

Background atoms

The concept of Atoms is fundamental to our modern scientific understanding of the world. The eminent physicist Richard P. Feynman pointed out that “[i]f, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the atomic hypothesis (or the atomic fact, or whatever you wish to call it) that all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are little distance apart, but repelling upon being squeezed into one another” (Feynman et al. 1963, I-3). This quotation is for several reasons relevant with respect to this historical background: On the one hand, Feynman is pointing out extremely clear how important the concept of an atomic structure of matter is to modern science. Yet, he also raises implicitly another issue that is very relevant if the genesis of this concept is analysed: Feynman speaks in this introduction to the first lecture of the ‘atomic hypothesis (or the atomic fact, or whatever you wish to call it)’, and in doing so he addresses and ignores at the same time a crucial detail: is the existence of the atom an hypothesis, or is it a fact, and if so, what really is part of this fact – which level of description can still be taken as being a fact, which are additional hypothesis. Feynman ignores this issue by leaving it to the reader how she or he wishes to call it – this appears to be a crude form of relativism that can possibly be explained by looking at the date of the publication: Feynman’s lectures date from the early 1960s, for that time it appears to be questionable whether a different position could be expected in epistemological or in nature of science categories. Such a statement appears to be somewhat irritating from our point of view, yet, it demonstrates how far the knowledge about the nature of science has developed in recent decades.

In order to teach this central concept, one aspect gets relevant which was also important in the historical development but will not be discussed in this historical background: The notion of a chemical element is a prerequisite for the formulation of the atomic model – this can be seen in the historical analysis booth for the development in the Greek antiquity as well as for the modern period, and it can also be identified in the educational conceptions. However, the historical development of the concept of elements will not be discussed in this background material but is assumed to already exist.

Ancient discussions about the structure of matter

The question how the material world is structured has been discussed in particular in Greek Antiquity (a knowledge which is in part due to the transfer of knowledge from this period to the Early Modern Era in Europe).¹ In this respect, the topic of a prime element that

constitutes all the other substances becomes relevant, however, it is of course not even synonymous with a simplistic atomic concept as this prime element could exist without any corpuscular structure. Philosophers such as Thales of Miletus, Anaximenes, Heraclites and Empedocles were among those scholars who developed or promoted respective conceptions. About 450 BC, two philosophers developed ideas that are relevant to the introduction of the atomic conception: Democritus and Leucippus. Both postulated that the material world is made from very tiny particles, which themselves cannot be any further separated into smaller parts. These atoms were distinguished from each other by their shape and size. According to Democritus, these atoms move in the empty space and collide with each other. By specific combinations of atoms, other substances are formed, yet, these combinations are not permanent but the atoms can separate again. However, the concepts of Leucippus and Democritus were not accepted by their contemporaries: “Two factors weighed against any widespread acceptance of the classical version of atomism. The first factor was the uncompromising materialism of this philosophy. By explaining sensation and even thought in terms of the motions of atoms, the atomists challenged man’s self-understanding. Atomism seemed to leave no place for spiritual values.

¹ There is evidence that models of the material world existed also in the Indian culture as well as in Babylonian culture, however, documentation is poorer and these concepts have not played any role in the introduction of an atomic theory into European science – thus they are not discussed in the background.

Surely the values of friendship, courage, and worship cannot be reduced to the concourse of atoms. Moreover, the atomists left no place in science for considerations of purpose, whether natural or divine. The second factor was the ad hoc nature of the atomists' explanations". (Loose 2001, 25) Additionally, there was a rival concept which appeared superior as it explained the behavior of matter: the four elements conception which explained all existing matter as well as its properties through four elements: Water, Air, Fire, and Earth.²

A central, if not the central figure for the rejection of this atomic theory was Aristotle, who advocated the four elements theory and added as a fifth: ether, which filled the space between the celestial bodies. This was relevant as – according to Aristotle – no empty space could exist – the horror vacui, nature's 'fear' of emptiness. Moreover, according to his conception, everything in nature is intentional; there is no superfluous action in nature. Additionally, each object has a natural position, and if displaced, it aims at getting back to this position. Consequently, Aristotle was able to explain observable processes with his principles. The atomists were not only unable to propose a superior explanation, even more: they assumed the existence of particles no one could see. This was a major criticism Aristotle made against the atomic theory, apart from that he did not accept the idea of the empty space which was according to his own conception impossible. And a permanent motion appeared absurd in Aristotle's understanding. All in all he opposed the atomic concept which was in contradiction to several of his central beliefs. Yet in some sense he is still relevant to the modern development of the atomic theory as the original works of Leucippus and Democritus were lost and were actually known only through his criticism.

Aristotle's works were kept and expanded in the Islamic culture, and through this culture, they came back to Europe and the Christian culture. For the scholastic period, this Aristotelian understanding became dominant, particularly as it was considered to be coherent with

the Bible. Yet, astronomers and slightly later natural philosophers developed a different understanding of natural processes – consequently the authority of Aristotle was more and more questioned throughout the 17th and 18th centuries – at the end of this period, it was the experimenting enlightened natural philosopher who was considered to be able to uncover the laws and structure of nature. In this process some experiments and considerations were developed that seemed to strengthen the ancient atomic hypothesis. Of particular importance was the demonstration of the existence of the vacuum.³ In another argumentation it was discussed that if a tiny bit of incense is burned, it can be smelled in the entire room. As this room is significantly bigger than the space the incense initially occupied, the initial piece has to be divided into more than 750.000.000 parts – these calculations were intended to show how small the particles have to be that form the piece of incense (see Beer & Pricha 1997). However, such a discussion remained on the level of simple calculations, there was no claim whatsoever that atoms exist or what their properties might be. Such an understanding was only developed in the early 19th century.

Structuring matter: Dalton

When looking into the genesis of modern science, probably the first scholar to establish an atomic conception is John Dalton, a chemist who was following Lavoisier's new, quantitative approach towards chemistry. Using a balance to analyze chemical reactions formed a major achievement of Lavoisier's new chemical system, and this enabled chemists to take a different perspective on chemical reactions. Lavoisier himself established the difference towards classical chemistry and the novelty of his approach several times, to give but one example: "Lavoisier wrote in the *Opuscles physiques et chimiques* (1774) that he 'applied to chemistry not only to the apparatus and methods of experimental physics but also the spirit of precision and calculation which characterizes that science'." (Nye 1993, 35). Yet, it was not only the methodological step or conceptual modifications that made Lavoisier's chemistry

² It has to be understood that these elements were not what we call Earth, Fire, Air, and Water, but they are elementary principles (see also the background on the development of the Periodic Table).

³ On some of the controversies with respect to the existence of a vacuum and the related philosophical implications see Shapin & Schaffer 1989.

distinct to the previous understanding. A key element in his chemistry was the different notion of chemical reactions that helped him to use the quantitative description, and the understanding that 'simple substances' can be interpreted as elements that cannot be decomposed any further. In this respect, Lavoisier stated explicitly: "I shall, therefore, only add upon this subject, that if, by the term elements, we mean to express those simple and indivisible atoms of which matter is composed, it is extremely probable we know nothing at all about them; but if we apply the term elements, or principles of bodies, to express our idea of the last point which analysis is capable of reaching, we must admit, as elements, all the substances into which we are able, to reduce bodies by decomposition." (Lavoisier 1794, xxiii) Remarkably, Lavoisier is already using the term 'atom', even though he is not using an atomic theory. However, this notion of element that gets evident in this quotation is also relevant to the introduction of the atomic theory.

A key understanding resulted from the quantitative observations at the end of the 18th century: most compounds are the result of the reaction of specific ratios of masses of the elements that form this compound. This rule became known as the law of constant composition. Even though this law appeared to be valid for the chemical reactions that had been analyzed quantitatively, there was another striking aspect, and this was first characterized by John Dalton. Dalton realized that there were some chemical reactions in which different compounds were formed through a combination of the same elements (i.e. from a reaction of copper with oxygen two different compounds can result, likewise carbon and oxygen, and so on). The resulting compound depended on the amount of the two initial substances that reacted with each other. However, there was also some regularity that Dalton noticed: there was a ratio of small integer numbers between the masses of element A that reacted with the same amount of element B to two different compounds. From this finding Dalton formulated another law. the law of multiple proportions characterizes that if two elements possibly react to more than one compound, then the masses of element A reacting with the same amount of B are small integer multiples. This law, together with the law of constant composition,

forms the starting point towards the stoichiometric approach in chemistry.

However, even though this law was based on empiric evidence, it was not the only conclusion that Dalton drew from his experiments: In a lecture delivered at the Royal Institution London⁴, he proposed the following ideas which form the basis of the modern atomic theory of matter:

"All matter is composed of atoms
Atoms cannot be made or destroyed
All atoms of the same element are identical
Different elements have different types of atoms
Chemical reactions occur when atoms are rearranged
Compounds are formed from atoms of the constituent elements."⁵

Evidently, Dalton's use of the term atom is different to the one of Lavoisier. Dalton's conception of the atom is characterized by their countability, they have a certain weight and so on, whilst in Lavoisier's conception it is more their chemical property which is relevant, and it is even unclear whether this is an actual particle.

This assumption enabled Dalton to prepare an explanation of the stoichiometric laws he and others had formulated. According to this understanding, the law of constant composition results both from the understanding that all atoms of the same element are identical, and that chemical reactions are a result of the rearrangement of the atoms. The law of multiple proportions can then be interpreted as being the result of different arrangements of the atoms that result in different compounds. In doing so, the knowledge about quantitative chemical analysis became based on a first paradigm in the Kuhnian sense (and in this respect, one could argue that this achievement turned stoichiometric chemistry into a science in the Kuhnian sense). Yet, things were not that easy: Even though Dalton's theory was adopted by several chemists very quickly, others rejected it. A key problem was the assumption that each element was formed by a different atom, as a result there were about thirty different atoms at the beginning of the 19th century, and their number was increasing. Thus, instead of simplifying the structure of matter, Dalton's atomic

⁴ According to Clarke (1803), the first presentation was made at the Manchester Philosophical Society.

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<http://www.rsc.org/chemsoc/timeline/pages/1803.html>, last access April 18, 2012

theory made nature more complex. Despite this criticism, the stoichiometric laws were used by chemists, and some of them used fractional numbers to express the ratio of masses – indicating that there was no inseparable particle. This was not just a problem of initial acceptance, even sixty years later, reservations against this theory were stated very explicitly, e.g. the President of the Chemical Society Williamson stated in a speech in 1869: “... that on the one hand, all chemists use the atomic theory, and that, on the other hand, a considerable number of them view it with distrust, some with positive dislike.” (quoted in Tilden & Glasstone 1926, 227). And some renowned chemists and physicists at the beginning of the 20th century still rejected the atomic theory – we will come back later to this issue. Yet, particularly for chemists, the atom became an entity that was used in their analysis of chemical reactions. However, it was not considered to be real (neither in the positivistic sense nor in the sense of a relevant theoretical description) but just a heuristic tool which was very adequate in terms of describing chemical reactions, but had nothing to do with the actual understanding of matter (Görs 1999).

The atom gets established

Despite the discussions amongst the chemists who accepted the atom as a useful hypothesis, the physicists started to use the atom as a real object with explanatory power. Particularly the developing science of thermodynamics played an important role in the establishment of a physical atom that is crucial for the kinetic theory (atoms in motion represent heat). However, this understanding was strongly criticized, particularly in the German speaking scientific community by eminent scientists such as Ernst Mach, Wilhelm Ostwald and Georg Helm.⁶ The controversy between these researchers (Ostwald was a Nobel Prize winner in 1909, Mach was also very prominent in his times) and the proponents of a statistical interpretation (most notably Boltzmann) was not just based on physical issues but involved also deep philosophical questions. A key aspect in

⁶ For other reasons, also Max Planck initially criticized atomism as he understood it in Boltzmann’s statistical interpretation, see Müller (2008). This discussion was not limited to the German speaking community; another example of the opponents of atomism is Poincare

this respect was the question whether individual atoms can be seen, or whether there is any evidence for the existence of individual atoms.

Actually, at the beginning of the 20th century, it appeared that the atomic theory was considered to be overthrown, and Boltzmann to be a relic from the 19th century. Things changed significantly when Planck’s theory of radiation was established and at about the same time Einstein and Smoluchowski published their interpretation of Brownian motion. This was a phenomenon described already in the 18th century by several observers. However, it was attributed to the biologist Robert Brown who noticed in the early 19th century that small pollen and dust particles that are floating on water moved in an erratic manner. The remarkable detail about this motion was that it never appeared to stop, moreover, the moving particles were certainly not alive. It remained an open question for about half a century how this motion was to be interpreted. Even though towards the end of the 19th century some researchers proposed solutions to this question which correspond to our interpretation, it was only in 1905/06 when Albert Einstein and Marian Smoluchowski presented independently their mathematical analysis of Brownian motion (actually Einstein’s paper was one of the three famous in his *annum mirabilis*, the other two dealt with the photoelectric effect and the special theory of relativity). Both researchers were able to explain that the motion can be caused by the motion of the particles of water due to their kinetic energy – thus, Brownian motion appeared to be a first macroscopic effect that had to be explained with the assumption of small particles and thus forming an empirical evidence for the kinetic theory and thus for the atomic theory. Actually, Ostwald is said to have been convinced of the adequateness of the atomic theory through the agreement of the description and the empirical data. At about the same time, there was another empirical evidence for the adequateness of the atomic theory, and this one is said to have convinced Mach: When radioactive particles are placed next to a fluorescent screen, minute flashes of light can be observed which are to be interpreted as results of individual α -particles. Thus, within a few years, the understanding of atomism had changed from almost complete rejection to almost complete acceptance. Boltzmann, the great proponent of the atomic theory, was at

that time already dead – he committed suicide in September 1906.

The atom gets a substructure

Even before Einstein's and Smoluchowski's work helped to establish a consensus about the correctness of the atomic description of matter, some researchers established empirical results that actually contradicted the initial understanding of the atom as being inseparable: Actually Faraday's work on electrolysis – which dated from the 1830s – could have been raised questions on the fundamental and inseparable nature of the atom as formulated by Dalton: According to Faraday's investigation, a certain amount of electricity releases a certain amount of an element in the process of electrolysis. However, this empirical result did not raise questions with respect to the atomic nature of matter, on the contrary: It remained unclear until well into the 20th century whether electricity has an atomic structure, or whether the ratio between electrical charge and released matter was the mean of several reactions that could take place at the same time. Only in the 1920's, when Millikan's measurements on the elementary charge were awarded with the Nobel Prize, this issue had been settled (at least for the vast majority of scientists, see Holton 1978). Yet, towards the end of the 19th century, further evidence was produced that questioned the indivisible character of the atom. Actually, the starting point was research that in retrospect can be taken as being further evidence for the atomic theory, even though it was not interpreted in this sense in the historical situation. In the 1860's, the chemist Bunsen showed, together with the physicist Kirchhoff, that the light emitted from a substance is very characteristic and that only special frequencies (or lines, if the spectrum is analysed) are emitted (or absorbed). This provided also a method to identify new elements, and the number of elements increased significantly over the next few years. Analysing spectra was a major issue, and became expanded towards analyzing also cathode rays and their interaction with gases that are filled into the tubes. In doing so, experimentalists had hoped to develop a further understanding about the constitution of matter (Müller 2004). Particularly the analysis of cathode rays appeared to be very promising; among the researchers working in this field was J.J. Thomson. Thomson analyzed these

cathode rays and established that they are formed by particles⁷ which have a mass of about 1/1000 of the hydrogen atom. He was also able to determine the mass-charge ratio by deflecting these particles in a magnetic field. However, what might be more relevant to this discussion are his experiments in which he used different cathode materials to emit the rays (which were basically emitted by heating up the cathode, the rays were then accelerated with an electric field). Thomson could show that all particles have similar properties, no matter from which material they were emanated. This could be seen as an indication that these particles (corpuscles, as Thomson called them) were a fundamental part of matter. However, there was a problem: When these corpuscles were that lightweight, but electrically charged, and they form a part of matter, then how can stability be created? Thomson finally came up with a solution: "We suppose that the atom consists of a number of corpuscles moving about in a sphere of uniform positive electrification ..." (Thomson 1904, 255).⁸

This meant that the (at this time still disputed atom) was no longer indivisible, and that the model of the atom had to be modified. Another modification became necessary soon afterwards, and this was related to another field which emerged in the very early 20th century: radioactivity - which will be discussed in the next chapter. One of the researchers who established their scientific career in analyzing this phenomenon was Ernest Rutherford, a physicist from New Zealand who did his early researches (which won him the Nobel Prize) in Canada and then moved to England again. In the Cavendish laboratory two of his assistants – Marsden and Geiger – carried out the experiment to scatter α -particles with metal foils (Geiger & Marsden 1909).

⁷ Quite remarkably, his son George Paget Thomson was also awarded the Nobel Prize in physics, this time for his work on electron diffraction. In some sense, it could be (admittedly oversimplified) argued that J.J. Thomson was awarded the Nobel Prize for demonstrating that electrons were particles, whilst his son was awarded the same honor for demonstrating that electrons are no particles but have also a wave character.

⁸ Actually the Japanese physicist Nagaoka came up with a similar solution one year earlier.

Rutherford had already suspected that a scattering is possible when he observed the passage of α -particles through sheets of mica. This experiment was taken up again, and the result was more than irritating (even though not completely unexpected: Geiger and Marsden observed that even though the vast majority of α -particles passed the metal foil (and in the course of the experiment they used gold foil as this could be prepared extremely thin), with some of them being scattered, very few of them were reflected.

“In retrospect, Marsden’s discovery was the ‘most incredible event’ that had ever happened to him [Rutherford, PH], almost as incredible, he would say, as if a fifteen-inch shell fired at a piece of tissue paper bounced back and hit the gunner. That the military imagery and the incredulity are later fabrications we can see easily from a lecture Rutherford delivered ... six month after the discovery of the diffuse reflection (Heilbron 1981, 264f.)

Be this statement as it may, the result was certainly unexpected to the scientific community, and Rutherford came up with an explanation that was certainly also unexpected: He calculated from the behavior of the α -particles that the atom had a small positively charged nucleus that contains almost all the mass, whilst most of the space of the atom was empty, except for the electrons that moved around somewhere in this space.

Atoms can change

As already mentioned, Rutherford became famous for his researches in radioactivity – yet he was not the person to open this field. The first researcher who actually observed radioactivity was the French physicist Henri Becquerel – his discovery (and one can use this term as this was completely unexpected even though some sensibility for radiation effects certainly existed due to Röntgen’s demonstration of the X-rays) opened a new field. Yet, this field was not entered immediately by Becquerel himself or other scientists, but the rays emitted from Uranium salts were just considered to be a curiosity not worth any further scientific attention. It was the collaboration of a young Polish chemist with a French physicist that actually made the importance of this new field evident: Marie and Pierre Curie could use the radiation

to show that within several radioactive samples other elements than Uranium have to exist as the radiation was stronger than the one emitted from pure Uranium. In a long and laborious analysis, they were finally able to prepare pure samples of the elements Polonium and Radium. Particularly Radium became central to the research in the new field of radioactivity as it was fairly active and produced different rays. Yet, it became evident, that a lot more chemical elements have the ability to emit such a radiation. However, there were several things that turned out to be really astonishing – among them certainly the transformation of one element into another in the process of an α - or a β -decay. This gets evident from an anecdote that brings us back to Rutherford: “Rutherford and Soddy found, for example, that radioactive thorium, atom by atom, was gradually turning itself into radium. At the moment he realized this, Soddy ... blurted out, ‘Rutherford, this is transmutation!’

‘For Mike’s sake, Soddy,’ his companion shot back, ‘don’t call it transmutation. They’ll have our heads off as alchemists’ (Weart 1988, 5f.).

Already the work of the Curies’ had established a fundamental idea: The radiation of a material is related to some properties of the element. Uranium has a different radiation than Polonium and Radium, and so on. Moreover, it became evident through experiments that the activity of a sample gets reduced over time – which is evident when the transformation of the atoms into those of another element is taken into consideration. However, there was also a problem with respect to the decrease of the activity, it became evident that the half-life was not a value that could be used for an individual atom, on the very contrary. The law of radioactive decay worked only for a statistical sample, a prognosis of the behavior of the individual atom was not possible. Initially, this was taken to be an indication of the required development in atomic physics, however, it became evident in the end that this is simply not possible and the decay can only be described mathematically in terms of the statistic of the ensemble.

Moreover, in analyzing the radiation, three different types could be identified and soon characterized. Another surprise came with the α -rays – they turned out to be helium, an element that until then was only detected in the

sun (with spectroscopic methods) and seemingly did not exist on Earth. Yet, as the α -rays appeared to be positive particles whilst the β -rays were electrons, this meant that not only the electrons could be emitted from the atom but also some of the positive substance.

Physical atoms and chemical atoms

Determining the properties of the different rays was one of the first things that experimenters did once it became evident that this was a relevant topic. Among other things, mass and charge of the particles that formed the rays were determined. This was done by applying a well defined magnetic field rectangular to the direction of the rays – from the deflection the charge/mass ratio could be determined. A comparable set-up was used to analyze atoms, and this provided another insight into their structure as well as it solved one of the remaining problems. Particularly through the work of Francis Aston, who modified this set-up into a mass spectrometer, it became evident that even though from a chemical point of view all atoms of an element are indistinguishable, this was not the case from the physical point of view. Aston could demonstrate that for several elements different atoms existed that could be distinguished (and only be distinguished) from their mass. This helped to explain why certain elements had an atomic weight that was not an integer multiple of the mass of the hydrogen atom. From Aston's data it became evident that the atomic weight was the weighted mean of the atoms' mass. Looking at the masses of each kind of atoms (which were predicted and called isotopes already before by Rutherford's collaborator Soddy) it became evident that the atomic weight of each individual isotope was (within the accuracy) an integer multiple of the Hydrogen atom.

Atoms can be changed

Whilst most experiments with radioactive substances aimed at analyzing the radiation, some researchers also attempted to modify atoms (artificial 'transmutation'). Initially, α -particles were used, they were shot towards matter and it could be observed that some atoms were able to integrate the α -particle in the nucleus, thus forming a new element. The first to establish this experiment was again Rutherford who could show that when α -particles are

sent through Nitrogen, Hydrogen and Oxygen are traceable. Rutherford's interpretation was that the Nitrogen nucleus was absorbing an α -particle, and the newly formed nucleus would immediately emit a hydrogen nucleus. This was the first successful attempt to modify an element and to create a new one – other such experiments quickly followed. Yet, it has to be understood that this is not a nuclear fission, this was still considered to be impossible.

Rutherford named the Hydrogen nucleus proton, and postulated that this proton is an elementary component of all nuclei. Yet, the mass of the nuclei does not form integer multiples of the mass of the proton, this was still a major problem. At the same time, two more questions still existed: Why can positive protons form the nucleus, and how to explain a β -decay. Rutherford assumed that also electrons exist in the nucleus and form pairs together with protons, and these pairs should keep the elementary particles in the nucleus together.

Among the researchers that tried to investigate the nucleus and the atom through interaction with α -particles were Irène Joliot-Curie (daughter of Marie Curie) and her husband Frédéric. They repeated some experiments which had been carried out in Berlin: Beryllium was irradiated with α -particles; as a result a significant radiation could be observed which they initially took as γ -rays. The particles of this radiation were not charged and appeared to have an extremely high energy. Even though the particles were not charged, they could interact with hydrogen and release electrons. Whilst the Joliot-Curies kept their interpretation of the result of their experiments being γ -radiation, James Chadwick, who was working with Rutherford, chose a different interpretation. According to Chadwick this radiation was to be explained with a new corpuscle and thus the radiation was a completely new type. Further experiments showed that the particles had a rest mass similar to the proton, and could be seen as the particle that replaces the proton-electron-pair Rutherford had assumed to explain the (relative) stability of the nucleus.

The neutron enabled further experiments on transmutation, as it is neutral, there is not the repulsive electrostatic force that was a problem in attempting to get an α -particle into the nucleus. Several researchers worked on

this field as it enabled the creation of new radioactive isotopes as well as new products of decay. Among those researchers were the Joliot-Curies in Paris, Fermi in Italy, and Hahn and Strassmann in Berlin. Both aimed at getting a neutron into the nucleus of Uranium, at that time the heaviest element to be known. The idea was to produce the so-called transuranium elements, elements with a greater atomic number than Uranium. This appeared to be the only possibility to develop new elements as the Periodic Table was considered to be complete.

Particularly the chemist Hahn was very unsatisfied with his results: It appeared that through his experiments, Uranium had been turned into Barium – which has significantly lesser atomic weight than Uranium. Hahn addressed this issue in a letter to the physicist Lise Meitner. She had been working with Hahn for a long time and recently had to flee to Sweden from the threat of fascist Germany after the so-called Anschluss of Austria. Meitner responded initially that such a result does not seem to be plausible.⁹ However, as she pointed out in the same letter, there had been so many surprises in the history of radioactivity that one could hardly say, this or that is impossible. Hahn insisted that he had verified Barium, and Meitner pointed out in another letter written a couple of days later that at least from the energetic point of view, a fission could have occurred. In a discussion she had with her nephew Frisch, Meitner came to the idea that possibly the model of the atom had to be thought like a drop – if an object with adequate energy hits that drop, breaks this drop into two smaller ones.

Hahn finally published his findings (together with Strassmann) and pointed out that for him as a chemist, he had to state that the resulting isotopes behave like Barium, yet he claimed that from the point of physics he was still not convinced that this element could be produced in such an experiment. This changed very quickly, and scientists immediately pointed out that in such a reaction not only a significant amount of energy would be released, but also

⁹ Before these experiments were carried out, however, the concept of nuclear fission had already been formulated by Ida Noddack already in 1934 when she was criticizing the discussion of Fermi in his experiments on transuranic elements.

other neutrons, thus, a chain reaction appeared possible.

Note that some audiofiles with Protagonists such as Thomson, Rutherford, Hahn etc. are to be found at
<http://www.aip.org/history/mod/fission/fission1/01.html>

I am indebted to D. Metz (University of Winnipeg) for his careful proof-reading as well as for comments on the previous version of this background material.

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Background atoms was edited by S. Klassen

Background atoms was written by Peter Heering with the support of the European Commission (project 518094-LLP-1-2011-1-GR-COMENIUS-CMP) and the University of Flensburg, Germany. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein