AUSTRALIAN ALMANAC

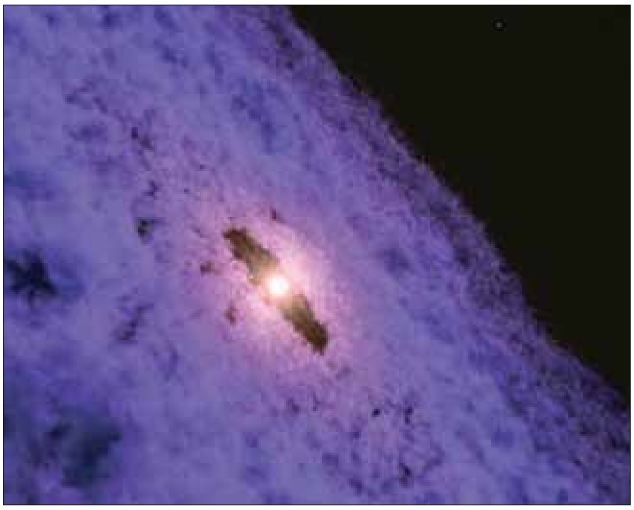
An introduction to Cosmic radiation:

What is radiation?

Part 1

Below we publish part 1 of an excerpt from "Science for Legislators: Is the Fear of Radiation Constitutional?" by Laurence Hecht, Summer 2009 21st Century Science and Technology magazine. For the sincere student of science, who may not have had the benefit/disadvantage of a formal scientific education, Larry's paper is an excellent introduction to the concepts of radiation and atomic particles of which a basic understanding is essential to any exploration of the field of cosmic rays.

A recent burst of high-energy X-rays and gamma rays from the Southern Hemisphere constellation Norma, should serve to remind us that the current widespread fear of anything to do with radiation is much out of harmony with those *Laws of Nature and of Nature's God,* famously invoked in our Declaration of Independence. As the rights defined in that document stand, along with our Constitution, as twin pillars of our nation's fundamental law, the question arises: Should not the incitement of such fears against a natural and necessary phenomenon, with the clear intent of misleading a frightened populace down a path of national self-destruction, rise to the level of a Constitutional violation? However that point may ultimately be decided at law, our urgent aim here is to aid that present majority of misinformed policymakers and citizens in general, to learn the truth about nuclear radiation, and the wonderful power for good that it holds out for mankind.



An expanding halo formed by X-rays coming from the neutron star SGR J1550-5418, as captured by the Swift satellite's XRay Telescope (XRT). The halo forms as X-rays from the brightest flares scattered off of intervening dust clouds. For a video of the event, see http://science.nasa.gov/headlines/y2009/10feb_sgr.htm

What makes this task urgent is the present, rapidly accelerating economic collapse. Denial of the clear immediate and future benefits to be derived from knowledge of the atomic and subatomic realms (a denial due in significant part to the ignorance and prejudice of the audience we now address), constitutes a serious and immediate threat to the survival of our own people as well as those of other nations[1]. Unless those widespread fears and prejudices respecting nuclear radiation are soon reversed, the threat to human civilisation as a whole will be catastrophic. The currently popular proposals to increase our reliance upon so-called renewable energy sources, such as wind and solar, demonstrate a level of incompetence respecting the elementary principles of physical economy, such as to doom to inevitable failure whatever other well-intentioned, even courageous, measures might be forthcoming from the present Administration. Motivated by such urgent considerations as these, we are convinced that the serious reader, even without prior familiarity with the subject matter, can gain a working grasp of the essentials of these matters, and overcome those ill-founded prejudices he or she may have previously accepted without examination.

Now, to the galaxy. As detected by NASA's Swift X-ray Telescope, a small object about 30,000 light years distant, lying within our Milky Way galaxy in the direction of the constellation Norma, began a series of forceful eruptions on Jan. 22, at times producing over 100 X-ray flares in as little as 20 minutes. The most intense of these were estimated to contain more total energy than the Sun produces in 20 years! In addition, the new Fermi Gamma-ray Space Telescope has detected 95 bursts of radiation from the same object in the gamma ray band of the spectrum, the same general type of radiation that comes from radioactive objects on Earth. The object, located about 30,000 light years away, is of a type known as a neutron star.

Despite the large numbers, there is nothing that unusual about these events. Bursts of radiation of this power, and far greater, are normal occurrences in the universe. Much of it ends up in our bodies. Another flux of radiation known as cosmic rays (we shall explain and distinguish the different common types of radiation shortly), is bombarding Earth's atmosphere continuously. This type of radiation consists mostly of very energetic protons (hydrogen nuclei), as well as the nuclei of heavier elements, all the way up the periodic table. The determination of the content of cosmic rays was an important focus of physics for the first half of the 20th Century.

Colliding with atoms in our atmosphere, the cosmic rays transform the elements in a way similar to a particle accelerator, creating many radioactive byproducts. Included among these is carbon-14, a radioactive isotope of the element carbon which is found in every molecule of our bodies. Green plants respire this naturally produced carbon-14, and use it to grow. When we eat vegetables, or the meat of animals that have eaten them, and when we breathe fresh air, we take this carbon-14 into our bodies. The carbon-14 present within the average human body is responsible for more than 3,000 radioactive disintegrations every second.[2]

Radioactive Elements in the Human Body

Radioactive Isotope	Half-Life (years)	Isotope Mass in the Body (grams)	Element Mass in the Body (grams)	Activity within the Body (Disintegrations/sec)
Potassium 40	1.26×10^{9}	0.0165	140	4,440
Carbon 14	5,715	1.9×10^{-9}	16,000	3,080
Rubidium 87	4.9×10^{10}	0.18	0.68	600
Lead 210	22.3	5.4×10^{-10}	0.12	15
Tritium (^{3}H)	12.43	2×10^{-14}	7,000	7
Uranium 238	4.46×10^{9}	1×10^{-4}	1×10^{-4}	3 - 5
Radium 228	5.76	4.6×10^{-14}	3.6×10^{-11}	5
Radium 226	1,620	3.6×10^{-11}	3.6×10^{-11}	3

Source: R. E. Rowland, "The Radioactivity of the Normal Adult Body," http://www.rerowland.com/BodyActivity.htm

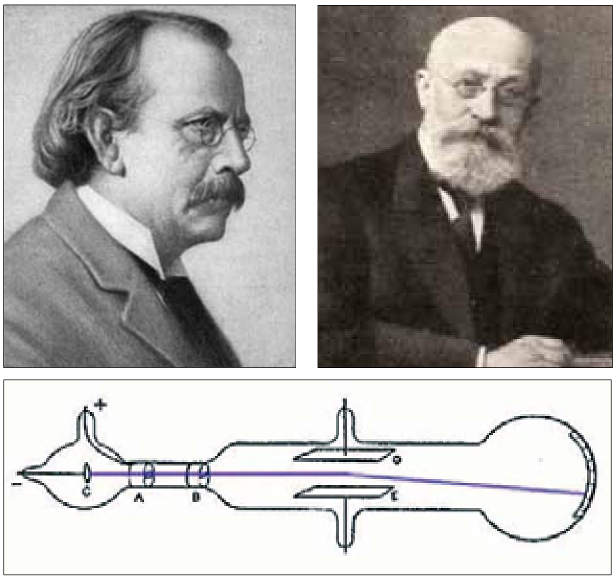
A conservative estimate of the radioactivity in the human body, showing the isotopes responsible for about 8,000 disintegrations per second. Other sources estimate a total of about 15,000 disintegrations per second.

Another naturally occurring isotope, potassium-40, is the most abundant radioactive substance in our bodies, responsible for 4,440 *disintegrations per second* inside the average adult. Potassium is an essential mineral for cell function, and with every gram of it that we consume, about 1/10 milligram is the radioactive isotope. We obtain potassium from eating fruits, vegetables, and meats. Potatoes, figs, chicken, hamburgers, citrus fruits, and bananas are all high in potassium-40.

If every radioactive disintegration represents a cancer threat, as so many people have been led to believe, then perhaps we should consider a legislative ban on cosmic rays and orange juice. Or, might it be wiser to first know a bit more about the whole subject?

1. What Is Radioactivity? Discovery of the Electron and Proton

We shall begin by attempting to understand what we mean by such terms as *radioactivity, isotope, proton, gamma ray, etc.* But first a warning. Most of these and other terms we shall employ here are, properly, not things, but concepts. We may, at times, form visual images of them, but we must remember that not only are they not generally perceptible to our senses, but even if they were, our conception of what they are would never be comprehended by a verbal definition. The same methodological warning applies here as to the inevitable failure of any effort to interpret *natural law* in the manner of the strict constructionist. An infinite number of readings of the Constitution will never yield the intent of the framers, if it is not known through other means. The same applies to the terms employed by science. A true understanding of them can only be gotten by studying and repeating the path of experimental discovery. No deep understanding of science is ever attained by any other means.



British scientist J.J. Thomson (left) showed a cathode ray was deflected by electrical plates (bottom), indicating a negative charge. Eugen Goldstein (right) discovered canal rays in the cathode ray tube.

And so we proceed. We shall start then with the experimental discovery of the *electron* and *proton*. A central focus of scientific investigations in the 1880s and 1890s was the behavior of gases contained within glass tubes, from which most of the air had been sucked out, and an electric potential (voltage) excited between metal wires placed at opposite ends of the tube. Depending on the gas or gases left in the tube, a beautiful, fluorescent glow, ranging from coral pink, to pale green, to a deep indigo blue, is observed. The ray seems to originate from the negatively charged electrode (*cathode*) at one end of the tube, hence the name cathode rays. However, despite its resemblance to a light beam, it turned out that the colorful ray, unlike an ordinary light beam, could be deflected by a magnet, or by strongly electrified plates placed parallel to the walls of the tube.

A very strange phenomenon is observed when small holes are drilled in the cathode, and it is placed in the center rather than at one end of the tube. It then occurs that in addition to the cathode rays, which pass toward the positive electrode, other rays shoot out from the back side of the cathode, like fiery sparks. Because they seemed to originate from the little holes (channels) drilled in the cathode, these were called *Kanalstrahlen* by Eugen Goldstein, who discovered them in his laboratory at the Berlin Observatory in 1886. The term was translated, somewhat over-literally, into English as canal rays, though channel rays might have been more accurate.

It turned out that, like the cathode rays, the *canal rays* could also be deflected, although in precisely the opposite direction, by a sufficiently strong magnetic or electric field. It was this common property that proved the key to the initial unmasking of both the cathode and canal rays. For in 1896, the assumption was made by J.J. Thomson at Cambridge University's Cavendish Laboratory, that the cathode rays, unlike light beams, actually consisted of tiny electrified particles of negative charge. Wilhelm Wien in Aachen found similar results, and, in 1898, Wien showed that the canal rays could be considered as positively charged electrical particles.

By measuring the amount of deflection produced by an electric or magnetic field of given strength upon the two different types of rays, it was possible to compare the bending of the ray to that of a larger body of known charge and mass experiencing the same amount of electric or magnetic force. After all the measurements and calculations were done, it turned out that the *cathode ray* possessed a mass more than a thousand times smaller than that of the least massive *canal ray* (today we know it more exactly as 1,836 times smaller). The least massive canal ray, it turned out, was that produced when the gas in the tube was hydrogen, and by this and other evidence, *canal rays* came to be seen as electrified versions of ordinary chemical atoms (today called *positive ions*).[3] The hydrogen ion thus became known as the elementary particle of positive electricity, or proton. The *cathode ray* particle, discovered first, became known as the elementary particle of negative electricity, or *electron*.[4]

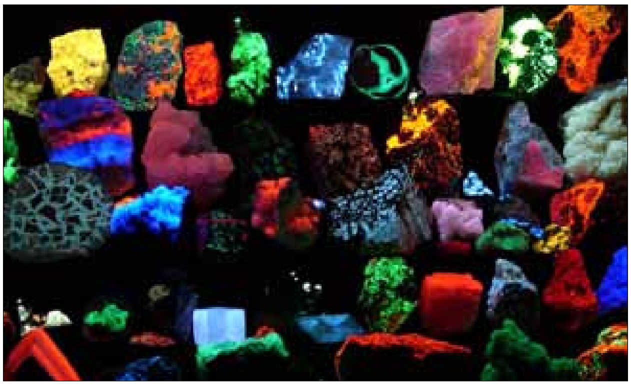
From X-rays to Radioactivity

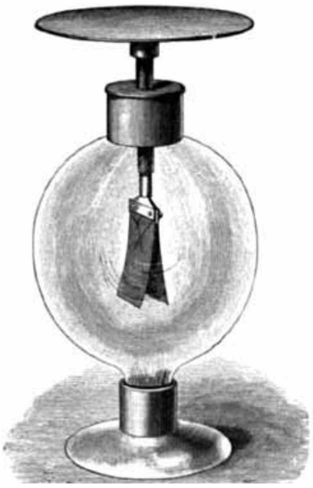
Slightly before the results just reported, a professor of physics at the University of Würzburg made an astounding discovery of both theoretical and immediate practical significance. While experimenting with various types of gas discharge tubes in November of 1895, Wilhelm Roentgen noticed that a screen painted with fluorescent material would light up when the tube was activated. A similar phenomenon had been noted by other observers back to 1875, but Roentgen was the first to thoroughly pursue it. He soon discovered that the rays could penetrate many materials. At the end of two weeks of intensive experimentation, eating and sleeping in his laboratory, he produced the world's first X-ray picture. It was an image of his wife's hand, showing the bones of the fingers and wedding ring.

Roentgen's discovery was quickly made known worldwide. Just weeks later, physicians in Dartmouth, New Hampshire, used photographs taken with an X-ray tube to set the broken arm of a boy. Roentgen also discovered in this early period that lead served as an effective shield against the radiation, and he used sheets of this metal to protect himself from direct exposure. Roentgen summarized his discoveries in a paper in 1896 calling them "Radiation X," or *X-rays*. They are also known as Roentgen-rays.

Wilhelm Roentgen and the first ever X-ray, of his wife's hand with wedding ring.

Excited by Roentgen's discovery, just months later Henri Becquerel in Paris discovered what was soon to become known as *radioactivity*. He found it while looking for something else. Henri Becquerel was the third member of his family to occupy the chair of physics at the Museum of Natural History in Paris. His father, Alexandre-Edmond Becquerel, had been the leading authority on the phenomenon of *luminescence*, the property of certain materials to glow in the dark, and Henri himself had written 20 scholarly papers on the topic. Observing an experimental apparatus for producing X-rays which was exhibited at a weekly meeting of the French Academy of Sciences, Becquerel thought that the unusual radiation might emanate from a part of the glass vacuum tube which glowed when struck by the cathode rays. He suspected that luminescence might be a prerequisite for the production of X-rays, and he thus began to examine various luminescent materials for X-ray production. Many rocks and minerals can be made to glow in the dark after exposure to sunlight, and others, by immediate exposure to ultraviolet light. Today these phenomena are termed *phosphorescence* when the light emission is delayed, and *fluorescence* when it occurs immediately; *luminescence* is the general term.





A collection of various flourescent minerals under UV-A, UV-B, and UV-C light (top). Henri Bacquerel (above). A gold leaf electroscope (right).

Among the materials Becquerel examined for X-ray production, were rocks containing a uranium compound known to be phosphorescent. His procedure was to expose the uranium rocks to sunlight, then wrap them in black paper, place them on top of a photographic plate, and store them in a dark place for a time. If the photographic plate became exposed, he might assume that *X-rays* were somehow being generated, and penetrating through the black wrapping paper onto the photographic plate. Sometimes he placed a coin or other object next to the rock sample, in order to see if its outline would be imaged on the photograph. Samples of the uranium-bearing mineral potassium uranyl sulfate showed an exceptional capability to penetrate the black paper and leave an image on the photograph.

By chance, a spell of bad weather caused him to leave some of the rocks in a drawer, wrapped in black paper next to photographic plates, but not exposed to sunlight. When his curiosity provoked him to develop these, he found that they too showed a photographic image. Yet the rocks had not been stimulated to emission by previous exposure to sunlight.

Within a few months, Becquerel had become certain that previous exposure to sunlight was not required to cause the rocks to radiate. Furthermore, even samples of uranium compounds that did not exhibit any phosphorescence were able to produce an image on the photographic plates. Finally, experimenting with a sample of nearly pure uranium metal, he found the power to expose photographs was greatly increased. That was convincing proof that the radiations were not related to luminescence, but were a property of the element uranium.

It was now late Spring of the year 1896. News of Becquerel's experiments travelled fast, and created a great conundrum among chemists and physicists. Where did the power of the rays come from? In phosphorescence, the energy for the light production was seen as coming from an external source of energy, the Sun. As long as the power to produce light seemed to derive from prior exposure to sunlight, the principle of the conservation of energy was not violated. The energy of the sunlight was stored in the rock and emitted later. Once that hypothesis was dashed, some new cause had to be found for the energy of the rays. Some began to suspect that some new power existed within the interior of matter. Perhaps the concept of the atom, the indivisible substance which had served chemistry so well for nearly a century, needed to be modified.

Some bold minds began already to suspect that perhaps the atom itself consisted of smaller parts. Perhaps the ordinary chemical means would not allow access to these, but by some other means not yet known, their powers could be released. But this was only speculation. Such a bold suggestion would first have to be proven experimentally.

It was not yet clear if the *Becquerel rays*, as they had come to be called, were *X-rays*, or some new kind of radiation. One of Becquerel's experiments had been to observe the effect of the uranium rays on an instrument known as an *electroscope*. Two thin strips of gold leaf, placed in contact with each other, are allowed to hang from a metallic clip which is placed within a glass container. Electrical contact is maintained from the metallic clip to a conductive ball or disk outside the container. (See drawing.) When an electrically charged object is put in contact with the ball, the charge is communicated to the gold leaf, and the two strips, being of the same charge, repel each other, rising into the air in opposite directions like spreading wings.

Over time, the charge dissipates, and the strips fall back to the vertical position. When the air in the surrounding atmosphere is more conductive, the charge will dissipate faster, causing the strips of gold leaf to droop sooner. Roentgen had already shown that his X-rays had the power to discharge the electroscope, causing the gold leaf to droop. When Becquerel brought a uranium sample near to a charged electroscope, it too caused a discharge. Was the effect caused by X-rays, somehow produced within the uranium ore, or was it by some other power?

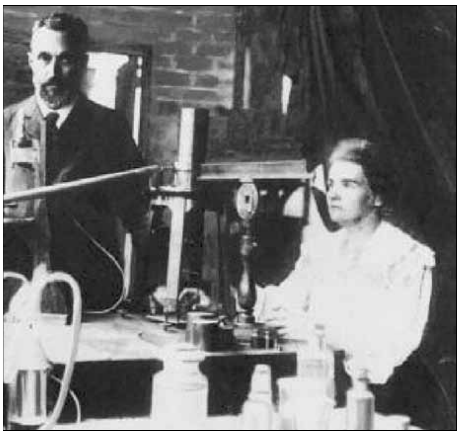
Two New Elements

It was going to take further investigation to determine the nature of the new *Becquerel rays*. By the Fall of 1896, another investigator, a young woman by the name of Marie Sklodowska Curie, had entered the search. Recently married to the physicist Pierre Curie, theirs was a marriage of true minds, built on an intellectual and scientific collaboration conjoined with the deepest love. She conceived the idea of applying a device, which her husband and his brother had invented 15 years earlier for another purpose, to the investigation of the *Becquerel rays*. The *electroscope* is capable only of a rough measurement of the strength of charge by the degree of deflection of the gold leaves. The ability of different substances to discharge the electroscope, known as the ionizing power, could be roughly estimated by the length of time it took for a sample held at a certain distance to accomplish this. However, with the new device known as the *Curie electrometer*, the measurement of the ionizing power of any material could be precisely measured.

By now the two Curies were partners in the quest to understand the curious powers of uranium. Pierre and Marie Curie soon began experiments with samples of uranium ore (pitchblende), most of them obtained from mines in Bohemia, then part of Austria. While still supposing that the effect might be due to the "Radiation X" identified by Roentgen, they soon came upon a crucial anomaly. Being accomplished chemists, the Curies tried experiments to remove the uranium from the pitchblende ore. By subjecting samples of the ore to acid, they could cause much of the uranium to precipitate out as a salt. When samples of the ore with most of the uranium removed were placed in the measuring device, a remarkable thing happened. They showed more ionizing power than the ore samples containing uranium.

The Curies then isolated pure uranium metal from the ore and compared its activity. The ore samples with the uranium removed showed an ionizing power three to four times greater than the pure uranium. They became convinced that a new element, many times more active than uranium, must be present in the ore. To find it, they began a process of chemical separation. Aided by the Curie electrometer, they were able to separate out the portions of the ore which showed greatest ionizing power. By June 1898, they had separated a substance with 300 times the activity of uranium. They supposed they had found a new element which they named polonium, after Marie Skłodowska-Curie's embattled Poland. There was still some doubt as to whether it was a new element. It had not been isolated yet, but always appeared together with the already known element bismuth. But continued work finally showed the polonium to be distinct.

By December of 1898, the Curies had separated another product from the Bohemian ores, which also showed strong ionizing power. This one appeared in combination with the known element barium, and behaved chemically much like barium. Again, it had not yet been isolated in a pure form, and there was uncertainty as to whether it was a distinct element. Spectral analysis showed mostly the spectral lines characteristic of barium, but their friend, the skilled spectroscopist Eugène-Anatole Demarçay, had detected a very faint indication of another line not seen before.[5] On the basis of the chemical and spectral evidence, and its strong ionizing power, the Curies supposed it to be a new element, which fit in the empty space in the second column (Group II) of Mendeleyev's periodic table, below barium. They named it radium.


Pierre and Marie Curie at work in their lab.


A sample of pitchblende, the ore containing uranium.


The Curie electrometer, invented by Pierre and his brother Jacques.

The Curies now dedicated themselves to obtaining pure samples of these new elements. It took four years of dedicated labor, working in an unheated shed behind the University of Paris, to isolate the first sample of pure radium. Polonium proved even more difficult. While they were engaged in this effort, research was under way in other locations, sparked by the earlier papers of Becquerel, and by the Curies' announcement of two new elements with such extraordinary powers.

Some time in the course of these discoveries, it was felt that a new name ought to be given for the unusual ionizing power of these new elements. Marie Curie proposed the term *radioactivity*.

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1. Such potential benefits include, but are not limited to: 1) nuclear-powered generation of electricity and industrial process heat; 2) production of hydrogenbased fuels for replacement of petroleum; 3) production of fresh water by nuclear- powered desalination; 4) nuclear medicine; 5) development of new materials and industrial processes through nuclear research; 6) research and development up to and through the engineering stage of more advanced forms of nuclear energy, including fission-fusion hybrids, and thermonuclear fusion devices of both the inertial and magnetic containment design; 7) research into anomalous phenomena in the subatomic domain, including but not limited to (a) "cold" fusion (low energy nuclear reactions); (b) anomalous coherence phenomena, including self-organizing phenomena in plasma; (c) non-linear spectroscopy, generally; 8) research into insufficiently explored regions of the biotic domain, including, but not limited to (a) biophoton emission and other manifestations of the relationship of life to the electromagnetic spectrum; (b) isotopic anomalies related to living matter; 9) matter/anti-matter reactions.

2. R.E. Rowland, "The Radioactivity of the Normal Adult Body," http://www.rerowland.com/BodyActivity.htm

3. Remarkably, the tiny mass of the hydrogen atom was already known, thanks to the hypothesis put forward by Count Amedeo Avogadro in 1811, that equal volumes of gases all possess the same number of molecules, and the work of the Austrian physical chemist Josef Loschmidt in calculating in 1865 what this number actually was.

4. The assumption made by the Cambridge scientists, that the cathode rays consisted of particles, was seriously doubted at first by most researchers. However, the experimental results could not be disputed, and the concept of *electron mass* took hold. Later it turned out that there had been some basis for the hesitations, for it was demonstrated in 1926 that the electron did indeed behave like a light wave, in being capable of refraction by a crystal and exhibiting interference patterns, and so the paradox of wave vs. particle was reborn, never yet to be put to rest.

This experimental proof carried out by Davisson and Germer at the Bell Laboratories was confirmation of a hypothesis proposed several years earlier by Count Louis de Broglie. Later it was seen that not only the electron, but also the heavier particles, such as the proton and neutron, showed wavelike characteristics, and from then on had to be thought of in a somewhat ambiguous way as particle/waves.

5. Upon heating, each chemical element shows a characteristic color. Most people have seen the green color produced in a flame by a copper-bottomed pot. If the light produced when the element is heated be passed through a prism, it is dispersed into a band of color, just as sunlight passing through a prism forms a rainbow. Within the colorful band, known as a spectrum, certain sharp and diffuse lines appear. Bunsen and Kirchoff began work in 1858 which established a means for identifying each element by its flame spectrum.