New Directions in Theoretical Physics

Higgs Centre for Theoretical Physics
January 8–10, 2014

Wednesday, 8 January **Appleton Tower, lecture theatre 4**

12:30–13:30 Lunch (Teviot Row House)

14:00-14:10 Welcome and Introduction
Speaker: Richard Ball (Edinburgh)

14:10–15:00 The Higgs and the excessive success of the Standard Model
Speaker: Guido Altarelli (Rome)

Abstract: We present a concise outlook of particle physics after the first Large Hadron Collider (LHC) results at 78 TeV. The discovery of the Higgs boson at 126 GeV will remain as one of the major physics discoveries of our time. But also the surprising absence of any signals of new physics, if confirmed in the continuation of the LHC experiments, is going to drastically change our vision of the field. At present the indication is that nature does not too much care about our notion of naturalness. Still the argument for naturalness is a solid one and we are facing a puzzling situation. We review the established facts so far and present a tentative assessment of the open problems.

15:00–16:00 Symmetry breaking and electroweak unification – an Imperial College perspective
Speaker: Tom Kibble (Imperial)

Abstract: This will be a historical account of the development of the idea of spontaneous symmetry breaking in gauge theories, and its use in constructing the unified electroweak model, from my perspective as a member of the Theoretical Physics Group at Imperial College led by Abdus Salam. I will talk about physics in the 1960s, early efforts at unification, the obstacles encountered, in particular the Goldstone theorem, and how they were eventually overcome by the Higgs mechanism. Later developments will be sketched briefly, ending with some comments on the present and future.

16:00–16:30 Tea

16:30–17:10 Higgs interferometry
Speaker: Lance Dixon (Stanford)

Abstract: The lifetime of the Higgs boson is a critical parameter of this newly discovered particle. However, at the Standard Model value, the lifetime is impossible to measure directly at the LHC: it is far too short to give rise to displace vertices, and far too long to generate an experimentally resolvable width. However, at the LHC, quantum interference between the continuum background and the Higgs boson resonance in the diphoton decay mode causes a small shift in the apparent mass. We discuss how this mass shift could be used in the future to bound the Higgs boson width to close to the Standard Model value. We also mention a few other properties of Higgs interference, such as its effect on angular analyses used to infer particle spin.

17:10-17:40 The ubiquitous top quark
Speaker: Eric Laenen (Nikhef)

Abstract: The top quark, now in its late teens, plays a central role in many analyses and searches for new physics at the LHC. I will review why this is so, and discuss in particular recent advances in how to describe the top quark production and decay processes precisely, including the spin of the top quark, and with possible new physics influences. Some recent theoretical advances, and experimental results will also be shown.

09:30–10:20 Transition to turbulence in pipe flow: a dynamical systems perspective
Speaker: Bruno Eckhardt (Marburg)

Abstract: The transition to turbulence to turbulence in pipe flow has been an outstanding problem in turbulence since the careful experiments by Osborne Reynolds in Manchester in 1883. It is not connected with a linear instability of the laminar profile, it does not seem to pass through a series of successive bifurcations of ever increasing complexity, and it spatially heterogeneous with patches of laminar embedded in the turbulence. In recent years a consistent picture of the fundamental processes underlying this transition has emerged. Its key features include fully nonlinear, three-dimensional flow states that have been identified numerically, their long-wavelength instabilities that give rise to spatial patterns, and analogies to directed percolation that explain the statistical properties of the spatio-temporal dynamics.

Ref: B. Eckhardt, Science 2011 vol. 333 (6039) pp. 165–166

10:20–10:50 Modeling of tunable reconfiguration of Janus colloidal particles
Speaker: Ronald Larson (Michigan)

Abstract: Colloidal particles can assemble into a myriad of structures by virtue of the many interaction forces available to them. Variable range attraction and repulsion and the recently explored non-isotropic character, exemplified by Janus particles, are examples of the versatility of colloidal particles as building blocks. A systematic approach to understand the assembly of Janus colloids, as a function of Janus balance and particle concentration is not yet available. In this work we study the phase behavior of Janus particles as a function of the strength of interaction, Janus balance and volume fraction of spherical particles. A secondary goal of this work is the assessment of re-configurability of the structures found. Our results show the range of stability of several structures, including a fluid phase of small clusters, bilayers and worm-like aggregates. We find the bilayer structures are very stable over a range of phase space and provide a good pre-cursor to hexagonally close-packed structures. These findings enable the understanding of the assembly process of Janus building blocks and provide a framework with which to study the kinetics of structure change.

10:50–11:10 Coffee

11:10–12:00 Probing fundamental physics with cosmological observations
Speaker: Robert Brandenberger (McGill)

Abstract: New cosmological windows are opening up which will allow us to probe high energy physics with new tools. I will discuss how quantum field theory models beyond the Standard Model of particle physics can be explored by means of cosmic microwave background and 21cm redshift surveys, and how gravitational wave measurements might reveal signals of Planck-scale physics.

12:00–12:30 Planck confronts the Standard Model(s)
Speaker: Andrew Jaffe (Imperial)

Abstract: The recent results from the Planck Satellite, combined with other astrophysical data, allow us to build a remarkable and simple description of the history and contents of the Universe. I will give an overview of these results and their implications for the Lambda Cold Dark Matter standard model of cosmology. This model is, however, not complete, and nor are the current data completely consistent between different experiments, even those using the same underlying data. I will also discuss some of these inconsistencies and whether they can be explained by statistical flukes, systematic errors in the analyses of the various datasets, or whether new physics beyond the standard models of cosmology and particle physics might be required.

12:30–13:00 Higgs role in inflation, baryogenesis & dark matter
Speaker: Anupam Mazumdar (Lancaster)

Abstract: I will discuss how the discovery of Higgs Boson and its mass has helped us shaping some of the key features of Beyond the Standard Model physics, in particular constructing models of inflation, creating matter-anti-matter asymmetry, and the dark matter constraints.

13:00–14:00 Lunch and Higgs Centre IAC meeting

14:00–14:40 Quantum physics without quasiparticles
Speaker: Subir Sachdev (Harvard)

Abstract: Many quantum critical points in condensed matter realize quantum ground states with long-range quantum entanglement, and have excitations which cannot be formulated in a quasiparticle basis. The simplest such states are described by conformal field theories in 2+1 dimensions, whose description is aided by dual gravitational theories. I will review these ideas using model systems, and discuss applications of their extensions to the high temperature superconductors.

14:40–15:10 Condensed matter: plenty of places to go but which direction to get there?
Speaker: Andy Schofield (Birmingham)

Abstract: Condensed matter physics has long-enjoyed a symbiotic relationship with the theoretical ideas of particle physics. At this point both fields face differing challenges. In condensed matter there are a wealth of puzzling experiments many of which suggest the possibility of universal physics but where we do not yet have a theoretical framework to account for the observations. High energy physicists have a wealth of intriguing theoretical ideas beyond the Standard Model which, though it must break down eventually, is yet to do so in current experiments.

In this talk I will discuss some of the experimental challenges and some hints at where the new ideas might come from. As a tangible example we consider the Luttinger liquid model of the one-dimensional metal and the possibility that this model might be more universal than previously thought [work with O. Tsyplyatyev].

15:10–15:40 Phase reconstruction near the high-symmetry point of the $O(2) \times O(2)$ nonlinear sigma model
Speaker: Chris Hooley (St Andrews)

Abstract: A recent topic of interest in several fields of theoretical physics has been the reconstruction of the phase diagram near a quantum critical point between two distinct bulk ordered phases. This becomes even more fascinating when the system is (2+1)-dimensional with an O(2) order parameter, since in this case exotic vortex-driven transitions can occur at finite temperatures. In this talk, I report on our recent work at the intersection of these two topics, discussing the change in the nature of the finite-temperature vortex-unbinding transition as a high-symmetry point is approached. In particular, I give a detailed analysis of this question in the classical limit, and indicate what is likely to change when quantum effects are included. Prospects for further work are also discussed.

15:40–16:10 Tea

16:10–16:50 On quantum tunnelling
Speaker: Neil Turok (Perimeter)
Abstract: I develop a first-principles, real time description of quantum tunneling in the semiclassical limit, employing complex classical solutions. Implications for experiments in condensed matter systems, for quantum field theory (including the metastable minimal Higgs theory) and for the reliability of the "inflationary landscape" are discussed.

16:50–17:20 Lattice QCD and search for BSM physics in neutron decays and nEDM
Speaker: Rajan Gupta (Los Alamos)
Abstract: The search for novel physics at the TeV scale is being pursued both at the highest energies at the LHC by direct detection of new particles as well as precision measurements at low energies that expose deviations from the standard model. A key input in using precision measurements to constrain TeV physics is precision measurements of matrix elements of relevant operators within hadrons that include QCD corrections. Lattice QCD is now providing the best non-perturbative estimates of these with control over all systematic errors. I will describe two such calculations, one which involves the search for new (scalar and tensor) interactions and the other that provides stringent constrains on possible extensions of the standard model (nEDM).

17:20–17:50 All-order perturbative results for gauge field theories
Speaker: Lorenzo Magnea (Torino)
Abstract: I will briefly review the ideas underlying exponentiation and resummation of gauge theory amplitudes and cross sections, and discuss some recent developments and selected applications to collider phenomenology.

19:30–21:30 Conference dinner (Playfair Library, Old College, South Bridge)

10:00–10:50 Gravity from squaring YangMills
Speaker: Michael Duff (Imperial)

Abstract: First we give a unified division algebraic description of $(D = 3, N = 1, 2, 4, 8)$, $(D = 4, N = 1, 2, 4)$, $(D = 6, N = 1, 2)$ and $(D = 10, N = 1)$ super-Yang-Mills theories. The well-known result that the maximally supersymmetric algebras close only on-shell is attributed directly to the non-associativity of the octonions. By tensoring left and right Yang-Mills multiplets, we then construct $N = N(L) + N(R)$ supergravity theories in $D = 3, 4, 6$ and 10. Their U-duality groups fill out a "magic pyramid" whose 4×4 base in $D = 3$ is the Freudenthal magic square.

10:50–11:20 Vacuum decay and the end of the Universe
Speaker: Ian Moss (Newcastle)

Abstract: An old idea has it that black holes could act as nucleation sites for vacuum decay, helping bring about the beginning of the universe or ending it in a cosmic catastrophe. Ruth Gregory, Ben Withers and I have recently found that the decay rate is far higher that previously believed, but the end of the universe is not nigh (probably).

11:20–11:40 Coffee

11:40–12:10 Symmetries and broken symmetries in non equilibrium systems
Speaker: Bernard Derrida (Paris 6)

Abstract: This talk will review a few examples of symmetries and broken symmetries in non equilibrium physics, starting with the Boltzmann theory of irreversibility which breaks the time reversal symmetry of microscopic dynamics, discussing the symmetry of current fluctuations predicted by the fluctuation theorem, the broken symmetry of fluctuations in non-equilibrium steady states, the appearance of phase transitions in one dimensional steady states.

12:10–12:40 Upside-down quartic potentials
Speaker: Carl Bender (St Louis)

Abstract: The quantum mechanics defined by a PT-symmetric Hamiltonian is a complex generalization of ordinary quantum mechanics. When quantum mechanics is extended into the complex domain, new kinds of theories having strange and remarkable properties emerge. In the past four years some of these properties have been verified in a wide variety of laboratory experiments. A particularly interesting PT-symmetric Hamiltonian is $H = p^2 - x^4$, which contains an upside-down quartic potential. We will explain in intuitive as well as in rigorous terms the surprising result that the energy levels of this potential are real, positive, and discrete.

The corresponding PT-symmetric $-\phi^4$ quantum field theory is remarkable. Like a conventional ϕ^4 theory, its spectrum is bounded below. However, unlike a ϕ^4 theory, it is asymptotically free and thus is nontrivial in four dimensions. Moreover, because parity symmetry is broken, the expectation value of ϕ is nonzero without resorting to spontaneous symmetry breaking. This may have applications in describing the Higgs sector of the Standard Model.

Finally, we discuss the double-scaling limit of an O(N)-symmetric quartic quantum field theory. This limit is inconsistent because the critical coupling constant is negative. Thus, at the critical coupling the Lagrangian defines a quantum theory with a quartic upside-down potential whose energy appears to be unbounded below. Worse yet, the integral representation of the partition function does not exist. To avoid these difficulties we replace the original theory by its PT-symmetric analog. The partition function for the PT-symmetric analog of a zero-dimensional O(N)-symmetric quartic vector model is calculated explicitly in the double-scaling limit.

12:40–13:10 How to make an invisibility cloak
Speaker: Chris White (Glasgow)

Abstract: Transformation optics is a rapidly developing field, involving modeling the passage of light rays in materials using the mathematics of curved spaces. This is typically applied to so-called meta-materials, with spatially varying properties, whose applications include the construction of invisibility cloaks. Such materials, however, can be costly to produce, and limited to particular wavelengths and polarisations. In this talk, we explore the use of novel two-dimensional windows in transformation optics devices, which are in principle mass-producable. We use these windows to design a cloaking device that works for any polarisation and wavelength, and perform detailed computer simulations to demonstrate its feasibility.

13:10–13:20 Concluding remarks