JiAPS

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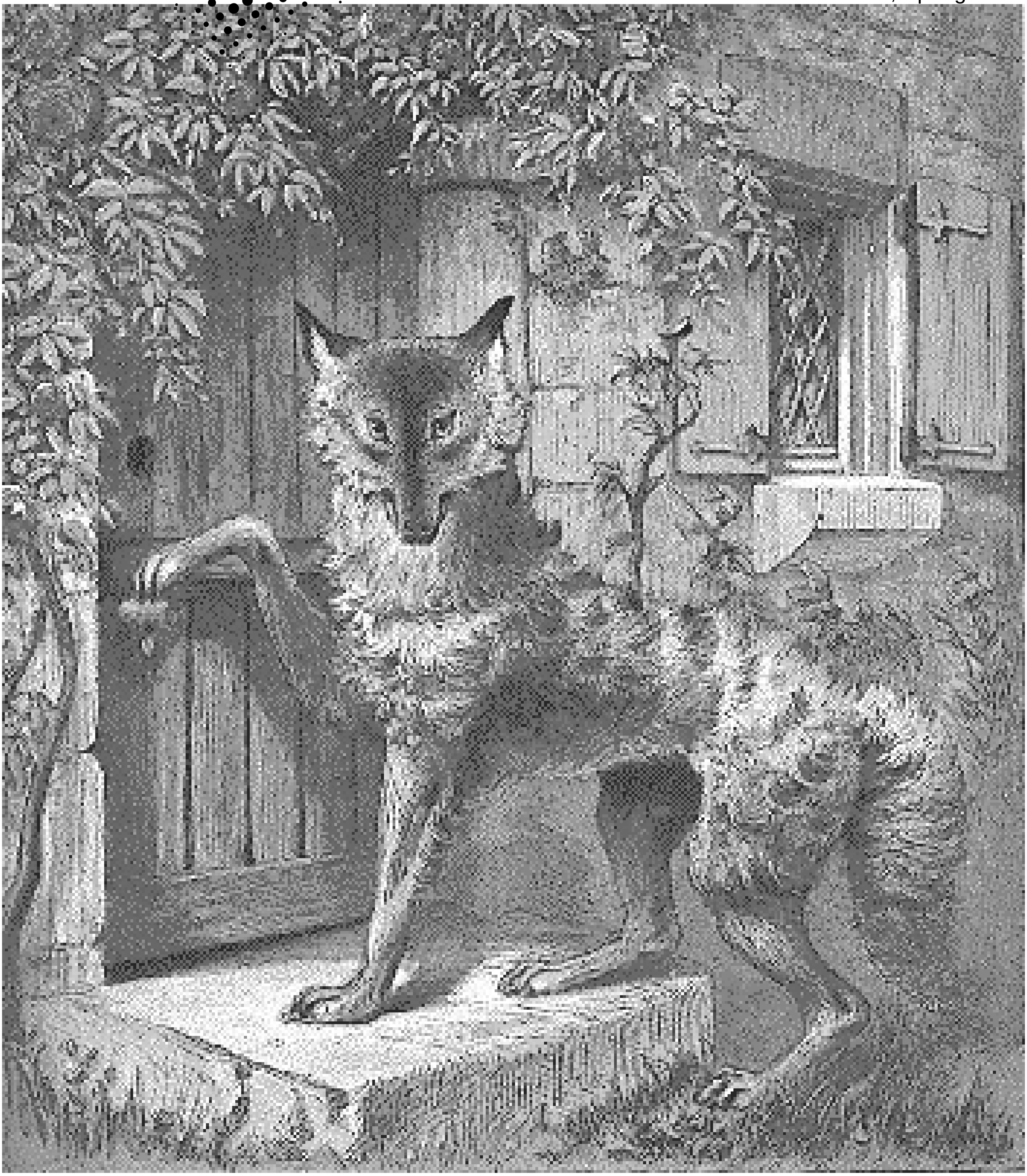


A Short Report on IAPS

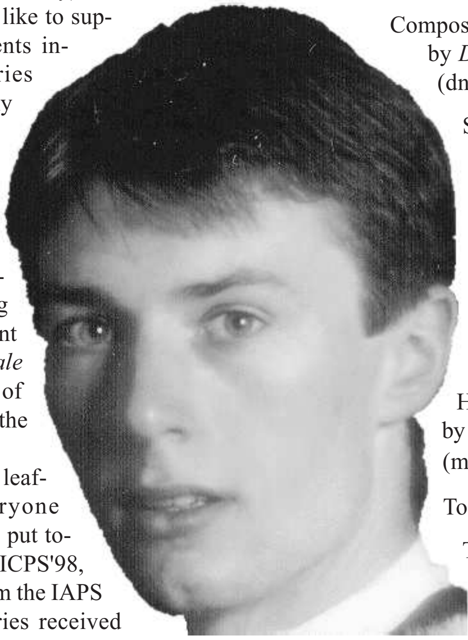
This is just a short note to report back to you on the results of the EPS meeting I attended in Leiden this past weekend (March 28—*the editor*).

I did not receive any 'official' IAPS promotional material, but I managed to put together a nice presentation on overhead projector sheets. I had about 15 minutes to introduce IAPS to the heads of the individual National Physical Societies and to tell them of our plans and that we want their help and support.

Everyone was very impressed to hear of the IAPS trip to CERN. There was much positive feedback. Many countries (e.g., France, Italy, …) who currently have (virtually) no contact with IAPS say they would like to support IAPS and get their students involved. Also, several countries were unaware that they had any students already involved!

I think the EPS are genuinely very keen on looking after us, so we are in a very fortunate position. "Young Physicists" is one of their current focus points. Another useful thing is that the newly elected President of EPS is Sir *Arnold Wolfendale* (past President of our Institute of Physics) and he is **very** fond of the next generation of physicists.

I have handed out our main leaflets, copies of JiAPS (everyone thought it was great!), a sheet I put together with information on the ICPS'98, and a list of contact persons from the IAPS CO, NCs and LCs. All countries received these. Hopefully it will have an effect!



Nigel Harris,
President of the IAPS
(iaps@damtp.cam.ac.uk)

I know that many countries are now inspired to send students to ICPS in Portugal. I have given them all the contact details and warned them of the deadline.

I had long discussions with Professor *Hendrik Ferdinande* and others about the EUPEN project and IAPS role in it. I think it is a very exciting thing for us to be part of.

Sue Jackson

The picture on the cover page is taken from the "*Little Red Riding-Hood Picture Book*" (London: George Routledge and Sons, 1870s?), which can be found in "*The de Grummond Children's Literature Research Collection*" (University of Southern Mississippi). The electronic version of the book is part of "*The Little Red Riding Hood Project*" at the URL: http://www-dept.usm.edu/~engdept/lrrh/lrrhhome.htm edited by *Michael N. Salda.*

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REGISTRATION FEES

(includes access to scientific sessions and exhibition, pre-conference abstracts book and some social functions):

Note: "Pts" stands for Spanish Pesetas

Regular, participants:	50,000 Pts
Each accompanying person (only social functions):	7,000 Pts
For registrations formalized before July 1st, 1998:	
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Students may apply to reduced rate of:	15,000 Pts

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Single room in a 3 stars hotel	7,500 Pts

Rates are per night and include breakfast and VAT.

End of Century Task: Resolve the Paradoxes of the Beginning.[1]

by Laszlo Tisza

Laszlo Tisza was born in Budapest in 1907. He had an early interest in mathematics, won the Eötvös prize jointly with Edward Teller. Studied at Budapest University mathematics with a minimal interest in physics. This was to change in Gottingen where in 1928 he attended Max Born's course on quantum mechanics. He was delighted to see modern mathematics applied to experience and switched his major to physics. Later he worked in Leipzig under Heisenberg and with Teller wrote his first paper. He received his PhD in Budapest and then joined Landau's group in Kharkov. He was much influenced by Landau's integration of thermodynamics into modern physics. In 1937 he went to Paris, to be associated with Fritz London. He advanced an early version of the two-fluid model of superfluidity which became standard for describing experiments on liquid helium. Immigrated to the USA in 1941 where he joined the Physics Dept. of MIT. He is now professor emeritus. His main lines of work were the foundations of thermodynamics, statistical physics, quantum mechanics, and the application of rigorous mathematics to the natural sciences. In recent years he has been still active and hopes to contribute to the paradox-free foundations of QM.

1. Introduction

In the December 1993 issue of Fizikai Szemle George Marx had a paper entitled: Fin de Siècle. He notes that a century ago people were way off the mark in their anticipation of the shape of physics in the new century and hopes that at the present juncture we would do better and will have something new to offer to young students, rather than repeating current wisdom. I think Marx touched on a most important topic and I wish to formulate some thoughts on how one might realize his expectation. This task is not trivial, because it calls for an examination of the nature of novelty.

The novelty brought about by the foundation of QM opened up new domains for study. However, in spite of the fact that QM is a flawless guide in the context of atomic physics, it is obscured by paradoxes connected with the gulf that separates it from the classical tradition. I suggest that the challenge to the next generation is to show that QM can be established also free from paradoxes as the gulf separating it from classical physics is being bridged. I hope to show that this is a viable and interesting project.

The gulf between the disciplines became apparent as both Einstein and Bohr proposed to approach atomic physics by extending the classical mechanics of point masses in its canonical form (CMP) into the microscopic domain. The inadequacy of CMP to deal with atomic physics was called the "breakdown of classical physics". This was altogether unwarranted, since mature classical physics consists, in addition to CMP, also of a plurality of phenomenological subdisciplines. The empirical base of CMP is celestial mechanics, whereas the phenomenological theories are rooted in chemistry. This pluralistic view of classical physics was instrumental in Max Planck's establishment of the quantum of action. See Tisza (1997a). Einstein was aware of the phenomenological theories as well, he made significant contributions to all and he stated very early: "…within quantum theory with its states and transitions it is no longer even possible to distinguish sharply between physics and chemistry", see Einstein (1914). This statement is charged with meaning. Before 1800 physics and chemistry had hardly any connection with each other. A century later Einstein no longer even discerned the boundary between them. During that period the physical content of Newtonian mechanics did not change at all, what happened was only that infinitesimal analysis replaced geometry. By contrast, chemistry displayed an extraordinary evolution from the macroscopic-technological to the microscopic-scientific. Moreover new branches of physics emerged, involving heat, light, electricity and magnetism, properties rooted in material structure, their theories constituting a natural bridge between physics and chemistry. Let me call this area of overlap *phenomenology.* It is appropriate to describe its evolution by the colorful term "inward bound", the title of a book by Pais (1986, 1988), one of several by this master of the history of 20th century physics.

> *"…within quantum theory with its states and transitions it is no longer even possible to distinguish sharply between physics and chemistry"*
>
> A. Einstein

In contrast to the above noted gulf between the classical and the quantal canonical theories, we find an evolutionary continuity within phenomenological classical physics which seems to join seamlessly with QM. Why did Einstein not pursue his insightful idea to establish this promising bridge between the classical and the quantum domain? He had strong *a priori* conviction on the hierarchy of disciplines, stemming from the problem of the coordination of the languages of mathematics and that of experience. The fact that there exists a mathematical language, distinct from common language, is the discovery of Greek philosophers, primarily Plato. The discovery of distinctness led first to a polarization between Platonism and empiricism emphasizing either mathematical elegance, or phenomenology.

The first major challenge to this separation of the two avenues of knowledge was Newton. He discovered, if not the term, the substance of phase space where empirical entities can be idealized so as to render them suitable for mathematical operations. He hit on what I like to call an *inter-*

[1] Edited version of a talk at the Hungarian Physical Society, October 8, 1997

face between mathematics and experience. Einstein and Bohr were in tacit agreement that the post-Newtonian CMP provides the *only* legitimate interface between the languages. Within this restrictive context the old methodological polarization was bound to reappear. The empiricist Bohr realized that the classical theory must be radically modified to account for atomic spectroscopy. Einstein was unwilling to sway too far from CMP, but his arguments had an oddly metaphysical character: his most interesting criterion against QM is contained in the famous EPR paper. This argument backfired, as experiment vindicated QM against the EPR criterion. The physics community cannot be faulted for standing by Bohr and by QM in spite of Einstein's critique. Yet it would be disappointing if the epic dispute of the masters should not lead to some more enlightening conclusion. I suggest that a slight modification of Einstein's criterion will turn it into a viable program. Instead of requiring that QM be rooted in CMP, we ought to open up the whole of classical physics including the phenomenological subdisciplines rooted in chemistry. As noted above, Einstein had advanced this idea himself, but then he abandoned it. All I suggest is to give it a try.

'I believe that our attitude with respect to great innovators ought to go through two phases. Credit for their discoveries need not be tarnished by early imperfections, but elimination of birth defects in due time becomes essential for the integration of their oeuvre into the permanent acquisition.'

The reader might be startled to be told that Einstein was torn between contradictory philosophical doctrines, yet John Stachel, the past Editor of the Einstein Papers, has carefully documented such an inner conflict, Stachel (1993). I believe that our attitude with respect to great innovators ought to go through two phases. Credit for their discoveries need not be tarnished by early imperfections, but elimination of birth defects in due time becomes essential for the integration of their oeuvre into the permanent acquisition. Einstein and Bohr received their well-deserved acclaim. It is our duty to live up to the advantage of hindsight, which we gained through their efforts, to free their efforts from flaws reflecting their early puzzlement. This also keeps us abreast of accumulated knowledge. This program of consolidation is my answer to Marx. The crux of the matter is whether chemistry-based phenomenological physics can be used to establish elegant mathematical formalisms. I will argue on three levels in favor of an affirmative answer.

First, there is the miracle of QM. In about 1925, as Bohr's empirical enterprise was losing momentum in its program of matching the finer aspects of atomic spectroscopy, the Platonic mathematics of Heisenberg, Dirac and others came to the rescue. Instead of marking a setback for empiricism, the experimental agreement reached unprecedented perfection and was extended to account for chemistry.This was a striking refutation of the need to choose between exclusive alternatives. It *is* possible to have both mathematical beauty and empirical validity. Unfortunately, we do not understand how this comes about. This sobering view was brought home to us in a well-known essay by Wigner (1960). "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve." Yet Wigner chose as his motto a quotation from C.S. Peirce: "and it is probable that there is some secret here which remains to be discovered." I decided to consider this a challenge and undertook to analyze the problem, see Tisza (1997). This is a philosophical paper which is abstract and lengthy, but has a simple conclusion: the association of mathematics with phenomenology is to be achieved by starting at a simple empirical beginning and proceeding in terms of an evolutionary dialectic of interlocking experiment and mathematics to more complex situations. I will not discuss the issue on an abstract level, but sketch the evolutionary path from Euclid and Newton to mature classical physics. I trust the argument is plausible enough to stand on its own, even as the outlines of QM come clearly into sight. The actual mathematical link connecting with QM is the subject of a forthcoming paper.

The daunting problem of presenting the evolution of classical physics in a single lecture becomes manageable as I highlight a few turning points or mutations. I don't think that any of these are new to you, but I hope to reach new insight by lining them up in proper order and without distracting detail.

2. The Evolution of Classical Physics

A. Euclid and the origin of deductive systems

I propose to construct an evolutionary path from Newton to QM. This project requires that two features in current thinking be modified. Newton believed that his mechanics would apply also to atoms. Although this conjecture is known to be incorrect, its influence lingers on in current thinking. More subtle is the fact that deductive systems continue to be the tools of theoretical physics although the very idea of *deduction* is in conflict with the empirical nature of physics. My main task is to show how to remedy this situation. Since the first deductive system is that of Euclid, this is a plausible departure for modernization, particularly, since Newton, a beneficiary of the Euclidean legacy, inherited also a major shortcoming.

The perennial usefulness of deductive systems stems from their economical organization: a large number of complex entities are constructed as a combination of a few primitives. The prerequisite for a precise construction is that the entities be abstract and mathematical, not as fuzzy as the objects of the real world. So far this is Platonic doctrine, but now we part ways and instead of letting the primitives be creations of the mind, I propose to follow Newton who abstracted them from a well-chosen domain of experience. I point out that such an empirical input can be imposed also on Euclid, without subtracting from the precision of Euclidean geometry, which deals with geometrical objects constructed by ruler and compass. It can be considered as the combinatorial composition of circles and straight lines.

For Euclid his deductive system was the *universe of discourse* for all of mathematics. By contrast, modern mathematics deals with many "vector spaces" and deductive systems, related or unrelated to each other. Deductive systems became *elements of discourse* which in mathematics may, but need not be, connected by intersystem relations. It is possible to conceive of this plural structure as a result of an evolutionary mechanism. A sample for such a mechanism follows.

Let us consider a sphere of radius R in Euclidean 3-space. The spherical geometry over this surface is within the Euclidean framework. However, we may rename the great circles on this sphere, call them "straight lines" and make them into the primitive concept of a new "non-Euclidean geometry". Specifically, this is Riemannian spherical geometry where a bundle of rays diverging from the north pole converges into the south pole. Any inconsistency of the non-Euclidean geometry would manifest itself as one in Euclid. Hence, the new geometry is no less consistent than the old one. This is the well-known procedure which gave legitimacy to the non-Euclidean geometries. It belongs in fact to meta-language, or metascience, and we may say that the Euclidean geometry "spawns" new deductive systems. I propose to call such an intersystem relation a *logical continuation,* an obvious allusion to *analytical continuation* in the complex plane. We have here two mathematical theories which are independent, with rules of their own, i.e. two languages which cannot be mixed, yet they have an intelligible relation to each other. Let us consider now a physical situation, say the Earth, but assumed to be precisely spherical. We construct a practical geometry, or geodesy, where it may be believed to be economical to use exclusively spherical geometry, which is equally valid over large and small areas. This economy is deceptive. In spherical geometry we have an absolute unit, the radius of the sphere R, and hence the geometry has no similarity laws, no scaling, and no blueprint can be drawn to scale for an engineering construction. All this is simple in plane geometry. The economical procedure will be to have the option to operate in terms of either one of the two geometries, depending on the scale of the map. For figures of size a, the plane geometry is admissible if $a/R \ll 1$, thus the sphere degenerates into a plane. We note that the limiting process displays a *non-uniform convergence* and the limiting system is utterly different from spherical geometry of even a very large radius; the plane is not contained in the sphere, nor is plane geometry contained in spherical geometry, since the latter does not contain any similarity laws. These can be added only after the limiting process has been carried out. It is interesting that the esoteric mathematical concept of *non-uniform convergence* is relevant for justifying the counterintuitive fact that even if the transition between deductive systems is described in terms of a continuous parameter, the systems may still exhibit qualitatively different features. The products of *logical continuation* need not have any relation to experience; they are abstract mathematical structures.Their minimal empirical basis does not impair their Platonic claim on precision. Empirical connections may arise, however, but these must be discovered and tested. The historic first is Newton. However, our evolutionary step to non-Euclidean geometry is already a foretaste of the forthcoming non-Newtonian versions of mechanics in branches of modern physics which involve absolute constants.

'Einstein arrived at special relativity theory (SRT), by showing that CMP and CED can not be made mutually consistent and that paradox is avoided only if Newtonian absolute time is abandoned…he might have argued that the experimentally supported wave-particle duality would cease to be paradoxical only if the Newtonian point-like particle were to be abandoned. He saw no way of doing this and accepted the paradox in his light quantum paper.'

B. Newtonian mechanics

The method of logical continuation leads from Euclidean space to the vector space of displacements. From here Newton proceeded to the vector spaces of velocities, of momenta and finally of forces. The fact that the primitive concepts of his deductive system were both observable and subject to mathematical manipulations was a unification of the two methods of acquiring knowledge and a defiance of the Platonic rejection of observation. Remember the chained prisoners in the parable of the cave. As a by-product of this *unification of methods* (UM), Newton showed also that his mechanics is equally valid for the orbit of planets as for the motion of projectiles. It is convenient to call this the *unification of domains* (UD). The immediate impact of UD was probably greater than that of the subtle UM. The impenetrable boundary between the "sublunary world" and the higher world of the heavens had seemed equally self-evident to the common man as to the philosopher. Overcoming it must have impressed everyone, whereas to appreciate UM you had to have a philosophical mindset. We know that the corner stone of Newton's philosophy was unity and the unification of celestial and terrestrial mechanics was a real fulfillment. He hoped that eventually this achievement would be crowned and the same mechanics would hold also for atoms. See Rule III of Reasoning in The System of the World. He was cautious enough to add Rule IV in which he granted experiment the last word. Newton could have of course no knowledge of the properties of the hypothetical atoms, but just as Euclid saw his system as the universe of discourse for all of mathematics, he saw his own system as the universe of discourse for all of natural science.

Accordingly, I suggest that Newton's legacy has two entirely different components. The first, which I consider the perennial one, the foundation of mathematical physics for all times, is what might be called mathematical phenomenology. This is the modern rendition of the full title of the Principia, it is a harmony of precise observation and rigorous mathematics. It is tantamount to taking responsibility for a quality of workmanship. The second legacy is a declaration of orthodoxy: claiming validity for his existing theory under entirely different experimental conditions. I indicated that Euclid was deprived of his excessive claim of being the universe for all of mathematics, by being given the due distinction of being the evolutionary beginning. I claim that the situation is somewhat similar with Newton. His system is not the closed universe of all natural sciences, but is its evolutionary beginning.

The well-documented analogy between the evolution in mathematics and physics has its limits. The deductive, or formal systems of mathematics need not be related to each other. By contrast, if we use different systems to account for different aspects of physical reality, then these must be mutually consistent. This is a necessary criterion for the use of the "physical reality". Einstein arrived at special relativity theory (SRT), by showing that CMP and CED can not be made mutually consistent and that paradox is avoided only if Newtonian absolute time is abandoned. In a similar vein he might have argued that the experimentally supported wave-particle duality would cease to be paradoxical only if the Newtonian point-like particle were to be abandoned. He saw no way of doing this and accepted the paradox in his light quantum paper. I return to this point in Sec.2.C. In order to ensure that his more rigorous method is applied systematically, one needs a general methodology as developed in Tisza (1997). However, for now I proceed with my survey of turning points by focusing on the post-Newtonian era.

The first turning point was the replacement of geometry by infinitesimal analysis expressed in terms of abstract symbols. The domain of physical application remained unchanged; everyone continues to speak of Newtonian mechanics, and CMP might be said to represent the optimal mathematics for the same physics.

The Newtonian idea to deal with nonmechanical phenomena was to admit new types of "forces". The electric and magnetic inverse square forces show how far one could get within the Newtonian framework. This use of the inverse square force was not objectionable, but it did not offer much insight into physical meaning. I turn now to developments which did provide meaning.

C. From Volta to Faraday and beyond.

After years of preparatory experiments Volta reported his powerful new source of electric current, the Voltaic pile in 1800: "The endless circulation or perpetual motion of the electric fluid may seem paradoxical, and may prove inexplicable; but it is nonetheless real, and we can, so to speak, touch and handle it." See Whittaker (1951). Volta's striking report came within months to the attention of British chemists, in particular of Sir Humphrey Davy whose research group became the founder of a new discipline electrochemistry that percolated into the electrical science of physics.

The origin of Volta's mysterious source of power was traced to chemical reactions involving electrolytes. Physicists do not consider it their business to dwell on the multiplicity of chemical reactions. In order to alleviate the concern that physics would be dragged into the morass of chemical facts, it should be noted that electrochemistry transcends the framework of classical chemistry in which the permanence of elements is axiomatic. This axiom is violated by the formation of ions. We are indebted for further steps in this direction to Davy's collaborator Faraday, who established that there is a constant charge, the "faraday", which is transported by a mole of monovalent ions. Divided by Avogadro's number this constant yields the elementary charge, a universal quantity. Although it emerged from a mass of chemical experience, it foreshadows modern physics. I suggest that Faraday was laying the foundation of a new discipline, say "subatomic chemical physics" (SCP). It must be admitted, however, that Faraday had no full clarity about the precise meaning of his discovery. The concept of valency was far from clear. Also Avogadro referred to molecules whereas his contemporary Dalton dealt with atoms and the relation of the two hypothetical entities was surrounded by confusion. Much of this was clarified in the context of three momentous developments around 1860, which take on added depth if discussed in the context of the emerging SCP.

Physicists are most familiar with Clausius' advancing the concept of free path which led to the kinetic theory of gases. The curious mixture of success and failure of this theory was among the mysterious flaws in the edifice of classical physics. The delimitation of success and failure could have been markedly advanced in light of the results of the international Congress of chemists at Karlsruhe in 1860 where Cannizzaro's classic paper on atoms and molecules was distributed. See Chaps. 1 and 2 of Nye (1984). The conceptual confusion came to a head for such gases as oxygen, nitrogen and hydrogen for which the smallest constituents were not atoms, but diatomic molecules. It was only after this date that the establishment of chemical formulas became an unambiguous procedure. For chemists the "inward bound" drive reached its goal, they knew enough of the building stones of matter to turn to analyzing and synthetizing anything in sight. Moreover, they could deal with moles, rather than worry about the existence of molecules and atoms.

For the physicists this drive should have been starting up, owing to the greatest of the three discoveries of the period: spectrum analysis. The physicist Kirchhoff and the chemist Bunsen discovered that spectra provide reliable fingerprints for atoms and molecules, and thus optical diffraction became an important tool for chemical analysis. Probably nothing shows the convergence of the disciplines as forcefully as this fact. It led to the dramatic exploration of the chemical composition of the sun and of the stars which had been considered beyond human reach. Unfortunately, the implications of spectrum analysis on the nature of atomic structure were not spelled out at the time as completely as they might have been, presumably because the implications were so damaging to the idea of the microscopic extension of the canonical particle concept. The fact that atoms emit a spectrum of sharp lines is an indication that they have well-defined oscillatory structures, a fact which is incompatible with the point-like nature of the canonical particle. The qualitative difference of molecular band spectra from atomic line spectra indicates that the hydrogen molecule cannot be conceived as a double star of atoms, because the atom is not recognizable inside the molecule. The clear distinction between atoms and molecules could have led to registering success for the kinetic theory in its handling molecular translations and admitting the failure of the canonical interpretation for dealing with intramolecular dynamics.

There is also a difference between the identity concept of the canonical and the chemical atom. For the former we have orbital identity: the evening star and the morning star are identical because they are on the same orbit and can be given the single name Venus.

A totally different identity concept is at play in the domain of the chemical atom. The helium atom discovered in the sun is the same as the laboratory version observed a generation later, because they have the same spectrum, i.e. the same intrinsic oscillatory structure. The name "helium" is attached to the class of identical entities. You ought to realize that it is the same class identity that is at work in QM. Specifically, the change from Boltzmann to Bose-Einstein statistics marks the change from orbital to class identity.

'There is at present a "science war" going on as sociologists of science claim that physics is no more exact than sociology…'

A striking implication not noticed at the time is that light emitted by an incandescent gas must have a discrete structure since the emission is tied to elementary acts associated with atoms.They differ from Einstein's light quanta inasmuch as the latter are based on the union of the concept of the canonical point particles with that of the classical wave. This union is paradoxical because the coherence domain of a classical wave is infinite, that of a canonical particle is zero. This issue played a role in the controversy between Planck and Einstein, see Tisza (1997a).

After this summary of the rich harvest of the 1860'ies let me return to Faraday whose somewhat tentative theory was put on a firm footing. Thus Helmholtz said in his Faraday Lecture that "…the most startling result of Faraday's law is perhaps this. If we accept the hypothesis that the elementary substances are composed of atoms, we cannot avoid concluding that electricity also, positive as well as negative, is divided into elementary portions, which behave as atoms of electricity." See Helmholtz (1881), or chapter 10 of Nye (1984). This was in 1881, 16 years before the experimental discovery by J. J. Thomson in the context of experiments on gas discharges. This was a natural continuation of the work with liquid electrolytes. The great difference was the experimental importance of vacuum techniques, which made it the natural preserve for physicists.

Thomson's proof of the corpuscular nature of the electron was hailed as a triumph of the canonical hypothesis. When his son proved thirty years later that it was also a wave, it became a paradox. An alternative view is that the particle has an internal oscillatory structure as the chemical atom does. Indeed, atoms, just as electrons are subject to creation and annihilation. I do not want to stretch my talk, but give it as a homework for you to notice that in a qualitative sense the particles of QM are direct descendants of the chemical atom, the basic entities of Faraday's SCP. What is missing is only the mathematical structure. Although I cannot enter into mathematics in this talk, I may note that I have published a mathematical paper several years ago, see Tisza (1989). This paper was based on a few postulates and had no response whatever. I realized that it needed an epistemological and a historical foundation. This was the motivation for Tisza (1997) and the present short paper to be followed by a longer one, including a link between the Faraday atom and the mathematics in Tisza (1989).

3. Conclusions

Finally, I wish to cut back to the beginning of my talk and reflect on why people thought a century ago that physics was already finished. I do not think that they had the foolish idea that they knew everything. It was widely believed, however, that atoms ought to be canonical particles and their impact on a macroscopic piston would not be measurable and the microworld would remain beyond the reach of human knowledge: ignoramus et ignorabimus. What happened, however, is that the momentum is inversely proportional to wavelength and is measurable by diffraction. Instead of rejoicing over this fact, it was declared paradoxical.

There is at present a "science war" going on as sociologists of science claim that physics is no more exact than sociology, while physicists counter that the combination of mathematics and experience assures them a special standing in the search for objective truth. I firmly believe that this is correct, but it is contingent on the scientists' willingness to abandon preconceptions found to be defective. A test case is abandoning the canonical dogma.

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Sigma Pi Sigma
The National Physics Honor Society

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Composers, Performers, and Appreciators

by Dwight E. Neuenschwander
(Director, Society of Physics Students, American Institute of Physics)

Ludwig van Beethoven and Ludwig Boltzmann lived in Vienna. During the 1997 ICPS in Vienna, we learned to know them better. Beethoven's Vienna address was Molker Bastei 8, where in the beginning of the 19th century he composed the Leonore and Fidelio Overtures, and his Fourth, Fifth, and Seventh Symphonies. From Beethoven's apartment window, one sees across the Ringstrasse to the University of Vienna, where at the end of the 19th century Ludwig Boltzmann laid the foundation of statistical mechanics. Through Ode to Joy, Beethoven showed us God's inner fire; through the partition function, Boltzmann provided the window into the atomic structure of matter. Beethoven and Boltzmann were artists. How fitting that their graves should lie a 30-second walk from one another in the Vienna municipal cemetery, so that we can pay homage to they and their art together.

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Three roles are required to communicate through music: the Composer, the Performer, and the Appreciator. The roles of the Composer and Performer are well-defined and clearly essential. The role of the Appreciator is no less essential. A concert delivered to an empty house offers limited opportunity for musical communication.

These same three roles are required to communicate through physics! The physics Composers include the Boltzmanns who write a score that never existed before. The Performers are found among the applied scientists and engineers who arrange the work of the Composers to build machines that fly or make a trillion calculations per second, and among professors who help students capture the spirit of the music. The physics Appreciators include anyone who has ever wondered what makes the sky blue or what holds up the Moon, and have asked the question with an inquiring mind.

Young school children are enthusiastic physics Appreciators.

Here are some written questions my students and colleagues have collected from second-graders before we visited them for our "Physics Circus":

Daniel: "What's in our brains?"
Jason: "What makes the air stay on the ground?"
Sarah: "How is snow formed?"
Corban: "How do planes fly? How does the sun move? How do boats float? How did the dinosaurs die?"
Chris: "I want to know if space ever ends, how magnets work, how lightning occurs, how electricity works, how sound works, if numbers ever end…"
Nikki: "How does the picture get through the TV?"
Ashlee: "How do planets shine? How was God made? Sometimes the moon is full and some times it's half a moon. Do they just cut it in half?"
Michelle: "I want to know how gravity works. And how does the sun shine?"
Tasha: "What holds the moon up when it's on nothing?"
Jordan: "How do we get shooting stars? And how do you feel about being a scientist? And how do you find out about things?"

Music and physics can be a source of tremendous joy to the Appreciator, even when one cannot read the technical notation. One of my friends offers this insight about life: "The real tragedy comes when you die with the music still inside you." One need not be a virtuoso soloist to experience of Ode to Joy bringing out the music inside. My grandfather was fascinated with astronomy and built his own telescope. Although he was never formally trained as an astronomer, all his life he was an astronomy Appreciator. It's music found meaningful expression in his life.

The role of the Appreciator has received the professional attention of music educators for many years. In a recent convention address later published as a journal article,[1] Bennett Reimer, professor emeritus of music education at Northwestern University, reminded his colleagues that nowadays, with tapes, CD's, radio, and television, everybody can access to all kinds of music. Learning to perform no longer is essential for one to experience music. However, Prof. Reimer raised concern that training in performance remains the dominant activity in music education. The music educators, he argues with great eloquence, must enlarge the scope of their activities to include instruction in listening to music with informed appreciation. Otherwise, he said, music education will be perceived at relevant only to specialists.

A similar concern exists in the physics teaching community. In the USA, only one of four pre-university students take a formal physics course.[2] Somewhere between second and seventh grades, the drive to learn what makes gravity work and why magnets stick gets lost. Another real tragedy comes when the music dies inside you.

The physics educational establishment is very effective at preparing future PhD researchers— our

Composers and Performers. That good work must continue. But what happens to the physics appreciation of the 75% of the American students who are never instructed formally in physics? My sons learned about the physical world by climbing trees, riding bikes, and looking through a backyard telescope. Such methods of learning essentially came to an end the first day of middle-school science class: *For tomorrow's quiz, name the six steps of the 'Scientific Method.'* Science becomes something to memorize from a book. Professor Reimer: *I would not argue with the claim that much of the teaching of listening we have done is, in fact, boring. But that is not because listening is boring— it is because we have often taught it in boring ways.*

Musical Composition and Performance are among the most highly developed creative arts. They demand the best of one's cognitive skills and intellectual faculties. But can the same be said for music Appreciation? Reimer cites several *myths* about music listening.

'My sons learned about the physical world by climbing trees, riding bikes, and looking through a backyard telescope. Such methods of learning essentially came to an end the first day of middle-school science class: ***For tomorrow's quiz, name the six steps of the "Scientific Method."*** *Science becomes something to memorize from a book.'*

There is the myth that listening-appreciating is passive. Not so: the Listener-Appreciator must construct and feel the relationships among sounds. Those sounds must be interpreted in a historical and culturally derived framework; they and the cultural context must be kept in memory.

There is the myth that listening-appreciating is uncreative. Not so: meaning gleaned from listening must be created anew in the mind of every listener.

The responses to parallel myths that exist about Physics Appreciation would be the same. At every level of Composing, Performing, and Appreciation, a minds-on interaction with physics is a highly creative act. Every student who studies physics with thoughtful attention must personally re-create the subject in his or her own mind. Science is the creation and testing of concepts in terms of which the universe becomes comprehensible. In physics, as in music, we endeavor to make sense of the world. The tools may be different, but the intellectual commitment and the aesthetic sense are the same.

For decades the view has survived among physics professors that our primary responsibility centers on training future PhD researchers. Of course the training of future PhD's is important, and this model of instruction has certain aspects, especially research experience, that are transferable to all students. For example, I have argued elsewhere[3] that undergraduate research experience is a vital experience for every physics major, because it taps skills and interests that course work alone cannot touch. Anyone who has ever attended an ICPS has witnessed such results. But two-thirds of our physics alumni find fulfillment and success in many fields besides traditional research in physics. This robust versatility of the physics major should be celebrated! The physics establishment is slowly beginning to realize how many friends it could have, through its own alumni, in all walks of life, not only the traditional physicists.

In a 1936 book, Music Education,[4] Lillian Baldwin *defines the goal of effective music education to be music appreciation.* Is music or physics appreciation merely a pedagogical issue about which only professional educators need trouble themselves? Of course not! The appreciation of physics or music develops only partially in a classroom. The attitudes and opportunities that enhance one's receptivity to learning are reinforced or diminished continuously outside the classroom. Physics students and alumni form a fellowship Physics Composers, Performers, and Appreciators who should take pride in being a unique community of both *Explicit Physicists* and *Hidden Physicists.* We are a voice for physics Appreciation whose circle of influence is much larger than the classroom physicist's alone will ever be.

The same sense of mystery that makes us gaze at the moon with wonder can both inspire a Newton to meditate on the force of gravity, and a Beethoven sonata to be named *Moonlight.* Our intellectual systems and aesthetic sensitivities lead us to admire counterpoint and Lagrangeós equations alike. Such systems and sensibilities are formed by encounters with quality music of all types, and by quality discoveries in nature and in our conceptual representations of it. Such encounters and discoveries must occur wherever we are, not only in the classroom.

In Vienna, we attended the 1997 ICPS where over 100 students presented papers on their research. It was an inspiring performance by young, talented physics appreciators and composers. That same week, the US delegation to ICPS '97 attended a performance of Anton Bruckner's Eight Symphony by the Junge sterreicher Philharmonic Orchestra, in the magnificent St. Stephen's Cathedral. We also listened to tapes of Beethoven's music in his own house, and heard Mozart's music in the apartment where he composed The Marriage of Figaro. We attended an open-air film festival outside the Vienna City Hall, where we watched Leonard Bernstein conduct the Vienna Philharmonic Orchestra in Mozart and Hayden symphonies. It was hard to distinguish between the art of physics appreciation and the art of music appreciation. Both deserve a multitude of Composers, Performers and Appreciators.

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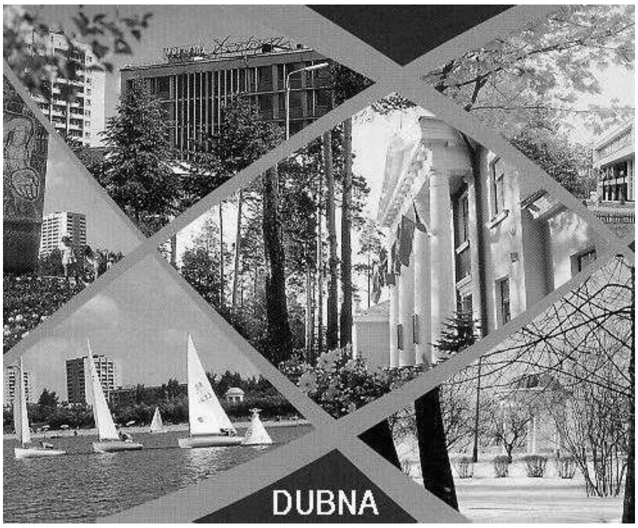
Studying Physics in Dubna

by *Negovelov S.S., Tchourin A.I.*

Historical background

Soon after the establishment in 1956 of the Joint Institute for Nuclear Research (JINR), now the largest scientific centre in Eastern Europe comprising 18 Member States, a branch of Moscow State University (MSU) opened in Dubna in 1961. It was organized on the basis of JINR to train MSU graduate students in nuclear physics. Two departments of the Physics Faculty were set up at the branch of MSU: the Department of Theoretical Nuclear Physics and Department of Elementary Particle Physics. The first heads of these departments were D.I. Blokhintsev and V.I. Veksler, the prominent scientists whose energy had allowed the branch of MSU to be created. They were first to realize how forward-looking is the idea of training students directly at a large scientific centre like JINR. At present, the existence of training departments of the higher education institutions or their



branches at the scientific institutes is ordinary, but in the sixties and during the next 20 years the joint work of the branch of MSU and JINR on training young specialists in nuclear physics was a rare exception in Russia. Further development of the branch of MSU went on under Prof. N.N. Bogoliubov, a member of the Academy of Sciences, who was director of JINR in 1966–1989.

During thirty years of its work, the branch of MSU has trained about one thousand graduate and post-graduate students. Many of them are now leading scientists at JINR and other scientific institutes of Russia, former Soviet Union republics, and JINR Member States of Eastern Europe, Asia, and Cuba.

In recent years, however, it has become clear that the existing structure of the branch of MSU is no longer able to meet the increased JINR need for scientific staff of different specialties, while training abilities of the branch of MSU did have some reserve and allowed the amount of education work to be expanded.

Therefore, JINR, MSU, Moscow Engineering Physics Institute (MEPI), and Moscow Institute of Physics and Technology (MIPT) have come up with a proposal on joint activities toward training in Dubna of students in a more extensive variety of specialties with introduction of some new forms of teaching. With this purpose, the University Centre of MSU, MEPI, and MIPT has been established at JINR and it received official status in 1991. It should be noted that the University Centre has been set up in addition to, and not instead of, the branch of MSU.

The university centre of JINR today

The UC students come from many institutes and universities of Russia, the former Soviet Union, and JINR Member States. Students of the 4th and 5th years and graduates are invited to study at the UC for two years.

The students complete here their university education. Classes include not only ordinary courses in physics, but also intensive courses on subjects defined on the basis of JINR research.

The Centre offers the following full-time graduate programmes:

Nuclear Physics, on the basis of the:
- Flerov Laboratory of Nuclear Reactions
- Frank Laboratory of Neutron Physics
- Department of Atomic Nucleus Physics of Moscow State University
- Department of Experimental Methods of Nuclear Physics of Moscow Engineering Physics Institute (MEPI)

Particle Physics, on the basis of the:
- Laboratory of High Energies
- Laboratory of Particle Physics
- Laboratory of Nuclear Problems
- Department of Elementary Particle Physics of MSU
- Department of Physics of High Energy Particle Interaction of Moscow Institute of Physics and Technology
- Departments of High Energy Physics and Experimental Nuclear Physics of MEPI

Condensed Matter Physics, on the basis of the:
- Frank Laboratory of Neutron Physics
- Department of Solid State Physics of MEPI

In the above three fields, the UC also offers the full-time theoretical physics programmes on the basis of the Bogoliubov Laboratory of Theoretical Physics.

Technical Physics, on the basis of the:
- Laboratory of Nuclear Problems
- Laboratory of Particle Physics
- Laboratory of Nuclear Reactions
- "A" (Automation and Electronics) faculty of MEPI

Radiobiology, on the basis of the:
- Department of Radiation and Radioboilogical Research of JINR
- Department of Radiation Safety of MEPI

The full-time educational programme of the University Centre is two years long, though it has also become a practice to accept students for shorter periods, such as one or two-month intense courses on some selected topic. The working language for foreign students is English.

Post-graduate students are also admitted to attend lectures on selected topics and take part in scientific research at the JINR Laboratories.

Students have wide access to the laboratories of JINR and can work with scientists and staff of the Institute, as well as to study under professors who are eminent in their fields. Graduate and post-graduate studies at the UC are based immediately on JINR's research conducted at a wide variety of world-renown facilities, for example, heavy ion accelerators U-200 and U-400, ion beam from the U-400M cyclotron, the nuclotron — a superconducting accelerator of relativistic nuclei, the IBR-30 neutron booster, and the IBR-2 pulsed reactor (which is especially fruitful in condensed matter research).

Special importance is attached to the language education. Russian and English are taught here as a second language.

The UC has a post-graduate training license from the State Committee of Higher Education of Russia. The post-graduate students are trained in the following specialties:

- Physics of nuclei and elementary particles
- Theoretical physics
- Charged particle beam physics and accelerator technique
- Computational mathematics
- Solid state physics
- Physical experiment technique, instrument physics, and automation of physical research
- High energy physics
- Radiobiology
- Mathematical and software support of computers, computational systems, and networks
- Application of computational techniques, mathematical modeling, and mathematical methods to scientific research

International contacts of the UC

International scientific educational contacts have become a regular and well-established UC's activity.

The UC has always kept high profile in the organization and conduction of international scientific schools and training courses. Here are some typical examples.

In 1995, the UC actively participated in the organization of two Schools – on theoretical physics (jointly with the Laboratory of Theoretical Physics) and on neutron physics (jointly with the Laboratory of Neutron Physics). In September – October 1995, the International Nuclear Informtion System (INIS) courses of IAEA were conducted in Dubna, which was largely assisted by the UC. In 1996, the UC and Laboratory of Particle Physics organized jointly the Young Scientist School on Problems of the Charged Particle Acceleration. Within the frames of the cooperation between IAEA and JINR, the 9-week International Regional Post-Graduate Educational Course on Radiation Protection was held in 1996 on the basis of the UC. In 1998, the UC will conduct the International Summer School in memory of Bruno Pontecorvo.

The UC is a participant of the European Mobility Scheme for Physics Students (EMSPS). The European Physical Society has appointed the UC one of the Russian Federation coordinators in the EMSPS.

UC also maintains ongoing contacts with CERN in the training of students and young scientists.

A number of graduate students from Western Europe had their specialized practice at JINR's laboratories, which was coordinated and assisted by the UC. UC also receives student groups from Europe coming here with visits of acquaintance.

The town of Dubna

Dubna, whose population is approximately 70,000, is situated about 100 km north of Moscow on both banks of the Volga, a major river of the European part of Russia. It is a quiet town comfortably fitted into the natural landscape of rivers, forests, and fields. Natural surroundings are within an easy foot, bicycle or ski trip from the town.

Dubna is a town of science and high technologies: most of its industrial and scientific potential is made up by the Joint Institute for Nuclear Research, the instrument plant designing and producing mainly in-reactor control systems and wide variety of electronic instruments, and the aircraft industry complex designing and producing supersonic air- and sea-based conventional missiles and small aeroplanes. Outside the town, there is a satellite communication station

The registry building in the town of Dubna

integrated in the INTELSAT system. In 1997, it became one of the EUTELSAT's control stations. There is also a global seismological control station outside Dubna.

At a small airfield near Dubna, the Russian national aerobatic team holds its training sessions several times a year.

Dubna has a yacht club. In the neighbourhood of the town, there is the biggest Russian privarte horse farm.

There is good railway communication between Dubna and Moscow. It takes less than two hours and a half to get to Dubna from the Savyolovsky railway station of Moscow by a non-stop train and about two hours to travel here by car from the Sheremetyevo-2 international airport.

How to contact the UC

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Topological defects and cosmological evolution

H.C. Stempels
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1 What are topological defects?

1.1 Mathematical introduction

In short mathematical terms, topological defects are phase transitions as a result of symmetry breaking in the Universe. Symmetry breaking can be characterized by a symmetry group G and a *Higgs field*. This field is a complex scalar field ϕ, with a non-zero expectation value for its ground (vacuum) state. When the group breaks into its unbroken subgroups, $G \rightarrow H$, each subgroup H will consist of all elements of G with a certain ground-state expectation value. In other words, the Higgs field can be thought to collapse into different ground states, with non-zero expectation values, as soon as the temperature T drops below a critical value T_c.

If this Higgs-field were the vacuum field, and the symmetry breaking would happen at different places in the universe which are not causally related to each other, the vacuum expectation value might happen to be chosen not identical for these different places. As the light-cones corresponding to the future of these events grow, they will eventually meet. At the sides contact-surfaces of these 'bubbles', the vacuum expectation value will change over an infinitesimal interval in space. Such a contact surface then can carry a high energy-density, which can also be interpreted as mass. For further reading I refer to Spergel in Scientific American [3] and the book by Vilenkin & Shellard [6].

1.2 The Goldstone model

Goldstone developed a simple model that illustrates symmetry breaking. Consider the symmetry group $U(1)$, consisting of unitary operators invariant under phase transformations. Define a rotationally invariant potential V :

$$V = \frac{1}{4}\lambda(\phi^\dagger\phi - \eta^2)^2$$

with positive constants λ and η. This is a potential with a local maximum at $\phi(x) = 0$, and a ring of local minima at $|\phi(x)| = \eta$. This potential is shown in figure 1, and is clearly rotational invariant : $\phi \rightarrow e^{i\alpha}\phi$.

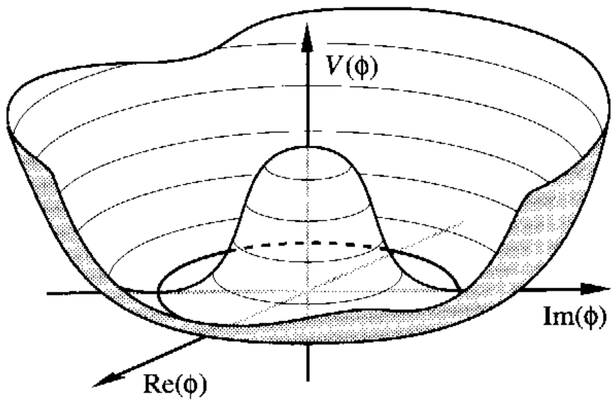

Figure 1: Potential corresponding to the Goldstone model.

The vacuum expectation value is given by :

$$\langle 0|\phi|0\rangle = \eta e^{i\theta}$$

But a phase transformation modifies the vacuum expectation value into $\eta e^{i(\theta+\alpha)}$, thus the vacuum state itself is not rotationally invariant. The symmetry is spontaneously broken when the energy of the system drops below the local maximum at $\phi(x) = 0$.

1.3 The zoo

Apart from phase transitions, it is possible to form other topological defects as well. A Higgs field with a complex configuration similar to the magnetic vortex field of a conducting wire will have a singular point at its core. This corresponds to a *cosmic string*. The field of a *monopole* is similar to the electric field of a single charge, and *textures* are unstable three-dimensional structures that carry an energy-density until these structures have unwinded. Cosmic strings and domain walls do not have ends, because that would mean the immediate destruction of the structure. They are either infinite, or closed loops. For hybrids and other creatures I refer again to Vilenkin & Shellard [6].

1.4 Cosmology at home?

The symmetry breaking in the Goldstone model can be compared to symmetry breaking in a ferromagnet.

This effect can also be described by a rotationally invariant Hamiltonian, but below a certain temperature (here the Curie-temperature), the symmetry breaks down, and the ferromagnet will form domains with parallel magnetic fields. The domain boundaries correspond to a quickly changing magnetic field, and carries electromagnetic energy. Other analogies are the growing of crystals, and the energy radiated away by alternating currents flowing through a wire.

2 Consequences

One could say that cosmic defects are only mathematical creatures, and are not relevant to cosmological evolution. This would be the case if the vacuum expectation value were zero, and the Grand Unification Theories didn't rely on symmetry breaking. However, from the simple fact that the vacuum consists of a continuous creation and annihilation of particles and its anti-particles, one can deduce that the vacuum expectation value is not zero[1]. Cosmic defects are then not only unavoidable, but an essential part of the cosmological evolution. Kibble [2] was one of the first to point out that symmetry breakdown produces cosmological phase transitions.

2.1 Cosmological evolution

In the early stages of the universe, most standard evolution models include an inflationary phase. In this hyper-adiabatic expansion the universe super-cools. and the Grand Unification group $SO(10)$, in which the fundamental interactions take their simplest forms, will break into several subgroups. I will not discuss this symmetry breaking, and I refer to Vilenkin & Shellard [6] and references therein. The breaking results among others in the $U(1)$ group, with the properties discussed above.

It is useful to note that newly born defects are also subject to the inflationary expansion of the universe, and that one therefore should focus on the structures that were formed after or at the end of the inflation era.

Of all defect structures, cosmic strings and textures are the best candidates to be present in our universe. Domain walls produces anisotropies that will overclose the universe, causing an almost instantaneous collapse of the universe. On cosmic strings and unwinding textures, matter can accrete. One can even speak of movement of cosmic strings, and such a moving string will leave behind a surface with increased density. Other observational evidence for the existence of strings would be a line of double objects, due to the gravitational lensing of the string along its axis.

[1] Here lies a fundamental problem, because this implies that empty space contributes to the cosmological evolution through the cosmological constant Λ. Currently, quantum field theories require Λ to be around 10^{120} times higher than corresponds to the universe we observe. This problem should be solved by finding a proper unification of quantum and macroscopic field theories.

2.2 CMBR

Because cosmic defects carry energy-densities, and can play a role in structure evolution, they must have some influence on the Cosmic Microwave Background Radiation (CMBR). Since the *COBE* satellite produced its map with 7° resolution, attempts have been made to calculate synthetic *CMBR* maps with different evolutionary models. Unfortunately, the calculation of a *CMBR* map including cosmic defects is a non-linear problem, but attempts have been made by Coulson et al. [1], and very recently by Turok [4]. Turok predicts that the *CMBR* should show non-Gaussian anisotropies of 5 σ at a scale of $20''$.

2.3 Future experiments

Several new *CMBR* satellites, such as *CMB/Planck*, are being developed, which will shed light on the cosmological evolution of our universe. Yoshida et al. [7] argues that annihilating cosmic defects can produce extremely high energy neutrinos (10^{15} GeV). These neutrinos are beyond the detection capabilities of modern detectors, but might be within reach of future huge surface area detectors that look for electromagnetic air showers.

The case for cosmological defects is certainly not closed yet, but experiments in the near future could decide its fate.

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1998 Conference on Computational Physics - CCP 1998

September 2-5 1998, Granada (Spain)

Sponsored by European Physical Society, International Union of Pure and Applied Physics, American Physical Society, and Institute of Physics
Organized by EPS Computational Physics Board and Institute Carlos I for Theoretical and Computational Physics of the University of Granada

The CCP 1998, to he held at the Exhibition and Conference Centre in Granada, initiates a new series that continues the tradition of both the APS-EPS Physics Computing conferences (Boston 1989, Amsterdam 1990, San José 1991, Prague 1992, Albuquerque 1993, Lugano 1994, Pittsburgh 1995, Krakow 1996, Santa Cruz 1997), and the Asian ICCP conferences (Beijing 1988 and 1993, Taiwan 1995 and Singapore 1997), some of which have also been supported by the IUPAP.

PROGRAMME

The CCP 1998 is planned to cover ALL fields of Computational Physics, in particular, Modelling Collective Phenomena in Complex Systems (including biology, chemistry, economy, environmental sciences, geology, sociology, etc), thereby enhancing contacts and the exchange of ideas and methods between these different fields of science. Therefore, the final programme will consist of invited lectures and other contributions on

Computer-aided Simulation and Modelling
Novel Monte Carlo Methods, Novel Methods in Fluid Dynamics, Quantum Computing Methods, High Performance Visualization, Large Scale Computing Systems, Symbolic Modelling, ...

And their Applications to
Condensed Matter and Materials Science, Statistical Physics, Nonlinear and Adaptive Systems, Astronomy and Cosmology, High Energy Physics and Accelerators, Nuclear and Plasma Physics, Atomic, Molecular and Optical Physics, Environmental and Geological Phenomena, Pattern Recognition and Classification, Artificial Intelligence and Neural Netwoks, Industry such as Modeling Industrial Devices, Materials and Processes, ...

Scheduled list of speakers and topics (when confirmed):

Albano E. (La Plata), MC simulations of irreversible reaction processes: phase transitions, oscillations and propagation of chemical waves;
Allen M.(Bristol), Simulations and theories of liquid crystals;
Andrade J.S. (Ceara);
Andreoni W. (IBM-Zurich);
Autin B. (CERN), Symbolic modeling of high energy beam optics;
Banavar J.R. (Pennsylvania), On river networks;
Barkema G. (Julich), Towards long-time dynamics of disordered materials;
Bastea S. (Michigan), Particle simulation of the Boltzmann-Vlasov equation;
Batrouni G. (Nice), Dual quantum MC for Bosonic Hubbard Models;
Benettin G.(Padova);
Biehl M. (Wuerzburg), A simple model of slope selection and coarsening in epitaxial growth;
Binder K. (Mainz), Understanding the glass transition and the amorphous state of matter: can computer simulation solve the challenge?;
Bonilla L.L. (Madrid), Complex dynamics in semiconductor superlattices;
Bowler K. (Edinburgh), Lattice QCD;
Bray A. (Manchester), First-passage exponents for coarsening phenomena;
Brey J. (Seville), Direct Monte Carlo simulation of dilute granular flow;
Cannas S.A. (Cordoba, Ar.), Modeling plant spread in forest ecology using cellular automata;
Ceperley D. (Urbana);
Chakraborty B. (Brandeis), Modelling the glass transit.;
Ciccotti G. (Roma);
Coppersmith S. (Chicago);
Cordero P. (Santiago de Chile), Non-Newtonian Boltzmann-Grad hydrodynamics: theory and microscopic simulations;
Dagotto, E. (Florida);
Davis J. (Livermore Nat. Lab.), Applications and challenges of teraflop computing in the environmental sciences;
Derrida B. (Paris), Selection of velocity and shape of propagating fronts;
Deutsch H-P. (Arthur Andersen), Computational methods in the pricing and risk management of modern financial derivatives;
Dhumieres, D. (Paris), Visco-elastic models using lattice Boltzmann equation;
Dickman R. (Florianopolis), SOC and absorbing-state transitions;
Dippel S. (Philips), Molecular dynamics simulations of granular flow on a rough inclined plane;
Domany E. (Weizmann), On protein folding or clustering of data;
Donnelly D (New York);
Dorso C.O. (Buenos Aires), Fragmentation of hot drops;
Droz M. (Geneva), Cellular automata and modeling of physical systems;
Duxbury P. (Michigan);
Ebeling W. (Berlin), Modelling and simulations of complex systems (including economical) - From individual to collective Dynamics;
Evertz H.G. (Wuerzburg), Quantum simulations: the loop algorithm;
Fernandez J.F. (CSIC-Zaragoza), Algorithms for generating good exponential and Gaussian random numbers;
Fisher D.S. (Harvard);
Fratzl P. (Vienna), Microscopic modelling of phase separation associated with elastic strains;
Goedecker, S. (Stuttgart), The solution of multiscale differential equations using wavelets;
Grosberg A. (Cambridge, MA), Computational models of kinetics of protein folding;
Gubernatis J.E. (Los Alamos NL), Constrained-path Monte Carlo};
Gunton J.D. (Lehigh), Phase turbulence in low Prandtl number fuids with stress free boundaries;
Havlin S. (Ramat Gan), Scaling in economics systems;
Jacob C. (Erlangen), Evolution and co-evolution of developmental programs;
Jain S. (Bangalore), Collective behavior in evolutionary games;
Janke W. (Mainz);
Jauslin H.R. (Bourgogne), Grid methods, Hilbert space basis and Laczos algorithms for simulations of quantum dynamics: control of molecular processes by strong laser pulses;
Kalos M.H. (Cornell), Correlated walkers for continuum systems in Fermion Monte Carlo;
Kinzel W. (Wuerzburg), Phase transitions of neural networks;
Kiwi K. (UC Chile);
Kolinski A. (Warsaw), High coordination lattice models in the protein folding problem;

Kremer K. (Mainz), Multiscale modeling of polymer materials;
Landau D.P. (Georgia), Kinetic MC simulations of nonequilibrium film growth;
Leath, P. (Piscataway);
Lebowitz, J.L. (New Brunswick, N.J.), Physical reality, mathematical models and computer simulations;
Leeuwen, J.M.J. van (Leiden), Large scale calculations of quantum groundstate properties;
Lomdhal P. (Los Alamos Nat. Lab.);
Lucena L.S. (Natal), Simulations of branched polymers in disordered media:complex behavior;
Mantegna R.N. (Palermo), Simulation of nonstationary stochastic processes in physics and finance;
Marder M. (Texas), Rapid fracture of silicon in the computer;
Mareschal M. (Bruxelles), Characterization of statistical properties in non-equilibrium fluids by NEMD;
Meakin P. (Oslo), Computer simulation of meandering rivers and fluvial fans;
Mendoza C. (IVIC Caracas), The IRON project};
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Houston, we have a problem!

by Miguel Carrión

Problems worthy of attack
Prove their worth by hitting back
—*Piet Hein*

This is the fourth instalment of JiAPS' problem section, and we are yet to receive a contribution from the readers. A problem section is for the readers to send in solutions and more problems, so without your participation there's not much point in going on with it.

The layout of this section is simple: first a list of proposed problems is given, and then come the solutions (hopefully yours!) to some of the problems from previous issues. No problem is ever closed. Even after a solution has been published, if a different solution, an extension, or a comment is received, it will of course be published. But let us get to the point.

The Problems

Problem #5: It is well known that an electric dipole in a uniform electric field experiences a torque tending to orient the dipole parallel to the field. For a neutral object without a permanent dipole moment, a non-uniform field gives rise to a net force. Prove or disprove the conjecture that a neutral conducting object in a uniform electric field will in general experience a torque. [Hint: a spherical object obviously experiences no torque]

Problem #6: Christiaan Huygens, the inventor of the pendulum clock, first observed the phenomenon known as 'entrainment' or 'phase locking', which can be described as follows. Two different clocks, having minute differences in length and mass of their bobs, would oscillate freely at slightly different frequencies and therefore develop a phase difference even if they started oscillating in phase. However, if those two clocks were mounted on the same wall, they would end up oscillating synchronously despite the difference in natural frequencies.
Write a simple model of two weakly-coupled nonlinear oscillators (e.g. obeying the simple pendulum equation) and explain how Huygens' 'phase locking' arises, possibly giving conditions the natural frequencies must satisfy for the phenomenon to arise. [Note: this should be an exceedingly difficult problem to solve with more than 'handwaving' arguments, but that's precisely the point]

Problem #9: A solid limited by a paraboloid of revolution and a plane normal to its axis is dropped on a denser fluid. Find the equilibrium position(s) and study their stability for all possible height-to-diameter ratios. [Note: this problem was completely solved by Archimedes (287-212 B.C.) using geometrical methods and without calculus! Think about *that* when you solve it.]

Problem #10: Consider the following simple model of a 1D atom with two electrons:

$$\hat{H} = -\frac{1}{2}\left(\frac{\partial^2}{\partial x_1^2} + \frac{\partial^2}{\partial x_2^2}\right) - Z\left(\delta(x_1) + \delta(x_2)\right) + \delta(x_2 - x_1),$$

with $Z > 0$. Find a stronger condition on Z so that there are bound states.

Problem #11: Write down an equation of motion for a soap bubble. What are the frequencies of its normal modes of vibration about the equilibrium configuration, namely a sphere of radius R? If the bubble stands on the rim of a funnel of radius r, what are the "quantization conditions" relating R, r, and the frequencies of the modes? [Hints: consider the contribution of surface tension and air pressure to the energy of a bubble. You may want to use a lagrangian formulation to derive the equation of motion. Once you have the normal modes for a "free" bubble the answer to the last part should jump off the page.]
This problem is based on Finn Macleod's lecture *"Resonance of Bubbles with Simple Harmonic Motion"* in the ICPS'97.

The Solutions

Problem #7: Consider a shallow canal filled with water to height h_0. A step-shaped wave front of height Δh moves with constant velocity. How does the velocity depend on the heights? What happens if a second step of height δh moves on top of the first?

Solution

We will assume that the wave front moves with velocity v, that the water before the front is static and that the water behind it moves with velocity u (it turns out that $u \neq v$). We will obtain the velocity from mass and momentum conservation.

Let $x = x_0$ be the position of the front at $t = t_0$. In a time Δt, a volume of water $(h + \Delta h)u\Delta t$ will have crossed the plane $x = x_0$, and the advance of the wave front covers a volume $\Delta hv\Delta t$. Mass conservation implies

$$\rho(h + \Delta h)u\Delta t = \Delta m = \rho\Delta hv\Delta t \Rightarrow \frac{v}{u} = \frac{h + \Delta h}{\Delta h}.$$

Now, as a result of the advance of the wave front, a stretch of still water of height h and length $v\Delta t$ is accelerated to velocity u. The gain in momentum is $\Delta p = \rho hv\Delta tu$, and the force accounting for this is caused by the difference in pressure on both sides of the front. The average pressure at x is ρg times the average height, and it acts on a surface proportional to the heigth ($h + \Delta h$ behind the wave fron, and h before it). The force is therefore $F = (1/2)\rho g\left[(h + \Delta h)^2 - h^2\right]$. Momentum conservation gives (using the mass conservation equation to eliminate u)

$$\rho hvu = \frac{1}{2}\rho g\Delta h(2h + \Delta h) \Rightarrow hv^2 = \frac{1}{2}g(h + \Delta h)(2h + \Delta h) \Rightarrow v^2 = gh\left(1 + \frac{\Delta h}{h}\right)\left(1 + \frac{\Delta h}{2h}\right).$$

The velocity v of the front is, for very low step heights, $v \simeq \sqrt{g}h\left(1 + \frac{3\Delta h}{4h}\right)$. If the water of the canal moves with velocity v_0, then this expression gives $(v - v_0)^2$ [Note: in fact, $\sqrt{g}h$ is the velocity of surface gravity waves in the general case, for example that of surface waves in the sea.]

The velocity w of the second smaller step can be obtained with the substitutions $v \to w - v$, $\Delta h \to \delta h$, and $h \to h + \Delta h$, *i.e.* $(w - v)^2 \simeq \sqrt{gh}\left(1 + \frac{3\delta h}{4(h+\Delta h)}\right)$. This indicates how rapidly the smallest step will catch up with the bigger one.

Problem #8: A simple model for a quantum dot —see the article *"Artificial Atoms"* by Jorg Jansen in issue 3— is a pillbox-shaped potential well of 'depth' V_0 (the ionization energy). Does this "artificial atom" possess infinitely many bound states? What conditions need to be imposed on the dot dimensions (diameter and thickness) for all the bound states to be two-dimensional?

Solution

The symmetry of the problem suggests the use of cylindrical coordinates, (r, θ, h). To represent the dot we will use the following symmetric potential:

$$V(\mathbf{r}) = \begin{cases} \infty & \text{if } r \geq r_0; \\ 0 & \text{if } r < r_0, h \geq h_0; \\ -V_0 & \text{if } r < r_0, h < h_0. \end{cases}$$

This describes a cylindrical well of radius r_0 and height $2h_0$. While the infinite potential may not be realistic, it has the virtue that it makes the potential is separable. In any case, it is true (see the diagram in Jorg's article) that it is much easier for electrons to enter or leave the dot moving parallel to the cylinder's axis. As the effect of the infinite potential is to make the wavefunction vanish at $r = r_0$, we can write this potential simply as $V(h)$.

We now seek solutions to Schrödinger's time-independent equation

$$-\frac{\hbar^2}{2m}\left[\left(\frac{\partial}{\partial_r} + \frac{1}{r}\right)\frac{\partial}{\partial r} + \frac{1}{r^2}\frac{\partial^2}{\partial\theta^2} + \frac{\partial^2}{\partial h_0^2}\right]\psi = E\psi$$

of the form $\psi(\mathbf{r}) = R(r)Y(\theta)H(h)$. The functions R, Y and H satisfy

$$\begin{cases} \frac{d^2Y}{d\theta^2} + l^2Y = 0, & (1) \\ \left(\frac{d}{dr} + \frac{1}{r}\right)\frac{dR}{dr} + \left(a^2 - \frac{l^2}{r^2}\right)R = 0, \quad R(r_0) = 0, & (2) \\ \frac{d^2H}{dh^2} + \left[2\left(E - V(h)\right) - a^2\right]H = 0, & (3) \end{cases}$$

where we have taken *atomic units* by letting $\hbar = m = e = 1$. This means distances are measured in units of the Bohr radius, and energies in Hartree (1 Ha = 2 Ry = 27.2 eV).

The solution to the equation (1) is simply

$$Y_l(\theta) \propto e^{il\theta}, \qquad \text{with} \quad l \in \mathcal{Z}.$$

Here l represents the orbital angular momentum of an electron in the dot. Only the z component of angular momentum is conserved in this case, and it can take all integer values (l and $-l$ represent different solutions).

With the substitution $\rho = ar$, $R(r) = J(\rho)$ equation (2) becomes Bessel's equation for J

$$\left(\frac{d}{d\rho} + \frac{1}{\rho}\right)\frac{dJ}{d\rho} + \left(1 - \frac{l^2}{\rho^2}\right)J = 0.$$

For each value l of the angular momentum the solution is the Bessel funcion of order l,

$$J_l(\rho) = \left(\frac{\rho}{2}\right)^l \sum_{q=0}^{\infty} \frac{(i\rho/2)^{2q}}{q!(l+q)!}; \qquad J_{-l} = (-1)^l J_l.$$

This closed form of the solution is not very important for our purposes. The interesting thing to note is that if the electron has angular momentum l, then the radial wavefunction has a zero of order l at the origin, as in the case of the hydrogen atom. Now, the boundary condition $J_l(ar_0) = R(r_0) = 0$ means that the edge of the the dot must coincide with a zero of the radial wavefunction. This means that the radial wavefunction must have at least $l + 1$ zeros (the ones at the origin, the one at the edge, and then any number of them in between). Following the convention of atomic physics that the principal quantum number n equals the number of zeros of the radial wavefunction including those at the origin, one recovers the rule that l can take the values $0, \cdots, n-1$. The boundary condition also fixes the energy because a^2 appears as a contribution to the energy in equation (3), and a is determined by the condition that $r_0 a$ be a zero of J_l. If z_{nl} is the $(n-l)$th zero of J_l, then $a_{nl} = z_{nl}/r_0$, so a table of the zeros of Bessel's functions gives the spectrum of a one-electron quantum dot.

It seems that the dot does have infinitely many bound states, but we still don't have an expression for the total energy, which must be less that 0 for a bound state. We will see that the dot has "bound states in the continuum", and that only finitely many have $E < 0$.

We now turn to the question of whether the states are all "two-dimensional". Equation (3) is that of a particle in a finite square well, which may or may not have more than one bound state. If there are more than one, then we will need a third quantum number apart from n and l, and the problem will cease to be "two-dimensional". We will derive the very reasonable condition that the dot is not too thick, and will obtain an expression for the maximum thickness.

Since the potential in equation (3) is even, the solutions will be either even or odd. We can therefore limit our discussion to the region where $h > 0$. Either

$$H(h) = \begin{cases} A\cos(\omega h) & \text{if } h < h_0, \\ Be^{-\kappa h} & \text{if } h > h_0; \end{cases} \qquad \text{or} \qquad H(h) = \begin{cases} C\sin(\omega h) & \text{if } h < h_0, \\ De^{-\kappa h} & \text{if } h > h_0; \end{cases}$$

where $\omega^2 = 2(E + V_0) - a^2$ and $\kappa^2 = a^2 - 2E$. The even (cosine) solutions and their derivatives are continuous at $h = h_0$ if $\kappa = \omega\tan(\omega h_0)$, and the odd (sine) solutions if $\kappa = -\omega\,\mathrm{cotan}(\omega h_0)$. Using $\omega^2 + \kappa^2 = 2V_0$, we get

$$\sqrt{\frac{2V_0 h_0^2}{(\omega h_0)^2} - 1} = \begin{cases} \tan(\omega h_0) & \text{if } H(h) \text{ is even,} \\ -\mathrm{cotan}(\omega h_0) & \text{if } H(h) \text{ is odd,} \end{cases}$$

with the condition that $\omega^2 \leq 2V_0$. There is always at least an even solution (the ground state of the well) with $\omega h_0 \leq \pi/2$, which is good because it means the well can bind at least an electron with $n = 1$ and $l = 0$. Now, there is an odd solution in the range $\pi/2 \leq \omega h_0 < \pi$ unless $2V_0 h_0^2 < \pi^2$; in other words, the condition for all the bound states to be two-dimensional is that $2V_0 h_0^2 < \pi^2$. If V_0 is of the order of 1 eV, the thickness of the well must be $2h_0 < 2\pi\sqrt{13.6} \approx 23.2 a_0 \approx 12.25$ Å. If the well is thicker (for instance, of the order of 10 nm) then the potential must be smaller (respectively one hundredth of an electron-volt).

With the expression for the energy we can go back to the question of the number of bound states. A state is bound if

$$E = \frac{a_{nl}^2 + \omega^2}{2} - V_0 < 0,$$

and if n or l are too high the inequality won't hold. Therefore there are only finitely many bound states with negative energy (maybe even none!), and if we try to increase their number by increasing V_0 we might exceed the bound $2V_0 h_0^2 < \pi^2$ and the dot would cease to be "two-dimensional".

[Note: Bessel functions appear whenever a problem has cylindrical symmetry. A very nice physical illustration of this can be found in *The Feynman Lectures on Physics*, vol. 2, ch. 23.]

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The Story of Little Red Boson String and the Ferocious Tachion

by Juan Antonio Martinez Rojas – translated by Miguel Carrión-Álvarez

Once upon a time, in a galaxy far, far away, there lived a little bosonic string who had, as a child, been mistaken for a crimson quark, and so everyone around the locus called her "Little Red Boson String".

One day, at some 10^{-43} seconds, her mother P-Brane said to her: "Little String, darling, why don't you go by your granny's cottage and bring her a basket of monopoles, axions, and those kinds of topological defects she is so fond of?"

Filled with joy, Little String took her basket and set out for her granny's cottage. As she traversed the Unification Forest, one could hear her carefree, happy singing. "I'm Little Red String, oscillating through the Quantum Vacuum to see my granny, the Little Fundamental Rope."

Meanwhile, an enormous 10^{-33}-metre behemoth, evil and swift, was stalking in the undergrowth. "Ah, ha, ha,... I'm the Ferocious Tachion and I run faster than light. Not even the photon can catch me, and I shall fill this theory with ghosts."

The Ferocious Tachion tied a knot on Granny, disguised himself in one of Little Rope's Higgs' sleeping gowns, and waited to devour Little String as soon as she let her Feynman diagram show in the 26-dimensional spacetime.

Shortly thereafter Little String came by and, baffled by the tremendous uncertainty of the disguise, started to ask: "Granny, what a big coupling constant you have!" "It's to interact better with you, dear child." "But Granny, what an imaginary mass spectrum you've got!" "It's to detect you better, Little String." "Plank-it, Granny, what a weird spontaneous symmetry breaking you have!" "It's to disintegrate you better, arghh...!"

At the precise (magnetic) moment that the Tachion jumped on Little String aiming to disintegrate her into a mole resonant modes of vibration, there appeared the unfathomably epic Hero from the compactified dimensions. "I'm Superbootstrap, and I shall supersymmetrize the Tachion before the self-consistency of the field messes me up." "Plank-it, Superbootstrap is going to join bosons and fermions in a single state and strip me of my Spin!" At that very instanton, the Tachion vanished not to be heard of again. In time, Little String became a very heterotic young lady and, finally, she and Superbootstrap fell in love, got married and had a little son who looked very much like a lace. So attractive was their son, that they decided to call him Graviton.

Graviton grew up to be a very important particle, despite his having been born massless; his range was so long that all other particles came to him to mediate their interactions, disregarding their own forces. He was even awarded the order of spin-2 for his active part in the Inflationary Crisis.

After Inflation he resigned his position in the Grand Unified Group and his public appearances are now limited to weak ripples cruising the Universe until he is needed again in his old capacity. Ever since, there is Gravity, but no-one can explain it, and…

…all is well that ends well.

Learning to trace particles

The Accelerator School, promoted by the Fermilab, offers courses related to accelerators. Those courses are given two times per year, during the summer and winter periods. This year the US Particle Accelerator School took place at the University of Texas at Austin. Previous editions were held at MIT.

Every year the turnout includes mainly students working on accelerator-related tasks, as well as degree and post-graduate students who are awarded credits they can transfer to their respective universities.

The courses, on topics such as "Linear Accelerators" (LINAC), "Electrostatic Accelerators", "Accelerator Fundamentals" (for undergraduate students), etc., are given by recognised teachers from Yale, Stanford, Fermilab, Italy (Trieste), Germany, etc.

I took part in the last course (Accelerator Fundamentals) thanks to a scholarship. The requisite to obtain the final grade were computer sessions and homework due to following morning. After two weeks, a final examination was taken.

The objective of the School is to specialize students, interested people and personnel working at accelerators, as well as to establishing stronger links between them. The course can be taken as "Credit" or "Audit". For those interested in Particles Physics, or wishing to know more about accelerators, taking a course in this School would not be a bad idea.

For further information contact USPAS (US Particle Accelerator School) :
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