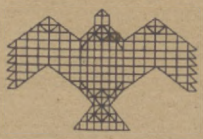


NATIONAL INSTITUTE OF ADVANCED STUDIES
Indian Institute of Science Campus
Bangalore 560 012

LIFE SCIENCES

NANO-SCIENCE

Life Sciences (Beck's book)

Unit of Life - The Cell

The cell theory was formulated in 1838 by Schleiden and Schwann.

① Plants are composed entirely of cells which are units of structure, physiology and organization

② Cells possess duality - they are independent lives within a higher form of life

③ Mechanism of cell formation - new cells arise by a process similar to crystallization (this is not correct link) - new cells are formed by cell division

Historical Notes

S.K. Majumder in Indian Journal of History of Science (INSA) Sept 2004 vol 39. No. 3

Life looks like a matter of Chemistry. A normal human cell contains 22 matched pairs of chromosomes and two sex chromosomes (X and Y). Every cell of our body has the same number of chromosomes except the reproductive cells (eggs and sperms) which have exactly half the usual numbers. These chromosomes from both parents fuse and new individual life is formed

and the exact diploid number is obtained.

* We have 60 trillion cells in our bodies and 30,000 genes
* The entire map of human genome (gene + chromosome) has been elucidated on June 26, 2000
* Human Genome contains 3 billion ~~pairs~~ pairs. But 90% are junk!

* "Not everything that can be counted counts and not everything that counts can be counted" Einstein (1921)

* Circulation theory of blood by William Harvey in 1628 (De Motu Cordis et Sanguinis Animalibus)

1543 →

- Vesalius's Anatomical book - 1543
- Copernicus - Helio Centric theory - 1543

Landmark year in medicine, Surgery, astronomy, physics, biology, physiology

* Gregor Johann Mendel)

Mendel (1822 - 1884)
Monk in Augustinian monastery at Brunn (now Brno in Czechoslovakia)

Started work on inheritance in 1856 and in 1865 communicated some of his results to Brunn Society of Natural Science. They remained in archives until discovered in 1900 35 years after publication and after his death. by three botanists pursuing similar path as Mendel - He discovered the basic statistical laws of heredity - supplied missing links in Darwin's theory (1809 - 1882)

=

Paul M Nurse (2001 Nobel Prize winner)

Biology looks set to dominate scientific achievement in the next half century and the structure of DNA will continue to play an important role in these advances.

One prediction is that we will understand in full how each cell receives a complete set of DNA instructions - genome - when it is formed at cell division. The cell is the basic unit of life and when it divides to form two new daughter cells, copies of the genome

must be transmitted to both cells.
The molecular basis of the copying process is explained by the complementary strands of the double helix, but what is not fully understood is how these copied strands are oriented correctly to each other and are accurately separated at cell division. There are range of equisitely precise mechanisms and controls that achieve both the copying and the separating. Knowing how these work will be very important for cancer because any mistakes in these mechanisms and controls leads to genomic instability and damaged genes can be passed on at cell division. If any of these genes are concerned with cell growth then daughter cells formed may become cancerous.
The second prediction arises from the information carried by DNA coded in the sequence of nucleotides (bases) the molecular building blocks of each DNA strand making up the double helix. Knowing how the information coded in the genome

translates into the amazing behaviour of cells should be worked out in the next half century.

* Cells are the simplest units ~~of life~~ that embody the characteristics of life, such as the ability to reproduce, to self-organize, to evolve. Knowing how genes work together to generate life will be first understood in the behaviours of the cell and will be a major intellectual ~~advancement~~ achievement (The Daily Telegraph London, Wednesday, April 16, 2003, Science p-14)

From "Sciences Scotland"
issue 4 Spring 2015

Cells:

All living things are made of cells, from the simple single-celled organisms such as bacteria to complex multi-celled organisms such as plants and animals.
Humans are made of billions of individual cells of many different types, including skin, muscle, and nerve cells, each of which has specialized roles in the body. Cancer and other major human diseases result in various ways from the basic defects in the normal working of healthy cells.

Proteins:

Proteins are both the building blocks and the machine tools of living cells. While DNA stores the genetic information, it is the many different types of protein molecules encoded by our

genes that actually do most of the work in the cells. The failure of proteins to perform their allotted role correctly is a main cause of disease. Some proteins have structural roles. For example, the fibres that make up the muscle are made of proteins. Enzymes are also proteins. - they catalyze the chemical reactions that break down food and provide cells with energy (metabolism). Other types of proteins are regulators - they catalyze the chemical reactions that ~~break down food~~ bind to specific regions of DNA.

The Proteome:

In the same way the complete chemical sequence of DNA for all genes in organisms is termed the 'genome', the full set of proteins encoded by the genome is called the "proteome". Proteomics can be described as (Proteomics

Can be described as the new art of identifying proteins enmasse and studying their structure and function. It is already established as an important area of science for the key task of interpreting the genome.

(From the Meaning of Evolution / George Gaylord Simpson)

Historical aspect of Evolution

Evolution of Evolution

- Aristotle made great progress in the description of nature, but little in the understanding of it and in on the whole placed impediments on the way of this
- The hypothesis of Special creation did nevertheless become so deeply involved in Christian belief that it was felt to be essential to that belief and still is by a considerable proportion of Christians
- Descartes (who died in 1650) hinted that he held privately in evolutionary views.
- The others who supported evolution Hooke (1635-1703), Ray (1627-1705) de Maillet (1652-1738), Maupertius (1698-1759), Buffon (1707-88) Erasmus Darwin 1731-1802 (Grand-father of Charles)

All these considered evolution as possible and proclaimed it as reality

- Lamarck (1744-1829) - second only to Charles Darwin. -
- Evolution behind all creation of life.
- All life forms represent progression with man as the highest form.
- Although this progression is the major feature of evolution and its principal cause (progression cause cannot be specified), it is perturbed and does not work out regularly because of local adaption to so many different ways of life.

- Adaption brought about by habit of animals. The environment requires appropriate habits which bring about structural changes and the use or disuse of organs and these changes would be inherited
- "We know now that changes arising from habits cannot be inherited, except in quite different and characteristically human inheritance of learning and there is no such thing as the old Aristotlean single progression from ~~imperfect~~ simple and imperfect to perfect

Yet, Lamarck observed, more clearly than many of his successors that evolution involves both oriented and random features and both must be explained in a consistent theory.

Lamarck also emphasized that adaptation is a universal fact in nature and must be faced in any attempt to explain evolution.

Charles Darwin (1809-82)

Darwin's theory involved four factors:

(i) Natural Selection

(ii) inherited of use and disuse (as in Lamarck)

(iii) inherited direct action on the organism by external conditions (denied by Lamarck)

(iv) "variations" which seem to us in our ignorance to arise spontaneously

Of these "Natural Selection" is associated with Darwin - most important, but not

only part of Darwin's theory.

- Modern concept of natural selection is considerably broadened and refined and not quite the same as Darwin's. In modern theory is Natural selection is Differential ~~production~~ reproduction. — in which there is complex interplay of heredity, genetic variation ...
- In Darwin's theory natural selection was elimination, death of the unit and survival of the fittest in a struggle for existence.

- Darwin's hints as to the operation of evolution had deficiencies because of insufficient knowledge of his time

- Birth of Genetics

It was during the turn of the 19th. century, when conflicts of the neo-Darwinism, neo-Lamarckism, vitalism, Finalism had thrown study of evolution into great confusion that the source of genetics was born

Even before the discovery of Mendelism, de Vries had noted the sudden and random appearance of new varieties of plants. (now attributed to Chromosome mutations). He decided that at last was the basis of evolution and he generalised it in his mutation theory in 1904.

But mutations are random. Therefore it was thought that evolution was random. Adaptation(?) had to be abolished!

But evolution is not Completely random. (Confusion worse confounded!) Progressive adaption does occur.

- Evolution studies became the focus of life sciences
  - Synthetic theory (Fisher, Haldane, Huxley Darlington, Waddington, Ford in England Wright, Muller, Dobzhansky, Mayr, Stebbins, Simpson in the US.)

Causes of evolution put on a more firm ground. Whole mystery not solved yet.

" Yet the origin of Cosmos and the causal principles of its history remain unexplained and inaccessible to science. Here hidden is the first

Cause sought by theology and philosophy. The first cause is not known and I suspect it will be never known to living man. We may if we are so inclined worship it in our own way, but we certainly do not comprehend it"

Simpson

- What we have is only an interim report

- The first grand lesson learnt from evolution is the unity of life.
- Man is vertibrate, mammal, primate
- It is not a fact that man is nothing but an animal. In a way a new kind of animal.
- He has characteristics not shared by other animals (primates)
- intelligence, flexibility, individualization, and socialization.
- In man, a new sort of evolution has appeared
  - heredity, inherence of learning
  (weak in other animals)
- Organic evolution rejects acquired characteristics of inheritance
- The new evolution peculiar to man operates directly by the inheritance of acquired characteristics of knowledge and

and learned activities - influenced by environment, social organization. organic evolution is limited in space and time by its rigid requirement of proximity and continuity.

The Modern Mind. (Peter Watson (2000)
Perenial 2002
Harper Collins NY.

Evolution of Evolution!

Progress is a notoriously elusive Concept.
History disgrace of humanity (?) mixed up
with Social Darwinism - Nazi theory,
and degeneration.
Bohr's - irrevocable linking of physics
and Chemistry - Atomic Structure and
Periodic Table

Consciousness and Persons (Unity and Identity) } Michael Tye.

1. Ego Theory: Rene Descartes (1641)

Cartesian Form:

- Persons are continuing, spiritual substances, whose essence is consciousness. What unites different experiences I have at the same time, indeed what unifies my entire mental history, is the fact that all the relevant experiences are had by the continuing spiritual substance - that is "me". The ego theory thus grounds subjective unity for experiences on the sameness of spiritual substance

(2) The bundle theory:

The bundle theory draws on the observation that experiences, thoughts and other mental states of a single person stands in various causal relations to one another. - for example, experiences cause

(NDS Lib)

Scientific Essentialism:

Brian Ellis (2001)

Preface:

- If the world has no intrinsic structure then in principle any single way of conceptualising it might be as good as any other (reaction a Bretton!)
- There would be an objective world and perhaps from human perspective, a best description of it. But such a one might not be the best for another

of Nature

① Are laws } imposed on things which are independent of the laws? (Dominant philosophy 17th, 18th century)

② or Are laws immanent in the world and not superimposed? – they depend on the essential properties of things.

(essentialism)

- According to Sheets, the world is not passive, but fundamentally active and ~~perfect~~ reactive.

Founding father of Western Philosophy → tradition
Descartes, Newton, Locke, Hume, Kant — (17, 18 Century)
" Laws of Nature are contingent and operate on things that are essentially ~~independent~~ inert and passive "
∴ What happens in the world depends on what the laws of Nature happen to be.

No dependence on kinds of things and the circumstances

(Essentialism) → Not accepted in Modern times More Aristotlean.

World is not passive. It is active - interactive - reactive.
Not a mechanistic kind of things having attributes of extension and impenetrability as Descarte's and Locke's beliefs are.
Transient objects that impact both each other. - processes dominate

Quantum Discreteness –

It is discreteness at the quantum level which guarantees that there are discrete, ontologically based distinctions of the kind in Nature –

generator of real distinctions

Chemical elements – Specific properties

Protons and Electrons both specific properties

What is in your Mind?

National Geographic
March 2005

- Brain processes information in parallel. The image is broken down into information about Color, form and orientation by segregated ~~modules~~ modules in the visual cortex. The output is sent along to specialized areas that analyze the components and interpret more complex aspects of the image

"In the old days people said that the brain is like a computer

From: Different Universe
R.B Laughlin Basic NY
(2005)

(1920)

- Quantum Mechanics is the deterministic law of motion of very small things — atoms, molecules, and subatomic particles
- Beautiful code that illustrates that Nature educates by making theories conform to experiment.
- Profound revision of classical concepts
- Commonsense turns on its head
- QM = Newtonian clockwork + Spooky probabilistic indeterminism — forced by experiment.
- Schrödinger's Cat —
  Until measurement is made, the system is inherently combination of dead + alive!

* According to Laughlin →
  The missing idea in QM is Emergence —
  the principle of symmetry breaking
  Largeness of the measuring apparatus essential —
  All quantum detectors are solids — exploit
  Symmetry breaking characteristic of solids —
  Various delicate quantum parts co-operate to
  become a classical object obeying Newton's Laws —
  the needle attached to the GM counter is
  a classical object
  The approach borne by transforming a
  quantum signal to classical one by means of
  the emergence of objects

Entanglement:

One reason why the Symmetry breaking is difficult to deduce from the underlying laws of QM is that the world is configurationally entangled

Entanglement - Everything is correlated with everything else.

Atomic Spectroscopy verifies it;

- Very Specific wave length of light depends on atoms. But their sharpness and distinctiveness do not.
- The probabilistic nature of QM ~~arises~~ measurement arises not from ~~nature~~ magic but from the turning of complexes - the bridges between the Quantum world and the classical one -

- Quantum Mechanical matter Consists of waves of nothing.
- In physics no distinction between unobservable and nothing - non existent ones
- In QM we accept as non-existence of the medium when waves of QM propagate

Emergence: (Views of Laughlin NL)

Which law is more ultimate, the details from which everything flows or the transcendent, emergent law that they generate?

the laws of the parts or the laws of the whole - the collective

Transition from Age of Reductionism to Age of Emergence - This brings to end the myth of power of mathematics

"The reason why our mind can anticipate and master what the physical world does is not because we are geniuses but because nature facilitates understanding by organizing itself and generate laws"

Traps - bad laws
- Barrier of Relevance

There are things that cannot be distinguished by experiments

Operations of Self-organization in the inanimate world associated with the process of crystal growth - unpredictable even though the underlying laws are mastered.

* Simplicity in physics is an emergent phenomenon, not mathematically self-evident state from which any deviations is considered anomaly
* Substitute "random" for "complex".

* Simplicity in nature is an exception than a rule.
* Life emerges if the microscopic circumstances are suitable - you cannot prove emergence - you can prove that this emergence is reasonable — Complexity theory (Chaos, Fractals, Cellular automata)

Nanotech –

① Atom-by-atom manipulation

② Chemical Self-Assembly

Atom-by-atom: high precision
Human control.

Requires deterministic classical understanding

Self-Assembly – Virtues of Nature. –
no deep understanding available
and NA required.

Nanoscale + capacity to measure directly
and manipulate matter at nanoscale
establish the condition for the convergence
of physics, chemistry, biology and engineering
→ Nano-Bio-info-cogno convergence

↓ new model of science – integration
of disciplines – holistic approach to
knowledge.

Higher levels are now regarded as irreducible for leading to problem of emergence that cannot be resolved in traditional terms.

(+) Nanoregion requires bridging the quantum and classical regions

unforeseen properties of collective systems emerge.

—

Defining moment for Nanoscience 1959. Feynman Lecture

"There is plenty of room at the bottom"

Miniaturise technologies – motto.

<u>The Systems Concept</u>

Alternative to – { Mechanisms in Biology and Vitalist impulses

Part → whole explanation in Biology closely leads to the discussions on "Complexity" with the recognition that alternate ~~systems are required for~~ forms of analysis are required for complex systems

Developmental Biologist Paul Weiss

" First, what is it (a system) not? It is not a haphazard compilation of items nor at the other extreme, a complex of rigidly linked pieces ~~of~~ or events ... for in either of these cases, the complexion of the total unit could be predicted unequivocally from the information about its constituent parts, pieced together. In a system we are faced with the opposite property, that is to say, the whole of a whole system must be known in order to understand the coordination of the collective behaviour of its parts; or if one prefers to objectivize this proposition, one can express it in terms of "control" of the components by their collective state."

Weiss (1971)

" The basic concepts of hierarchic systems in Hierarchically Organized Systems in Theory and Practice"

New York Hafner Publishing Co

J. C. Schmidt

Nano-technology – Umbrella technology
↓
Core technology → Fundamental Technology
Similar to Grand Unification in physics

Nano-Tech Scale < micro = 1000 nm
No access to Nanocosm with our senses

The Vision of Feynman
(speech to American Physical Society 1959)
"There is plenty of room at the bottom"

(1) Tiny machines can be programmed to replicate at one half their size
(2) It would be possible to manipulate individual atoms and molecules to form exactly the products desired
(3) The principles of physics do not speak against the possibility of maneuvering things atom by atom
(4) In practice it has not been done because we are too big.
(5) In principle it would be possible for a physicist to synthesize any substance that the chemist writes down
(6) This is a development which cannot be avoided.

- $ 1000 prize information ~~is~~ in a page to be written in (1/25,000) Smaller area and can be read by an Electron Microscope
- $ 1000 prize — Operational electric motor only 1/64 inch Cube
  ↙ you can see it at CIT

Will Nano-tech unify ~~QM~~ QM, Solid State physics, Molecular Biology, inorganic Chemistry ?

DREXLER was convinced that the same principles behind manipulation of DNA molecule should be applicable to other molecules -

Nano tech the bridge between physics and Chemistry - unification of Sciences

Can NT become the root technology - the basis for all other technologies ?

NT = Science based unification of all techs - not just Nano-region → not scale restricted

* UT = Unifying Tech may be more appropriate than NT

Nano-umbrella:

- Electron beam and Ion beam fabrication
- Molecular beam epitaxy
- Nanoimprint lithography
- Projation electron microscopy
- Atom by atom manipulation
- Spintronics
- Micro Electro Chemical Analysis

NSF - Converging technologies for Human Welfare

NBIC - Holism, Synergism

If Nanoscientists (NSF Report)
If Cognitive Scientist Can think it
the Nano people Can build it
the Bio people Can implement it and
the IT people Can monitor and control it

Convergence is based on material unity at the nanoscale and technical integration in that scale

- Nature = Ontology
- Knowledge and explanation of Nature = Epistemology
- Unity of the levels = Methodology

* Discipline Centric Outlook must be discouraged -

Technological Reductionism:
Assumed: (i) Shaping the World Atom by Atom.

(ii) ~~The World can be Controlled~~ by (i)
(ii) The World can be effectively Shaped manipulated and Controlled by Shaping atoms and Molecules

Bottom-up Approach

Nanocosm - Microcosm - Megacosm

Many doubt the thesis that nature can be constructed atom by atom
∴ Non-Linear Dynamics, Chaos Theory and theories of Self-Organization do not permit this.
* Instabilities in nature and technical apparatuses - inflate of small changes in initial Condition
Nature is dynamically unstable and open. Not an invariant watchmaker clock

Michio Kaku (1998)

" For most of human history, we could only watch like bystanders, the beautiful dance of Nature. But to-day, we are on the cusp of epoch-making transition, from being passive observers of Nature to being active Choreographers of Nature. The Age of Discovery in Science is coming to a close, opening up Age of Mastery"

NSF document (Roco & Bainbridge 2002)

" If we make the correct decisions and investments to-day many of these visions could be addressed within 20 years' time. Moving forward simultaneously along these paths could achieve an Age of innovation and prosperity that could be a turning point in the evolution of human society"

Francis Bacon On Science

(Bacon F. (1959) Neu-Atlantis Berlin Akademie Verlag
(1990) Neues Organon Hamburg (Meiner) (VERLAG)
(MEINER)

- Science is an instrument to extend power of man as far as possible (1959)
- Knowledge is power
- Nature should be hunted by Science like an animal in order to unveil her secrets;
- Nature has for man to milk.

David Hume (1990

"Enquiries concerning Human understanding"
Oxford University Press (1990)

"The only immediate utility of all Science is to teach us how to control and regulate further events (in Nature)

Kant (1969 Kritik der reinen Vernunft - Stutgart Reclam

"

We understand nature only as far as we can constitute and construct her"

—

The vision of Nanotech

"Everything will be shaped, designed and controlled with in the limits of the laws of Nature"

Does this overestimate the power of Science and power of men ?

—

Power of Simulation in Nano Scale.
(Uzi Landman) 1990 Science.

The Simulation showed that-

" To our amazement, we found that gold atoms jumping to contact the Nickel probe at short distance. Then we did retraction in which we withdrew the tip after contact and found that a nanometer-sized gold wire was created.

This was later proved experimentally by AFM

Thus has unexpected behaviours.
well known laws at the atomic level
served as the basis of simulation.
The unexpected behaviour has the
formation of good bits.

=

B | Theoretical Applied Science

Drexler

Theoretical analysis of demonstrating the possibility of a class as of yet unrealisable devices — technological possibilities. (Von Neumann — theory of automata)

(i) analogies

Explores ~~similarity~~ between biological phenomena and events at Nanoscale

NT { Von Neumann's work on self-reproducing automata + Drexler — Biological examples in reproduction

DREXLER'S BOOK Engines of Creation (1986)

We can build molecules that have similar functions as the DNA-RNA protein systems found in nature — new molecules may be engineered that can be part of self-reproducing systems → new drugs, new IT, new human tissues, ...
The tool — STM.

* ALSOS Mission - Twisted Tooth Paste Episode
Sparkling teeth - DNA may become a reality

USA 21st Century Nanotechnology R&D act 2003
3.7 billion dollars (2005-2008)
Europe $125 million / year Current Spending
UK £1.9 million / year (2003-2009)
(for NT Research)
India ?

NT in Medicine

① Drug delivery systems
② Sensors
③ Biocompatible materials for both part replacements and implants
④ Polymeric nano particles

Feynman's Lecture 1959

ERic Drexler (1970) – Bottom-up.
(Engine of Creation)

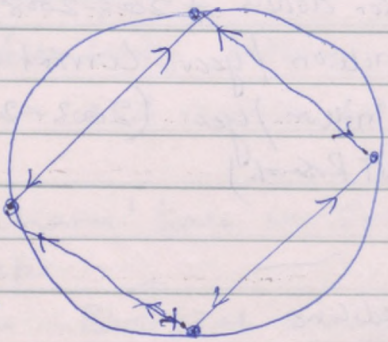
NT in Materials, Computing, Robotics
Biotech, genomics, IT

Nano Machine
{ STM – Scanning Tunneling Microscope (1981)
Slow, expensive –

AFM = Atomic Force Microscope
5 Å° along X.Y } Resolution
0.5 Å° Z }

imaging of biomolecules }
surface of polymers }

Nano – Nano Science
Nano materials



Miracle of unification – Convergence
Caused by Material Size Unity
(Nano)