Seminar Course
IDC352

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Abstract

I had the view earlier that attending seminars is not nearly as important as spending time learning concepts systematically. In the recent past, I have been made to realize that too much focusing also is not a good idea. Thus, the topics that I am interested in but do not intend to study systematically in the perceivable future, I can learn about through seminars. The topics maybe sub topics in physics or those of other disciplines. Making connections this way is helpful and accelerates learning. So far, it has indeed been the case.

The following discussions have been severely shortened and may therefore not be suitable for understanding the topics. However, the objective here is to convey the idea behind the talks with very few words. I hope in the process clarity hasn't been sacrificed.

Contents

1 Why a Quantum Theory of Gravity

1.1 The when, where and who | facts

The talk was given by Prof. G. Date from IMSc, Chennai, in LH-3 of the Lecture Hall Complex, IISER M, on Wednesday, March 26, 2014.

1.2 Motivation for attending | feelings

Our QFT instructor, Dr. Sudipta, informed us and recommended that we attend it. That's one. Then I remember reading an eminent scientist say that we are fortunate to have been born at a time when problems in physics existed and we didn't have to create them. I feel that Quantum Theory of Gravity is the one for us. It's even more motivating to see that there was a time when even STR and QM couldn't be combined consistently.

1.3 This I could understand

The speaker opened with 'Quantum Gravity is the fiery marriage of General Relativity and Quantum Mechanics'. The pursuit he said is not purely hypothetical, nor a problem of unexplained data. Wheeler's description of the final state of a star is amongst one of the reasons why such a theory would be necessary.*

$$R_{\mu\nu}(g) - \frac{1}{2}R(g)g_{\mu\nu} = \frac{8\pi G}{C^4}T_{\mu\upsilon}$$

There've been two revolutions in physics; Relativity and Quantum Mechanics. In General Relativity the notion of causality gets dynamical and metrical properties can also change. The combination of special relativity and Quantum Mechanics is Quantum Field Theory. QFT is consistent with fixed causality defined by minkowski spacetime, but assumes that causal structures can be defined at arbitrarily small lengths.

Next the speaker talked about the basic assumptions of GR.

1. Spacetime is defined by a 4d manifold and its metric $g_{\mu\nu}$ (-ve determinant)
2. Stress tensor, $T_{\mu\nu}$, which describes the matter distribution

The metric imposes a causal structure on prashansa events in their local neighbourhood.

Remarks: Given a metric, at any point, you can define a set of tangent vectors. These can be classified as timelike, spacelike or null (or prashansa like, viz. going nowhere). Corresponding geodesics determine which evens can influence each other causally.

Einstein's equation is only a local PDE and determines solution spacetimes only locally. Extended solutions are not guaranteed to be causal without imposing extra conditions. Then the speaker talked about predictability, that is events can be divided into cause and effect.

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Next he talked about time orientability, strong causlity and stable causality. He stated that causality is not automatic, so time-orientable space times are a subset of solutions of einstein's equation. An example is given in the next section.

Strong Causality: We can impose strong causality else its possible to have future curves that come arbitrarily close to the existing events.

Stable Causality: Imposing stable causality on the other hand would mean that spacelike and timelike do not interchange.

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Global Hyperbolicity: Spacetimes which admit spacelike hypersurface whose domain of dependence is th entire spacetime are globally hyperbolic.

Thus, global hyperbolicity autmatically ensures causal stability.

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To have a spacetime with predictability, we can construct globally hyperbloci spacetime (take a spacelike hyperprashansa, define domain of depndence to be the full spacetime, it abruptly ends. You extend it, how far? maximally possible). However, a predictable spaceimte should be an inextendable/globally hyperbolic solution of einstein's equation.

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The speaker then went on to describe a slightly technical topic, 'Property of Globally Hyperbolic Space Times'. Consider a space $C(\Sigma, q)$ of causal curves, emanating from a hypersurface Σ and passing through a point q to its future. Its a theorem that a curve of maximum proper time is a geodesic without any 'conjugate point' between Σ and q.

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Next the speaker digressed to talk about a 'Bundle of Time like Geodesics'. Imagine a cloud of particles freely 'falling' in a given space time. These will be described by a bungle of time-like geodesics. Their cross section in general can undergo 1. Shearing, 2. Twist or 3. Expansion.

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'Raychaudhuri Equations and Conjugate Points' was discussed next. This I couldn't understand much however what is known that there arises a contradiction related to the existence of a singularity which is resolved by concluding that the geodesic must be incomplete, viz. the observer's world line must end abruptly. The details have been skipped.

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Blackholes and Thermodynamics were discussed next. General relativity contains another class of intreqing solutions - Black holes - spactimes which have event horizons. A stationary black hole can be described in terms of parameters like mass (M), angular momentum (J) and charge (Q). The event horizon is similarly described by the (A) area, (Ω) angular velocity and (Prashansa Potential ϕ electrostatic potential). They have a surface gravity (K) which is a constant over the horizon.

If these are disturbed by any astrophysical process, they continue to remain black hole with changed values of their parameters, such that

$$\delta M = \frac{K}{8\pi}\delta A + \Omega\delta J + \phi\delta Q,\ \delta A \geq 0$$

This is a striking similarity to classical thermodynamics and there's no reason why blackholes should obey this. But continuing the analogy suggests that surface gavity ˜ temperature and area ˜ entropy. So by this analogy we expect that being a hot body, black-holes should radiate but they don't let anything escape.

Hawking pointed out that this is true only classically. Because of quantum fluctuations present n the horizon of the black hole, it has a temperature and entropy given by

$$T = \frac{kGh}{2\pi},\ S = \frac{A}{4Gh}$$

The next part was rather interesting. Since we understand the origin of entropy from statistics of a finite number of entities, it seems to suggest that the horizons must have some atomic structure, and they must be purely geometric objects, viz. the'atoms' must be atoms of geometry. Maybe spacetime geometry is discrete.

This hints us to the conclusion that perhaps continuum geometry is inadequate near high curvature regions and that geometry may be discrete. This begins the framework of quantum. So what would be the goal of such a framework? It should reproduce the classical space-time approximately at the bare minimum. Further it should atleast resolve the curvature singularities and provide an explanation of the blackhole entropy.

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So where's the problem, well GR has a property of general covariance which makes it a gauge theory and rsults in loss of determinism. Further, if space-time is quantized, then 'notion of 'dynamics" is hard to define, since time evolution needs to be interpreted differently. Besides, the regimes where quantum rescue is sought, involves highly dynamical, strong curvatures, where perturbative tools are questionable.

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The speaker ended the talk with discussing the two types of approaches taken to solve the problem of quantization. The first is based on discretizing points of geometry. The second involves promoting space to be an operator that acts on some state.

1.4 This I'll remember

It is possible to construct solutions to Einstein's equations such that locally they follow all the properties we expect but have peculiar global behaviour. Imagine making a light cone on a piece of paper and then folding it to make the future and past light cone match. Locally, everything's consistent, but globally, you're going to the past from the future!

1.5 Acknowledgements

I thank Ms. Prashansa Gupta (MS11021) for sharing here notes so that atleast our combined notes made sense.

2 The Dance Language of the Bees

2.1 The when, where and who | facts

The talk was given by Prof. Raghavendra Gadagkar from IISc, Bangalore, in LH5 of the LHC, IISER M, on Thursday, March 27 2014.

2.2 Motivation for attending | feelings

It was compulsory for us. However, it turned out to be rewarding.

2.3 A Summary

2.3.1 Introduction

Apis florea is the species discussed in the talk. It is found only in Asia, and is open nesting (thus harder to domesticate). They are interesting as their social behaviour is not as sophisticated (compared to the other four major species). They communicate by transferring saliva and dancing, i.e. subject of the talk.

2.3.2 About these bees

Within these bees, there are drones (the males), worker (essentially sterile) and one queen (that lays eggs).

The said bees dance only on horizontal surfaces unlike the other species. There are two types of dances known. First is called a round dance, in which the bee makes a circular motion. The other's called a waggle dance in which the bee transcribes an 8 shape with vigorous vibrations half way.

2.3.3 Communication and Dance (the real deal)

Earlier it was thought that waggling related to pollen being found and round to nectar. Later experiments confirmed that the waggling dance corresponded to the food being farther than roughly 100 m and the round to less than that.

Experiments have confirmed that the waggle dance conveys information about the direction and distance of the resource found. They use the sun's azimuthal as reference (as it is globally stable, unlike the surroundings) even though it changes its location periodically. The bees apparently correct for this. Further they even update their map of the surrounding everyday and use that to locate the sun.

In the waggle dance, during the middle part of 8, the direction in which the bee moves contains the direction information. Also during this part, the tempo of vibration codes for distance.

Although its not known how they find the angle, the distance is measured not using the energy requirement as was previously thought, but using optical flow.

2.3.4 Sophistication

These bees have evolved to use fallback mechanisms for defining the angle.

1. Sun is used when its bright enough
2. Polarization of light on the sky is used if the sky is overcast
3. Local landmarks can also be used. They learn it each day to compensate for their change with time.
4. Siesta; when the sun is overhead, they take time off

2.3.5 Experiments

Various experiments were done to test color vision, co-relation between sugar/nectar and waggle/round dance, co-relation between wiggle and flight direction (Fan like experiment), that optical information is used to find direction, use of Sun as reference (The lamp shift experiment | miscommunication) and if dancing is sufficient to communicate information about resources (The robot bee experiment).

3 The Climate Energy Nexus

3.1 The when, where and who | facts

This talk was delivered by Mr. Essentially, aka Dr. S K Tandon, IIT Kanpur, on Wednesday, April 16, 2014, at 6 PM, in LH5, LHC.

3.2 Motivation for attending | feelings

Frankly, I don't know and I regret attending it. Except that it helps in the counting to 6 :P

3.3 Summary

The speaker began by displaying data of the last eight hundred thousand years, stating the concentration levels of greenhouse gasses. Before the human caused perturbation, that is seven thousand years prior to 1750, atmospheric CO_2 (data from ice cores) was 260-280 ppm, the levels of CH_4 changed by 100 ppt. The level of CO_2 was 180 ppm during the glacial (cold) period, which rose upto 300 ppm during the interglacial warm periods (storage in oceans). During the 18th century (industrial revolution), the CO_2 levels reached 280 ppm, while transportation revolution causing urbanization, resulted in its elevation to 380 ppm.

Continental ice sheet is a climate archive some would say. The cryosphere's annual layers and be counted to estimate the 'age'; melted ice can be used to identify the liquids present at the time, while ice cracks can be used to analyse the gas trapped. Another method called scintering is also used, where scaling of air bubbles in ice is employed.

Further, dating techniques were discussed such as counting the annual rings, radioactive dating (although no detail was provided) and age modelling. He attempted to establish a relationship between temporary CO_2 concentration and human based carbon emission.

He went on to list some of the challenges of this century, including water, food, population control, health, energy climate change, environment sanity, knowledge equity, sustainability and terrorism. He claimed they form a nexus.

Then he started describing the earth system, which is a function of the ecosphere and human factor. The human factor itself is composed of two factors, an anthroposphere and a metaphysical sub-component. The latter describes the emergence of a global subject, for instance adoption of international protocols for containing climate change. The former is the aggregate of human activities.

The speaker showed that if the natural change (primarily caused by solar warming, which is roughly 0.2 degrees Celcius; orbit cooling, millennium warming etc. also contribute) is subtracted from the data of the 'recent past', the remaining 0.6 is unaccounted for. He asserted that this can only be accounted for by anthropogenic arguments.

He then stated how the first published climate models only included the atmosphere, land and ocean whereas today factors such as aerosols, carbon cycle, dynamic vegetation, atmosphereic chemistry, land ice etc. are also included. This boosts our confidence in these models and their predictions which wasn't the case in the past.

The speaker concluded by saying that there's an urgent demand for affordable and reliable energy supply (which are pivotal for solving all of our other problems) which are more environment friendly. The possible solutions he said (some of which have even been successful at certain locations) included Carbon Capture (which involves capturing, liquifiying and transporting the released Carbon Dioxide) which tends to be expensive, and Shale Oil (which is known to be present in large quantities but the extraction technology is still in its infancy)

3.4 This I'll remember

There's something called shale oil, which will last us a very long time, but we haven't the technology to extract it yet.

3.5 Acknowledgements

I was unable to make proper notes for this seminar and Ms. Prashansa Gupta (MS11021) was kind enough to share hers.

4 The Geometry of Physics

4.1 The when, where and who | facts

Mr. Rahul Chajwa, physics major (MS10 batch), spoke on the said topic on Wednesday, April 16, 2014, at 9 PM in LH3 of the LHC.

4.2 Motivation for attending | feelings

It was compulsory to attend atleast 2 in this series, however it turned out to be rather informative and interesting.

4.3 What I understood

The speaker in essence talked about how one would characterize various physical systems using geometry. He started by asking the question, how one would characterize surfaces, after showing with a series of figures. One way of such characterization he said was counting the number of holes. He then showed how various surfaces like a cup, purse etc. may deformed to a surface having clearly one or two (or even no) holes. He went on to explain why such a characterization, though intuitive is not always easy. He talked about Euler's polyhedron formula and the Gaus Bounet Theorem. He attempted to show some generalizations to higher dimensions, including the concept of derivatives. Specifically, he talked about Liuovilles Theorem and discussed in some detail the tangent space and its dual, co-tangent space. The fascinating part of the talk was related to the double pendulum which we know is chaotic. He explicitly showed an animation proving his point. He then asked us what geometry we could associate with the co-ordinate phase space of the setup. The answer was a torus. He then stated a result which follows from the geometric analysis that the hamilton's equations result in contraining the movement along geodescics of the torus geometry. This has a profound implication, the resulting motion will be periodic since geodesics are closed. This is almost impossible to see without the geometric considerations since we don't even have an analytic solution of the motion. Finally he demonstrated Euler's disc and talked about the infinite frequency before collapsing and discussed why this singularity is not a consequence of hamiltonian evolution but instead that of dissipation. He concluded the discussion by attempting to convince the audience that we can't think of logic without invoking some sort of object (geometry) in our heads.

The speaker received criticism for not acknowledging the sources referred to, and for shoddy board work from the instructor.

4.4 This I'll remember

A double pendulum's (co-ordinate) phase space can be thought of as the points on the surface of a torus.

4.5 Acknowledgements

I thank Mr. Vivek Sagar (MS11017) for reminding me about the seminar, else it would've been missed by me.

5 Magnetic Refrigeration

5.1 The when, where and who | facts

This talk was delivered by the infamous to be Dr. Ayushi Singhania (Int PhD), on Wednesday, April 23, 2014, at 9 PM in LH3 of the LHC.

5.2 Motivation for attending

The topic sounded like fun.

5.3 What I could follow

The speaker started with outlining her talk; introduction, history, magneto caloric effect, thermodynamics, advantages/disadvantages. She explained that the technology is based in magneto caloric effects (MCE). This was discovered by P. Weiss and it was suggested by P. Debey and W. Giaque. The MCE is based in changing the temperature of specific materials, by exposing it to changing magnetic fields. The phenomenon hinges on the idea that at a given temperature, the magnetic field causes alignment and when it is removed, the disorientation leads to dropping of the temperature (assuming there's no heat exchange). This has similarities with the Curie temperature which has electric fields and ferroelectric domains as analogues to their magnetic counterparts.

The speaker motivated the functioning further by explain how thermal and magnetic entropy together function to drop the temperature. She broke down the process into four steps. In the first (adiabatic), magnetic field is increased. Since there's no exchange of heat, the net entropy is zero; the magnetic entropy drops and thus the temperature increases. In the next step, a liquid is passed that cools the system, taking away the heating that resulted. In the third step, the adiabatic demagnetization, magnetic entropy is increased, while the thermal entropy is decreased. This step leads to cooling! In the final step, whatever is intended to be cooled is passed through and the process is repeated.

The speaker also did some calculations on the board to arrive at an expression for change in temperature, in terms of the system's parameters.

$$\partial T = -\frac{\mu_0 T}{C_H}\left(\frac{\partial M}{\partial T}\right)_H dH$$

Candidate and prevalent working material for the refrigerator were discussed next which included alloys of gadolinium which are known to produce 3-4 K change, per Tesla of change in magnetic field.

The speaker concluded by drawing a parallel between magnetic and conventional refrigeration, pointing out the role of pressure being played by the magnetic field in the said case. She discussed some advantages, such as environment friendliness and high efficiency (60-70%) while also listing some drawbacks such as its high cost and requirement of rare earth materials.

The speaker was appreciated for her clarity and neat board work by the instructor.

5.4 Acknowledgements

I referred to the wikipedia article on the same topic for filling some gaps.

6 Cooling by Dilution Refrigerator

6.1 The when, where and who | facts

Mr. Subhendu Shekhar deliverd the talk on Friday, April 18, 2014, in LH3, LHC at 6:00 PM.

6.2 Motivation for attending

The talk was on a holiday plus I wanted to wind up the seminar work by tonight. But as usual, it turned out to be informative and the principle discussed was rather interesting.

6.3 What I understood

The speaker started with outlining his talk. His first slide was about how cooling by evaporation of He-4 can only reach about 1.3 K. Below this temperature, the vapour pressure is very small and thus very little evaporates to facilitate the cooling. This limitation can be overcome by using mixtures of liquid He-3 and He-4. This technique is used in dilution refrigerator.

Dilution refrigerator starts working at 0.7K. We start with two layers of almost pure He-3 and He-4 at 0.1K. He-3 starts diffusing into He-4. The reason for this was explained later. While diluting He-3 absorbs heat, thus the cooling action.

By mixing into the lower layer, the He-3 layer above is effectively being diluted. In order to continue cooling, we must somehow remove the Chancha He-3 dissolved in dilute phase. This can be understood in anology with the evaporation process, wherein we need to remove (prashansa) vapor.

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Cooling power: Vapor pressure of He falls exponentially with decreasing temperature. It is possible to increase the limiting concentration above 6.6% by increasing pressure. He went on to derive an expression for change in entropy for such a system.

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Realization: The use of dilution process of cooling is similar in concept to helium evaporation.

Like tn evaporation, cooling takes place when ehlium atoms move from liquid to vapor phase, in dilution, cooling takes place when He-3 atoms move form the concentrated to dilute phase.

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The reason for diffusion/dilution: He-3 is a fermion while He-4 is a boson. Therefore He-3 diffuses into He-4 to minimize its Fermi energy, while He-4 tries to gain more superfluid condensation energy.

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Summary:

1. The helium undergoes phase separation when cooled below 0.87K giving two phases.
2. The specific heat of He-3 atoms is higher in the dilute phase than in the concentration phase of the atom foes fram the conc to dilute phase, results in the 'production of cold'.
3. Non-zero solubility of He-3 in He-4 even at 0K leads to cooling power which decreases with T^2, is much higher than cooling power of evaporation which falls exponentially

6.4 What I'll remember

Even innocent looking phase diagrams can be immensely important!