



DREAM 2047

April 2001

Vol.3

No. 7

VP News

Inside

VIPNET STRENGTHENS ITS ROOTS IN RURAL BIHAR & BENGAL

In the second fortnight of March 2001 two major workshops were organised by Vigyan Prasar for the benefit of rural science clubs of Bihar and West Bengal.

Workshop at Barauni

The Bihar workshop was held in the Barauni Refinery DAV (BRDAV) School at the Indian Oil Corporation (Barauni) complex. Shri Arup Kr. Misra (VP), Shri B. K. Tyagi (NCSTC), Md. Jawaid Alam and Shri M.M. Prasad were the resource persons for the workshop. Sixty participants from 26 science clubs of North Bihar and ten invitees from Jharkand and South Bihar attended the workshop.

The Bihar workshop started on 23 March 2001 with an inauguration function, which was graced by Shri K.P. Sahi, Executive Director of IOC as the Chief Guest. An innovative and interesting Science Exhibition was put up by the students of BRDAV School. The first session began with a slide show. A detailed explanation

EDITORIAL

Discovery of Radioactivity



Development of Cometary Thought
PART - II



Vipris clipset



Prof. V.S. Ramamurthy, Secretary, DST and Chairman, Governing Body, Vigyan Prasar, handing over the FIE Foundation National Award 2000 to Dr. Subodh Mahanti of Vigyan Prasar at Technology Bhawan. Dr. Mahanti was given the Award for his contribution in the field of Science Popularisation. The function was originally scheduled to be held at Ichalkaranji (Maharashtra). However, due to the devastating earthquake in Gujarat, the organisers decided not to hold the function. Also seen in the picture (L to R) Shri D.D. Deshpande, Hon. Secy. FIE Foundation and Dr. V.B. Kamble, Acting Director, Vigyan Prasar.

of salient features useful for established and prospective clubs/NGOs etc., was made by Shri A. K. Misra. Shri B. K. Tyagi (NCSTC) introduced the NCSTC training modules. In the post lunch session the participants were divided into three groups of 20 each and were exposed to Nature Assessment and Study by Shri Tyagi, Ham radio by Shri M. M. Prasad and Hydroponics (soil-less plantation only in water or pebbles or sand) by Md. Jawaid Alam.

The second day (24 March 2001) started with a general discussion on the types of activities suitable for clubs and resources (material and intellectual) required for these activities. This was followed by a demonstration of some peculiar soil-less culture/plants by Md. Alam, which evoked a lot of interest. After this Shri M.M. Prasad took a brief session on how to get started in HAM as a hobby. The post lunch session was a feedback session.

The highlight of the workshop was the live Ham Radio demonstration wherein the participants got the experience to communicate with the NCSTC Ham station in the premises of DST, New Delhi operated by Shri Sandeep Baruah.

(Contd. on page... 19)

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

Literacy Campaigns – A Decade Later

Just over a year ago, we celebrated the birth of *Astha*, the billionth baby of the country. Ever Since, we have added another 27 million babies taking the population of the country to 1.027 billion. In the year 1991, our population stood at 866 million, however, there has been an addition of 161 million persons during the decade 1991-2001. The annual growth rate still hovers around 2 per cent. But, every cloud has a silver lining. There is something to cheer about, as the provisional results of the census of India 2001 indicate. Today 65 per cent of country's citizens can read and write, compared to 52 per cent in 1991. Nearly 76 per cent of the males and 54 per cent of females are literate today, in 1991 their per centage stood at 64 and 39 respectively. This implies that more than three fourths of the males and more than half of the females can read and write today. What is more, there has been a net decline in the "absolute" number of illiterates during 1991-2001.

Undoubtedly, the spectacular growth in the literacy rates has been a result of the major initiative during the last decade in the area of adult literacy by organisations like the Kerala Sastra Sahitya Parishad and backed by the People's Science Movement. With the setting up of the National Literacy Mission in 1989, and formation of Bharat Gyan Vigyan Samiti by the constituent organisations of People's Science Movement, the effort spread to the entire country in the form of Total Literacy Campaign in various districts. In fact by 1997, the campaign spread to some 400 districts. There is no gainsaying the fact that the literacy growth rate achieved during this period was a direct result of the voluntary and mass involvement of over ten million volunteers.

An important fall out of the literacy campaigns was the demand by parents for the education of their children. The recent efforts of the Department of Elementary Education and Literacy include initiatives like the Sarva Shiksha Abhiyan to provide elementary schooling to all children in the age-group 6-14 years by 2010, extension of the District Primary Education Programme aimed at Universalisation of Primary Education, Education Guarantee schemes for out-of-school children, and the third phase of Lok Jumbish and Shiksha Karmi projects for improving the quality of elementary education. As regards the Adult Education, the National Literacy Mission would be revitalized with an aim to attain full literacy in the age-group 15-35 years by 2005. Further,

Continuing Education Centres for life long learning in all villages and more Jan Shikshan Sansthan to promote vocational and skill development programmes for neo-literates are also planned to be set up.

Despite the fact that the above initiatives owe their origin to the Government, to translate them into a concerted effort to accomplish the stated goals of total literacy by 2005, in the age group 15-35 years, it would be necessary to build upon the experience gained in the decade gone by. First and foremost, it would be imperative to ensure that the literacy campaigns essentially maintain the participatory nature of a people's movement, as it did during 1990-2000, with its army of volunteers from various Government/non-Government organisations and motivated individuals, which interacted and maintained a close contact with the beneficiaries. Government and voluntary organisations will need to work hand-in-hand for the purpose. Further, to prevent the skills acquired by the neo-literates from being lost, it is required that the same be utilised to understand and appreciate the issues directly affecting their lives – these may include issues like health, environment, sanitation and hygiene, nutrition, appropriate technology, agriculture and so on. In addition, a conscious effort would be needed to inculcate a scientific temper among them. This calls for continuous post-literacy follow-up activities with the neo-literates, and an evaluation of methods, structures and the primers developed till date for suitability and propriety of such materials, and their improvement. Otherwise, there is every likelihood that the neo-literates would lose the skills acquired and fall back into the trap of illiteracy, thereby negating the progress thus far.

What is described above is really a ready-made opportunity for the constituents of the Vigyan Prasar Network (VIPNET) of science clubs to contribute their might and be an integral part of the literacy campaigns and activities like the Sarva Shiksha Abhiyan. The clubs could engage themselves in a few of the activities outlined above with the neo-literates. Then our cherished goals of total literacy, inculcation of scientific temper and self-reliance will not look too distant a dream. Please do write to us how we could together contribute to the effort. We still have a long way to go.

□ 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>

Discovery of Radioactivity

□ V.B. Kamble

Antoine-Henri Becquerel (1852-1908) is known for his discovery of radioactivity, for which he received the Nobel Prize for Physics jointly with Marie Curie (1897-1934) and Pierre Curie (1859-1906) in 1903 and the contributions he made to that field. He was a member of the Academy of Sciences, became its President, and was elected to the far more influential post of permanent Secretary. He held three chairs of Physics in Paris – at the Museum of Natural History, at the École Polytechnique, and at the Conservatoire National des Arts et Métiers – and attained high rank as an engineer in the National Administration of Bridges and Highways.

Henri's father, Alexandre-Edmond Becquerel, and his grandfather, Antoine César Becquerel, were renowned physicists, both members of the Academy of Sciences and each in his turn professor of Physics at the Museum of Natural History. Henri Becquerel was born on December 15, 1852, and was educated at the Lycee Louis-le-Grand, École Polytechnique (1872-1874) and at the École des Ponts et Chaussées (1874-1877), where he received his engineering training. On leaving the Polytechnique, he married Lucie-Zoe-Marie Jamin, daughter of J.C. Jamin, academician and professor of Physics in the Faculty of Sciences in Paris. Before the end of his schooling, he had begun both his private research and his teaching career at the Polytechnique. His wife died in March 1878, a few weeks after the birth of their son Jean. Becquerel succeeded to the post of his father at the Museum, and from then on, his professional life was shared among the Museum, the Polytechnique, and the Ponts et Chaussées.

Becquerel's early research was almost exclusively in optics. His first extensive investigations (1875-1882) dealt with the rotation of plane-polarised light by magnetic fields. He next turned to infra-red spectra, making visual observations by means of the light released from certain phosphorescent crystals under infra-red illumination. He then studied the absorption of light in crystals. With these researches, Becquerel obtained his doctorate from the Faculty of Sciences of Paris (1888) and election to the Academy of Sciences (1889). In 1890, he married his

second wife. Following the death of his father in 1891, he succeeded in the following year to his father's two chairs of Physics at the Conservatoire National des Arts et Métiers and at the Museum. Thus, in the beginning of 1896, at the age of forty three, Becquerel was established in the rank and responsibility, his years of active research behind him and all that for which he is now remembered still undone!

There are few scientific discoveries whose circumstances are known as minutely as those around the almost accidental finding of radioactivity. On January 7, 1896, the great French mathematician Jules-Henri Poincare (1854-1912) received a letter containing several astonishing photographs of the bones in someone's hand. The bones belonged to Wilhelm Conrad Röntgen (1845-1923), a scientist Poincare had never visited. The letter explained that the pictures had been taken with the aid of a new discovery, X-rays that Röntgen had turned up the previous month, and that he was publicizing his findings by

mailing off prints all over Europe. Publicized they were: The photographs created a sensation across the globe. Within three weeks, little Eddie McCarthy of Dartmouth, New Hampshire, became a local celebrity when his broken arm was set by physicians armed with X-rays images of the fracture. It is easy to imagine Poincare's amazement-photographs of the inside of a human being! -and he quickly asked two local doctors if they could duplicate

Röntgen's work. On January 20, they showed their own X-ray photographs to the assembled members of the French Academie des Sciences. The reaction was immediate and extreme. In the next fortnight, five members of the Academie presented papers on the new phenomenon.

Antoine-Henri Becquerel too, was sitting in the audience when the X-ray photographs were shown. He was fascinated by the strange ghostly images and the mysterious emanations that produced them. Both he and his father had studied the phenomenon of phosphorescence—the museum laboratory was filled with lumps of stone and wood that shone in the dark. Although he had not done much active research in the last few years, he thought immediately of putting some phosphorescent rock on photographic paper to see if it would darken it in the same way as one of



Antoine Henri Becquerel



Pierre Curie



Marie Curie

Röntgen's X-ray sources. It would not be all that much work.

Born on December 15, 1852, Becquerel was the third in the line of Becquerels who held the chair of applied physics at what is today called the National Museum of Natural History in Paris. Like his grandfather Antoine-Cesar Becquerel, and father Alexandre-Edmond Becquerel, before him, he was a member of the French Academy of Sciences and attended its weekly meetings. During the meeting of January 20, 1896, he felt that the X-rays appeared to emanate from the area of a glass vacuum tube made fluorescent when struck by a beam of cathode rays. Poincare wondered aloud if such radiation was emitted by other luminescent bodies.

Becquerel was immediately challenged by this question. In fact, he was ideally suited to answer it. Not only was he expert in the investigation of various luminescent effects, a common activity in physical laboratories of the 19th century, but he had studied the phosphorescence of some uranium compounds in particular. He also was skilled in laboratory applications of photography. And, like most physicists, he sought a better understanding of the nature of matter, so perhaps the mechanics of phosphorescence would bring him closer to reaching this final, philosophical goal.

An expert on uranium phosphorescence

In the second half of the 19th century, Henri's father, Alexandre-Edmond Becquerel (1820-1891), was the leading authority in Europe on the subject of the phosphorescence of solids. It was an important field, made prominent by Robert Wilhelm Bunsen's (1811-1899) and Gustav Robert Kirchhoff's (1824-1887) recent spectroscopic analyses. Incidentally, "Fluorescence" is defined as the emission of light only during stimulation by external radiation. "Phosphorescence" persists after the external radiation ceases. "Luminescence" is the



Sir William Ramsay



Ernest Rutherford

umbrella term. Edmond was drawn to the investigation of uranium salts because of their exceptionally bright phosphorescence and their interesting spectra. One of his contributions was to show that the **uranic** series of salts is phosphorescent and that the **uranous** series is not. His son, Henri, began publishing on phosphorescence in 1883, and wrote twenty papers on this and related areas of study over the next 13 years, being attracted especially to the effects of infrared radiations. Like his father, Henri was fascinated by uranium salts, and he examined their absorption bands in both infrared and visible regions.

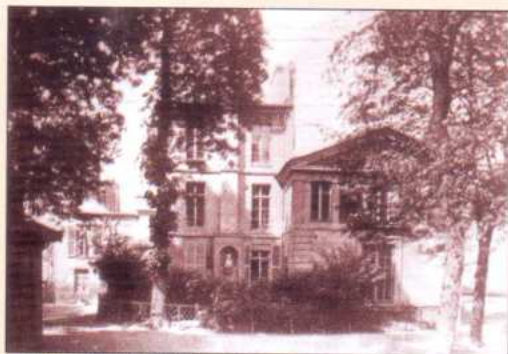
What is Radioactivity?

Imagine that you are holding a water melon in your hands. All of a sudden, for no apparent reason, one of its seeds comes flying out through the thick skin. At the same time, you find that the water melon has turned into a musk melon. Before you realise what happened, the musk melon throws out a seed and turns into an apple. As you are looking at the apple wondering to bite into it or not, a seed shoots out of it, and now what you have in your hand is an orange. By the time you try comprehend this unbelievable chain of events, the orange throws out a seed and becomes a lemon. Surely, you would not like to eat a lemon, so you wait for it to turn into a berry or into a grape. You keep waiting, but nothing happens. The lemon remains a lemon. You may think that may be the magician is trying to keep you awaiting from eating, or that there is a hitherto unknown power which is responsible for the entire chain of events. Fortunately, we never find one fruit changing into another kind of fruit the way it is described here. However, you may like to note that a very similar process is called Radioactivity.

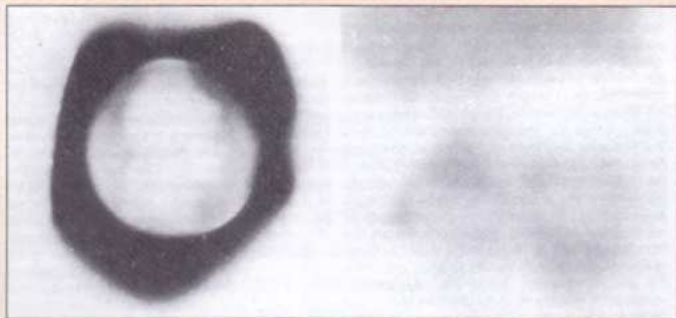
Atoms are the smallest constituents that make up of elements, and hence all matter. At the centre of each atom, there is a much smaller nucleus that contains even tinier particles called Protons and Neutrons. The nucleus of a "Radioactive" atom—throws out one or more of these tinier particles, sometime particles other than proton or neutron thereby changing into a different element, or sometimes electromagnetic radiation. Such a nucleus is said to decay, or break apart when the decay of a nucleus occur. One type of atom is changed into a different type., and hence one element into another.

Although uranium and its compounds interested the Becquerels, the study of these substances remained in something of a scientific backwater throughout the 19th century. Uranium had been discovered in 1789 by a German analytical chemist, Martin Klaproth, while he had been examining pitchblende from Saxony. Its name was chosen in honor of William Herschel's discovery of the planet Uranus in 1781 (a practice continued in the 20th century with the naming of neptunium and plutonium). Not until 1841, however, was it recognized that Klaproth had obtained only the oxide. Eugene Peligot, a noted French chemist, then succeeded in separating the metal.

Attention was again directed to uranium when Dmitri Ivanovich Mendeleev (1834-1907) formulated his periodic table in 1869 and showed it to be the heaviest element. But in an age of burgeoning chemical production, few applications for it were found. Compounds were tried as toning agents in photography, as dyes or stains for leather and wool and as mordants for silk and wool, and attempts were made with the metal to form an alloy with steel. The greatest use was in the ceramic and glass industries, in which uranium was



NATIONAL MUSEUM OF NATURAL HISTORY in Paris. On the second floor, at the left hand side of the building, is the window in which Becquerel exposed uranium compounds to sunlight, mistakenly believing that the invisible penetrating radiation, which we know today as radioactivity, was associated with phosphorescence.



Early images made by uranium rays

valued for making coloured glazes and coloured clear glass. By varying the percentage of the salt used, one could get yellow, orange, brown, green or black.

Photography entered the laboratory around the middle of the 19th century, being used to complement the microscope, telescope and balloon (for aerial photography), and to capture events such as sound waves, flying bullets, drop splashes, the motion of animals and lightning. Röntgen's encounter with X-rays, which evoked tremendous public interest, relied heavily on photography for its fame. By far the greatest scientific use of this tool came in the century's last two decades, which suggests the impact of dry, gelatin—emulsion plates. By 1896 Becquerel would probably have had at his disposal dry photographic plates of relatively good quality, uniform emulsion and long shelf life. Luminescence, uranium, photography—Becquerel was in the right place at the right time. But he still might have failed to recognize radioactivity as a phenomenon separate from phosphorescence if he had not been an accomplished physicist.

A model of scientific method

Becquerel's working hypothesis was that a body had to luminesce to emit penetrating radiation such as Röntgen had found. His technique was to wrap a photographic plate in light-tight black paper, position the mineral on the plate, and leave the experiment on his window sill where sunlight would stimulate the mineral to glow. At a meeting of the Academy of Sciences on 24 February 1896, he claimed success, reporting that several materials—in particular, phosphorescent crystals of potassium uranyl sulfate—emitted rays that penetrated thick black paper and exposed the photographic plate. This exposure was little more than a smudge. To refine the results and to make them more attractive to others Becquerel also placed coins and other thin, metallic objects under the crystals, producing interesting silhouettes and showing their penetrating power. It must, however, be



Image of a hand

stated that X-rays, which produced far sharper photographic images in less time were overwhelmingly more popular.

On Wednesday and Thursday, 26 and 27 February, 1896, Becquerel prepared several arrays of crystals and photographic plates. The Parisian winter, however, brought half a week of overcast skies, forcing Becquerel to postpone the experiments; he felt that he needed strong sunlight. The plates rested in a dark drawer until Sunday, 1 March, when Becquerel developed them, "expecting to find very weak images. To the contrary", he wrote in his memoirs, "the silhouettes appeared with great intensity".

The following day, on 2 March 1896, Becquerel reported to the Academy of Sciences that the potassium uranium sulfate crystals could be stimulated to emit the new rays by diffuse daylight through a thin cloud cover, as well as by reflected and refracted direct sunlight. He also described using different thicknesses of copper foil to examine the absorption of the rays. But the most astounding result that Becquerel offered was that **stimulation of the crystals by sunlight immediately before or during the experiment was apparently not necessary.**

The Uranium, it seemed, was spitting out X-rays all by itself. This, too, was not entirely correct. In fact, the lump of potassium uranyl sulfate was emitting a whole spectrum of radiation, of which only a small portion was X-rays. Nonetheless, the discovery caused a sensation, in part

Why does an apple remain an apple?

Most atoms are not radioactive, fortunately. Their nuclei are "stable", i.e. they do not decay. This is why an ordinary object, such as an apple or a watermelon with millions and millions of atoms with stable nuclei, always remains the same. Incidentally, we call a radioactive nucleus unstable because it can decay. When it does decay, both the number of protons and neutrons can change. Will the resulting nucleus be stable? Well, it may be stable or it too may be radioactive. If it is radioactive, it may be further decay to form yet another new nucleus, which could be radioactive as well. This is how a "decay series" could occur. Each kind of chemical element in the series changes into the next kind. Ultimately, the series may end with an element such as lead, i.e. not radioactive. The atoms in this element are stable, they do not decay. Thus after a sufficiently long time one may find that radium or uranium has completely changed into lead!

because it was so easy to duplicate. Almost every laboratory in the world had construction paper, photographic plates, and chunks of uranium ore. Within weeks, scientists across the continent were looking in astonishment at the blurred black patches on their photographs making Becquerel a celebrity.

Within weeks, news of Becquerel's findings had spread to Germany, Great Britain, Italy, and the United States, further exciting researchers already stirred by the

discovery of X-rays. Tests of the two phenomena were often conducted on the same workbench. The consequences of

each discovery, however, were far different. X-rays were found to be simply pulses of light — light of an intensity and power never before seen, but light nonetheless. Radioactivity, on the other hand, was something entirely new, something that did not fit anywhere. The existence of radioactivity — metal that somehow shot out energy! — was a direct attack on the most ardent beliefs of Becquerel and his colleagues. When the strange behaviour of uranium was first noted, Becquerel wrote in his memoirs, "There was no reason to presume that the phenomenon was [anything but] a new example of a known type of energy transformation. Contrary to every expectation, the first experiments demonstrated the existence of an apparently **spontaneous** production of energy" ... They had spent many years, those nineteenth century scientists, establishing the law of conservation of energy: Energy was neither created nor destroyed. But every single piece of uranium seemed of its own accord to produce radiation that fogged photographic plates, electrified gases, and sometimes even burned physicists — **and the energy needed to do these things evidently came from no place at all.** The metal just sat there, its atoms quietly working away, continuously beaming out penetrating rays in seeming disregard for the conservation of energy.

What prompted Becquerel to develop the plates?

But why had Becquerel bothered to develop those plates, which he thought were faintly exposed at best? His behavior has been explained as thoroughness: Jean Becquerel has suggested that his father planned to resume his experiments and wished to use fresh plates, so why to develop the old ones anyway? The explanation (proffered by G.E.M. Jauncey in a 1946 paper in the *American Journal of Physics*) is "impatience after awaiting four days for the sun to shine". Yet other reasons, suggested, are "simple thrift ... or an overriding curiosity". We can dismiss the belief that Becquerel planned to resume his experiments on that



Frederick Soddy



Harold Clayton Urey

Sunday: Meteorological records indicate that the day was less sunny than the average of the preceding four days.

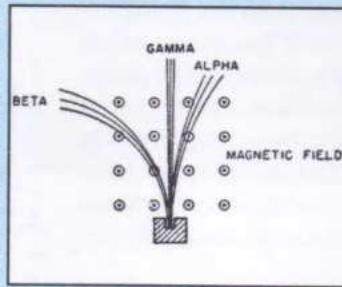
A better explanation for Becquerel's activity is that he wanted to have sufficient material to report at the next day's session of the academy. In previous experiments he had already found, or so he believed, that weak illumination triggered his crystals somewhat. Perhaps he thought that these newly prepared plates had been exposed to some diffuse daylight, if not a short period of sunlight, before he placed them in the dark drawer. Thus, even if he could not describe many additional experiments, he might furnish evidence of the connection between the intensity of the photographic image and the intensity and duration of phosphorescence.

That he found the plates as blackened as they would have been had the crystals phosphoresced continuously, and that he recognized the significance of his surprising observation, shows that the discovery of radioactivity was not simply a happy accident but also a product of genuine scientific talent. Becquerel's example is comforting to us: His genius emerged because he mistakenly believed in a connection between the penetrating rays and phosphorescence, and because he felt compelled to speak at the academy's meeting.

Though a major step, this event does not deserve to be called the discovery of radioactivity. **The discovery was a process, not an instantaneous occurrence,** for even at this point Becquerel had not sufficiently localized the phenomenon. No doubt Becquerel was a skilled and ingenious experimenter. However, in this early research he was not sufficiently meticulous to exclude extraneous influences and to see that some of his experimental results could bear more than one explanation. Thus, he often concluded that his experiments proved uranium rays to possess a certain physical property, only to have it shown later that the effect was due to another cause. **Indeed, his**

A page from the doctoral thesis of Marie Curie (1903)

Marie Curie's representation of alpha, beta and gamma rays in a magnetic field from a radioactive material placed in a narrow but deep cavity in a block of lead. The magnetic field is applied in a direction perpendicular to and out of the plane of the paper (In the absence of electric and magnetic fields, the rays would emerge as a thin vertical beam). The alpha particles, being positively charged and relatively heavy, would be slightly deflected to the right. The beta particles, being negatively charged and light, would be deviated to a greater extent to the left, whereas the gamma rays, carrying no electric charge, would not be deflected at all.



Alpha, Beta and Gamma Rays



Frédéric Joliot



Irène Joliot-Curie

investigations are particularly interesting for their many false trails, unreproducible results and misinterpreted effects.

Yet, his erroneous conclusions inexorably led him to further experiments, which often revealed the true nature of the phenomenon. This uneven progress is perhaps the most striking facet in the story of the discovery of radioactivity. But it must be understood that few scientists are able to avoid false trails.

He recognized that the next step must be to determine if any light at all was necessary to stimulate the crystals. Working in a dark room, he placed different minerals atop photographic plates in an opaque cardboard box. When developed five hours later, the plates showed strong images in samples in which the crystals lay directly on the emulsion and less

intense images in those in which the crystals were separated from the emulsion by sheets of aluminum and glass. Besides showing attenuation, the samples involving aluminum and glass also indicated that chemical action was not the explanation for the photographic smudges. Nor could the smudges result from the luminous radiation, because the phosphorescence of uranium salts is perceptible only for about 0.01 second, too short a time to expose a plate. Becquerel therefore suggested that phosphorescent bodies might give off an invisible emission that lasts much longer than the visible radiation.

Even before Röntgen's discovery of X-ray, it had become almost a standard procedure for scientists exploring various types of radiation to perform some of the experiments that Röntgen conducted to determine the properties of X-rays. Becquerel followed suit, as was only logical, because he

believed that his own rays were similar to X-rays. He only had to substitute a layer of uranium salts for a cathode-ray tube, for example, to show that the separate gold leaves of an electroscope were made to fall. Having established this electrical property, he next examined whether the rays were reflected and refracted — and he claimed they were. This conclusion, however, would be corrected by Rutherford some three years later.

Through March and the succeeding months of 1896, Becquerel found that those crystals kept in darkness retained their ability to expose a photographic plate. Surely, he felt, this was a remarkable example of long-lived phosphorescence.

But he was at a loss to explain the equally intense images produced by non-phosphorescent uranium sulfate.

This discovery led him on a new path of investigation. Since uranium nitrate ceases to luminesce when dissolved or melted in its water of crystallization, Becquerel, in darkness, heated a crystal in a sealed glass tube, protecting it even from the light of the alcohol flame. He then allowed it to recrystallize in darkness. All phosphorescence had been destroyed in this process, yet the salt still produced results on a photographic plate as strong as crystals exposed to light. Indeed, Becquerel admitted the anomalous behaviour of his samples: **All salts of uranium emitted the invisible radiation, while other phosphorescent bodies did not.** Finally, he tried a disk of pure uranium metal and found that it produced penetrating radiation three to four times as intense as that he had first seen with potassium uranyl sulfate. With this last announcement, on May 18, 1896, Becquerel's discovery of radioactivity was complete, although he continued with ionization studies of his penetrating radiation

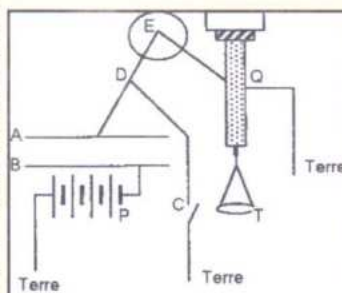


Marie and Pierre Curie

One more page from Marie Curie's doctoral thesis describing the set-up for measuring the ionisation power of "uranium rays"

The method employed consists in measuring the conductivity acquired by air under the action of radioactive bodies; this method possesses the advantage of being rapid and of furnishing figures which are comparable. The apparatus employed by me for the purpose consists essentially of a plate condenser, AB (Figure 1). The active body, finely powdered, is spread over the plate B, making the air between the plates a conductor. In order to measure the conductivity, the plate B is raised to a high potential by connecting it with one pole of a battery of small accumulators, P, of which the other pole is connected to earth. The plate A being maintained at the potential of the earth by the connection CD, an electric current is set up between the two plates. The potential of plate A is recorded by an electrometer, E. If the earth connection be broken at C, the plate A becomes charged, and this charge causes a deflection of the electrometer. The velocity of the deflection is proportional to the intensity of the current, and serves to measure the latter.

But a preferable method of measurement is that of compensating the charge of plate A, so as to cause no deflection of the electrometer. The charges in question are extremely weak; they may be compensated by means of a quartz electric balance, Q, one sheath of which is connected to plate A and other to the earth. The quartz lamina is subjected to known tension, produced by placing weights in a plate, T; the tension is produced progressively, and has the effect of generating progressively a known quantity of electricity during the time observed. The operation can be so regulated that, at each instant, there is compensation between the quantity of electricity that traverses the condenser and that of the opposite kind furnished by the quartz. In this way, the quantity of electricity passing through the condenser for a given time, i.e., the intensity of the current, can be measured in absolute units. The measurement is independent of the sensitiveness of the electrometer. (Source : Resonance, March 2001)



until the following spring. The new rays emerged from the element uranium, and with the implicit consequence that this was an atomic phenomenon, it may be said that the process of the discovery of radioactivity was essentially over. It was a process that took several months, notable for a number of conclusions that were later overturned!

Enter Marie and Pierre Curie

Marie Curie (1867-1934) leaped into this exciting new field. She soon discovered—at roughly the same time that Becquerel and Ernest Rutherford (1871-1937) did—that the radiations given off by uranium were composed of more than one type. Some

rays were bent one way by a magnetic field; others were bent another way. Rutherford named the positively charged rays alpha rays and the negatively charged ones beta rays (also known as alpha particles and beta particles). Exactly what these rays or particles were composed of, no one knew, but by 1898 Marie Curie suggested a name for these radiations — **radioactivity** — and that is the name that stuck. And in 1900, Paul Ulrich Villard discovered a third, unusually penetrating type of ray in radioactive radiation, one that did not bend at all in a magnetic field, which he named the gamma ray. The use of Greek letters to name these rays simply meant that their identity was unknown, as with the X in X-ray.

Marie Sklodowska, a Polish girl came to Paris at the Sorbonne University to study physics and mathematics and qualified with honours and distinction. She married Pierre Curie (1859-1906) of the same university in 1895. Pierre was already famous for his discovery of piezo electricity — a property shown by some crystals such as quartz of developing an electrical voltage between opposite ends when subjected to pressure. Marie Curie used the discovery of her husband (see Box) to measure



Enrico Fermi



Ernest Orlando Lawrence

radioactivity. Radioactive rays, like X-rays, ionized any gas they passed through (including air) making it capable of conducting electricity. She found that she could measure the current so conducted with a galvanometer and offset it with the potential of a crystal under pressure. By measuring the amount of pressure it took to balance the current, she could obtain the reading of the intensity of the radioactivity. She systematically tested radioactive salts and succeeded in showing that the degree of radioactivity was in proportion to

the amount of uranium in the radioactive material — thereby narrowing the source of the radioactivity in her samples down to uranium. Then in 1898 she made yet another find: the heavy element thorium was also radioactive.

It was already known that natural pitchblende is three or four times more active than uranium. Even more interesting is the fact that as Marie was working to separate uranium out of pitchblende, she found that the residues she produced had a much higher measurement of radioactivity than the uranium content alone could account for. Since the other minerals present in the ore were not radioactive, that could mean only one thing. Some other radioactive element, in

amounts too small to detect, must also be present!

By this time, Marie's work had developed so much potential that her husband Pierre joined her to help with the backbreaking, tedious work of crystallizing the elements from the ores. Though himself a fine scientist with a successful career, he set his own work aside and spent the remaining seven years of his life assisting her, recognizing both her extraordinary gifts as a scientist and the importance of the path she was following.

By July 1898 the two had succeeded. Working together, they had isolated a tiny amount of powder from the uranium,

The Law of Exponential Decay

Rutherford and Soddy observed in 1902 that the activity of a radioactive element was diminishing in an exponential (or logarithmic) manner. This implied that the rate of decay of an active species, that is, the number of atoms that disintegrate in a unit interval of time, is proportional to the total number of atoms of that species present at that time. If we suppose that at a given instant, there are N atoms present of a particular radioelement, the rate of disintegration is represented by dN/dt . Since the rate of disintegration is proportional to the total number of atoms N , the relationship between the two, following methods of simple calculus, can be written as

$$-dN/dt = \lambda N$$

where λ is a constant which Rutherford and Soddy called the "radioactive constant". It is now referred to as the disintegration constant or the decay constant of the element under consideration. The negative sign is due to the fact that the number of atoms of the radioactive element decreases with time, and hence the rate dN/dt is a negative quantity. The value of λ depends on the property of a given radioelement and is independent of the physical condition or state of chemical combination. In an equivalent exponential form, the above equation yields the result,

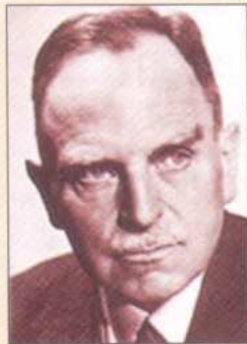
$$N_t = N_0 e^{-\lambda t}$$

where N_0 is the number of atoms present at any arbitrary zero time and N_t is the number remaining after the lapse of a further time t .

Another constant introduced by Rutherford in 1904, called the "half-life" is the time required for the radioactivity of a given amount of the element to decay to half its initial value, that is, when half of the N_0 atoms present at the zero time have decayed.



George de Hevesy



Otto Hahn

ore from the fraction that contained bismuth. It was a new element, never before detected, with a level of radioactivity 400 times higher than uranium. They named the new element **polonium**, after Marie's home country. But something still seemed strange. The ore still gave off more radioactivity even than the uranium and polonium combined could account for. There must still be something else. In December 1898 they found the answer: another, even more radioactive element obtained from the fraction that contained barium which was 900 times more active than uranium. This one they named **radium** (from Latin *radius* meaning ray).

Marie and Pierre could not really offer a good description of new element radium because the amount they were able to derive from the ore they had was so minuscule. They could measure its radiations, and Eugene Demarcay, a specialist in elemental line spectra, was able to provide the spectral characteristics. (Different elements give off different wavelengths of electromagnetic radiation or light, and these can be observed as discrete lines.) The next project was to produce



Sir John Douglas Cockcroft



Ernest Thomas Sinton Walton

a large enough quantity of radium that they could weigh it and measure it and see it. For this, they required a much bigger laboratory and financial resources which Sorbonne University could not provide. Undaunted by the circumstances, they set to work in a make-shift laboratory housed in a neighbouring abandoned court-yard. Through the courtesy of the Academy of Sciences, Vienna, they

managed at a reasonable cost, stacks of the required ore, pitchblende. The new laboratory was damp with a leaky glass roof, walls made of card-boards, a few tables knocked together as the work tables, a gas stove and no exhaust to remove noxious fumes arising from the work upto 20 kg of the ore every day. It was a back breaking, hazardous and almost suicidal adventure with no help coming from

any quarters. They spent their life savings to obtain large masses of waste ore from a nearby mine, and they began the monumental task. They spent four years, during which Marie lost 15 pounds, purifying and repurifying the ore into small amounts of radium, say, about 0.1 gram.

Marie Curie wrote her doctoral dissertation on the

Nobel Prizes awarded for work with radioactivity

The discovery of radioactivity brought about a revolution in our conceptual understanding of the matter and found applications in various fields of human activity. Here is a list of Nobel Prizes awarded for work with radioactivity.

1903	Antoine Henri Becquerel Pierre Curie	France France	in Physics for his discovery of spontaneous radioactivity in Physics for extraordinary services rendered by research on the radiation phenomena discovered by Professor Henri Becquerel
	Marie Curie	France	-do-
1904	Sir William Ramsay	Great Britain	in Chemistry for his services in the discovery of the inert gaseous elements in air, and his determination of their place in the periodic system
1908	Ernest Rutherford	Great Britain	in Chemistry for his investigations into the disintegration of the elements, and the chemistry of radioactive substances
1911	Marie Curie	France	in Chemistry for her services to the advancement of chemistry by the discovery of the elements radium and polonium, by the isolation of radium and the study of the nature and compounds of this remarkable element
1921	Frederick Soddy	Great Britain	in Chemistry for his contributions to our knowledge of the chemistry of radioactive substances, and his investigations into the origin and nature of isotopes
1934	Harold Clayton Urey	USA	in Chemistry for his discovery of heavy hydrogen
1935	Frédéric Joliot Irène Joliot-Curie	France France	in Chemistry in recognition of their synthesis of new radioactive elements
1938	Enrico Fermi	Italy	-do-
1939	Ernest Orlando Lawrence	USA	in Physics for his demonstrations of the existence of new radioactive elements produced by neutron irradiation, and for his related discovery of nuclear reactions brought about by slow neutrons
1943	George de Hevesy	Hungary	in Physics for the invention and development of the cyclotron and for results obtained with it, especially with regard to artificial radioactive elements in Chemistry for his work on the use of isotopes as tracers in the study of chemical processes
1944	Otto Hahn	Germany	in Chemistry for his discovery of the fission of heavy nuclei
1951	Sir John Douglas Cockcroft Ernest Thomas Sinton Walton	Great Britain Ireland	in Physics for their pioneering work on the transmutation of atomic nuclei by artificially accelerated atomic particles
1951	Edwin Mattison McMillan	USA	-do-
	Glenn Theodore Seaborg	USA	in Chemistry for their discoveries in the chemistry of the transuranium elements
1960	Willard Frank Libby	USA	-do-
			in Chemistry for his method to use Carbon-14 for age determination in archaeology, geology, geophysics, and other branches of science
1977	Rosalyn S. Yalow	USA	in Physiology or Medicine for the development of radioimmunoassays of peptide hormones"

subject in 1903, for which she, Pierre and Henri Becquerel shared the Nobel Prize in physics that year. In 1906, two years after receiving an appointment as professor of physics at the Sorbonne, Pierre Curie was run over by a horse-drawn truck at the age of 47. Marie was appointed in his place and she became the first woman to teach physics at the Sorbonne. Eight years after Pierre's death (1914), she received another Nobel for her discovery of two new elements, viz. Polonium and Radium, this time in chemistry and this time alone, Pierre – her partner and collaborator – no longer at her side. Years later, in 1935 to be precise, their daughter Irene and her husband Frederic Joliot-Curie – the second husband and wife team – were awarded the Nobel Prize in chemistry for their discovery of artificial radioactivity.

Parent Transforms Into Daughter

When Ernest Rutherford (1871-1937) arrived on scholarship at the Cavendish Laboratory from his native in New Zealand, he was 24 years old, a large dark haired man with strong opinion, plenty of ambition and no money. He was tireless in every quest and loved his role as one who put endless questions to nature. A consummate experimentalist, Rutherford had a talent for designing experiments and an uncanny ability to pick out one significant fact from a mass of confusing detail. Rutherford began by examining the Becquerel rays from uranium. Indeed, until about 1904, the emission from radioactive elements received far more attention than the emitters. Passage of the radiation through foils revealed one type that was easily absorbed and another with greater penetrating ability, which Rutherford named alpha and beta. In 1898, he took up the professorship of physics at the McGill University, Montreal, the authorities of which were convinced by Sir J.J. Thomson's testimonial that said, "I have never had a student with more enthusiasm or ability for original research than Mr. Rutherford". While in Cambridge, Rutherford's work in radioactivity was solely with uranium salts; in Montreal his first inclination was to examine thorium substances, since the activity of these substances had been noticed only a few months earlier. With passage of time, the number of radioelements had increased. Rutherford added several more to the list.

Rutherford was joined by Frederick Soddy (1877-1956) in May 1900. Soddy was the youngest son of a London merchant and was raised in the Calvinist tradition by his dominant half-sister. Before coming to McGill, he was engaged in independent chemical research at Oxford. Soddy joined with Rutherford in a series of investigations which produced the theoretical explanation of radioactivity.

Rutherford and Soddy proposed in 1902 the theory of "radioactive disintegration". They suggested that the atoms of radioelements, unlike those of inactive elements, undergo spontaneous disintegration with the emission of alpha or beta particles and the formation of atoms of new elements. In their words: "The disintegration of the atom (the parent) and the expulsion of a charged particle leaves behind a new system (the daughter) lighter than before and possessing physical and chemical properties quite different from those of the original parent element. The disintegration process once started, proceeds from stage to stage with measurable velocities in each case". **It appeared to Rutherford and Soddy that the activity was diminishing in what the mathematicians call an exponential (or logarithmic) manner.** This would mean that the rate of the decay of an active species, i.e. the number of atoms which disintegrate in a unit interval of time, is proportional to the total number of atoms of that species present at that time. Given the disintegration is taking place continuously, the number of atoms present is changing, and so also is the rate of disintegration (see Box: the law of exponential decay).



Edwin Mattison McMillan



Glenn Theodore Seaborg

In 1903, Soddy joined Sir William Ramsay (1852-1916), the great chemist, best known for the discovery of the inert gaseous elements. They experimentally confirmed the prediction of Rutherford and Soddy that disintegration of radium would continuously produce helium (or what was termed alpha particle earlier). It may be of interest to note that helium was first detected in the Sun way back

in 1868 by the French astronomer Pierre J. Janssen (1824-1907) while studying a total solar eclipse in the tobacco fields of Guntur, Andhra Pradesh. Yet another important contribution by Soddy was that of the existence of "isotopes". **It turned out that decay of several species of radioactive elements disintegrated to products which had identical chemical properties but they differed in their atomic weights.** Soddy called them isotopes (from the Greek, *iso*-same and *topos*-place). Today we know that such atoms have the same number of protons (i.e. the atomic number) but may have different number of neutrons. Further studies established that the phenomenon of radioactivity involved emission of alpha particles (helium nuclei), beta-rays (electrons) or gamma rays (electromagnetic radiation like X-rays, but of very short wave-length) transforming the "parent" nucleus into a "daughter" nucleus.

Alpha particles help Unravel the Structure of the Atom

The discovery of radioactivity shattered the age old ideas about the indivisibility of atoms. It also helped develop our understanding about their structure. In 1908, Rutherford

had returned to England, to the University of Manchester, where a young German physicist named Hans Geiger teamed up with him. Together, they bombarded thin pieces of gold foil with alpha particles from radium. Based on his discovery of the electron, Sir J.J. Thomson (1856-1940) had suggested in 1898 that atoms were spheres of positively charged matter with negatively charged electrons embedded in them, something like "raisin in poundcake". However, the results of the scattering of alpha particles from the gold atoms (1911) suggested that atoms consisted of a tiny positive nucleus with electrons circling outside it – somewhat similar to our solar system. Most of the atom's mass would be contained in the nucleus, and an equal number of negatively charged electrons would be found in motion around it. Rutherford's idea about the atomic nucleus was indeed extra-ordinary, for which he earned the title "the Newton of physics".



Willard Frank Libby

Making Stable Atoms Unstable

In 1934, Irene Joliot Curie (1897-1956) and Frederic Joliot (1900-1958) discovered "artificial" radioactivity. In the course of a study of the effect of alpha particles from the naturally occurring radioelement polonium (discovered by Irene's parents Marie and Pierre Curie), on the nuclei of aluminium in particular, Irene and Frederic found that after the source of alpha particles was removed, the aluminium foil on which alpha particles were irradiated became radioactive and followed the exponential law of radioactive decay described earlier. The same phenomenon was observed with boron and magnesium as well. The "transmutation" of boron, magnesium and aluminium by alpha particles had given birth to new radioelements! These new elements not found in nature, would then be the radioactive species which decays with the emission of a positron (i.e. a positive electron) or what is also called beta decay. An alpha particle bombarded on an aluminium atom would transform it into an isotope of phosphorus atom, which being unstable, would in turn emit a positron to transform into a stable, naturally occurring isotope of silicon. The discovery of artificial radioactivity opened up altogether a new field. Man-made radioisotopes found applications in industry, biology, health, agriculture, archaeology and many other areas of human activity.

Legacy of radioactivity

The discovery of radioactivity evolved into the study of nuclear physics almost a century ago. The applications that have flowed from the work of Becquerel and others are primarily nuclear medicine, nuclear reactors, and nuclear weapons. In the field of medicine, diagnostic procedures such as tracer techniques, therapeutic applications like the treatment of cancer by radiation, have proved to be highly

valuable. For example, gamma rays from an isotope of cobalt are used in the treatment of cancer. The radioactivity of isotopes of elements used as tracers enables the scientists to locate them, even inside a living body. One isotope of carbon, known as carbon-14 (i.e. with 6 protons and neutrons), has a sufficiently long half-life (that is, the time in which half of the initial number of carbon-14 atoms would decay in a given sample containing this isotope). It is present in the bones and woods. When an archaeologist digs them up, a comparison of radioactivity of carbon-14 present in them with that in the living specimens allows him to estimate their age.

But, the future of the nuclear reactors and weapons appears to be problematic. This is so, because the nuclear reactors are always fraught with possible meltdowns (remember the Three Mile Island and the Chernobyl disasters?), and the skyrocketing costs. Nuclear weapons, too, seem to share similar concern. No doubt, after a hundred years of the discovery of radioactivity, we now face even newer challenges through its all pervading influence.



Rosalyn Yalow

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Radioactivity: Glossary

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

Alpha particle : Charged particles emitted from a radioactive atom. Each charged particle consists of two protons and two neutrons.

Atom : This is the smallest unit of an element. It contains a nucleus with neutrons and protons, surrounded by orbiting electrons.

Atomic mass : The mass of an atom usually expressed as atomic mass unit (amu).

Beta particle : (often designated beta rays) Charged particles emitted from a radioactive atom. These particles are identical except for their charge. The charge is classified as positive (positron) or negative (electrons or negatron).

Carbon-14 : A naturally occurring radio isotope of carbon having a mass number of 14 and half-life 5780 years. Used in Radio carbon dating for determination of age of ancient objects.

Cathode rays : Electrons originating at the cathodes of gaseous discharge devices. These electrons are often focused in a small area such as a tube and intensified on a surface. The most familiar form of a cathode-ray tube is the television picture tube.

Conductivity : The ratio of electric current to the electric field in a material. Passage of electric charge which can occur in a variety of ways such as passage of electrons or ionized atoms.

Curie : A unit of radioactivity, defined as that quantity of any radioactive nuclide which has $3,700 \times 10^{10}$ disintegrations per second.

Deuterium : The isotope of element hydrogen with one neutron and one proton in the nucleus.

Electrons : A negative charged particle that orbits the nucleus of an atom. It is lighter in weight than a proton or neutron.

Elements : An element is a substance made up of atoms with the same atomic number. 75% of the elements are metals and the others are nonmetals. A few examples are oxygen, iron, gold, chlorine, and uranium.

Fluorescence : Electrons absorb energetic radiation (for example ultraviolet light) raising an electron to a higher "Bohr" orbit. The energized electron soon drops down in a series of steps through lower energy states and in the process releases photons at lower energy states corresponding to visible light. The bright color occurs because the photons are concentrated in a narrow range of wavelengths.

Geiger counter : A radiation counter that uses a Geiger-Müller tube in appropriate circuits to detect and count ionizing particles, each particle crossing the tube produces ionization of gas in the tube which is roughly independent of the particle's nature and energy resulting in a uniform discharge across the tube. Also known as Geiger-Müller Counter.

Geiger-Müller tube : A radiation-counter tube usually consisting of a gas-filled cylindrical metal chamber containing a fine-wire anode at its axis. Also known as Geiger-Müller Counter tube.

Half-life : The period of time it takes for half the nuclei of a radioactive element to undergo decay to another nuclear form.

Heavy water : A compound of hydrogen and oxygen containing a higher proportion of the hydrogen isotope deuterium than does naturally occurring water.

Ionization chamber : A particle detector which measures the ionization produced in the gas filling the chamber by the fast-moving charged particles as they pass through.

Isotope : An atom having the same number of protons in its nucleus as other varieties of the element but has a different number of neutrons.

Luminescence : An umbrella term denoting either fluorescence or phosphorescence.

Magnetic field : All magnetic fields are created by moving electric charge. The single moving electron around a nucleus is a tiny electric current. These orbiting electrons create magnetic fields and their net effect is to provide the atom with a magnetic field.

Neutron : A particle with no charge that is located in the nucleus of an atom.

Nuclear physics : A branch of physics that includes the study of the nuclei of atoms, their interactions with each other, and with constituent particles.

Nucleus : The central part of every atom that contains protons and neutrons.

Nuclide : A species of atom characterized by the number of protons, number of neutrons, and energy content in the nucleus, or alternatively by the atomic number, mass number, and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable life time. Also known as nuclear species.

Pitchblende : A brown to black fine grained, amorphous, variety of uraninite which has a dull luster and contains small quantities of uranium. Also called pitch ore or nasturan.

Phosphorescence : Luminescence that persists after a light source has been removed. Materials such as phosphors or phosphorogens are activated

from a light source to emit the light in the form of photons of light.

Polonium : A naturally radioactive chemical element, Po, atomic number 84. It is used in photographic film to reduce the static charge.

Proton : A positively charged particle that is located in the nucleus of an atom.

Radiation effects : The harmful effects of ionizing radiation on humans and other animals, such as production of cancer, cataracts, and radiation ulcers, loss of hair, reddening of skin, sterilization, nausea, etc.

Radioactive contaminant : A radioactive material which has spread to places where it may harm persons, spoil experiments, or make products or equipment unsuitable or unsafe for consumption by living beings, or for some specific purpose.

Radioactive decay : The spontaneous transformation of a nuclide into one or more different nuclides, accompanied by either the emission of particles from the nucleus, nuclear capture or ejection of electrons. Also known as radioactive transformation, radioactive disintegration or radioactivity.

Radioactive element : An element all of whose isotopes spontaneously transforms into one or more different nuclides, giving off various types of radiations, examples include uranium, radium and thorium.

Radioactive emanation : A radioactive gas given off by certain radioactive elements, all of these gases are isotopes of the element radon. Also known as emanation.

Radioactive waste : Liquid, solid, or gaseous waste resulting from mining of radioactive ore, production of reactor fuel materials, reactor operations, processing of irradiated reactor fuels, and from use of radioactive materials in research, industry, and medicine.

Radioactive waste disposal : The disposal of waste radioactive materials and equipment contaminated by radiation: the two basic disposal methods are concentration for burial underground or in the sea, and dilution for controlled dispersion: reprocessing of reactor fuel is a major source of radioactive waste.

Radioactivity : A behaviour of an element in which nuclei are undergoing change and emitting particles. This occurs naturally in approximately fifty elements. It can be produced artificially.

Radioactivity equilibrium : A condition which may arise in the decay of a radioactive parent with short-lived descendants, in which the ratio of the activity of a parent to that of a descendant remains constant.

Radiochemistry : Area of chemistry concerned with the study of radioactive substances.

Radio isotope : An isotope which exhibits radioactivity. Also known as radioactive isotope.

Radio isotope assay : An analytical technique including procedures for separating and reproducibly measuring a radioactive tracer.

Radiometric dating : A technique for measuring the age of an object or sample of material by determining the ratio of the concentration of a radio isotope to that of a stable isotope in it: for example, the ratio of carbon-14 to carbon-12 reveals the approximate age of bones, pieces of wood, and other archaeological specimens. Also known as radioactive age determination or radiogenic dating.

Radium : A naturally radioactive chemical element, Ra, that has an atomic number 88. It is used as a source of neutrons and alpha particles.

Radon : A gaseous radioactive element, Rn, produced by radioactive decay of radium. It has 28 known isotopes, three of which occur in nature. Radon does not readily react with other chemicals.

Thorium : A naturally radioactive chemical element, Th, that has an atomic number 90. It is used as fuel in nuclear reactors called the "breeder" reactors. Thorium is available in India on the Kerala coast in the form of monzile sand.

Tracer : A foreign substance, usually radioactive, that is mixed with or attached to a given substance so the distribution or location of the latter can later be determined; used to trace chemical behaviour of a natural element in an organism. Also known as tracer element.

Transmutation : A nuclear process in which one nuclide is transformed into the nuclide of a different element.

Tritium : The hydrogen isotope having mass number 3. It is one form of heavy hydrogen.

Uranium : A chemical element, U, that has an atomic number 92. It reacts with nearly all nonmetals and is used as fuel for nuclear reactors, available in the mineral form at Jeduguda in Bihar.

X-rays : Invisible electromagnetic radiation with wavelengths shorter than visible light. X-rays are produced when high energy charged particles collide with other charged particles or with atoms.

• • •

Development of Cometary Thought (Part-II)

□ Subodh Mahanti

On the other side,
Incensed with indignation, Satan stood
Unterrified, and like a comet burned,
That fires the length of Ophiuchus huge,
In the arctic sky, and from his horrid hair,
Shakes pestilence and war
John Milton (1608-74) in *Paradise Lost*.

As it was mentioned in the first part of this article, the first work on the comet of 1577 to be published was that of Mastlin, whose observations showed the comet to be a celestial object. Mastlin assumed that the comet moved on a circular path (the true orbit for this comet was parabolic) slightly outside the orbit of Venus. Though Mastlin's observations indicated the celestial nature of the comet but he himself believed it to be a new and horrible prodigy. He discussed its portents in detail. Mastlin believed that while the mysterious nature of the comet was beyond the comprehension of human but once they are created (by God) they became celestial phenomena and could be treated accordingly.

Nicolaus Copernicus (1473-1543) observed the comet of 1533. He wrote a brief treatise about this but it was published posthumously in 1878. In his magnum opus, *De revolutionibus* (1543), Copernicus mentioned comet only once. He also considered comets as terrestrial objects and from their motion he concluded that the highest region of the air follow celestial motion. He wrote :

"It is said — that the highest region of the air follows the celestial motion. This is demonstrated by those stars that suddenly appear—I mean those stars that the Greeks called *cometae* or *poganiae*. The highest region is considered their place of generation, and just like other stars they also rise and set. We can say that this part of the air is deprived of the terrestrial motion because of its great distance from the Earth".

Tycho Brahe (1546-1601), whose systematic and meticulous observational data enabled Johannes Kepler to formulate his planetary laws, wrote a treatise in German on the comet of 1577, which he first noticed on November 13, 1577, and continued to observe for the next two and a half months. This important treatise though written in 1578

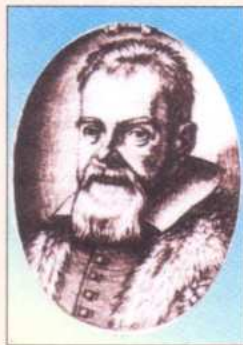
was first published by Johann Louis Emil Dreyer (1852-1926) in 1922. Before this it existed only in the form of two manuscripts. This was translated into English in 1979 by J.R. Christianson. Tycho rejected the Aristotelian notion of comets by stating that the comet was certainly above the Moon's sphere. However, Tycho also believed in astrological implications of a comet. He wrote : "Although this comet appeared in the west and will realise its greatest significance in those lands that lie toward the west, yet it will also spew its venom over those lands that lie eastward in the north, for its tail swept thence". Tycho was the first to suggest that a comet's orbit may not be circular.

At the beginning of seventeenth century the telescope was first used for cometary observation. Though this was a significant forward step in the cometary science its development was eclipsed by the backward views on comet held by Galileo and Kepler, the most influential astronomers



Nicolaus Copernicus

of the period. Johannes Kepler (1571-1630), the founder of celestial mechanics, firmly believed in the straight line motion of comets. Kepler's ideas on comets consisted of a basic Ptolemaic framework interwoven with his own brand of mysticism. Kepler believed in the ominous significance of comets. According to him the cometary influence was due to a disruption in the sympathy of nature. According to Kepler comets were spontaneously created from impurities or fatty globules in the ether. Kepler also observed that at the time of the creation of the comet, a special spirit and intelligence was also formed to guide it. But then



Galileo Galilei



Tycho Brahe



Johannes Kepler

on the physical nature of comet, Kepler was much ahead compared to his contemporaries. On the cometary tail formation Kepler wrote : "The head is like a conglobulate nebula and somewhat transparent; the train or beard is an effluvium from the head, expelled through the rays of the

Sun into the opposed zone and in its continued effusion the head is finally exhausted and consumed so that the tail represents the death of the head".

Galileo Galilei, (1564-1642), the founder of experimental physics, pointed out that comets were not periodic. He believed that comets originated from the Earth — cloud of vapour moving vertically upward from the Earth's surface at a uniform rate and in a rectilinear fashion. Galileo

ridiculed Tycho's observation on comets.

Although the authoritative views of Galileo and Kepler had adverse effect on the contemporary cometary ideas but notable scientists like Willebrod Snel (1580-1626), Pierre Gassendi (1529-1655), Seth Ward (1617-1689) and Rene du Perron Descartes (1596-1650) advanced their enlightened viewpoints.

Before Newton essentially solved the dynamical behavior of the comets, two schools of cometary thought existed. One school constituted by Jean-Dominique Cassini (1625-1712), Andrien Auzout (1622-91), Pierre Petit (Ca. 1594-1677), Giovanni Alfonso Borelli (1608-79) and others believed that comets were permanent celestial objects and hence they had circular or at least close orbits. Johannes Hevelius (1611-87), Christian Huygens (1629-95) and others who constituted second school took comets as transitory objects and their intrinsic motions as uniform and rectilinear. According to Aristotle transitory objects have rectilinear paths and permanent bodies have close orbits. And almost everybody believed Aristotle and so to decide the orbit of the comets (rectilinear or close circular) it was to decide whether comets were transitory or permanent bodies. Newton, based on his three observations of the comet of 1680 and also drawing upon the ideas of Kepler, Johannes Hevelius (1611-87), Robert Hooke (1635-1702) and John Flamsteed (1646-1719) developed a technique for

determining the parabolic orbit of the comet. Using his orbit determination technique, he successfully accommodated the observations of Flamsteed and others. Newton argued that comets were actually seen in the region interior to Saturn's orbit. While suggesting this he was perhaps influenced by Descartes's suggestion that comets were located beyond Saturn. Newton suggested that the nucleus of a comet is a compact object whose light is derived from the Sun. While not dismissing Kepler's notion of tail particles carried along by the action of solar rays, he suggested his own theory for the formation of the tail of the comet of 1680. He suggested that it was a very fine vapour which cometary nucleus emitted after being heated near perihelion. While Newton successfully solved the dynamical behavior of the comets (which was subsequently refined) the physical nature of comets remained obscure. Using the modified Newton's method Halley computed parabolic orbits for 24 well-observed comets and he predicted the return of the comet of 1607

Edmond Halley's ideas that comets were bound to the

Sun and return after very long periods of time were expressed in his 1705 work but for the next two hundred years there was no definite clue about the birthplace of the comets. He had also demonstrated that none of 24 comets for which he computed orbits had obvious hyperbolic motions.



Frontispiece from Johannes Hevelius' *Cometographia*. Three allegorical figures showing the Aristotelian idea that comets are sublunar (left), the Keplerian notion that comets move on straight line paths (right) and the idea of Johannes Hevelius (centre) that comets originate in the atmospheres of Jupiter and Saturn and move about the Sun on a curved trajectory

In 1755 Immanuel Kant (1724-1804), the German philosopher, published his cosmology. Kant envisaged the solar system as a part of a vast system of stars making up the Galaxy. According to Kant comets also formed with the planets from the solar nebula. But the comets formed at the much greater distances from the Sun. As the comets formed in the remotest regions of the solar system they were composed of the lightest particles and this also explained their vapour and tails. The importance of Kant's work lies in the fact that he anticipated, though in a qualitative way, the nebular theory of Pierre Laplace and after it is referred to as the Kant-Laplace theory. Unfortunately in the eighteenth century Kant's book was not available as the many of the freshly printed copies were impounded after the printer went bankrupt. Laplace in his *Exposition of the System of the World* published in 1796 proposed his nebular hypothesis. Laplace argued that the solar system evolved from the rotating mass of a gas that had condensed to form the Sun. The rotating solar nebula flattened and formed rings of material, as it contracted which eventually coalesced into planets. In

a similar fashion the extended rotating atmospheres of protoplanets themselves formed rings of material that eventually became their satellite system. However, Laplace's nebular theory soon ran into trouble with the discovery of retrograde orbits in the solar system.



Christian Huygens (portrait kept in the Paris observatory)

Sir Frederick William Herschel (1738-1822) who expressed his cometary ideas in 1808 and 1812 (and which were published in the *Philosophical Transactions of the Royal Society of London*), considered comets objects of interstellar origin. While the comets travelled through interstellar space they collected nebulous matter and transferred it to stars they passed, thus replenishing the fuel used in making light. As the

comets grew older they lost most of their nebulous matter and produced much shorter tails. As the comets pass from one stellar system to another they become more consolidated and dense. This way a comet loses all of its nebulous materials and form a planet.

The extremely eccentric and highly inclined orbits of comets could not be fitted into Laplacian hypothesis. Taking

note of Heinrich Olbers' (1758-1840) idea that the asteroids' originated from a fragmented planet between Mars and Jupiter, Comte Joseph Louis Lagrange (1736-1813) decided to investigate the conditions under which explosive events on the planets would lead to produce bodies travelling on a comet-like orbit around the Sun. He came up with formula giving the velocity required to eject a body into a comet-like orbit at any given inclination. Lagrange thought bodies could be ejected from the planet's surface due to extreme pressure from the hot interior.

In the eighteenth century scientists focussed their attention on the dynamics of comets. The techniques for computing cometary orbits, originally initiated by Isaac Newton and Edmond Halley, were successfully developed by Rudger J. Boscovic (1711-87), Leonahrd Euler (1703-83), Achille-Pierre-Dionis du Séjour (1734-94), Pierre-Simon Marquis de Laplace (1749-1827), Heinrich Wilhelm Matthias Olbers (1758-1840) and Carl Friedrich Gauss (1777-1855). The general belief of the astronomers was that the comets were solid, permanent, celestial bodies whose motion could be followed by the application of the same Newtonian mechanics as applied in the case of planets.

The nineteenth century astronomers also concentrated their attention on the dynamics of comets. After the return of comet Halley the next successfully predicted return was comet Encke named after its discoverer Johann Franz Encke (17980-1865), in 1822, followed by comet Biela named after its discoverer Wilhelm von Biela (1782-1856) in 1832. The orbital size and period of Encke's comet found to be decreasing with time, thus it deviated from purely Newtonian motion. Only a force acting against its orbital motion can decrease the period of a comet. Encke believed that the opposing force resulted from the friction of comet moving through a resisting medium surrounding the Sun. So while Encke's comet revealed a dynamic behaviour which was inconsistent with Newtonian mechanics, the comet Biela which disappeared after disintegration showed that comets were not permanent celestial bodies. The comet Biela was observed to split into two pieces in 1847. The double comet reappeared in 1852. The connection between cometary debris and meteor shower became obvious in the nineteenth century.

Friedrich Wilhelm Bessel (1784-1846) based on his observations of sunward jets or emanations from the nucleus of Comet Halley in 1835 suggested that reactive force acting on the comet itself could reduce its period with time.



Leonhard Euler as he appeared on a Swiss 10 Franc note

Laplace expressed his views on the origin of comet in 1813. Like Herschel, Laplace also subscribed to the theory of interstellar origin of comets. According to Laplace comets existed in an interstellar field, outside the sphere of influence of the Sun. Laplace calculated the sphere of influence of the Sun as 100,000AU. The velocities of comets may range from zero to infinity, each velocity being equally probable. As the field of interstellar comets moved pass, the Sun attracted comets whose velocity was nearly zero. Most of the comets would reach the Sun on nearly parabolic orbits but in few cases the size of cometary orbits may decrease because of planetary perturbations or some resisting medium. Thus Laplace had anticipated the mechanism by

which near parabolic path of comet become short-period orbits. Laplace did not take into account the Sun's motion with respect to the interstellar stars and comets. In 1783 William Herschel had shown that the stars are in motion with respect to one another. Herschel not only assumed that the Sun had a so-called proper motion with respect to other stars, but he also correctly anticipated that the Sun was moving towards a point in the constellation Hercules.

Ernst Julius Opik (1893-1985), the Estonian astronomer, based on his study of the orbits and perturbations of comets predicted in 1932 that comets would remain bound to the Sun at distance of one million AU. Opik's work demonstrated the feasibility that comets may reside in a cloud extending to interstellar distances and even then they would bound to the Sun inspite of the passing stars.



Heinrich Matthias Olbers

The English astronomer Raymond A. Lyttleton published one of the few theories put forward during the period 1948-51 that attempted how and where comets formed. Lyttleton argued that comets were formed when the Sun passed through an interstellar cloud of dust. Sergey Vsekhsvyatskij, the Russian astronomer, resurrected Lagrange's hypothesis. In 1930 and 1931 Vsekhsvyazskij put forward the idea that major planets were the source of comets. Then in 1951 Vsekhsvyatskij argued that the satellite systems of the planets mainly of Jupiter as the better sources of comets. This is because the escape velocity from those smaller satellites is only a fraction of that is required to escape Jupiter. According to him while short period comets continue to form but long period comets formed millions of years ago during cataclysmic eruptions from the outer, major planets.

In 1948 Adrianus Jan Jspers Van Woerkom brought out the inconsistencies with the picture of interstellar comets being captured into long-period comets by repeated interaction of Jupiter. He discussed the objections to the

interstellar origin of comets in detail and while doing so he casually pointed out that a cloud of comets moving permanently with the Sun may be free from some of the objections raised by him.

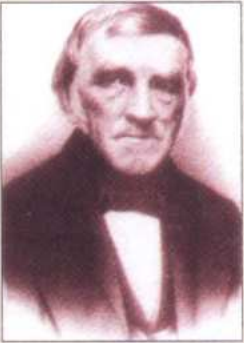
In 1950 the Dutch astronomer Jan Hendrik Oort (1900-92) in a paper entitled 'The structure of the cloud of comets surrounding the solar system and a hypothesis concerning its origin' and published in the Bulletin of the Astronomical Institute of the Netherlands concluded that the observed distribution of cometary orbits could be explained by assuming a cometary cloud of some one hundred

ninety billions comets which orbits the Sun at a distance of between 50,000 to 150,000 AU. The cloud is not free from the effects of passing stars. In 1951, that is one year after the publication of Oort's hypothesis about the formation of comets, Gerard Peter R. Kuiper (1905-73) pointed out that comets were likely to be composed of icy materials but if comets formed as close to the Sun as the asteroid belt then ice could not be a chief constituent of comets. He was of the view that comets formed between 35 and 50 AU from the Sun and they were the condensation products of the outer solar system. Oort's work brought nearly universal agreement about the source, if not the origin of comets.

Here we summaries the ideas on different aspects of comets that are generally accepted.



Pierre-Simon Marquis de Laplace



Johann Franz Encke

- A comet is a small body composed of ice and dust. The cometary ice is frozen water, plus some methane (CH_4), carbon monoxide (CO), and carbon dioxide (CO_2). Other Carbon containing compounds detected in comets are : formaldehyde, (H_2CO), hydrogen cyanide (HCN) and methyl cyanide (CH_3CN).
- The nucleus of the comet, a small solid body, composed of frozen water and gas plus embedded dusty material at the centre of a comet's head contains essentially all the mass of the comet. It is the source of activity in a comet. When very distant from the Sun, a comet's nucleus is inert. However, within 3-4 AU solar heating leads to gas sublimation and production first of a coma, then a tail
- The part of a comet containing dust and gas released from the comet's nucleus is called cometary tail. Tails are always directed away from the Sun. Tails do not normally develop until a comet is within about 2AU of the Sun. Comet tails have two



Wilhelm Von Biela

components. The Type I or gas tails consist of ionised gas carried away from the head of the comet by the solar wind. Dust tails can reach 10^8 km or more in length. The Type II or dust tails consist of micrometre size solid particles which are pushed away from the head by radiation pressure on hyperbolic trajectories. Dust tails are usually shorter but still can reach 10^7 km.



Carl Friedrich Gauss

The envelop of gas and dust that surrounds the solid nucleus of an active comet is called cometary coma. The coma often appears as tear drop being largely shaped by the solar wind flowing around the comet. The coma form when the comet is within 3-4AU of the Sun. Near perihelion the coma may be 100,000 km wide.

- Comets were formed in the region of Uranus and Neptune. They were formed as the icy debris from the outer planet formation process. They are believed to be left over from the formation of the outer planets.
- The primordial comets, which are on near-circular orbits, comprise the Kuiper belt.



Friedrich Wilhelm Bessel

Long-term planetary perturbations increase the eccentricities of the orbits of the primordial comets.

When their perihelia are raised well beyond Neptune's orbit the comets are placed in the inner comet cloud which may begin just beyond the orbit of Neptune and merge into the Oort cloud. Once the comets are in the inner comet cloud they are immune from planetary perturbations.

Some inner cloud comets are eventually lifted into the outer Oort cloud by continued galactic plane perturbations that is the perturbation due to an unequal gravitational attraction of the galactic disk on the Sun and a particular comet.

From the outer Oort cloud comets can be striped away by galactic tide perturbations and close stellar encounters. In fact it is assumed that more than 50 per cent of the comets present at the time of formation of the Solar System have been lost from the Sun's sphere. It is assumed that presently there are approximately 10^{11} to 10^{12} comets in the outer Oort cloud.

The inner Oort cloud of comets or simply the inner cloud of comets begins with a flattened disk of comets just beyond the planetary region and it extends to approximately 10,000 AU. The long axis of the outer Oort cloud which is directed towards the centre of the galaxy is roughly 200,000 AU from end to end. The shorter axis is approximately 160,000 AU wide.

- There is no definite idea about the relative positions of the inner and outer comet clouds. In fact there is little more than hints that the inner cloud exists at all.
- It is likely that the comet belt, as well as the inner and outer comet clouds have merged to form one continuous distribution of comets extending beyond Neptune's orbit to the very edge of the Solar System.
- Comets thrust towards the planetary system from the outer Oort cloud have long-periods or nearly parabolic orbits.
- The source of short-period comets may be a flat belt of comets just beyond the planetary system.
- Currently around 900 comets are known of which 75% are long periods comets.
- No comet with definite hyperbolic orbit has been observed. It tends to indicate that comets are not now arriving from interstellar space.
- Observed long-period comets do not evolve into observed short-period comets and the reverse is also not true.
- During their passage through the inner Solar System comets can have their orbits altered by gravitational influence of the planets notably Jupiter. One spectacular example was comet Shoemaker Levy, which hit Jupiter in 1994.
- The ultimate fate of the observed comet is not well understood. It can not be said with certainty that the comets eventually end up in inactive asteroid like bodies. Many long-period comet are hurled into interstellar space and some short-period comets disintegrate into dusty debris.



Immanuel Kant



Ernst Julius Opik



Jan H. Oort

Today we know a great deal of comets but there are many things about them yet to be known. To quote Lucius Annaeus Seneca (4B.C.-AD 65).

"The day will yet come when posterity will be amazed that we remain ignorant of things that will to them seem so plain. Men will some day be able to demonstrate in what regions comets have their paths, why their course is so far removed from the other stars, what is their size and constitution. Let us be satisfied with what we have discovered and leave a little truth for our descendents to find out'.

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Letter to the Editor

I have been reading with much interest your valuable Monthly Newsletter of Vigyan Prasara "DREAM 2047". I have had several copies of the article on Earthquakes photocopied and have circulated them to several teachers and students. The article is so well written. Every reader has not only enjoyed reading it but has learnt much from it.

The second article I have enjoyed is an Bhaba Centre for Science Education. Our Trust runs tutorial classes for 750 children of Government Schools (education slums) located in the most down trodden areas of Mysore City. The results of this supplementary education has proved most gratifying. We have not only found blossoms in the dust but the school attendance has gone up from 29% to 89%. We have made every effort to raise the knowledge base of our teachers but have helped them to create a vision to generate creativity among children.

Dr. H.A.B. Parpia

Formerly Director of Central Food Technological Research Institute, Mysore
cwhabp@bgl.vsnl.nen.in

