

## FIFTYFOURTH ANNUAL MEETING OF THE INDIAN ACADEMY OF SCIENCES HELD AT CALCUTTA—SUMMARIES OF LECTURES DELIVERED

**Foundations of Quantum Mechanics: Open Questions and New Challenges** by Dipankar Home, *Department of Physics, Bose Institute, Calcutta 700 009, India.*

*"Anyone who is not shocked by quantum theory has not understood it"*  
—Niels Bohr

Quantum mechanics is now more than sixty-years-old. It is a strange theory. Despite tremendous empirical success covering a wide range of areas, it remains laced with daunting conceptual difficulties. Worrying doubts persist about its subtle interpretational aspects, reflections which continue to offer new surprises and puzzles. In recent years there has been a considerable upsurge of interest in this subject<sup>1</sup> owing to the emerging interface between experimental studies and foundational problems<sup>2</sup>. Thanks to technological advances, it is now possible to perform delicate experiments probing some of the recondite conceptual issues. Within the short duration of this talk I shall only attempt to enumerate briefly a few key problems in this topic:

1. Can the indeterminacy of quantum theory be removed by the addition of 'hidden' parameters that determine the result of individual measurement? The standard interpretation of quantum mechanics (advocated by Niels Bohr and his school) implied that the statistical character of quantum theory was irreducible even in principle. However, formulation of various hidden variable models indicate that it is at least logically permissible to develop self-consistent theories providing 'realistic' description of individual micro particle behaviour and the individual measured result, which nevertheless reproduces the standard quantum mechanical results at the statistical level. But then the question arises: 'Do these hidden variable models have, if at all, testable consequences different from those predicted by the standard formalism of quantum theory?' Currently, investigations are being pursued to pinpoint such cases<sup>3</sup>.

2. The measurement problem is known to be one of the 'notoriously ill-understood features of the quantum doctrine'. It is generated if one attempts to describe the measuremental interaction, including the observed microsystem and the measuring macro-apparatus, within the framework of quantum

mechanics. A measurement, after all, is a physical process and it is logical to demand that whatever happens, ought to be self-consistently explained by treating the observed system and the measuring apparatus on the same footing. However, a straightforward extrapolation of the quantum mechanical formalism to the macro-level for describing the measurement process gives rise to rather intriguing conceptual paradoxes. In recent years the quantum measurement problem has been critically studied from a perspective that brings into focus an acute incompatibility between the notions of realism at two different levels of our physical perception (macroscopic and microscopic)<sup>4</sup>. An exciting possibility emerging from these investigations is that such an incompatibility appears to be amenable to experimental studies in a way which in the early years of quantum theory might well have been difficult to imagine. In this context, the experiments using neutron interferometry<sup>5</sup> and SQUID rings<sup>6</sup> promise to provide critical tests of the quantum mechanical superposition principle at the macroscopic level. On the theoretical front, considerable effort is being made to enlarge the standard framework of the quantum mechanical formalism in order to incorporate the measurement process, including the so-called collapse of the wave function. One such notable approach is being developed by Namiki and his group<sup>7</sup> through formulation of the many-Hilbert Spaces theory of quantum measurements.

3. The seminal paper by Einstein, Podolsky and Rosen (EPR)<sup>8</sup> in 1935 pointing out a bizarre non-local effect in quantum mechanics ('Spooky action-at-a-distance') sprouted animated discussions and vigorous debate which still persist unabated. Modern investigations have unravelled fascinating facets of the non-local quantum correlation between spatially separated systems originating from the same source. After the advent of Bell's theorem<sup>9</sup> it has become possible to formulate in the context of EPR-type example an experimentally testable incompatibility between quantum mechanics and the notion of 'local realism' which implies the following 'natural' assumption: Individual measuremental results pertaining to the physical attributes of a given system are independent of the measurements performed on a spatially separated system with whom the given system may have interacted in the past but at

present they are non-interacting. However, despite concerted attempts, the related experimental studies have not yet provided an unambiguous verdict on the question of local realism versus quantum mechanics. A significant current trend is to search for new examples of the EPR paradox from hitherto unexplored domains in order to subject this question to a more critical scrutiny<sup>10</sup>. Recently, Datta *et al*<sup>11</sup> have provided a new twist to it by considering the effect of CP noninvariance. This has evoked considerable controversy<sup>12</sup> and calls for deeper studies to clarify the issues involved<sup>13</sup>. Finally, the crunch of the issue remains how to reconcile such non-local effects implied by quantum mechanics with the notion of causality and relativistic space-time description<sup>14</sup>. It seems appropriate to conclude by quoting N. D. Mermin: 'The EPR nonlocality may be regarded as a weird counterintuitive but unavoidable characteristic of quantum mechanics, or a sharp reminder of its inadequacies'. Which of these two viewpoints will be ultimately vindicated by the experimental scrutiny is still an open question.

1. Lahti, P. and Mittelstaedt, P. (eds), *Proc. Symp. Found. Mod. Phys.*, World Scientific, Singapore, 1985; *Open questions in quantum physics*, (eds) G. Tarozzi and A. Van der Merwe, Reidel, Dordrecht, 1985; *Fundamental questions in quantum mechanics*, (eds) L. M. Roth and A. Inomata, Gordon and Breach, New York, 1986; *The lesson of quantum theory*, (eds) J. de Boer *et al.*, Elsevier, Amsterdam, 1986; *Quantum implications*, (eds) B. J. Hiley and F. D. Peat, Routledge and Kegan Paul, London, 1987.
2. Namiki, M. *et al.* (eds) *Proc. 2nd Int. Symp. Found. Quantum Mechanics in the Light of New Technology*, Physical Society of Japan, Tokyo, 1987.
3. Tarozzi, G. and Van der Merwe, A. (eds), *Microphysical reality and quantum formalism*, Reidel, Dordrecht, 1987.
4. Greenberger, D. M. (ed.), *New techniques and ideas in quantum measurement theory*, New York Academy of Sciences, New York, 1986.
5. Rauch, H. in Ref. 2 and references therein.
6. Leggett, A. J., In: *Directions in condensed matter physics*, (eds) G. Grinstein and G. Mazenko, World Scientific, Singapore, 1986; Leggett, A. J. *et al.*, *Rev. Mod. Phys.*, 1987, 59, 1.
7. Namiki, M., *Ann. N. Y. Acad. Sci.*, 1986, 480, 78; Machida, S. and Namiki, M., *Progr. Theor.*

*Phys.*, 1980, 63, 1457; 1980, 63, 1833.

8. Einstein, A., Podolsky, B. and Rosen, N., *Phys. Rev.*, 1935, 47, 777.
9. Bell, J. S., *Physics*, 1964, 1, 195; In: *Proc. Int. School of Phys.*, (ed.) B. d'Espagnat, Academic Press, New York, 1971.
10. Selleri, F. (ed.), *Quantum mechanics versus local realism*, Plenum, New York, 1988.
11. Datta, A., Home, D. and Raychaudhuri, A., *Phys. Lett.*, 1987, A123, 4; 1988, 130, 187; Home, D., *Curr. Sci.*, 1988, 57, 455.
12. Ghirardi, G. C. *et al.*, *Europhys. Lett.*, 1988, 6, 95; Squires, E., *Phys. Lett.*, 1988, A130, 192; Corbett, J., *Phys. Lett.*, 1988, A130, 419 and references therein.
13. Home, D., In: *Proc. Int. Meeting on epistemology commemorating Schrödinger birth centenary*, Delphi, Greece, 1987, to be published by Kluwer, Dordrecht; Home, D. and Selleri, F., *Phys. Rep.*, 1988, (in press).
14. Penrose, R., In: *Threehundred years of gravitation*, (eds) S. W. Hawking and W. Israel, Cambridge University Press, 1987.

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**Disturbing the de-Sitter Universe** by N. Panchapakesan, Department of Physics and Astrophysics, University of Delhi, Delhi 110 007, India.

The cosmological model currently accepted by most scientists is the Big Bang Model in which our universe was created about 15 billion years ago in an explosion. The model is based on the Theory of Gravitation given by Einstein generally known as General Theory of Relativity. In this theory Gravitation modifies the flat space time which is specified by a metric. The metric which describes the Big Bang model is called the Friedmann Robertson Walker (FRW) metric. The model was used by Gamow and his collaborators to predict the existence of a radiation which should pervade the whole universe and which is a remnant of the hot radiation present in early universe. The discovery of this radiation in 1965 is one of the main successes of this model. The model is based on the cosmological principle, which is the assumption that every point in space is equivalent to any other point, i.e. isotropy and homogeneity of space. The cosmic microwave background (CMBR) observed in 1965 is very highly isotropic (to 1 in 10,000) and justifies the cosmological principle (a bit too well perhaps!).

The success of the study of nucleosynthesis in early universe based on the big bang model has led us to ask more refined questions and also face some of the problems posed by the observations. The high degree of isotropy of CMBR mentioned above raises a problem known as Horizon problem. This is the realization that two parts of the universe which are isotropic have had no chance of interacting at all. To assume the isotropy as an initial condition is not very satisfying. To overcome this and other related problems it has been suggested that the universe went through a very rapid or exponential expansion normally called 'inflationary expansion'. During this stage the universe is described by a metric called the de-Sitter metric.

We (Bhabani Majumdar and I) have studied the quasi normal modes of the de-Sitter metric. These are characteristic decaying modes of the metric when it is disturbed. These modes are found by solving the linearized equations of the perturbations of the metric with suitable boundary conditions at the horizon of the universe and at the origin where the observer is. The first few modes have been obtained by solving the recursion relations, which arise, by using the method of Hill determinant.

The gravitational radiation corresponding to these modes, if present now, would be a strong evidence in favour of the inflationary models. The frequencies (or wavelengths) would, of course, have changed (in a calculable way) due to expansion of the universe subsequently. The gravitational radiation can disturb the pulses emitted by millisecond pulsars which are otherwise very regular in their pulse emissions. Systematic attempts are now being made by astronomers to analyse the data from millisecond pulsars and look for the presence of gravitational radiation. One has to await these results.

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**Some Recent Advances in Digital Differentiators** by S. C. Dutta Roy, *Department of Electrical Engineering, Indian Institute of Technology, New Delhi 110 016, India.*

A new class of finite impulse response digital differentiators (DD) is described, which uses maximal linearity at a specific frequency as the criterion of optimality. Conventional DDs use minimax relative error (MRE) approximation, using the McClellan, Parks and Rabiner algorithm. Such designs suffer from two disadvantages. Firstly, they are inflexible

in the sense that they cannot be efficiently adopted for differentiators required to perform over a limited frequency range. Over performance leads to accentuation of out of band noise, and hence a degradation in the signal to noise ratio. Secondly, the coefficients are obtained through optimization methods, which are sensitive to finite wordlength effects; this results in the degradation of frequency response for fixed point implementations. The new designs described in this paper overcome both of these drawbacks. They perform efficiently over a limited range at low, midband or high frequencies. Also, the optimality criterion itself leads to elegant mathematical formulas for the weighting coefficients. A very remarkable by-product of these investigations is a novel and efficient architecture of DDs for variable frequency range of operation in the low or midband region of the frequency range. In this, one can obtain a desired operating frequency range simply by changing the output point, without changing any internal structure. This has opened up the possibility of fabricating a universal differentiator chip, and has led to a patent application.

An ideal DD has the frequency response  $\tilde{H}_d(\omega) = j\omega = j\tilde{H}(\omega)$  for  $-\pi \leq \omega \leq \pi$ . In this paper,  $\tilde{H}(\omega)$  has been approximated as follows:

(i) at low frequencies, by  $H_l(\omega) = \sum_{i=1}^n d_i \sin(i\omega)$ , where  $n = (N-1)/2$  and  $N$  is the length of the filter, assumed to be odd; (ii) at midband frequencies, by  $H_m(\omega) = (\pi/2) + \sum_{i=1}^n d_i \cos(i\omega)$ , where  $n = (N-1)/2$ , and  $n$  and  $N$  are odd, for magnitude only, and by

$$H_M(\omega) = (\pi/2) \sum_{\substack{i=1 \\ i \text{ odd}}}^{n-1} d_i \sin(i\omega) - (1/2) \sum_{\substack{i=2 \\ i \text{ even}}}^n d_i \sin(i\omega),$$

where  $n = (N-1)/2$ ,  $N$  is odd, but  $n$  is even, for magnitude and phase; and (iii) at high frequencies, by

$$H_h(\omega) = \pi \sum_{i=1}^n c_i \sin[(i-1/2)\omega] - \sum_{i=1}^n d_i \sin(i\omega)$$

where,  $n = N/2$ , and  $N$  is even. The optimality criteria chosen are that there should be exact match of the value of the function and as many differential coefficients as possible at  $\omega = 0, \pi/2$  or  $\pi$ . It has then been shown that  $d_i$ s and  $c_i$ s can be computed either

recursively or through explicit formulas. It is to be noted that unlike the MRE design, the new design does not require the undesirable non-integral delays at midband frequencies; at high frequencies, however, both designs do require one half sample delay. However, in each case, the new design requires substantially lower length  $N$  as compared to MRE designs, for a given frequency range of operation and tolerance.

The variable frequency DDs are obtained by expressing  $H_m(\omega)$  or  $H_l(\omega)$  in a power series of  $\cos \omega$  or  $\sin \omega$  and by exploiting the surprising result that the coefficients of the power series are independent of  $n$ .

The new designs would find various applications, some important ones being as follows:  $H_l(\omega)$  in Doppler radar and sonar, autopilotage, auto-navigation and weapon control systems;  $H_m(\omega)$  or  $H_M(\omega)$  in interferometer radar and phase comparison monopulse radar; and  $H_n(\omega)$  in homomorphic processes and image enhancement.

#### Radiation Safety Aspects of Nuclear Power Reactors, by S. D. Soman, Health and Safety Group, Bhabha Atomic Research Centre, Bombay 400 085, India.

While dealing with the topic of radiological safety of Indian nuclear power programme, I will be covering two important aspects of public interest, viz. low level radiation exposure and its effects and the radioactive waste management and disposal.

With the introduction of SI units, particularly Becquerel (Bq) for activity in place of the old unit Curie (Ci) the public perception has undergone a change in relation to the magnitude, e.g., the earlier  $1 \mu\text{Ci}$  is presently expressed as large number, viz. 37,000 Bq.

Radioactivity is primordial in nature and pervades different matrices of the natural environment in various forms of  $^{40}\text{K}$ , U, Th and their daughters. This gives rise to a natural radiation exposure of nearly 200 mrem\*/y. Estimates of human exposures from different modes are given in table 1. It is important to note that nearly 50% of this is caused by Rn, Tn and their daughter products mainly as internal radiation exposure. The terrestrial radioactivity component is varying from place to place

Table 1 Estimates of human exposure to natural radiation\*

	Average annual exposure (mrem)	% of total
Extra Terrestrial		
External (Cosmic Rays)	30	15
Internal ( $^{14}\text{C}$ )	1	0.5
Terrestrial		
External (U, Th, $^{40}\text{K}$ )		
a. Outdoor	6	3
b. Indoor	29	15
Internal		
(i) $^{40}\text{K}$ , $^{87}\text{Rb}$ and $^{238}\text{U}$ and $^{232}\text{Th}$	33	16
(ii) Rn + daughters: Tn + daughters		
a. Outdoor	9	5
b. Indoor	94	47
Total (rounded)	200	100

UNSCEAR (1982)

the average per caput external dose for Indian sub-continent being  $69 \pm 20$  mrem/y and in certain areas such as the Monazite areas of Kerala, it is comparatively high.

Apart from the natural radiation exposure human beings are exposed to other sources of radiation such as medical diagnostic X-rays, air travel, etc. Another source of global radiation exposure is the weapons' fall out which reached a peak value in 1963, since when the atmospheric test ban treaty came into being. The occupational exposures due to the growth of nuclear industry is to be viewed in this context.

#### Philosophy of Radiation Protection and Radiation Protection Standards

The basis for radiation protection standards which have been evolved by groups of experts and used universally is that: a) Early (non-stochastic) effects, e.g., skin erythema/skin burns, GI symptoms, etc are totally avoided, and, b) Long term (stochastic) effects e.g., cancer and genetic effects should be acceptably low.

Threshold value for non-stochastic effect is 50 rem. Even temporary changes in the blood can occur only beyond 25 rem.

There is no threshold value for stochastic effect and the probability of cancer induction is assumed to be increasing linearly with radiation exposure. Risk factors have been obtained from studies on the survivors at Hiroshima and Nagasaki and this risk

\*100 Rem = 1 Sv; 1 Ci =  $3.7 \times 10^{10}$  Bq.

factor is estimated as  $1.2 \times 10^{-4}$ /rem. Compared to the spontaneous cancer risk to the population, the additional risk associated with peaceful uses of nuclear energy is so small that it is actually indistinguishable from natural cancer incidence, by any medical studies. As far as the genetic effects of radiation are concerned even in Hiroshima and Nagasaki, they have not been able to observe any case even after 42 years and no other human experience exists. The estimates for genetic effects are made from animal experiments and are considered for setting standards for radiation protection.

The main features of radiation protection standards are given in table 2, which gives the exposure limits for occupational workers as well as for the members of the public. It can be seen that at these levels no early effects can occur and even the late effects will be negligibly low that they cannot be distinguished from the fluctuations in natural incidence for such effects. The radiation protection standards are set at such values so that the safety of the individual is ensured while keeping the societal risk at acceptably low levels.

#### *Radiation Exposure Control and Performance Assessment of Nuclear Power Plant Operations*

The radiation monitoring and environmental surveillance programmes of the nuclear industry is unique in the sense that the individual monitoring of workers is carried out regularly and their radiation dose data are carefully recorded. The radiation hazards control measures additionally cover area and air monitoring, issue of protective equipment and special work permits.

The occupational exposure data for the three

Table 2 ICRP dose limits

Occupational workers	
Effective dose equivalent	5000 mrem/y (50 mSv/y)
Planned exposure	
a) In any single year	10000 mrem (100 mSv)
b) Once in a life time	25000 mrem (250 mSv)
Members of the public	
Average over lifetime	100 mrem/y (1 mSv/y)
Maximum in a year	500 mrem (5 mSv/y)

nuclear power stations in the country indicate that the average doses received by the workers is ~15-20% of the ICRP (International Commission on Radiological Protection) dose limits and nobody has exceeded these limits.

The radioactive liquid and gaseous effluent discharges from the reactors can reach man through different routes including food-chain pathways and hence need to be controlled. To implement safety of environment the philosophy which governs the nuclear operations are:

- Specifying the radioactive discharge limits by regulatory authorities.
- Continuous monitoring of radioactive liquid and gaseous discharges from the stations.
- Environmental monitoring programme to check radioactive contamination of land, water, vegetables and other food stuff around the nuclear plants extending to nearly 30 km radius.

The Environmental Survey Laboratories at the different Nuclear Power Station sites regularly carry out the environmental surveillance as indicated above. The baseline data for determining the impact, if any, of the nuclear power station operations on the flora and fauna are collected much before the start up of the plant.

Over the years it is seen that the gaseous and liquid effluents from the three power stations are generally low and are only small fraction of the specified limits set by the Technical Specifications for operations. The major components of gaseous releases in PHWR stations are tritium ( $^3\text{H}$ ),  $^{41}\text{Ar}$ , iodines and particulates while in the liquid stream they are tritium and gross beta and gamma activities due to activation and fission products.

Experience over the past two decades has shown that the average radiation dose to the public within ~5 km is <3 mr/y (<30 uSv) at TAPS and <0.5 mr/y (<5uSv) at RAPS and MAPS. At the fence post of the station even a 24 h stay will not result in annual dose of more than 20 mr (200 uSv) at TAPS while at RAPS and MAPS it will be <5 mr (<50 uSv) only.

These releases do give some (though very small) radiation dose to population and using the environmental and dosimetric models one can work out the population dose due to nuclear power plants in terms of manrem in order to get an idea of societal risks. The collective dose from the three nuclear power stations in India during 1974 to 1987 varies between 650 and 800 man-rem (6.5 to 8 person-Sv).

From this it is clear that the health effects in a population of a few million will not amount to even one cancer per year whereas normal incidence is around a few thousand and hence statistically indistinguishable.

Thus the present techniques and methods adopted for radiation protection and environmental surveillance have resulted in a high level of safety.

### Radioactive wastes

The radioactive wastes are to be considered in terms of the constituent radionuclides (radio-toxicity, half-life and concentration) rather than considering any waste as equally hazardous. Radioactive half-lives of most of the radionuclides produced in reactors are less than one year. The more important long lived ones are  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  in fission products,  $^3\text{H}$  and  $^{60}\text{Co}$  isotope in activation products and  $^{239}\text{Pu}$  and  $^{240}\text{Pu}$  isotopes as transuranics. The concentration and types of radioactivity in liquid wastes are different in different nuclear fuel cycle facilities. In reactor operations even the medium level wastes are short lived at concentrations of  $\sim 10^{-3} \mu\text{Ci/ml}$  which on treatment reduce to  $10^{-6} \mu\text{Ci/ml}$  or lower and hence amenable for release to the environment after dilution to ensure that the concentrations are well below (a few per cent of) drinking water levels.

The relatively higher concentrations of radioactive wastes from fuel reprocessing plants are of the order of  $10^2$  to  $10^5 \mu\text{Ci/ml}$  and these also contain long lived radio nuclides like Sr, Cs, Pu, etc. Hence the 'problem' of waste management apply to these wastes and not to reactor wastes *per se*. One bundle of CANDU type fuel will result in 16000 Ci of FP wastes whereas the actinides associated with such wastes will be only a few curies. These wastes are converted and fixed into glass (borosilicate) and double metal encapsulated. If one sees the relative toxicity of this at different time periods one finds that FPs achieve radiotoxicity of naturally occurring pitchblende in 2 to 3 hundred years whereas for transuranics it takes  $\sim 2$  thousand years (figure 1). Total isolation from biosphere is provided when such cannisters are emplaced in deep geological formation for about  $10^6$  y (figure 2). The periods for isolation from biosphere provided by vitrified waste in geological formations are therefore considered adequate to meet the requirements. Attempts are being made to put such wastes in synthetic rock

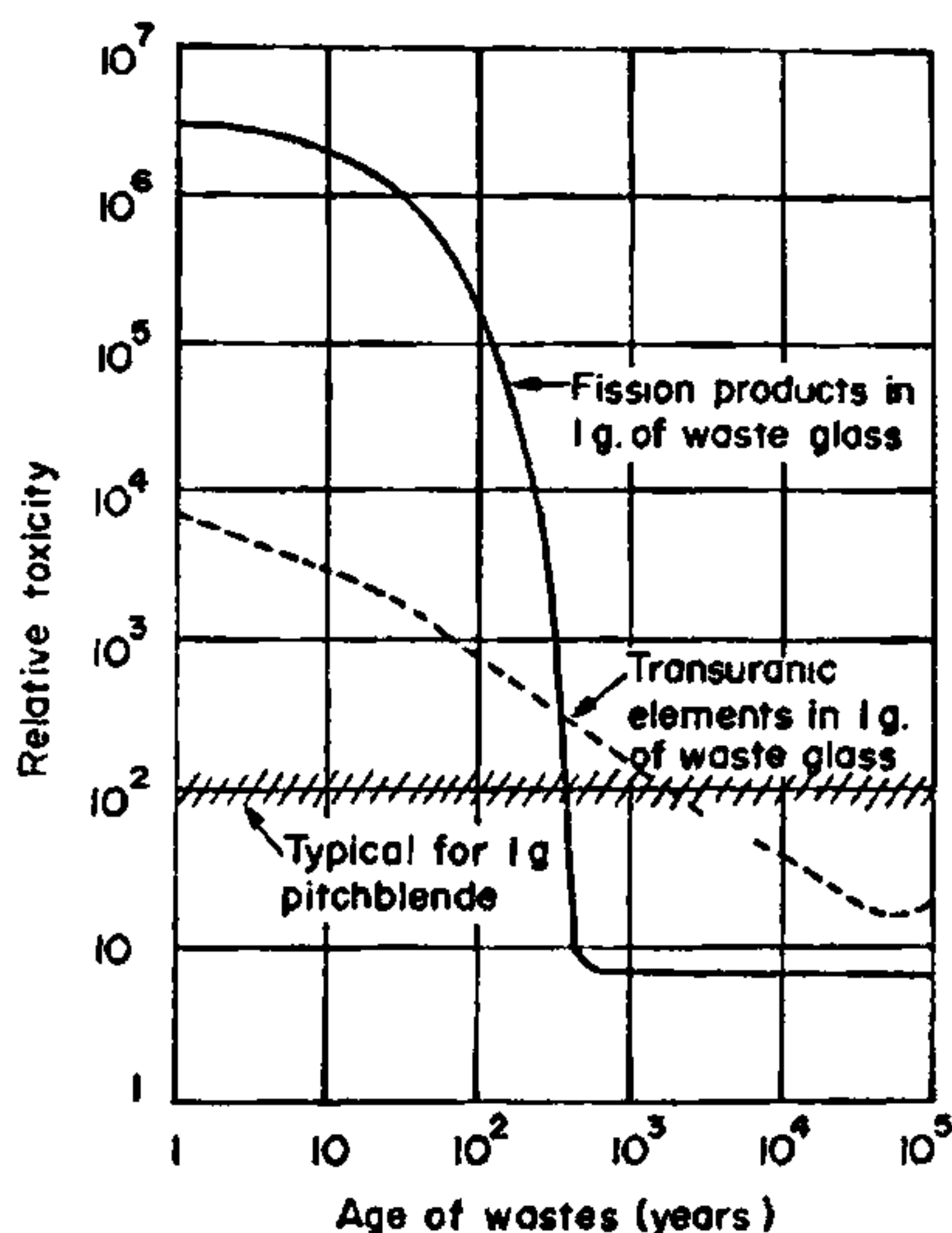
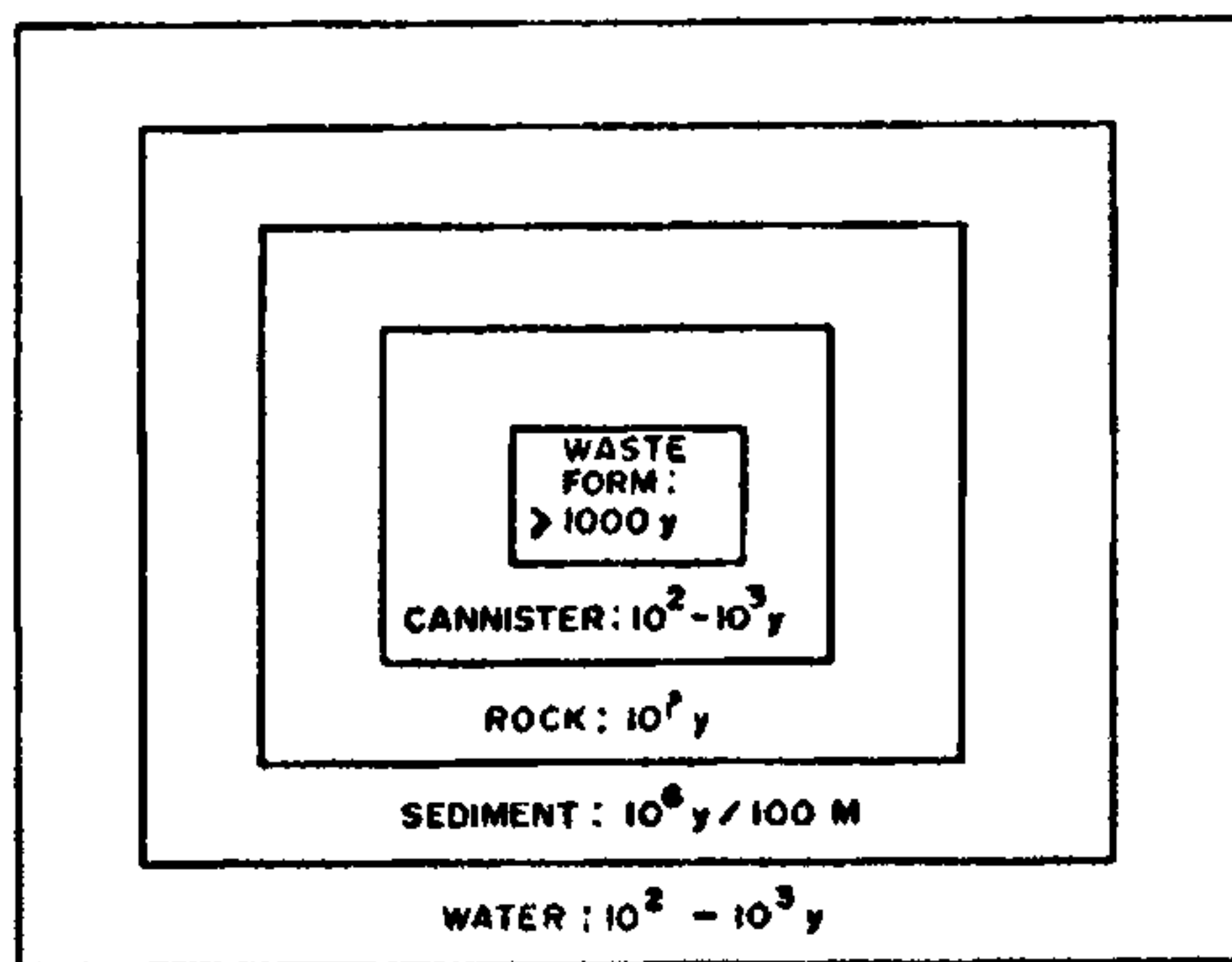


Figure 1. Relative ingestion radiotoxicity of components of highly active waste and naturally occurring radioactive pitchblende.

(Assumption: Pressurized water reactor fuel, uranium fuel cycle, 1% plutonium in waste, 15% waste in solidified (glass) material, typical pitchblende toxicity normalized to unit weight.)

After Mc Grath 1974 (report KFK 1992). Additional data for pitchblende provided by B. Skytte Jensen 1977.



$$\text{CONTAINMENT} \geq 10^6 \text{ y} = T \text{ WASTE} + T \text{ CANNISTER} + T \text{ ROCK} + T \text{ SEDIMENT} + T \text{ WATER}$$

Figure 2. Isolation of high level waste.

(synrock) matrices whose behaviour and stability over geological times are well studied and known.

In 1972, it was discovered that the uranium deposit in Oklo mine in Gabon had undergone spontaneous criticality about two billion years ago. The energy released is estimated to have a total of 15,000 MW-year over a period of perhaps as long as one million years. The fission products and plutonium have since decayed but the stable end products of decay were studied for their distribution around the places of occurrence. It was established that the original radioactive products have remained close to their places of formation without any significant migration.

A study was begun in 1979 at Morro do Ferro hill in the State of Minas Gerais in Brazil. This hill has an estimated 12000 metric ton of thorium at and above ground surface and is dated to be around 80 million years old. This deposit is in an advanced state of weathering. The distribution of thorium around the hill has shown that the migration is limited to 100 m. Because of close chemical similarities between thorium and plutonium, information on the migratory properties of thorium will be useful in understanding the behaviour of plutonium in geological repositories.

Thus the lessons learnt from nature at Oklo, Gabon uranium mine and thorium deposits at Morro do Ferro in Brazil have shown that the radioactive nuclides in geological repositories too are expected to remain close to their sites of emplacement without any significant migration.

### Conclusion

The safety experience in various nuclear power reactors as well as in other parts of the nuclear fuel cycle in the country has shown that the average radiation exposure to workers is small compared to the dose limits set by ICRP for occupational workers. Similarly the average dose to the population from these installations is negligibly small and is only a small per cent of the natural background radiation dose to the population. The problems associated with nuclear waste management/disposal are to be assessed on the basis of their radio-toxicity and concentration, rather than considering the entire waste as equally hazardous. On the basis of this the technological know how existing today is capable of handling this problem in a satisfactory manner.

**Quantum Mechanics and Chemical Valency** by M. S. Gopinathan, *Department of Chemistry, Indian Institute of Technology, Madras 600 036, India.*

The concept of valency has been used traditionally to rationalize bonding and electronic structure of molecules. In the classical theory valency is equated to the number of covalent bonds formed by the atom in the formal valence structure of the compound. Recently the concept of valency has been quantified in terms of the density matrix of the system<sup>1</sup>. This quantum chemical formulation of valency has turned out to be quite useful in the study of molecular structure and molecular energies.

Since the density matrix is normally constructed from molecular orbitals, it is possible to define a *molecular orbital valency* as the molecular orbital (MO) component of the total valency in the molecule. A comparison with results from photoelectron spectra and Mulliken overlap population analysis establishes<sup>2</sup> that MO valency is a quantitative measure of the bonding power of the molecular orbital. MO valency is close to unity for strongly bonding orbitals and nearly zero for non-bonding and anti-bonding orbitals. This property of the MO valency leads to the remarkable result that quantitative correlation diagrams can be drawn for molecules with MO valency as the ordinate and valency as the abscissa. Further, MO valency is found to satisfy various general criteria which we have formulated<sup>3,4</sup> as necessary for the ordinate of a universal correlation diagram for a given symmetry species. Such universal MO valency correlation diagrams closely resemble the well-known Walsh diagrams<sup>5</sup> which were originally constructed from qualitative arguments. Most previous attempts at the quantification of the ordinate of Walsh diagrams have used the canonical orbital eigenvalue and have achieved only partial success.

The fact that the universal MO valency correlation diagrams are similar to the celebrated Walsh diagrams suggests that valency is intimately related to molecular shape. Further, since MO valency is a theoretically well defined quantity, unlike the 'binding energy' of Walsh, the above finding opens up possibilities of quantitative correlations between valency and molecular structure. Thus molecular valency, which is also simply the sum of MO valencies, reaches a maximum around the equilibrium bond angle of the ground state of molecules.

To investigate whether the extremum property of molecular valency holds good for electronically

excited and ionised states also, we have devised a simple procedure to obtain MO valencies for such states solely from the MO's of the ground state. It is then straightforward to map the variation of MO valency with bond angle for any desired state of the molecule. The structure corresponding to the maximum of the molecular valency can then be compared with the results of extensive configuration interaction results or with experiment. This study shows that molecular valency has an extremum property for excited and ionised states and that the predicted bond angles are in very close agreement with exact values.

The close connection between valency and structure discussed above is indicative of the possible existence of a more basic relation between valency and total molecular energy. Our numerical investigations<sup>6</sup> reveal that the experimental heats of atomization of molecules are quantitatively related to the valencies associated with the bonds in the molecule and electronegativities of the constituent atoms. Further, for a given molecule, the total energy is found to be linearly related to molecular valency.

The quantitative relation between heat of atomization and valency suggests that the loss of stability in a strained molecule should be accompanied by a loss of molecular valency or equivalently a reduction of bond valencies. From a knowledge of the unstrained bond energies and the calculated values of the reduction of bond valencies in strained ring systems compared to unstrained reference compounds, it is possible to estimate the molecular strain energies. This procedure has been implemented by us and it is found to be quite successful in predicting strain energies<sup>8</sup>. This procedure is also suited for the analysis of the origin of molecular strain in terms of bond contributions.

Other interesting avenues of application of valency are the determination of the allowed reaction pathways and of the radical or biradical nature of reaction intermediates<sup>9</sup>.

It is clear from the above that the chemists' intuitive and qualitative concept of valency becomes on quantification a powerful concept for understanding the structure and energetics of molecules.

1. Gopinathan, M. S. and Jug, K., *Theor. Chim. Acta*, 1983, 63, 497, 511.
2. Gopinathan, M. S., *Proc. Indian Acad. Sci. (Chem. Sci.)*, 1986, 96, 167.
3. Gopinathan, M. S., Siddarth, P. and Ravimohan,

- C., *Theor. Chim. Acta*, 1986, 70, 303.
4. Siddarth, P. and Gopinathan, M. S., *J. Am. Chem. Soc.*, 1988, 110, 96.
5. Walsh, A. D., *J. Chem. Soc.*, 1953, 2260.
6. Siddarth, P. and Gopinathan, M. S., *Proc. Indian Acad. Sci. (Chem. Sci.)*, 1987, 99, 91.
7. Siddarth, P. and Gopinathan, M. S., *Proc. Indian Acad. Sci. (Chem. Sci.)*, Communicated.
8. Siddarth, P. and Gopinathan, M. S., *J. Mol. Struct. (Theochem.)*, 1986, 148, 101.
9. Jug, K. and Gopinathan, M. S., *Theor. Chim. Acta*, 1985, 68, 343.

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Clays: Nature's Gift to the Chemist by P. K. Ghosh, *Alchemie Research Centre, P. O. Box 155, Thane-Belapur Road, Thane 400 601, India.*

Clays may be defined as finely divided ( $< 2 \mu\text{m}$ ) crystalline layer lattice minerals comprising octahedral sheets of alumina/magnesia sandwiched between tetrahedral silicate sheets. Partial substitution of Al/Mg with lower valent ions leads to charge imbalance in several clay types. Electroneutrality in these clays is restored through incorporation of exchangeable cations, either on the external surface or between clay platelets (intercalation).

Expandable layer lattice clays—popularly known as smectites—are of special interest since they possess a high cation exchange capacity (c.e.c.  $\sim 1 \text{ meq/g}$ ) and large surface area ( $\sim 750 \text{ m}^2/\text{g}$ ). These clays can be bestowed with a variety of physical and chemical properties simply by altering the nature of the exchangeable cation. Thus, while  $\text{Na}^+$ -exchanged clays are strongly hydrophilic and employed as rheological aids in aqueous systems, exchange of  $\text{Na}^+$  with  $\text{R}_2(\text{CH}_2)_2\text{N}^+$  ( $\text{R} = \text{long chain alkyl}$ ) yields materials which are oil-compatible, with diverse applications as lubricants, additives in paints and w/o emulsions, and adsorbents for ground-water pollution control. On the other hand, exchange with aquometal ions such as  $\text{Al}^{3+}$ , yields powerful acid catalysts while incorporation of oligomeric ions, e.g.  $\text{Al}_3\text{O}_4(\text{OH})_2^{\delta+}$ , leads to 'pillared' clays suitable for shape selective reactions. Simple strategies can also be evolved for incorporation of finely dispersed semiconductor (e.g. CdS) and metal particles within the clay matrix. Suitably modified smectite clays, e.g. Fe-montmorillonite, can also induce oxidative polymerization of monomers such as thiophene and pyrrole, leading to potentially useful clay-polymer



composites. Clays can also strongly bind neutral pre-formed polymers such as polyvinyl alcohol. (It is anticipated that macro defect-free materials can also be produced from such clays.) Clays also promote spontaneous racemic and 'pseudo' racemic interactions between optically active poly(pyridyl) metal chelate ions. This observation is particularly intriguing since it may have some bearing on the question of chiral enrichment during prebiotic evolution; more importantly, from a practical point of view, it may be possible to develop versatile chromatographic columns for optical resolution.

Clearly, clays are useful materials and it is hoped that their properties will be fully exploited in the coming years.

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**Proterozoic Chronology and Evolution of the Singhbhum Region, Eastern India** by Dhruba Mukhopadhyay, *Department of Applied Geology, Indian School of Mines, Dhanbad 826 004, India.*

The Archaean nucleus of Singhbhum is made up of granites and enclaves of supracrustal rocks. There is some controversy about the age of the oldest rocks in this region, but it is certain that by 3.2 Ga a stable microcontinent was established in this terrane. Continental rifting and subsidence led to the formation of the Iron Ore basins which are now preserved all around the Singhbhum Granite massif. The lavas which were erupted were dominantly of tholeiitic affinity but trachytic lavas and volcanic ash and tuff of rhyodacitic composition are also present. It is not certain whether new oceanic crust was formed or not. Contribution of iron from volcanic sources and restriction in circulation caused by volcanic build up promoted conditions favourable for the deposition of banded iron formation. Biogenic activity may also have played a role in the deposition of the iron-bearing rocks. Structures characteristic of shallow water deposition are present in the rocks of these basins. Eventually the spreading activity ceased and the troughs closed resulting in the folding of the rocks. This sequence of events happened either in late Archaean or early Proterozoic period.

North of the Singhbhum Granite massif is the E-W trending mobile belt of North Singhbhum. At some time earlier than 2.2 Ga, extension in the old continental crust was caused by an upwelling convection current or a mantle plume. This gave rise to subsidence and formation of a basin in which

sediments were deposited. Coarse sandstone and conglomerate were deposited near the southern shore line and finer clastics were deposited in the more distal parts of the basin. A large part of the sediments are turbidity current deposits and are often described as a metaflysch sequence. Volcanic activity accompanied the sedimentation and the central belt of volcanic rocks—the Dalma Volcanics—consisting of basalt, ultramafic lavas and pyroclastic rocks probably represents a segment of the oceanic crust produced by the spreading process. The emplacement/crystallization age of granites intrusive into these supracrustal rocks is 2.1–2.2 Ga. During this early stage of earth history because of the high temperature the strength of the crust-mantle boundary was probably low. Mafic melt and hot asthenosphere could consequently spread along the boundary facilitating the decoupling of the subcrustal lithosphere from the crust above. Subcrustal lithosphere being denser than the asthenosphere would sink leading to intracontinental subduction and orogenic compression. Polyphase fold movements affected the rocks of this belt and a ductile shear zone with south directed movement developed near the southern margin of the belt. Metamorphism of both Barrovian and low pressure type is recognised, pointing to variable P–T gradients during the orogenesis. The age of deformation and metamorphism in the ductile shear zone, as deduced from Rb–Sr isochron data, is 1.4 to 1.7 Ga, which is comparable to the oldest K–Ar date (1.55 Ga) obtained from the metamorphic rocks in the central part of the belt. A late thermal event at 0.8–0.9 Ga is widespread. Thus the main evolutionary process of the North Singhbhum mobile belt took place during early to middle Proterozoic time.

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**Repair of DNA Damage in *Vibrio cholerae*** by Tapan K. Bera, Rupa Bandyopadhyay and Jyotirmoy Das, *Biophysics Division, Indian Institute of Chemical Biology, Jadavpur, Calcutta 700 032, India.*

Living cells are continually subjected to deleterious alterations in their genome which arise either spontaneously or by chemical and physical agents. The inherent stability of the DNA molecules is not sufficient to maintain the structural integrity of the genome. The ability to repair damage in its DNA is essential to maintain the genetic continuity. Recent studies have shown that most repairable DNA

damage are both mutagenic and carcinogenic<sup>1,2</sup>.

Living cells have adopted several conceptually different strategies for repairing DNA damage. While some of the repair pathways produce error-proof DNA repair, other repair the DNA in an error-prone fashion. The nature of the damage and the timing of repair determine whether error-proof or error-prone repair pathways will be operative. Studies on DNA repair, besides understanding the repair mechanism as such in an organism, also helps to develop genetics of organisms like *Vibrio cholerae* for which the information on genetics is extremely meagre.

From a series of experiments we have delineated the different error-proof repair pathways operative in this highly pathogenic gram-negative bacterium. It has been shown that these cells though efficient in repairing DNA damage by the photoreactivating mechanism, do not possess efficient excision repair system<sup>3,4</sup>. Furthermore, the excision repair capability is a direct function of the toxinogenicity of the strain. The hypertoxinogenic strains of *V. cholerae* can partially repair ultra violet (UV) light induced DNA damage using the excision repair scheme. The mild and nontoxinogenic strains completely lack this mode of repair<sup>5</sup>. Studies of irradiated cell DNA indicate that the UV-induced pyrimidine dimers are not excised in cells which lack the excision repair mechanism. It has been shown that UV-irradiated cells after saturation of dark repair can be further photo-reactivated, a phenomenon not reported in any other organism.

In course of our study, it has been observed that the excision repair capability of the hypertoxinogenic strain of classical vibrios is reduced during laboratory subculturing along with the reduction of its toxinogenicity. A single passage of the laboratory culture through the guinea pig restores the repair capability and the virulence. This phenomenon was not observed when laboratory maintained and animal passaged mild toxinogenic and nontoxinogenic strains were examined<sup>5</sup>. A radiation-sensitive mutant of the hypertoxinogenic strain 569B was isolated and the mutant cells failed to produce any detectable amount of cholera toxin as measured by ileal loop assay<sup>4</sup>.

When the repair of photodynamic damage induced by acriflavine and visible light was examined in cells efficient and inefficient in repairing UV-induced DNA damage, it was observed that there is no difference in their capabilities to repair damage following photodynamic treatment<sup>6</sup>.

DNA repair proficient and deficient strains of *V. cholerae* were used to examine host cell reactivation (HCR), Weigle reactivation (WR) and photo-reactivation (PR) of UV-irradiated cholera phages. Phages belonging to different morphological and serological groups<sup>7,8</sup> could be efficiently photo-reactivated. HCR of different groups was different on the same indicator host. However, attempts to demonstrate WR of UV-irradiated cholera phages were not successful, although UV-induced filamentation of host cells was observed<sup>9</sup>. These observations led us to examine the error-prone repair processes in this organism.

Using interspecific complementation of an *Escherichia coli* recA mutant with the plasmids containing the gene bank of *V. cholerae*, the recA gene of *V. cholerae* has been identified, cloned and sequenced. The recA gene of *V. cholerae* codes for a 39,000 Da protein. The properties of the protein have been examined in detail<sup>10</sup>. In view of the fact that the recA gene of *V. cholerae* is functional and uvrA, B, C gene products are present in hypertoxinogenic strains, the absence of WR of UV-irradiated phages and the UV-nonmutability of *V. cholerae* cells prompted us to examine the status of the umuDC gene functions in this organism.

We have shown that *V. cholerae* cells lack the umuDC gene function. This observation was supported by the fact that when the plasmid pKM101 carrying the mucAB genes (which can complement umuDC gene functions) is introduced into *V. cholerae* cells, they acquire the UV-mutable phenotype and UV-irradiated cholera phages can be Weigle reactivated<sup>11</sup>.

In spite of its inefficiency in repairing DNA damage induced by external agents, the spontaneous mutation frequency is comparable to organisms proficient in DNA repair. We have started examining the status of the network responsible for controlling spontaneous mutation frequency. This mechanism known as DNA mismatch repair process involves co-ordinated functioning of a set of gene products designated as mutator genes. Besides, a DNA adenine methylase gene (dam) plays an important role in this mode of repair<sup>12</sup>. We have cloned the mutL and mutS genes of *V. cholerae* as well as the dam gene. The functions of these gene products in maintaining the normal frequency of spontaneous mutation are yet to be determined.

1. Witkin, E. N., *Bacteriol. Rev.*, 1976, 40, 869.

2. Walker, G. A., *Microbiol. Rev.*, 1984, 48, 60.
3. Das, G., Sil, K. and Das, J., *Biochem. Biophys. Acta*, 1981, 655, 413.
4. Das, G. and Das, J., *Mutat. Res.*, 1983, 109, 21.
5. Roy, N. K., Das, G., Balganes, T. S., Dey, S. N., Ghosh, R. K. and Das, J., *J. Gen. Microbiol.*, 1982, 128, 1927.
6. Sil, K., Das, G. and Das, J., *Photochem. Photobiol.*, 1983, 38, 185.
7. Mukherjee, S., *Bull. WHO*, 1963, 28, 337.
8. Chatterjee, S. N., Das, J. and Barua, D., *J. Med. Res.*, 1965, 53, 934.
9. Palit, B. N., Das, G. and Das, J., *J. Gen. Virol.*, 1983, 64, 1749.
10. Paul, K., Ghosh, S. K. and Das, J., *Mol. Gen. Genet.*, 1986, 203, 58.
11. Ghosh, S. K., Panda, D. and Das, J., *Mutat Res.*, 1988, (In press).
12. Radman, M. and Wagner, R., *Annu. Rev. Genet.*, 1986, 20, 523.

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**Meiotic Chromatin** by M. R. S. Rao, *Department of Biochemistry, Indian Institute of Science, Bangalore 560 012, India.*

Chromosome pairing and genetic recombination between the two homologues are important events during meiosis. Pairing of the chromosomes is initiated at the leptotene stage which is completed at the zygotene interval of the meiotic prophase. At the subsequent pachytene interval recombination takes place between the paired homologous chromosomes. During the meiotic prophase of mammalian spermatogenesis, there is extensive reorganization of chromatin structure mediated through replacement of the somatic histone subtypes with the testis specific variants, namely H1t, TH2A and TH2B. Since the histones are now believed to be primarily involved in the structural organization of the eukaryotic chromatin, we have carried out extensive investigations on the structural aspects of pachytene chromatin.

Initial studies on the circular dichroism spectra and thermal denaturation properties of rat pachytene nucleosome core particles revealed that there is a loosening of the DNA-histone interactions as a result of replacement of H2A and H2B by TH2A and TH2B. This result has been further confirmed by analysing the DNase I sensitivity of 5' end labelled pachytene core particles. These studies

clearly showed that the strength of histone-DNA interaction in the pachytene core particle, at 30-40 nucleotides away from the 5' end, the site at which H2B (TH2B) interacts with the DNA, is at least 5-fold weaker than in liver nucleosome core particle containing only H2B subtype. The weakened histone-DNA interaction was not only observed in isolated nucleosome core particle but also in native pachytene chromatin. Such a loosened histone-DNA interaction at the nucleosome core particle level may facilitate 'disentanglement' of the DNA strands from the duplex to undergo strand exchange between the two paired homologous chromosomes.

Histone H1t, a testis-specific histone subtype has been purified to electrophoretic homogeneity and polyclonal antibodies were elicited in rabbits. Although antigenic sites were present both in the globular domain and c-terminal half of the molecule, the histone H1t molecule was antigenically distinct in that the antibodies did not cross-react with any of the somatic H1 subtypes and chicken erythrocyte H5.

Nuclear matrix isolated from rat pachytene spermatocytes retains the characteristic 'synaptonemal complexes'. A comparison of the polypeptide components of the rat pachytene and liver nuclear matrices revealed the presence of a 110 KDa polypeptide only in the pachytene matrix. Polyclonal antibodies against 110 KDa polypeptide were elicited in rabbits. Immunoblotting studies showed that this protein is unique to germ cells and not present in the somatic tissues. Moreover, this protein was also detected in the rat ovaries. Immunofluorescence studies have shown that an antigenically related polypeptide is conserved in diverse species such as mammals, amphibians, avian, insects and plants. Hence, it is possible that this protein may play an important role in meiotic events such as chromosome pairing and genetic recombination.

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**Some Recent Developments in Neuro-oncology** by Chitra Sarkar, *Department of Pathology, All India Institute of Medical Sciences, New Delhi 110 029, India.*

In the recent past many advances have occurred in the field of cancer research. Neuro-oncology which involves the study of tumours arising from brain and related intracranial structures has emerged

as a very important discipline. Accurate diagnosis is now possible with the introduction of sophisticated imaging techniques like the CAT (Computerized Axial Tomogram) scan, NMR (Nuclear Magnetic Resonance) scan and the PET (Positron Emission Tomography) scan. Concomitantly tremendous progress has been made in the basic research for understanding the biological behaviour of these tumours. This in turn has resulted in much better modes of therapy and prognostication. Some of the techniques used in the study of these tumours other than routine light microscopy (LM) include electron microscopy (EM), immunohistochemistry (IHC), immunoelectron microscopy (IEM), tissue culture, cell kinetics and molecular genetics.

A large variety of tumours arise from the brain and related intracranial structures like pituitary and pineal. Some of these are benign and others are malignant. We have studied tumours arising from the anterior pituitary called pituitary adenomas. These tumours constitute 4.4–17.9% of all intracranial space occupying lesions in different series.

The pituitary adenomas have long been traditionally classified into chromophobe, acidophil and basophil adenomas on the basis of their tinctorial characteristics shown by various staining techniques. The chromophobe adenomas were considered to be non-functioning while the acidophil and basophil as functioning. However, now it has been realised that this classification is no longer tenable as it does not always give a true indication of the functional status of these tumours. Hence this study was undertaken in order to get a better insight into the biology of these tumours and their clinicopathological correlation.

One hundred cases of pituitary adenomas were studied using light and electron microscopy, immunohistochemistry with antibodies to various hormones, serum radioimmunoassay (RIA), IEM microscopy and tissue culture. The results of these studies were then correlated with the clinical profile of these patients.

Clinically, the patients could be divided into two broad groups namely, Group I 'non-functioning' (48 cases) and Group II 'functioning' (52 cases) based on the absence or presence of overt clinical features of increased endocrine activity.

The Group I could further be subdivided into two groups (IA and IB) based on the results of the other studies. In Group IA (29 patients), there was a male preponderance with a median age of 40 years. All were chromophobe adenomas and at EM were seen

to be composed of cells with poorly developed rough endoplasmic reticulum (RER) and Golgi apparatus (GA). These were considered as secretorily inactive cells. Serum hormone levels were within normal limits and IHC showed no evidence of hormone in them. These are the null cell adenomas. Group IB (19 patients) was also characterized by male preponderance with a median age of 32 years. Though clinically and light microscopically indistinguishable from Group IA, ultrastructurally these tumours were seen to be composed of secretorily active cells with prominent RER and GA and a few secretory granules. Serum prolactin (PRL) was markedly elevated in all the cases and IHC consistently demonstrated PRL in all the tumour cells. Thus this group IB comprising of PRL-secreting tumours (Prolactinomas) could only be identified by serum RIA and IHC. It is very important to diagnose these tumours as they can now be treated with a drug called Bromocryptine.

The clinically hyperfunctioning Group II could further be subdivided into 3 subgroups. In Group IIA, all the patients (42) had acromegaly as the main presenting feature, but in addition 11 patients had amenorrhea and/or galactorrhea. Unlike patients in Group I, there was a female preponderance in this group and they were of relatively younger age (median 28 years). By LM, 24 were chromophobe adenomas, 15 were acidophil and 3 were mixed adenomas. Ultrastructurally they were composed of a mixture of secretorily active cells and well-granulated cells. In many cells, spherical filamentous bodies were noted. In all these cases, the serum growth hormone (GH) was raised and in 40% of the cases, the PRL was also simultaneously increased. By IHC, all the tumours showed strong positivity for GH. In addition, 30 tumours showed the presence of 2 or more hormones, the commonest combination being PRL along with GH. These tumours producing 2 or more hormones are called pleurihormonal adenomas, which we will shortly discuss.

In Group IIB, the patients (6) presented with amenorrhea and galactorrhea. Most of the patients were females with chromophobe adenomas and raised serum PRL levels. By IHC, PRL was demonstrated in all the tumours.

In Group IIC, all the 4 patients were females who presented with Cushing's syndrome. By LM, two were chromophobe and two were basophil adenomas with classical EM features of well-granulated cells having diffusely spread cytoplasmic microfilaments. By IHC, all tumours were positive for ACTH.

At the present stage, the following conclusions can be drawn from the above study:

1. Light microscopy is of limited value as it does not reflect the clinical status of these tumours; 77.5% were chromophobe adenomas in this series of which 65% were associated with hyperfunction.

2. Electron microscopy is useful for assessing the secretory capacity of the cells but the secretory granule size is of little help in identifying the hormone within the tumour.

3. IHC, IEM and serum hormone studies have been very useful in understanding the functional aspect of these tumours. The clinically non-functioning prolactinomas can be diagnosed only by the use of these techniques. Also the existence of pleurihormonal adenomas has been established.

The demonstration of pleurihormonal adenomas by IHC has been of great interest in the field of research of pituitary adenomas today. The commonest combination seen was of GH and PRL, though other combinations like GH and TSH; GH, PRL and ACTH; GH, PRL and TSH, etc. have also been found. One interesting finding in these pleurihormonal adenomas was that the immunohistochemical demonstration of hormones was not always reflected in the serum and/or clinical picture. The reason for this is not exactly known although there are various hypotheses.

Also there is some debate in the literature as to whether GH and PRL in these pleurihormonal adenomas are secreted by different populations of cells or by the same cells. We therefore investigated these adenomas further, using double labelling immuno-electron microscopy and tissue culture. *In vitro* culture showed that these tumours secreted both GH and PRL in the culture medium. IEM

revealed the presence of GH and PRL inside the same tumour cells and sometimes within the same secretory granules. These cells which contain both GH and PRL have been called mammosomatotrophs and the tumours as mammosomatotroph adenomas. Mammosomatotroph cells have now been seen in normal rat and human foetal pituitary. Their significance is not exactly known—whether they represent a normal stage of the cell cycle or whether they are the stem cells from which GH and PRL cells then differentiate. We feel that the mammosomatotroph adenomas are the more common pleurihormonal adenomas than true mixed GH and PRL adenomas, i.e. tumours which have two distinct population of cells, one producing only GH and the other only PRL.

The importance of demonstration of mammosomatotroph adenomas is 2-fold. Firstly, it has refuted the 'one cell—one hormone' hypothesis. Secondly, it has practical implications for the management of patients with pituitary adenoma. It is now established that Bromocryptine causes regression of prolactinomas. Likewise, somatostatin analogues have been demonstrated to be beneficial for patients with GH secreting tumours. Whether multi-therapy should be used for these mammosomatotroph adenomas is a question which remains unanswered.

In conclusion we feel that the classification of pituitary adenomas needs to be revised and the new classification proposed by Horvath and Kovacs is more suitable as it correlates to some extent with the ultrastructure and functional status of these tumours. However, it has its drawbacks and with the increasing knowledge acquired by the use of new scientific techniques, this classification may also have to be revised in the near future.

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