Sara Rodriguez Martinez

Synthesis Paper – On X-Rays & Radioactivity

Historical Context

Little was known about radioactivity until the beginning of the 20th century. A discovery that led us to a nuclear age in less than 50 years was not even formally studied until very late in our history of science. Even if I was unable to find evidence of earlier scientists studying radioactive properties of materials or elements, there are some indications that at least the Greeks did indeed benefit from radioactivity. It is argued that in ancient Greece people used to believe in mythical properties of the island of Icaria, where in the sixth century B.C., Greeks and Romans alike used to travel for health reasons, to benefit from their hot springs and relieve their skin, joint and other ailments (Buettner, 2009). Jumping back to the present, some studies have been pursued showing that the waters of Icaria have very high concentrations of radon, deeming the spas that now sit in its shores as "radioactive spas" (Danali, 1986), and suggesting that the exposure to low-level radiation may help DNA-aging and health preservation (Buettner, 2009). There's no evidence that shows ancient Greeks formally studied these properties, but I'm sure they at least did some qualitative observations.

The position for discoverer of x-rays seems to not be very contended, for everybody seems to agree that it was Wilhelm Roentgen's feat, who accidentally noticed the luminescent properties in a plate with barium platinocyanide while studying the phenomena of electric currents going through gas at very low temperature (The Nobel Foundation, n.d.). After other experiments, he also noticed that even different materials such as human tissue showed variable transparency when recorded on a photographic plate and even tested it on her wife's Bertha's hand, thus capturing the first x-ray (designating the unknown). Of course, research on x-rays did not stop here and was followed by other physicists and scientists, such as Barkla, Max von Laue (who stablished the short wavelengths of x-rays), the Braggs (father and son), who even won a Nobel Prize for studying the crystal structures of common solids through x-rays, (Stark, n.d.) and even Marie Curie with her development of mobile x-ray units. However, the first steps in the discovery of radioactivity weren't as defined, nor as widely accepted. As we have seen in several of the examples in Hal Hellman (1998) or Thomas Kuhn (1996), there are also some controversies regarding when exactly radioactivity was discovered. Most people tend to credit this discovery to Henri Becquerel, who, interested by Roentgen's discovery decided to replicate and further investigate his experiments. He tied Roentgen's discovered properties to his own earlier work on phosphorescence and decided to expose potassium uranyl sulfate to the sun (he believed that it was the sun that gave them the energy that was later emitted as x-rays); when he later exposed the salts under a photographic plate covered with opaque paper, the plate was fogged (The Nobel Foundation, n.d.). Others, however, argue that this observation was already made thirty years earlier by Niepce de St. Victor, who reported in 1858 that a uranium nitrate solution (even without being previously exposed to light) left large marks or "strokes" on a piece of covering paper when printing its image (Habashi, 2001). Others also argue, that it wasn't until Marie and Pierre Curie isolated radium and properly defined radioactivity that it was truly discovered (Kragh, 1997).

Regardless of who was the discoverer or in what moment exactly was radioactivity discovered, the concept was not immediately accepted, as usually happens in a paradigm change. After Becquerel announces his results with his uranium experiments, Marie Curie starts working on uranium salts to determine where this energy comes from, but notices that after exposing the substance to heat and sunlight, the intensity of the waves does not decrease or increase (Frontczack, 2014). In that moment, she began to theorize that those properties were indeed not due to phosphorescence as Becquerel assumed, but possibly an atomic property of the element uranium.

Pierre Curie, who at the time was working on his theories of quartz crystals and piezo-electricity, becomes captivated by Marie's experiments and together they start working on the rays (Frontczak, 2014). After testing all known elements looking for this property (they find it also in thorium) they decide to look in composites of uranium, especially in pitchblende, which is supposed to have a bigger concentration of uranium. But while isolating uranium from pitchblende, Marie notices that the liquid residue actually emits 10 times more rays than the uranium itself. Through fractal crystallization, they are able to isolate not only one, but two new elements, one which she names Polonium (after her home country of Poland) and the other Radium (ray in Latin). They discovered additional properties of radium also accidentally, by giving a high concentration of radium-barium solution to Becquerel, who, carrying it his jacket pocket, received a burn in his chest. Pierre replicated this experiment on his own arm, which burned through his skin and finally produced deeper injury after 40 days. After this experience, interested due to his mother's death of cancer a year earlier, Pierre tested high concentrations of radium on sick tissue and discovered that it grew back healthy. Thus, radiotherapy was born (Frontczak, 2014). Through all the evidence that the Curies provided, it took them several years for Becquerel to leave behind his phosphorescence theories and accept the "materialist theory of radioactivity" from the Curies, according to which "the rays consisted of atoms or subatoms endowed with energy originating from within the radioactive atom" (Kragh, 1997, p. 336). Other scientists took much longer to convince.

During this time of paradigm change, many scientists came up with their own speculations. Among them, William Crookes speculated that the energy was coming from the surrounding air, by light molecules colliding with the heavy atoms in radioactive elements (Kragh, 1997). Following this idea, Mendeleev suggested that it was a concentration of ether atoms on heavy atoms causing this disturbance (Kragh, 1997). Others, followed Becquerel's original idea saying that it was an "uunusual form of luminescence, hence of chemical nature" (Kragh, 1997, p. 334), such as Henry Armstrong and Martin Lowry or that it was a simple chemical reaction of the neutrons reacting with ordinary elements, as was believed by Walther Nernst. Other theories included gravitational energy as an external source of radioactivity (as believed by Robert Geigel) or that through "spontaneous transformation" within the atom (as concluded by Rutherford and Soddy) rays were emitted (Kragh, 1997). If nothing else, something that seems apparent from the early 1900 is that they may not have had a consensus on how radioactivity worked, but definitely a lot of people were trying to find out.

At the same time, several scientists were developing theories on the structure of the atom, most connected also to their models of radioactivity, as was the case with Stark and his speculation on large internal potential energy of atoms, the electron-based models of the atom from J. J. Thomson's model or the proposed idea that atoms were congregations of negative ions as per James Jeans (Kragh, 1997).

Following this line of adapting or creating atomic models to explain radioactivity was Lord Kelvin (William Thomson), who also refused to accept Marie's materialist theory. Among other things, he went as far as proposing a new atomic theory that included negative particles called *electrions* (both electron and ion) and suggested to "introduce different laws of force between the different atoms" and proposed that radioactivity came from these *electrions* escaping the atom or that it came from outside energy for radium, given the high amount of energy it apparently emitted (Kragh, 1997, p. 344). Kelvin appears to continue to only accept these theories until his death in 1907.

Claims against the materialist theory continued as late as 1923, even when it was widely accepted, as was the case of Jean Perrin who still argued that radioactivity “was not a spontaneous process, but triggered by some kind of radiation of either cosmic or terrestrial origin” (Kragh, 1997, p. 336). It appears that the discussion of determining what exactly was the mechanistic basis of radioactivity that “by 1910 most physicists either ignored the problem or adopted a pragmatic attitude according to which the phenomenological laws took priority over mechanistic explanations” (Kragh, 1997, p. 356). They considered radioactivity as a problem that could be solved in principle and that there was no atomic model that could explain it, so it would have to wait for the future. Thus, after 1913 they considered the atomical explanation of radioactivity a “non-problem” or that it didn’t really matter if the origin of radioactivity could be explained or not (Kragh, 1997).

It wouldn’t be until the 1920 with the development of quantum mechanics that radioactivity would finally be explained, by using it to explain the atomic nucleus and providing a satisfactory explanation of alpha decay (Kragh, 1997) (Luntz, n.d.). As argued by Kragh (1997), the mechanism of radioactivity had no solution in the early stages of study of radioactivity basically because it was framed “in terms of an inadequate dynamical theory” (p. 358) and therefore could not be solved. With quantum mechanics, it could be recognized that particles’ behavior was governed by probability, which allowed scientists to “develop a consistent theory of the atom that explained its fundamental structure and its interactions” (Bertsch, n.d.). These included Einstein’s wave-particle duality or Schroedinger’s equation, which allowed to explain particle behaviors that classical physics would have forbidden. Through the dedicated research of many scientists around the globe in the early decades of the 20th century, the introduction of quantum mechanics allowed nuclear and subatomic physics to advance into better x-rays, a deeper understanding of radioactivity and ultimately, among many others, to a new form of energy through nuclear fission.

Reflection

It was fascinating to me to read about the development of radioactivity and x-ray theories and how much that advancement differed from one historian or scientist to the other. Some portrayed an optimistic path vaguely mentioning the "losers" in the story, others portrayed an apparently more realistic or accurate view of the disagreements of the time. In my opinion, the latter were better than the former; apart from enjoying the detail, the optimistic portrayals appear to have too many gaps. One of the facts that surprised me the most was the authorship or discovery of radioactivity itself. Most sources concluded that it was Becquerel who first discovered, but when explaining the process, they recognized that he had "only" made an *observation*. I tend to agree with Kuhn that attempting to put a date to a discovery is quite arbitrary, as he exemplifies with Lavoisier and oxygen, given the complexity of the process, and that for something to be discovered one must know "*that* something is and *what* it is" (Kuhn, 1996, p. 55). However, Becquerel technically only did qualitative observations on uranium and radioactivity, and it was Marie and Pierre Curie who actually pursued the quantitative study that led to defining radioactivity. How come this discovery is not considered that arbitrary? I couldn't find any discussions regarding this topic, but I believe that the fact that one of the main people involved in this research was a woman had something to do with it.

As we have seen in the section above, it took over ten years and a completely new field of study to really understand radioactivity. I believe the development of radioactivity goes very much in line with Kuhn's paradigm theory and the characteristics of all new discoveries that lead to new sorts of phenomena: "awareness of anomaly, gradual and simultaneous emergence of both observational and conceptual recognition, and the consequent change of the paradigm categories and procedures often accompanied by resistance" (1996, p. 62).

On another note, I agree with Hellman (1998) that one of the reasons why it took so long for scientists to accept the Curie's materialist theory of radioactivity came from Kelvin's influence on the scientists of the time, refusing the reality of radioactivity and holding on to his theory on the age of the Earth. Nevertheless, just as Kuhn (1996) points out as well, it would have been very difficult either way for Kelvin (or any of the other scientists) to truly accept these new theories, given that a revision of the major paradigm, in this case classical physics, was needed.

Moving Forward

The topic of radioactivity tends to find its way into most of my educational efforts, in classes about energy sources and storage, or even sometimes with polymers (I work mainly with complex materials). Also, Marie Curie's research and story serve as a very inspirational tool for young women and men alike; I have used her living history movie portrayed by engineer and Marie Curie scholar Susan Marie Frontczak (2014) in a lot of my public programs with great success for all ages. That being said, while this approach still remains useful, there's so much more about the parallel evolution of theories and the very diverse backgrounds of the scientists that were involved in this particular paradigm shift that I have learned through the development of this synthesis paper, and which I intend to portray in my future efforts. Like Kuhn says, scientists never just learn "concepts, laws and theories in the abstract and by themselves" (1996, p. 46). I intend to integrate this more cohesive approach and make my students understand that history has indeed been taught from the side of the winners, that theories can take a very long time to be accepted and that progress is very much linked not only to the people that are involved in the research, but also their accessibility to information. It is true that, as most people agree, curriculum is already packed with activities and targets to be reached. However, I believe that the idea behind this paper, having more of an overarching view of what really happened, reading the conversations that scientists had and learning about what was also happening socially at the time, can be scalable to the point of introducing it in class as a day activity, maybe as a group project or homework that can be shared among all students in class.

Hopefully, this will lead them to a better understanding of how science works, an increased curiosity and skepticism towards history portrayals (and science theories), and an eagerness to contribute their own grain of salt to this fast-changing world someday.

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