J P V Madsen & Beta Particle Scattering 1909.

Electron & Beta Particle History.

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Introduction.

In April 1909 J P V Madsen (1879-1969) published his paper “The Scattering of the Beta Rays of Radium” as a transaction of the Royal Society of South Australia which was later published in the Philosophical Magazine in London in December 1909. The apparatus devised by Madsen for his experiment of scattering Beta rays of radium through thin foils of aluminium, gold, copper & paper in some respects owes its design to earlier experiments by J J Thomson (1895-electron), E Rutherford (1899-Alpha, Beta particles of uranium) & J A Crowther (1907-Beta rays of uranium). An unexpected result of this paper was to draw attention to the single collision of a Beta ray with an atom discovered by analysis of the ratio of more scattered rays to less scattered rays being nearly constant for the 2 thinnest foils. [Slide 15ii]. This result was of the utmost importance to Ernest Rutherford (1871-1937) in early 1911 at Manchester who by analysing the large scattering of Alpha & Beta particles developed a unified theory to explain this scattering in terms of his nuclear atom first publicly announced at the Manchester Lit & Phil Society on 7 March 1911.

On 12 January 1911 Madsen delivered a paper to the Australasian Association for the Advancement of Science in Sydney on “The Scattering of Cathode rays” which was reported in the Telegraph newspaper the following day as “Radium Beta Rays-Atoms like solar systems-Beta rays the comets” which evidently was arrived at independently of Rutherford but based on a knowledge of the same experimental results.

In May 1911 Rutherford published a more developed paper after further tests by Geiger (1882-1945) on the Alpha scattering as proof of the theory & on 8 March 1911 Rutherford had written to Madsen in Sydney setting out his theory & asking for further tests on Beta scattering with thinner foils & a possible relationship to the atomic weight of Aluminium, Gold, Silver & Carbon.

The role of W H Bragg (1862-1942) at Leeds from 1909, after being at Adelaide University doing research with Madsen from 1904, was significant in that he drew to Rutherford’s attention the details of Madsen’s experiment in which he had a great deal of confidence.

A brief account of the early history of electrostatics & the electron up to 1895 is given & also significant developments of the electron after 1911 relating to energy levels in the atom (Bohr), X-ray scattering (Braggs & Moseley) followed by developments in the 1920’s on spin, sub-shells & wave energy.

A very comprehensive account of Madsen’s role in the development of Rutherford’s atom is given by John L Heilbron (1934-) from California in his paper “The scattering of Alpha & Beta particles & Rutherford’s atom” published in February 1968 which can be accessed on line by using a State Library or University card number. The main purpose of this paper is to support Heilbron’s thesis by preparing a table of Madsen’s results for the thinnest foils, from Madsen’s graphs, which demonstrate a calculation of the numerical ratio of the more to less scattered rays as being 1.3 for aluminium & 1.1 for gold.

This paper consists of notes to 22 slides which follow & a copy of J P V Madsen’s 1909 Phil Mag paper on Beta scattering.

1. Electron & Beta Particle History. (Bragg-Madsen Beta Particles & the 1911 Rutherford Atom).

After J J Thomson's 1897 experiment at Cambridge to confirm the existence of the electron, as a separate sub particle of the atom, he developed a theory of the atom as a "Plum Pudding" model in which target Beta particles would be bent around by multiple scattering & it was in contrast to this that Rutherford presented his case in 1911 for a nuclear atom where both Alpha & Beta particles could suffer a large scatter by a single collision with the central point charge.

Lawrence Badash (1934-2010) in his biography of Rutherford for Princeton University in 1975 states that "Thomson's multiple-scattering theory was challenged regarding Beta particle encounters, its area of special competence: John Madsen, in Australia, obtained data on Beta deflections that suggested that this type of scattering was done in a single collision".

In 1899, following Becquerel's discovery of uranium as a radioactive source, Rutherford by measuring the electrical conduction of uranium emanations which had passed through up to 13 layers of metal leaf (Slide 10) from 4 different uranium & thorium salts, could see that there were at least 2 separate particles of different penetrating power & possibly a 3rd. The less penetrating he called the Alpha & the more penetrating the Beta, which subsequently became identified as the Helium nucleus & the electron (the 3rd became the Gamma radiation). This simple electrical technique had a great many advantages (compared to the photographic) & was the central idea behind Madsen's 1908-1909 experiment, his other idea being for a "balanced" arrangement similar to J J Thomson's 1897 experiment (Slide 8) & which, in a similar way, was used by J A Crowther (1883-1950) at Cambridge in his 1907 Beta experiment with Uranium (Slide 13).

The use of graphs with the plot points marked against thickness (mass per unit area) on the X axis & electrical current on the Y axis was clearly the way data was presented, including by Madsen who extended it to show accurate derived information (Slide 15i. -curves A & B the more & less scattered rays).

W H Bragg (1862-1942) first presented a scientific paper in 1891 to the AAAS & Phil Mag on the subject of electrostatic theorems & Presidential Addresses of the Physics/Maths section in 1892 (Hobart) & 1904 (Dunedin) dealing with magnetism & the theory of ionization. In his lifetime Bragg authored over 290 papers & an early paper with Madsen was in 1907 on the ionization due to Beta rays. In 1896 Bragg's interest in the new Roentgen X-rays led to his demonstrations in Adelaide first using a borrowed Crooke's tube then with an X-ray tube made to his specification by his Lab technician Arthur Rogers (1860-1939) in June 1896 (Slide 6) & this marks his start into original research. A summary of the Bragg-Madsen Beta single collision experience of 1911 as portrayed by John Heilbron is at Slide 15. In 1903 Bragg gave an Extension Lecture on the electron & from his notes, under the Zeeman Effect the ratio e/m (charge to mass ratio) a factor of 10^7 is given & that e is negative. (The diameter of an atom at this time was given as 10^-8 cms) .

2. Early Electrostatics & Magnetic Poles.

The ancient Greeks knew that when a piece of amber resin is rubbed with wool or fur it is able to attract light objects such as feathers or pieces of straw & it is from the Greek word electron, meaning amber, that the adjective electric is given to describe the force of attraction. In 1539 the location of Magnetic North was vaguely conceived as the "Island of Magnets" off modern day Murmansk. A Norse hero "Starkad" is seen holding the rune staff as part of the first map of place names of Nordic countries.

The early European navigators & scientists believed that magnetic compass needles were attracted to a hypothetical “magnetic island” to the far north but by 1600 the north magnetic pole came to be defined as the point where the Earth’s magnetic field (Earth having been seen as a giant magnet) points vertically downwards, which is the current definition.. The North Seeking pole of a magnet was defined to have the north designation according to their use in early compasses & as opposite poles attract this means that as a physical magnet, the Magnetic North pole of the Earth is actually in the southern hemisphere. The direction of magnetic field lines is defined such that the lines emerge from the magnet’s north pole & enter into the magnet’s south pole.

3. Triboelectric Series & Benjamin Franklin.

By 1753 the Royal Society in London had recognized Benjamin Franklin’s (1706-1790) work with electricity. In October 1752 Franklin described his well known kites experiment (successfully extracting sparks from a cloud) in Philadelphia & subsequently noted that it was essential to stand on an insulator when doing this. In Franklin’s words of October 1752: “At this key the Phial may be charged & from the Electric Fire thus obtained, spirits may be kindled, & all the other Electric Experiments be performed, which are usually done by the help of a rubbed glass globe or tube & thereby the sameness of the Electric Matter with that of Lightning completely demonstrated”.

By rubbing glass with silk & sealing wax with wool, Franklin got a spark between the glass & wax when brought close together. The idea developed that there were 2 kinds of electricity & that opposite kinds of electricity attract one another, whereas similar kinds repel one another. In the case of the glass rod Franklin described this as being positively charged, meaning that it had an excess of the electric fluid that had been transferred to it from the silk, & the silk cloth had a deficiency & hence was negatively charged. Franklin admitted that he did not know in which direction the electric fluid had been transferred but as an arbitrary decision, positive being the excess of the electric fluid was taken to be on the glass rod. It is known however that when the glass rod is rubbed with a silk cloth, negatively charged particles, the electrons, are transferred from the glass rod to the silk, & that Franklin thus made the wrong decision.

The direction of the movement of electrons between 2 materials which are rubbed together has been tabulated in the Triboelectric series going from positive to negative as shown on Slide 3.

4. W Whewell, M Faraday & W Crookes.

William Whewell (1794-1861) of Trinity College Cambridge, like Franklin was a polymath & in science there are terms coined by him such as “scientist”, “physicist” & including those as suggested to Michael Faraday (1791-1867) the terms “electrode”, ïon”, “anode” & “cathode”.

As a chemist Faraday discovered the laws of electrolysis & hence are known as Faraday’s Laws viz: 1. The quantity of electrolyte decomposed is proportional to the quantity of electricity which passes & 2. The mass of any ion liberated by any quantity of electricity is proportional to the chemical equivalent weight of the ion. When a current is passed through an electrolyte, such as sulphuric acid in water, by dipping 2 platinum plates into the solution & connecting one of these, called the anode with the positive pole of a battery & the other called the cathode, with the negative pole, decomposition of the electrolyte will accompany the passage of the current.

William Crookes (1832-1919) was both a chemist & physicist from England who was a pioneer of vacuum tubes & in 1875 invented the Crookes tube which was of very great significance to both fields of science. In his investigations of the conduction of electricity in low pressure gases, he discovered that as the pressure was lowered, the negative electrode (cathode) appeared to emit rays- “cathode rays” ie. a stream of free electrons. (Faraday & Geissler {1814-1870] had used comparable devices in the 1830s & 1850s). One of Crookes most famous tubes is the Maltese Cross Crookes tube used to demonstrate that cathode rays travel in straight lines. Crookes included a paddle wheel in 1879 that turned when bombarded with cathode rays & he used a Y shaped tube to show that cathode rays would travel towards an anode even if it was not located directly in front of the cathode. Crookes found that cathode rays can be bent by a magnetic field & was the first to note the dark space near the cathode at very low pressure.

5. Joachimsthal, J Plucker & G Stoney.

Joachimsthal (now known as Jachymov) in the Ore Mountain region of the Czech-German border, in 1518 became a major silver producing location where the Joachimsthaler coin was produced (shortened to “thaler” & in the Spanish known as the “dollar”) The silver coins were produced in various forms from 1566 to 1875 & the mine tailings known in German as “pechblende” enjoyed a renewed value with the discovery of uranium in the pechblende in 1789 by a German chemist & new boom followed for some years. In 1898 the Curies (Pierre [1850-1906] & Marie [1867-1934]) isolated a sample of Radium from the Joachimsthal pechblende which created interest as a possible medical treatment as well as for scientific investigation.

Julius Plucker (1801-1868), professor of physics at the University of Bonn from 1835 & working with a colleague Heinrich Geissler (1814-1879) using vacuum tubes found that the action of a magnet on the electric charge in rarefied gases caused a fluorescent glow to form on the glass walls of the vacuum tube & that the glow could be made to shift by applying an electromagnet to the tube & later it was shown that the glow was caused by cathode rays. Plucker identified that the lines of the spectrum were characteristic of the chemical substances which emitted them & was apparently the first to see the 3 lines of the hydrogen spectrum.

George Stoney (1826-1911) published his scientific papers mainly through the Royal Dublin Society (he was an FRS in 1861) the most important of which was his conception & calculation of the magnitude of the “atom of electricity”. In 1891 he proposed the term “electron” to describe the fundamental unit of electrical charge which he calculated to be 1/16 th of the modern value.

6. Roentgen & Bragg X-rays 1896.

In November 1895 Wilhelm Roentgen (1845-1923) at the University of Wurzburg was working with vacuum tubes by passing an electrical discharge through them of different voltages. In darkness Roentgen noticed a shimmering effect coming from a nearby bench & speculated that a new type of ray might be responsible & over the next 6 weeks working in secrecy he was able to produce an image of his flickering skeleton & then a clear picture of his wife’s hand using his x-rays. Roentgen’s original paper “On a new kind of rays” was published on 28 December 1895 & he observed that the rays are not deflected by a magnet, could penetrate matter impervious to ordinary light & could produce fluorescence in various substances & blacken a photographic plate.

Following Roentgen’s discovery, W H Bragg at Adelaide University arranged a similar experiment in late May 1896, using a borrowed Crookes tube from Samuel Barbour the Chemist at F H Faulding & Co & a battery & induction coil from his father-in-law, Charles Todd (1826-1910) & was able to produce an X-ray image of his hand taken by Arthur Rogers on 1 June 1896 in which a childhood injury from his father’s turnip chopping machine can be seen.

Bragg was able to have Arthur Rogers make an X-ray tube to his specification & it is thought to be the 1st successful X-ray tube made in Australia. In 1896 also, X -ray tubes were made in Ballarat by J (John) M Sutherland (1877-1963) in the Electrical Dept of the Ballarat School of Mines.

The schematic of a cold X-ray apparatus is shown which is typical of how they were made up to the 1920's when they became "hot" X-rays with electron emitters.

7. Henri Becquerel 1896 Radioactivity.

Professor Henri Becquerel (1852-1908) in Paris in February 1896 after Roentgen's discovery of X-rays conducted experiments with uranium salts (probably uraninite-uranium oxide U3O8 from Joachimsthal) passed on to him by his father Prof. Edmund Becquerel (1820-1891) who was interested in light (& discovered the photovoltaic cell) & phosphorescence. The experiments were to see if the uranium emanations were the same as X-rays but by accident he discovered that uranium salts spontaneously emit a penetrating radiation that can be registered on a photographic plate but it became clear that the radiation was something new & not X-ray radiation. Becquerel & the Curies shared the 1903 Nobel Physics prize for their work on radioactivity, as was Rutherford in 1908 for Chemistry.

8. J J Thomson 1897 Electron.

Prof. J J Thomson (1856-1940) in April 1897 at the Cavendish set out in his Phil Mag paper on Cathode Rays details of his tests to examine the electrified-particle theory. Thomson carried out a refinement of Jean Perrin's (1870-1942) experiment of December 1895 to show that something charged with negative electricity is shot off from the cathode, travelling at right angles to it & will be deflected by a magnet & further showing that however we twist & deflect the cathode rays by a magnetic force, the negative electrification follows the same path as the rays, & that this negative electrification is indissolubly connected with cathode rays.

The essential feature of Thomson's experiment (illustrated by the 2 schematics) is to mathematically equate the electric & magnetic forces applied to the cathode rays such that they are counterbalanced to fluoresce on the centre scale of the outside glass.

The electrodes used by Thomson were generally made of aluminium with an 1800 volt difference between the cathode & anode. The deflection of cathode rays by an electrostatic field gets smaller as the pressure diminishes & the cathode voltage increases. The velocity of the cathode rays at the pressures used in the experiment exceeded 10^9 cm/sec & the e/m in air was calculated to be 7.7 X 10^6. With a mass of 1/2000 that of hydrogen. Thomson received the 1906 Nobel Prize in Physics for his electron discovery.

9. Pierre & Marie Curie, Radium 1898.

Pierre (1859-1906) & Marie (1867-1934) Curie met in 1894 while working on magnetism. As a thesis topic in 1896 Marie chose to investigate Becquerel's X-rays being rays of a peculiar character & using piezoelectric equipment designed by Pierre to measure tiny amounts of energy being released by uranium & also thorium. Marie started to study uranium & thorium ores & was surprised to find that pitchblende was much more active than it should be from its uranium content & there had to be another radioactive element in pitchblende not already recognized. With Pierre's assistance & after much chemical analysis they ended up with something about 300 times more active than uranium which they called Polonium & a few months later they discovered another new radioactive element, Radium. To prove the existence of these elements tons of pitchblende had to be processed by hand & after a year they realized that radium was easier to separate out than polonium & by 20 April 1902

Marie had been able to collect about 1 decigram of almost pure Radium Chloride. (1 gramme of pure Radium metal requires about 7 tonnes of pitchblende).

In 1911 Marie won a 2nd Nobel Prize, this time in Chemistry. The Institute of Radium is in Paris including recognition of work by daughter Irene (1897-1956).who also won the Nobel Prize in 1935.

10. Rutherford & the Alpha-Beta particles 1899.

In January 1899, Rutherford then recently Professor of Physics at McGill University in Montreal , published a paper [the paper was written in September 1898 whilst at the Cavendish Lab] in the Phil Mag “Uranium Radiation & the Electrical Conduction produced by it” in which the method of investigation was far superior to the photographic method which was subject to long time delays. The object of the paper was to investigate in more detail the nature of uranium radiation following the results of Becquerel who showed that Roentgen & uranium radiations were very similar in their power of penetrating solid bodies & producing conduction in a gas exposed to them but there was an essential difference between the 2 in that uranium could be refracted & polarized, while no definite results showing polarization or refraction have been obtained for Roentgen radiation.

Rutherford’s simple method was to use 4 different sources of uranium & thorium passing emanations through up to 12 layers of different foils & to measure the “leak” or conduction, by an electroscope. The graph of his results for “Rate of Leak” on the Y axis plots against the X axis in thickness of Aluminium in divisions of 0.00012 cm & indicated that at least 2 types of radiation were apparent which he called the Alpha & Beta. Rutherford also had tables of his data including successive ratios of the leak for the layer numbers of aluminium foil.

11. Bragg & Radium supplies 1903-1904.

In the first isolation of Radium, the Curies used the residue after extraction of uranium from pitchblende using sulphuric acid leaving radium sulphate. Several steps were involved leading to the separation of sulphates by fractional crystallization monitored by spectroscope where radium gives characteristic red lines in contrast to green barium lines.

Several scientists started to isolate radium in small quantities & also small companies purchased mine tailings from Jachymov (Joachimsthal) & started isolating radium. In 1904 the Austrian Government nationalized the Jachymov mines & stopped the export of raw ore so as to create a monopoly.

In May 1904 W H Bragg obtained from W G Pye in Cambridge 15 mg of Radium Bromide & at this time in London Armbrecht, Nelson & Co as well as Mr Isenthal were selling Radium Bromide quite cheaply (probably 50% radium). Frederick “Fritz” Geisel (1852-1927) a German chemist who worked at a quinine factory in Braunschweig became interested as a side line in radiochemistry & the production of radium as early as mid 1899 & published his results on Radium. Using bromides instead of the chlorides for fractional crystallization he produced large quantities of pure radium & polonium for commercial applications from uranium ore.

Madsen, in March 1911, with the assistance of Rutherford & Bragg purchased 30 mg of Radium Bromide from Geisel at the by then expensive price of 500 pounds which was to replace a loaned supply from Dr H Laurence, a Melbourne dermatologist who appears to have obtained his radium in London in 1903 whilst on an overseas trip.

12. Planck & Einstein- Quantum Physics.

The German scientist Max Planck (1858-1947) in 1900 proposed a theory to explain the emission & absorption of light of a given wavelength by hot bodies whereby the hot body must emit or absorb a certain quantum of energy of light of that wavelength. Although Planck's theory did not require that light itself be considered as consisting of bundles of energy- light quanta or photons- it was soon pointed out by Einstein (1879-1955) in 1905 that other evidence supports this concept. [light of short wavelengths consists of large bundles of energy & light of long wavelength of small bundles of energy].

In July 1910 Madsen wrote to Bragg that he had engaged a translator to translate Einstein's publication as his own German was not sufficiently satisfactory. The quantum theory was central to Niels Bohr's (1885-1962) theory of the atom as an enhancement to Rutherford's whereby electrons orbit the nucleus of the atom at specific energy levels depending on their position in the periodic table's 7 periods.

13. J A Crowther 1907 Beta Experiment.

In the introduction to Madsen's 1909 Beta paper, he points out that J A Crowther (1883-1950) at the Cavendish had recently shown that the Beta rays are subject to scattering by even very thin layers of material & it has become of special interest to see whether any parallel can be drawn between the effects of scattering in the case of the material Beta particles & the gamma rays { with which Madsen was familiar in his March 1909 paper to Phil Mag on "Secondary gamma Radiation}. In conclusion Madsen states that his experiments with the Beta rays of Radium support the results previously obtained by Crowther using uranium, upon the scattering of the rays of thin films of material.

The experimental arrangement used by Crowther as described in his paper "On the scattering of the Beta rays from Uranium by matter" of December 1907 was to have a compensation or balanced method of measurement to give greater sensitivity whereby 2 identical chambers are arranged so that one had a shutter that could be opened or closed to regulate the amount of radiation entering this chamber until it equalled the measurement of the first & thereby give an accurate measurement. Crowther's results were graphed for Aluminium, Copper, Silver & Gold by mass per unit area on the X axis & also tables of data for Aluminium.

In Crowther's book "Ions, Electrons & Ionising Radiations"8th edition in 1952 at para 118 "Rutherford's theory of the scattering of Beta particles" he acknowledges that the results of scattering with very thin foils are in general agreement with Rutherford's theory of 1911 that scattering of both alpha & beta particles follow the same laws-"mutatis mutandis".

14. Rutherford-Geiger-Marsden Gold Foil Alpha Scatter 1908.

In July 1909, Hans Geiger (1882-1945) & Ernest Marsden (1889-1970) published a paper "On a diffuse reflection of the Alpha particles" in which they state that Beta particles falling on a metal plate are scattered to such an extent that they emerge again at the same side of the plate & for alpha particles a similar effect has not previously been observed, which perhaps is not to be expected, however from their experiments conclusive evidence has been found of the diffuse reflection of the alpha particles. A small fraction of the alpha particles falling upon a metal plate have their directions changed to such an extent that they emerge again at the side of incidence. The experiments used different metals of different thicknesses & the fraction of the incident alpha particles which are reflected, measured.

This was quite astonishing to Rutherford who came to realise the enormous forces which were involved in the nucleus of the atom& took 2 years of consideration before proposing his nuclear theory of the atom in 1911.

15. J P V Madsen 1909 Beta Scattering Experiment.

The experiment was first published in January 1909 by AAAS & was carried out in Adelaide before Bragg left for Leeds & Madsen had returned to Sydney University, in 1909.

In the description of his experiment Madsen points out that because the initial effect of the Beta rays being reflected was so large it was necessary to use a balanced chamber (Fig II) so that the effect to be measured could be accurately obtained. This involves 2 measurements in the balanced chamber for each foil of which there were approximately 10 for each material (Aluminium, Gold, Silver & paper). None of Madsen's experimental notebooks or apparatus have survived & it is only from the 6 curves of the 4 graphs with each measurement marked that the calculations for the 2 derived curves (A & B) can be proven ie. The More & Less scattered rays. It is evident that the number of calculations in the main chamber with 3 positions (A,B,C) for each foil & each material is probably approximately 300 including the ratio calculations. The recorded curves C, D, E & F have the following relationships: C=D-E (the total emergent radiation), Graph A (foil positions B-C) + Graph B (foil positions A-B) = Graphs D-E (=the foil positions A-C).

Of interest from the point of view of Madsen's deduction that when the scatter ratio (Graph) A/B remains nearly constant for the 2 thinnest foils of each material, only a single encounter with an atom by an electron has occurred, is the table drawn up by the author which shows that for Aluminium this constant was 1.3 & for Gold 1.1 & that the number of atoms through which these encounters have occurred is approximately 148,000 & 13,000 respectively for Aluminium & Gold.

John Heilbron (1934 -) [left photo] & Lawrence Badash (1934-2010) both from America, have dealt with the significance of Madsen's data on the single scatter by Beta particles. Heilbron in 1967 gives a very favourable account of Madsen's 1909 paper in relation to Rutherford's 1911 theory in contrast to the work of J J Thomson & J A Crowther which in summary he states:

1.(page 283) The Thomson-Crowther (1910 paper) approach at Cambridge was suspect at Manchester not only because of the implications of Geiger's work, it also conflicted with results of exceptional importance on the scattering of Beta particles by thin foils, precisely its field of competence, which had been published in the Phil Mag for December 1909 by J P V Madsen.

2.(p283) Madsen's paper seems not to have attracted much attention at the Cavendish, perhaps because its author was Lecturer in Electrical Engineering at the University of Adelaide.

3.(p283) Madsen pointed out that when the ratio of large to small scattering is practically constant, we are concerned with only a single collision of any Beta particle.

4.(p284) The opposition between this conclusion & the multiple scattering theory Thomson was shortly to propose, could not be clearer. Madsen's conically collimated beams supported his conclusions, but if one accepted them, one would have to jettison the entire Thomson-Crowther approach.

5.(p284) Here Bragg played a key role. He knew Madsen, whom he had taught in Australia, & respected his work.

6.(p285) Following the ideas of Bragg & Madsen that the scattering of Beta rays arose from a single collision, Rutherford shared these views & the "Manchester Approach" to the scattering of Alpha &

Beta rays rested on the hypothesis of single encounters & the belief that the same process scatters both kinds of rays.

7.(p294) Bragg responded on 12 February 1911 to Rutherford's request that Bragg should write down his objections to Crowther's paper of 1910 ("On the scattering of homogenius Beta rays & the number of electrons in the atom") with a grand slam at Crowther & a re-affirmation of the theory of single scattering. Madsen's original experiment on the scattering of Beta rays (December 1909 Phil Mag) showed quite clearly that the distribution of scattered rays amongst themselves was not at first a function of the thickness of the plate, for these rays well deflected. I have always held that the meaning of that was that they suffered but one deflection that counted & this makes everything much clearer as well as more interesting.

8.(p299) Finally Rutherford in his May 1911 paper comes to grips with the enemy, though there is little he can say in print of his feelings about Crowther's experiments. He points out that 2 tests fail to discriminate between the theories & that the peculiar bend in the Thomson-Crowther curve conflicts with the extrapolations from Madsen's results & "considering the importance of the point at issue" he writes "further experiments on this question are desirable".

9. (p290) Rutherford in a letter to B Boltwood (1870-1927) on 14 December 1910 refers to his new theory & about this time described it to Bragg who responded in a letter of 21 December 1910 in which he says "the atom sounds fine".

16. Rutherford's 1911 atom, Manchester.

John Dalton's (1766-1844) theory of atoms as billiard balls began in 1800 when he became Secretary of the Manchester Literary & Philosophical Society & previous papers on gases. Also at the Lit & Phil on 7 March 1911 it was that Rutherford first publicly announced his theory of the nuclear atom. In 1904 J J Thomson had suggested his plum pudding model of the atom incorporating negatively charged electrons surrounded by a volume of positive charges so that there was no net charge.

On 8 February 1911 Bragg wrote to Rutherford describing a model of an atom he had shown at an RI discourse: "6 upright electromagnets which stood upright in a hexagon about 3 inches apart & a swing electromagnet which just cleared the 6. The latter could be made to stand up stiffly to represent a lead atom or on spiral springs so as to give way readily & represent an aluminium atom & it was quite interesting to see the way the swinging magnet went through the atom if its speed was great enough: as it died down it got through with greater & greater difficulty & spent energy setting the 6 rocking on their springs: finally it could not get in at all & just kept hammering at the outside. It would be quite easy to put a big positive as the centre or any number of positive or negative arranged anyhow; your big positive centre could be illustrated quite easily. When you give me permission I'll put a big positive or negative at the centre & watch the movements".

In Madsen's discourse to the AAAS in Sydney on 12 January 1911 he described the atom as he saw it based on many experiments in recent years as follows: " The atom would appear to be similar in some respects to a solar system the centre or nuclei being electrons possessing some form of orbital motion, their negative charge being compensated for by corresponding positive charges occupying the whole extent of the atom, but large compared to the electrons. The passing of a Beta ray through such a system with a given velocity would be similar to the movement of a comet. Such comets proceeding into a solar system with a given velocity are deflected more the nearer they approach any one of the centres of the system. In the special case when the approach is very close the collisions may result in the complete absorption of the comet. In general however a large number of comets passing at random through the system will suffer little deflections: a smaller number will have their direction of motion almost reversed".

The 1913 Bohr atom incorporated the idea of quantum energy held by electrons at different levels around the nucleus & the 1926 version of the atom further refined the position of the electrons into various orbitals.

The schematic of the trajectory of particles in the Coulomb field of a target nucleus shows the impact parameter "b" & the scattering angle phi. In Rutherford's letter to Madsen on 8 March 1911 his "Abstract of Theory" uses the following parameters which can be considered in relation to the schematic:

Ne=Central charge on atom

E=Charge on scattered particle

M=its mass

U=its velocity

Phi=angle of deflection

P=Perpendicula distance from centre of atom on direction of motion of entering particle [shown as "b"on the schematic]

ER then states "If we suppose the central charge positive, an alpha particle directed straight to the centre of the atom will be turned back at a distance: b=2NeE/mu^2 ; b is an important constant".

17. Wilson Cloud Chamber 1911.

The cloud chamber which came to fruition in 1911 at the Cavendish by Charles Wilson (1869-1959) & for which he received the Nobel Prize in Physics in 1927, was initially put to very great use in plotting the track of alpha particles & by 1925 at the Cawthron Lecture in NZ ER states that " Photograph Fig 2 will show that at one point an electron encountered an atom & liberated another electron which came out at a fairly high speed & ionized other molecules encountered in its path. At another point it may be found that the encounter with the atom has turned the path of the electron through a right angle. The Alpha particle track is shown in Fig 1 by course lines whereas the electrons moving at approximately 100,000 miles a second are shown by faint lines only. These effects were first deduced by theory & experiments in 1911".

18. Niels Bohr & Hydrogen Spectra 1913.

Niels Bohr (1885-1962) further developed Rutherford's 1911 nuclear atom by proposing that the electrons revolve in stable orbits around the nucleus but can jump from one energy level to another- in the case of an electron dropping from a higher energy orbit to a lower one, a quantum of discrete energy is emitted. Bohr analysed the spectral lines of hydrogen from the Balmer series of 1885 & was able to derive from his model explanations for lines such as those of ionized helium.

19. Bragg X-ray Spectometer, H G Moseley.

W H Bragg became interested in X-ray crystal diffraction following the publication of the German Max Von Laue (1879-1960) in June 1912 on X-ray diffraction recorded on a photographic plate, for which he obtained the Nobel Physics Prize in 1914. The X-ray spectrometer or Bragg's Ionisation Spectrometer developed by W H Bragg at Leeds University in the winter of 1912-1913 appears in some respects to owe its design from his experiences at Adelaide University on X-rays, ionization & familiarity with Madsen's Beta scattering experiment which he described as "striking".

Bragg's Law was first presented by W L Bragg (1890-1971) on 11 November 1912 in Cambridge & was soon known as a very powerful tool for crystal research. The Braggs describe their spectrometer as being able to measure variations in the scattering angle arising either as a result of variations in wavelength or as a result of variations in interplanar spacings in crystals.

The X-ray tube is operated from an induction coil which provides intermittent high voltage. The X-rays pass from the target through a hole in a lead screen & strike the crystal mounted on a graduated turntable. Reflected X-rays pass through a slit of variable width into an ionization chamber which records their intensity & which also is independently rotatable.

Henry Moseley's (1887-1915 Gallipoli) spectra of various chemical elements (mainly metals) obtained in 1913 using Braggs diffraction showed that elements could be placed in their correct positions in the periodic table based on atomic numbers & in fact was able to identify missing elements in the table thus confirming the sound physical basis of chemical data- Moseley showed that the periodic table was arranged by the charge of the protons in the nucleus.

20. Radium Hill 1913, Belgian Congo 1917, Radium paint.

Radium Hill in the Olary area of South Australia was first found to have Radium deposits in 1906 & by November 1911 Madsen was able to tell W H Bragg that S Radcliffe the Chemist for the Radium Company was to come to Sydney at Woolwich where processing of the ore was to be carried out & at the then current high prices of Radium the business should do well. The supply of radium was increased significantly in 1917 by the discovery of high grade ore in the Belgian Congo causing the price to fall & the Sydney operation folded. In America deposits were also found in Colorado & the demand for radium as a luminescent paint on instruments at night, particularly for military use increased although the extremely negligent practice imposed on female workers of requiring them to lick the tip of radium paint brushes led to horrendous injuries.

21. Electron Spin 1925 & Sub shells.

The spin of the electron as rotation about an axis similar to the Earth was discovered in 1925 by 2 Dutch physicists G Uhlenbeck (1900-1988) & S Goudsmit (1902-1978). A free electron can orient itself in either one of 2 ways as in parallel up to the field or in anti parallel.

It appears that the final version of the electron shell arrangement comes from 1925 & Wolfgang Pauli (1900-1958) with his exclusion principle & the Afbau principle where electrons 1st fill sub shells of the lowest available energy.

In 1924 Louis de Broglie (1892-1987) in Paris found a striking analogy between the properties of electrons & the properties of photons if a moving electron was assigned a wavelength now called the de Broglie wavelength of the electron which decreases with the increase in velocity.

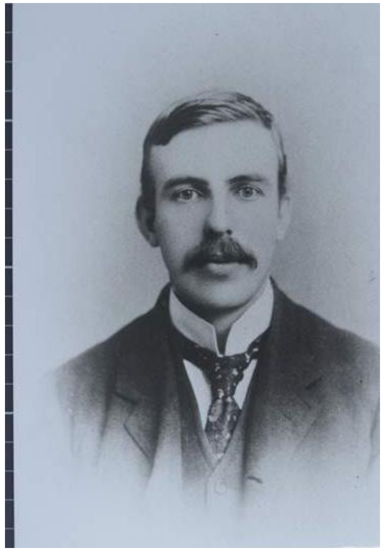
The electron negativity of an element is the power to attract electrons in a covalent bond. Approximate scales have been drawn up such as by Linus Pauling (1901-1994). The farther away 2 elements are from one another in the electronegativity scale the greater is the ionic bond between them.

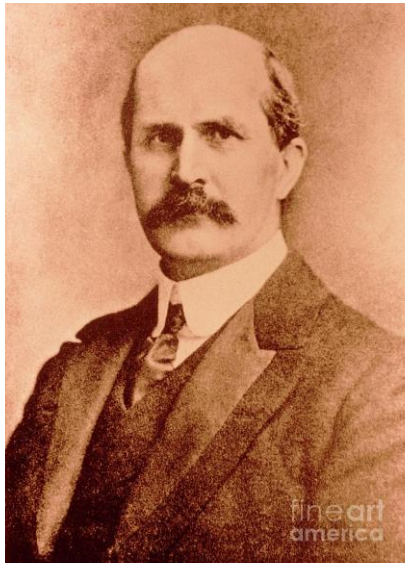
22. Beta Backscatter

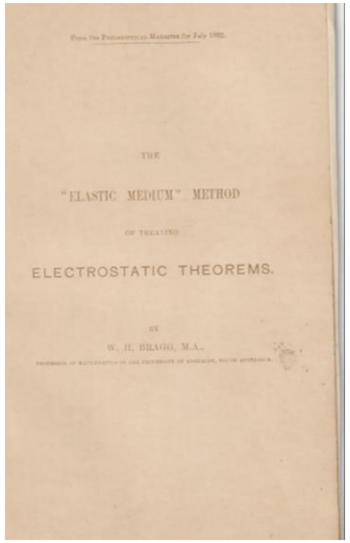
A modern day use of Beta Backscatter is with instruments using strontium 90 isotopes to produce electron beams which are scattered backwards to allow the calculation of the thickness of thin coatings covering steel & non-ferrous metals with at least a 20% difference in density from the coating to the substrate.

1.Electron & Beta Particle History

Bragg-Madsen Beta Particles & the 1911 Rutherford Atom.







THE

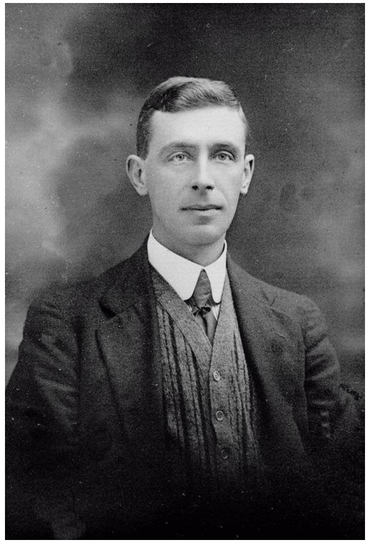
"ELASTIC MEDIUM" METHOD

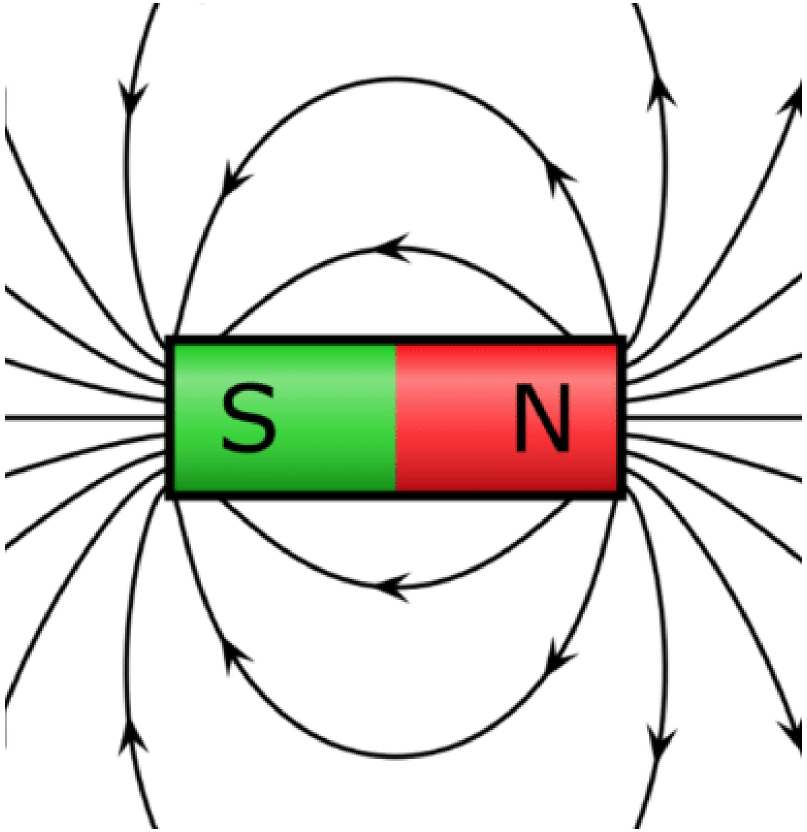
OF TREATING

ELECTROSTATIC THEOREMS.

BY

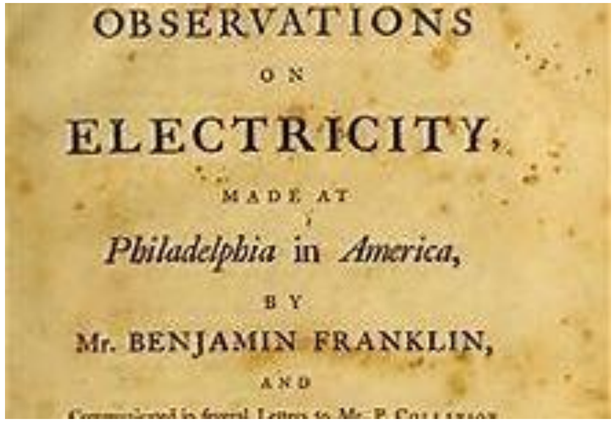
W. H. BRAGG, M.A.,



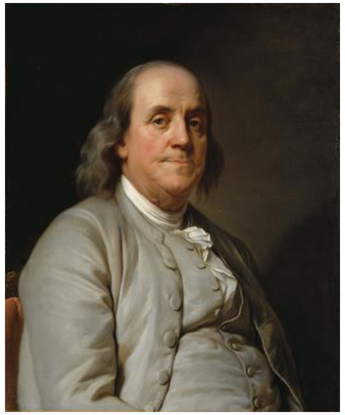


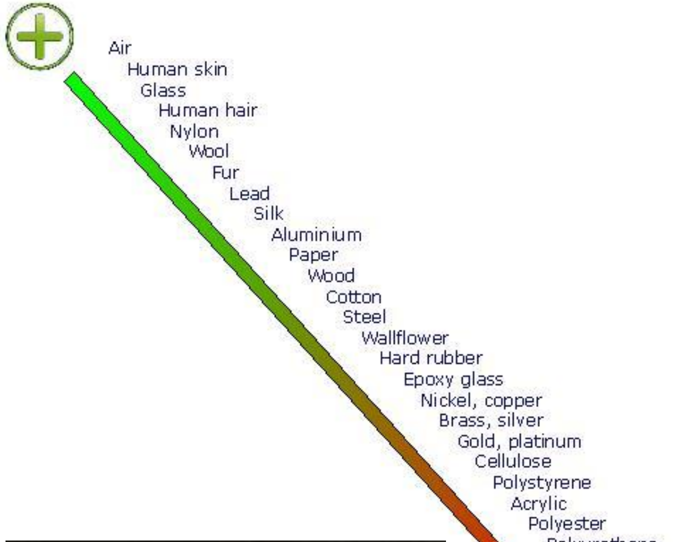
2.Early ElectroStatics & Magnetic Poles.

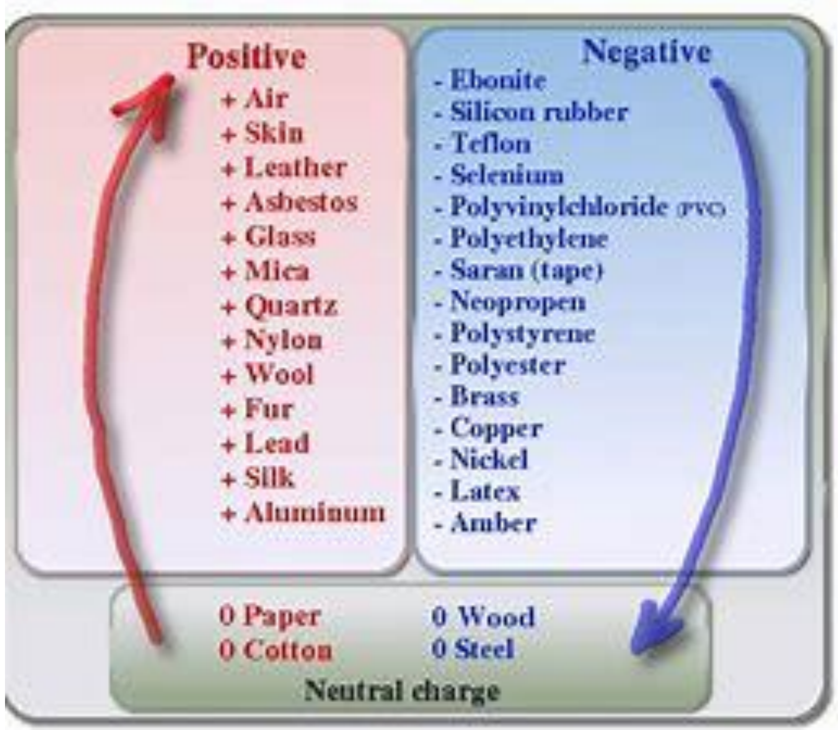
3.Triboelectric Series & Benjamin Franklin.



OBSERVATIONS
ON
ELECTRICITY,
MADE AT
Philadelphia in *America*,
BY
Mr. BENJAMIN FRANKLIN,
AND





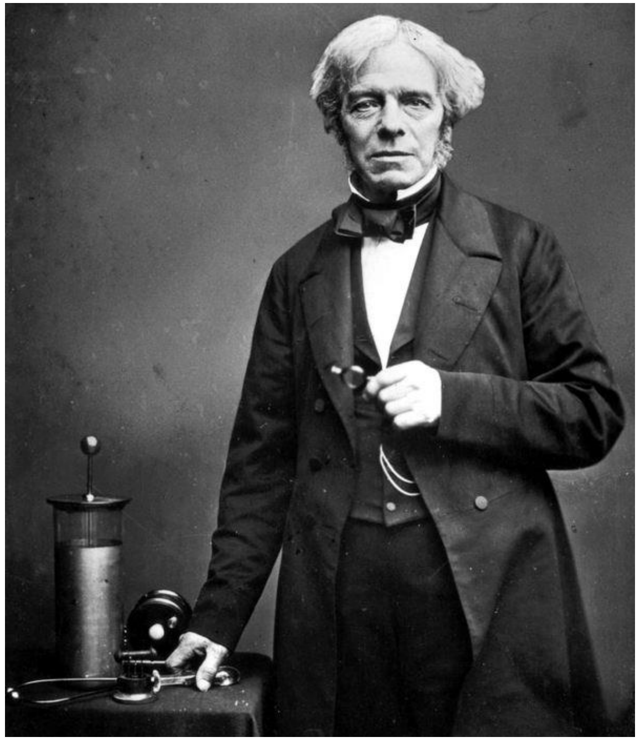


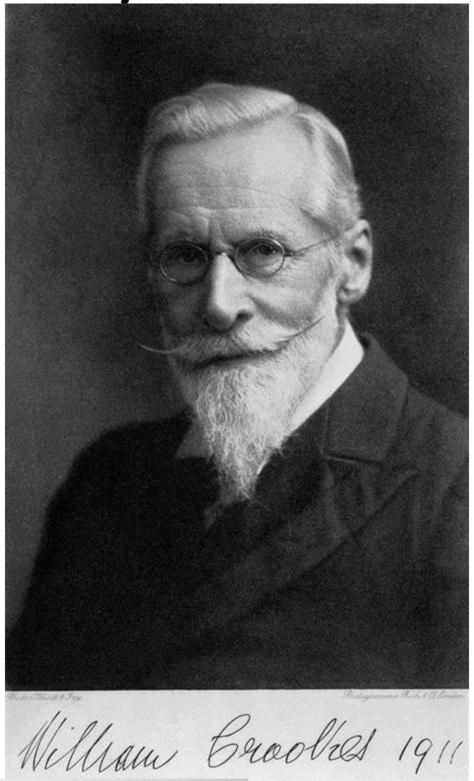
Positive	Negative
+ Air	- Ebonite
+ Skin	- Silicon rubber
+ Leather	- Teflon
+ Asbestos	- Selenium
+ Glass	- Polyvinylchloride (PVC)
+ Mica	- Polyethylene
+ Quartz	- Saran (tape)
+ Nylon	- Neopropen
+ Wool	- Polystyrene
+ Fur	- Polyester
+ Lead	- Brass
+ Silk	- Copper
+ Aluminum	- Nickel
	- Latex
	- Amber

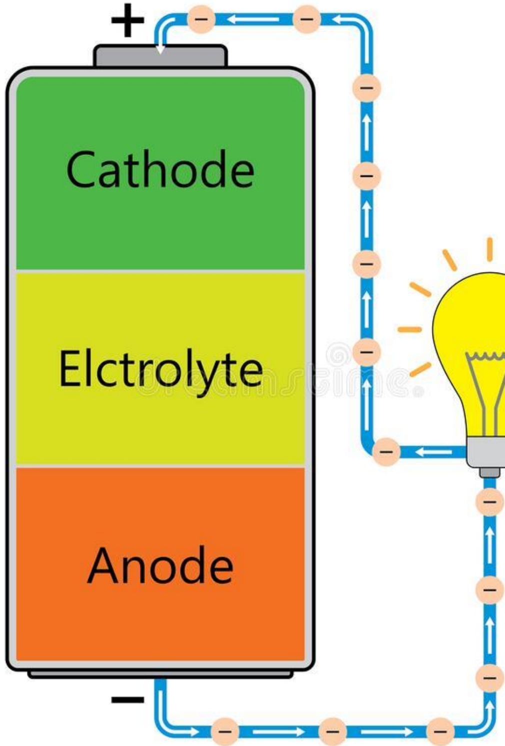
0 Paper	0 Wood
0 Cotton	0 Steel

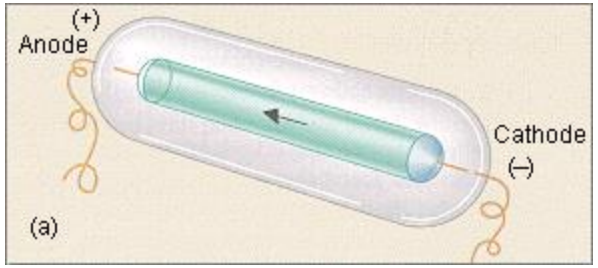
Neutral charge

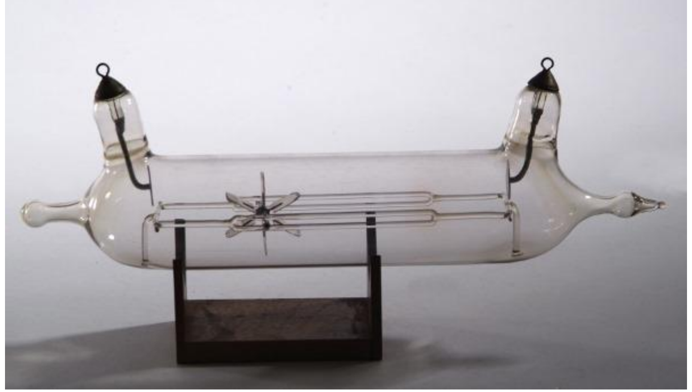
4. W. Whewell, M. Faraday, W. Crookes



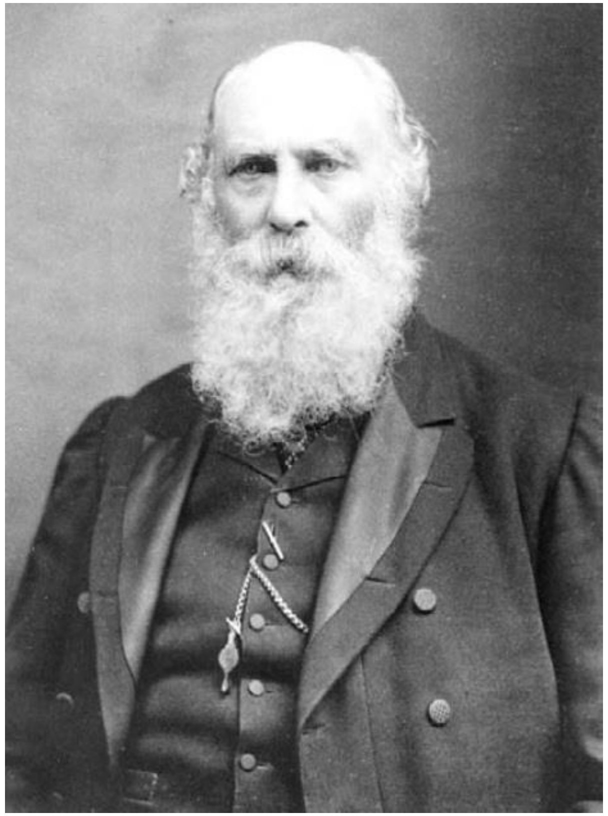




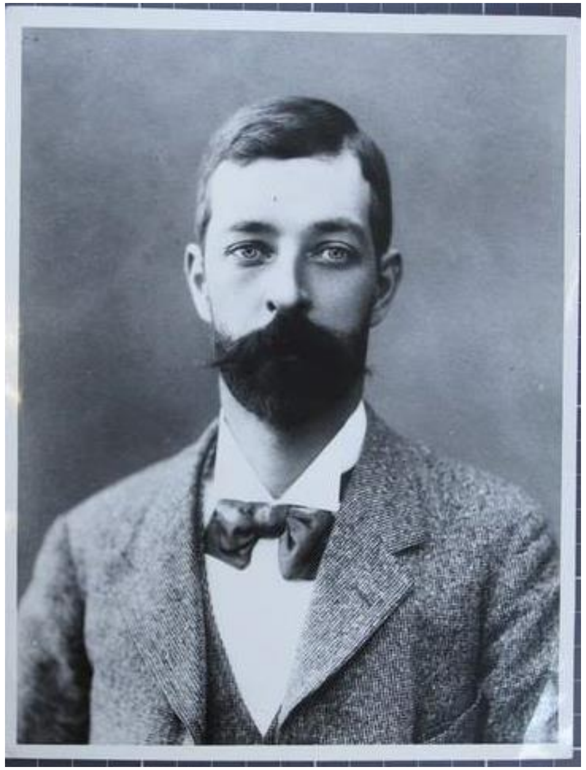




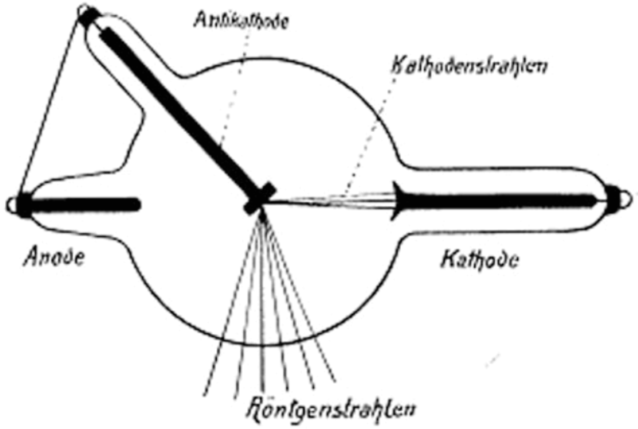
5. Joachimsthal, J.Plucker, G. Stoney.



6. Roentgen & Bragg X-rays 1896.

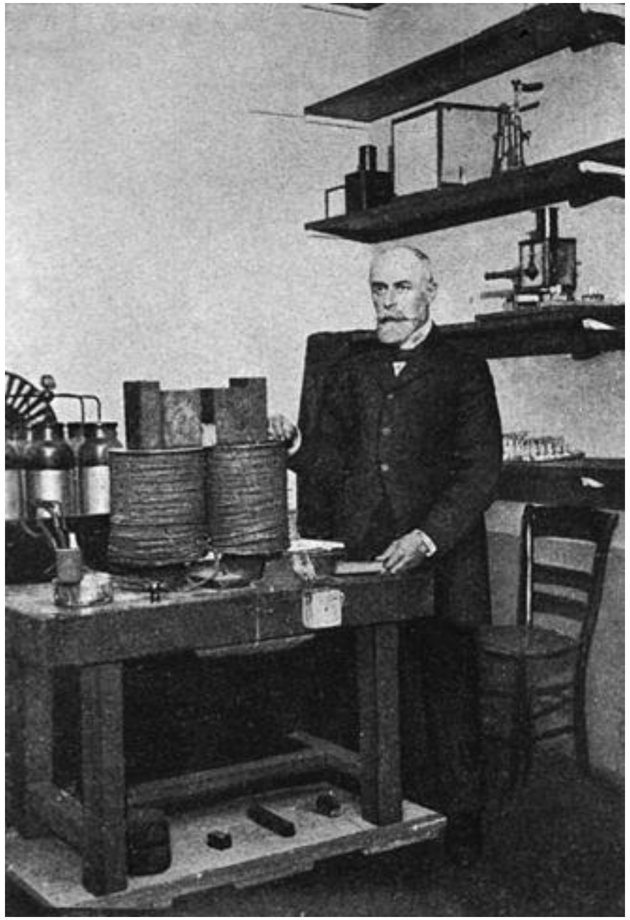


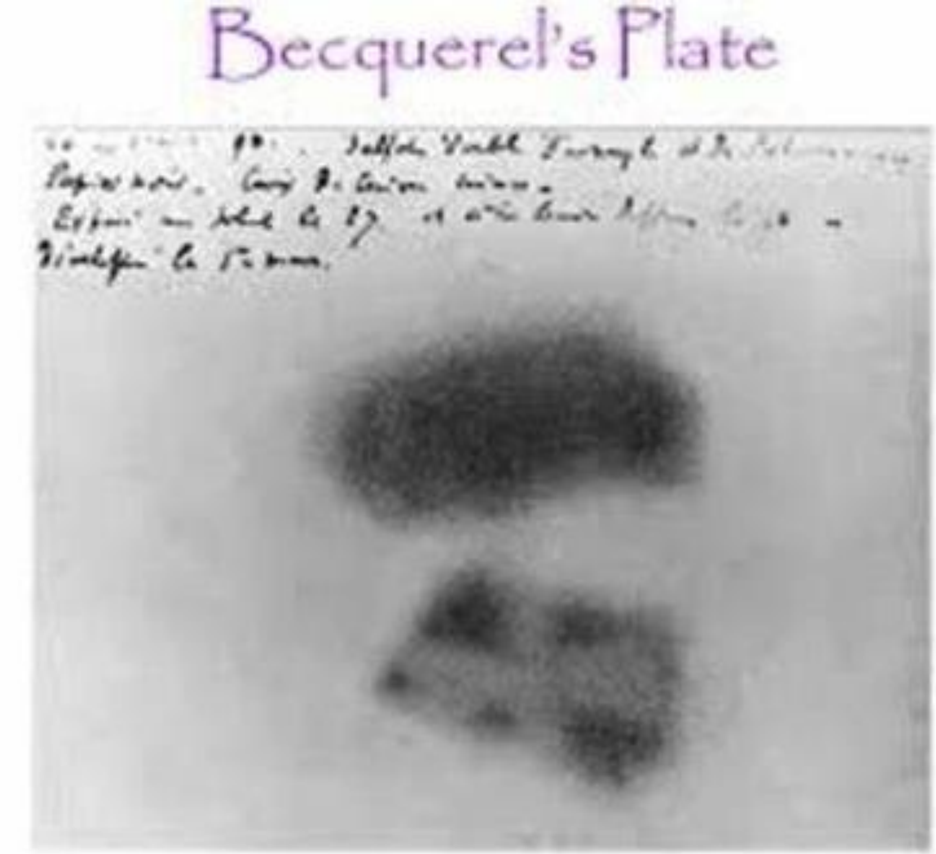
These x ray tubes
were used in 1896 by Mr. T.M. SUTHERLAND.
of this school, in pioneer work on
x rays in Australia
→ See "Salute to the Pioneers of x rays"

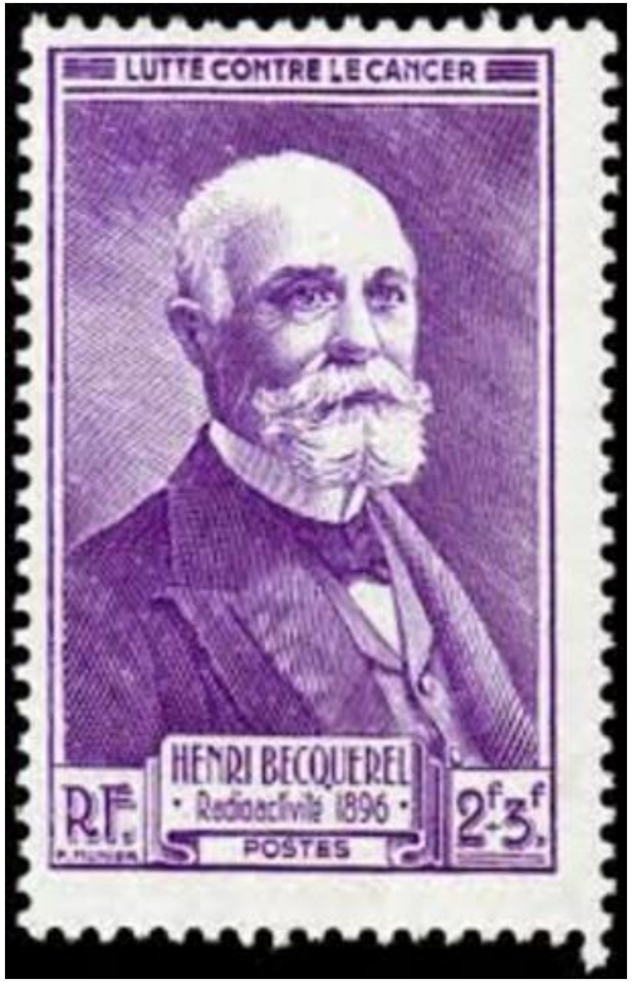


THE BRAGG X-RAY TUBE
MADE FOR PROFESSOR (LATER SIR WILLIAM) BRAGG
EARLY IN 1896 BY MR. A.L. ROGERS, FOLLOWING
THE DISCOVERY OF X-RAYS BY PROFESSOR WILHELM
CONRAD RONTGEN IN NOVEMBER 1895. BELIEVED TO
BE THE FIRST SUCCESSFUL X-RAY TUBE MADE IN
AUSTRALIA.

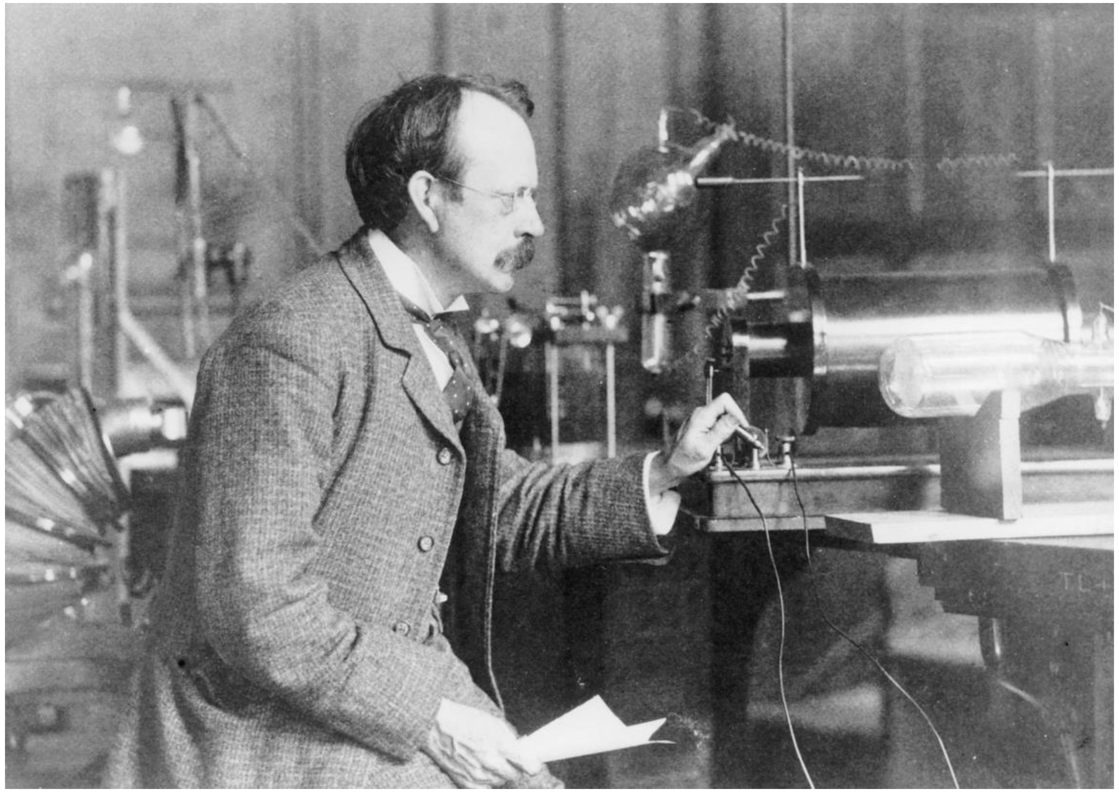
7. Henri Becquerel 1896 Radioactivity.

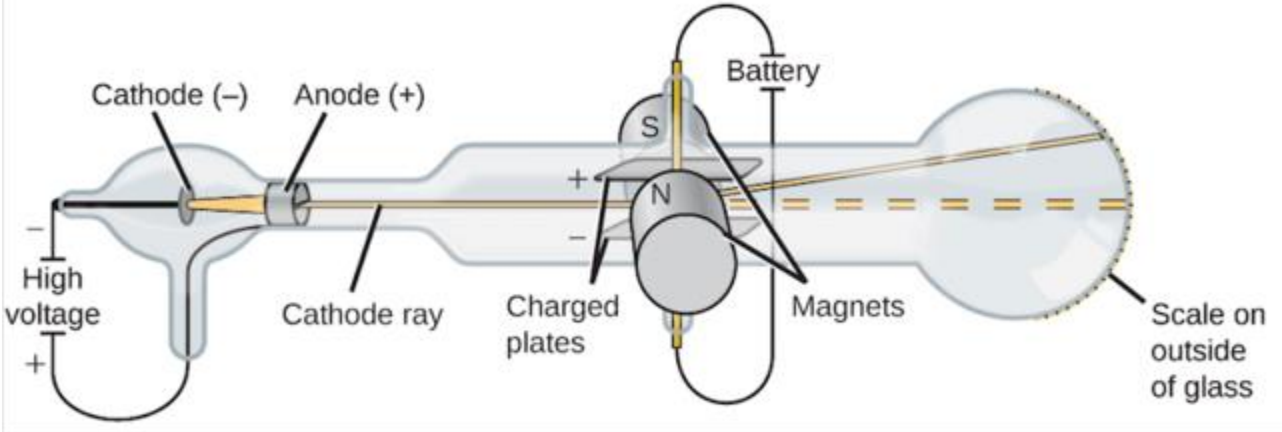


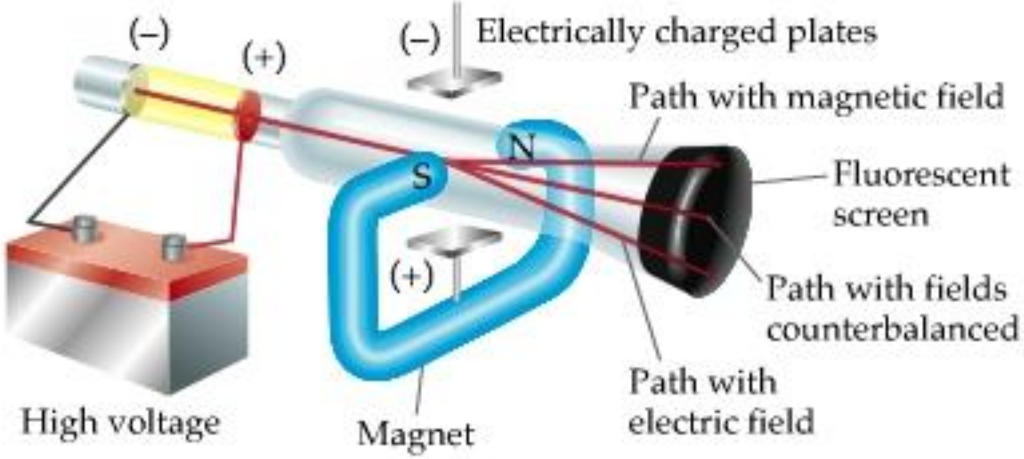




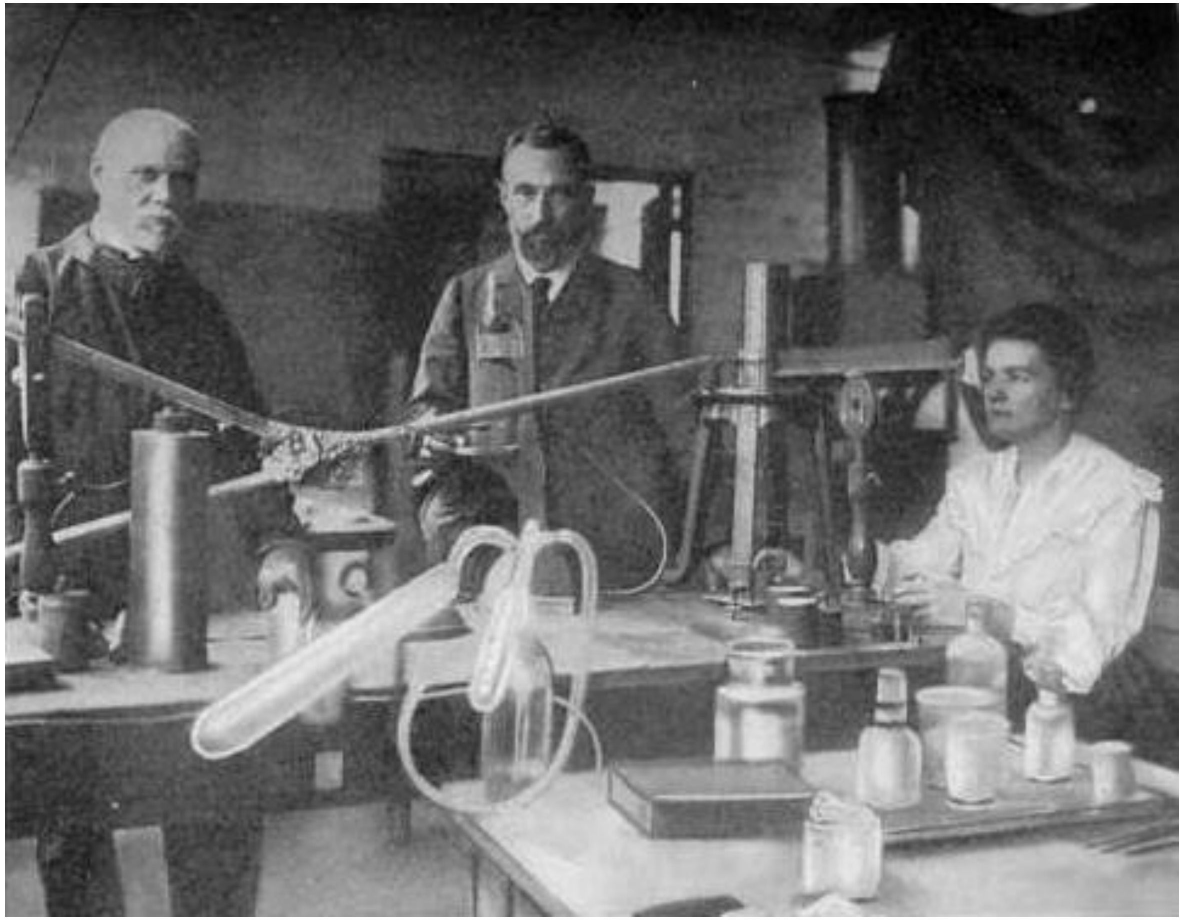
8. J.J.Thomson 1897 Electron.

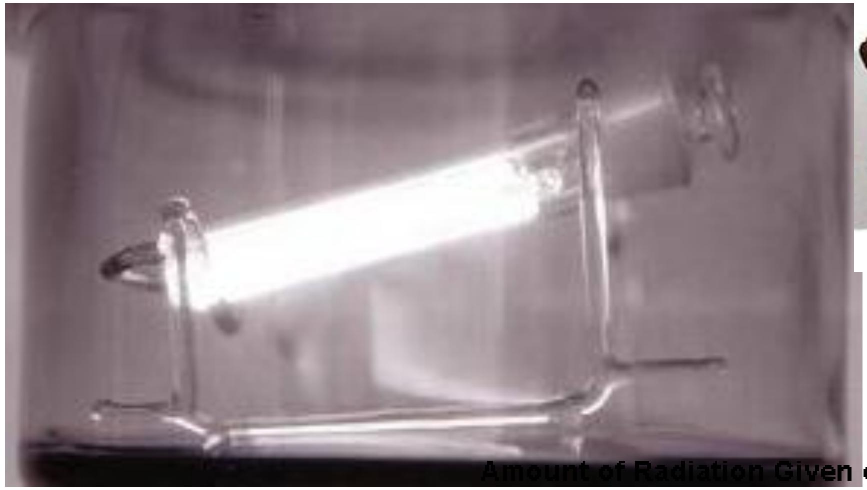




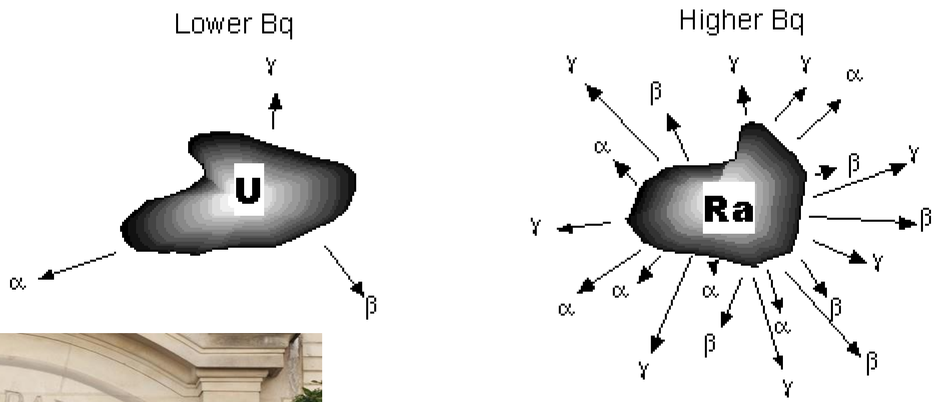


9. Pierre & Marie Curie, Radium 1898.

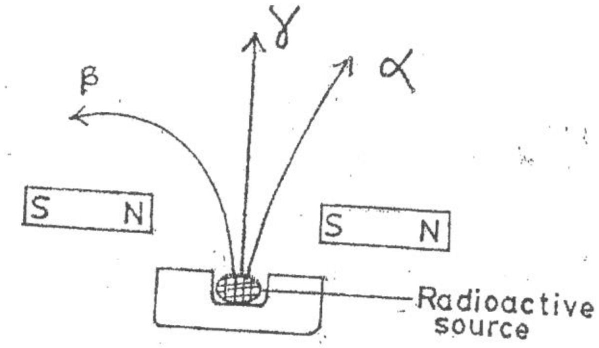




Amount of Radiation Given off Measured in Bq or Ci

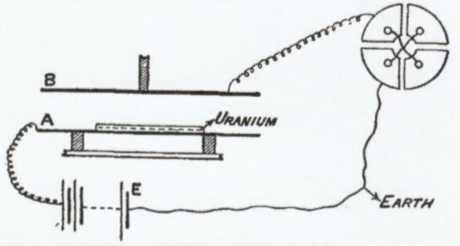


10. Rutherford & the Alpha-Beta Particles 1899.



VIII. *Uranium Radiation and the Electrical Conduction produced by it.* By E. Rutherford, *M.A., B.Sc., formerly 1851 Science Scholar, Coutts Trotter Student, Trinity College, Cambridge; McDonald Professor of Physics, McGill University, Montreal**.

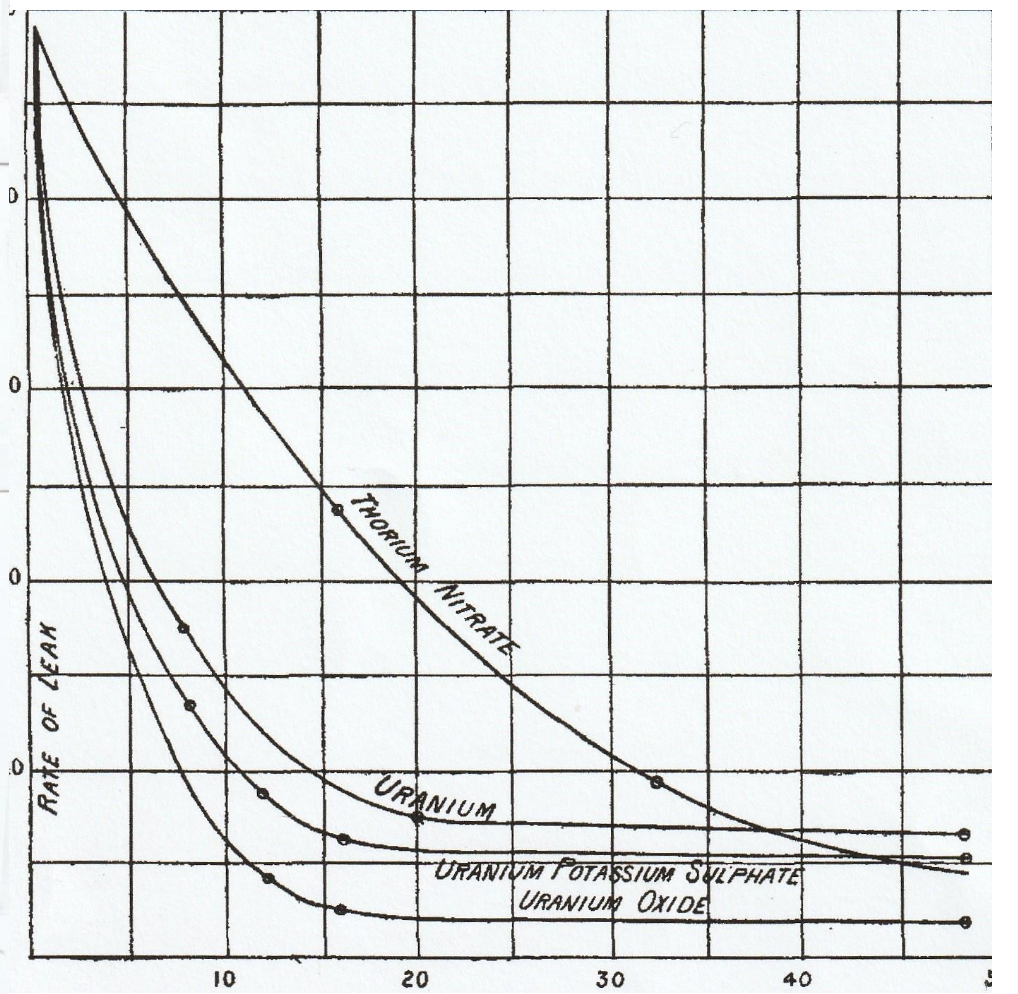
Fig. 1.



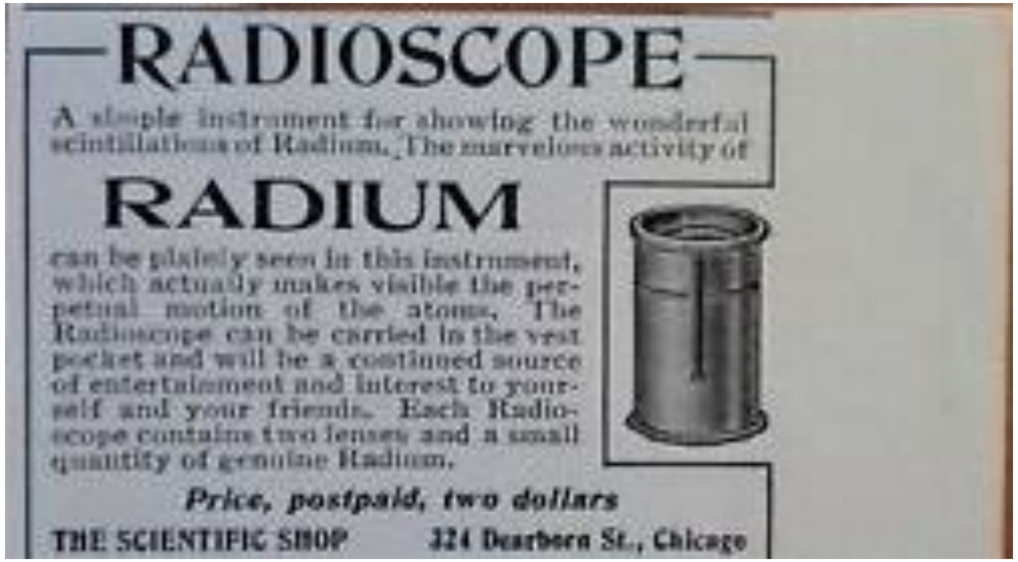
the Electrical Conduction produced by it. 115

Thickness of Metal Leaf ·00008 cm.
Layer of Uranium Oxide on plate.

Number of Layers.	Leak per min. in scale-divisions.	Ratio for each layer.
0	91	·85
1	77	·78
2	60	·82
3	49	·86
4	42	·79
5	33	·75
6	24·7	·79
8	15·4	·77
10	9·1	·86
13	5·8	



11. Bragg & Radium supplies 1903-1904.



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RADIUM

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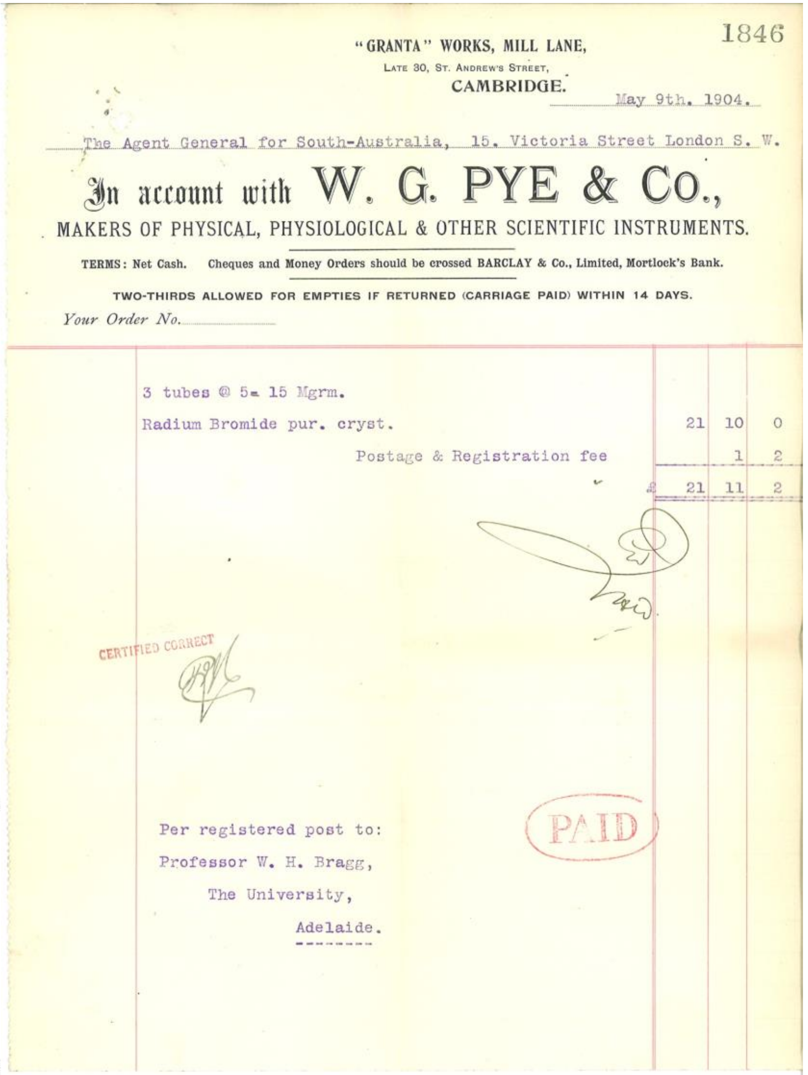

1846

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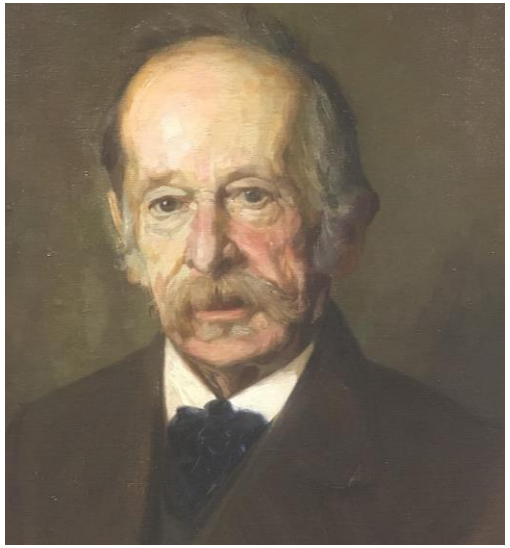
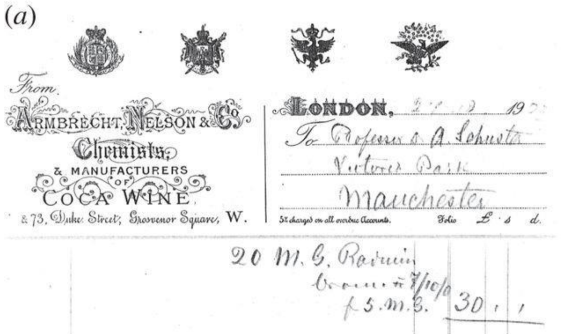
The University,
Adelaide.



(a)



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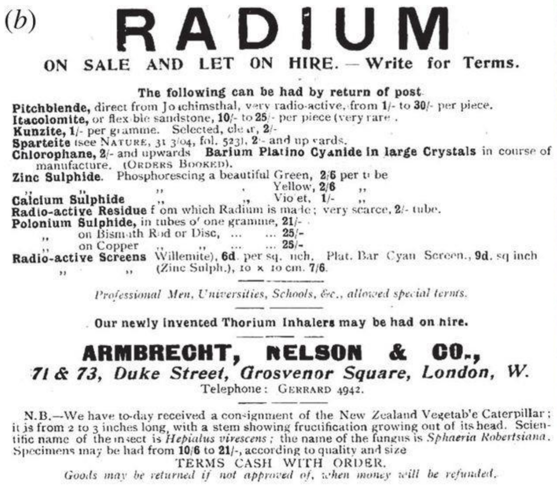
bromide @ 7/10/0
f 5 M.G. 30 , ,

(b)



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Sparteite (see NATURE, 31 3/04, fol. 523), **2/-** and upwards.
Chlorophane, 2/- and upwards **Barium Platino Cyanide in large Crystals** in course of manufacture. (ORDERS BOOKED).
Zinc Sulphide. Phosphorescing a beautiful Green, **2/6** per tube
" " " Yellow, **2/6** "
Calcium Sulphide " " Violet, **1/-** "
Radio-active Residue from which Radium is made; very scarce, **2/-** tube.
Polonium Sulphide, in tubes of one gramme, **21/-**
" on Bismuth Rod or Disc, ... **25/-**
" on Copper " " **25/-**
Radio-active Screens (Willemite), **6d.** per sq. inch. Plat. Bar Cyan Screen., **9d.** sq inch
" " (Zinc Sulph.), 10 × 10 cm. **7/6.**

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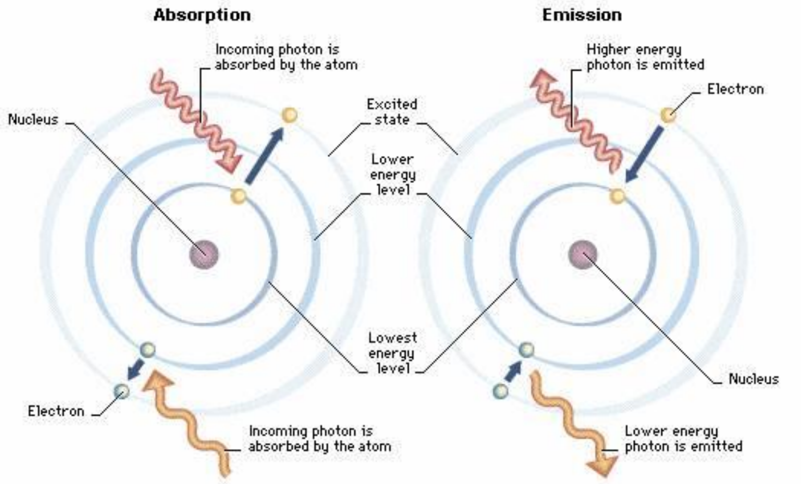
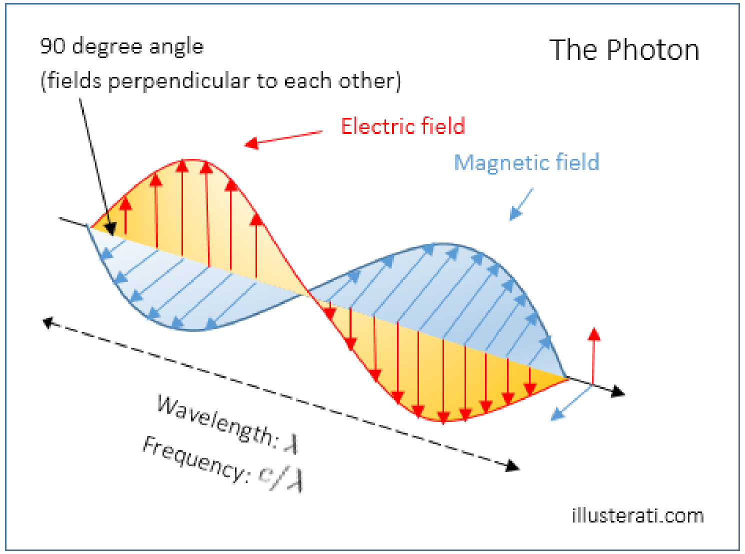
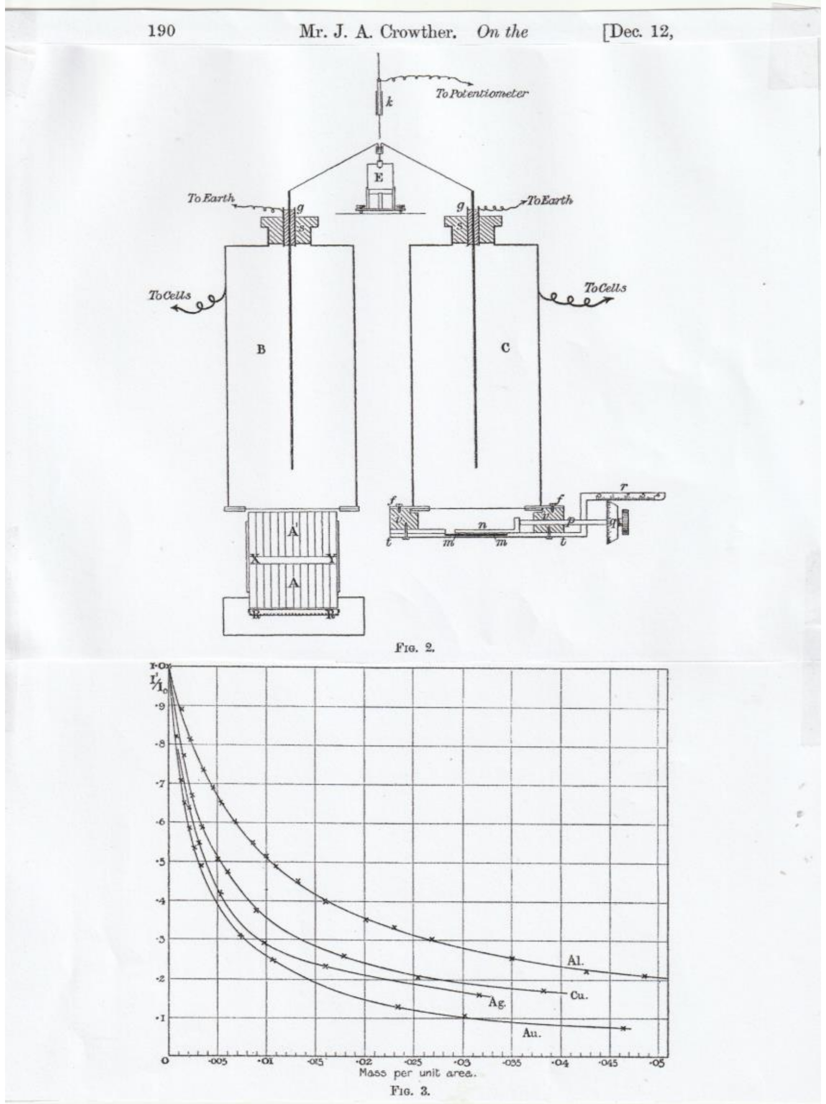
12. Planck & Einstein- Quantum physics





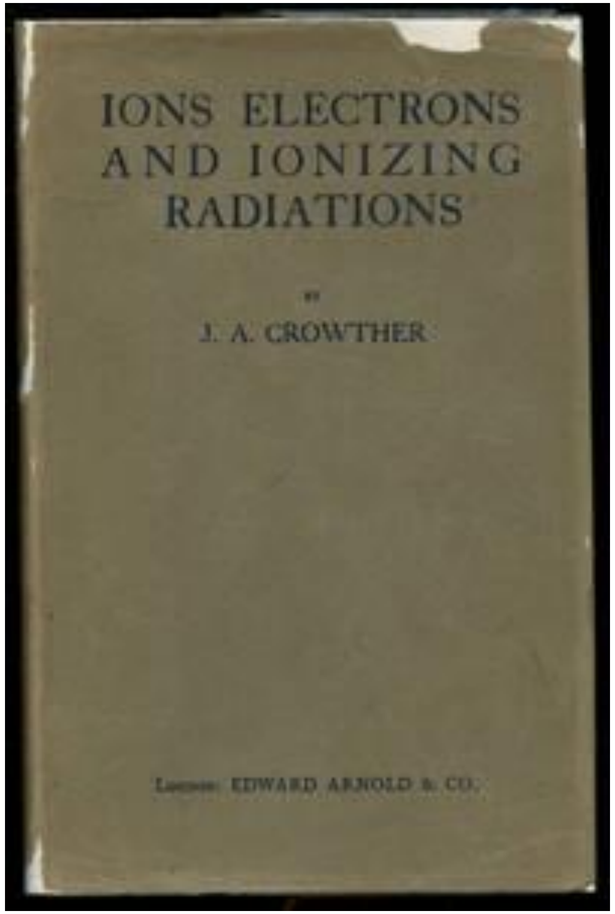
13. J.A.Crowther 1907 Beta Experiment.



190 Mr. J. A. Crowther. *On the* [Dec. 12,

Fig. 2.

Fig. 3.



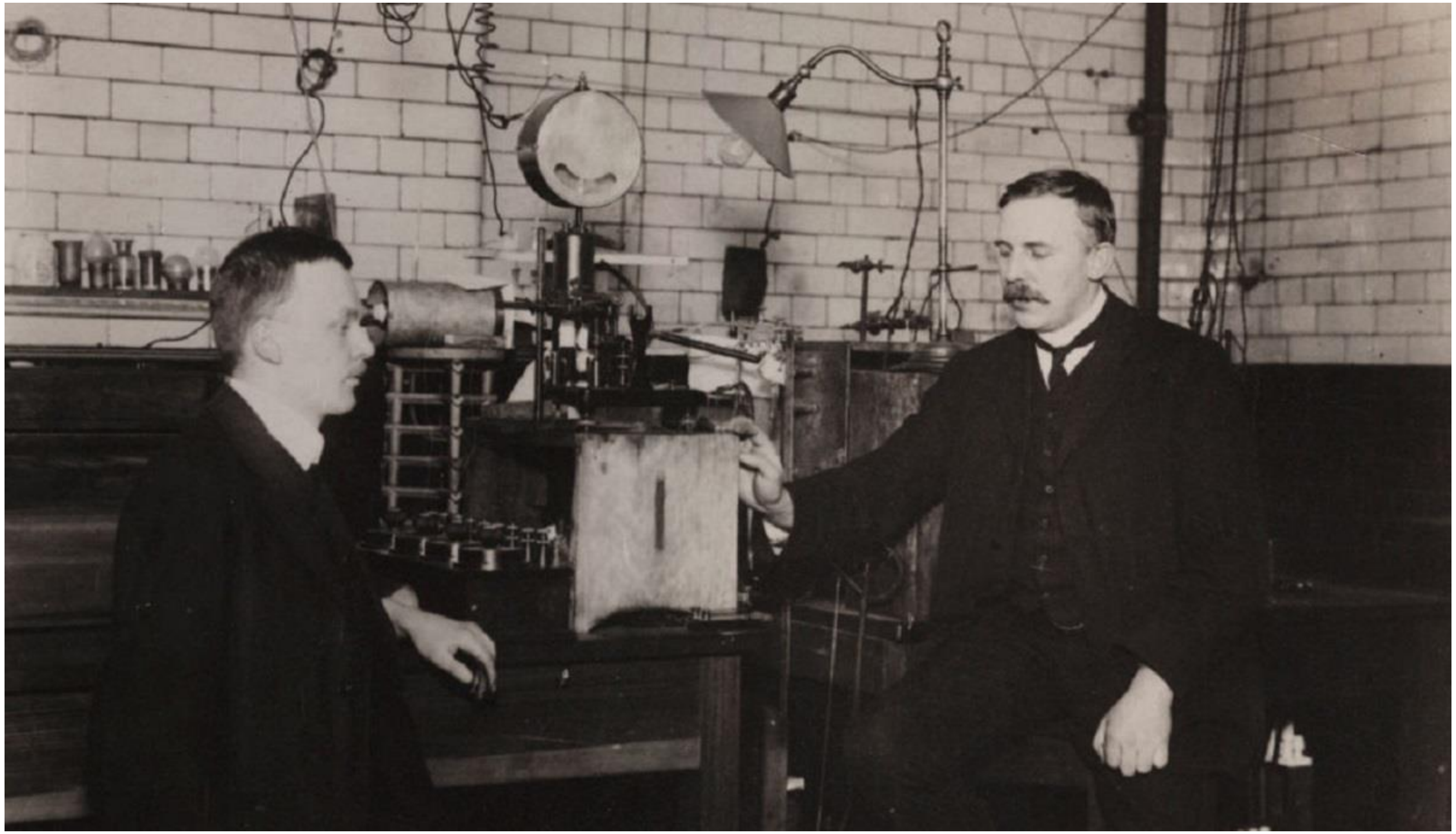
IONS ELECTRONS
AND IONIZING
RADIATIONS

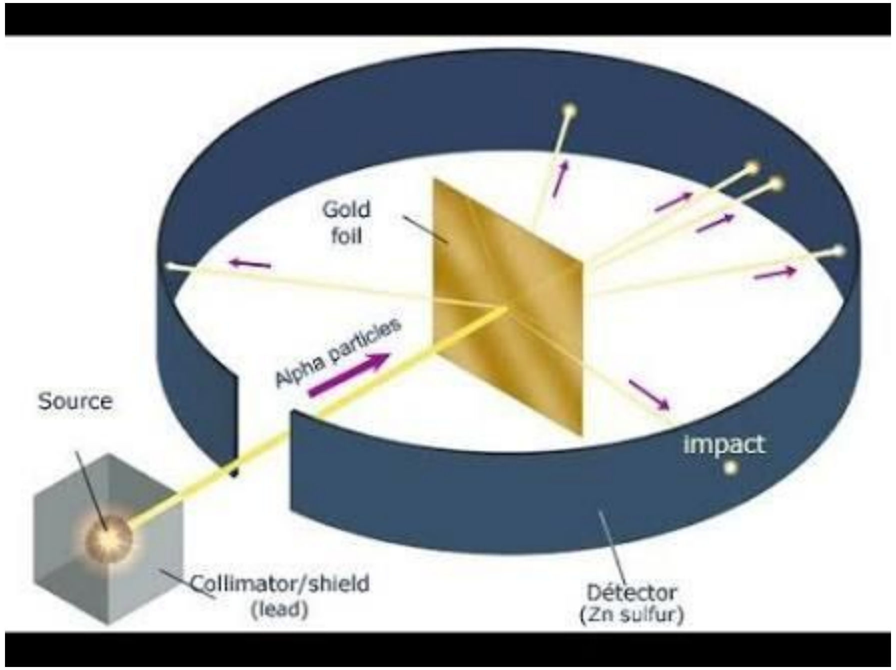
BY

J. A. CROWTHER

LONDON: EDWARD ARNOLD & CO.

14. Rutherford-Geiger-Marsden Gold Foil Alpha scatter 1908.





15i. J.P.V.Madsen 1909 Beta Scattering Experiment.

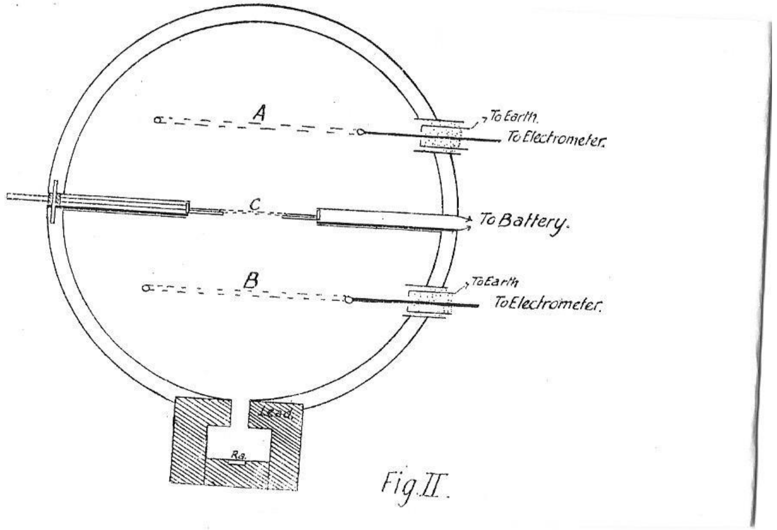


Fig.II.

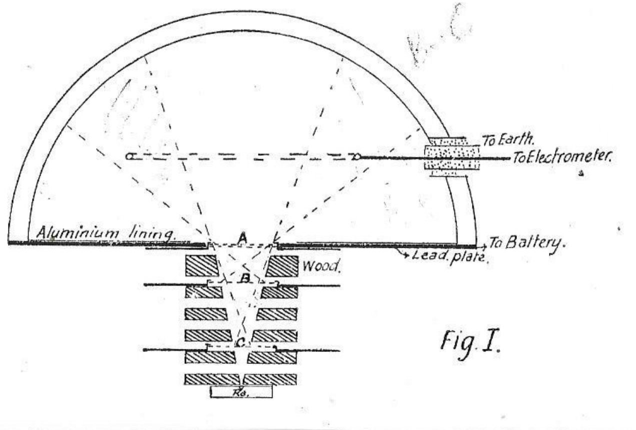
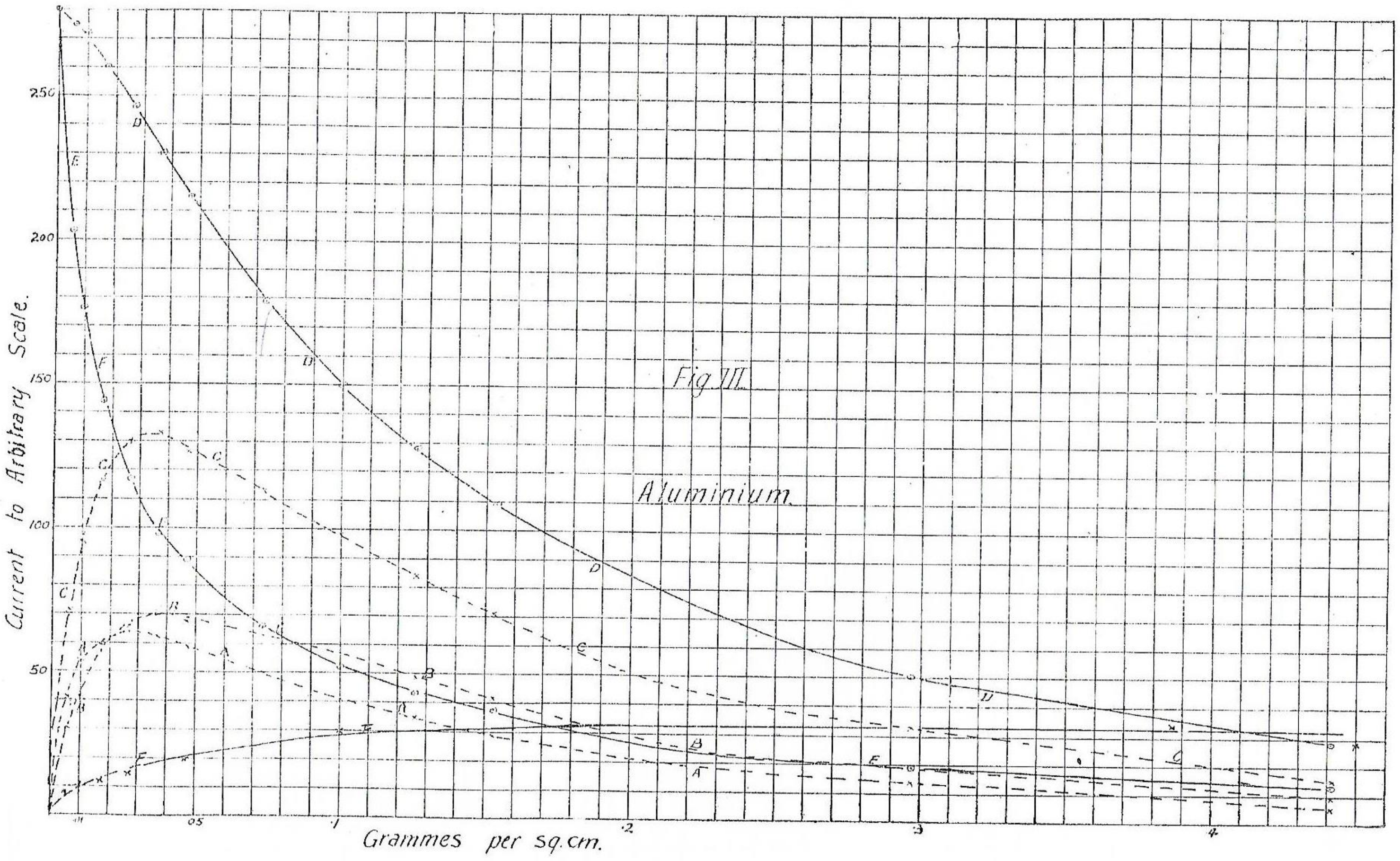
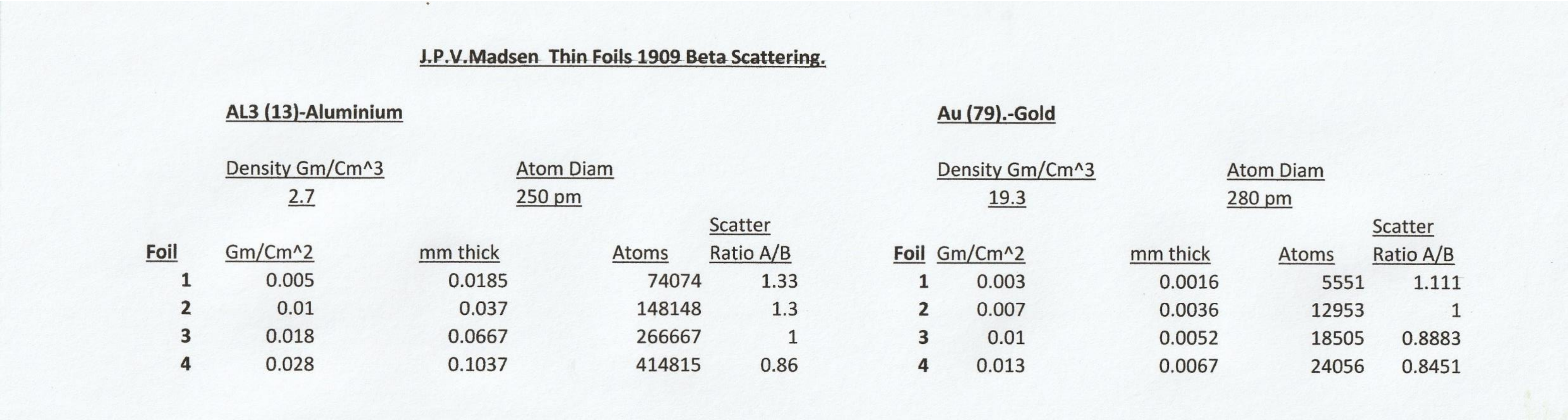


Fig.I.



15ii. Madsen 1909 Beta Single Scatter.



J.P.V.Madsen Thin Foils 1909 Beta Scattering.

AL3 (13)-Aluminium

Density Gm/Cm^3 2.7

Atom Diam 250 pm

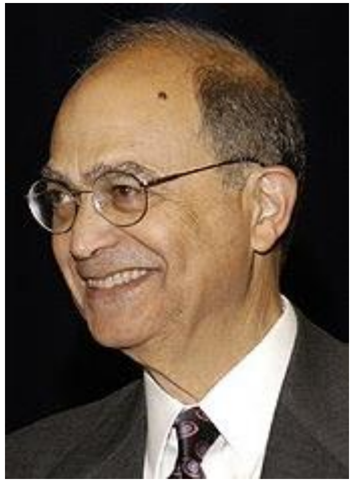
Foil	Gm/Cm^2	mm thick	Atoms	Scatter Ratio A/B
1	0.005	0.0185	74074	1.33
2	0.01	0.037	148148	1.3
3	0.018	0.0667	266667	1
4	0.028	0.1037	414815	0.86

Au (79).-Gold

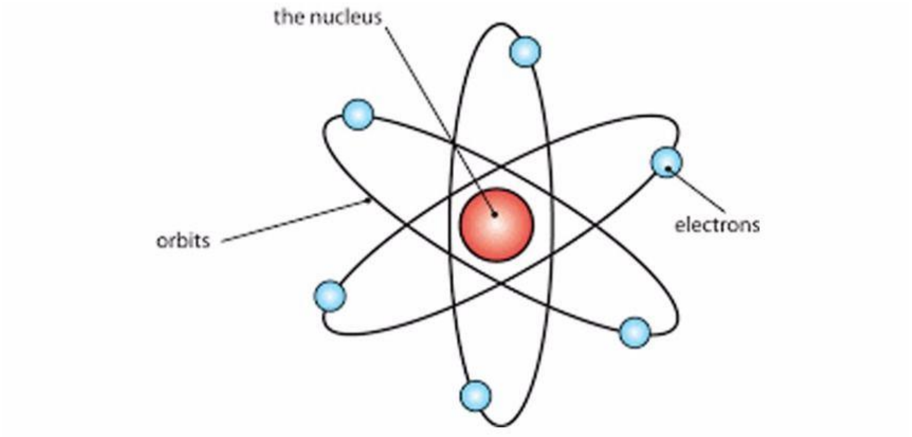
Density Gm/Cm^3 19.3

Atom Diam 280 pm

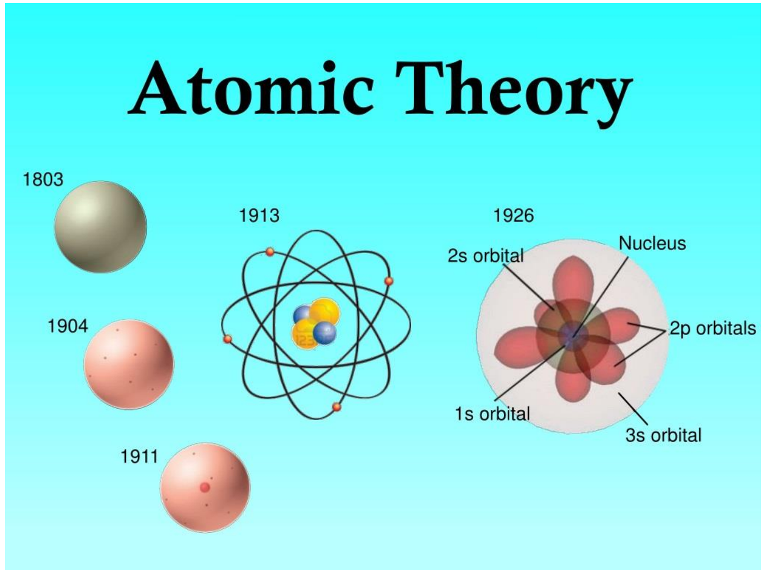
Foil	Gm/Cm^2	mm thick	Atoms	Scatter Ratio A/B
1	0.003	0.0016	5551	1.111
2	0.007	0.0036	12953	1
3	0.01	0.0052	18505	0.8883
4	0.013	0.0067	24056	0.8451

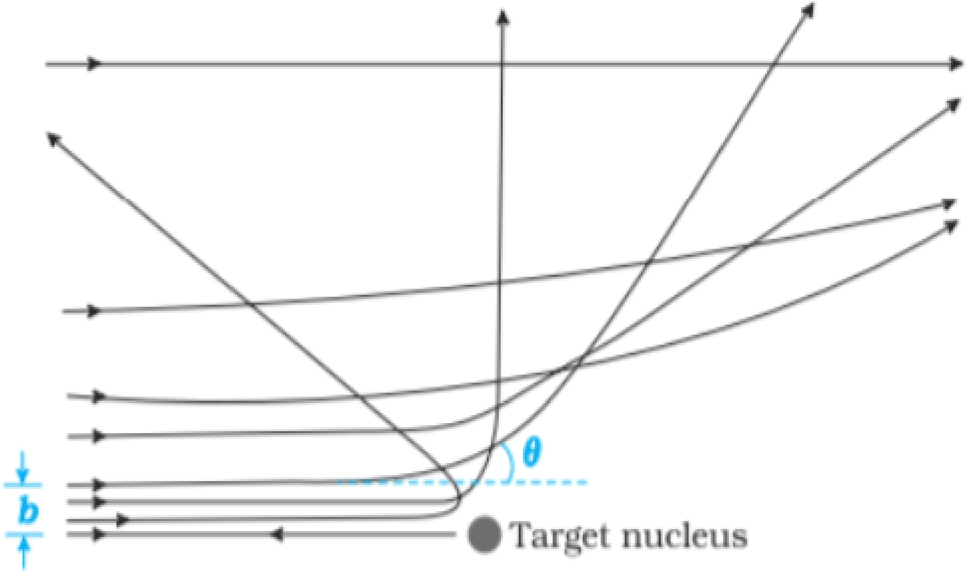


16. Rutherford 1911 Atom, Manchester.



Rutherford's Model Of An Atom





Trajectory of α-particles in the coulomb field of a target nucleus. The impact parameter, b and scattering angle θ so depicted.

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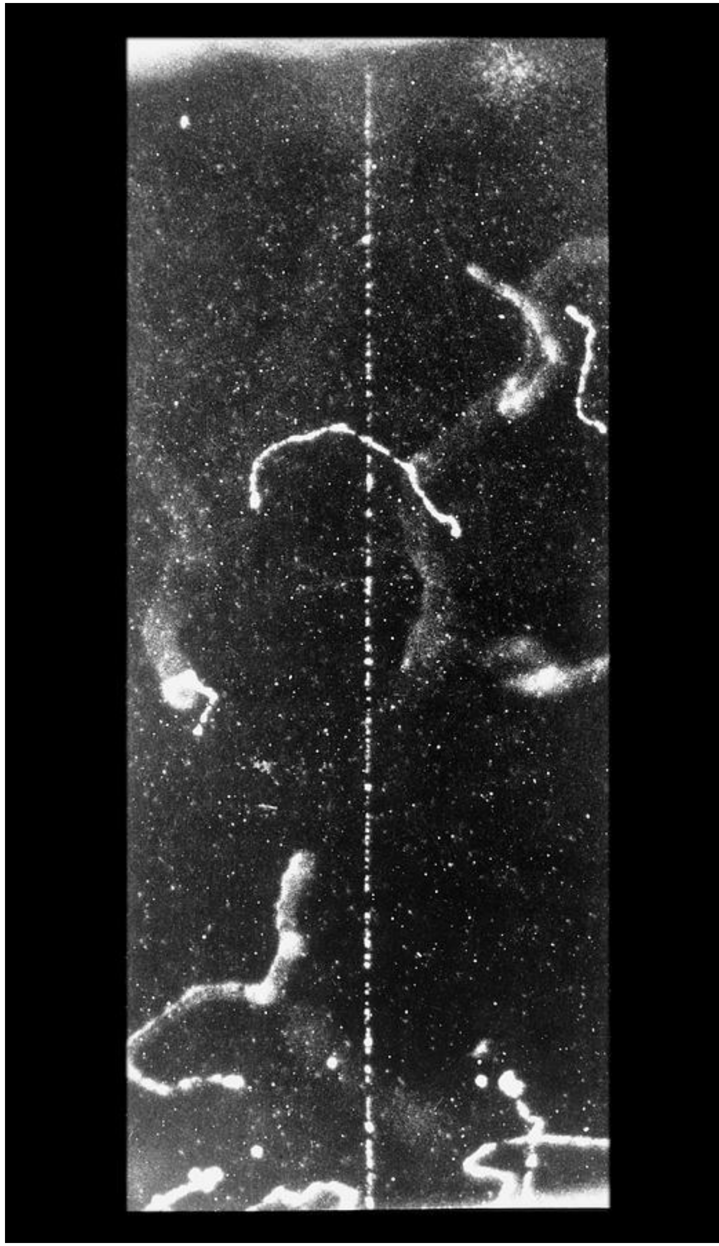
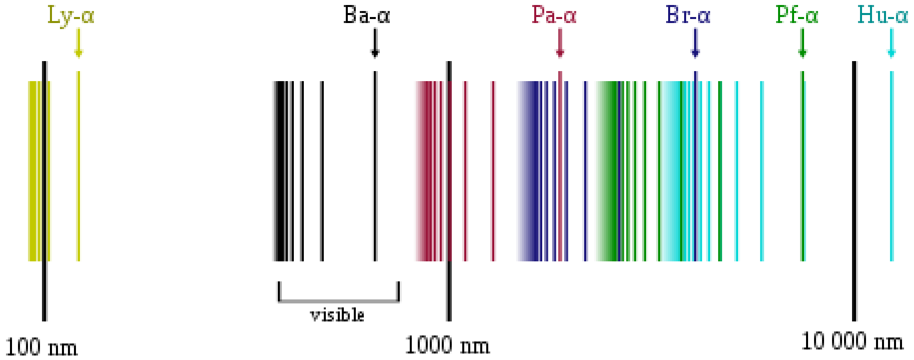
17. Wilson Cloud Chamber 1911.

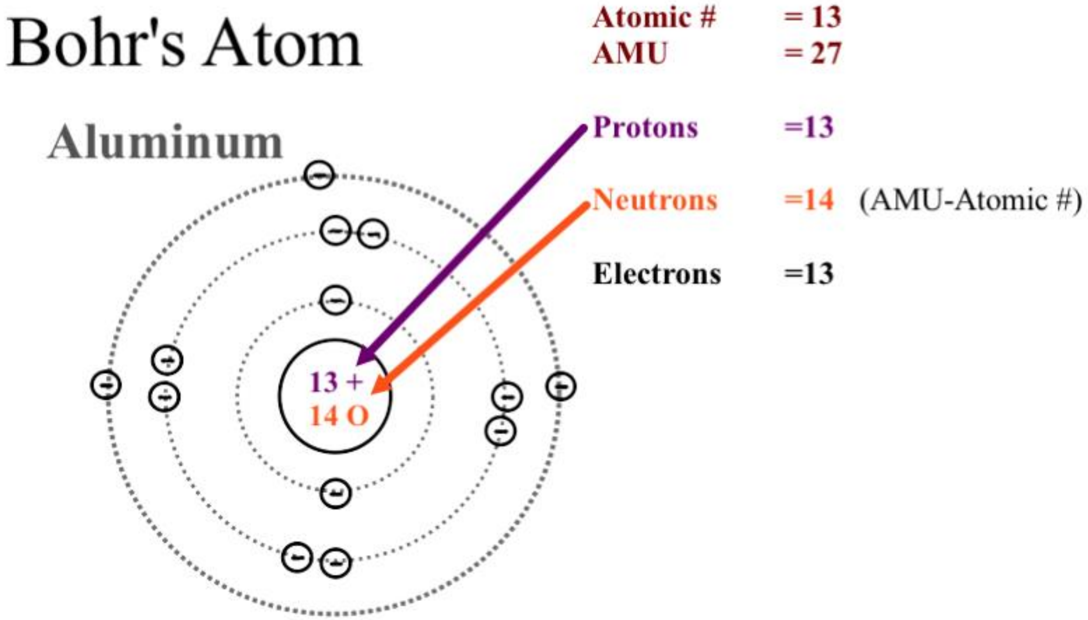
FIG. 1.

FIG. 2

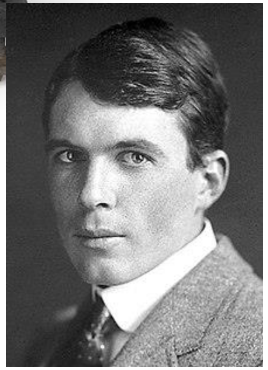


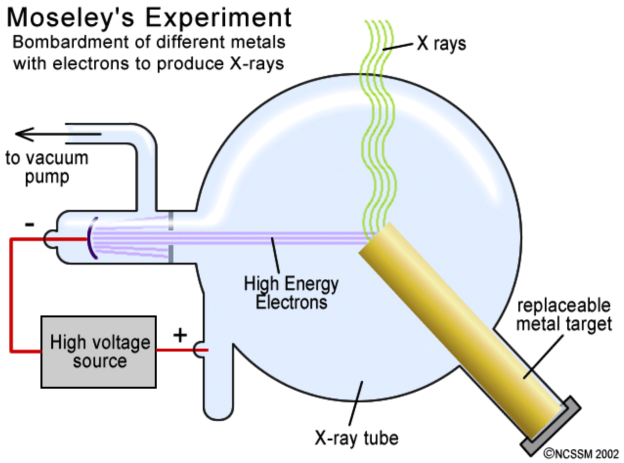
18. Niels Bohr & Hydrogen Spectra 1913.

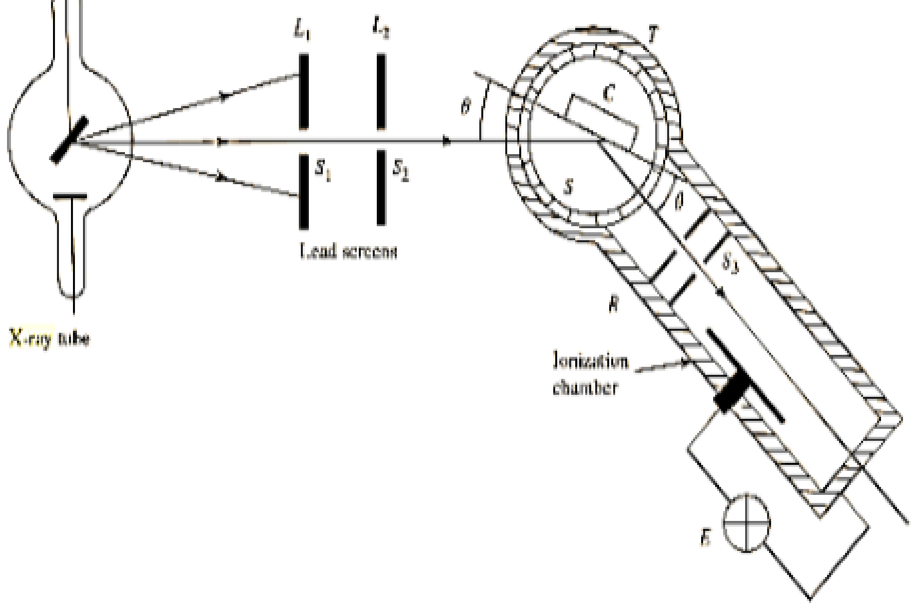




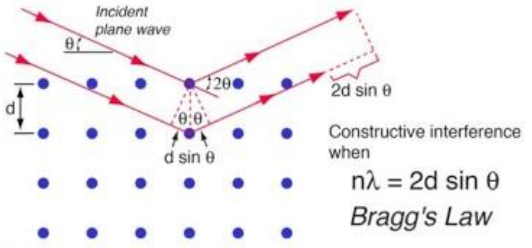
19. Bragg X-ray Spectrometer, H.G. Moseley.





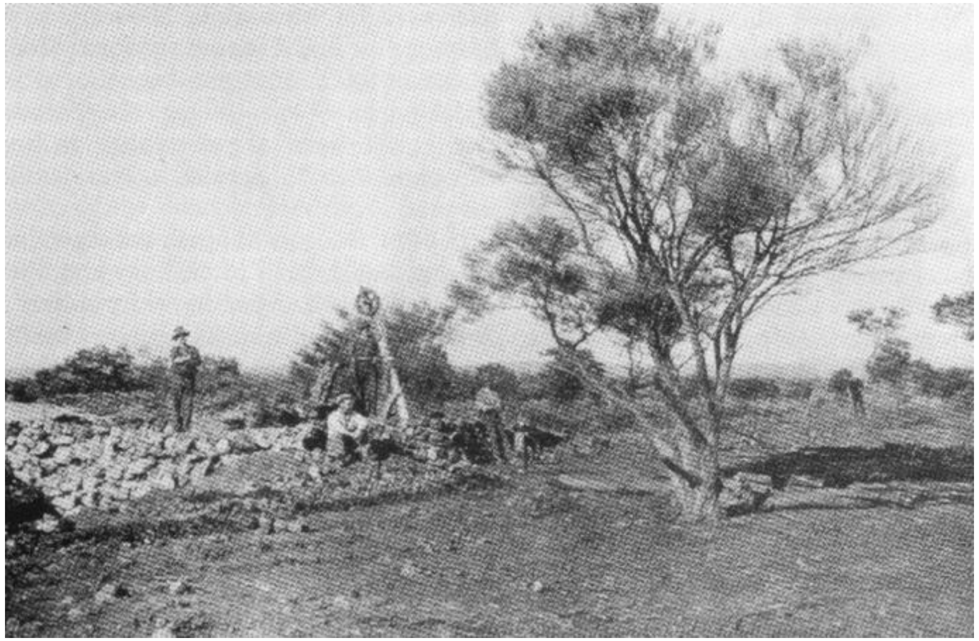


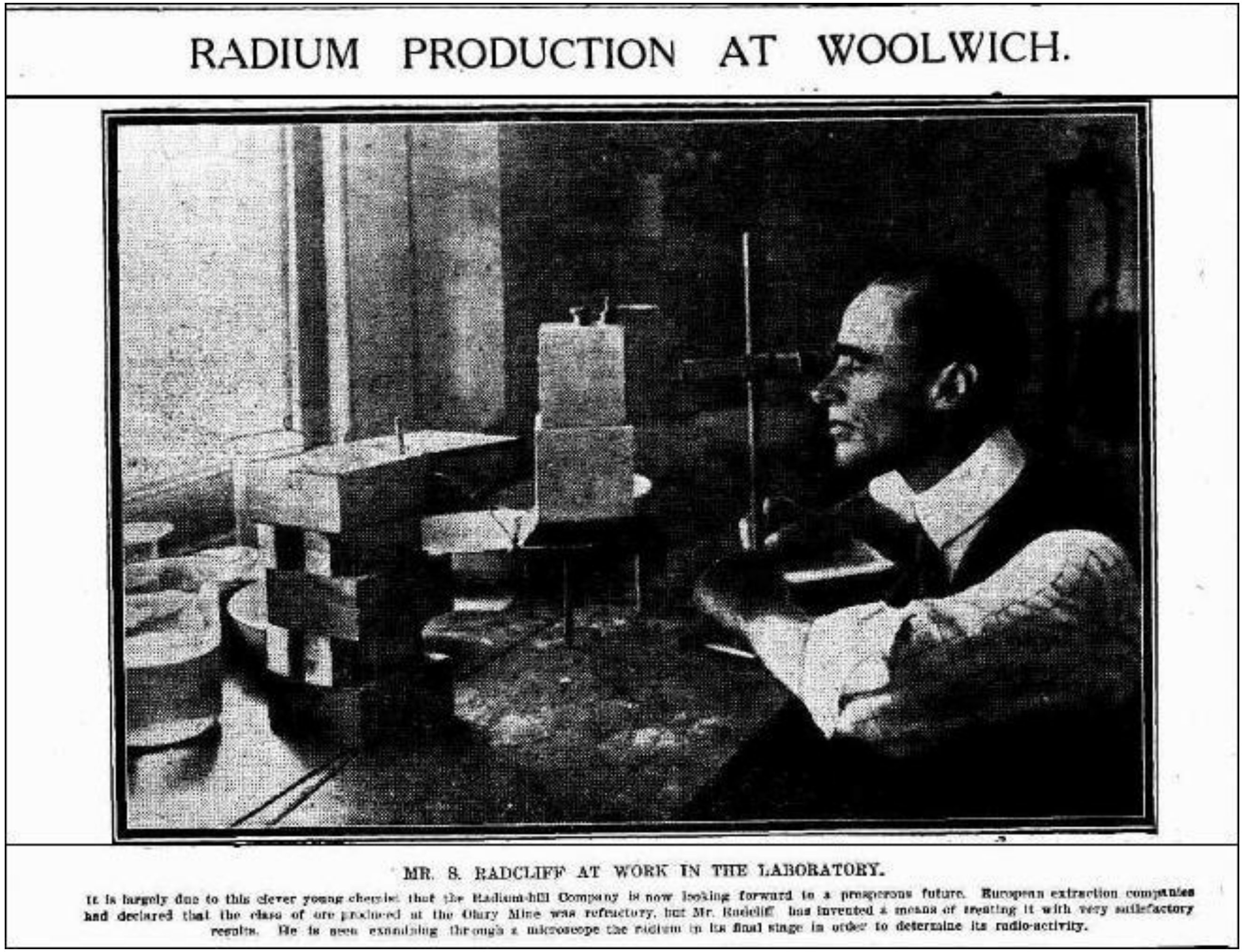
Bragg's X-ray spectrometer



Bragg's Law

20. Radium Hill 1913, Belgian Congo 1917, Radium Paint.



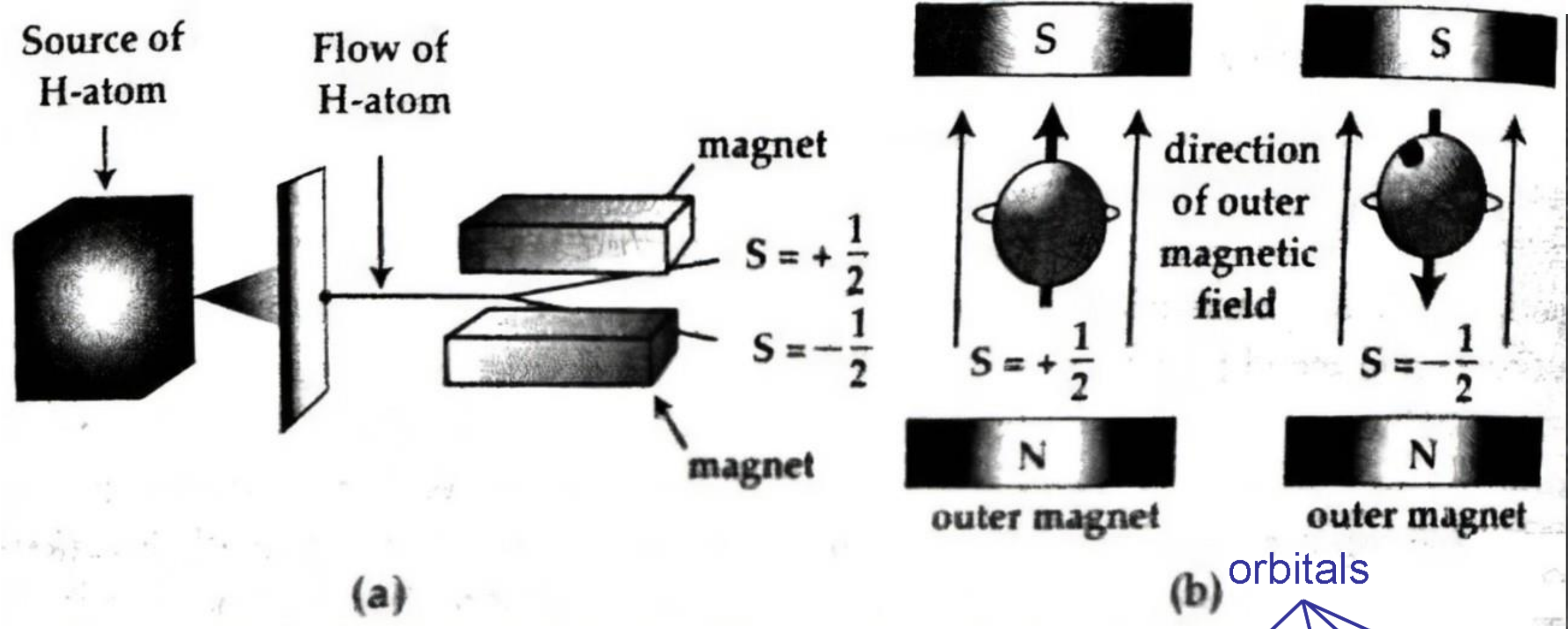


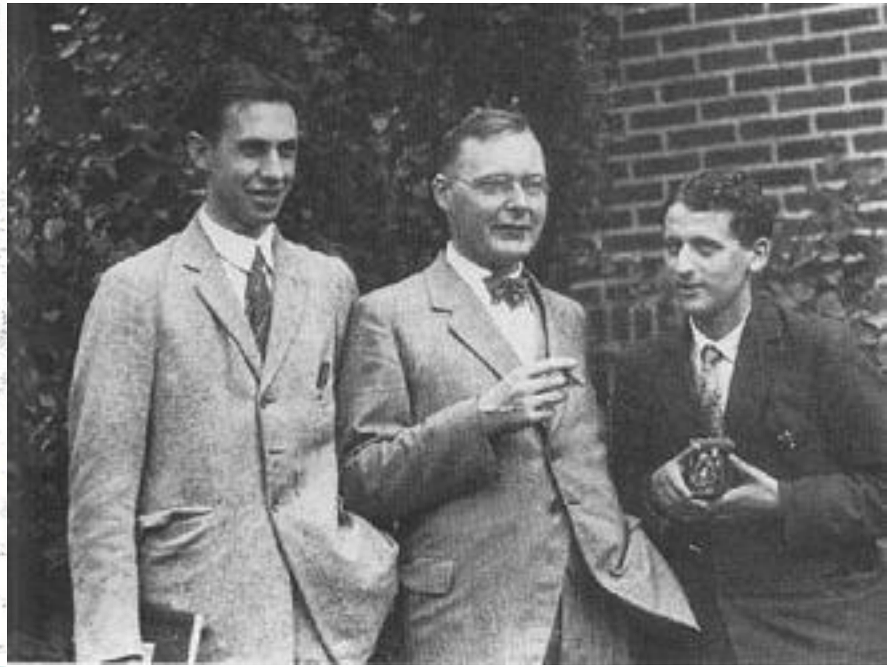
RADIUM PRODUCTION AT WOOLWICH.

MR. S. RADCLIFF AT WORK IN THE LABORATORY.

It is largely due to this clever young chemist that the Radium-hill Company is now looking forward to a prosperous future. European extraction companies had declared that the class of ore produced at the Olary Mine was refractory, but Mr. Radcliff has invented a means of treating it with very satisfactory results. He is seen examining through a microscope the radium in its final stage in order to determine its radio-activity.

21. Electron Spin 1925 & Sub-Shells.





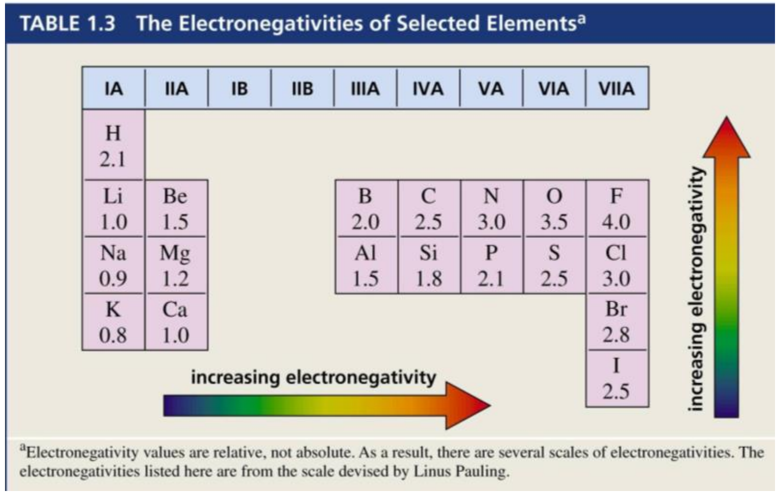


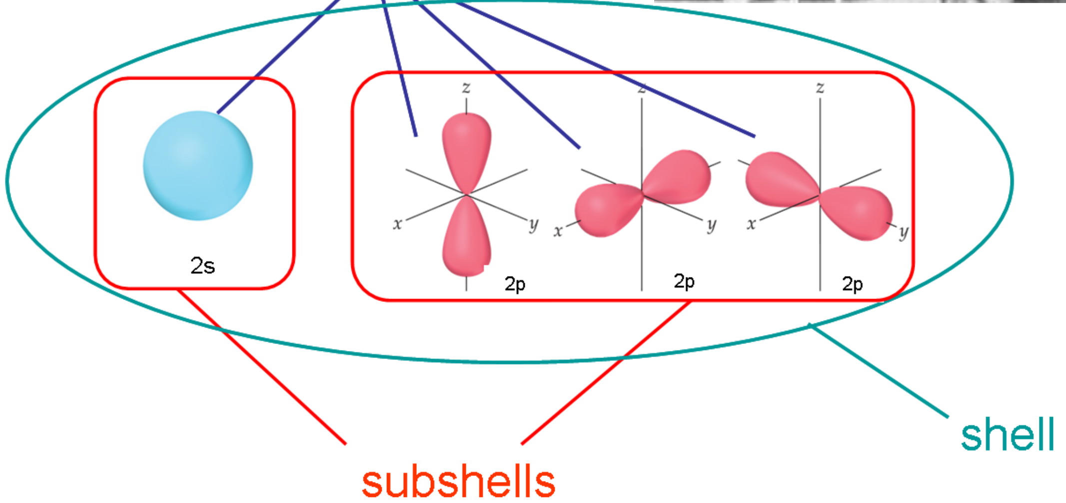
TABLE 1.3 The Electronegativities of Selected Elements[a]

IA	IIA	IB	IIB	IIIA	IVA	VA	VIA	VIIA
H 2.1								
Li 1.0	Be 1.5			B 2.0	C 2.5	N 3.0	O 3.5	F 4.0
Na 0.9	Mg 1.2			Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0
K 0.8	Ca 1.0							Br 2.8
								I 2.5

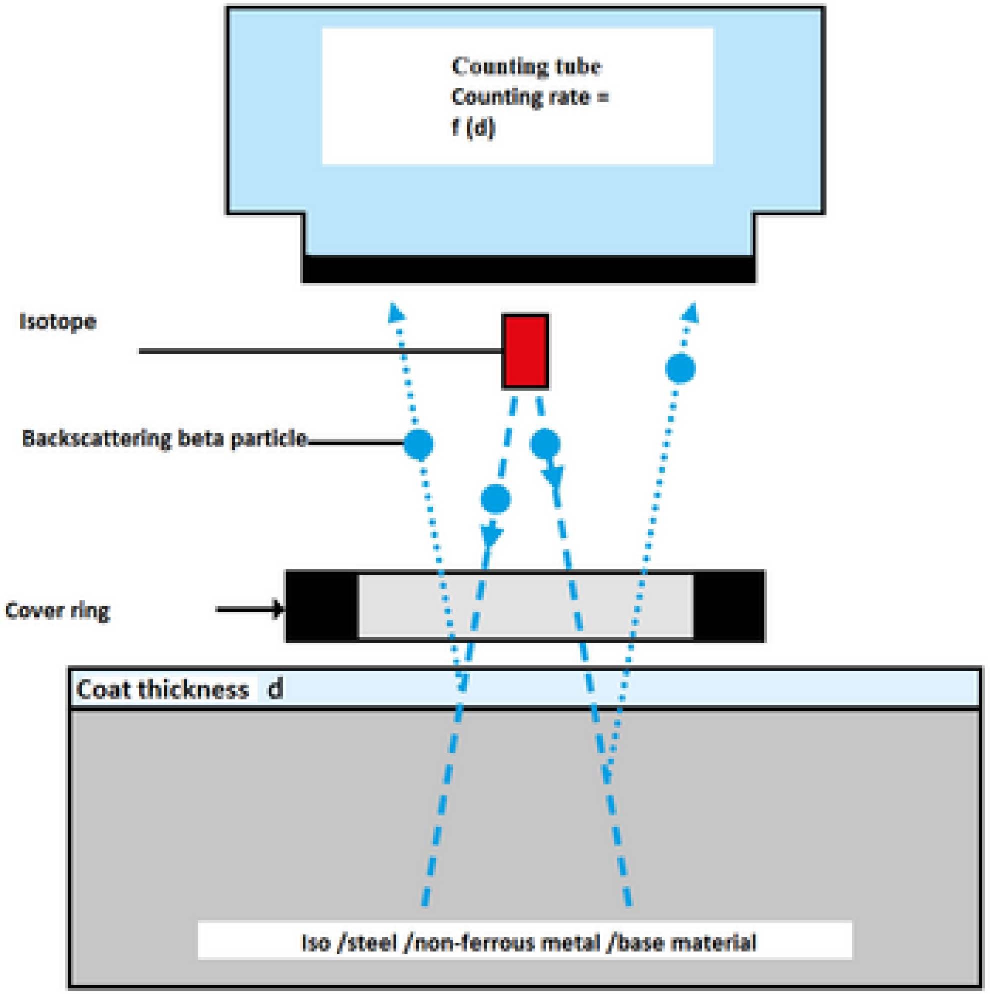
increasing electronegativity

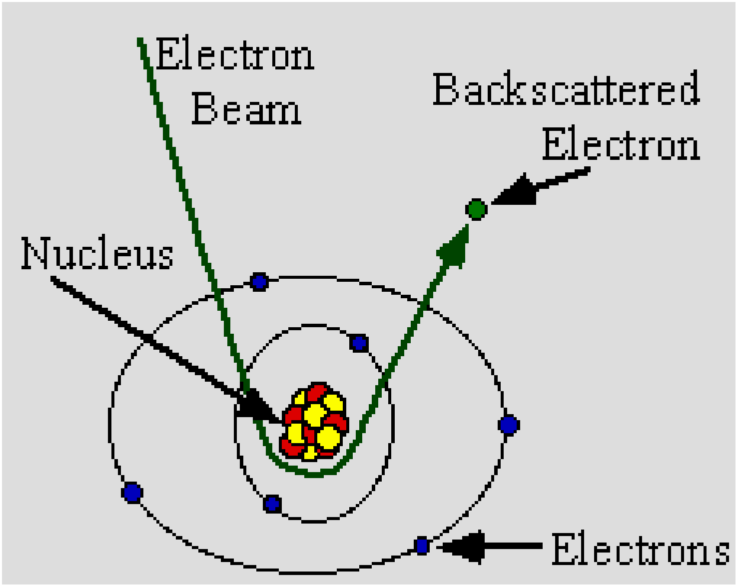
increasing electronegativity

[a] Electronegativity values are relative, not absolute. As a result, there are several scales of electronegativities. The electronegativities listed here are from the scale devised by Linus Pauling.



22. Beta Backscatter.





XCVIII. *The Scattering of the β Rays of Radium.*

By J. P. V. MADSEN, *D.Sc.* (*Adel.*), *B.E.* (*Syd.*), *Lecturer in Electrical Engineering, Univerity of Adelaide*[*].

[Plate XXX.]

§ I. *Introductory.*

IN a paper by the author upon the secondary γ rays[†] it was shown that in passing through matter the γ rays were scattered and softened. The scattered radiation showed a distinct lack of symmetry about a plane perpendicular to the direction of the original stream, more scattered radiation moving on in the direction of the original stream than was turned back. The distribution of the scattered radiation was found to depend upon the quality of the incident radiation and also upon the nature of the medium in which the scattering occurred.

As the results arrived at in that investigation were used as an argument in support of the material theory of γ rays proposed by Bragg, and as Crowther[‡] has recently shown that the β rays are subject to scattering by even very thin layers of material, it became of special interest to see whether any parallel could be drawn between the effects of scattering in the case of the material β particles and the γ rays.

It will be seen from the present paper that the parallel is very close in many respects, the differences being such as might reasonably be expected on the theory that the γ ray is a neutral pair.

At the same time it is hoped that some of the results to be described may help to clear up some of the difficulties which have arisen in the study of the absorption of β rays.

§ II. *Apparatus.*

The apparatus used in these experiments is shown in fig. 1. The radium contained in a small conical hole cut in a piece of Al was covered by a sheet of Cu foil ·002 cm. thick. The β rays passed up through a conical hole cut in a block of

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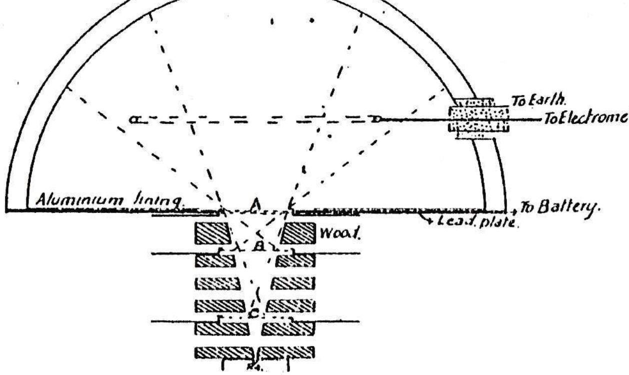
[*] Communicated by the Author. From 'Transactions of the Royal Society of South Australia,' vol. xxxiii. 1909. Preliminary Account read before the Australasian Association for the Advancement of Science, Brisbane, January 13, 1909.

[†] Trans. Roy. Soc. S.A. vol. xxxii. (1908).

[‡] Proc. Roy. Soc., A, vol. lxxx. (1908).

wood, portions of the block being removed as shown to allow of the introduction of the screens in different positions as at A, B, C. The ionization-chamber was hemispherical and made of wood, with the inner surface covered with very thin

Fig. 1.



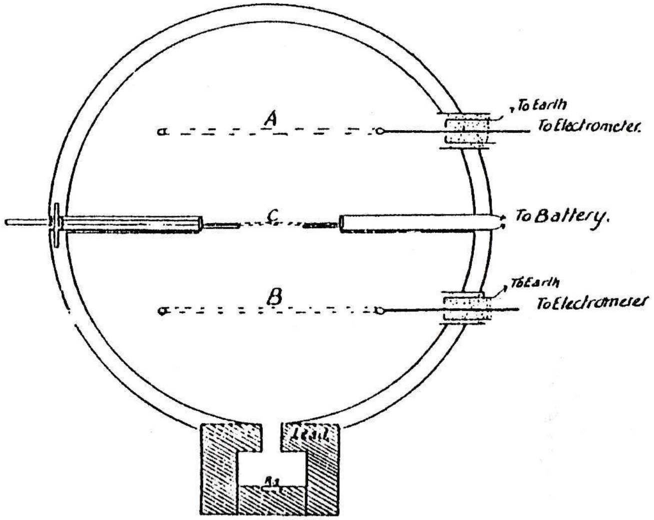
Al foil. The electrode connecting to the electrometer was in the form of a circular ring of wire, suitably protected by the usual methods. The hemispherical chamber rested upon a circular plate of Pb, above which was laid a sheet of Al. A circular hole cut centrally in the Pb and Al plates enabled the screen to be placed in the position A. In this position practically all the emergent scattered radiation was able to produce its effect to the same extent as the rays in the main stream, all rays having the same length of path in which to produce ionization, and the complications of secondary effects being reduced by having the walls of the chamber wood.

If we may for the present neglect any alteration in speed of the scattered radiation and consider the original stream of rays more or less homogeneous, the current may be taken approximately as a measure of the number of β particles which enter the chamber, no matter what their direction, proper correction being made for the effect produced by γ rays.

By subtracting the readings taken with a screen at A and at C a measure is obtained of the amount of radiation which has been turned out of its original path or scattered by that screen. Another reading with the screen at B enabled the distribution of the emergent scattered radiation to be followed out.

To obtain a measure of the returned, or incident, scattered radiation the apparatus shown in fig. 2 was used.

Fig. 2.



The top chamber, A, was the one already described, and a similar hemispherical chamber, B, was placed as shown with the Ra outside, contained in a Pb block provided with an opening through which the β rays could pass, impinging on screens placed in the position C. A stronger sample of Ra, kindly lent by Dr. Hermann Laurence, was used in these experiments, but care was taken to cover it with Cu foil, as in the first set of experiments. Either of the electrodes A or B could be connected to the electrometer, and as the chambers were made as nearly as possible alike no appreciable change in capacity was introduced, using either chamber separately. It was necessary to use a balance chamber, as the initial effect was so large compared with that which was to be measured. By placing a thin Al foil at C and then a thick Pb plate, a measure was obtained of the incident and of the maximum return radiation for that substance, from the effects measured separately in the chambers A and B. This enabled the readings for the incident scattered radiation to be reduced to their correct values relatively to those of the emergent rays, using the maximum return radiation from Pb as a standard of reference.

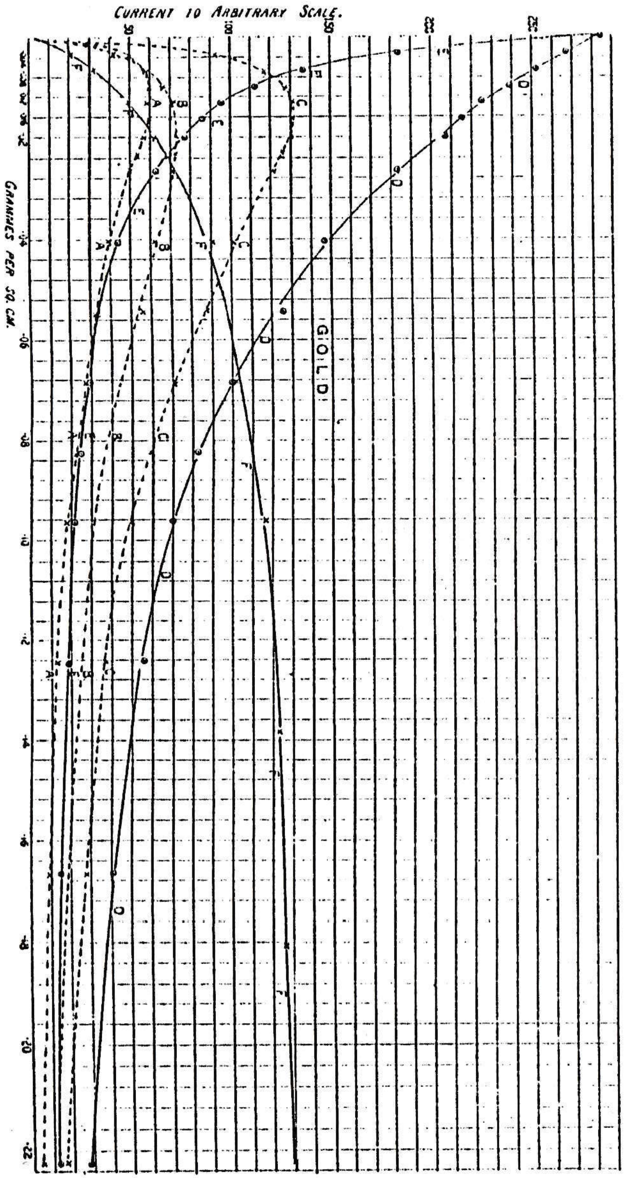

CURRENT TO ARBITRARY SCALE.
50
100
150
200
250
GRAMMES PER SQ. CM.
GOLD
A
B
C
D
E
F

FIG. 4.

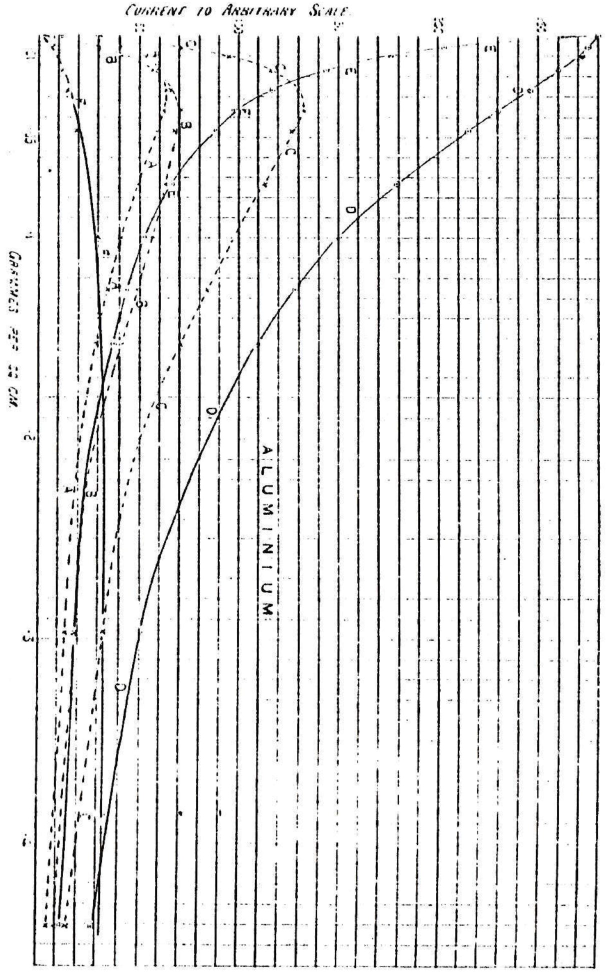

CURRENT TO ARBITRARY SCALE.
GRAMMES PER SQ. CM.
ALUMINIUM
A
B
C
D
E

FIG. 3.

§ III. *Results of Experiments.*

Fig. 3 (Pl. XXX.) shows the results of experiments performed with the apparatus of fig. 1, using Al screens.

Curves D and E give the currents for different thicknesses of screen, with the screens in the positions A and C respectively. The abscissæ represent grammes per square cm. from which the thickness of screen may be immediately deduced, knowing its density.

Curve C is obtained by subtracting the values of D and E corresponding to any screen, and is a measure of the total amount of emergent scattered radiation.

It will be seen from fig. 1 that the whole of the scattered radiation is not quite included, as the effects are somewhat interfered with by geometrical conditions. When, for example, the screen was brought nearer the Ra than C a slight rise was observed in the reading. The intensity of the radiation falling on the screen was slightly increased owing to some of the more oblique rays from the Ra being now able to fall upon the screen.

Curves A and B represent the results of subtracting readings with the screen at B and C and A and B respectively (fig. 1), and are measures of the amount of radiation slightly deflected, and of that which has suffered much larger deflexion.

Curve F represents the returned radiation from aluminium screens of different thicknesses. Similar curves to the above are shown in fig. 4 for Au screens.

§ IV. *Discussion of Results.*

In fig. 3, from curve C, it is seen that the total emergent scattered radiation increases rapidly to a maximum, and then steadily decreases as the thickness of screen is increased. The maximum occurs at about ·013 cm.

Comparing the curves C and F, it is seen that for thin screens the emergent is much greater than the incident scattered radiation. The greatest value of the ratio is about 9 : 1.

Comparing the similar curves for Au, fig. 4, it is again seen that a considerable lack of symmetry exists between emergence and incidence radiation, though not so marked. In this case the greatest value of the ratio is about 4·5 : 1. The maximum for the emergence radiation is reached at about ·0008 cm.

The effects of scattering in the case of β rays are thus very similar to those observed for γ rays, a material of high atomic weight being able to turn back in the process of scattering more of the original radiation than a material of smaller atomic weight.

Comparing curves A and B, it is observed that A reaches a maximum sooner than B. A more careful examination of A and B for smaller thicknesses of screen has shown that the ratio of A to B is practically constant until about one-third of the maximum reading is reached, after which the ratio gradually decreases. It would appear that while the ratio remains constant we are concerned with only a single collision of any β particle, that as the screen is further thickened it becomes possible for a β particle to suffer more than one collision before emerging, thus making the emergent beam appear to gradually swing round from its original direction, a greater thickness of screen being required to produce the maximum intensity for very oblique rays than for those corresponding more nearly with the direction of the original stream.

A fuller consideration of the effects of scattering and absorption for very thin films will be reserved for a future paper.

A theory of scattering similar to that proposed by Sir J. J. Thomson in 'Conduction of Electricity through Gases' seems capable of explaining the observed results. The nearness of approach of a β ray to a constituent of an atom will determine the amount and nature of the deflexion experienced, the speed of the β ray and the constitution of any particular atom being also necessary factors.

Until a β ray is subject to more than one collision the distribution is approximately constant for a given material, the intensity of the radiation deflected by an angle θ from the original direction being a function of that angle for any one material and with rays of a given quality.

We are to consider this function of θ as being different for the different atoms.

The lack of symmetry in the distribution of scattered X-rays has been shown by Bragg[*], and assuming, as seems reasonable on many grounds, that X- and γ-rays are of the same nature, it appears from that investigation that the softer radiation shows less want of symmetry when falling on a given material than does the harder.

Now although the lack of symmetry shown by the scattered β rays is much greater than that found for γ- and X-rays, even though the former are less penetrating, the general nature of the effect has been shown to be much the same in

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[*] Trans. Roy. Soc. S. A. vol. xxxii. (1908).

the case of all three, and the difference in magnitude may possibly be explained by the difference in distribution of the fields of the rays concerned.

Curves similar to C, figs. 3 and 4, have been obtained for Ag and paper; they show the same general characteristics. It is remarkable, however, that the maximum value of the curve C is very nearly the same for all the substances tested.

In a recent paper by McClelland[*] an account is given of the distribution of the returned β radiation from plates of different substances when the incident beam of radiation is inclined to the plate. The results seem capable of explanation, in view of the effects which have just been described, upon a theory of scattering without the need of introducing the idea of a true secondary radiation proceeding from the atoms affected by the incident β rays.

The general effect observed by McClelland is that the distribution of the returned radiation is more uniform for Pb than for Al. This is to be expected in view of the nature of distribution of the scattered rays from thin films of such substances as Au and Al, which has been described in the present paper.

From the results shown in figs. 3 and 4 it is at once seen that the effects of scattering may considerably modify the results obtained in the usual form of absorption experiment with β rays. The shape of the ionization-chamber and the positions of the screen and active material relatively to the chamber and to each other may produce considerable modifications in the results.

Again, in studying the absorption of β rays it would seem necessary to deal with very thin screens as is necessary in observing the effects of scattering; for thicker screens the results are likely to become considerably complicated.

It would seem almost better to replace the name of "absorption coefficient," as it is usually employed, by that of "transmission coefficient," reserving the former as a measure of effects which, as has been explained, can probably be obtained only from a study of very thin screens.

If the interpretation of the foregoing experiments be correct it seems that the β particle in traversing a thick screen may suffer many collisions and deflexions.

Now it has been shown by Allen (Phys. Review, Aug. 1906) that the secondary or reflected β radiation consists of electrons moving on the whole with a somewhat slower speed than the original radiation.

As the experiments described in the present paper indicate that in some cases these reflected electrons have suffered many collisions before emerging, it would appear that the loss of energy due to a single collision is as a rule not very great, even though the effect of the collision may have produced a considerable change in the direction of motion of the electron. It is not surprising, then, that some of the returned rays have been found to have practically the same speed as some of the original rays; they would appear to be electrons which have suffered only one collision of sufficient violence to cause them to reverse their original direction of motion, or several minor collisions leading to the same result.

From the curves shown in figs. 3 and 4 (Pl. XXX.) it is seen that for small thicknesses of screen, before much actual absorption has occurred, the number of β rays turned back may be large, so that many of the original rays would appear to lose their energy gradually, rather than by a very sudden stoppage and complete absorption. Since the cathode rays behave in many respects like the β rays, it seems difficult to understand how the whole of the energy of the X-rays can be derived from the stoppage of the cathode particles, for, as pointed out by Professor Bragg[*], the stoppage must be very sudden for this to be the case.

Summary.

Experiments with the β rays of radium support the results previously obtained by Crowther, using uranium, upon the scattering of the rays by thin films of materials.

The distribution of the scattered β rays is unsymmetrical, about a plane of right angles to the direction of the original stream.

A close parallel thus exists between the scattering of β rays and that of γ and X rays.

The shape of the so-called absorption curve may be modified by the shape of the ionization-chamber and the position of the screen and active material relatively to the chamber and to each other.

Absorption of a beam of β rays, combined with the effects of scattering and softening, seem sufficient to account for observed effects without the introduction of the idea of a true secondary radiation proceeding from the atoms affected by the primary stream of rays.

An electron appears to be able to suffer collisions, producing considerable change in its direction of motion, without any great loss of energy.

In conclusion, I wish to express my best thanks to Professor Bragg for the suggestions he has kindly given me from time to time during this investigation.

University of Adelaide, Jan. 5, 1909.

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[*] Proc. Roy. Soc., Series A, vol. lxxx.

[*] Trans. Roy. Soc. S. A. vol. xxxi. (1907),