graviton detectors are possible and fail to detect gravitons, then the first hypothesis is false and the second and third are open. If a graviton detector is in principle impossible, then all three hypotheses remain open. Even if their existence is not experimentally testable, gravitons may still exist.

The conclusion of the analysis is that we are still a long way from settling the question whether gravitons exist. But the question whether gravitons are in principle detectable is also interesting and may be easier to decide.

In conclusion, I wish to thank Tony Rothman and Steven Boughn, [16] for helpful conversations and for sharing their thoughts with me before their paper was published.

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This article is based on an invited talk given at the Conference in Honour of the 90th Birthday of Freeman Dyson, Institute of Advanced Studies, Nanyang Technological University, Singapore, 26–29 August 2013. It is a reprint of *Is a graviton detectable?* by Freeman Dyson, Int.J.Mod.Phys.A28, 1330041 (2013),

We thank World Scientific for the permission to reprint it here.

Call for nominations for the 2015 Henri Poincaré Prize

The Henri Poincaré Prize, sponsored by the Daniel Iagolnitzer Foundation, was created in 1997 to recognize outstanding contributions in mathematical physics, and contributions which lay the groundwork for novel developments in this broad field. The prize is also created to recognize and support young people of exceptional promise who have already made outstanding contributions to the field of mathematical physics. The prize is awarded every three years at the International Congress of Mathematical Physics (ICMP), and in each case is awarded usually to three individuals.

The prize winners are chosen by the Executive Committee of the IAMP upon recommendations given by a special Prize Committee. The Executive Committee has made every effort to appoint to the prize committee prominent members of our community that are representative of the various fields it contains. However, to be able to do its job properly the Prize Committee needs input from the members of IAMP. For this purpose the Executive Committee calls IAMP members to provide nominations for the Henri Poincaré Prize to be awarded at ICMP 2015 at Santiago, Chile.

A proper nomination should include the following:

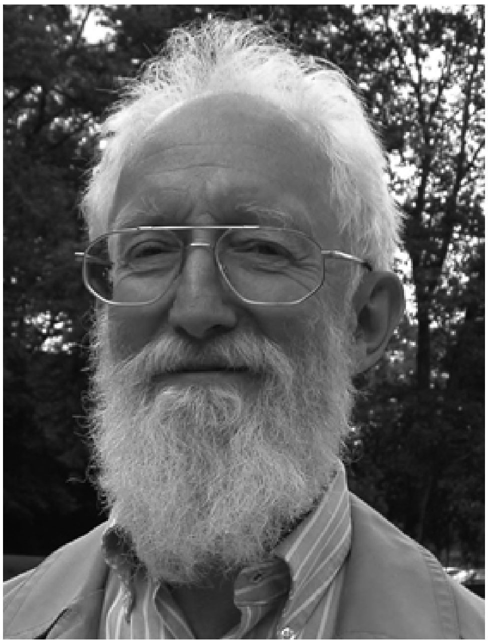
- Description of the scientific work of the nominee emphasizing their key contributions.
- A recent C.V. of the nominee.
- A proposed citation, should the nominee be selected for an award.

Please keep the length of your nomination within a page and submit it to the President (president@iamp.org) or the Secretary (secretary@iamp.org). A list of previous winners can be found at: http://www.iamp.org.

To ensure full consideration please submit your nominations by **September 30, 2014**.

Oscar E Lanford III

(January 6, 1940 – November 16, 2013)



Oscar Lanford passed away on November 16, 2013, after a battle with cancer, at the age of 74 years. With him, the community of mathematical physics, and of mathematics, loses a scientist of very high standards who gratified us with interesting and important results.

Oscar was born in New York, got an undergraduate degree from Wesleyan University (which gave him later an honorary PhD degree) and graduated with a PhD in quantum field theory under the direction of Arthur Wightman. He soon became professor at UC Berkeley, then at the IHES in France, and was since 1987 professor at the ETH in Zürich, where he retired in 2005. He continued teaching at the Courant Institute until 2012.

His papers, not numerous by today's standards, contain several gems which have influenced directions that mathematical physics would take. The Boltzmann equation, a computer assisted proof of the Feigenbaum conjectures, the Dobrushin-Lanford-Ruelle equations, just to name the (probably) most prominent among them. They will certainly continue to be of importance for the study of many questions in mathematical physics.

Highlights of Lanford's research

- Consider statistical mechanics on a lattice Z^d. It is natural to define *equilibrium states* as probability measures invariant under translations, and satisfying a variational principle. One can also consider states such that in any finite region they are in equilibrium with the outside of the region: these are the *Gibbs states*, defined by the so-called DLR equations. It turns out that equilibrium states are just the same thing as translationally invariant Gibbs states. We have thus equivalence of a global and a local definition.

- The Feigenbaum equation is a functional equation which plays an important role in chaos theory. The existence of a solution is a highly nontrivial problem, first solved rigorously by Oscar Lanford. He used a computer-aided proof, where difficult inequalities are proved using *interval arithmetic* and a computer. This work launched a whole new field of research.

- The Boltzmann equation is an approximate description of a gas of colliding particles. In a suitable limit (Grad limit) two particles that collide will never touch again, and the Boltzmann equation is then rigorous. In this situation, Oscar Lanford proved the existence of a solution for a finite time. During this finite time, there is actually a nonzero increase of entropy! This may be Lanford's most spectacular result. It is and will remain of fundamental importance for our understanding of non-equilibrium physics.

Oscar was a modest, somewhat shy person, and perhaps only those who were closer to him could fathom the inner workings of his personality. Then, a warm person would shine through, always curious about new things, and wanting to understand them from scratch, and on his own terms. Those who knew him in the beginnings of serious electronic computing will remember his enthusiasm when the first (trans-)portable computers appeared. He would immediately learn the standards of numerical computations, dig into computers to understand their inner workings—and in the end, this would allow him to define the field of computer-assisted proofs, of which he gave a brilliant example by proving Feigenbaum's conjecture, as explained above. This example just shows the typical working method of Oscar, which he applied with success to his other famous papers: Go to the bottom of a problem, find its elementary pieces, and then construct a solution from the bottom up.

This same method also made him an excellent teacher, especially at longer summer schools, such as Les Houches (1981) or at Battelle (1971), which are still a very good read. The care and detail of the exposition are simply impressive and set standards that may be somewhat forgotten these days. These standards are also the reason that much of his work never made it into print, just into “drafts”, which the more lucky among us got to read for inspiration

Apart from the science, there is of course the person, whom both of us, the elder and the younger, learned to appreciate over the years. Picnics, discussions on literature, family, are some of the memories we shall keep of him. We will miss him, and keep a fond memory of his exemplary standards, as well as his continuous friendship and help. We hope that our appreciation of having known him will serve as a consolation for his wife Regina and their daughter.

Jean-Pierre Eckmann and David Ruelle

News from the IAMP Executive Committee

New individual members

IAMP welcomes the following new members

1. Prof. Michael Bishop, Department of Mathematics, University of California at Davis, USA

2. Dr. Sébastien Breteaux, Institut für Analysis und Algebra, Technische Universität Braunschweig, Germany.

Recent conference announcements

50^{th} Karpacz Winter School on Theoretical Physics

March 2-9, 2014, Karpacz, Poland

organized by
Institute of Theoretical Physics, University of Wroclaw
Institute of Low Temperature and Structure Research, Polish Academy of Sciences

Web page http://conferences.ift.uni.wroc.pl/conferenceDisplay.py?confId=0

11^{th} German Probability and Statistics Days (Stochastik-Tage 2014)

March 4-7, 2014, Universität Ulm, Ulm, Germany

Programme Committee
Nicole Bäuerle, Achim Klenke, Michael Neumann, Rene Schilling, Volker Schmidt, Evgeny Spodarev, Ulrich Stadtmüller, Robert Stelzer

Web page http://gpsd-ulm2014.de/home.html

Nonequilibrium Problems in Physics and Mathematics

June 1-6, 2014, Centro Stefano Franscini, Monte Verita, Ascona, Switzerland

organized by
Jean-Pierre Eckmann and Antti Kupiainen

Web page http://theory.physics.unige.ch/NPPM/

Spectral Days 2014

June 9-13, 2014, CIRM Marseille, France

Web page http://www.cirm.univ-mrs.fr/index.html/spip.php?rubrique2&EX=info_rencontre&annee=2014&id_renc=1041&lang=fr

organized by
Simone Warzel, Jean-Marie Barbaroux, François Germinet, Alain Joye.

This conference is partially funded by the IAMP.

Solid Math 2014

June 16-18, 2014, SISSA (Trieste)

Web page https://sites.google.com/site/solidmath2014/home

organized by
Gianfausto Dell'Antonio, Alessandro Giuliani, Domenico Monaco, Gianluca Panati

This conference is partially funded by the IAMP.

NSF/CBMS Regional Conference on Quantum Spin Systems

June 16-20, 2014, University of Alabama at Birmingham, USA.

The distinguished lecturer will be Bruno Nachtergaele (UC Davis), who will give 10 lectures accessible to newcomers to the field of quantum spin systems, but leading to advanced topics and open problems. The program also includes additional lectures by other experts in the field.

organized by Shannon Starr, Paul Jung, Gunter Stolz

Web page http://www.uab.edu/cas/mathematics/events/nsf-cbms-conference-2014

Mathematics Meets Physics

June 24-27, 2014, Helsinki, Finland

A four day conference exploring the frontiers of mathematical physics on the occasion of Antti Kupiainen's 60th birthday.

The aim of the conference is to foster the exchange of recent breakthroughs, new ideas and advances in methodology by bringing together world-leading experts, ranging the full spectrum from pure mathematics to physics.

Web page http://wiki.helsinki.fi/display/mathphys/mathphys2014

Quantum Roundabout

Student conference on the mathematical foundations of quantum physics

June 29-July 3, 3014, University of Nottingham, UK

Web page http://quantumroundabout.weebly.com

organized by Gerardo Adesso, Thomas Bromley, Ioannis Kogias

This conference is partially funded by the IAMP.

XXX$^{\text{th}}$ International Colloquium on Group Theoretical Methods in Physics

July 14-19, 2014, Ghent University, Ghent, Belgium

Web page http://www.group30.ugent.be

organized by
Joris van der Jeugt, Jean-Pierre Antoine, Francoise Bastin, Pierre Bieliavsky, Fred Brackx, Stefaan Caenepeel, Frans Cantrijn, Hennie De Schepper, Simone Gutt, Marc Henneaux, Erik Koelink, Piet Van Isacker, Pierre Van Moerbeke

This conference is partially funded by the IAMP.

Summer School on Mathematical Physics

July 21-26, 2014, Universität Heidelberg, Germany

Web page http://www.thphys.uni-heidelberg.de/summerschool2014

organized by
Christoph Kopper and Manfred Salmhofer

This summer school is partially funded by the IAMP.

99 years of General Relativity: The ESI-EMS-IAMP Summer school on Mathematical Relativity

July 28-August 1, 2014, The Erwin Schrödinger Institute for Mathematical Physics, University of Vienna, Austria

Web page http://homepage.univie.ac.at/piotr.chrusciel/SummerSchool2014/

organized by
Robert Beig and Piotr T. Chruściel.

This summer school is partially funded by the IAMP.

Trimester program on Non-commutative Geometry and its Applications

September-December, 2014, Hausdorff-Institut für Mathematik, Bonn, Germany

organized by
Alan L. Carey, Victor Gayral, Matthias Lesch, Walter van Suijlekom, Raimar Wulkenhaar

Web page http://www.him.uni-bonn.de/programs/future-programs/future-trimester-programs/non-commutative-geometry-2014/description

Selected Problems in Mathematical Physics

September 1-5, 2014, La Spezia, Italy

organized by
Riccardo Adami, Michele Correggi, Rodolfo Figari, Alessandro Giuliani

Web page http://sp2014.tqms.it/index.html

This conference is partially funded by the IAMP.

Open positions

Postdoctoral Position in Mathematical Physics at TUM

A postdoctoral position in Mathematical Physics will be available on March 1, 2014 at the Technical University of Munich. The exact starting point (after the above date) is negotiable. The appointment is for 2 years with the possibility of extension by one year. This position is a part of the project 'Asymptotic Completeness in QFT', which will be coordinated by Wojciech Dybalski. The project is funded by the Emmy-Noether Programme of the DFG.

The successful candidate should have a respectable research record in one or more of the following topics: quantum field theory (relativistic and/or non-relativistic), spectral and scattering theory of quantum systems, operator algebras with applications in physics. He/She will work on scattering theory of quantum systems including the question of complete particle interpretation and/or infrared problems. Transfer of methods between relativistic and non-relativistic QFT belongs to the scope of the project.

The application should contain: (i) Letter of motivation. (ii) CV. (iii) List of publications. (iv) Contact information of 2 referees.

Applications should be sent to Wojciech Dybalski, dybalski@ma.tum.de, before March 1, 2014.

PhD Position in Mathematical Physics at TUM

A PhD position in Mathematical Physics will be available on March 1, 2014 at the Technical University of Munich. The exact starting point (after the above date) is negotiable.

The appointment is for 3 years, and the salary is based on 75% of the standard work week. This position is a part of the project 'Asymptotic Completeness in QFT', which will be coordinated by Wojciech Dybalski. The project is funded by the Emmy-Noether Programme of the DFG.

The successful candidate should have interest in and basic knowledge of quantum mechanics and analysis. Research experience in one or more of the following fields is of advantage: quantum field theory (relativistic or non-relativistic), spectral and scattering theory of quantum systems, operator algebras with applications in physics. He/She will work on scattering theory of quantum systems with focus on infrared problems.

The application should contain: (i) Letter of motivation. (ii) CV. (iii) List of publications (if applicable). (iv) Contact information of 1 referee. (v) Transcript of academic records.

Applications should be sent to Wojciech Dybalski, dybalski@ma.tum.de, before March 1, 2014.

Professorship in Mathematical Physics at ETH Zurich

The Department of Mathematics at ETH Zurich invites applications for a full professor position in Mathematics with a focus in Mathematical Physics. We are seeking candidates with an outstanding research record and a proven ability to direct research work of high quality. Willingness to participate in collaborative work both within and outside the school is expected. Furthermore, the new professor will be responsible, together with other members of Department, for teaching undergraduate (German or English) and graduate courses (English) for students of mathematics, natural sciences and engineering. Please apply online at http://www.facultyaffairs.ethz.ch. Applications should include a curriculum vitae, a list of publications, and a statement of your future research and teaching interests. The letter of application should be addressed to the President of ETH Zurich, Prof. Dr. Ralph Eichler.

The closing date for applications is 30 April 2014.

Professorship in Mathematical Physics at University of Vienna

The Faculty of Physics of the University of Vienna announces the position of a

Full Professor of Mathematical Physics

(full time, permanent position under private law). We are searching for a researcher with high international standing in theoretical physics, with a particular emphasis on mathematical physics, a person with a record of research funding who participates in the teaching and supervision of students at all levels. The successful candidate should establish (and lead) a research group at the Faculty of Physics. A thematic overlap in the research interests of the successful candidate and other members of our faculty is welcome.

The field of mathematical physics has a long tradition in Vienna and belongs to one of the Faculty's research focus areas. The University of Vienna has become a particularly attractive place for theoretical and mathematical physics through its close interconnection to the *Erwin Schrödinger Institute for Mathematical Physics*, which is operated at the interface between the Faculty of Mathematics and the Faculty of Physics.

Successful candidates will have the following qualifications:

- PhD and post-doctoral experience at a university or other research institution (Austrian or equivalent international academic degree in the relevant field).
- Outstanding research and publication record, with an excellent reputation as an active member in the international academic community (Habilitation (venia docendi) or equivalent international qualification in the relevant field is desirable).
- Experience in designing, procuring and directing major research projects, and willingness and ability to assume the responsibility of team leadership.
- Experience in university teaching, and willingness and ability to teach at all curricular levels, to supervise theses, and to further the work of junior academic colleagues.

The University of Vienna expects the successful candidate to acquire, within three years, proficiency in German sufficient for teaching in Bachelor programmes and participation in committees.

The University of Vienna offers attractive terms and conditions of employment with a negotiable and performance-related salary, associated with a retirement fund, a "start-up package" for the initiation of research projects, an attractive and dynamic research location in a city with a high quality of life and in a country with excellent research funding provision, and support for relocation to Vienna, where appropriate.

Candidates should send an application containing at least the following documents:

- Academic curriculum vitae
- Brief description of current research interests and research plans for the immediate future
- List of publications together with

  (a) specification of five key publications judged by the applicant to be particularly relevant to the advertised professorship together with an explanation of their relevance

  (b) PDF versions of these five publications provided either as email attachments or through URLs of downloadable copies

- List of talks given, including detailed information about invited plenaries at international conferences
- List of projects supported by third-party funds
- Short survey of previous academic teaching and list of supervised PhD theses

University professors will be classified according to the Collective Bargaining Agreement for University Staff into the salary group A1. The salary will be individually negotiated under consideration of the previous career development and, in case of an appointment from abroad, of the different tax situation.

Applications in English should be submitted per e-mail (preferably as PDF attachments) to the Dean of the Faculty of Physics, Univ.-Prof. Dr. Markus Arndt, Boltzmanngasse 5, 1090 Vienna, (dekanat.physik@univie.ac.at) no later than March 31st, 2014, with reference 5e-20/14.

More job announcements are on the job announcement page of the IAMP

`http://www.iamp.org/page.php?page=page_positions`

which gets updated whenever new announcements come in.

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