

The periodic table and other wallcharts in the teaching of chemistry in St Andrews, 1884–1919

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Summary

The teaching of the chemistry of the elements at the University of St Andrews by Professor Thomas Purdie FRS is examined with reference to selections from a collection of recently discovered historic wallcharts and extracts from his detailed hand-written lecture notes. Together these reveal a comprehensive and exciting programme of lectures incorporating numerous practical demonstrations which were continually updated to reflect the latest state of knowledge in what was a rapidly changing field.

Main Text

In the summer of 2014 a rolled up wallchart of the periodic table of the elements was discovered during a clear-out of a storage space in the Purdie Building (School of Chemistry) at the University of St Andrews (Figure 1). Subsequent research revealed that this had been ordered from the catalogue of C. Gerhardt of Bonn in October 1888 and was produced in Vienna in 1885, making it quite possibly the earliest surviving printed periodic table wallchart [1]. The details of its dating, its relation to other early periodic table wallcharts, as well as how it is likely to have figured in the teaching of the then Professor of chemistry in St Andrews, Thomas Purdie FRS (1843–1916) have been described by us in a recent article [2]. We now look in more detail at the early teaching of the chemistry of the elements in the University of St Andrews and, in particular, how it developed during Purdie's tenure of the chair of chemistry (1884–1909) and in the following decade, a period of rapid development in understanding in this area. In this, we make use both of Purdie's extensive and detailed hand-written notes on his lectures over this period, which have been carefully preserved [3], and several of the forty-five other early chemistry wallcharts that were discovered at the same time as the St Andrews periodic table.

Thomas Purdie [4] was born in Biggar in southern Scotland and attended Edinburgh Academy. As a young man, he spent a period in South America as a cattle rancher [5] but in the 1870's he returned and studied chemistry briefly in St Andrews before transferring to the Royal School of Mines (a component of today's Imperial College, London) to study with Sir Edward Frankland where he completed a B.Sc. in 3 years.

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He then went to Germany to work with Wislicenus in Würzburg, completing his doctorate in 1881. After acting as interim in St Andrews during the absence of Professor Matthew Heddle in 1882 and 1883, Purdie was elected to fill the chair of chemistry in 1884 and held the position until 1909. He was elected a Fellow of the Royal Society in 1895. As a researcher, Purdie made highly significant contributions to the study of stereochemistry of simple organic compounds and was the first person to resolve lactic acid [6,7]. He is perhaps best known, however, for developing the Purdie-Irvine method for methylation of hydroxyl groups (silver oxide and methyl iodide) [8]. This played a key role in elucidating the structure of simple sugars and underpinned the development of a world-class school of carbohydrate chemistry in St Andrews in the early 20th century and it is still in use today.

Reihen	Gruppe I R ² O	Gruppe II RO	Gruppe III R ² O ³	Gruppe IV RH ⁴ RO ²	Gruppe V RH ³ R ² O ⁵	Gruppe VI RH ² RO ³	Gruppe VII RH R ² O ⁷	Gruppe VIII RO ⁴
1	H=1							
2	Li=7	Be=9,4	B=11	C=12	N=14	O=16	F=19	
3	Na=23	Mg=24	Al=27,3	Si=28	P=31	S=32	Cl=35,5	
4	K=39	Ca=40	Sc=44	Ti=48	V=51	Cr=52	Mn=55	Fe=56, Co=59 Ni=59, Cu=63
5	(Cu=63)	Zn=65	Ga=68	--=72	As=75	Se=79	Br=80	
6	Rb=85	Sr=87	Yt=88	Zr=90	Nb=94	Mo=96	--=100	Ru=104, Rh=104 Pd=106, Ag=108
7	(Ag=108)	Cd=112	In=113	Sn=118	Sb=122	Te=125	J=127	
8	Cs=133	Ba=137	Ce=137	La=139	--	Di=145?	--	--
9	(-)	--	--	--	--	--	--	--
10	--	165	169 Er=170	--173	Ta=182	W=184	--	Pt=194, Os=195(?) Ir=193, Au=196
11	(Au=196)	Hg=200	Tl=204	Pb=208	Bi=210	--	--	--
12	--	--	--	Th=231	--	U=240	--	--

Figure 1: The St Andrews 1885 Periodic Table Wallchart as discovered. R. Alan Aitken, 2014.

Purdie was an enthusiastic teacher who clearly enjoyed his subject. To quote from his obituary [4]: "His teaching was above all thorough and the treatment of the subject philosophic and scholarly, and thus many students from other faculties found their way to the chemistry class-room and thence to the laboratory. They came through the personal attraction of the professor; they remained, fascinated by the subject and the man; and in due course many worked their way to the research bench." The syllabus was extensive and in session 1889-90 for example [3], we have details of a series of almost 90 lectures, starting with introductory general and physical chemistry, and going on to cover in full detail the whole of main-group inorganic chemistry. This is perhaps the more impressive when we realise that Purdie's own research interests were entirely in organic chemistry (on which there were separate lectures). However as Professor of Chemistry he taught all aspects of the subject. An extract from this is illustrative:

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Syllabus 1889-90

Lecture 41. Halogens. General relations. Occurrence. Fluorine. Preparation & General Properties. Hydrofluoric Acid. Preparation, Physical & Chemical Properties. Bromine. Discovery. Preparation from Sea water. Physical & Chemical Properties.

Lecture 42. Bromine. Chemical Properties. Hydrobromic acid. Iodine.

Lecture 43. Hydriodic Acid. Oxides & Oxy acids of Chlorine

Lecture 44. Perchloric Acid & Perchlorates. Chloric Peroxide. Chlorous Anhydride & Chlorous Acid Hypochlorous Anhydride & hypochlorous Acid. Hypochlorites.

Lecture 45. Oxides & Oxy acids of Bromine & Iodine. Compounds of Halogens with each other. General review of relations of halogens. Oxygen group. General relations of the group. Sulphur. Occurrence in nature. Sources of, for industrial purposes. Refining of Sulphur. Physical Properties

Lecture 46. Sulphur continued. Chemical properties. Sulphuretted Hydrogen. Occurrence in nature. Production & Preparation, Physical & Chemical Properties

Lecture 47. Sulphuretted Hydrogen. Chemical Properties. Action of electropositive elements. Feeble acid properties. Action on oxides of metals. Action on Salts. Use of sulphuretted hydrogen in analysis.

Lecture 48. Oxides and Acids of Sulphur. Sulphur Dioxide or Sulphurous Anhydride. Occurrence in nature. Preparation. Physical properties.

Lecture 49. Sulphur Dioxide. Chemical properties. Properties as an anhydride. Uses. Test for. Composition & deduction of formula.

Lecture 50. Sulphur trioxide. Preparation. Physical properties. Chemical properties.

Lecture 51. Sulphuric Acid. Various modes of production. Modern Method of manufacture. Chemical properties. Nordhausen sulphuric acid. Its composition, Manufacture & Use.

Lecture 52. Sulphuric Acid. Action of water on. Action of heat. Acid properties. Sulphates. Nordhausen sulphuric acid. Its composition, Manufacture & use. Hydrogen Peroxide. Occurrence in nature. Preparation. Properties. Test for. Various methods of production. Formula.

Lecture 53. Hydrogen Persulphide. Preparation & general properties. Selenium & Tellurium. Review of the relations of the oxygen group. Nitrogen group Oxides & Acids of Nitrogen. Names & Formulae. Processes in which Nitrogen & Oxygen Combine.

Lecture 54. Nitric Acid. Preparation & Manufacture. Physical properties. Chemical properties.

Lecture 55. Nitric Acid, Action on Organic Substances. Uses. Tests. Nitrous Oxide. Nitric Oxide.

Lecture 56. Nitrogen trioxide. Nitrous Anhydride. Nitrous Acid. Nitrites. Nitrogen tetroxide. Nitrogen Pentoxide – Nitric Anhydride. Chlorides & Iodides of Nitrogen.

Lecture 57. Phosphorus. Occurrence in nature. Manufacture from tricalcium phosphate. Purification. Physical Properties. Chemical Properties. Poisonous Properties of P & method of detection.

Lecture 58. Allotropic Forms of Phosphorus. Phosphine.

Lecture 59. Oxides & Acids of Phosphorus.

Lecture 60. Arsenic. Arsine. Oxides & Acids of Arsenic.

Lecture 61. Arsenious Acid. Arsenic anhydride & Arsenic Acid. Arsenic as a poison.

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Purdie was a firm believer in the importance of numerous lecture demonstrations and kept careful notes on a daily basis on the successes and failures of these, how they were received by the students, and how they could be improved. A key element in the successful delivery of the daily classes was careful preparation of the required materials by the Assistant. Particularly the generation and collection of the required gases for lecture demonstrations must have been an onerous task in the days before cylinder gases. In an image from 1907 we see Purdie in action, with the Assistant on hand, in the lecture theatre of the new chemistry building opened in 1905 (Figure 2).

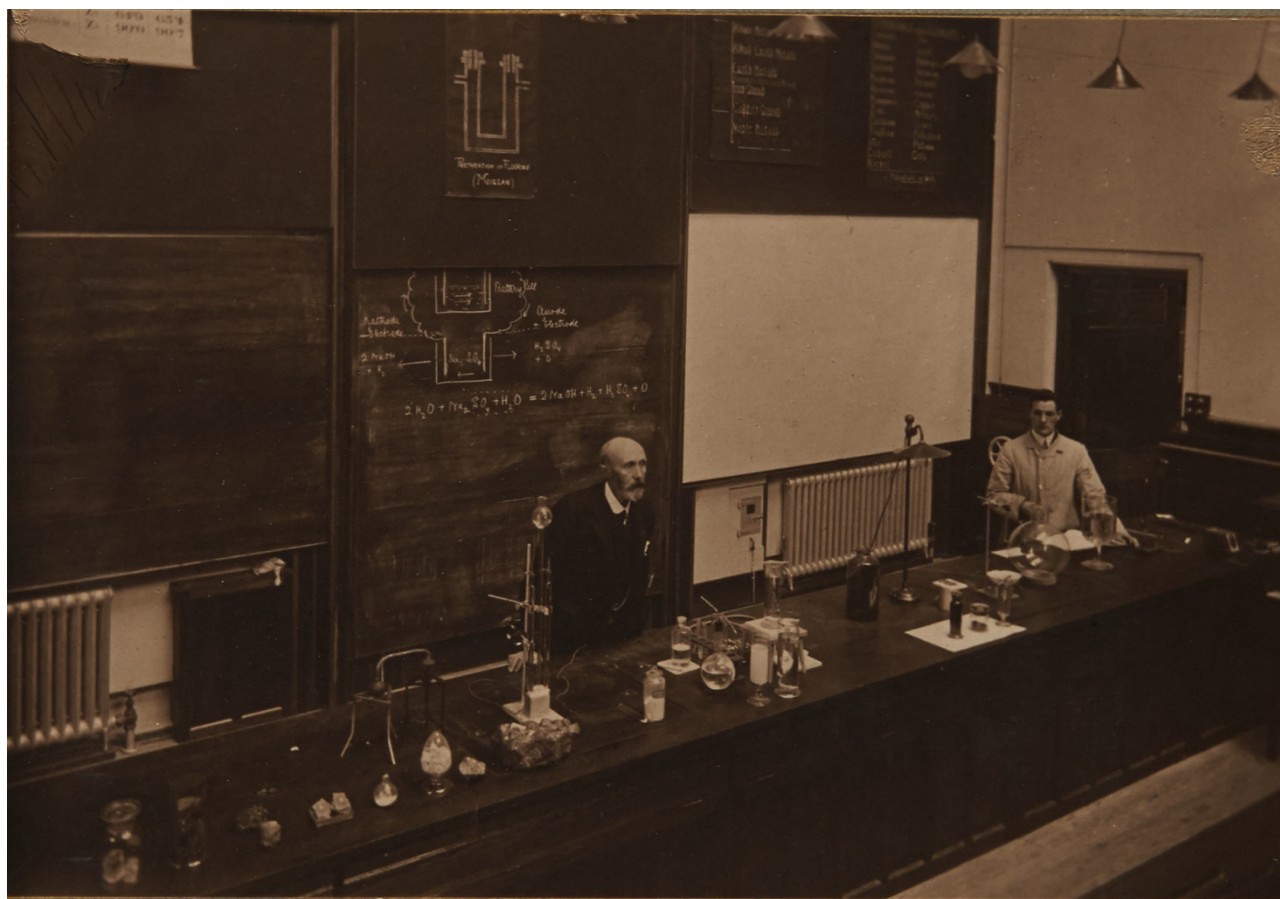


Figure 2: Thomas Purdie FRS lecturing in St Andrews, 1907. Courtesy of St Andrews University Library: ms38187/22.

A range of wallcharts can be seen in use and these would have been regularly used to complement material written on the blackboard. Several series of these were commercially available and one of the earliest is a series of 15 charts produced by Drs Georg and Julius von Schroeder with the title "Tafeln für den Unterricht in der allgemeinen Chemie und chemischen Technologie" and published in 1885 by Theodor Fischer in Kassel. They were often used to illustrate major industrial processes or complex apparatus. Invoices in the archives of

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the University of St Andrews show that Purdie ordered the first five of these at the same time as the periodic table on 16th October 1888 and the remaining ten were ordered on 11th January 1889. Only chart No. 3 illustrating the production of nitric acid ("Taf. III Salpetersäure-Fabrikation") survives in our collections and is shown alongside a somewhat later chart showing a sulfuric acid factory (Figure 3).

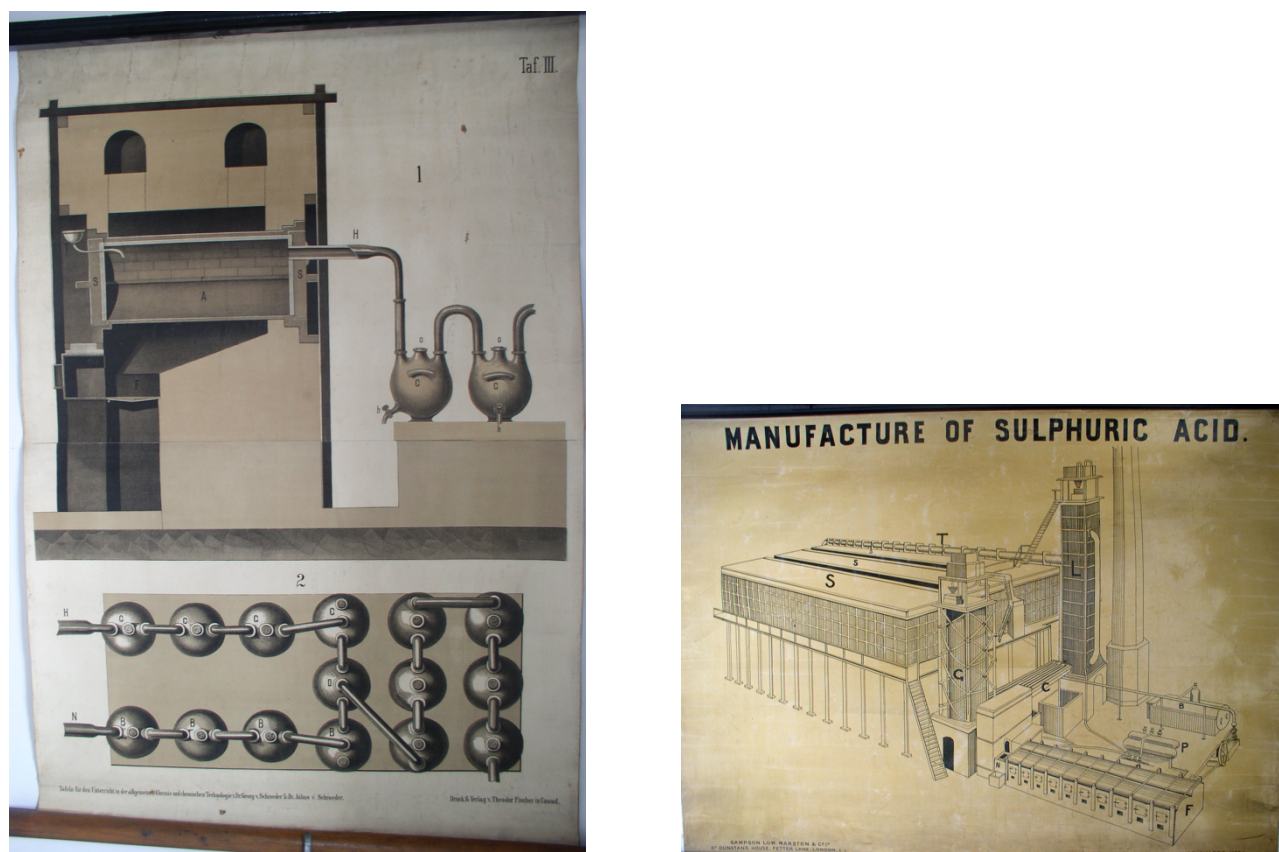


Figure 3: Two early wallcharts illustrating manufacture of nitric acid (1885) and sulfuric acid (ca. 1895). R. Alan Aitken, 2014

The latter chart is one of a series produced in London by Sampson Low, Marston and Co. in 1895 under the title "Low's Chemical Lecture Charts" and for which there is a contemporary and somewhat critical review [9]. The same publisher later issued an extensive series of charts under the title "Dr Geoffrey Martin's Chemical Lecture Diagrams" of which over 30 are preserved in St Andrews.

To show how these may have been used, we examine a small selection of them in conjunction with Purdie's notes on the lectures and corresponding lecture demonstrations in the period 1889–1891. In November of 1891 the lecture topics included the determination of molecular weight and on Monday 9th November the lecture covered the "Composition of water, from decomposition by Cl to the Dumas Expt. inclusive" (Figure 4). The relevant lecture charts are shown (Figure 5) and Purdie notes the following:

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"Expts. were scarcely ready, & the Lecture therefore not very good.

Cl. Expt yielded oxygen, but slowly. Tube should be examined to see if enamel is gone. Kipp's apparatus with CaCl_2 tube should be used for jet of hydrogen & a better apparatus than the funnel arrangement, say glass funnel with small condenser & aspirator for collecting H_2O on large scale.

Burning H in O & O in H. – The hydrogen went out very soon, water rose only a little. The O was collected by exhausting jar first. On standing dew collected on glass. The O might be collected by displacement of water, & the jar placed in front of fire for a little time to dry the glass surface. – Oxygen in H; the flame extremely small; the oxygen was in bag and pressure was not steady. Both expts. should be tried again before lecture.

Cavendish expt; nearly 2in of gas left. It would be better to use Hoffmans' tube; make up the mixture of H & O in bell jar & try it before hand.

Dumas apparatus wants overhauling; it should be placed right in middle of table." [10]

Lecture IX. Monday 9th November
Composition of water, from decomp. by Cl. to
Dumas Expt. inclusive. –
Expts. were scarcely ready, & the Lecture therefore
not very good.
Cl. Expt yielded oxygen, but slowly. Tube
should be examined to see if enamel is gone.
Kipp's apparatus with CaCl_2 tube should be used
for jet of hydrogen & a better apparatus than the
funnel arrangement, say glass funnel with
small condenser & aspirator for collecting H_2O
on large scale.
Burning H in O & O in H . – The hydrogen went out
very soon, water rose only a little. The O was
collected by exhausting jar first. On standing
dew collected on glass. The O might be collected
by displacement of water, & the jar placed
in front of fire for a little time to dry the
glass surface. – Oxygen in H ; the flame
extremely small; the oxygen was in bag

and pressure was not steady. Both expts.
should be tried again before lecture.
Cavendish expt; nearly 2in of gas left.
It would be better to use Hoffmans' tube;
make up the mixture of H & O in bell jar
& try it before hand.
Dumas apparatus wants overhauling; it should
be placed right in middle of table.

Figure 4: An extract of Purdie's hand-written notes from 1891. Courtesy of University of St Andrews Library: ms38620.

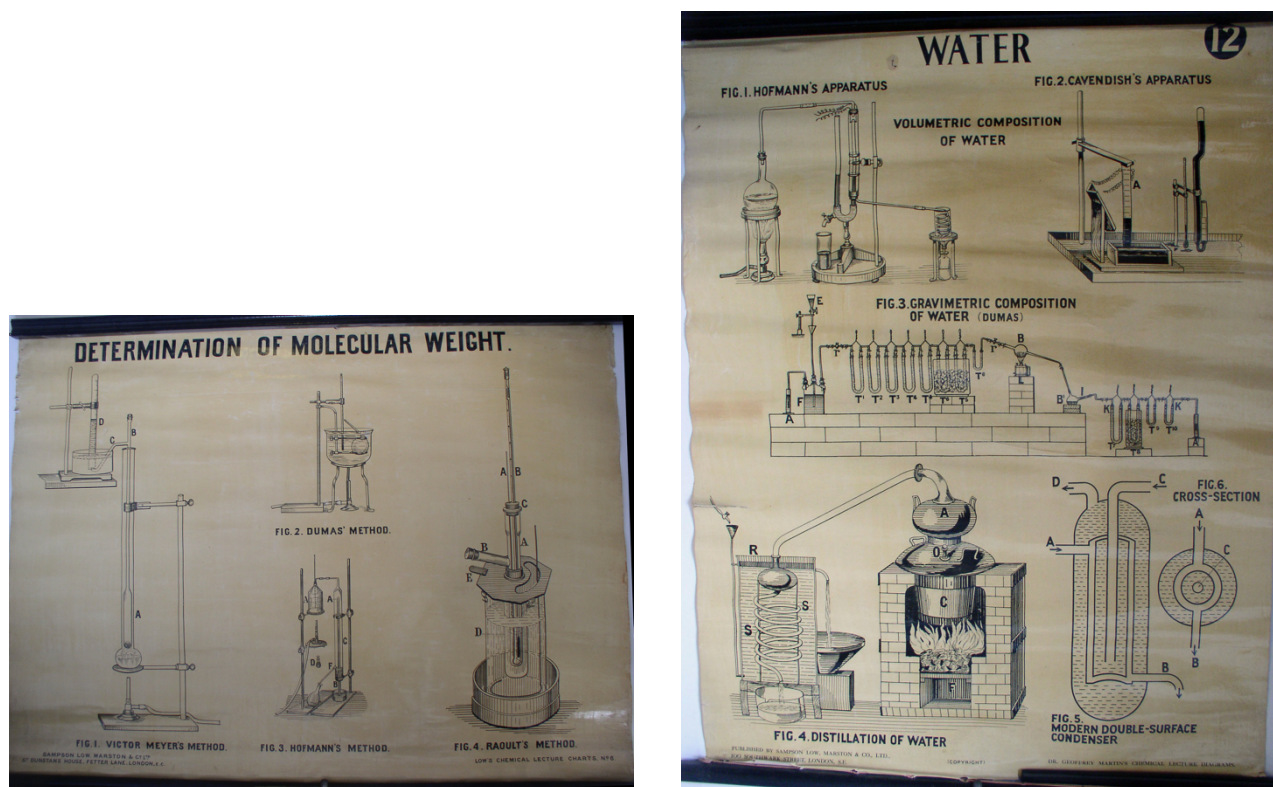


Figure 5: Wallcharts covering the determination of molecular weight and composition of water. R. Alan Aitken, 2014.

The next main topic in the course was the halogens (Figure 6) and in the lecture covering chlorine the main lecture demonstrations were to illustrate the combination of chlorine and hydrogen, both by burning a stream of one gas in the other each way round and by explosion of a mixture of the two. As we hear, things were not entirely satisfactory:

"Phenomena attending the combination of
Hydrogen & Chlorine.

Note. Expts. were not ready & lecture unsatisfactory. Absorption of Cl by water not well shown, air entered cylinder. After burning H in Cl, cylinder was shaken with water, absorption scarcely perceptible HCl having been mostly driven out. Set of Cl for burning in H not ready, expt. not performed. Cylinder of mixed gases did not explode first trial with gun cotton & Mg, taper should be ready for firing the gun cotton, as the cylinder being only covered with cardboard H may escape. On second trial explosion took place. The explosion of the electrolytic gas was not successful. The last bulb of the series had been tried on Friday night, when the bulbs were prepared; and exploded but at the lecture four or five were tried unsuccessfully.

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Gun cotton & Mg were used; perhaps too little Magnesium powder was used.

In the Chlorine lectures each expt. must be carefully seen to. Each cylinder or jar should be placed ~~under~~ beforehand in the funnel and its height adjusted." [11]

In the account of the corresponding lecture from another year, the key role of the Assistant is emphasised:

"Explosion of H & Cl by light. Cl had been collected by Mr Mackenzie over water. H. was taken from Kipp. Mixture would not explode behind blue glass with gun cotton & Mg, nor with NO & CS₂; gun cotton & Mg without blue glass did not cause explosion. -The Cl was collected at lecture direct from generator over water, the generator had been going a long time & must have been free of air. Gun cotton & Mg did not explode it behind blue Glass. On trying after lecture with H. from small Kipp & with Cl collected by Mr McK over water without blue glass, mixture exploded well with Mg fillings in flame. Either the H. from large Kipp was not good, or (which is more likely) the mixture was not sensitive enough to explode even with CS₂ & NO behind blue glass, & the gun cotton & Mg not strong enough to explode even without glass." [12]

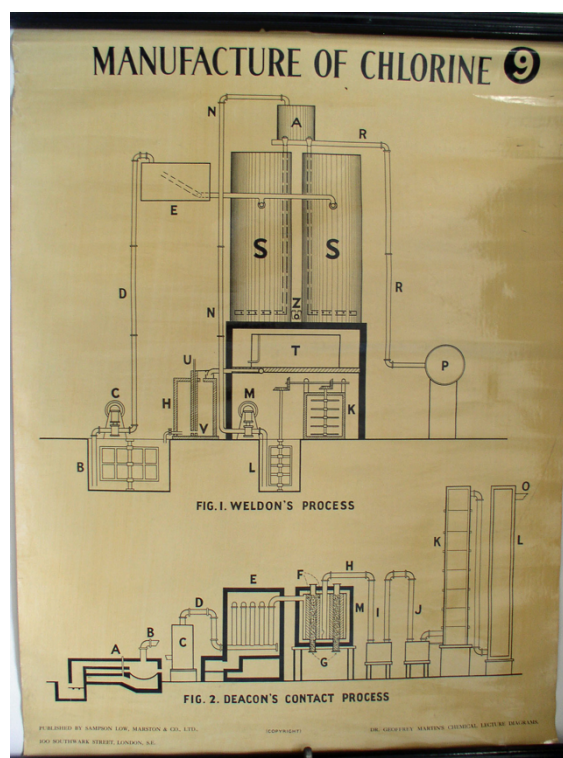
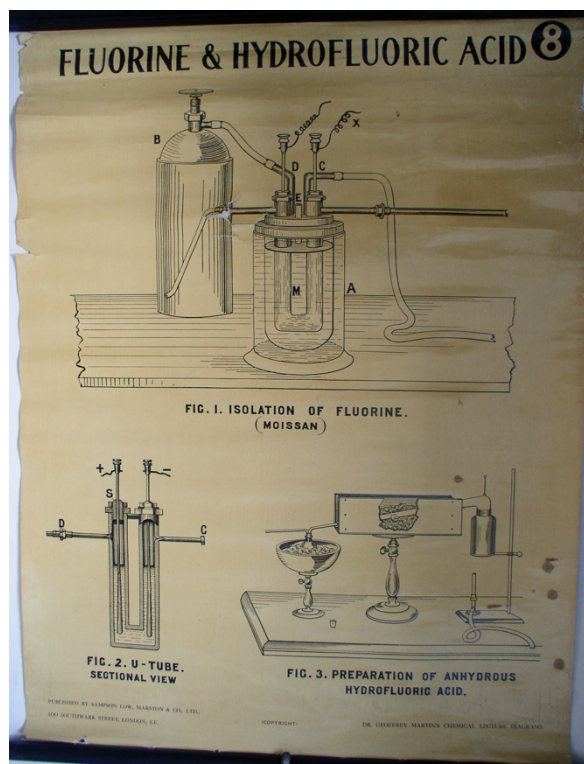


Figure 6: Wallcharts covering fluorine and chlorine. R. Alan Aitken, 2014.

The lecture course then moved on to bromine and iodine and then to sulphur (Figure 7) and Purdie wrote the following comments:

"Assistant is required to see to heating of flasks in preparation of Br from KBr which if not carefully heated is apt to froth & possibly to crack." [13]

"The interest of the lecture was pretty well sustained. Burning & H & Br. The blue paper was not quickly or easily reddened & yet there was fume enough. Perhaps the paper should be more moistened Bromine & Arsenic. The arsenic powder did not take on fire." [14]

"Oxycomps of Br & I & compds of Halogens with each other were only mentioned. Of allotropic forms two only were given. Lecture till 12 o'clock. The lecture was pretty well given, students were attentive & seemed interested, but there was not much note taking." [15]

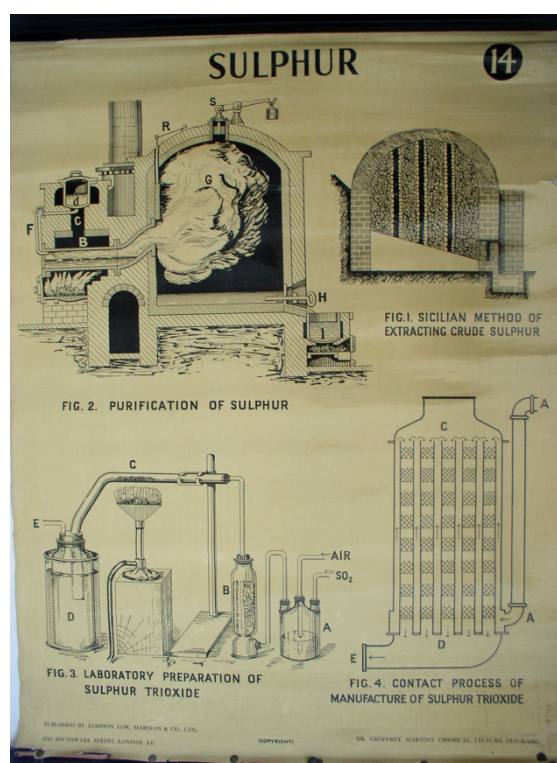
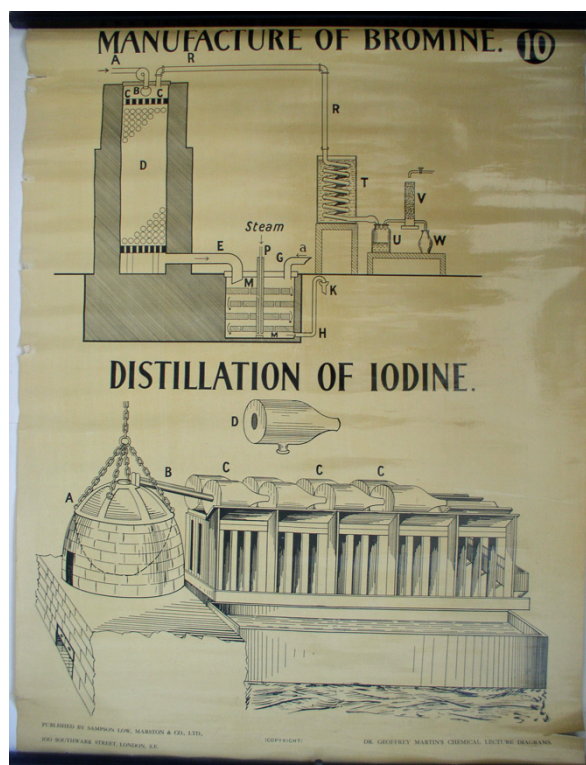


Figure 7: Wallcharts covering bromine, iodine and sulfur. R. Alan Aitken, 2014.

Quantitative experiments were also sometimes included in the lectures although these did not always go according to plan as the following reports from the lectures of 11th and 12th November 1891 illustrate.

"Laws of Multiple & Equivalent Proportions
Explanation & Defs. Of Combining Weights.

Equal vols. H & O exploded in Hoffmanns' eudiometer. Use of latter explained. The tube was filled nearly 2/3 full of the mixed gases; too much mercury must not be run out of the open limb. If a thin splinter of wood is used, the oxygen is sufficient to make it burst into flame.

An attempt was made to determine the equivalent of sodium. The tube exploded violently though it only contained at first .3 gram." [16]

Not deterred by this, the Assistant was instructed to perform the experiment before the following day's lecture and got a good value. However in the actual lecture there was another mishap:

"Illustrations of the determination of Combining Weights.

Sodium Equivalent. Using sodium in a lead tube Mr MacKenzie got 23.4. In the lecture there was a slight explosion at the end, & on measuring the H it was found to be considerably less than it should have been. The calculation was not proceeded with.

Zinc Equivalent. Expt. successful, result worked out during lecture by Mr. MacKenzie 32.6"[17]

The demonstrations were often designed to be spectacular and to make a lasting impression on the audience but, as Purdie notes with commendable honesty, this was not always successful.

"P was burned as before in a large wide cup on upright stand with lead foot. A pretty large piece of P. was used & the combustion was very brilliant. Students listless." [18]

" To show alkalinity of K_2O , K was burned in copper spoon in air & spoon then dipped in litmus. An iron spoon would perhaps be better; potassium seemed to attack spoon, & the flame of the burning K was scarcely visible." [19]

It is important to remember that, in addition to a full programme of lectures packed with demonstrations, each student also had laboratory classes, which formed a significant part of their training. In this respect St Andrews was relatively well equipped and the facilities are illustrated in an image of the teaching laboratory from around 1906 (Figure 8).



Figure 8: Students in the "elementary laboratory" in St Andrews around 1906. Courtesy of St Andrews University Library: ID: 2012-12-16.

It is interesting to note that, although concepts such as atomic weight and classification of the elements are present right through the course, it is only at a late stage, lectures 80 and 81, that we come to "Periodic system of classification of the elements" as a specific topic and its coverage is justified by inclusion of "practical application", namely ability to predict hitherto undiscovered elements. The period covered by Purdie's tenure in St Andrews coincides with the discovery of sub-atomic particles and the resulting transition from regarding the table as a purely empirical arrangement to being able to rationalise it in terms of atomic structure. To emphasise the magnitude of the changes involved and the resulting challenges in keeping the course material up to date, we compare the 1885 periodic table (Figure 1) with that shown on a later wallchart also used in St Andrews which dates from after 1918 (Figure 9).

Both the charts are clearly derived from a version of the periodic table published in a journal. In the case of the 1885 table, this is Dmitrii Mendeleev's second version of 1871 that was published in a supplementary volume of *Liebigs Annalen* [20]. The table in Figure 1 is essentially identical to the figure appearing on page 151 of the article, whose title is "Die periodische Gesetzmäßigkeit der chemischen Elemente", with the important exceptions that elements discovered in the intervening period have been added. Thus scandium (isolated 1879) and gallium (discovered 1875) have been added and the positioning of "didymium", cerium and lanthanum has been rearranged, with a few further adjustments to atomic weights. Importantly for the dating of this version, a gap at atomic weight 72 is left which would be filled by germanium (discovered 1886). A slightly later table by the same publisher, dated at 1893 and housed in Kyoto *Phil. Trans. R. Soc. A.*

University library [2], has germanium added and the inverted positions of lanthanum and cerium corrected. Curiously, the version of Figure 1 also has the order of the third row transition elements mixed up as compared both to Mendeleev's original [20] and the later Kyoto version [2] where the error, resulting mainly from a false atomic weight for osmium, has been corrected. We might also note that Mendeleev admits in his article [20] (Page 150) that some of the atomic weights have been altered from the experimentally determined values to fit in with order of the periodic system for example tellurium ("Einige Atomgewichte sind in der Tabelle nach dem periodischen Gesetze abgeändert (s. Cap. 5); so steht beim Tellur in Ubereinstimmung mit dem periodischen Gesetze 125?, und nicht 128, nach Berzelius u. A.") and this confirms his great confidence in the new system. There is little doubt that the table of Figure 1 was used regularly in Purdie's teaching from its purchase in 1888 right through to the early years of the 20th century since the noble gases including neon, krypton and xenon (discovered 1898) have been added in chalk at the right hand side.

The table forming the upper part of the wallchart in Figure 9 is taken directly from a publication by the physicist Herbert Stanley Allen FRS (1873–1954) in 1918 [21]. This is now clearly based on atomic number with the resulting argon/potassium, cobalt/nickel and tellurium/iodine atomic weight anomalies specifically noted. Although J. J. Thomson discovered the electron in 1897 it was not until 1920 that Rutherford named the proton and in the note on Figure 9 we see an attempt to explain the relatively new concept of atomic number: "The number representing the position of the elements coincides with the number of + and – charges composing the atom. Thus $U = 92$ means that uranium is composed of a positive charged nucleus of 92 positive electrons surrounded by 92 negative electrons." In this version we see all the noble gases present, including "Nt" for Niton or Radon (disc. 1900) but none of protactinium (disc. 1913), hafnium (disc. 1923) or rhenium (disc. 1925) yet present. Alternative symbols are also used for argon (A), glucinium (Gl, beryllium) and colombium (Cb, niobium). Although H. S. Allen, who had conducted research under J. J. Thomson earlier in his career, was at Kings College London when he published the 1918 paper, he moved in the following year to the University of Edinburgh to join his former boss Charles Glover Barkla FRS (1877–1944) who had been awarded the Nobel Prize for physics in 1917 [22]. In 1923 he took up the chair in Natural Philosophy at the University of St Andrews, a post that he held until his retirement in 1944. It is recorded that his inaugural lecture in St Andrews dealt with atomic structure and it is interesting to speculate that when chemistry students met the chart of Figure 9 in their lectures there in the 1920's, the reference to "after H. S. Allen" would have had a particular local significance to them. The lower half of this chart shows an unusual and fascinating attempt to represent the periodicity of elemental properties in a series of coils and is due to the pioneer of radioactive decay Frederick Soddy and dated 1911 [23].

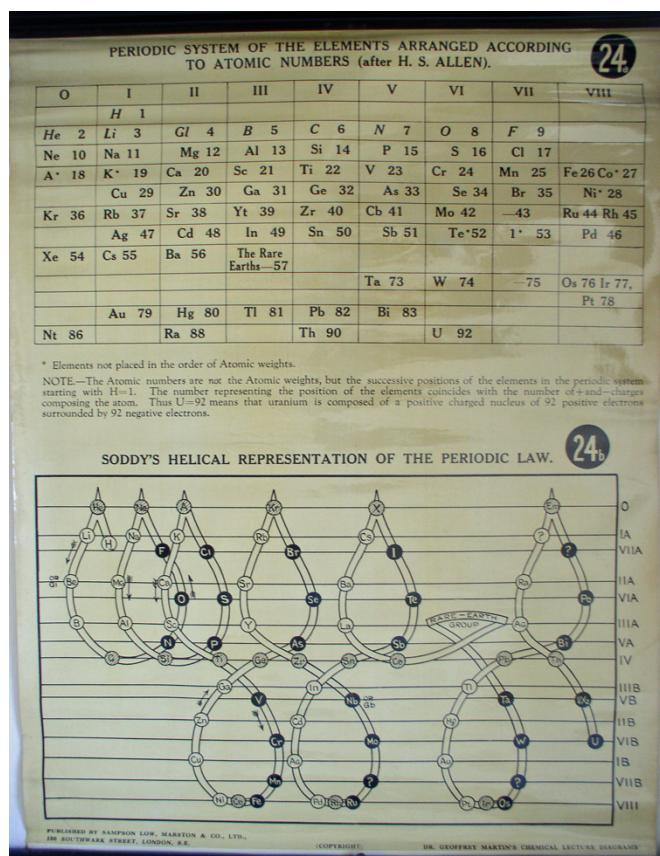


Figure 9: Wallchart of the periodic table and its "helical representation" (1918 or later). R. Alan Aitken, 2014.

The development in understanding of the periodic table, from the earliest chart delivered to St Andrews in 1888, through the discovery of the noble gases which were added to it by hand, to eventual rationalisation in terms of atomic structure as shown in Figure 9, covered the whole period of Purdie's tenure of the chair, into his retirement and indeed continued after his death in 1916. Purdie became a Fellow of the Chemical Society in 1875 and was later elected to its Council and was invited to act as a Vice-President in 1899 [4]. Partly as a result of his regular attendance at its meetings, he was certainly well aware of the latest exciting developments in the area of atomic structure. An interesting insight into his developing understanding of atomic theory is provided by his notes for a major lecture on the "Genesis of the Elements" extending to forty-five pages and noted as "intended for the University Chemical Society" [24]. There is no record in the University archives of when or indeed whether this lecture was actually given but its content shows things at an interesting intermediate stage of understanding between the pictures conveyed by Figures 1 and 9. From the phrase "[radium] "emanation" now christened Niton by the International Committee on Atomic Weights" the notes can be dated to 1912 or later, and the lecture may have been given towards the end of Purdie's life, or indeed pre-empted by his death in 1916. The scene is first set by a summary of the major recent developments:

1. The discovery, first & foremost, of the Periodic Law by Mendeleeff in 1869.
2. The discovery of the Cathode rays by Crookes

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and following on this the investigations (during the last ten years) on the discharge of electricity through gases by Sir J J Thomson & his school.

3. Spectroscopic researches by many physicists.
4. Astrophysical discovery by Lockyer & others
5. The discovery of radioactivity." [24 p5]

A little later we find a detailed explanation of atomic structure according to the latest understanding. Purdie uses the term "corpuscle" favoured by J. J. Thomson, who first identified the particles in 1897, in preference to "electron" which was coined earlier by Irish physicist Johnstone Stoney in 1891.

"An atom is not a big thing, but it is colossal when compared with the corpuscles which swarm inside it. To picture to ourselves an atom of oxygen, we must imagine it, if we can, magnified to say the size of the dome of St Pauls. Inside this expanse we should then perceive some 16 or perhaps as many as 64 tiny specks like so many small flies, flying not each at its own sweet will, but revolving with enormous velocity in orbital courses like a planetary system; we should also perceive an equal number of positively electrified spheres, much larger than the corpuscles and much heavier, **uniformly distributed throughout** the atom & by their attractive force holding the corpuscles from dashing into external space. The corpuscles being so light will constitute but a small fraction of the weight of the atom, which may be taken in the main therefore as the sum of the weights of the positive particles, and if the mass of each of these is equal to the mass of a hydrogen atom, then the oxygen atom cannot contain more than 16 such masses." [24 p12-13]

Purdie then gives a simple explanation of reactivity in terms of the recently discovered electron.

"We must picture to ourselves what happens when the atom of an electropositive element, like say sodium combines with the atom of an electronegative element such as chlorine. Both atoms are electrically neutral: why should they combine? According to our theory, it is because the atom of sodium readily loses a corpuscle, & the atom of chlorine readily assumes a corpuscle. Supposing then the two neutral atoms to collide, a corpuscle is transferred from the sodium to the chlorine atom, the former thus becoming a positively charged and the latter a negatively charged radical. The two oppositely & equally electrically charged radicals then attract each other & unite to form a neutral molecule of common salt." [24 p16]

Perhaps more interestingly, there is also a visionary speculation on whether the elements might have been formed in a process analogous to Darwinian evolution. The scene is first set:

"The time has in fact come when the chemist is compelled to apply the doctrine of evolution to the elements themselves, & to regard them, like chemical compounds, as the fittest survivals from a struggle for existence, a struggle however between things of a simpler and entirely different order to any we have hitherto known"[24 p3]

"At the present day the position of the chemist with respect to the problem of the constitution of the elements & their synthesis is like that of the organic chemist prior to Wöhler's synthesis of urea. He was acquainted with the products of the decomposition of organic compounds. He could resolve organic compounds into their elements by laboratory methods & he could observe their decomposition in nature; their synthesis in nature was also open to his gaze, but as yet he had not produced an organic compound out of its elements. So it is with respect to the elements at the present time. We have in the laboratory resolved elementary matter into its constituents & its resolution into simpler forms is to be seen in the disintegration of radium & its congeners. The synthesis of the elements also by natural means is proceeding at the present time in heavenly bodies & is revealed to us though dimly, by spectroscopy. Artificial synthesis is not yet achieved, but it is not rash to predict that before very long that final problem will also be solved." [24 p5verso]

We then continue with a vision of the creation of atoms. The unusual term "protyle" is a historical one meaning a hypothetical base substance from which the elements were made

"Having concluded that atoms are clusters of negatively and positively charged particles, arranged in such definite groupings as to determine the periodic chemical properties exhibited by the elements, we must give flight to the imagination & try to conceive how these corpuscular clusters or constellations came into being.

We must carry our thoughts back to a time when our earth was without form & void; and yet not really void, but consisting of a nebulous mist of corpuscles seething with electric energy.

Out of this negatively electrified cosmic dust, positively charged particles first emerge, which

with the cloud of corpuscles, still remaining free constitute the two fold protyle from which flaring atom streams are in due time to be born. The positively charged particle is the subatom or germ which gathering round it the requisite number of negative corpuscles gives birth to the neutral atom. Such an atomic system once formed will in turn with falling temperature throughout the ages incorporate still more of the two fold protyle, and so produce a heavier neutral atom capable of separate existence." [24 p23]

The possible role of an evolutionary process in the formation of the different elements is then considered:

"The birth of each new element, whether direct from the protyles or from the union of ready made atoms, must be heralded by a far greater outburst of energy than the familiar chemical change ever presents.

The evolution of elements, however, need not be regarded as a cataclysmal process. Like other evolutionary processes, it may be supposed to progress in a smooth & continuous manner. Innumerable unstable systems will come into being, will have their day & cease to be, and only those which are stable will survive the clash of the mighty forces in play, and serve as resting places, from which new & still heavier atoms will arise." [24 p24]

"And here the problem presents itself as to the precise order in which the elements have appeared on our earth. As already said the evolution must have been in general from the simple to the more complex, from the lighter to the heavier atom. With this proviso, a glance at the Periodic System suggests two possible lines of descent. Evolution may have followed the road of the horizontal periods in which case like did not produce like. On this hypothesis an energetic powerfully negative, monovalent element like fluorine gave birth to lazy non-valent neon, & this in turn to the strongly positive monovalent atom sodium, which again would beget divalent magnesium. Remembering what marvellous changes in properties result from ordinary chemical combination, & the relations of Thomson's atom-models, it must be said that there is nothing inherently improbable in this hypothesis.

On the other hand, the descent may have been in the line of our perpendicular columns of closely related elements. On this supposition sodium is the son of lithium, potassium its grandson, rubidium its great grandson and so on." [24 p26]

The lecture finishes with Purdie acknowledging how much things had developed over the previous century and appealing to his audience to spend some time thinking about such fundamental matters:

"In the year 1818 Faraday spoke these words 'To decompose the metals to reform them, and to realise the once absurd notion of transmutation; these are the problems now given to the chemist for solution.'
The opinion of that far-seeing philosopher, expressed nearly a hundred years ago, was doubtless premature, but I think you will agree with me, that the time has now come when chemists should give their serious attention to such problems. I do not wish to bring you down to earth from the high flights of organic chemistry, in which many of you are engaged, but I venture to express the hope that in the intervals of other work you may find some time for at least speculation on the subject of the inner nature and origin of the 'beggarly elements'." [24 p40]

Purdie's 25-year tenure of the chair of chemistry at the University of St Andrews coincided with a period of rapid development in the understanding of the periodic system of the elements. As this moved from Mendeleev's initial empirical observations, as represented in the 1885 table, towards a modern understanding in terms of atomic structure, it is clear that students were kept abreast of the latest progress at each stage by means of well-constructed lectures using up to date wallcharts and numerous practical demonstrations. The students of that time were well served by their Professor and his teaching laid a firm foundation for the future development of chemistry in St Andrews.

Additional Information

Authors' Contributions

RAA and MPG contributed equally to the preparation and writing of the manuscript.

Competing Interests

The author(s) declare that they have no competing interests.

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Figure and table captions

Figure 1: The St Andrews 1885 Periodic Table Wallchart as discovered. R. Alan Aitken, 2014.

Figure 2: Thomas Purdie FRS lecturing in St Andrews, 1907

Figure 3: Two early wallcharts illustrating manufacture of nitric acid (1885) and sulfuric acid (ca. 1895)

Figure 4: An extract of Purdie's hand-written notes from 1891

Figure 5: Wallcharts covering the determination of molecular weight and composition of water

Figure 6: Wallcharts covering fluorine and chlorine

Figure 7: Wallcharts covering bromine, iodine and sulphur.

Figure 8: Students in the "elementary laboratory" in St Andrews around 1906

Figure 9: Wallchart of the periodic table and its "helical representation" (1918 or later)