

Monthly Newsletter of Vigyan Prasara



DREAM 2047

March 2001

Vol.3

No. 6

VP News



Prof. Murlidhar Manohar Joshi, Hon'ble Minister of Human Resource Development and Science & Technology Govt. of India, releasing Vigyan Prasara's publication "Where God's Come Alive" : A Monograph of the Bronze Icones of South India, during the National Science Day function held at Technology Bhavan on 28 February 2001. Also

present are (L to R) Dr. Manju Sharma, Secretary, Department of Biotechnology; Shri Bachi Singh Rawat, Hon'ble Minister of State for Science & Technology and Prof. V.S. Ramamurthy, Secretary, Department of Science & Technology, GOI.

Inside

EDITORIAL

X-rays: The Unknown Glimmer



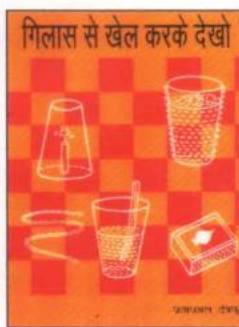
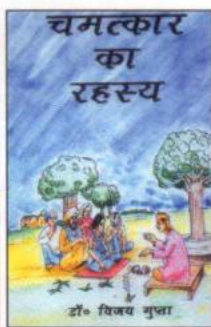
EXPLORING YOUR WAY THROUGH SCIENCE!



Development of Cometary Thought PART - I



New Publications



IODINE SAINIK : The deficiency of Iodine has been found not only in India but also in developed countries. It is estimated that there are one billion people suffering from this deficiency. This book tells about the effects of the deficiency of Iodine and how it can be removed. The subject has been explained

in a story form which is interesting to read not only by children but by adults also.

Iodine Sainik : by *Dr. Vijay Gupta*

CHAMATKAR KA RAHASYA : There are many people who cheat gullible people by showing some miracles, where as there miracles are nothing but an art based on some scientific or technological principle. The book exposes some such miracles through interesting stories.

Chamatkar ka Rahasya : by *Dr. Vijay Gupta*

GILAS SE KHEL KARKE DEKHO : The book deals with some interesting experiment which can be performed just with the help of a glass. Children can do it themselves. They can get the necessary material easily for these experiments. It is an interesting and useful activity book for children

Gilas Se Khel Karke Dekho : by *Pratapmal Devpura*

... think scientifically, act scientifically ... think scientifically, act scientifically ... think scientifically, act...

Investment In Real Terms

Indeed the last few weeks have brought enormous excitement. We had the first global view of the genomic landscape of human beings. The map of life unfolded by the genome explorers threw up quite a few surprises – the most crucial being that the difference in genomes between different races is minuscule, only 0.1 per cent; that is 99.9 per cent of all humans have the same DNA. This implies that there is no “superior” race on this planet. The other surprise was that the number of human genes are actually much less than estimated earlier – only about 30,000 as against the initial estimate of 100,000. This is just twice as much as the number of genes that make up a fruit fly! Further, the large tracts of human DNA which don't contain any genetic material (also called desert regions or junk DNA), may not be garbage after all. What is striking is the fact that we are a product of the unique orchestration of our genes, proteins, pre-historic bacteria and environment. May be, it is this environmental factor that let hundreds of bacterial genes find their way into human genome and not through evolution. In addition, the belief that one gene is responsible for one protein no longer holds. It is now thought that it is actually a network with control genes kicking other genes into life to make proteins. Instead of producing only one protein per gene, the average human gene produces three different proteins!

Next, the Near Earth Asteroid Rendezvous – Schumacher spacecraft touched down on Eros, the kidney-bean shaped asteroid, or the geologic relic formed some 4.5 billion years ago and more than 300 million kilometres from the Earth, ending journey of some 3 billion kilometres and a full year in its orbit. Eros belongs to a group of large asteroids with orbits relatively close to the Earth, like the one which is believed to have slammed into the Earth and wiped out dinosaurs some 65 million years ago. The data has given scientists clues about the history of solar system and work out means of averting such catastrophes in future.

No doubt, all that is great news for science, and full of excitement. Whether it is the universe outside the Earth, or inside the living cell, it is bound to fire anybody's imagination. What is intriguing is the fact that why does

it fail to fire the imagination of our younger generation? What makes our students turn a blind eye towards a scientific career? One reason oft-quoted is that science is no more a lucrative profession! But, the crux of the matter is our school children are rarely exposed to the excitement of science. They are unaware of the challenges and thrills offered by a scientific career. In the absence of such an exposure, no wonder students shy away from this challenging profession. The warning bells have already started tolling. It is becoming increasingly difficult to recruit the right type of scientific personnel in our R&D labs, universities, and even science teachers in schools. Given that the social and economic development of a country depends on how strong its scientific base is, it becomes all the more imperative to convey the thrill and excitement that a scientific career offers to our children, especially at secondary and senior secondary levels.

What is the remedy, then? A few years ago, the Indian Institute of Science, Bangalore, evolved a programme of Extension Lectures in Science and Engineering by the faculty members of the institute on modern scientific developments in schools and colleges within a radius of 500 kilometres from Bangalore. The lectures are delivered on voluntary basis by the faculty members in addition to their regular academic and research commitments and are supported by demonstrations, slides or models. The schools/colleges need only play the host and organise the lectures, the travel and other expenses being borne by the institute. The programme has proved to be immensely popular and effective in triggering an interest in science among the children, and at the same time encouraging them take up a scientific career in their chosen areas. The lectures, if brought out in the printed form – especially in the local languages, would go a long way in furthering this noble effort. It is high time scientists from our R&D labs, universities and industries also followed the suit with active support from their respective organisations. Indeed, this would be an investment in real terms for the social and economic growth of the country.

□ V.B. KAMBLE

Editor : V.B. Kamble
The team : Vigyan Prasar Staff

Vigyan Prasar

Address for correspondence : C-24, Qutab Institutional Area, New Delhi-110 016
Tel. : 6967532; Fax : 6965986
e-mail : vigyan@hub.nic.in
website : <http://www.vigyanprasar.com>

X-rays: The Unknown Glimmer

□ V.B. Kamble

"Experimentation is the most reliable lever enabling us to extract secrets from nature" – Wilhelm Conrad Röntgen.

Wilhelm Conrad Röntgen (pronounced Ryoentgen) was born at Lennep in Bergischen in the Rhine province of Germany on March 27, 1845. He was the only son of Friedrich Conrad Röntgen, a cloth manufacturer and merchant of Lennep. His mother, Charlotte Coustanze Frowein was born in Holland, although her family came originally from Lennep. When Wilhelm was three, they moved to Holland. Here Wilhelm attended a private boarding school, the Institute of Martinus Herman Van Doorn. He was not a particularly studious boy, but preferred to remain out-of-doors and use his hands. He entered the Utrecht Technical school in 1862 at the age of sixteen. As the story goes, he was expelled from the school for refusing to identify a classmate who had drawn a caricature of one of the teachers! As a result, continuity of his formal progress towards university education was broken, and he was never accepted as a regular student by the University of Utrecht. After two and a half years at the Technical School, and nine months of philosophy classes of the university, he passed an examination to enter the Polytechnic at Zurich, as a student of mechanical engineering.

Apparently, Röntgen was extremely happy in Switzerland, both in his work and in his social life. He received his diploma as a mechanical engineer in 1868 and the degree of Doctor of Philosophy a year later. These qualifications won him the assistantship with the Professor of Physics, August Kundt, whose friendship and support greatly shaped Röntgen's career. It was in Zurich, that Röntgen met his future wife, Anna Bertha Ludwig. In 1871, Röntgen accompanied Kundt to the University of Würzburg. In 1872, he married Bertha (Unfortunately, they had no children, but, they adopted Bertha's niece in 1887).

It was in Würzburg that Röntgen's academic career truly took off. This was despite the fact that he was refused any academic position due to the lack of formal educational requirements. Shortly after his marriage, he moved to Strasbourg with Kundt, where he became a tutor at the Agricultural Academy of Hohenheim in 1875, he returned to Strasbourg to teach theoretical physics. The series of papers he produced during the period 1876-1878 won him the chair



Wilhelm Conrad Röntgen

of physics at the University of Giessen. During the period 1879-1888 he worked at Giessen, until the Royal University of Würzburg offered him the joint posts of Professor of Physics and Director of the Physical Institute. In 1894, he became the rector of the University of Würzburg.

In 1895, Röntgen made his momentous discovery of X-rays, which brought him international fame. He was made an honorary doctor of medicine of Würzburg in 1896, and a corresponding member of the Berlin and Munich academies. On November 30, 1896, the Royal Society of London jointly awarded to Röntgen and Philipp Lenard (1862-1947) – about whom we shall read later – the Rumford medal. Columbia University awarded Barnard medal in 1900. His statue was erected on the Potsdam Bridge at Berlin, and he was awarded the first Nobel Prize in Physics in 1901. He gave his prize money to further scientific studies at the University of Würzburg.

In the year 1900, Röntgen moved from Würzburg to the chair of physics and the directorship of the Physical Institute at Munich at the request of the Bavarian Government, where he stayed until 1920.

November 08, 1895

On that Friday afternoon, November 08, 1895 the professor of physics and recently elected rector of the Julius Maximilian University of Würzburg, Germany, was unusually late for dinner. And when he did arrive at the family living quarters above his laboratory in the Physical Institute, he did not speak, ate little and then left abruptly to return to the experiments that had so disturbed him that afternoon.

Only hours before, working in his laboratory at the University of Würzburg in Bavaria, Röntgen was suddenly distracted by a mysterious glimmer in one far-off corner of the room. He took a closer look. The strange gleam came from a piece of paper coated with barium platinocyanide, a substance, he knew, that glowed with an eerie luminescence when exposed to cathode rays. But this time, there could be no rays to reflect: the cathode ray tube he had been working with was covered with a heavy piece of cardboard, and, anyway it was clear across the room! Yet when he turned the cathode ray tube off, the paper stopped glowing. When he turned the tube back on, the light shone eerily again. He put his hand between the cathode ray tube and the coated paper. His hand cast a shadow in the light, and he could see the *bones in his*



Sir William Henry Bragg



Sir William Lawrence Bragg

THE GOLDEN DECADE : 1895-1905

During the decade 1895 - 1905, several remarkable discoveries, especially in Physics, took place, say, for example; X-rays in 1895, radioactivity and Zeeman effect in 1896, the electron in 1897, quantum theory in 1900 and explanation of photoelectric effect and relativity in 1905. Individually, each discovery had enormous significance, while collectively, they heralded what we today call "Modern Physics". This was also the period that witnessed tremendous advances in the field of biochemistry with discoveries like conversion of sugar into alcohol outside the living cell, location of malaria parasite in the anopheles mosquito, and discovery of human blood types. Further, this period witnessed the first trans-Atlantic telegraphic radio transmission and the existence of ionosphere. Technological advances, among others, included the first successful air-plane, first electric locomotive, first vacuum tube, flat disk form of phonograph, first practical photoelectric cell, to name a few.

Practitioners of Classical Physics

It may be of interest to note that the "practitioners" of classical physics of that period claimed that all the great discoveries had already been made and that physics would be reduced merely to measurements of greater and greater accuracy! As a matter of fact, some discoveries did lie in the next decimal place as revealed by the discovery of argon during very accurate measurements of the constituents of air. Surely, they did not have any idea of the shape of things to come!

A Fascinating Story

No doubt, there is no story more fascinating than an account of the development of science as a whole, especially the physical sciences, in the decade 1895-1905. We find that with a few exceptions, the ideas, concepts and the laws of physics have evolved gradually. Only occasionally, do we find a few outstanding discontinuities. The discovery of photoelectricity, X-rays, and radioactivity represent such discontinuities and hence are correctly designated as "discoveries"

An Accidental Discovery

The enormous advances around 1895 brought into question or directly contradicted theories that appeared to have been strongly supported by experimental evidence. For example, the experiments of Hertz demonstrated, beyond doubt, the fundamental nature of Maxwell's electromagnetic theory of light. And yet, by an irony of fate — that makes the story of modern physics full of most interesting and dramatic situations — these very experiments of Hertz brought to light the new phenomenon of the photoelectric effect, which played an important role in establishing the quantum theory.

Discovery - a Process Rather Than an Event

The history and development of science in this period - of events and the people who made them possible - is most enlightening and inspiring. A peep into the lives of these makers of modern science, their approach and methods, dedication and sacrifice with an ardent desire to share their knowledge with others, provides an insight into the process and methodology of science. The discovery of radioactivity by Becquerel is a beautiful example of the scientific method at work - that goes on to show that discovery is more of a process rather than an event. True, chance favoured Becquerel with cloudy days that hid his phosphorescent uranium salts from the sun. However, the fact that he found the photographic plates blackened even though the crystals of uranium salts were not exposed to sunlight, and that he recognised the significance of his surprising observations, shows that the discovery of radioactivity was not simply a happy accident; but also that it was a product of genuine scientific intellect. Indeed, discoveries rarely take place by accident!

A Great Opportunity

Described above are only a few golden pages from the History of Science and Technology that has shaped our present day lives. It is inspiring and it is enlightening, not only for scientists but also for the common man. Recognition did not come instantaneously to the scientists mentioned above; they had their own share of misfortunes and failures. But a trait common to all of them was a positive approach and a scientific outlook in whatever they did. Celebrating the centennials of discoveries and the people concerned may, therefore, offer a great opportunity to science communicators in the coming years to utilize them to communicate the basic scientific aspects of these discoveries, promote the method of science, and spread a scientific outlook among the people. We shall be describing some of the golden pages from the History of Science & Technology in the series "Emergence of Modern Science" beginning with this issue.

Emergence of Modern Science : 1895 - 1905

YEAR	DISCOVERY	SCIENTIST(S)
1895	(C) Discovery of Helium on Earth (P) Discovery of X-rays* (Nov.8, 1895) (C) Development of Cloud chamber	William Ramsay Wilhelm Konard Roentgen Charles Thomson Rees Wilson
1896	(P) Discovery of Radioactivity (March 1, 1896) (P) Zeeman Effect	Antoine Henri Becquerel Peter P. Zeeman
1897	(B) Beginning of Biochemistry** (M) Malaria parasite in the anopheles mosquito located and determined that the mosquito transmits the parasite from one human to another. (P) Discovery of Electron and e/m ratio	Eduard Buchner Ronald Ross (b.Almora, India May 13, 1857 J.J. Thomson
1898	(C) Discovery of Polonium (July 18) and Radium (Dec. 26) (P) Thorium gives off "uranium rays" which Marie renames Radioactivity	Marie Sklodowska Curie & Pierre Curie (with Gustave Be'mont) Marie & Pierre Curie
1899	Measurement of electronic charge	J.J. Thomson
1900	(B) Gregor Mendel's work ignored for 40 years independently rediscovered (P) Quantum theory of radiation (Dec. 14) (P) Discovery of Gamma-rays (M) Types of human blood-A,B&O some of which incompatible	Hugo Marie De Vries (Netherlands). Karl Franz Joseph Correns (Germany) & Erich Tschermak Von Seysenegg (Austria) Max Planck Paul Ulrich Villard Karl Landsteiner (Austria)
1901	(T) Radio Communication*** (P) Thorium left to itself decays to isotope of radium	Guglielmo Marconi Ernest Rutherford & Frederick Soddy
1902	(ES) Existence of ionosphere	Heaviside & A.E. Kennely
1902	(P) Formation of helium by radio active decay of Radium (T) Electric locomotive (T) First Successful Air Plane (Dec. 17)	William Ramsay & Frederick Soddy W. Siemens Wilbur & Orville Wright at Kitty Hawk
1904	(A) Discovery of interstellar Matter (Interstellar Cloud of Atoms) (T) Flat disc form of phonograph, an improvement over Thomas Alva Edison's Wax Cylinder System (T) First practical photoelectric cell (T) First Vacuum Tube (a diode) (T) Offset Printing	Johannes Franz Hartmann (Germany) Emilie Berliner (German-American) John Phillip Ludwig Elster John Ambrose Fleming W. Rubel
1905	(A) Relationship between colour and Luminosity of Stars**** (A) Prediction and existence of a ninth planet with an orbit beyond Neptune. (B) Discovery that female mammals have two "X" and males have an "X" and paired with a "y" (P) Explanation of photoelectric effect : Postulate of light quantum (March 17) (P) Special Theory of Relativity (June 30)	Einer Hetszprung (Denmark) and Henry Norris, Russel Percival Lowell Clarence McClung A. Einstein A. Einstein

* Less than three months after the discovery of x-rays by Roentgen, Eddie McCarthy of Dartmouth, MA, became the first-person to have a broken arm set with their help.

** Discovers that a cell-free extract of yeast (Zymase) can convert sugar into alcohol

*** Marconi receives letter "S" in St. Johns, New Foundland, transmitted from England - the first transatlantic telegraphic radio transmission.

**** 10 years after Hertzprung, makes the same observation and gives it currency

Note 1: The list is only representative and not exhaustive.

Note 2 : A-Astronomy & Astrophysics, B-Biology, C-Chemistry, ES-Earth Sciences, M-Medicine, P-Physics, T-Technology.

□ V.B. KAMBLE

hand! He took the coated paper with him to another room, shut the door and pulled the blinds. It still glowed when the cathode ray tube was turned on. It stopped glowing when the tube was turned off. The mysterious rays that were causing the glow had actually passed through the wall! Röntgen had discovered a new ray, which he later called "X-ray" meaning "unknown ray" – a name that has stuck, even though his ray is no longer so mysterious. This marked the beginning of the era of atomic physics and of an undreamed of succession of medical applications. Indeed, this was the beginning of the Emergence of Modern Science.

Röntgen was looking for the invisible high frequency rays that Hermann von Helmholtz had predicted from the Maxwell's theory of electromagnetic radiation. Years earlier, von Helmholtz had prevailed upon both Heinrich Hertz and Röntgen to test the experimental predictions of James Clerk Maxwell's new theory. In 1887 Hertz, at the University of Bonn, produced electric spark discharges and demonstrated the propagation of electromagnetic waves through space. The next year Röntgen verified that a dielectric moving in an electric field induces a magnetic force that acts on the dielectric. More recently von Helmholtz had predicted the existence of electromagnetic radiations with frequencies much higher than the natural frequencies of inducible dipoles in matter. These radiations would therefore interact minimally with matter and exhibit great penetrating power. Since cathode rays were then thought by the German school of physics to be "ether" phenomena (that is, similar to light rays passing through the hypothetical medium "ether"), it was proposed that these high-frequency radiations might be present in cathode-ray discharges. A paradox arose: If these radiations interacted minimally with matter, that would explain why they had not yet been detected—but how could their existence be verified?

This was precisely the type of research problem in which Röntgen excelled: the painstaking measurement of difficult-to-detect electromagnetic phenomena. It may be of interest to note that Röntgen was red-green colour-blind, and *colour-defective individuals tend to become extremely discriminating observers*, unconsciously compensating for their deficiency by correlating shapes, shades and textures of familiar objects with their true colours.

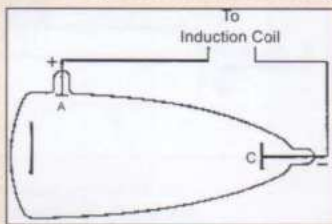
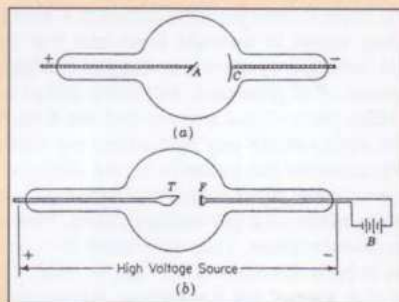


Diagram of the tube with which Röntgen discovered X-rays



'HAND MIT RINGEN,' Röntgen's second x-ray "shadowgraph" of his wife's hand.



(a) An early form of X-ray tube;
(b) the Coolidge tube.

The early experiments

Röntgen was studying the discharge of electricity through rarefied gases. A large induction coil was connected to a rather highly evacuated tube, the cathode *C* being at one end and the anode *A* at the side. The tube was covered "with a somewhat closely fitting mantle of thin black cardboard". With the apparatus in a completely darkened room, he made the accidental observation that "a paper screen washed with barium-platino-cyanide lights up brilliantly and fluoresces equally well whether the treated side or the other be turned toward the discharge tube". The fluorescence was observable two meters away from the apparatus. Röntgen soon convinced himself that the agency which caused the fluorescence originated at that point in the discharge tube where the glass walls were struck by the cathode stream in the tube. Röntgen's early training as an engineer and his years as Kundt's assistant in Würzburg formed his lifelong habit of making his own apparatus (there was no laboratory mechanic at Würzburg!). Indeed, he was a meticulous experimenter. He invariably worked alone in the laboratory, and with nothing to disturb his concentration, he was able to develop acute powers of observation.

Realizing the importance of his discovery, Röntgen at once proceeded to study the properties of these new rays—the unknown nature of which, as stated earlier, indicated by calling them "X-rays". In his first communication he recorded, among others, the following observations:

- ★ All substances are more or less transparent to X-rays. For example, wood 2 to 3 cm thick is very transparent. Aluminum 15 mm thick "weakens the effect considerably, though it does not entirely destroy the fluorescence". Lead glass is quite opaque, but other glass of the same thickness is much more transparent. "If the hand is held between the discharge tube and the screen the dark shadow of the bones is visible within the slightly dark shadow of the hand".

Many other substances besides barium-platino-cyanide fluoresce—calcium compounds, uranium glass, rock salt, etc.

- ★ Photographic plates and films "show themselves susceptible to X-rays". Hence photography provides a valuable method of studying the effects of X-rays (An X-ray photograph of his wife's hand is shown in this article).

- ★ X-rays are neither reflected nor refracted (so far as Röntgen could discover). Hence,

"X-rays cannot be concentrated by lenses."

- ★ Unlike cathode rays, X-rays are not deflected by a magnetic field. They travel in straight lines, as Röntgen showed by means of "pinhole" photographs.
- ★ X-rays discharge electrified bodies, whether the electrification is positive or negative.
- ★ X-rays are generated when the cathode rays of the discharge tube strike any solid body. A heavier element,

such as platinum, however is much more efficient as a generator of X-rays than is a lighter element such as aluminum.

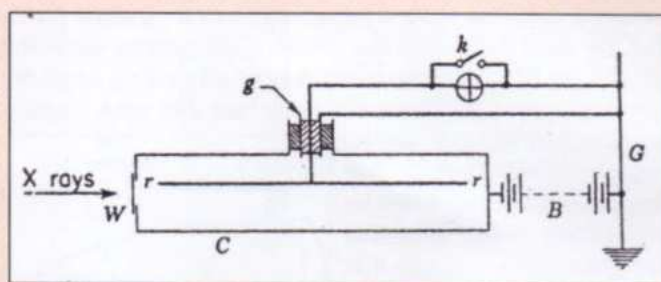
Indeed, it is a stirring tribute to Röntgen's masterly thoroughness that most of the basic properties of X-rays were described in the paper in which the discovery was first announced. His discovery excited intense interest and work on X-rays began at once in many laboratories both in America and in Europe. It is worth noting that this early work is beautifully illustrative of the qualitative phase of development of a typical field of physics.

Production and measurement of X-rays:

Indeed, tubes for the production of X-rays were similar to a form suggested by Röntgen. They were essentially cathode-ray-tubes in which a residual gas pressure of the order of 10^{-3} mm Hg provides,

when voltage is applied, a few electrons and positive ions. These positive ions, bombarding the cathode C, release electrons which, hurled against the anode A, give rise to X-rays. A curved cathode converges the electrons into a focal spot on A of desired shape and size. In this type of tube, known as the "gas" tube, the anode current, applied voltage, and gas pressure are more or less interdependent, and it is essential that the gas pressure be maintained at the desired value. Various ingenious devices were introduced for accomplishing this. It would be of interest to note here that only much later, in 1913, however, an important improvement was introduced by William David Coolidge (1873-1975), American physical chemist and inventor. He evacuated the tube to the highest attainable vacuum and incorporated in the cathode a hot spiral filament of tungsten to serve as source of electrons. The filament was heated by an adjustable current from a battery. Thus the current of electrons in the tube could be controlled independently of the applied voltage.

For quantitative meas-



An ionization chamber used for measuring electrically the intensity of a beam of X-rays.

urements, the ionization method was early adopted. The discharging effect of X-rays upon charged bodies was traced to ionization of the molecules of the surrounding gas. The effect was found to increase rapidly with density, and also to depend

on the nature of the gas, the following being increasingly active in the order given: H_2 , CO , air, CO_2 , ether vapour, and CS_2 . At first the rate of discharge of an electroscope was used in measuring the intensity of an X-ray beam, but later an "ionization chamber" was introduced. The metalline cylinder C is filled with a like argon or methyl bromide. X-rays enter the window for making the gas within the cylinder conducting. Due to the electric field maintained between C and the rod r, the rod acquires a charge at a rate which can be measured by an electrometer, which is a measure of the intensity of the X-ray beam.

Why did X-rays play hide and seek with earlier workers

The discovery of cathode rays had followed continued improvements in the art of pumping gases out of closed containers. The first step in the chain of discovery leading to X-rays was the Geissler discharge, the same gas discharge now used for advertising displays, such as the neon signs. In the late 1870s William David Crookes (1832-1919),



William David Crookes



Max von Laue



Philipp Eduard Anton von Lenard

heavy gas

bromide. X-rays enter the window for making the gas within the cylinder conducting. Due to the electric field maintained between C and the rod r, the rod acquires a charge at a rate which can be measured by an electrometer, which is a measure of the intensity of the X-ray beam.

The Nature of X-rays

Röntgen took the first steps in identifying the nature of X-rays by using a system of slits to show that **they travel in straight lines** and that **they are uncharged** because they are not deflected by electric or magnetic fields. The discovery of X-rays aroused the interest of all physicists, and many joined in the investigation of their properties. In 1896, Bertin-Sans showed that the X-rays could be scattered from glass or paraffin plate just the way light waves are scattered by particles. In 1899, Haga and Wind provided the evidence for the diffraction of X-rays by using wedge-shaped slits only a few thousandths of a millimetre wide and observing a slight broadening of the image on a photographic plate. **This showed that x-rays are a wave motion phenomenon.** They concluded through this experiment the wavelength of X-rays to be of the order of 10^{-8} cm. In 1906, Charles Glover Barkla (1877-1944) proved that **X-rays are transverse waves by showing that they can be polarised by scattering from many materials.** Following a suggestion by Max von Laue (1879-1960) in 1912, the father and son team, Sir William Henry Bragg (1862-1942) and Sir William Lawrence Bragg (1890-1971), perfected the technique of measuring wavelength of X-rays using a crystal (say NaCl) as a diffraction grating. Röntgen had observed that the X-rays could not be reflected or refracted, however, the first positive evidence for their refraction and reflection came from the work of Stenström by passing a beam of X-rays through a crystal.

There is, of course, no longer anything unknown about the nature of X-rays. They are electromagnetic radiation of exactly the same nature as visible light, except that their wavelength is several orders of magnitude shorter. This conclusion follows from the properties of X-rays described above with similar properties for visible light. This, however, was postulated by Sir J.J. Thomson (1856-1940) several years before all these properties were known!

applied high vacuum techniques to the Geissler discharge, thereby discovering the "Crookes dark space". At the low pressures Crookes produced, the Geissler discharge disappeared and as the voltage was increased a new type of visible discharge appeared: a beam moving in straight lines from the cathode.

By increasing the applied voltages (necessary to produce the discharge) Crookes also inadvertently produced the conditions for the generation of X-rays. Only a small fraction (of the order of 10^{-4}) of the energy of Crookes's cathode rays was emitted as X-rays. The remainder was dissipated as heat. Therefore, cathode-ray tube operation was normally limited to gas pressures and voltages (approximately 9 kV) sufficient to produce visible beams, but not so great that the glass faces of the tubes would melt where the rays impinged.

In the 1880s Crookes also developed the prototype of the modern X-ray tube. Using a concave cathode to focus cathode rays to a spot on an iridio-platinum anode, he unknowingly optimized the efficiency for production of X-rays. **During this research he was occasionally bothered by unaccountable fogging of unexposed photographic plates that he stored near his equipment. On occasion he even returned the plates to their manufacturer as defective.**

In 1888, seven years before Röntgen's discovery, Philipp Lenard, attempted to observe high-frequency ultraviolet radiations from a cathode-ray tube. He failed. Had he evacuated his tube to Crookes's low pressures, he would have had to apply higher voltages that generated energetic X-rays and would have immediately detected fluorescence of crystals placed just outside the blackened 2.4 millimeter-thick quartz face of his tube. But he produced only soft X-rays, which the

quartz absorbed completely. Lenard missed the golden opportunity a second time in 1893, when he served as Hertz's assistant. This time he did produce much lower pressures in his cathode-ray tubes, requiring much higher operating voltages. The much-higher-energy cathode rays that resulted

were able to penetrate thin aluminum windows into the outside air, where they produced brilliant fluorescence of a calcium sulfide phosphor. Lenard subsequently used fluorescent screens of pentadecylparatolyketone (what a tongue-twister!) crystals. Lenard saw intense, easily visible fluorescence of the ketone screens and

intense blackening of photographic plates, but "only for a distance in air of a few centimeters". He did find occasional

unexplained blackening of a photographic plate covered by a sheet of cardboard thick enough to stop his cathode rays, and his extracted rays "still showed electrical discharge effects at much greater distances", say, up to 30 cm in air. **It is strange that although these were X-ray effects, Lenard was unprepared to recognize them!** It apparently did not occur to him to repeat his experiment of 1888 under his improved high-vacuum conditions. It could have been so because he was concentrating on the study of cathode rays, and hence missed the side-effects. Further, his research was interrupted by the sudden death of Hertz on the first day of 1894 and then assuming Hertz's duties as director of Physical Laboratory at Bonn. He spent the year completing the editing and publication of Hertz's three-volume final specific work. By January 1896, he had finally returned to his cathode rays. He discovered that Röntgen Rays (Röntgenstrahlen) rather than Lenard Rays (Lenardstrahlen) were being announced in the newspapers!



Charles Glover Barkla



Kai Manne Georg Siegbahn



Arthur Holly Compton

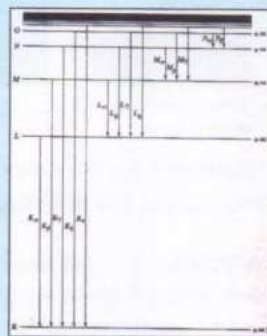
X-rays: The Mechanism of Production

Late in the nineteenth century, a series of experiments revealed that electrons are emitted from a metal surface when light of sufficiently high frequency falls upon it. This is called photoelectric effect and it provides convincing evidence that photons (or quanta of light—the "packets" of energy) of light can transfer energy to electrons. The production of X-rays can be likened to the *inverse* photoelectric effect, in which part or all of the kinetic energy of a moving electron can be converted into a photon.

The Bremsstrahlung X-rays exhibit a continuous x-ray spectrum and is the result of Maxwell's electromagnetic theory which predicts that an accelerated (or decelerated) electric charge will radiate electromagnetic waves, and a rapidly moving electron suddenly brought to rest is certainly decelerated. This is what happens when the electrons moving in a cathode ray discharge tube are suddenly brought to rest at the glass surface of the tube.

The characteristic X-rays, on the other hand, are produced when an energetic electron strikes the atom and knocks out an electron from the shell it is moving in and thus creating a "hole". An atom with a missing electron in a particular shell would give up most of its excitation energy in the form of an X-ray photon when an electron from an outer shell drops into this "hole", thus giving off an "X-ray characteristic" of that shell. It is conventional to speak of electrons in complex atoms as occupying different shells denoted by the capital letters K, L, M, N, O, etc. Electrons in the orbital K (i.e., $n=1$) are closest to the nucleus and hence require maximum energy to dislodge them, the electrons in the L (i.e., $n=2$) shell are further away from the nucleus and require much less energy to be dislodged, and so on. Schematically, the situation is shown in the so-called energy level diagram below.

Suppose that the energetic electron moving in a cathode ray tube knocks out a K-shell electron and that an electron from an outer shell (L, M, N, O, etc.) drops into the "hole" in the K-shell. The resulting possible characteristic K-series X-ray photons produced are shown by K_{α} , K_{β} , ... etc. (obviously, in the diagram, the O-shell electron dropping into K-shell (K_{ϵ}) would give rise to the X-ray with maximum energy). Also shown are L, M and N series of characteristic X-rays.



The origin of X-ray spectra

Nobel Prizes for Research with X-rays

It all began with Röntgen! X-rays have contributed in the growth of our knowledge and advancing the frontiers of science in many fields be it atomic physics, crystallography, medicine, structure of haemoglobin and DNA, Computer Assisted Tomography (CAT scan), chemistry of proteins and so on. Here is a list of Nobel Prizes awarded for research with X-rays.

1901	W.C. Röntgen	Germany	in Physics for the discovery of X-rays.
1914	Max von Laue	Germany	in Physics for the discovery of the diffraction of X-rays by crystals
1915	Sir William Henry Bragg Sir William Lawrence Bragg	Great Britain Great Britain	in Physics for the services in the analysis of crystal structure by means of X-rays -do-
1917	Charles Glover Barkla	Great Britain	in Physics for the discovery of the characteristic Röntgen radiation of the elements
1924	Kai Manne George Siegbahn	Sweden	in Physics for the discoveries and research in the field of X-ray spectroscopy
1927	Arthur Holly Compton	USA	in Physics for the discovery of the effect named after him (scattering of X-rays by electrons)
1936	Petrus Josephus Wilhelmus Debye	the Netherlands	in Chemistry for the contributions to our knowledge of molecular structure through his investigations on dipole moments and on the diffraction of X-rays and electrons in gases
1946	Hermann Joseph Muller	USA	in Physiology or Medicine for the discovery of the production of mutations by means of X-ray irradiation
1962	Max Ferdinand Perutz John Cowdery Kendrew	Great Britain Great Britain	in Chemistry for the studies of the structures of globular proteins -do-
1962	Francis Harry Compton Crick James Dewey Watson Maurice Hugh Frederick Wilkins	Great Britain USA Great Britain	in Physiology or Medicine for the discoveries concerning the molecular structure of nucleic acids and its significance for information transfer in living material -do- -do-
1964	Dorothy Crowfoot Hodgkin	Great Britain	in Chemistry for her determinations by X-ray techniques of the structures of important biochemical substances
1979	Allan McLeod Cormack Godfrey Newbold Hounsfield	USA Great Britain	in Physiology or Medicine for the development of computer assisted tomography -do-
1981	Kai M. Siegbahn	Sweden	in Physics for the contribution to the development of high resolution electron spectroscopy
1985	Herbert A. Hauptman Jerome Karle	USA USA	in Chemistry for the outstanding achievements in the development of direct methods for the determination of crystal structures -do-
1988	Johann Deisenhofer Rober Huber Hartmut Michel	Germany Germany Germany	in Chemistry for the determination of the three-dimensional structure of a photosynthetic reaction centre -do- -do-

Bizarre, Serendipitous, Fortuitous

Röntgen made one of the most bizarre and serendipitous observations in the history of science when he held a small lead disk in front of the brightly glowing green screen. **What he saw was not only the anticipated dark circular shadow of the disk but also the shadows of the bones of his own fingers** – an apparition so unearthly as to undoubtedly stir in him thoughts of his own mortality. He quickly withdrew his hand and the dark skeletal shadows of his fingers moved slowly across the still brightly glowing screen.

He recounted in his lecture at Würzburg, "I ... still believed that I was the victim of deception when I observed the phenomenon of the ray" – he turned to photographic film for greater objectivity and for permanent records. True to his nature, in the following weeks Röntgen was driven to secrecy and to feverish experimental verification and reverification of

X-rays. Shortly before Christmas, he invited his wife, Bertha, into the laboratory and had her place her hand for 15 minutes on a film cassette opposite his cathode-ray tube. Little could

he have known that the morbid image of the bones of Bertha's fingers would catapult him to worldwide celebrity.

It may be remarked that the glimmer of the platinum screen at the far end of the Röntgen's laboratory table was orders of magnitude dimmer than the bright fluorescence produced by

the cathode rays in the glass walls of the cathode ray tubes used by the experimenters then. In the few minutes required to adjust the curtains to exclude the outside light, his visual sensitivity must have increased by a factor of 1000. The retina has two types of light sensitive cells – rods and cones, so named for their shapes. The rods are sensitive to low intensities of light and enable the viewers to see objects even in dim light. The cones work when there is sufficient light intensity, but can register red, blue and green light and so distinguish



Petrus (Peter) Josephus
Wilhelmus Debye



Max Ferdinand Perutz



John Cowdery Kendrew

between the colours. In the dark, his eyes would have changed to "rod" vision from the "cone" vision, thus becoming more sensitive to the dark. Also made such circumstances, peripheral vision helps one see the dim objects much more easily through the corner of the eye rather than directly looking at it. (This is why it is easier to spot a faint star while looking at it sideways rather than looking directly at it!). May be, this factor also helped Röntgen to see the glimmer. In addition, the blue-green fluorescence emission of the heat treated barium platinocynide crystals of Röntgen's test screen was optimally effective in stimulating the rods of his retina.

What type of X-rays were observed?

In Röntgen's experiments the X-rays were produced by the cathode rays striking the walls of the discharge tube (Better

results may be obtained by allowing the cathode rays to impinge on a piece of metal, called an *anticathode*, placed in their path; the X-rays are then emitted from the anti-cathode).

In general, any stream of fast moving, i.e. high energy, electrons – no matter how they are formed will produce X-rays when they lose

energy and are slowed down upon striking a suitable material. This is due to the emission of radiation due to acceleration or deceleration in the atomic fields – also called *bremstrahlung* (German for braking radiation – as if applying brakes to electrons and suddenly slowing them down!).

As a rule, the wave lengths of the radiations emitted from an anticathode cover a considerable range, but if the X-rays are allowed to fall on a given material, most are absorbed leaving only radiations with wave lengths characteristic of the elements present in the material; this was recognized much later by Charles Glover Barkla (1877-1944), in England, in 1911. These "characteristic X-rays", as they are called, can be produced in other ways, e.g., by permitting cathode rays of high velocity to impinge directly on a target (anticathode) made of, or containing, the particular element. The rays fall into several groups (or series) distinguished by the letters *K*, *L*, *M*, *N*, etc., in order of decreasing *hardness*, i.e., of decreasing energy and ability to penetrate matter (see box). For a given element, the rays of the *K* series are the most difficult to produce, i.e. they require electrons (cathode rays) of the highest energy; production of the *L*, *M*, etc., series can occur at lower and lower energies. For elements



Francis Harry Compton Crick



James Dewey Watson



Maurice Hugh Frederick Wilkins



Allan M. Cormack



Godfrey N. Hounsfield

of increasing atomic weight, the characteristic X-rays of each series become more and more difficult to excite.

Of the two types of X-rays — characteristic rays and *bremstrahlung* — only the latter were detected in Röntgen's experiments. (Characteristic X-rays emitted from the silicon atoms of the cathode ray tube's glass face or from an aluminum window were less than 2 keV in energy and could not penetrate to the outside of the tube). Incidentally, one eV (electron-Volt) is the energy an electron possesses while passing through a potential difference of one volt. KeV stands for kilo electron-volts. Judging from his reported relative transmissions in aluminum, Röntgen's *bremstrahlung* distribution had maximum energies of 30 - 50 keV, with peak intensities at around 20 - 30 keV as a result of energy losses by the incident electrons in the thick glass face of the tube. At such energies,

X-rays interact with matter predominantly by the photoelectric effect.

How the world came to know about the discovery of X-rays

It seemed impossible that such easily observable effects had not been seen by Lenard, Crookes, J.J. Thomson (who established that cathode rays were indeed a stream

of electrons) or any of the other cathode ray researchers during the previous two decades. How is it then only Röntgen saw it — the glows and the shadows of the bone! **But the fact is no one had reported the amazing penetrating power of these new rays.** No one had seen bizarre shadows of bones on a fluorescent screen! And that they were different from cathode rays.

In the weeks following his discovery, Röntgen became uncommunicative and preoccupied, working, eating and even sleeping in the laboratory for days at a time. After Christmas, armed with experiments demonstrating the physical reality and unusual properties of X-rays, with shadow photographs of the bones of his wife Bertha's hand and, more prosaically, of a set of brass weights enclosed in a wooden box, Röntgen composed, with uncharacteristic speed, a summary of his results. On December 28, 1895, he asked his good friend Karl Lehmann, president of the Physical Medical Society at Würzburg, to prevail upon the editors of the *Sitzungsberichte der Physikalisch Medizinischen Gesellschaft zu Würzburg* to include his handwritten manuscript, "Über eine neue Art von Strahlen" (on a new type of rays), in its December 1895 proceedings, even though the

paper had not been presented at the December meeting and even though the proceedings were already at the printers. It was not possible at that late date to include his revolutionary X-ray shadowgraphs.

In the next three days he hurriedly produced enough copies of the crucial shadowgraphs to distribute them, along with preprints of the paper, to the leading physicists in Germany, England, France and Austria. He mailed the packages himself, on New Year's Day 1896. As he did so, he acknowledged his anxieties and his unseemly haste about achieving priority of discovery, remarking to Bertha, "Nun wird man dem teufel zahlen müssen" — "Now the devil must be paid".

On 5 January 1896 Röntgen's discovery was described on the front page of the Sunday Edition of "Die Presse" in Vienna. Soon after, the discovery of X-rays was reported throughout the world, even before the paper was published in the scientific journal.

X-rays change the face of the society:

People immediately saw the potential for the use of X-rays for medical diagnosis (although, unfortunately, it was not until many years later that they discovered that X-rays could also be dangerous). X-rays could pass easily through soft-body tissue, while being largely blocked by bone structures or other more solid materials. So if a photographic plate is placed behind a patient, a photo can be taken showing bones as a white shadow on black. Tooth decay looks gray against the white of the teeth. Metal objects also show up clearly, and within four days after Röntgen's news arrived in America, X-rays were used to locate a bullet lodged in a patient's leg. Just three months after Röntgen's announcement, a boy named Eddie McCarthy in Dartmouth, Maine, became the first person to have a broken bone set using the new way to view bones.

Röntgen had caused a great furor, not entirely positive. In the state of New Jersey, legislators worried that X-rays meant the end of personal privacy (they were particularly concerned about the modesty of young women) and proposed legislation to prevent the use of X-rays in opera glasses — an unnecessary worry, of course.

But for scientists, Röntgen's X-rays (initially known as Röntgenstrahlen — Röntgen Rays) would become one of the

greatest tools in biological research, and their discovery marked the beginning of a second scientific revolution in

physics. For his discovery, in 1901 Wilhelm Röntgen became the first person ever to be awarded the Nobel Prize in physics.

From Röntgen's X-rays, two big boulders started rolling. One would begin an avalanche of revolutionary new ideas about the atom, and the other would lead to the

discovery of a strange instability in certain elements, a characteristic that would enable us to tap nuclear power. We shall glance at these pages of the Golden Decade (1895-1905) in future articles. At the time Röntgen discovered X-rays,

however, the idea of an atomic nucleus did not even exist!

X-rays Over 100 years

X-rays have played and have been playing a significant role in our lives even since their discovery by Röntgen. They make the unseen visible in our bodies; they make possible testing of a wide variety of materials in a non-

destructive way; they make our air travels safe. Further, through X-ray diffraction and spectroscopy, they make it possible to probe the order of matter at the atomic level (remember Bragg's law ($n\lambda = 2d \sin\theta$)).

The discovery of X-ray diffraction in crystals laid the foundation for the field of X-ray crystallography. Early in their history, scattering of X-rays — Compton Scattering — revealed the energy and momentum distributions of electrons as well as vividly illustrating Heisenberg's uncertainty principle. From hospitals to airports, in physics and in biology labs, in the fabrication of nanostructures of electronics and machinery, X-rays have come to permeate the modern world.

X-rays have had a profound impact in advancing the field of biology. Through the awesome powers of the recombinant DNA technology and synchrotron radiations, as combined in modern day X-ray crystallography, ever — more — complicated molecules and assemblages are being worked out in atomic detail. The insight into the biological processes derived from these studies are transforming cell and molecular biology.

X-ray sources in space are serving as valuable laboratories for astrophysics, nuclear physics, relativity, plasma physics and cosmology. X-rays from space have revealed new objects and physical processes hidden from the view of the optical



Kai M. Siegbahn



Herbert A. Hauptman



Jerome Karle



Johann Desisenhofer



Robert Huber



Hartmut Michel

telescopes. Today we know of some 100000 celestial sources of X-rays. Neutron stars were detected in the X-ray band five years before the first detection of the cosmic microwave background which were followed by discoveries about the hottest and most violent places in the universe. It may be interesting to note that even the basic energy sources for the X-ray and optical emitters detected are different! Visible universe is dominated by the objects that derive energy from nuclear reactions, whereas most objects detected in the X-ray regime are powered by gravity, magnetic fields or kinetic energy. One of the most significant accomplishments of X-ray astronomy is the experimental confirmation that black holes exist! Further nearly 50 supernova remnants have been detected at X-ray wave lengths in the Milky way, and other nearby galaxies. It may be stated that several X-ray observations in space have contributed to the program of X-ray astronomy in the past. Now it is the CHANDRA X-ray observatory advancing the frontiers of this wonderful field.



Hermann Joseph Muller

Pride in One's Profession, Not Professional Conceit

Before we end this article, let us briefly look at the values this great and unassuming person stood for and what he thought of science as a profession.

In all, Röntgen wrote fifty eight papers, some with collaborators. His first work was published in 1870 dealing with the specific heats of gases. A few years later, he wrote a paper on the thermal conductivity of crystals. Among the other problems he studied were the electrical and other characteristics of quartz; the influence of pressure on the refractive indices of various fluids; the modification of the planes of polarised light by electromagnetic influences; the variation in the functions of the temperature and the compressibility of water and other fluids; and the phenomena accompanying the spreading of oil drops and water.

Despite several honours having been showered upon him, Röntgen retained the characteristic of a strikingly modest and reticent man. He was a great mountaineer and more than once got into dangerous situations! Amiable and courteous, he was always understanding the views and difficulties of others.

While his discovery could have been patented for tremendous personal benefit, **Röntgen instead gave it to humankind and sought no recognition for himself.** He gave the cash he received through the Nobel Prize over to the University of Würzburg. After his discovery of X-rays, Röntgen turned his attention to other experiments. After his wife's death on October 31, 1919 at the age of 80, Röntgen resigned his position at the University. In the

inflation that followed the World War I, he found his savings of a lifetime wiped out. Röntgen himself died on February 10, 1923 with only his devoted housekeeper nearby. He had been weakened by the cancer of intestine which was diagnosed only in its terminal stage.



Dorothy Crowfoot Hodgkin

Röntgen's attitude to his profession is clearly defined in the address he gave in 1894, when he became rector of Würzburg University:

"The University is a nursery of scientific research and mental education, a place for the cultivation of ideals for students as well as for teachers. Her significance as such is much greater than her practical usefulness, and for this reason, one should endeavour, in filling vacant places, to choose men who have distinguished themselves as investigators and promoters of science, and not only as teachers; for every genuine scientist, whatever his line, who takes his task seriously, fundamentally follows purely ideal goals and is an idealist in the best sense of the word. Teachers and students of the University should consider it a great honour to be members of this organisation. **Pride in one's profession is demanded, but not professional conceit, snobbery or academic arrogance, all of which grow from false egotism**".

References

1. *Wilhelm Conrad Röntgen and the glimmer of light*, Howard H. Seliger, *Physics Today*, November, 1995. A beautiful article. The present article draws heavily on it.
2. *Introduction to Modern Physics* F.K. Richtmyer, E.H. Kennard, and T. Lauritsen McGraw Hill Book Co., 1955. A classic reference book for historical development of Modern Physics. References to original research works mentioned in this article could be found in this book.
3. *The History of Science (from 1895 to 1945)* Ray Spangenburg and Diane K. Moser Universities Press (India) Ltd., 1999. A five-volume series with short biographical sketches of scientists and their work. Highly readable.
4. *Sourcebook on Atomic Energy*, Samuel Glasstone, D. Van Nostrand and Co. 1969. Yet another classic. Discusses historical aspects and development of ideas and technology in a lucid style.
5. *Dictionary of Scientific Biography*—vol. 13 Editor-in-Chief, Charles Coulston Gillispie, Charles Scribner's Sons, New York 1975. A wonderful resource in 14 volumes.
6. <http://www.nobel.se>, the website of Nobel Foundation.

X-rays: Glossary

Important terms used in connection with X-rays are given below. The terms given do not necessarily appear in the present article.

Black holes : A region of space-time from which nothing, not even light can escape, because gravity is so strong. However, as a result of the effects of General Relativity and quantum mechanics, they must radiate like hot bodies emitting a lot of gamma rays (electromagnetic radiation much shorter in wavelength than X-rays) and X-rays, as predicted by Stephen Hawking.

Bragg's Law : It defines the relationship between wavelengths (λ) of X-rays falling on a crystal, spacing of planes of atoms in the crystal (d) and the angle of incidence (θ) of X-rays, all of which together contribute to X-rays diffraction effects. Mathematically, the relationship can be written as $2d \sin \theta = n\lambda$ (where n is an integer). Using this relationship, and a beam of X-ray of known wavelength, the positioning of atoms in a crystal can be determined from the observed pattern of diffracted X-rays.

Bremsstrahlung : Braking (decelerating) radiation. A spectrum of X-rays of different intensities, wavelengths and energies, produced when fast moving electrons are suddenly stopped or slowed down on striking a metal. X-rays produced in this manner are used for medical examination purposes.

CAT scan : Computerised Axial Tomography, a means of imaging internal structures of objects using beams of X-rays that probe different parts of the object from different angles.

Cathode Rays : A beam of electrons emitted from the cathode of a high-vacuum tube.

Cathode Ray Tube : A high vacuum tube in which cathode rays produce a luminous image on a fluorescent screen.

Chandra X-ray Observatory : NASA's advanced X-ray Astrophysics space telescope launched in 1999 for detecting far away sources, producing images with five times greater details than the optical ones.

Characteristic X-ray : X-ray produced when an electron in the higher energy shell in an atom drops into a "hole" in a lower energy shell (created due to the electron in the lower shell being knocked out by another energetic electron in a cathode rays tube).

Compton Scattering : Collision between a photon and an electron. The wavelength of electromagnetic radiation (photon) in the X-ray or Gamma ray region increases when it is scattered by electrons. Part of the photon energy is imparted to the electron.

Crooke's dark space : When pressure in a Cathode-ray-tube is about 1mm of mercury, the cathode glow is detached from the cathode and a dark space appears between the cathode and the cathode glow.

Diffraction of X-rays : Similar to light rays from a single slit or a grating. However, the wavelength of X-rays being very small (of the order of 10^{-8} cm) one needs to use a crystal in which these are families of parallel planes with characteristic separation defined by arrays of atoms as a grating.

Electron Volt (eV) : Unit of energy widely used in Atomic and Nuclear Physics. It is the energy or work done on an electron (or a charged particle with equal charge) when passing through a potential difference of one volt. $1 \text{ eV} = 1.602 \times 10^{-19}$ joules. $1 \text{ keV} = 1000 \text{ eV}$. $1 \text{ MeV} = 1000,000 \text{ eV}$.

Neutron Stars : A cold star, supported by the exclusion principle repulsion between neutrons. Formed when a star heavier than 1.4 times the mass of the Sun is depleted of its hydrogen fuel and collapses under its own gravity. Fast rotating neutron stars (also known as

pulsars) may emit pulses in optical or even in X-ray regions.

Polarisation of X-rays : Being electromagnetic waves and hence transverse, the X-rays can be polarised with their field vibrations taking place in a particular plane.

Radiodiagnosis : The use of X-rays and ionising radiation to identify the cause of physical disorders such as tumours.

Radiography : The technique of producing a photographic image of an optically opaque object by passing a beam of X-rays or Gamma-rays through it, onto a photographic film.

Radiology : The branch of medicine dealing with the use of X-rays, radioisotopes and non-ionising radiation (such as ultrasound) in diagnosis of disease.

Radiotherapy : The use of X-rays or radioisotopes to treat a disease, mainly cancer.

Synchrotron Radiation : Intense light or X-rays emitted when electrons move in a circular orbit at relativistic speeds.

Uncertainty Principle : Enunciated by Werner Heisenberg in 1927 which states that position and momentum of a particle both simultaneously cannot be determined accurately. One can accurately measure at a time only the position or momentum of the particle. This principle has become one of the basic tenets of quantum mechanics.

X-ray : 1) Photon produced when an energetic electron loses energy by bremsstrahlung or when an atom in a state of high energy decays to states of lower energy. Their wavelength may range from 10^{-11} to 10^{-6} m (i.e. 0.1 to 100 Å). 2) X-ray shadowgraph on a photographic plate when X-rays are made to pass through the object of study.

X-ray Astronomy : The study of X-rays coming mainly from sources lying outside the solar system, like novae and supernovae in the Milky Way Galaxy, and other extragalactic radio sources. Satellites are used for X-ray Astronomy since X-rays are absorbed by the Earth's atmosphere.

X-ray Crystallography : The study of crystal structures by X-ray diffraction techniques.

X-ray Energy Levels : Energy levels of an atom, usually defined by a set of numbers called the quantum numbers – total quantum number n . $n = 1$ corresponds to K-shell, $n = 2$ to L-shell and so on.

X-ray Photoelectric Effect : A high energy photon (corresponding to wavelength in the region 0.1 Å to 100 Å) knocking out an electron from a shell corresponding to a particular energy level in an atom.

X-ray scattering : Similar to scattering of light rays by particles. Scattering of X-rays can, however, be observed from the parallel planes defined by arrays of atoms in a crystal.

X-ray Spectrometer : An apparatus for measuring wavelength spectrum of the radiation emitted from an X-ray tube using crystal as a diffraction grating, and using Bragg's law.

X-ray Star : A star mainly emitting radiation in the X-ray region (the Sun emits X-rays but radiates mainly in the optical region and hence is not an X-ray star).

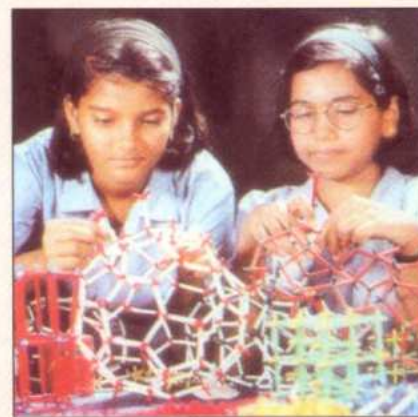
X-ray Tube : An electronic device to produce X-rays, essentially a cathode ray tube, but designed to produce X-rays on collision of cathode rays with a metallic target.



EXPLORING YOUR WAY THROUGH SCIENCE!

□ Dilip M. Salwi*

"Experiment is the highest court of appeal in science," said the eminent physicist and Nobel Laureate Richard Feynmann once. But an experiment implies the need for abundant curiosity, free and wild thinking, considerable time and patience, the necessary paraphernalia, and on top of all, no fear of going wrong or breaking an equipment or wasting a chemical! For these very reasons, Indian schools and colleges avoid the hullabaloo of experiments. Instead, they conduct practical classes and demonstrations to safely tide within the prescribed time limits! Obviously, fun is taken out of science and innovation and creativity is shown the door. The number of bright students opting for science as a career is therefore on the decline all over the country, "If this trend continues," said Prof B.G.Bhide, an eminent scientist and the brain behind the 'Exploratory', "the country is heading for disaster".



Children explore Physical Phenomena

To reverse the present negative trend so that bright students stay on in science, a small experiment called 'Exploratory' begun in some rooms of Bharatiya Vidya Bhawan on April 8, 1992, in Pune, which can act as a beacon in the stormy weather of science education in the country. "As the very name implies," said its Director, prof C.K. Desai, "Exploratory is the place where a student can explore science without any kind of fear. It is neither a lab nor a museum. Here teachers are available simply as guides". Today, 'Exploratory' has five well-equipped labs on physics, chemistry, biology, mathematics and electronics.

The concept of 'Exploratory' occurred to Prof Bhide, when after long innings as a scientist at National Physical Laboratory, New Delhi, he assumed the Vice Chancellorship of the University of Poona and felt something seriously wrong with science education in schools and colleges. His studies convinced him that bright students were shying away from science because it was no more an exciting subject worth spending one's life on. Moreover, the toppers in schools and colleges later turned out to be mediocres in real life conditions. Obviously, science education was more dependent upon memory rather than problem-solving abilities of students. To stimulate these abilities, prof Bhide realised, 'Exploratory' was the answer. At a ceremony of Indian Association for Physics Teachers in 1992, where prof Desai received the best teacher's award, he (Prof Bhide) lured the eager Professor to the Exploratory. Eager to break the mould of the present science education system, Prof Desai took voluntary

retirement from his Professorship at a college in Sangamner and shifted to Pune to manage the Exploratory.

"At a time we've a batch of not more than 40 students," said prof Desai, showing the various displays, exhibits, charts and apparatuses available in the five labs, "This batch is further divided into groups of 5 to 6 students which get disbanded after every third experiment". About 350 students both from English and Marathi medium therefore get an exposure to the exploratory way of doing science every year on a first come-first serve basis. Also, about 2000 students visit the Exploratory every year. In recent times, the programme has also been extended to college students. A select group of ten is exposed to a series of lectures on different aspects of science and is also given the opportunity to work on research projects in the local scientific institutions like National Chemical laboratory, Inter University Centre for Astronomy and

Astrophysics, National Centre for Radio Astronomy, etc. Besides, students are also exposed to the research and work environment in the local industries and factories. Results are highly encouraging. Exploratory-trained students have bagged prizes and awards in various national and international Olympiads in science and mathematics. Even some students have been offered scholarships to study in some U.B. universities.

"We're keen that our experience at Exploratory is reproduced all over the country," said Prof Bhide with pride, "The NCERT is already intending to do so in their regional centres". These are encouraging signs, provided the Exploratory's free spirit of exploring (including the funding which is purely non-Governmental) is not tied down by a new system of education. Meanwhile, the Exploratory's success is slowly spreading by word of mouth to neighbouring towns and cities. School and college teachers from Hubli. Nanded. Nasik. Yavatmal. Pali, etc, are regularly visiting the Exploratory and are acquiring the knowhow and experience to set up one in their own schools and colleges. A programme to orient teachers to the Exploratory's way of doing science is also in progress. In the near future, the Exploratory also intends to bring the expertise of its best teachers to the doorsteps of students through CDs and books. Healthy signs for science education, isn't it?

*Shri Dilip M. Salwi is a popular science writer and lives at M.I.G. Flat, No.-132, Pkt.-8B, Sec.-4, Rohini, New Delhi-110085

• • •

Development of Cometary Thought

(PART - I)

□ Subodh Mahanti

No man is so utterly dull, with head so bent on Earth, as never to lift himself up and rise with all his soul to the contemplation of the starry heavens, especially when some fresh wonder shows a beacon-light in the sky. As long as ordinary course of heaven runs on, custom robs it of its real size. Such is our constitution that objects of daily occurrence pass us unnoticed even when most worthy of our admiration. On the other hand, the sight even of trifling things is attractive if their appearance is unusual... So natural is to admire what is strange than what is great. The same thing holds in regard to comets. If one of these infrequent fires of unusual shape have made its appearance, everybody is eager to know what it is. Blind to all the other celestial bodies, each asks about the newcomer; one is not quite sure whether to admire or fear it. Persons there are who seek to inspire terror by forecasting its grave import. And so people keep asking and wishing to know whether it is a portent or a star.

Lucius Annaeus Seneca (4B.C.-A.D.65) in Natural Questions

... In thick smoke of human sins, rising every day, every hour, every moment full of stench and horror, before the face of God and becoming gradually so thick as to form a comet, with curled and plaited tresses, which at last is kindled by hot and fiery anger of the Supreme Heavenly Judge.

Andreas Celichius in The Theological Reminder of the New Comet (1578)

If there is a central theme that runs throughout the history of comets, it must be the public concern they have commanded—concern completely disproportionate to their infrequent visits, subtle radiance, and modest sizes. Before the seventeenth century, comets were considered portents— warning shots fired at a sinful Earth from the right hand of an avenging God. In the post-Newtonian era, when their paths were understood to intersect that of the Earth, they were considered actual agents of destruction. At one time or another, they have been blamed for presaging war and pestilence and held responsible for the deaths of great men and the birth of good wine, for periods of drought and Noah's flood, for severely cold weather and the London fire of 1666. They have been described as the carriers of both life-seeds to the early Earth and horrific missiles that will one day snuff out life as we know it.

Donald K.Yeomans in Comets : A Chronological History of Observations, Science, Myth and Folklore (1991).

The development of the scientific understanding about comets has a long and intriguing history. For centuries people (common people and scientists alike) have pondered over the appearance of these mysterious apparitions. People's fascination for them, as Seneca pointed out, was because they were unusually strange phenomena. They appear rarely. Before the seventeenth century, comets were not considered as celestial bodies but as signals at a sinful Earth from God. Celichius as quoted above was no doubt expressing the majority view of the comet prevalent in the 16th century. Of course, there were opponents, though their number were few. For example Andreas Dudith (1533-89), the Hungarian scholar, countered Celichius' views by stating that if comets were caused by the sins of the mortals then they would never be absent from the sky.

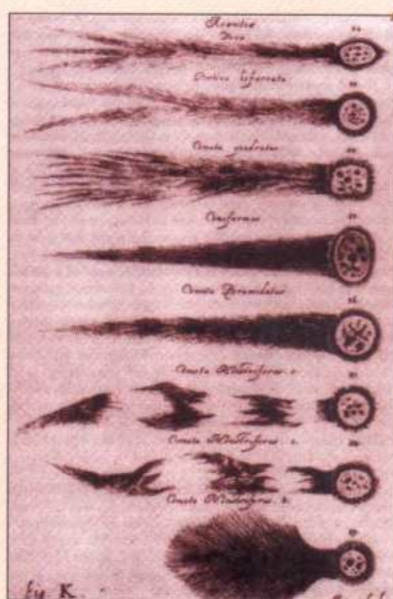
The range of phenomena associated with comets is truly extraordinary. Of course, much of it was nothing but nonsense. But then all of this adds to their considerable mystique and thus making them a subject of universal interest. Comets have been described as the carriers of carbon-rich organic molecule to the Earth which eventually helped life evolve. They are also seen as horrific missiles that will one day destroy life from the Earth.

Today we know that comets are small remnants from the Solar System. Comets are of profound

importance. Their study enables us to examine the condition and composition from which the major planets formed some 4.5 billion years ago. Their small size is no way proportional to their scientific importance.

Here we attempt to give some glimpses from the vast literature on the history of cometary ideas. One may wonder that when we know a great deal of scientific aspects of comets then why one should muse over the ideas which were proved wrong long back. But then the study of comets is not only historically important but also scientifically compelling. What is more it is exceedingly entertaining. The history of cometary thought is also a glaring example of how scientific concepts often emerge from the labyrinth of confused and conflicting ideas. This also shows how otherwise great scientists held ideas which subsequently looked to be so ridiculous. It is simply not possible to narrate here such a long bewildering history. We have just captured some stray incidents.

Aristotle (384-322 BC), whose importance in the history of western thought cannot be exaggerated, dominated almost every aspects of western thought for nearly 2000 years. Aristotle documented his cometary ideas in his book, *Meteorologica*, which dealt with the sublunar or terrestrial world. Besides stating his own



These eight types of comets were illustrated in 'Johannes Hevelius' *Cometographia*(1668)

views, Aristotle presented the views of his Greek predecessors from the sixth to the fourth century BC including those of Pythagoras (c.560-480B-C), Hippocrates of Chios (fl.440B.C.) and Anaxagoras of Clazomenae (c.500-428B.C.). According to Aristotle the Pythagoreans believed in the existence of only one comet. Further they believed that it was a planet, which appeared infrequently and like Mercury it rose only a little above the horizon. Hippocrates like Pythagoreans believed in the concept of a single comet. According to Hippocrates a comet's tail was formed when the comet drew up moisture from the Earth below and it appeared at greater intervals than other stars, as it was the slowest to move about the Sun. Aristotle described in his *Meteorologica* that according to Anaxagoras, comets were caused by planetary conjunction. Though Aristotle dismissed the idea by noting that comets were formed in regions of the sky where no planets travel it remained popular well into the seventeenth century.

To understand Aristotle's own ideas about comet we must have some idea about Aristotelian cosmology. Aristotle viewed the universe as finite spherical and geocentric where the first four elements viz. earth, water, air and fire moved naturally along straight, finite lines but they remained confined to the imperfect sublunar world. A fifth element or essence, Quintessence, permeated the supralunar space where the planets, Moon and the stars moved eternally in perfect circles. Aristotle placed the four concentric spheres in the following order — the Earth, the watery sphere, the airy sphere and the fiery sphere. According to Aristotle, comet formed from the dry, warm exhalation emanated from the Earth as the result of the Earth being heated by the Sun or planets. The cooler moisture also evaporated but it remained in the lower region. Only the warm, dry, windily exhalation rose upwards but at the border of the fiery sphere, the friction of their motion ignited them and resulted in comet. The resultant comet alongwith neighbouring dry exhalation was carried about the Earth by the circular motion of the heavens in the fifth sphere. The form of the comet and how long it would sustain would depend on the comet and form of the exhalation. Aristotle's views on the nature of comets survived for two thousands years. Today we know that they have proved to be wrong. But it is worthwhile to note that Aristotle's cometary theories were physical and not metaphysical in nature. There was no place for superstition .

Like the *Meteorologica* of Aristotle, the *Natural Questions* of Seneca is an important source of the earliest ideas about comets. It is from Seneca's *Natural Questions* we know the views of comets of the Chaldeans or Babylonians. From Seneca we also learn the cometary ideas of some Greek scholars like Ephorus of Cyrene (fl. 340 BC), Epigenes (fl. 4th century BC), Apollonius of Myndus (fl. 4th century BC) and Posidonius (135-51 BC). Ephorus had observed the splitting of a comet into two separate pieces and this enraged Seneca to ridicule him. But now we know many instances where comets have split. Epigenes' cometary ideas were modified version of Aristotelian ideas. According to Apollonius comets were neither illusions nor the

results of planetary conjunctions.

Pliny the Elder or Gaius Plinius Secundus (AD 23-79), who was a lawyer, traveller, administrator and head of the western Roman fleet under the emperor Vespasian, is much known for his *Natural History* which influenced thinking of people throughout the Middle Ages. Pliny was not a scientist. But he was one of the most prolific writers of antiquity. In his *Natural History* (37 volumes). Pliny wanted "to give a general description of everything that is known to exist throughout the Earth." Pliny's writing was not at all critical. It has plenty of half-truths, myths and even nonsensical things. As Donald K. Yeomans has noted Pliny's "comments are important only because the *Natural History* was so well known and respected during the Middle Ages." While writing about comet Pliny had not taken note of the views of his contemporaries. He took comets as portent. He made them 'terrifying apparitions' by describing in detail the disasters that followed a few cometary returns. He even formulated certain rules for predicting the nature of



Paolo Toscanelli

disaster that would follow a particular cometary appearance. Pliny noted that while some comets move, others do not. They could appear in any directions but those in the south had no tails.

Pliny developed a system of classification of comets and as noted by Yeomans. He described 10 types comets.

1. Pogonias - comets with a beard or mane hanging down from the lower part.
2. Acontias - vibrating like a javelin with very quick motion.
3. Xiphias - short and pointed like dagger.
4. Discus - like a quoit or discus, amber, in colour
5. Pitheus - figure of a cask and emitting a smoky light .
6. Ceratias - appearance of a horn.
7. Lampadias - appearing as burning torch.
8. Hippeus - like a horse's mane in rapid motion.
9. Argenteus - silver in colour, so bright that it is difficult to look at.
10. Hircus - goat comets ringed with a cloud resembling tufts of hair.

Pliny's *Natural History* was so popular that even in the late seventeenth century of the cometary types described by Pliny could be recognised in serious scientific works.

Ptolemy or Claudius Ptolemaeus (c AD 100-175) was considered a dominant scientific authority until the seventeenth century. We virtually know nothing about Ptolemy's life except that he lived and worked in Alexandria. Ptolemy did not describe about comets in his celebrated *Almagest* in which he treated the motion of heavenly bodies. This is because Ptolemy did not consider comets as heavenly bodies, rather he considered them as portents of evil. He described about comets in his work on astrology, *the Tetrabiblos* - a companion volume of the *Almagest*. While describing about the astrological implications of comets, he had even surpassed Pliny.

According to Ptolemy the part of the world to be affected by a comet could be guessed from the part of the sky in which the

comet first appeared and the direction of its tail. The kind of disaster and the persons to be affected can be guessed from the shape of the comet. The comet's position with respect to the Sun would decide when disaster would strike. Disaster would strike soon if the comet appears near the rising Sun; but if it appears in the west the disaster is delayed. Because of Ptolemy's unassailable influence many astrological work were incorrectly attributed to Ptolemy in the Middle Age. One such work titled *Karpos* or *Centiloquy* laid down specific rules for predicting comet related disasters. This work which often accompanied the *Tetrabiblos* in medieval Latin manuscripts. These two manuscripts were used for centuries to correlate appearances and disaster. Throughout the middle ages and also in renaissance times most of the writers on comets did not deviate from Aristotelian origin of comets and its astrological implications highlighted by Ptolemy.

Albertus Magnus (1193-1280), the German philosopher and cleric and who was known as *Doctor Universalis*, considered comet as a coarse, terrestrial vapour originating from the lowest region of the airy sphere. The vapour in the course of its upward movement when rises to concave surface of the fiery sphere is ignited and people see it as a comet. It remains visible till the fuel supply lasts. His pupil Thomas Aquinas (C.1225-1274) heightened the fear of comet by stating that comets were among the 15 signs preceding the God's coming to judgement. Roger Bacon (1214-94) also a student of Albert Magnus and who played a pioneering role in the advancement of science, thought comet as portent and his ideas of comet had more to do with contemporary superstition than with scientific method. Martin Luther (1483-1546) referred comets as harlot stars and works of the devil.

Up to the end of fourteenth century the ancient Chinese astronomers were ahead of their European counterparts. They were aware of the antisolar nature of a comet's tail as evident from Li Chung-feng's description as depicted in the history of the Chin Dynasty (AD 265-419), which was completed in AD 635.

"Among ominous stars the first are the hui-xing, commonly known as broom stars. The body is sort of star while the tail resembles a broom. Small comets measure several inches in length, but the larger ones may extend across the entire heaven. The appearance of a comet predicts military activities and great floods. Brooms govern the sweeping away of old things and the assimilation of the new. A comet can appear in any one of the five colours, depending on the essence of that one of the five elements which has given birth to it.

According to the official astronomers, the body of the comet itself is non-luminous but derives its light from the Sun. So that when it appears in the evening it points toward the east while in the morning it points toward the west. If it is south or north of the Sun, its tail always points following the same direction as the light of the Sun then suddenly fades. The length of the rays is a measure of the calamity foretold by the comet."



Johannes Müller

With the disintegration of the Roman Empire the importance of the knowledge of the Greek language diminished. As a result the widespread knowledge of the early Greek sciences gradually disappeared. Only in the twelfth century Latin translations of early Greek works on science became widely available. The Church dominated the European thought in the medieval period. It was the age of superstition — for everything people looked back. So in case of comets the ideas were mostly derived from Aristotle and Ptolemy. The cometary views during 1200 to 1577 (in the year 1577 a great comet appeared and which was scientifically observed by many well known astronomers of the day including

Tycho Brahe) was dominated by superstitious astrological considerations. But there were very few observers who attempted, may be hesitatingly, to study comets scientifically. One of them was Palo Toscanelli 1397 -1482), the Florentine astronomer and physician. He made detailed observations (both descriptive and positional) of six comets that appeared in the 15th century (1433, 1449-1450, 1456 (Halley), 1457 I, 1457 II and 1472. Unfortunately his observations remained unknown till 1864 when Giovanni Celoria, Director of Milan Astronomical Observatory, successfully used them to compute the orbits of the comets.



Michael Mästlin

George von Peurbach or Purbach (1423-61), the Austrian astronomer and mathematician, had tried a cometary parallax determination as early as 1456 but that time the techniques and instruments were not accurate enough to confirm whether comets were terrestrial or celestial phenomena. However, it was Regiomontanus or Johannes Muller (1436-76), who was a student of Peurbach, is generally given the credit for devising the techniques required for cometary parallax determination. It was in 1577, the comet's position was put beyond the Moon by Michael Mastlin (1530-1631), Tycho Brahe (1546-1601) and Cornelius Gemma (1535-79). They all came to this conclusion after parallax measurement of the great comet of 1577.

• • •