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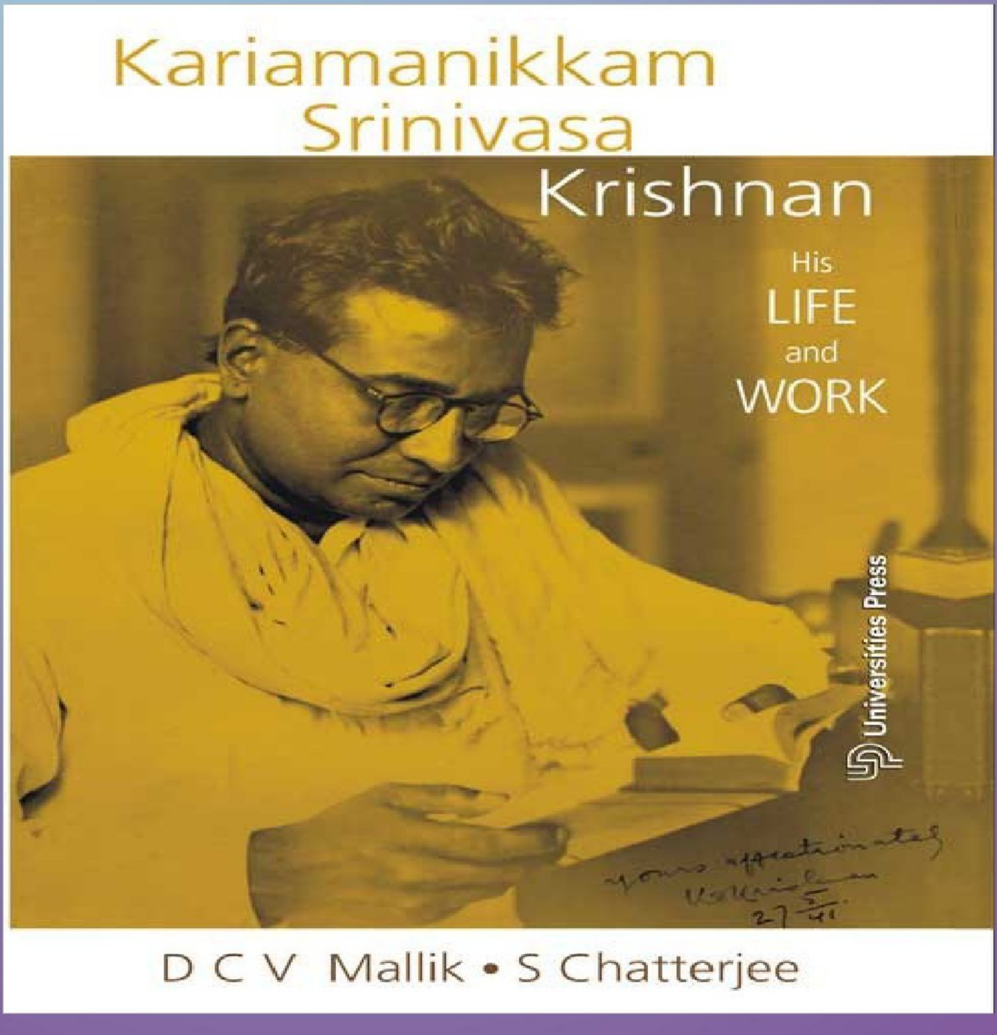

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Book Review

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In this Issue

Editorial

Roll back of Four Year Undergraduate Program

at

Delhi University

(*Submitted* 27-06-2014)

I am writing this editorial soon after the news report that Delhi University accepted the diktat from the University Grants Commission and will resume the three year degree format for admissions very soon. This episode leaves a very bad state on several different points of you.

1. What happens to the autonomy of an academic body like Delhi University? Are its constituent bodies such as the Academic Council having no power to decide on the content of the program? Are they not the expected to be guardians of quality?
2. Admissions in 2013 already ushered in the FYUP. Assuming that UGC is to exercise control over various study programs of various Universities, why did they take one whole year before asking DU to rollback, scrap the program and readjust the 2013 batch students, so that they will also graduate with 'honours' in three years. Do they possess any special expertise, not available to DU to consult in arriving at the suitability of the program. Or is it plain arrogance of the regulator insisting 'One who pays the piper calls the tune'?
3. Why this obsession with the uniformity of form rather than the content? What is so sacrosanct about 10 + 2 + 3 partition? And who should decide about it. Academic body or Funding Agency or the Government? [I recall several years ago a very rich and comprehensive 5 year B Tech program was changed to 4 year B Tech form and it was thrust upon IITs to re-jig its curriculum to suit the whims and fancies of the then Minister of Education, who as the chair of the All India Council for Technical Education ruled so for the colleges under the jurisdiction of AICTE and made it a *fait accompli for* IITs as well. The senate of IIT Kanpur was very unhappy at the blatant interference even though parents rather than the students were happy (since the child will graduate sooner) and the Ministry as the financier of technical education felt they had cut the expenses on making an Engineer.] The extra year of FYUP was to provide a broader basic foundation and greater employability. Is that of no consequence?
4. I notice that the FYUP matches the standard practice of four year Bachelor program in the US and that may have been one of the motivations for DU recommending a four year structure. Many UK and European universities typically

have three year Bachelor equivalent terminal non-research degree; however after a 13 years in all of School curriculum. Is the left lobby objecting to FYUP, since it smacks of aping US system?

5. There are many valid criticisms of the design of FYUP of DU; for instance as many as that 11 or 12 Foundation level basic courses, all of them being compulsory, among 50 odd courses student will pursue in four years makes the program too lopsided with general stuff that leaves too little time for the development of chosen discipline. But that calls for review of the curriculum and allowing the program evolve with time rather than *throw the baby with bathwater*.
6. Why should we be so much obsessed with the duration of the program? It is time that we move to a measurement of credit hours for all the courses and define how many credits constitute a Bachelor degree (with or without honours) or Master degree or even allow simple diploma that is not a University degree but is an official transcript that lists all courses the candidate has accumulated. With options of advanced standing or with a capacity for overload one may complete a degree sooner than norm. Likewise, for the less prepared, particularly if they happen to be first generation learners in a college, it should be prudent to allow slower paced options or more foundation courses in the initial few years. Does it at all matter if (s)he takes a little longer to graduate?
7. Almost all our Universities appear to have programs that are so rigidly structured and there is no room for innovating study programs. While the current trend of many disciplines transcending the traditional boundaries, all our University programs have remained in a time warp. For example Maths Physics and Chemistry fall in one set, with eventual objective of becoming an Engineer in sight. Biology, Physics and Chemistry forms the complementary set leading to professional Doctors. Just a few carry on for careers in Sciences. Many interesting developments in Physics draw phenomena and applications from Biology. Biology is based on molecular level processes needing both advanced Physics and Math notions. IISERS have therefore actively promoted interdisciplinary study and research. Apart from the core courses that draw from all four departments, even advanced courses get benefited by drawing expertise from two or more disciplines. It is therefore more appropriate to encourage students of life sciences to pick up enough Maths and Quantum Physics and students of Physics and Chemistry acquire a strong dose of biology.
8. It is time we pull all stops and remove all barriers. Curriculum content may only specify minimal number of various type of courses and overall number of total credit hours and leave the student to build up his/her own composition. Let University be a place like a cafeteria with many courses as available and each student will make up his/her personalised list, based on the taste and aptitude.

9. I felt that Delhi University's FYUP had many features that are progressive and worth getting emulated elsewhere. That the program allows options to leave at the end of two, three or four years and that can take the exit from the program acquiring an Associate Baccalaureate diploma after 2 years or Baccalaureate/ degree after 3 years and even return later for a more advanced option is particularly noteworthy and can be fine-tuned to the needs of individual students. It allows sandwich programs of study-work-study type or go back to University for some specific needs.
10. University Grants Commission's role should be to ensure that there are mechanisms, such as National Accreditation Board, by which the programs of University/College gets evaluated and accredited by sound mechanisms and based on the ranking provided by such process, enable requisite funding. It should act more like a banker than a regulator, exercising authority over another autonomous organisation. Main issue, I believe with FYUP is a) too many foundation courses over which student has no choice and b) a possible dilution of content in chosen discipline as the major and **not** the duration of the program. Since there is a neat exit option available at the end of 3rd year, it meets the prevalent National Education Policyof 1986 with (10+2+3) structure in both letter and spirit. I wish UGC had directed that the program is improved upon, taking in various stakeholders' and experts' views rather than throw out unceremoniously.

We carry another article in this issue – an insider's view on the topic provided by Dr Shobit Mahajan. Readers may wish to carry on the discussion and we invite the pages of the journal for an informed debate – a process that will be invaluable in the evolution of a good College Curriculum.

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Role of Partition Function in Statistical Mechanics

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Abstract

In this article we give a simple method of introducing statistical mechanics and also highlight the importance of Partition Function[PF] in Statistical Mechanics[SM].

1 Introduction

In every branch of physics there will be some key equation or equations around which the whole subject is developed. In classical mechanics for undergraduates, the subject is developed around the equation

$$\vec{F} = m\,\vec{a}$$

where $\vec{F}$ is the force m is the mass and $\vec{a}$ is the acceleration of an object. In post graduate classical mechanics course we have Lagrange's equations

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial L}{\partial \dot{q}_j}\right) = \frac{\partial L}{\partial q_j}$$

or Hamilton's equations of motion

$$\frac{dp}{dt} = -\frac{\partial \mathcal{H}}{\partial q}$$

$$\frac{dq}{dt} = +\frac{\partial \mathcal{H}}{\partial p}$$

In quantum mechanics we have Schroedinger equation

$$H\psi = E\psi$$

where H the Hamiltonian, ψ is the wave function which can be found and E is the energy eigen value. In electrodynamics we have Maxwell's equations,

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{B} = \mu_0 \left[\vec{J} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right]$$

where $\vec{E}$ is the electric field, $\vec{B}$ is the magnetic field, ρ is the charge density, $\vec{J}$ is the current density, μ_0 is the permeability of free space and ϵ_0 is the permittivity of free space. Thus any branch of physics is developed around some central equation or equations. Here we are discussing about SM. There fore in statistical mechanics which is the central equation?. In the preface to his book [1] Daniel Mattis comments that once when he started studying statistical mechanics and asked about it to his friend he simply wrote $e^{-\beta H}$. Feynman starts his statistical mechanics book [2] by saying ' The key principle of statistical mechanics is as follows- If a system in equilibrium can be in one of N states, then the probability of the system having energy E_n is $\frac{1}{Q}e^{-\frac{E_n}{kT}}$ where $Q = \sum_{n=1} e^{-\frac{E_n}{kT}}$. Q is called partition function.' The above two comments highlight the importance of partition function. From where these equations come from? They are obtained from Gibbs[3] ensemble theory. Gibbs in his ensemble theory defines three ensembles Micro Canonical Ensemble (MCE), Canonical Ensemble (CE) and Grand Canonical Ensemble (GCE). These ensembles give three equations for probability. They are

$$p_i = \frac{1}{\Omega}$$

for constant energy

$$p_i = \frac{e^{-\beta E_i}}{\sum_i e^{-\beta E_i}}$$

if energy is varying and

$$p_{r,s} = \frac{e^{-\beta(E_s - \mu N_r)}}{\sum\limits_{r,s} e^{-\beta(E_s - \mu N_r)}}$$

if both energy and number of particles are varying respectively for MCE, CE and GCE where E_i or E_s represents instantaneous energy of a system, N_r represents instantaneous number of particles and $\beta = \frac{1}{kT}$. Using these equations we can obtain the three bridging equations that link a microscopic quantity with a macroscopic thermodynamic quantity. They are

$$S = k \ln \Omega(E, V, N) \tag{1}$$
$$A = -kT \ln Q(T, V, N) \tag{2}$$
$$\phi = -kT \ln \mathcal{Z}(T, V, \mu) \tag{3}$$

for respective ensembles, where S is the entropy, A is the Helmholtz free energy and ϕ is the Landau free energy which are macroscopic parameters and the microscopic parameters Ω is the number of micro states available for particles, Q is the canonical partition function and $\mathcal{Z}$ is the grand partition function.

The importance of the partition function

Statistical mechanics is a branch of physics whose basic objective was to find the physical properties of matter which are temperature dependent. Now a days statistical mechanics goes beyond this objective but, in principle this was primarily the aim while formulating this subject. Based on this principle physicists applied statistical mechanics to obtain properties of blackbody (Planck's distribution law, Stefan-Boltzmann law), solids(specific heat), metals(photo electric effect, thermionic emission)etc. All the explanations regarding magnetism, Pauli para magnetism, Landau diamagnetism and Ising Ferro magnetism are applications of statistical mechanics. Thus we can see hundreds of applications of statistical mechanics in text books. Recently, statistical mechanics is even used in politics[4], economics[5], biology[6] and almost all walks of life. It is interesting to see that it can be even used to explain the swinging movement of a ponytail[7]. Going back we see that Eq[1,2,3] show that all thermodynamics of a system can be obtained if we know Ω or Q or $\mathcal{Z}$. Finding Q or $\mathcal{Z}$ is much easier than finding Ω. Thus in SM we will heavily depend on partition functions in CE and GCE. Thus PF has a central role in statistical thermodynamics because once it is known as a function of the variables on which it depends, all thermodynamic quantities may be calculated from it directly. Now let us briefly go through ensemble theory[8],[9] and find out how these equations are obtained.

Ensemble theory

We want to obtain equations for thermodynamics quantities of a system. The system may be a collection of atoms, electrons, quarks, photons etc. An ensemble is an idealization (mental construction) consisting of a large number of virtual copies of a system, **considered all at once**, each of which represents a possible state that the real system might be in. Thus the system at different time is considered together. We usually construct three different types of ensembles with $E, V, N = constant$, $T, V, N = constant$ and $T, V, \mu = constant$ in physics to solve our problems in Statistical mechanics and they are called MCE, CE and GCE respectively.

Micro Canonical Ensemble

Consider two systems with number of micro states Ω_1 and Ω_2 with entropies S_1 and S_2. If they are made to contact then their resultant entropy $S = S_1 + S_2$ because of the extensive property of entropy. We can show that

$$\Omega = \Omega_1 \Omega_2$$

Boltzmann proposed that

$$S \propto f(\Omega)$$

For the first system

$$S_1 \propto f(\Omega_1)$$

For the second system

$$S_2 \propto f(\Omega_2)$$

Then to satisfy the Boltzmann proposal

$$S \propto \ln \Omega$$

Shortly Max Planck introduced the constant of proportionality k and hence the Boltzmann equation takes the form

$$S = k \ln \Omega$$

where, k is the Boltzmann constant.

Thermodynamics

We got $S = k \ln \Omega(E, V, N)$. Now S is a constant and will be a function of E, V and N. The statistical mechanics ends here and we will use thermodynamics to derive other physical quantities by varying the quantities mathematically or mentally. The I law of thermodynamics is given by

$$TdS = dE + PdV - \mu dN$$

Taking partial derivatives

$$\left(\frac{\partial S}{\partial E}\right)_{V,N} = \frac{1}{T}$$

$$\left(\frac{\partial S}{\partial V}\right)_{E,N} = \frac{P}{T}$$

$$\left(\frac{\partial S}{\partial N}\right)_{E,V} = \frac{-\mu}{T}$$

Thus from I equation we get E and from others we get P and μ and we can derive C_P, C_V and other thermodynamics from these quantities. If we need other thermodynamic quantities we can modify 1st law of thermodynamics suitably and obtain them.

Canonical Ensemble

We will consider an ensemble with T, V and N constants. To make T constant the system has to be immersed in a heat reservoir. Then we have $E_{tot} = E_{res} + E_i$ where E_i is the system energy at any instant i or state i. E_i is continuously changing. Hence another property of the system is known to us which is the average energy U can be defined as $U = \sum_i p_i E_i$. Taking U we can write

$$E_{res} = E_t - U - (E_i - U)$$

Similarly

$$E_{tot} = E_{tot} - U + U$$

The probability that system will have energy E_i is

$$p_i = \frac{\Omega_{res}(E_{tot} - E_i)}{\Omega_{tot}(E_{tot})}$$

$$p_i = \frac{\Omega_{res}(E_t - U - (E_i - U))}{\Omega_{tot}(E_{tot} - U + U)}$$

The numerator is function of the form $f(x + h)$ which demands an expansion using Taylor series and denominator is like $f(a)$ which cannot be expanded.

$$f(x + h) = f(x)|_{x_0} + \frac{\partial f}{\partial x} h$$

We modify the Boltzmann equation as

$$\Omega = e^{\frac{S}{k}}$$

and we get

$$p_i = \frac{e^{\frac{S_{res}}{k}}}{e^{\frac{S_{tot}}{k}}}$$

$$p_i = \frac{e^{\frac{S_{res}}{k}}(E_t - U - (E_i - U))}{e^{\frac{S_{tot}}{k}(E_t - U + U)}}$$

Since entropy shows additive nature and now using Taylor expansion for numerator

$$p_i = \frac{e^{\frac{S_{res}}{k}(E_t - U) - \frac{1}{kT}(E_i - U)}}{e^{\frac{S}{k}(E_t - U) + \frac{S}{k}(U)}}$$

$$p_i = e^{\frac{-(E_i - U)}{kT}} e^{\frac{-(ST)}{kT}}$$

$$p_i = e^{\frac{-E_i}{kT}} e^{\frac{U - TS}{kT}}$$

$$p_i = e^{-\beta E_i} e^{\frac{A}{kT}}$$

$\sum_i p_i = 1$ and defining $\sum_i e^{-\beta E_i} = Q$

$$e^{-\beta A} = Q$$

or

$$A = -kT \ln Q$$

Thermodynamics

$$A = U - TS$$

Differentiating and using I law of TD we get

$$P = -\left(\frac{\partial A}{\partial V}\right)_{N,T}$$

$$\mu = \left(\frac{\partial A}{\partial N}\right)_{V,T}$$

$$S = -\left(\frac{\partial A}{\partial T}\right)_{V,N}$$

Substituting the value of S in the equation for A we get

$$U = kT^2 \left(\frac{\partial}{\partial T} \ln Q\right)_{V,N}$$

Thus all thermodynamics can be obtained. For N free particles

$$Q_N = \left(\frac{V}{\lambda^3}\right)^N$$

where V is the volume and λ is the thermal wavelength. For N harmonic oscillators

$$Q_N = \left[\left(\frac{kT}{\hbar\omega}\right)^3\right]^N$$

Grand Canonical Ensemble

Consider a reservoir which can supply both energy and particles so that our system has two variables, energy and number of particles. We have then

$$E_t = E_{res} + E_s$$

$$N_t = N_{res} + N_r$$

As done in canonical ensemble we can write

$$E_{res} = (E_{tot} - U) - (E_s - U)$$

$$N_{res} = N_{tot} - N - (N_r - N)$$

where N is the average number of particles.

$$\Omega_{tot} = \Omega_{tot}(E_s, N_r)$$

$$\Omega_{res} = \Omega_{res}(E_{res}, N_{res})$$

$$p_{r,s} = \frac{\Omega_{res}}{\Omega_{tot}} = \frac{e^{\frac{S_{res}}{k}}}{e^{\frac{S_{tot}}{k}}}$$

Substituting and canceling terms as in canonical ensemble and using the equation

$$\left(\frac{\partial S}{\partial N}\right)_{T,V} = \frac{-\mu}{T}$$

$$p_{r,s} = e^{-\beta(E_s-\mu N_r)}e^{+\beta(U-TS-\mu N)}$$

Taking $\phi = U - TS - \mu N$ which is called Landau free energy and taking the sum over all the states,

$$e^{\beta\Phi}\mathcal{Z} = 1$$

$$e^{-\beta\Phi} = \mathcal{Z}$$

$$\Phi = -kT\ln\mathcal{Z}$$

where

$$\mathcal{Z} = \sum_{r,s} e^{-\beta(E_s-\mu N_r)}$$

Let us define fugacity

$$z = e^{\beta\mu} = e^{\frac{\mu}{kT}}$$

Then

$$\mathcal{Z} = \sum_{r,s} z^{Nr}Q_{Nr}$$

Thermodynamics

$$\Phi = U - TS - \mu N$$

Differentiating and substituting I law

$$d\Phi = -PdV - SdT - Nd\mu$$

$$S = -\left(\frac{\partial\Phi}{\partial T}\right)_{V,\mu}$$

$$P = -\left(\frac{\partial\Phi}{\partial V}\right)_{z}$$

$$N = -\left(\frac{\partial\Phi}{\partial\mu}\right)_{V,T}$$

$$\ln z = \beta\mu$$

$$N = z\left(\frac{\partial\ln\mathcal{Z}}{\partial z}\right)_{V,T}$$

$$\Phi = U - TS - \mu N$$

Multiplying with β and taking a partial derivative with β

$$U = \left(-\frac{\partial}{\partial\beta}\ln\mathcal{Z}\right)_z = kT^2\left(\frac{\partial}{\partial T}\ln\mathcal{Z}\right)_z$$

If single particle PF is known we can find the GPF as

$$\mathcal{Z} = \sum_{r,s}(zQ_1)^{Nr}$$

which will become

$$\mathcal{Z} = \frac{1}{1 - z\,Q_1}$$

for distinguishable particles and

$$\mathcal{Z} = \sum_{r,s}\frac{(zQ_1)^{Nr}}{N_r!}$$

which is equal to

$$\mathcal{Z} = e^{z\,Q_1}$$

for indistinguishable particles. All the thermodynamics are obtained as partial derivatives of logarithm of PF. Thus we can see that the aim of statistical mechanics to determine TD will be satisfied only if we know PF. Thus PF plays a **key role in SM**

Conclusions

The partition function is a measure of the degree to which the particles are spread out over, or partitioned among, the energy levels. In canonical ensemble we have $\sum_i e^{-\beta E_i} = Q$. Energy and β have the same units and exponent becomes a number and hence Q is a number and is dimensionless. This appears as mysterious to many students that, how a dimensionless quantity is so much important. We had large number of similar situations in physics. We know that refractive index(n) which is dimensionless plays a great role in optics. In dispersion n plays decisive role. Another example is Reynolds number which has a value 2500. Actually it is the ratio of inertial forces to viscous forces in a liquid flowing in a pipe. The lowest possible value for the partition function is 1, the value it could have when the temperature of the system is 0 K, the temperature at which all particles in the system are in the ground state and the fractions in the excited states are zero. The highest value for the partition function can be very large, but not infinite. In the history of statistical mechanics there are many cases like Ising model where the whole concept of Ferro magnetism was changed when the proper partition function is obtained for the system.

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FYUP- The Delhi University Experience.

A critique

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Abstract

An invited report on the current flip-flop on the Four year Undergraduate Program at the Delhi University, introduced in the preceding academic year 2013-14 and forced to be rolled back now, when processes of admission had already began. A clear example of how a well intentioned initiative can be botched up by not engaging with all stake holders in the process and proceeded with an avoidable haste. An unnecessary emphasis on the popular media and several sections on the duration of the course – four years instead of three - miss the focus completely.

As I write this, the fate of about 250,000 applicants to the undergraduate program at the University of Delhi is still undecided. The applicants are unsure as to what they are striving to attain- admission into a three year undergraduate program or a Four Year Undergraduate Program (FYUP).

A bit of background- about a year ago, the University decided to shift from its time tested 3 years undergraduate program to the FYUP. With the change in government last month, the University Grants Commission (UGC) has directed the University to revert to the old three year system. As I write this, it is unclear whether the University has agreed to the diktats of the UGC. Will this be an opportunity to have a fresh thinking on the principles behind the FYUP and return with a better option than both the proposed FYUP and existing three year format? Or simply status quo ante.

There has been a lot that has been written about the desirability or otherwise, the real or imaginary motivations behind and the hurried way in which this revolutionary change is being brought about.

First of all, it is obvious that there is no *a priori*, fundamental reason for an academic course to be 3 year, 4 year or indeed 6 years long. One can see several different models operating in various countries. How long a particular degree/diploma course is of course decided keeping in view the prevalent view amongst experts and in society as to how long would it take for a student to absorb the material that is considered necessary at that time so as to be ready for the next stage of life- either the job market or a higher academic degree. This is therefore, clearly a function of the particular historical and social conditions prevailing at a particular point in space and time.

So the issue is not about the duration of the course. It is about what the course would contain and whether it would be an improvement on the existing undergraduate program which has been running successfully for decades at the University of Delhi. As the Yankee saying goes, “if it ain’t broke, don’t fix it”.

The stated aim of introducing the FYUP has been increasing the employability of students, increasing their exposure to other fields apart from their specialisations, increasing trans-disciplinarity (whatever that means) and interestingly, find time for sports and cultural activities.

Of course, it would hard to argue about the desirability of these stated aims. However, as always, the devil is in the details and not in rhetoric laced with choicest quotations from our ancient scriptures. The manner in which such a crucial change has been implemented, the academic implications of the change and past experience however do not portend well.

Let us first look first, at the manner of the evolution of the program.. It is well established by now that in any large system, with diverse stakeholders, any lasting and fundamental change can only come about if all the stakeholders are taken on board. This is not just because democratic principles prescribe it- it is essential for the success of any such exercise. For a change of this magnitude, one would have thought that the students, the teachers and the non-academic staff of the University, as well as the civil society at large would have been consulted, the concept debated in depth, diverse opinions taken into consideration etc. Once a consensus was achieved on the conceptual apparatus, then the larger teaching community at the University and its constituent colleges would be asked to prepare the detailed courses of study etc.

Of course none of this happened. What we had instead were a series of proclamations in the mass media about the impending change and some academic jamborees of carefully selected students and teachers to demonstrate “wide-ranging” support for the new program.

The structure of the program - the mix of foundation courses, skill based courses and discipline courses, their numbers, their sequencing and indeed their titles were then decided by a carefully chosen “task force” of teachers. Interestingly, this august body of about 5 dozen teachers didn’t have a single teacher in Physics, a subject which would be taught to all students!

The Foundation Courses and the skill based courses were designed by some handpicked teachers. The discipline or subject courses were to be designed by the post graduate departments. On March 5th, 2013, the University authorities asked the departments for a detailed syllabus and course of study by March 20, 2013! To think that a meaningful, major overhaul of the syllabus and courses could be achieved in 2 weeks would be hilarious if it wasn’t so tragic. The University was helpful though in giving some guidelines to perform this superhuman exercises- like, for instance, there should not be too many topics in any paper! The impact of such overarching principles in framing of courses of study across disciplines would be obvious in the actual content and form of the courses.

What about the courses themselves? The Foundation courses, which are common and mandatory for everyone, are 12 in number, including the curiously titled “Integrating Mind, Body and Heart”! Let us look at two of the more down to earth and plebeian courses: ‘Information Technology’ and ‘Science & Life’. It seems that the framers of these courses have a total disconnect with reality.

Let us take up the design of ‘Information Technology’ first. An average undergraduate (and here we are not even speaking of those coming from elite public school backgrounds today) would find it tiresome that she is supposed to sit through classes where she is lectured on things like shortcut keys, WiFi, Bluetooth etc. In this day of smartphones and pervasive connectivity, this would seem as obsolete to her as teaching students to write with a ball pen in our times. She would find it even more tiresome, indeed hilarious that - she is supposed to write an email to her teacher and a group as a project. Or connect her computer or mobile using WiFi! Projects are not just an important part of all courses, but have a 50% weight in the assessment. It seems that the people who designed this particular course have been living on another planet. And to claim that courses such as these would "enhance the employability" of our students, is not just laughable but disingenuous.

The Science and Life course does a little better. Although it is not clear what the science component of this course is per se, there seems to be some effort to connect science with everyday life. However, teaching about fuses and water filtration to undergraduate students can only be described as dumbing down. The framers of this course might have looked at a Class VIII science textbook or even what used to be called "General Knowledge" book used by schools to see that the students know these things-they have been drilled into them for years. Once again, the suggested projects truly take one's breath away. Most of them, at best involve a quick Google search and at worst they are truly pedestrian.

Though the objectives of the foundation courses are indeed lofty and include things like "…develop scientific temper…" etc., the reality is that there is a fantastic dumping down of curriculum. Things which are taught in middle and high school are now being made a part of a mandatory curriculum for all. And the much touted project work only enhances the ability of students to use Google and Wikipedia.

But can't one argue that any course which allows students to choose between studying different disciplines and subjects (a so called cafeteria approach) would be better than a rigidly imposed curriculum and program of study? Of course, in an ideal world this would be certainly desirable. Unfortunately, we are not living in an ideal world and there are real world constraints which need to be factored in before one can meaningfully implement such a change.

For instance, the 80 odd constituent colleges of the University are tremendously resource starved- both infrastructural and human resources are stretched to their limits. There are just not enough class rooms, labs, library and IT facilities, and most importantly teachers. In such an environment, giving students a hypothetical choice to choose between papers becomes a comical exercise. The other important issue regarding what exactly is being taught, that is the actual content of some of the courses we have already commented upon.

Once again, I think there is nothing sacrosanct at all about a particular duration or structure of the course. But whatever changes are made should at least pass the test that the new system is *in reality* better than what it is replacing. And for that to happen, it is critical to have a reasonable knowledge of the constraints of the system and its strengths and weaknesses. And finally, any change has to be debated, discussed and deliberated by all the stake holders for it to be successful. Sadly, the events of the last one year have shown that the University administration doesn't -care much about any of these principles. And tragically, this neglect of the fundamental principles has resulted in the complete devastation of the undergraduate system at the University as it hitherto existed.

Web-Design, and NSES Content and Process Standards Analysis of Teacher-Published High School Physics Websites

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Abstract

This study investigated high school Honors Physics (N = 76) and Advanced Placement Physics (N = 76) websites for Web-Design, National Science Education Standards (NSES) Physics Content and Science Process Standards. The websites used in the study were accumulated using the Google™ search engine. The evaluation of each website was performed using an instrument developed based on three attributes: Web-Design, NSES Physics Content, and NSES Science Process Standards. The results of the study indicated that there was a significant difference between high school Honors Physics websites and those of AP Physics in terms of NSES Physics Content Standards. It was found that Advanced Placement Physics websites contained more NSES physics content than Honors Physics websites. There was no significant difference found between the websites in regards to Web-Design, and NSES Science Process Standards. Implications for Physics Content Standards in web-based physics education are discussed.

1. Introduction

Teachers in high schools have traditionally focused on the in-depth instruction of specific subject matter to prepare students for post-secondary education, or, specifically, to provide sufficient background to succeed in a college curriculum. Particularly challenging to teachers today is the digital divide between teachers and students, especially students who are maturing in a world where computers, the Internet, video games, and cell phones are common, and where expressing themselves through these tools is the norm [1, 2]. Consequently, teachers need to include in their instruction engaging content materials and assessments with more hands-on science and multimedia-based activities than printed textbooks. One approach to help teachers meet this need is through well-designed websites. This enhancement to traditional instruction is usually referred to as Web-Assisted Instruction (WAI). WAI has been defined as using the Internet with email and World-Wide-Web (WWW) browser software to set-up and maintain a webpage in order to supplement conventional classroom instruction [3].

2. Web-Assisted Instruction and the Classroom

Within the realm of education, WAI can be implemented in so many different ways that it is frequently regarded in an over-simplified manner as "teaching with the Internet." Consequently, misinterpretations usually occur because the World-Wide-Web (WWW) can be applied in a myriad of ways to pedagogy. It seems that the most common conclusion that some may draw is that the Internet is being used in the classroom as a teaching tool. But for this research proposal, the term WAI is intended to mean instruction and communication outside the classroom via a teacher-authored class website. The students use it to electronically access content-related learning materials while practicing inquiry, conducting simulations, performing self-assessments, and maintaining communication with each other along with their teacher.

3. Benefit of Web-Assisted Instruction

The benefit of WAI appears to be its ability to offer a way for students to remain connected to their instructional setting beyond the walls of the classroom [4,5,6]. The teacher includes weekly plans and assignments on the website along with lecture notes and links to other sites for enrichment and practice. The teacher can occasionally post quizzes and tests on the Website for students to complete, supported by a file upload link for submission of their work. Additionally, the website should have an email link for communication outside of class, and include streaming video along with audio (MP3) files to support webcasting. The email capability is especially useful for students who may be hesitant to ask questions in class or for those who may have thought of something later.

Having a class website could be useful in a subject like high school physics, for example, because more class time can now be devoted to essential demonstrations, discussions, student lab work, inquiry, and other discovery-related activities. Basically, class websites can give the course content the same "anytime, anywhere" communication appeal to which the technology-literate students of today have become accustomed in their everyday lives. In fact, studies suggest that the internet has become the medium of choice for young people in doing their research and homework, compared to newspapers, magazines, books, or libraries [5].

4. Web-Assisted Instruction and Physics Education

According to Mottmann [7], two of the more important reasons for introducing technology and other instructional innovations into physics education are "(a) to improve students' physics ability, and (b) to improve students' negative reactions toward physics" (p. 75). Rios and Madhavan [8] identified four classifications of technologies that are appropriate for physics instruction and provided brief descriptions of a few examples. The classifications were (a) computer interfacing equipment to collect and process data, (b) experimental or theoretical modeling, (c) computer simulations requiring graphics, and (d) research/reference/presentation programs for gathering, reporting, and/or displaying information. However, there seems to be a lack of published attempts by researchers to gauge the use of Web design standards for WAI in physics at the high school level. It may be difficult to single-out a particular reason why more advantage is not taken of Web-Assisted Instruction. Schell's [9] research may be providing a clue. Teachers may simply feel that it is too time-consuming, and they may not have enough expertise.

5. The Promises of Technology

Many times in the past "modern technology" has led us to believe that it will improve education but this has not always been the case. For example, in the 1950s, television was once promised as a great asset to education. Some may contend that it has yet to prove any educational usefulness [10]. Now, even though the Internet can be used in a variety of settings for a range of purposes, its use can place unexpected demands on even the most experienced teachers, at times reducing them to novices. Equally disappointing is that, with regard to infusing technological innovations in their pedagogy, teachers have usually been left to figure things out on their own.

The current-day technologies have shown great promise to teachers and students. It is the latter who seem to expect more from the former in terms of their educational experiences. Students, particularly those in upper-level math and science courses, are arriving to the classroom with a technological savvy that many teachers may find intimidating. These students expect their educational experiences to include Web technologies, such as multimedia presentations of subject content, interactivity, simulations, streaming video, and access to their instructors through email, on-line forums, and chat-rooms [11].

With all this exposure to technology available to students, the Internet has already become the medium of choice for young people in doing their research and homework, compared to newspapers, magazines, books, or libraries [5]. It now becomes apparent that educators should at least consider including in their pedagogy some well-designed Web-based instructional techniques and strategies. By doing so, teachers can provide their students with a structured, virtual learning environment outside the classroom, whose rudiments have evolved with the growth of the Internet, an entity that their students have already become accustomed to using.

6. Statement of the Problem

The purpose of the study was to investigate whether statistically significant differences existed between high school Honors Physics websites and those of AP Physics in terms of Web-Design, National Academy of Science (NSES) Physics Content Standards, and NSES Science Process Standards [12]. A total of 152 sites were evaluated comprising two groups with sample sizes of 76 each for the types of physics classes in the study.

7. Method

The websites used in the study were accumulated using the Google™ search engine. For example, to find Honors Physics websites, the search query “honors physics high school” was entered into the search engine. This produced approximately 222,000 results. For the query, “advanced placement physics high school,” the search engine estimated about 190,000 results. In both cases the results were examined sequentially until the required amounts of websites published by physics teachers were selected and evaluated using the instrument developed by the researcher. The selection process was based on the order in which the search engine ranked the results of the query. All 76 of each type of high school physics websites were found by going no more than 27 pages deep into the search results which listed 10 websites per page that contained the search words.

8. Website Evaluation Protocol

Protocols for analyzing curriculum and instructional websites have been reported [3, 6] and they vary depending on the subject matter and the purpose of the analysis. For this study, once a website is found it was evaluated according to the presence of three major attributes: Web design structure, physics content standards, and science process standards. There were five criteria for each attribute listed in the instrument to aid in determining if the website possessed the given attribute (Table 1).

Evaluation Criteria		
For 4 or more criteria, Score = 1. For less than 4 criteria, Score = 0.		
A. Design Structure	**Score**	
1. Homepage title begins with Physics website name. 2. Similar format on every page that links from the homepage.		

3. All multimedia resources work properly. 4. Page footer area -- copyright, last update, contact e-mail address. 5. Short paragraphs and bulleted lists are used.		
B. National Science Education Standards for Physics Content	**Score**	
1. History and nature of science. 2. Conservation of energy and increase in disorder. 3. Study of motion and forces. 4. Interactions of energy and matter. 5. Nature of Light and Optics.		
C. National Science Education Standards for Science Process	**Score**	
1. Includes opportunity to conduct scientific inquiry. 2. Incorporates critical thinking skills. 3. Provides practice for problem-solving. 4. Emphasizes the Scientific Method. 5. Provides practice for analyzing and synthesizing data.		

Table 1. High School Physics Web-Design, NSES Physics Content and Science Process q Checklist

Websites could only receive a score of “1” or “0” for the attribute. A “1” is scored if the website contains four or more out of the five criteria for each attribute, otherwise a “0” is given. The advantage of using a “1” or a “0” in the evaluation process for each website attribute is that the mean also returns the probability, in a frequentist sense, that similar sites will possess the attribute under consideration.

For example, to evaluate the design structure of the website, look for the presence of the following criteria: page title begins with physics website name, similar format or appearance to every page that links from the homepage, short paragraphs and bulleted lists are used, all multimedia resources work properly, and the page footer area contains either copyright or last update as well as a contact e-mail address.

In order to determine if the website contained NSES Physics Content Standards references to the following information were searched: the history and nature of science, conservation of energy and increase in disorder, the study of motion and forces, interactions of energy and matter, and the nature of light and optics.

When deciding whether or not the website contained the NSES Science Process Standards, the following criteria must be present: opportunities to conduct scientific inquiry, use of critical thinking skills, practice for problem-solving, emphasis on the Scientific Method, and practice for analyzing and synthesizing data. A flowchart illustrating how to find and evaluate for example an Honors Physics website is shown in Figure 1.

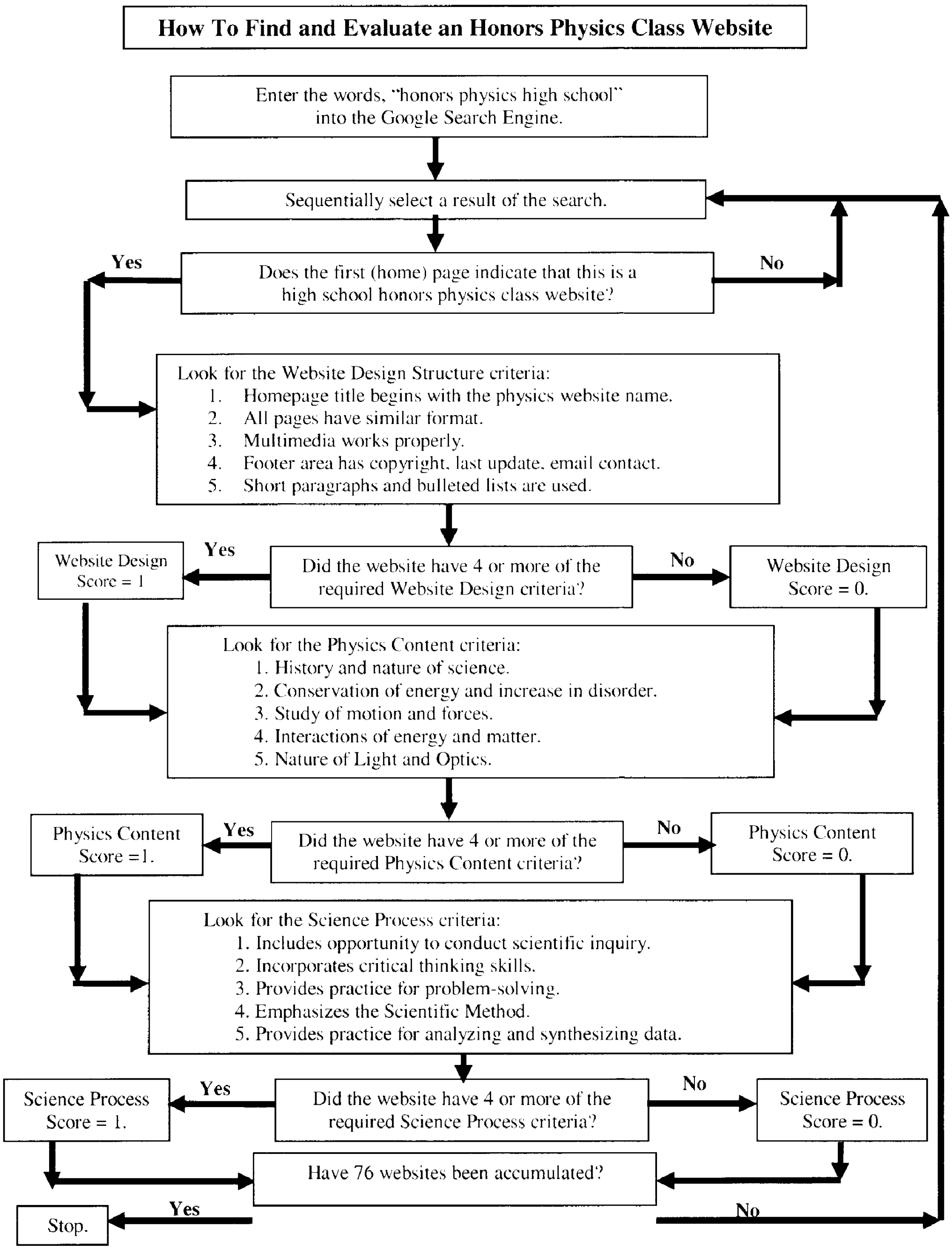

Figure 1. How to Find and Evaluate an Honors Physics Class Website

9. Results

To examine if there is a significant difference on the website elements Web-Design, Physics Content, and Science Process by Website Type (Honors vs. AP), three independent samples *t* tests were conducted.

9.1. Web-Design

$H1_O$: There is no significant difference between Honors Physics and AP Physics websites in Web-Design structure.

The results of the *t* test on Web-Design were not significant, *t* (150) = 0.83, *p* = 0.41, indicating that no significant difference existed in Web-Design by Website Type (Honors vs. AP) (Table 2). Web-Design for the Honors sites (*M* = 0.59, *SD* = 0.50) was not significantly different than Web-Design for the AP sites (*M* = 0.66, *SD* = 0.48). The Levene's test for homogeneity of variances returned a value of .134 with a significance of .143. The post hoc power returned a value of .054 for the probability of rejecting the null hypothesis when it is false.

			Honors		AP	
Website Elements	*df*	*t*	*M*	*SD*	*M*	*SD*
Web-Design	150	0.83	0.59	0.50	0.66	0.48

Table 2. Independent Samples t Test on Web-Design by Website Type (Honors vs. AP)

9.2. Physics Content

$H2_O$: There is no significant difference between Honors Physics and AP Physics websites in terms of NSES Physics Content Standards.

The results of the *t* test on Physics Content were significant, *t* (150) = 2.15, *p* = 0.03, indicating that a difference existed in Physics Content by Website Type (Honors vs. AP) (Table 3). Physics Content for the AP sites (*M* = 0.51, *SD* = 0.50) was slightly higher than Physics Content for the Honors sites (*M* = 0.34, *SD* = 0.48). To determine the effect size of this significant effect, the value of the Cohen's d was .35, with a Confidence Interval from .23 to .45, indicating a small to moderate effect. The Levene's test for homogeneity of variances returned a value of 2.46 with a significance of .906. The post hoc power returned a value of .123 for the probability of rejecting the null hypothesis when it is false.

			Honors		AP	
Website Elements	*df*	*t*	*M*	*SD*	*M*	*SD*
Physics Content	150	2.15*	0.34	0.48	0.51	0.50

Note. ** $p < 0.01$ and * $p < 0.05$.

Table 3. Independent Samples t Test on Physics Content by Website Type (Honors vs. AP)

9.3. Science Process

$H3_O$: There is no significant difference between Honors Physics and AP Physics websites in terms of NSES Science Process Standards.

The results of the *t* test on Science Process were not significant, *t* (150) = 1.25, *p* = 0.21, indicating that no significant difference existed in Science Process by Website Type (Honors vs. AP) (Table 4). Science Process for the Honors sites (*M* = 0.14, *SD* = 0.35) was not significantly different than Science Process for the AP sites (*M* = 0.22, *SD* = 0.42). The Levene's test for homogeneity of variances returned a value of .537 with a significance of .574. The post hoc power returned a value of .064 for the probability of rejecting the null hypothesis when it is false.

			Honors		AP	
Website Elements	*df*	*t*	*M*	*SD*	*M*	*SD*
Science Process	150	1.25	0.14	0.35	0.22	0.42

Table 4. Independent Samples t Test on Science Process by Website Type (Honors vs. AP)

10. Discussion and Summary

The results of the study indicated that there was only one statistically significant difference between high school Honors Physics websites and those of AP Physics. This was in terms of National Science Education Standards (NSES) Physics Content Standards. AP Physics websites had more Physics Content than did those of Honors Physics. There was no significant difference found between the two types of high school physics websites in regards to Web-Design, and NSES Science Process Standards.

Based on the findings of this study, several conclusions may be drawn that can be applied to high school physics teachers who attempt to build their own websites. Even though a rubric exists for Web designers to use when constructing websites, high school physics websites developed by teachers are lacking in such things as a homepage title beginning with the website name, similar design format on every page, working multimedia resources, a page footer area containing a copyright, last update and email contact, and the usage of short paragraphs and bulleted lists.

The physics content of all high school physics websites does not seem to completely reflect that which is recommended by NSES. Teachers are not including all of the following content on the site: history and nature of science, conservation of energy and increase in disorder, study of motion and forces, interactions of energy and matter, and nature of light and optics.

All high school physics websites are not providing students with opportunities for Science Process which is recommended by NSES. Teachers may not be including all of the following on the site: opportunities to conduct scientific inquiry, incorporating critical thinking skills, providing practice for problem-solving, emphasizing the Scientific Method, and providing practice for analyzing and synthesizing data. More comprehensive analyses incorporating both quantitative and qualitative methods [13] are necessary to gain a clearer picture of teacher authored physics websites in high school physics education.

It may be useful to find out if similar results exist across other subject areas with corresponding degrees of variation. For example, a replication of this study may need to be conducted using data from other instructional settings in other content areas e.g. mathematics, language, and other sciences.

Follow-up studies need to be undertaken to compare the performance of high school physics students on comprehensive and/or standardized tests based on whether or not their teacher utilizes Web-Assisted Instruction (WAI). This could help in determining the efficacy of WAI.

Teaching in the 21st century implies that practitioners become skillful at designing instruction that includes opportunities for their students to interact with learning materials published on the Internet. Those who are adept at designing online learning materials should share their knowledge with their colleagues, especially novice teachers. They should also try to establish an online repository of best practices to improve instruction.

Further research may be needed to try to determine why more high school teachers, in general, do not utilize WAI for their students outside the classroom. This could provide in-service trainers, curriculum developers, and policymakers with valuable information. For example, Web designers should be invited to participate in teacher in-service programs in order to provide information and expertise in the development of a knowledge base of best practices to facilitate Web-Assisted Instruction. Curriculum developers need to continue to review the emerging published research concerning Web-Assisted Instruction to determine its importance in the design of curriculum. Policymakers must realize that pushing any web-based technology measures may not be adequate. Emphasis must be placed on NSES-based physics content. This is critical to replenishing the scientific workforce critical to development.

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Looking at the sky with a digital spectrophotometer

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Abstract

Digital spectrophotometers allow a variety of educational measurements of emission and absorption spectra of light sources. As an example we report the observation of the skylight under different conditions, showing both the most prominent absorption Fraunhofer lines and the slight differences which can be observed in the spectral composition of the light for different orientations and time during the day. The measurements can be carried out with a simple digital spectrophotometer - now available at a reasonable cost - as an educational activity for college or undergraduate physics students.

1. Introduction

Digital spectrophotometers operating in the visible range are now a common and reasonably accessible tool even in the college or undergraduate physics laboratory.Spectral analysis in these devices is usually accomplished by letting the light from outside enter through an optical fibre into a mirror which focuses it on a diffraction grating. The different wavelengths of the composite light are then dispersed and focused on a segmented CCD, which gives the intensity spectrum, i.e. the light intensity as a function of the wavelength.

Such instruments provide an easy and fast way to measure the composition of the light emitted by a source, either by those producing continuous spectra (for instance incandescent lamps) or by those emitting discrete spectra, as for instance for spectral lamps. The comparison between the spectrum measured directly looking at the source and that obtained interposing a material (either solid or liquid) between the source and the detector also permits the investigation of the transmission properties of that material, and to extract the absorbance curve for chemical solutions, which is in turn related to the structure of the energy levels of that compound. Several of these measurements are now carried outsince many years in our lab for third year physics students.

Looking at the sky with a digital spectrophotometer may result in additional educational applications of such devices, since many features of the spectral composition of the skylight provide a way to discuss with students several aspects of classic and modern physics. One of these aspects is the emission and absorption of spectral components, either due to phenomena occurring in the Sun or in the Earth atmosphere.Absorption lines in the spectrum of the light emitted by the Sun were observed for the first time at the beginning of 1800 byJoseph von Fraunhofer,who carried out a detailed investigation of this phenomenon, measuring and classifying several hundred lines, which are now called Fraunhofer lines. Such absorption lines are now believed to originate from atomic transitions in the various chemical elements or molecules, either in the Sun or in the Earth atmosphere. Additional observations of the sky may be carried out looking at the spectral composition of the daylight along the day or – at a given hour – at the light originating from different orientations.

2. Experimental results

To carry out the measurements discussed here, we employed the 3B Scientific Mod.U17310 digital spectrophotometer [1]. It allows the measurement of the light spectrum in the approximate range 360-940 nm by means of a 2048 pixel CCD with a pixel resolution of 0.5 nm and a precision of 2 nm. Similar devices are produced also by different Companies.

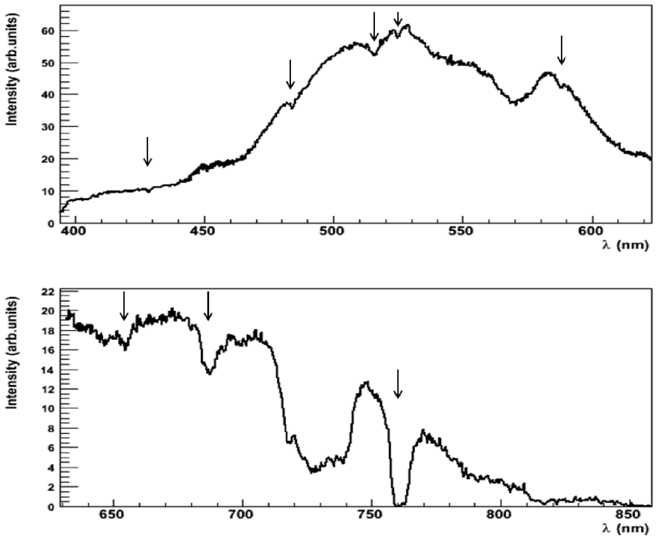

FIG. 1: A spectrum of the skylight obtained during a sunny day with the digital spectrophotometer employed in the present investigation. Arrows mark the wavelengths where observed absorption lines or bands are known (see text).

Fig.1 shows a typical spectrum which can be obtained pointing towards the sky (not directly to the Sun) the optical fibre through which the light enters into the instrument.

The spectrum which can be measured is broad, with a maximum located around 500-550 nm, and extends from the violet region to the red. Even though the shape of light spectra, as measured with basic digital spectrophotometers, is distorted by the spectral response of all such instruments, and needs to be corrected for this effect, it is apparent that the observed spectrum contains roughly all the components in the visible range. The old question of understanding why the sky is "blue" is discussed in many introductory textbooks, and it is usually related to the influence of Rayleigh scattering which is strongly dependent on the wavelength. However, the interpretation of the color of the sky has produced many discussions on the topic, and the question has been addressed by several authors in the past. Among these, Raman has long discussed this topic also in educational lectures [2], in terms of the absorption of the yellow components and the relative intensities of the blue and violet with respect to the red, yellow and green components.

Another important feature of a typical daylight spectrum is the presence of several absorption lines (or bands).These manifest themselves as narrow (or broad) dips in the spectrum, whose position may be interpreted according to the known list of Fraunhofer lines [3] and it is related to the possible atomic or molecular transitions taking place either in the Sun or in the Earth atmosphere. The detailed shape of such dips depends however on several factors, including the scattering of light in the atmosphere and the quality of the measuring instrument. By a comparison to the known absorption features in the skylight, several lines may be identified in the spectrum shown in Fig.1. For instance, the band around 430 nm is known to be due to the elements Ca and Fe,while the broad band around 760 nm is due to Oxygen.Other lines which can be easily identified even with an educational tool like that employed in the present work are some of the

Hydrogen lines (H_α at about 656 nm and H_β at about 486 nm), which are due to Hydrogen atomic transitions following the Balmer series. The same lines were observed in the lab with the same instrument, as emission lines, by the use of a Hydrogen spectral lamp.Table I shows the correspondence between the observed absorption features marked by arrows in Fig.1 and the known transitions [3]. A more detailed study of the spectral Fraunhofer lines which can be observed by such instrument, including also the presence of several elements in the outer regions of the Sun, waspreviously reported by us [4].

Wavelength (nm)	Elements (Notation)
430	Ca, Fe, H_γ (G, G')
486	H_β (F)
518	Mg, Fe (b)
527	Fe (E2)
588	He, Na (D, d)
656	H_α (C)
687	O_2 (B)
759	O_2 (A)

Table I: List of the main observed Fraunhofer lines in Fig1 (marked by arrows), together with their common spectroscopic notation and the involved chemical elements.

To check for possible small differences (if any)in the spectral composition of the skylight when pointing to different regions of the sky or at different hours along the day, several measurements were taken at different orientations, in the morning, at noon and early afternoon, pointing at the main geographical orientations (North, South, East and West) with an angle of approximately 45° from the horizon. Since the measurement of the complete spectrum with these instruments takes a very short time (fraction of a second), an additional series of measurements was taken at the same time pointing with the instrument to the East, for different polar angles (from the Zenith to 70° with respect to Zenith). Some of these measurements were repeated in the same day at 12.00 and 15.00 local time.

Fig.2 shows the spectra measured to the same (East) direction at approximately 9:30 a.m., 12.00 and 3.00 p.m. . Though reported in arbitrary units, as given by the instrument, the integrated intensity reflects the different luminosity measured in the morning, at noon and in the early afternoon on a December day. The main features are seen on all spectra; however small differences in the shape may be observed,especiallyat wavelengths larger than 600 nm. Small differences in the relative intensity of various absorption lines with respect to the smooth trend of the spectrum in that region may be also observed in the three spectra.

The overall intensity of the skylight spectrum in a given moment depends of course on the orientation with respect to the Sun apparent position in the sky.

Although in December thesunrise is not exactly in the East direction, one expects that the largest intensity in the morning come from observing the sky towards approximately East, which is indeed observed in Fig.3, showing three spectra measured at 9:30 a.m. local time at the Zenith, 20° and 45° from the Zenith. Apart from the different integrated intensity, even in this case small differences may be observed in the spectrum measured at the Zenith with respect to the other two, particularly in the region above 600 nm (red and infrared components).

Finally, a comparison between the spectra taken at the four geographical orientations, with a polar angle of approximately 45° from the horizon and at the same time (9:30 a.m.), is shown in Fig.4. Again, while the central region in all the spectra has nearly the same shape, small differences may be noted around 450 nm, where the spectrum is flatter for the North and West orientations, and above 600 nm, where the North and West spectra do not exhibit in a clear way the absorption features which are observed at East and South.

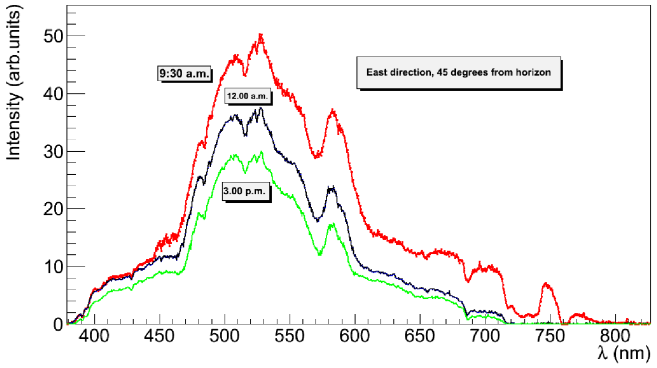

FIG. 2: Spectra measured at different times during the day, towards the East direction, approximately 45°from the horizon.

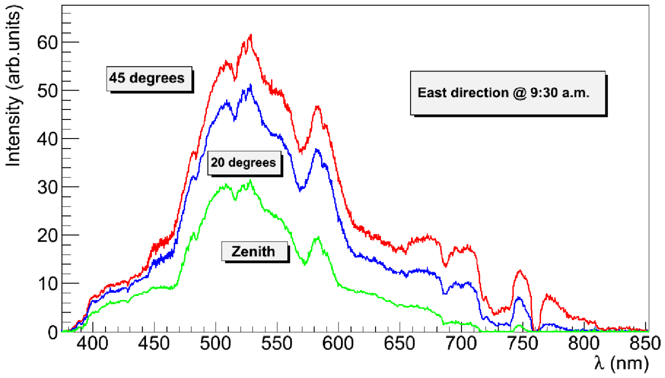

FIG. 3: Spectra measured at different inclinations with respect to the zenith, pointing in the morning to the East direction.

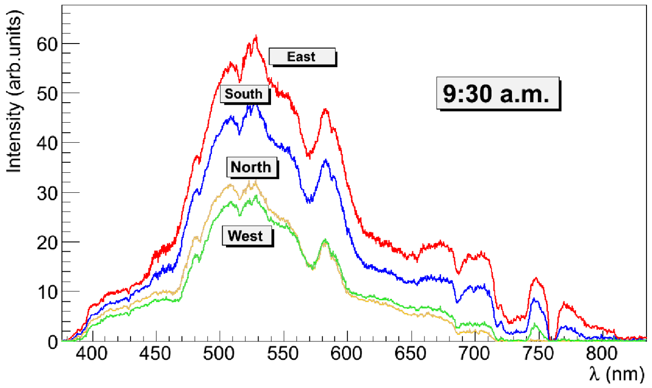

FIG. 4: Spectra measured at the same time, pointing at different geographical orientations in the morning.

3. Conclusions

The use of a modern, low-cost digital spectrophotometer in educational experiments allows a variety of measurements to be carried out in classical and modern physics. The characterization of continuous and discrete light sources may be an important part of undergraduate activity, which allows to quantitatively measure the light spectra originating from various sources of natural and artificial light. In comparison to traditional spectrometers based on a diffraction grating, as the Kirchoff-Bunsen spectrometer, where the values of each observed wavelength must be evaluated by the measurement of the diffraction angle with a goniometer, digital instruments based on the use of a CCD allow to obtain the overall spectrum in a single step, thus permitting a fast way (although not so precise as classical instruments) to visualize the spectrum.

In addition to a long list of activities which can be done by such instrument in the lab, including the quantitative study of various emission spectra and of the transmission properties of solids and liquids, the observation of the sky through digital spectrometers is able to reveal many details of the skylight. The absorption of the light either in the Sun or in the Earth atmosphere with the observation of the main Fraunhofer lines, or the search for differences in the intensity or in the spectral composition of various regions of the sky are among such investigations. More quantitative studies for the observation of such differences could be carried out by the use of a more sophisticated setup, with the measurement of the light originating from a small portion of the sky through a collimation system and a telescope mounting, allowing to measure the polar and azimuthal angles with better precision.

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Community Science Center, Ahmedabad, on Dec.22nd, 1968. Presently available on-line at http://playpen.meraka.csir.co.za/~acdc/education/Dr_Anvind_Gupa/Learners_Library_7_March_2007/Resources/books/readings/raman.pdf

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Physics Through Problem Solving XXVIII: Density of States

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Abstract

Density of states is a quantity of fundamental interest in quantum physics. We will introduce this quantity and work out some examples using simple systems studied in introductory quantum mechanics classes such as harmonic oscillator and hydrogen atom problem.

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1 Introduction

In the standard text books on quantum mechanics, the idea of density of states is not given much importance though it is one of the characteristics of a given quantum system. Knowledge of density of states will allow us to calculate the occupation probability of eigenstates, level spacing statistics, density of carriers in a semiconductor, number of conducting electrons in a free electron gas and in general gives us information about how crowded is a given spectral regime. In this piece, we will mainly discuss about the density of states of quantum systems with discrete energies using simple examples.

Let us consider a quantum system which has discrete set of states with energy eigenvalues $E_i, i = 1, 2, 3 \ldots\ldots$. We denote by $\Omega(E)$, the total number of states less than the energy E. Then, the density of states, which is the number of states in unit interval of energy, is given by,

$$\rho(E) = \frac{d\Omega(E)}{dE}. \tag{1}$$

This is a function of energy E indicating that number of discrete states in any interval depends on the which energy scale we are looking at.

2 Examples

Harmonic oscillator : Consider the simple case of harmonic oscillator whose energy is given by,

$$E_n = \left(n + \frac{1}{2}\right)\hbar\omega$$

where ω is the angular frequency of the oscillator and n is the quantum number. In this case, it is easy to see that the total number of states below energy E is

$$\Omega(E) = \left(\frac{E}{\hbar\omega} - \frac{1}{2}\right).$$

Then, using Eq 1, we get the density of states to be,

$$\rho(E) = \frac{1}{\hbar\omega}.$$

This tells us that for harmonic oscillator density of states is a constant and is not dependent on the energy E. This result should not surprise us since we know from Eq. 1 that the energy eigenvalues are equi-spaced. Thus, in general, whenever quantum systems have energy dependence of the form $E_n \propto n$, density of states will be a constant.

Anharmonic oscillators : Consider one-dimensional quantum system whose energy is of the form, $E_n = C\ (n + 1/2)^\alpha$ with C being a constant and $1 \leq \alpha \leq 2$. Quantum systems whose potential is of the form $V(x) = x^m$, where $m > 0$ is an integer, will have such energies in the semiclassical limit, *i.e*, in the limit where WKB approximation would hold good [1]. This is generally the limit of large energies or high quantum numbers. In such case, the total number of states below energy E is given by,

$$\Omega(E) = \left(\frac{E^{1/\alpha}}{\hbar\omega} - \frac{1}{2}\right).$$

Then the density of states can be easily obtained by using Eq. 1 and we get,

$$\rho(E) = \frac{E^{\frac{1}{\alpha}-1}}{\alpha\hbar\omega} \tag{2}$$

For an anharmonic oscillator with the potential $V(x) = x^4$, it is easy to use the above results to show that $\rho(E) = KE^{-1/3}$ and I will leave this as an exercise for the reader. It is clear from Eq. 2 that in the entire class of anharmonic oscillators the density of states decreases with energy. For identical interval of energy, there are more eigenstates near the ground states than at higher energies.

Infinite potential well : In this case, the energies are given by, $E_n = C_1\ n^2$, where C_1 is a constant that depends on system parameters and Planck's constant. The total number of states below an energy E is,

$$\Omega(E) = \left(\frac{E}{C_1}\right)^{1/2}.$$

The density of states is given by,

$$\rho(E) = \frac{1}{2C_1\sqrt{E}}.$$

Thus, in the case of infinite potential well, the density of states goes as $E^{-1/2}$. Note that this result we could have obtained by taking $\alpha = 2$ in Eq. 2. I leave as an exercise for the reader to figure out why $\alpha = 2$ should correspond to the infinite square well potential.

Hydrogen atom : This is another useful illustrative example. The discrete energy levels are hydrogen atom problem are given by,

$$E_n = -\frac{C_2}{n^2}, \quad n = 1, 2, 3...$$

where n is the principal quantum number. Using our recipe, we get for the total density of states,

$$\Omega(E) = \sqrt{C_2}\ E^{-1/2}$$

and the density of states turns out to be

$$\rho(E) = \frac{\sqrt{C_2}}{2E^{3/2}}.$$

Typically, in the hydrogen atom case, $E_n = -13.6/n^2 eV$. Thus, the magnitude of energy tends to zero as n increases. In this problem, higher values of principal quantum number n corresponds to $E << 1$. Hence, as $n \to \infty$, the energy tends to zero, and as a result $\rho(E) \to \infty$. This explains the crowding of energy levels near $E = 0$. For $E > 0$, there is a continuum of energies.

Black body radiation : Even though the arguments above were motivated primarily from quantum physics perspective, there would be many occasions to compute density of states in classical systems as well. One such example is the enumeration of the number of modes in a black body which is used in the calculation of Rayleigh-Jeans formula and the Planck's radiation law. We will only briefly recount the steps involved and refer the reader to text books for details [2].

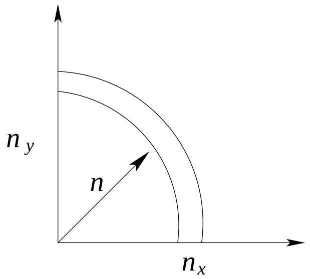

Figure 1: *Number of standing waves in the frequency range [$\nu, \nu + d\nu$]. We should determine the number of points in the shell of radius n. However, if the points are close enough we can simply assume them to be continuous and calculate the area of the shell.*

In principle, in a black body, standing waves of all possible wavelengths should be present. However, the boundary condition that waves should have a node at the walls of the cavity allows only modes of certain wavelengths to be present inside the cavity. The allowed wavelengths are obtained from the condition for standing waves in a cavity in one dimension to be $n = 2L/\lambda$, where λ is the wavelength of the standing wave and n is the number of half-wavelengths. In a 3D cavity, this condition is generalised to,

$$n_x = 2L/\lambda, \qquad n_x = 1, 2, 3, ...$$

$$\begin{aligned} n_y &= 2L/\lambda, & n_y = 1, 2, 3, ... \\ n_z &= 2L/\lambda, & n_z = 1, 2, 3, ... \end{aligned}$$

In 3D, each triplet of integers (n_x, n_y, n_z) correspond to a possible mode of standing wave inside the cavity. In a cube of side L, evidently the largest allowed standing wave will have a wavelength L. This sets the upper limit for the allowed wavelengths or equivalently frequencies in the cavity. The number of standing waves above a given value of wavelength, say $\bar{\lambda}$, is the number of such triplets (or modes) which have wavelengths above $\bar{\lambda}$. There is an easier and approximate way to calculate this quantity. Consider a 3D space of integers (n_x, n_y, n_z) and every point in this space corresponds to one possible mode of standing wave. Since there are large number of modes, we can regard this space as being essentially continuous and ask how many independent modes lie in the range of wavelengths λ and $\lambda + d\lambda$. This is given by the surface area of a shell in one octant of sphere (see figure 2) as,

$$2\left(\frac{1}{8}\right)\ 4\pi n^2\ dn \tag{3}$$

The factor 2 comes from two possible states of polarisation for each standing wave. We want the result in terms of frequency and so we write n in terms of frequency as,

$$n = 2L/\lambda = \frac{2L\nu}{c} \qquad dn = \frac{2L}{c}d\nu. \tag{4}$$

In this, c is the velocity of light. Substituting for n from Eq. 4 in Eq. 3 we get the result for number of standing waves in the cavity in $[\nu, \nu + d\nu]$ to be,

$$\rho(\nu)\ d\nu = \frac{8\pi L^3}{c^3}\nu^2\ d\nu \tag{5}$$

This is essentially the density of states for standing waves in black body. As frequency increases, number of modes is proportional to the square of the frequency. This application should not be surprising at all if we recognise that the eigenstates of quantum systems are essentially 'standing waves' or stationary states as we would properly call them in quantum physics.

Thus, the problem finding the density of states, at some level, boils down to the problem of enumerating all the states below a certain energy. It is essentially a counting problem. I leave it as a problem to the reader to plot these functions $\rho(E)$ for various systems. I must put in a word of caution that we have barely scratched the surface in dealing with density of states. There are other advanced methods of computing density of states, that does not apriori require the knowledge of how the energy is dependent on quantum numbers. So, in principle, given any Hamiltonian system, it may be possible to calculate the density of states without actually solving the full quantum system.

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Physics through Computation – a new paradigm

An Overview

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1. Historical view in the Indian context: 40 years of development

I belong to that generation of physicists who began their carreers in early 1970's where there were hardly any major computer centers. I recall IIT Kanpur with IBM 7044 and TIFR with CDC 3600 as the only well equipped computing centers in the country.. That was the era of punched cards and punching machines. Job submission meant carrying boxes of punched cards early in the morning to the computer center. It will take almost the entire day to get the results of the submitted job. The rest of the day one was then free to indulge in non-computational issues, if you wish to. Interestingly, in those days purists use to look down with disdain upon researchers using computers for their calculations - sometimes overtly but most of the times in more subtle ways. Certainly it was not prestigious to do computation and hope to advance the fronyiers of research!

What a change in 40 years!

The change has been revolutionary: In every aspect of scientific endeavor, Computers play a key roll. Computing is now an integral part of the skill sets of every physicist. Almost every research student knows some programming language or other; has rather easy access to moderate computing power, uses internet to remotely access supercomputing if needed and uses rather routinely a variety of software for graphics, visualization, statistical analysis and data mining. A few hundred megaflops of power is routine and a few tera flop is no big deal. Prestigious universities and research institutes look for young researchers with expertise in numerical simulations of this or that kind, want to have groups in high performance computing applications and proudly announce post graduate degree courses or research programmes in computational science. The number of conferences devoted to computational physics / chemistry, numerical simulations, data mining etc are growing and are now indispensable part of academic world. More importantly the boundaries between different disciplines have melted. Computational techniques have cut across the disciplines and have yielded very rich dividends.

2. What has driven this change?

There are three main developments which are responsible for this change.

- **Revolutionary change in computing environment**.

In late seventies, computing environment always meant a central computing center with huge machine requiring a good deal of power and human resource. The available languages and tools for user interface were very limited. There was no versatile operating system such as linux. We did not talk of megaflops! CPU clock speeds were in Kilo Hertz. To give an example, in late seventies diagonalizing 100*100 matrix was considered as a decent work! It all changed with Intel coming up with 8086- 8087chips and quickly within a span of two decades we saw evolution to X86, Pentium ,Xeons, FPUs, attached vector processors (no more popular), RISC architecture and then parallel machines. FORTRAN evolved, standards were set, more versatile and powerful languages were designed, and excellent quality numerical analysis libraries were made available. Very versatile Unix operating systems became standard and user friendly interfaces made its appearance. Now a few hundred megaflops are our desk, a few Giga flops affordable and a few tens of teraflops accessible remotely.

- **Super Computing – High Performance Computing.**

Even with ever increasing computing power available in even desktop PCs, the need for orders of magnitude more power was always felt for a class of problems. This is the era of Grand Challenge Problems giving rise to computing facilities with multiple processors, parallel machines etc. A few tens of thousands of cores with each node having a 10-16 cores is now not uncommon. Available memory (RAM) also grew accordingly and a 128GB Ram per node is now common. Ever decreasing price per Gigaflop was always fuelling the proliferation of computing power everywhere.

- **Towards understanding real life complex world.**

Perhaps the most significant reason for gaining respect for computing as a technique and its acceptance was compulsion for attacking real life problems with accuracies going much beyond toy models. In a number of areas problems demanded higher accuracies of results than what simplified models could provide. Let us consider age old dictum: Physics lies in making meaningful approximations. Almost all real life problems (in physics or elsewhere) are very complex. We built models as realistic as possible. However approximations are dictated by our ability to solve the resulting mathematical formulation. There are only a few models that can be analytically solved. The demands from engineering disciplines, climate modeling, weather forecasting, real time control systems, nuclear and space science left with no choice but to use numerical methods and computer models which are much closer to reality than the highly simplified, exactly analytically solvable models. During the last few decades' material science exploded. Almost continuously, newer materials are discovered, designed with specific targeted properties. These incredibly complex materials ranging from new superconductors to nano materials need detailed microscopic and quantitative predictive tools which invariably mean realistic models and numerical tools. Thus, high performance computing, large data base mining became standard paradigms for physics and indeed for other branches of science.

Today computational science is a matured interdisciplinary area. Almost all leading universities and institutes run post graduate courses in Computational physics, chemistry, bioinformatics and modeling and simulations. It is very common to hear about workshops and conferences in areas such as computational finance, social computing, bio computing applied and Industrial mathematics, computing in statistics and data mining in sciences.

3. What is Computational Science and Computational Physics?

Since it is easy to say what is NOT we begin with that!

It is not computer science; it does not deal with study of compilers and operating systems, languages, hardware etc.. It is not about gates such as AND / OR /NOR / NAND etc.. We do not worry about design and architectural issues in computing and certainly do not address formal questions like what is computing!

We are simple folks and like to use computer as a tool to solve physics problems. We do not get involved into questions like: "How human are today's machines?" "Do these machines have programmable human intelligence?" We simply want these tools to solve our complex problems faster and with greater accuracy. We do firmly believe that if the answer turns out to be wrong, we are to blame ourselves only.

Let us look at Wikipedia View: (Google it, as they say!)

Computational science

Computational science is an interdisciplinary field in which realistic mathematical models combined with scientific computing methods are used to study, usually through computer simulation and modeling, systems of real-world scientific or societal interest.

While Computing means

Computing is any goal-oriented activity requiring, benefiting from, or creating algorithmic processes - e.g. through computers. Computing includes designing, developing and building hardware and software systems; processing, structuring, and managing various kinds of information; doing scientific research on and with computers; making computer systems behave intelligently; and creating and using communications …. (Wikipedia).

Thus computing happens to be more general activity. Further, the field is different from theory and laboratory experiment which are the traditional forms of science and engineering. The scientific computing approach is to gain understanding, mainly through the analysis of mathematical models implemented on computers.

Computational science and engineering (CSE) is a relatively new discipline that deals with the development and application of computational models and simulations, often coupled with high-performance computing, to solve complex physical problems arising in engineering analysis and design (computational engineering) as well as natural phenomena (computational science). CSE has been described as **the "third mode of discovery"** (the other nodes being theory and experimentation). In many fields, computer simulation is integral and therefore essential to business and research. Computer simulation provides the capability to enter fields that are either inaccessible to traditional experimentation or where carrying out traditional empirical inquiries are prohibitively expensive. CSE, let us emphasize, should neither be confused with pure computer science nor with computer engineering.

A few comments are in order.

Evidently this is a multidisciplinary area. When the problems are complex, use of computational techniques is warranted. Using computers does not mean abandoning rigor. You may notice simulations and numerical analysis being used interchangeably. In fact both are very powerful techniques and at time the boundary is blurred. Simulation techniques allow us to carry out "experiments" when carrying these in fields is dangerous or too expensive. One of the most important aspects is its predictive power. Thus computational science has following ingredients.

1. Existence of a complex problem not having analytical solution
2. A mathematical model based on underlying theory
3. Reduction of this model to computationally tractable form. This may need some level of approximation
4. Development of algorithm(s) for obtaining numerical solution
5. Translation of above to working code using suitable language.
6. Validation and testing of the code
7. Simulating the model (in step 2) for further analysis.

What do we plan to achieve in this series?

Evidently Computational physics has evolved into a powerful discipline, inevitable part of the skill sets that must be acquired by any working physicist (indeed by any working scientist). It is multidisciplinary field. One has to master a number of facets such as Numerical analysis, algorithms, computing language (may be a few scripting ones), learn parallel computing - may be GPU programming. Some may focus on large data base handling, while others on tools like Mathematica for carrying out analytical computations. The list is endless and quite clearly a young students needs to pick up and master a few of these as a part of PhD/ Post doc training. At the same time it must be emphasized that he or she is expected to be good at, in fact master of the domain area. Given the complexity and the variety it is no wonder that many have and will turn out to be specialists in some technique of other, perhaps leaving the basic physics aspect secondary! So be it!

There is another reason for this series. With proliferation of a variety of easily accessible, high quality, and user friendly (What I call click- click codes) codes , young (and even old) researchers tend to use these as Black boxes, at times not paying careful attention to and not spending enough time on studying the underlying numerical approximations, formalism and methodology. A general consequence is likely hood of loosing desire to develop own codes / algorithms / methods. Although we do not claim that our articles will fill this gap, we hoped to introduce standard techniques and hope to present the basic algorithms.

We plan to bring out article on (But not limited to),

- **Understanding Numerics**

  A discussion of errors: Integer and floating point representation in fixed bytes, Errors due to finite precision, numerical approximations, statistical sampling etc.
- **Understanding Algorithms**

General algorithms: Simple algorithms well known as warming up exercises for analysis of algorithms, developing good habits for code writing – clean and readable codes, efficiency considerations, reliability and testing, importance of documentation etc.

- **General Techniques**

  Handling and storage of spare matrices, obtaining extreme few eigen values by Lanczoz method and variants.

  Optimization methods and applications

  Conjugate gradient methods

  Fast Fourier transforms, wavelet transforms

  The power of Visualization tools
- **Determinist methods**
- **Stochastic methods**
- **Model Hamiltonians such as Heisenberg and Hubbard models**
- **Non Linear dynamics**
- **Cellular automata**
- **Simulation and modeling of some real life systems such as transport dynamics, pray-predator models, foraging behavior etc..**
- **Bio Computing**

And hopefully many more

Quite clearly the above list is just representative as the field is vast. We cannot do justice to even these topics unless experts in the field participate actively. We invite computational scientist to contribute by sending articles. Finally we end this article by quoting well known, time tested and irrefutable quote.

Garbage in Garbage out

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Book Review:

Kariamanikkam Srinivasa Krishnan: His Life and Work

D C V Mallik and S Chatterjee University Press 2012; xxiii +451 pages

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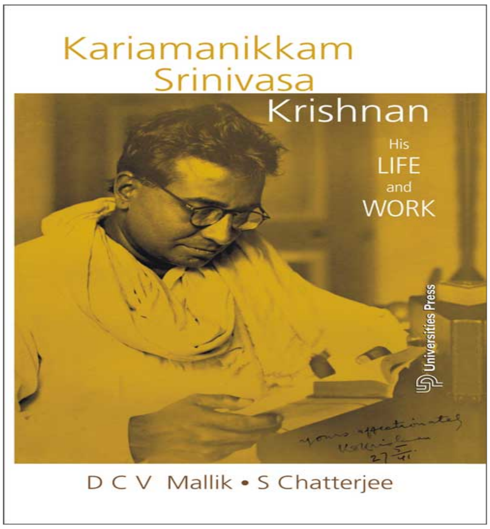

The celebrated *Raman Effect,* several of us are aware, is a joint effort of Sir C V Raman and his then fellow researcher Dr K S Krishnan, who went on to become an independent Scientist of great distinction, but may not know that he was also an exponent of the *Vishishtadvaita* philosophy as well as a scholar of *Tamizh* and *Sanskrit.* This book is a well-researched monograph telling 'the story of the life and work of a person who, along with the luminaries of his generation, assumed the task of giving India the thrust needed in scientific and technological endeavours to make her a strong and self-dependent nation'.

There is much speculation on whether K S Krishnan received due credit for the discovery. While the published papers ('A new class of Spectra due to Secondary Radiation' *Indian J. Phys.* **2**, 399 (1928) and 'A new type of secondary radiation' *Nature* London **121** 501 (1928) and many more) on the work carried both C V Raman and K S Krishnan in that order as authors, the nomination for the Nobel award by Rutherford/Bohr mentioned only C V Raman, the senior author of the work. However, it is claimed that Subrahmanyan Chandrasekhar, the well-known Astrophysicist, who was well aware with the developments at the Science Association in that period during 1928-29 and had interacted with Krishnan later had made his own assessment. Mallik and Chatterjee quote Chandra thus:

> 'My own view is clear, in a genuine sense, the discovery of Raman Effect was possible because two absolutely

> original scientists complementing each other, worked together. It is not the sharing of the discovery between the two, as giving the whole credit to each'.

Krishnan was genuinely too respectful to his *Guru* to ever press his own recognition. His personality was marked by modesty and unassuming nature about his own work - a typical characteristic of scholars among *Thenkalai Iyengars,* comments my good friend S Arunachalam, a former Editor of *Pramana* –Journal of Physics. Krishnan never expressed his sense of disappointment at being left out, no matter what his inner feelings might have been. His relationship with Raman remained as cordial and respectful as ever. It is to be noted that Raman recognized Krishnan's role in the discovery and he was generous in the praise of him in his announcement address to the South Indian association of Science at Bangalore as well as in the Nobel Prize lecture at Stockholm in December 1930.

The biography by Mallik and Chatterjee is a gentle appraiser of the greatness of K S Krishnan, who apart from his distinctive contributions to many fields of research in basic Physics, had a serious role in nurturing and building up Institutions of Research in independent India. The book begins with a couple chapters on the social milieu of the period and the place where Krishnan was born on December 4, 1898 and spent his early childhood, wades through his college years to arrive at Calcutta, where his Science education and collaboration with C V Raman took shape. The middle chapters capture the discovery of Raman Effect and Krishnan's academic engagements at Dacca, Calcutta and Allahabad. This is the period when historic development of Quantum Physics was taking place in Europe and the US, one could feel its tremors in the laboratories at Calcutta and Dacca and the corridors of Allahabad and Bangalore. Raman was a classical physicist and is not regarded as a contributor to the quantum fervor, save the important work leading to the discovery of Raman Effect. Nevertheless he got excited when he heard about the Nobel award for Arthur Compton in 1927 for Compton Effect on Xray scattering, which needed the electromagnetic waves to possess corpuscular nature that became identified with the quantum aspect of radiation. He felt that there must be an optical analogue of Compton Effect and his work was initially referred to by him as such. While Compton Effect is kinematical effect of elastic scattering of radiation and the wavelength shift depended on the scattering angle and not the scatterer, Raman effect is inelastic scattering of the radiation and the wavelength/frequency shift does not depend on the scattering angle, but on the molecular levels of the scattering medium. That Raman shifts match the infrared spectrum of the sample firmly establishes the quantum ethos and Raman effect emerged as a reliable probe of quantum levels of the molecules. This was keenly appreciated by Krishnan as he observed Raman effect in many samples, sixty odd liquids and a few vapors as well and 'each one of them showed the effect in greater or lesser degree' - obviously characteristic measure of the scatterer. This sets the stage for Krishnan to move to studies of Magnetism and Electrical resistivity of metals, both needing Quantum Physics for suitable explanation. His scientific activities in Dacca as well as his efforts to rejuvenate research at Allahabad in the areas of lattice dynamics, experimental research in thermionic emissions further enhanced the same. Apart from being a skillful experimentalist Krishnan displayed his skills in the mathematical subtleties that was all pervading in understanding

Quantum phenomena. The final chapters describe the widening vista and brings out the role Krishnan played in building Institutions, playing advisory role to many people, such as Harish Chandra (who was advised to pursue theoretical study under Homi Bhabha at Bangalore; he went on to become a reputed Mathematician at Princeton) and his decision making roles at the higher echelons of Science and Technology policy making at New Delhi.

The book gives a very lucid explanation, appropriate for a general reader of the many aspects of Research carried out by Krishnan. There are extensive references necessary to authenticate and trace the history of development of the story. The book portrays the underlying politics among Scientists, who were wielding power in those days and the responsibility that they assumed in discharging their duties. This reviewer found in the book very balanced well authenticated account of an important facet of Indian Science.

There is a lot of information that is buried in the volume, snippets that many may not know. His initiative in the nomination of the Nobel Peace Prize for Mahatma Gandhi is one of them. He made a good use of his acquaintance with Harald Wegerland, a Norwegian theoretical Physicist and entered into correspondence with him for considering Gandhi for Nobel Peace Prize by the Norwegian Academy. He sought C Rajagopalachari to provide him the material needed for a nomination to be sent to Nobel Prize Committee at Oslo. Rajaji got a prominent Quaker Mr Horace Alexander to prepare the Memorandum recommending the award for 1947. Krishnan forwarded the documents to Oslo and hoped for fair assessment. Gandhi did not get the award and from the diaries of Gunnar Jahn, who headed the committee then, it is now clear, why he didn’t – a sad commentary on the political compulsions of the day prevailing then in the West.

This reviewer enthusiastically recommends this book for anyone interested in the History of Science in India. It is a nontechnical exposition, but gives sufficient level of the Physics content necessary to appreciate the narration. I regard it as a **must read** for all students and teachers of Physics, as it will surely inspire them in their pursuit of Science.

I compliment the excellent efforts of Drs D C V Mallik and S Chatterjee and believe this to be a work of distinction, should reach many readers, particularly the aspiring Scientists.

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