The Nuclear Era

Man Controls the Atom

by Liona Fan-Chiang

Reach for the stars, and you may find one right here on Earth. If you do find one, it will have been created by man.

The nuclear age began more than a century ago, yet it still hovers in an adolescent stage. The prospect of full control of the atom, both by having taken control of splitting up or splintering large atoms (fission), and by the intentional merging of small atoms (fusion), was born not long after. After more than a century, one would have expected a society which had already graduated from performing small-scale experimentation on, and application of, matter and energy conversion, to having full reign over the natural and artificial transformation of material, the associated electromagnetic effects, and much more, with more precision than that performed by the sun and life. Yet, something unnatural intervened. Anti-human policies, including know-nothing, anti-radiation environmentalism, exercised political and cultural control to stunt the advance of human evolution.

Here, we tell the short story of how the nuclear age was born, from investigations of naturally occurring phenomena, to the human attempt to master those processes and recreate them ourselves, in order to perhaps make clear where we are today and what it means to create states of matter and energy entirely natural, but yet entirely new.

Natural Transformations

Energy from Matter

Our experience with the constant flux of all material began with the discovery of radiation in the late 1800s and early 1900s.

Wilhelm Röntgen noticed in 1895 that when electricity was passed through a tube from which almost all the gas had been evacuated, a green glow appeared at one end of the tube. More astonishing was that an accompanying light, invisible to the eye but visible to his photographic plate, was detected. This light was so penetrating that even when passed through black paper or thin metal, it could be detected by his photographic plates.

Henri Becquerel, excited by Röntgen's discovery, began investigating. He had been studying fluorescent materials[1] intensely and thought this glow might be related to the mysterious fluorescing property of some materials. Choosing uranium potassium sulfate, a fluorescent substance, he indeed detected Röntgen's penetrating rays.

Events turned, however, when on a cloudy day, Becquerel's sample no longer fluoresced. Thought to be use-

Wilhelm Röntgen

Wilhelm Röntgen's first X-ray image, his wife's hand, December 22, 1895.

1. Fluorescent materials emit light after exposure to sunlight. It was found that they also emit light after exposure to radium. In WWI, fluorescent material excited by radium was used for gun sights in order to aim in the dark.

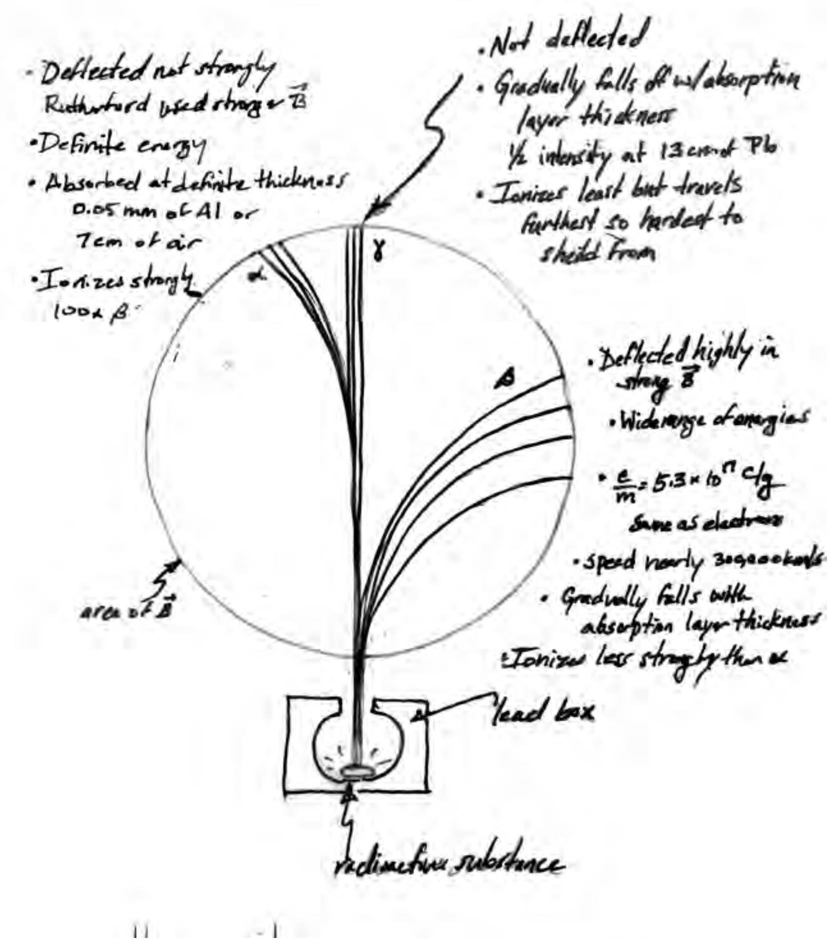
less for his studies, he tossed the sample, photographic plate, and black paper in a drawer for several days. When he came back to it, discouraged, he developed the plate out of curiosity. Surprisingly, though the sample received no light and had not fluoresced, the clear imprint of the sample appeared brightly on the photographic plate.

Becquerel's rays, unlike Röntgen's, had not been stimulated: they seemed to emanate ceaselessly from the rock with no input at all. How could this be? Where was the energy coming from? Did conservation of energy cease to be a law?

To see what kind of force might have been at play, the uranium salt was subjected to the most demanding obstacle course: extreme pressures, extreme heats, magnetic fields, strong chemical reagents—nothing seemed to affect the rapidity of this constant efflux.

Marie Curie tested a tremendous number of substances, searching for other materials that emit Becquerel rays. She found that thorium salts also emit these Becquerel rays. The more salt, the more emanation. Becquerel's earlier discovery that the air around the emanation becomes a conductor of electricity greatly aided this search.

Marie Curie and her husband Pierre also isolated two other previously unknown elements, polonium and radium, the latter of which radiates one million times more than uranium.



With a strong magnetic field, radiation was able to be split into three different rays with very different properties. They received their names, alpha, beta and gamma, from their different penetration depths. Alpha particles are charged opposite to beta particles, while gamma rays are not charged at all. Alpha particles came out with the same energy, while the energy of beta particles varied widely.

Although the rate of radiation being emitted seemed not to be influenced by any force, Curie did notice that under strong magnetic fields, the rays, once emitted from the sample, could be affected, slightly deflecting and separating out into two beams: one that deflected in a strong magnetic field, and one that did not. When Ernest Rutherford applied an even stronger field, the undeflected beam again split into two: resulting in a beam that was undeflected and one that curved the opposite direction with respect to the first.

The characteristics of the first deflected beam resembled electrons in mass and charge, while the other deflected beam seemed to be a much heavier and oppositely charged matter. This posed another challenge. Was matter being continually emitted as well? Was matter being born? Where were these radiations being produced?

An Element Born

Röntgen made a bold hypothesis that part of the radiation was the helium ion, a hypothesis that was reinforced when helium was found in radioactive mines and not in others. This rule was so durable that the existence of helium was used to detect radioactive materials.[2]

2. Rutherford and Royds came up with an experiment to test this hypothesis. They placed a sample of radium inside of a tube which was thin enough to let alpha particles, the less deflected radiation, through. This tube was then placed in another tube with electrodes at each end and from which all the air was evacuated. When voltage was first applied to the electrodes, since there was no gas inside of the tube to conduct electricity, no current flowed. Two days later, current was able to flow in the larger tube, indicating now the presence of some gas. The characteristic glow of the gas betrayed its nature to be helium, confirming the hypothesis that alpha particles were actually the helium

In addition, already in 1899 the Curies had noticed that the air around thorium and radium was also radioactive. To confirm this observation, Rutherford and Soddy passed this radium air by fluorescent willemite.[3] The willemite glowed until the radium air was let out, at which point fluorescence stopped.

When current was passed through this radium air, the air glowed not only the characteristic colors of oxygen and nitrogen, but also of helium.

Most remarkably, during the course of their experiments, the radium air gradually lost its radioactivity. This was the first time that radioactivity from a radioactive material had been observed to decrease, and even drop below detectable levels. Experiments on other materials confirmed that they too had finite emission rates, but decreased much more gradually.[4]

The question still remained: If helium was being emitted from radium, what was becoming of the radium? Could it be staying the same, which would mean that helium was born from nowhere, or was the helium being fragmented off, thus leaving an element two steps down on the periodic table from radium? This product would be element 86, an as-yet undiscovered element whose existence was forecasted by Mendeleev.

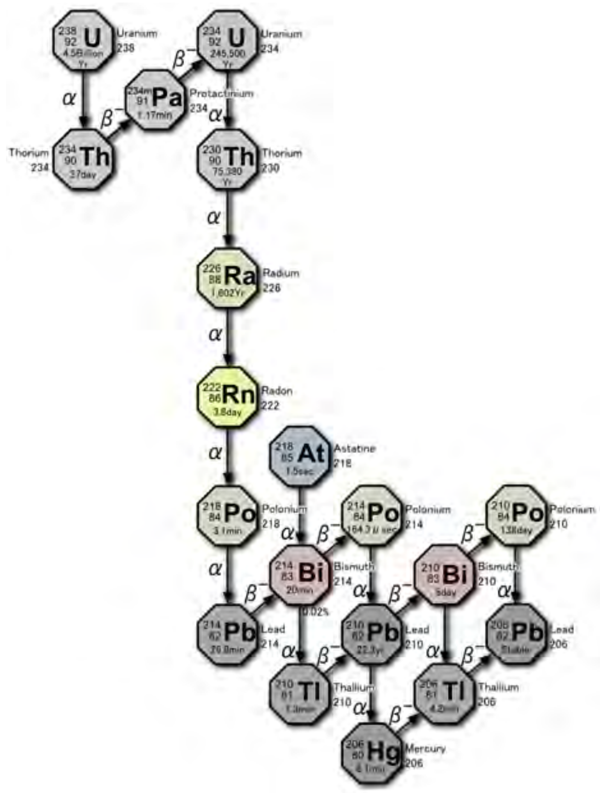
When the radioactive radium emanation was carefully weighed by Ramsay and Gray (1910), they found an atomic weight of 222 atomic units, never before observed. Its chemical inertness placed the element in the column of the periodic table of elements occupied by xenon, placing the emanation squarely at element 86. It was subsequently named radon, to signify that it is a product of radium and has chemical properties of noble gases such as xenon, neon, and argon.

This resolved the challenge of the possibility of infinite quantities of mass. Matter was not just being emitted from a fixed material. Rather, radioactivity results from a process of a transformation of matter. Moreover, the process of transformation, its rate and type, was unique to each type of material, indicating that this transformative property is as much, if not more, an intrinsic property of matter as mass or chemical potential.

Artificial Transformations

In 1919, Rutherford accomplished and observed the first artificial disintegration of atomic nuclei. After many scattering experiements, in which he bombarded many different materials with alpha particles, he postulated that atoms have solid nuclei. He even arrived at a general formula that related the scattering angle of alpha particles to the charge of the target nucleus. Among these experiments, however, he found that when the target was a lighter element, his generalized equation did not work, in such a way that he was led to hypothesize that perhaps the projectiles were coming too close to the nucleus. He further hypothesized that this circumstance might potentially be used to splinter the nucleus.

He used the fastest bullets around: alpha particles traveling at 19,200 km/s emitted from what was then known as Radium C,[5] a product of radium. Several elements disintegrated into lighter elements when bombarded, but none heavier than potassium. Some elements lighter than potassium such as helium, lithium, beryllium, carbon, and oxygen also did not budge.



Wikipedia user Tosaka

Nuclei have unique characteristic transformation properties. Each has its own unique transformation rate, and its own way of transforming. The transformations form families of related nuclei, one of which is represented here. Even after people had discovered that thorium-D (ThD), a decay product of thorium-232, was just another isotope of lead-208, it was still called ThD. Why is that? As a product of thorium, it has more kinship with thorium than its chemically identical cousin, lead-207.

nucleus.

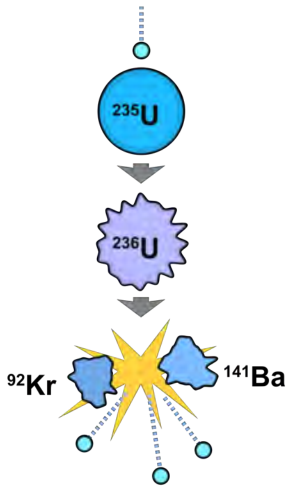
3. Like the sun, radium rays can excite fluorescent materials. Microscopic amounts of radium make screens of zinc sulfide, barium platinocyanide, willemite etc., glow in the dark.

4. Since the decrease was found to be asymptotic, radioactive lifespans are measured in half-lives, the time it takes for half the sample to decay, and therefore only half the emission rate to be measured.

5. Bismuth-214.

Enrico Fermi also began transforming materials artificially. He took the heaviest known element, uranium, and attempted to create a new, even heavier element. He got a surprise. When he bombarded uranium with neutron radiation, the sample began to exhibit a new, complex radiation consisting of beta rays. It took Fermi over five years to disentangle the complex radiation data, and he found at least four different decay rates

Fermi found three isotopes of uranium, that is, three different weights of the same element uranium. These isotopes had exactly the same chemical properties, differing by weight, and, as was to be discovered, by nuclear transformation properties. Half lives of 10 seconds, 40 seconds, 13 minutes, and 90 minutes were measured. Fermi expected that at least one of these products must be element 93, the next higher element after uranium. None of the elements from 86-92 had half lives in the range of 13-90 minutes, so Fermi assumed that the products must be elements with atomic number of 93 or above.



When uranium-235 is bombarded by a neutron, it fissions, or splits apart. Besides its fission fragments, it also releases neutrons, stimulating other uranium atoms to fission, etc., resulting eventually in a self-sustained chain reaction, and a continuous energy source, until so much of fuel has been converted that the reaction is no longer self-sustaining.

Lise Meitner, Otto Hahn, and Fritz Strassman were convinced the problem was more complicated. The curve of intensity of attenuation of radiation was different at different times, indicating that other radioactive substances were arising sometime *after* irradiation. Their experiments showed nine half lives, with the highest element being element 97. After meticulous separation, they found three parallel series of transformation.

Something else was also occurring. Some of the radiation products were chemically indistinguishable from lanthanum (element 57) and barium (56). These were elements much too small to have been a disintegrated product of uranium (92), a process which was assumed to end at lead (element 82). Or so they thought.

Lise Meitner alone came up with the bold hypothesis that these products were in fact not results of simple addition and subtraction, such as in a decay or bombardment process, but of *division*. She hypothesized that if the atom had actually split nearly in half, then there should be two corresponding elements which belong in the region of the periodic table at nearly half the atomic number of uranium, and that then there should be a corresponding energy release equivalent to the mass lost that can be calculated from Einstein's $E=mc^2$.

U-236	Mass = 236.0455 u
Ba-141	Mass = 140.9144 u
Kr-92	Mass = 91.9261 u
3 neutrons	Mass = 1.0087 u

Mass Defect = U-236 − Ba-141 − Kr-92 − 3 neutrons = 0.1790 u

$$E = mc^2 = \text{extra energy released}$$
$$= 0.1790\ \text{u} \times 1.66\times10^{-27}\ \text{kg/u} \times (2.998\times10^{8}\ \text{m/s})^2$$
$$= 2.67\times10^{-11}\ \text{J extra energy}$$

If fission had in fact occurred, if her hypothesis was correct, a specific amount of extra energy should be detected in the reaction. This was indeed confirmed.

Other fission products were subsequently found, including technetium (43), ruthenium (44), and rhodium (45). Over 100 papers on fission were published in the following year. Afterward, many others, from germanium (35) to samarium (62) were found in the fission products.

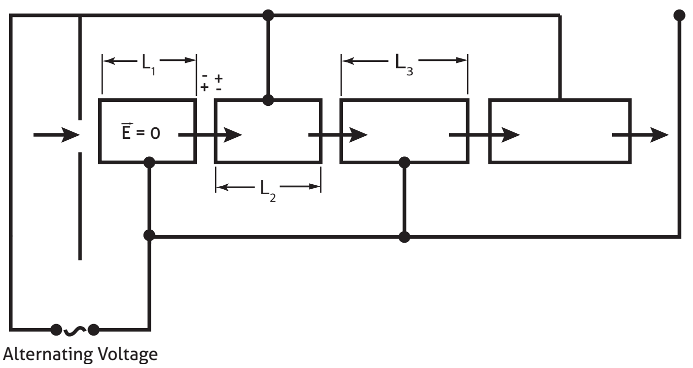
A whole new domain of the elements became potentially open to control by society. New isotopes and new elements were found among the fragments. In addition, the idea to harness the relatively large amounts of energy released by the atom soon became obvious and inevitable.

By looking at the mass excess of each element, it was hypothesized that the fusing together of the nuclei of very light atoms (such as hydrogen) would produce new atoms that would weigh less than the total weight of the original constituents, thus releasing energy in the process. By using the lightest ones, such as hydrogen, helium, etc., as in deuterium-helium-3 fusion, the energy released could be an order of magnitude more than from fission.

Particle Accelerators

In order to have more control and more power to transform the atom, artificially energized particles, much more energetic than those available naturally, were sought after.

The first successful attempt to transform nuclei by accelerating protons was by Cockcroft and Walton. Since



A linear particle accelerator which uses alternating current. Inside of the tubes there is no electric field so the particle does not accelerate. Once it exits the tubes, the particle experiences an electric potential which accelerates it across the gap into the next tube.

the proton is charged, it can be influenced and accelerated by a voltage difference. By placing several voltage differences in succession, they were able to accelerate a particle to 800,000eV.[6] At this potential, a proton would be accelerated to about 12,000 km/s.

This room-sized apparatus, however, reached its limit. The next step was advanced by Lauritsen, who came up with a way to use AC voltage. Alternating current was much easier to supply than DC voltage, and this apparatus greatly improved particle acceleration.

Terminals are connected to the AC voltage supply. The space inside the tubes is electric field free: in them, the particle stops accelerating and travels at whatever speed it entered.

The difficulty this apparatus introduced was that as the particle accelerated, the length of tube it travelled before the voltage shifted increased, so that each successive tube had to be longer $L_1 : L_2 : L_3 : L_4 : L_n = 1 : \sqrt{2} : \sqrt{3} : \sqrt{4} : \sqrt{n}$, eventually requiring enormous sizes.

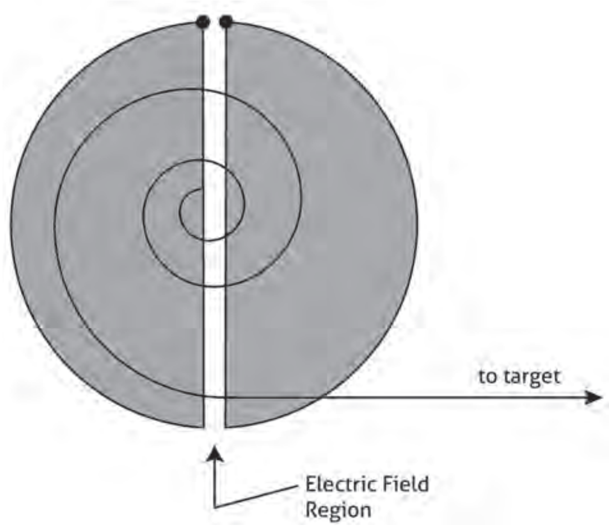
The next step would be to introduce a magnetic field. By introducing a magnetic field, the particle can be made to move in a circle, around the axis of the field. The key to this design was the fact that given a constant magnetic field, and a constant mass of particle, the period of rotation remained constant no matter what speed. In other words, as the particle was accelerated by two electrodes placed on either side of a short gap that cuts from the center of the circular apparatus to its circumference, the particle's path would increase its radius, but maintain the same period. Thus, if the frequency of the alternating electric field were set to the corresponding period, the particle could be accelerated continuously, limited only by the radius of the apparatus.

Further challenges were posed by this. Remember that the period stays the same as long as the mass and magnetic field stay the same. However, as a particle accelerates to velocities on the order of the speed of light, this is no longer the case. The particle's mass begins to change, and so does its period of rotation, resulting in eventual desynchronization with the frequency of the alternating field and thus eventually deceleration.

Particle accelerators have continued to improve to this day, resolving this issue and introducing others which result from conditions never before created by man. Humans now create artificial transmutations with artificially accelerated particles.

This ability has expanded the periodic table of elements to over 3,000 isotopes, each with their unique nuclear transformation properties.

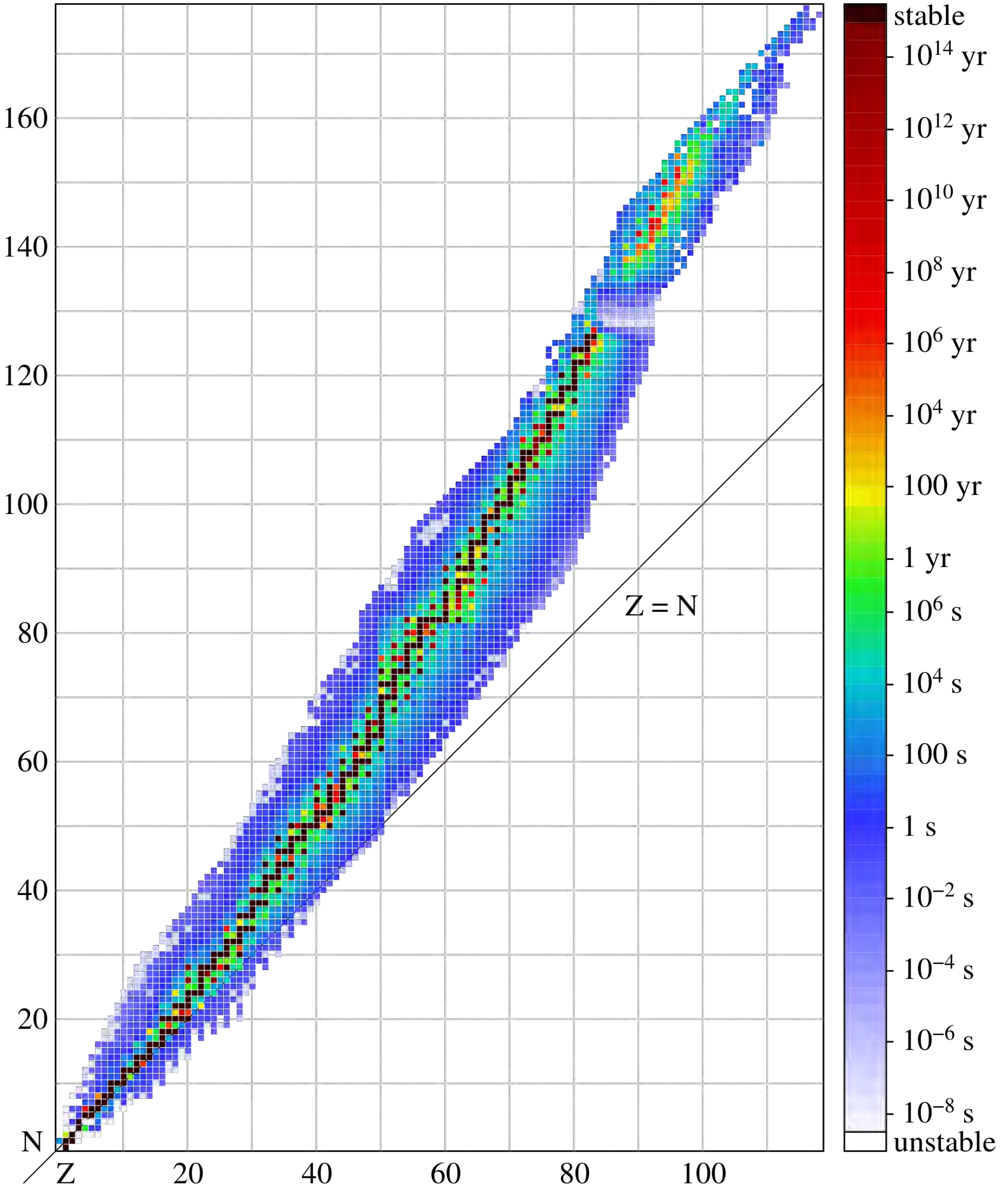
Among these are new elements, unique to the nuclear age. For instance, for a long time, besides the transuranic elements, sub-uranic elements 43, 61, 85 and 87 were unknown. Even to this day no stable isotopes of these are found (technetium, promethium, astatine,[7] and



In a cyclotron, particles are injected into the device in the center of the apparatus, after which they orbit about the magnetic field, which in this case is directed perpendicular to the page. As long as the mass of the particle and the strength of the magnetic field remain constant, the orbit of the particle will only increase in size, while the period will remain constant. An electric field is generated in the gap, fluctuating at a rate that coincides with the orbital period of the particles. This electric field accelerates the particle every time it crosses the gap.

6. eV refers to a unit of energy called an electron-volt. It is the amount of energy gained or lost when an electron traverses an electric potential difference of one volt. It is equivalent to 1.602×10^{-19} joules.

7. From the Greek *astatos*, meaning *unstable*.



This table of nuclides lists all of the known nuclei. The x-axis represents the number of protons, while the y-axis represents the number of neutrons. Therefore, any column of nuclei represent the isotopes, or variations of the same element. The colors here signify the strength of radiation of each, by indicating the half-life of that particular nuclide, the amount of time it takes for half of any sample to decay. Black indicates stable nuclei.

francium). Only through artificial nuclear transformations have these elements existed in large enough quantities to determine some of their chemical properties.

Many of the radioactive isotopes play a crucial role in medical diagnosis and treatment. Some ten million medical diagnostic procedures annually use the artificially created technetium-99m, derived from molybdenum-99, a product of uranium fission.

Though now in the realm of possibility, we have not yet reached the point where we can freely traverse the now over 3,000 known nuclides, integrating the use of their various characteristics of transformation throughout the economy.

More advanced control over the process of fusion, in combination with our knowledge of the fission process, which still has much room for advance, will be required to fully realize this new potential.

The first chemical separation of technetium-99m from molybdenum-99.

Conclusion

The launching of this great era now lies over one century ago. Yet, despite all of the advances of the 20th and now 21st century, we are far behind what we had set ourselves up for. We still cannot at this point say that the nuclear age has matured. Many fundamental questions have yet to be addressed, and many citizens educated about their heritage, before we can truly say that the nuclear age is here.

Still so many open questions are waiting. For example, what is the structure of the atom? William Draper Harkins[8] and Robert Moon posed unique hypotheses about the structure of nuclei, hypotheses which, if developed, could potentially enable us to order the various characteristic properties of nuclides, such as their unique decay rates and energies, and even forecast them. Their work is yet to be followed through to the point that a higher universal principle can serve to organize all nuclides, just as the periodic table, formed out of a higher organization, involving relations of action with respect to all others, rather than any isolated physical description, served to organize all elements, known and unknown.

Is there a whole domain of material and even principle which remains subdued by the noise of mixtures of isotopes? What new types of properties will become apparent once isotopically pure materials and compounds are fully explored and mass produced? There are already examples of diamonds made of pure carbon-12 or carbon-13 which are harder than regular diamonds, and of isotopically controlled silicon for computing.

What is the relationship between a full understanding of the nucleus and the study of life? Life is very sensitive to isotopic variations. It has isotopic preferences much like its preference for right-handed sugars and left-handed proteins. What is the role of nuclear transformations within the body? What can we learn about life were we to take full control over the nuclear domain? Or, rather, what can life teach us about the nature of the nucleus? There are already some very important medical applications in use. Much more needs to be done, and can be done once the these degrees of freedom are explored and conquered.[9]

Uniqueness of isotopic ratios in astronomical data has shown, and will continue to show us unpredicted generating processes, invisible to the purely chemical domain.

Ultimately, the fundamental shift from a matured nuclear age to the next platform will be seen not in new technologies, but in how people identify themselves. Do most people think of themselves as conductors of stars? And as a species which lives among the great powers that control elements? Why not? And what would be the consequences if we did?

That is the story of Prometheus.

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8. Harkins made many hypotheses based on experiments done on nuclear decay at the beginning of the 1900s. Based on alpha decay, he hypothesized that the structure of the nucleus might consist of units of helium and hydrogen nuclei.

9. Rouillard, Meghan, "Isotopes and Life, Considerations for Space Colonization," *EIR*, Vol. 37, No. 25, 2010.