



The Discovery of the Inert Gases



neon
helium
krypton
xenon



argon

11

12

13

14

15

16

17

18

19

20

If the room in which you are sitting is of average size – say 12 feet long, 12 feet wide, and 8 feet high – it contains no less than $11\frac{1}{2}$ cubic feet of inert gases. These gases, sometimes called the 'rare gases', or the 'noble gases', are a group of elements which form about one per cent of the volume of the earth's atmosphere. By far the most common of them is argon, nearly 800 times as abundant as neon, the second most common. Argon hardly deserves to be called a rare gas, for whenever you take a deep breath you inhale about 5cm^3 of it into your lungs.

Nevertheless, the existence of argon, and of a whole family of elements in the air, remained undiscovered until the 1890s; indeed the first of these elements to be given a name, helium, was discovered in the gases surrounding the sun over twenty years before anybody suspected it could be here, in the air we breathe. How could an element unknown on earth be discovered on the sun? The technique which made such a discovery possible is one which has a vital rôle in our story. The scene of its origin was the famous German University of Heidelberg, in the year 1854.



A solar eclipse in 1868 provided the occasion for the discovery of helium in spectrographs of the sun's chromosphere. Other solar phenomena, such as the prominence shown here, are also spectacularly visible during eclipses.
Royal Greenwich Observatory.

part one

BUNSEN AND KIRCHHOFF

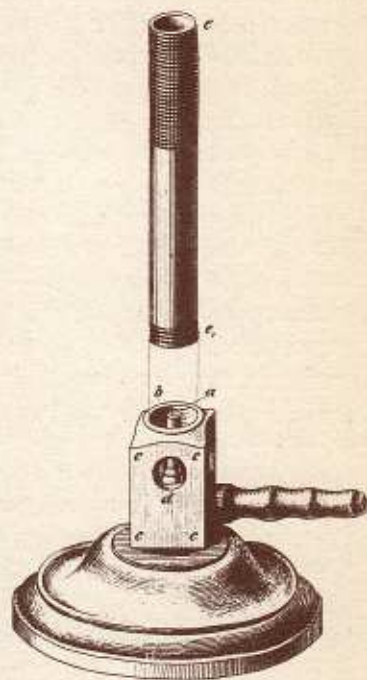


Robert Bunsen (1811-1899). His observations with his burner led him to discover a new method of chemical analysis and two new elements. Ronan Picture Library.

Discovery in Heidelberg - In 1854 the Heidelberg gasworks were built. Gas was piped to the University and gas burners could be used in the chemistry laboratory. But the professor of chemistry, the great Robert Bunsen, found none of the burners on the market suitable for his purpose. He therefore decided to invent one of his own, and invented one so good, and of such simple design, that it is still used today in laboratories all over the world.

The Bunsen burner has many advantages; one is that it can be made to burn with an almost invisible flame. Bunsen, who liked to make some of his own apparatus by blowing glass (he is said to have moulded the hot, semi-molten glass with his bare hands, an accomplishment which never failed to impress his students), noticed that whenever he held a glass tube in the colourless flame of his burner the flame turned yellow. Soon he was experimenting with different substances in the flame, holding them on the end of a platinum wire. Different chemicals, he found, produced flames of different colours: sodium gave a bright yellow flame, calcium a red flame, barium green, strontium crimson, potassium lilac. Was this a short cut past some of the complicated and difficult tasks of chemical analysis? Could you accurately identify substances simply by holding them in the colourless flame and watching what colour appeared? It was a promising idea but there was a serious drawback: it seemed to work only for fairly pure compounds. A mixture of salts containing, say barium, strontium, sodium, and potassium, would give a flame that told nothing: except that the ever dominant bright yellow of sodium would usually be visible, obscuring all the rest.

Bunsen found he could get no further with his idea. He tried various devices such as looking at the flames through glass of different colours, but nothing came of them. One day,



A simple invention which led to great discoveries. Bunsen's original gas burner. Crown Copyright. Science Museum, London.

however, he mentioned the problem to his friend and colleague, the professor of physics Gustav Kirchhoff.

'My advice as a physicist', said Kirchhoff, 'is to look not at the colour of the flames, but at their spectra.'

Study of the spectrum had been an important part of physics ever since Newton had split up the light of the sun with a prism and demonstrated that white light is a mixture of different colours and, to prove his point, had painted a disc in different coloured segments and shown that when the disc was spun the colours intermingled and appeared white. But as physics and chemistry were sharply divided branches of science, nobody before Kirchhoff thought the spectrum could have an important part to play in the study of chemistry.

Now, the sun is not the only light from which you can get a spectrum. If you do an experiment much like Newton's, but with artificial light, letting a beam of light shine through a small hole in a piece of dark material and fall on a prism, you will get a spectrum just as Newton got one from sunlight; and like the sun's spectrum it will have bands of colour, each colour in its own particular place. But it will not look exactly like the sun's spectrum: every kind of light has its own characteristic spectrum, with certain bands of colour in certain particular places, and some colours missing altogether so that there is just a black band in their place. The colours in the light are separated because the prism refracts the shorter wavelengths more than the longer ones. Each wavelength of the light is 'bent' a certain amount and thrown into its own place as a band in the spectrum. Between some of the bands of light are dark lines in the place of those wavelengths which are not present in the light. The dark lines in the sun's spectrum are called Fraunhofer lines after the man who discovered and charted them.

Each element, which can be made to give out light when heated, emits its own special wavelengths, and shows its own characteristic spectrum when its light passes through a prism; even if several elements are mixed up, the light of each one is distinguishable when assigned to its place in the spectrum. This is what Kirchhoff had guessed when he made his suggestion to Bunsen, and this is what the two scientists confirmed when Kirchhoff had built the first spectroscope.

Like many of the really great inventions, Kirchhoff's spectroscope started off as a rather makeshift piece of apparatus: a cigar box from which protruded two old telescopes.

The cigar box was pasted over with black paper to keep out the light. The light was admitted through one of the telescopes, the aperture of which was covered up except for a narrow slit slightly to one side, and fell on the prism inside the box. The spectrum was viewed through the other telescope.

First they tested the instrument with sunlight. A splendid spectrum was seen, in all its bright colours, with the Fraunhofer lines showing clearly. Next, in the darkened room, they viewed the flame of the Bunsen burner. The almost colourless flame gave hardly any spectrum, but when Bunsen held some

Gustav Kirchhoff (1824–1887), inventor of the spectroscope and discoverer, with Bunsen, of spectral analysis.
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sodium chloride in it, the room was flooded with yellow light. In the spectroscope, Kirchhoff saw just two yellow lines side by side. That was all, and every sodium compound gave the same two yellow lines in exactly the same place. Strontium gave a bright blue line and some dark red ones, lithium a bright red line and a dimmer orange one. But what about mixtures? Kirchhoff looked away while Bunsen mixed different salts together. Bunsen held them in the flame and Kirchhoff put his eye to the spectroscope. 'Sodium, potassium, lithium, and strontium', he said, and he was quite correct.

Original apparatus used by Joseph von Fraunhofer (1787–1826) to chart over 500 dark lines in the sun's spectrum. Crown Copyright. Science Museum, London.



For years scientists had been attacking minerals, breaking them down with heat, reagents, and electrolysis, looking for new elements. Gradually the minerals yielded up their secrets, until many people thought there were no more elements left to discover. Then came spectral analysis, so sensitive that it can detect a three thousand millionth of a gram of sodium present in a flame. Using the spectroscope, Bunsen discovered two new elements in the foul-tasting medicinal water of Durkheim Spa. He called them caesium and rubidium, the Latin names for sky blue and dark red denoting the colours of their spectra. Early on Kirchhoff had introduced a scale into his spectroscope, so that he could tell the exact position of the bands in each element's spectrum, and the two researchers made charts of the spectra of all the known elements. Soon other scientists were studying spectra and the elements thallium and indium were discovered.

A sun element – In 1868 there was a total eclipse of the sun; the moon, passing between the sun and the earth, obscured the sun's burning centre, leaving the incandescent gases surrounding it clearly visible. Pierre Janssen, the French astronomer, made very careful observations of the sun's spectrum during the eclipse. In the spectrum was a yellow line where no yellow line should be.

Normally the blinding light of the sun's centre would not allow the relatively faint rays from its surrounding gases to be seen; the spectrum during a total eclipse is quite different from the sun's everyday spectrum, because it comes from precisely these incandescent gases whose light is normally invisible.

Inspired by their observations of the eclipse, both Janssen and the English astronomer Joseph Norman Lockyer, working independently, studied these gases, named them the 'chromosphere', and devised instruments for viewing their spectrum in normal conditions. Both deduced the presence of an unknown element in the chromosphere from the new yellow line, and their announcements were published almost simultaneously – a coincidence which, curiously enough, led to their becoming the best of friends. The new element was christened 'helium', the sun element. Both astronomers were alive to hear, some quarter of a century later, that their element had been discovered on earth.

part two

RAYLEIGH AND RAMSAY

Lord Rayleigh (1842–1919)
who started off the search for
the inert gases and was
co-discoverer of argon with
Ramsay.
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A 0.1 per cent discrepancy – In the 1880s Lord Rayleigh, the physicist, set himself the task of making more accurate determinations of the densities of gases than had ever been made before. He weighed oxygen and hydrogen successfully, but when he came to weigh nitrogen he discovered a curious thing. The nitrogen he got from the air was denser by 0.1 per cent than the nitrogen he got from ammonia.

0.1 per cent – one part in a thousand. Some scientists would not have bothered about such a small discrepancy, but Rayleigh was trying to make extremely accurate measurements and he was a very thorough experimenter. Could that 0.1 per cent be due to some error, he wondered; a leaky tube perhaps? Again and again he repeated his experiments, but still the discrepancy persisted, entirely outside what was allowed for experimental error. Every time Rayleigh prepared a litre of nitrogen by absorbing all the oxygen, carbon dioxide, and water vapour from some air, the litre weighed a thousandth of a gram more than a litre of nitrogen obtained from ammonia. Was the nitrogen from the air too heavy, or was the nitrogen from ammonia too light? The atmospheric nitrogen could have still had some oxygen in it, but the amount of oxygen needed to make such a difference would be 1 per cent and this amount would have been detectable with alkaline pyrogallol. Rayleigh tested with alkaline pyrogallol and found no oxygen. The nitrogen from ammonia could have been contaminated with a lighter gas: hydrogen, or ammonia, or water vapour. Rayleigh tested and excluded all these possibilities. Could it be that he had found two different molecular states of nitrogen?

Puzzled, Rayleigh sat down and wrote a letter to *Nature*, the magazine founded by Lockyer in 1869, just about the time when he was studying the chromosphere, and still one of the

world's leading scientific periodicals. Rayleigh's letter stating his difficulties, attracted the interest of the central figure of our story, the chemist, Professor (later Sir) William Ramsay.

Back to Cavendish – Nobody is quite sure who told Rayleigh to look up the notes of Cavendish; some say it was Ramsay himself, some say it was Professor Dewar. It was shortly after Rayleigh had read a paper to the Royal Society in 1894 (nearly two years after the letter to *Nature*), on *An anomaly encountered in the determination of the density of nitrogen*, and Ramsay had just asked and received Rayleigh's permission to look into the problem. Somebody in the Royal Society said to Rayleigh, 'Have a look in the old journals. Didn't Cavendish say something about this?' Rayleigh looked and found that indeed Cavendish had said something about it.

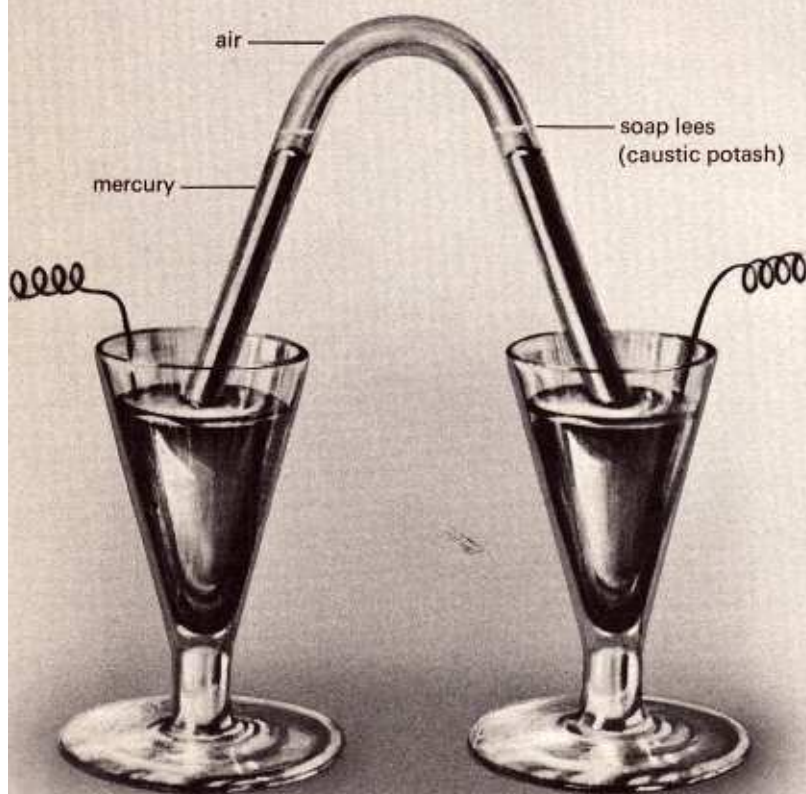
Henry Cavendish (1731 – 1810), an eccentric genius of noble birth, is chiefly remembered as the discoverer of hydrogen. A lonely man of extreme shyness, afflicted with a stammer, he lived frugally in spite of his immense wealth and devoted his life to scientific investigations. His biographer, Monsieur Biot, said of him: 'Il était le plus riche de tous les savants, et le plus savant de tous les riches.' The experiment that Rayleigh looked up more than a hundred years after it had been performed, was one of a series which Cavendish did to find out more about the composition of air, and one which you may have repeated in your school laboratory. He passed electric sparks through a mixture of air and oxygen confined in a bent tube over mercury and potash solution.

A solution of nitre (potassium nitrate) was formed and all the gas gradually disappeared except for a very small bubble.

In previous experiments Cavendish had discovered that sparking a mixture of nitrogen and oxygen in the presence of

Henry Cavendish (1731–1810) who was the first to notice that air contained a small quantity of inert gas.





Cavendish's apparatus in which he discovered that, on sparking air in the presence of caustic potash, about 1/120 of the gas was left unabsorbed.

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water resulted in the formation of nitric acid, which in turn reacted with potash solution to form nitre. But what of the small residue of gas that he was unable to make react? At that time, Cavendish had no way of finding out, but to sum up his extraordinarily accurate experiment in his own words (and the quaint language of the phlogiston theory):

'... only a small bubble of air (gas) remained unabsorbed, which was certainly not more than 1/120 of the bulk of the phlogisticated air (nitrogen) let into the tube; so that, if there is any part of the phlogisticated air of our atmosphere which differs from the rest, and cannot be reduced to nitric acid, we may safely conclude, that it is not more than 1/120th part of the whole.'

Here, then, was a clue to the extra density of atmospheric nitrogen. Rayleigh and Ramsay agreed that each would, in his own way, investigate Cavendish's mysterious bubble.

Discovery of argon - 'Now, no one (wrote Ramsay in a letter in April 1894) has ever taken all the nitrogen out of air, or rather after all the oxygen has been removed from air, no one has combined all the nitrogen. It is quite possible that there is some inert gas in nitrogen which has escaped notice. So Williams (Ramsay's assistant) is at it now combining the nitrogen of the air with magnesium and seeing if anything is over - anything not nitrogen. We may discover a new element!'

All that summer Ramsay worked at taking nitrogen out of air. His method was to pass some air freed from carbon dioxide, water vapour, and dust, over heated spongy copper to remove the oxygen; he then passed the 'nitrogen' that remained back and forth over red-hot magnesium turnings, which he knew to be a good absorbent for nitrogen, until there was no further visible shrinkage. In this way he obtained nearly 50cm³ of gas which would not be absorbed. Weighing it, he found it to be 14.8 times as dense as hydrogen. Nitrogen is only 14 times as dense.

This looked promising, so Ramsay repeated the experiment on a larger scale, using the apparatus shown in the diagram. This time he passed the gas from one gas holder to the other back and forth over red-hot magnesium, for several days, and, taking weighings of the residual gas as the experiment proceeded, he managed to obtain a gas with a density 19 times that of hydrogen.

Finally, with Cavendish's experiment in mind, he mixed a portion of this gas with oxygen and sparked the mixture in the presence of caustic potash. This time he was left with a gas 20 times as dense as hydrogen, and no matter what he did to it he could neither increase its density nor further diminish its volume.

What did the spectroscope say about this gas? Ramsay fused electrodes into a glass tube, evacuated the tube, filled it with the gas, and switched on the current. The gas glowed coldly. Its spectrum showed red, green, and blue lines, lines not belonging to any known element.

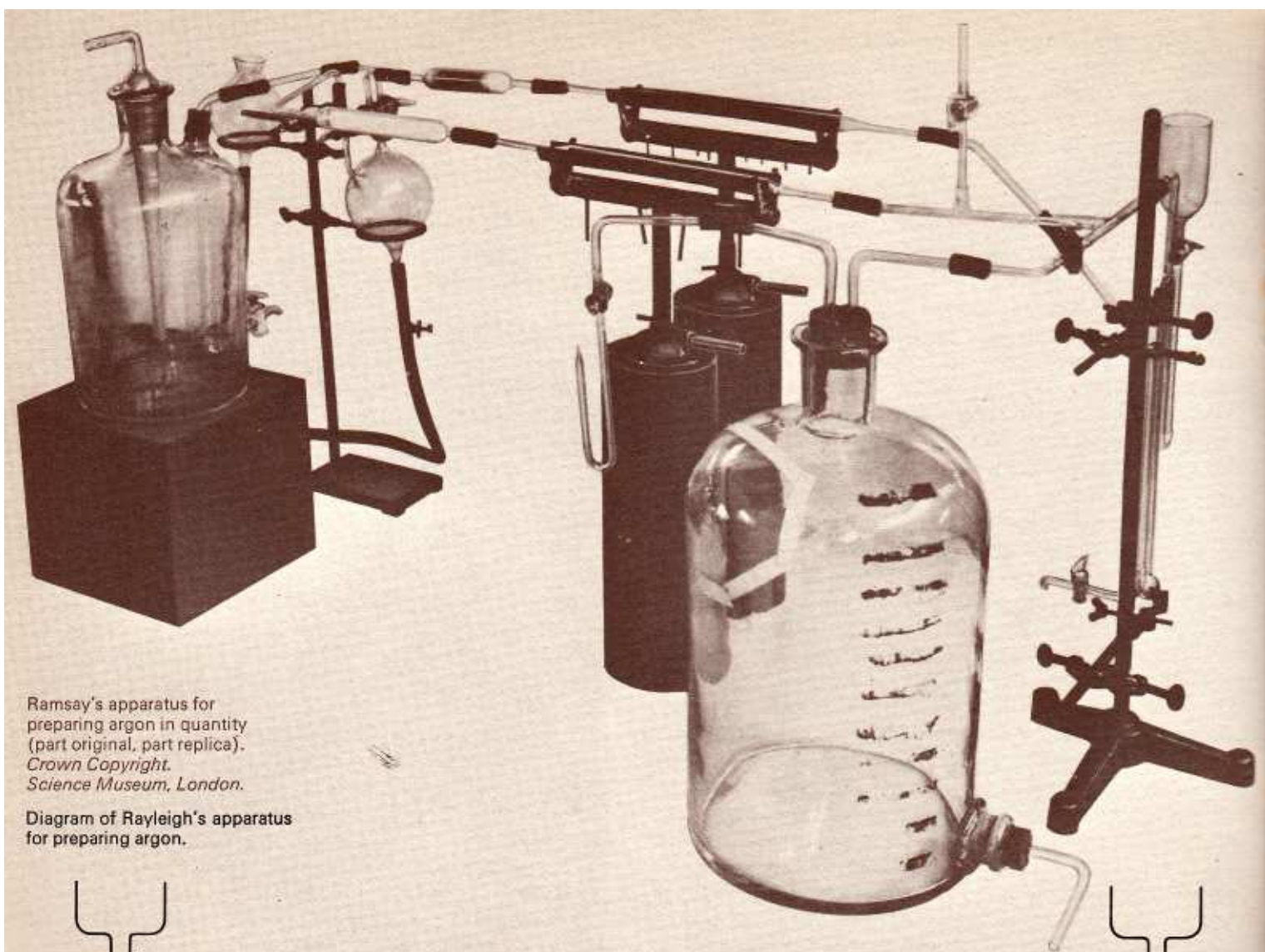
So, Ramsay had isolated a new gas. Some idea of the strain involved in the work may be gained from a letter he wrote to Rayleigh on 4 August 1894, in which he describes his work in detail, and then towards the end of the letter, writes: 'it is very dreary work absorbing nitrogen day after day, making finely divided magnesium, etc., etc. However, "le jeu vaut la chandelle".'

Rayleigh, meanwhile, had also isolated a small amount of the gas, by repeating Cavendish's experiment, and was able to demonstrate that the amount of unabsorbed residue was proportional to the amount of air used. On 13 August 1894 the two men made a joint announcement of their discovery to an astonished meeting of scientists at Oxford. The chairman of the meeting christened the new element *argon*, from the Greek meaning idle or lazy, an appropriate name. Ramsay tried argon with every reagent he could find; it would react with none of them. He tried to burn it with phosphorus; nothing happened. It was unaffected by acids. Heat and electricity left it indifferent. Argon remained inert, refused to combine with anything. Here of course is the explanation of why argon was not discovered sooner: an element which makes no compounds can easily remain undetected, even if there are $11\frac{1}{2}$ cubic feet of it in a moderate sized room. It may be true that every time we breathe deeply we take in 5cm^3 of argon, but then, when we breathe out again we exhale the same 5cm^3 of argon back into the atmosphere.

When it became evident that larger samples would be needed if the properties of the new gas were to be studied more fully, Ramsay and Rayleigh joined forces, using an improved version of Cavendish's apparatus. They passed a discharge of about 7,000 volts from a transformer between heavy platinum electrodes projecting upwards through the

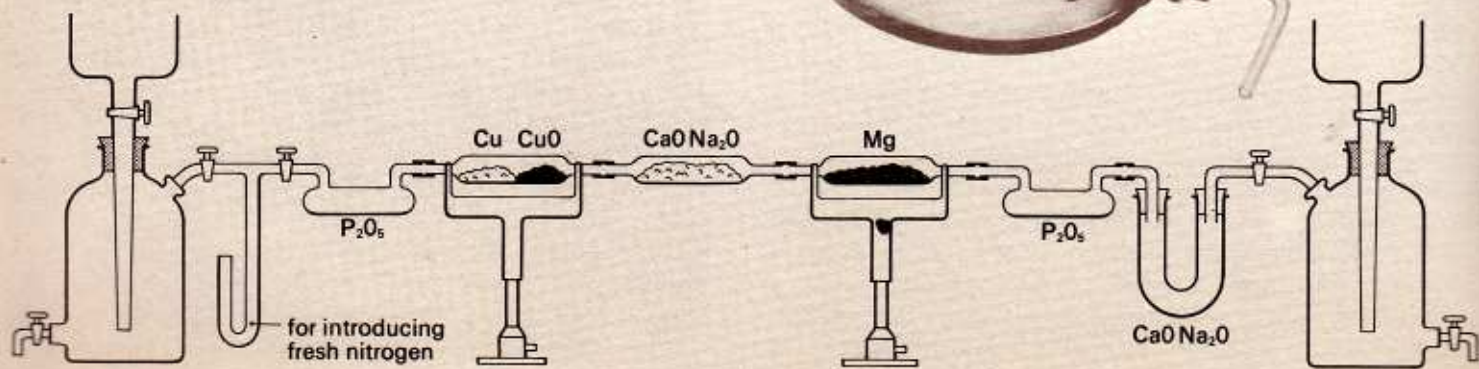
Sir William Ramsay (1852–1916) who discovered five inert gases.
Ronan Picture Library.



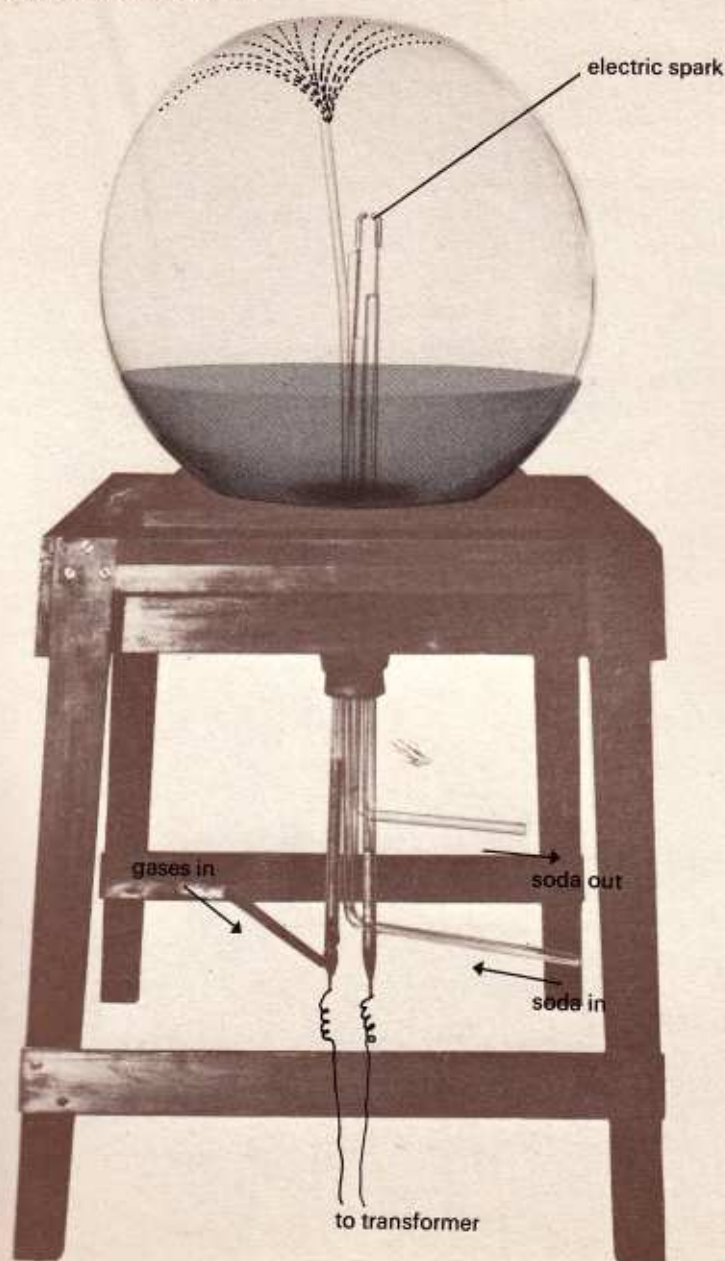


Ramsay's apparatus for preparing argon in quantity (part original, part replica).
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Diagram of Rayleigh's apparatus for preparing argon.



Replica of Rayleigh's apparatus for preparing argon in quantity.
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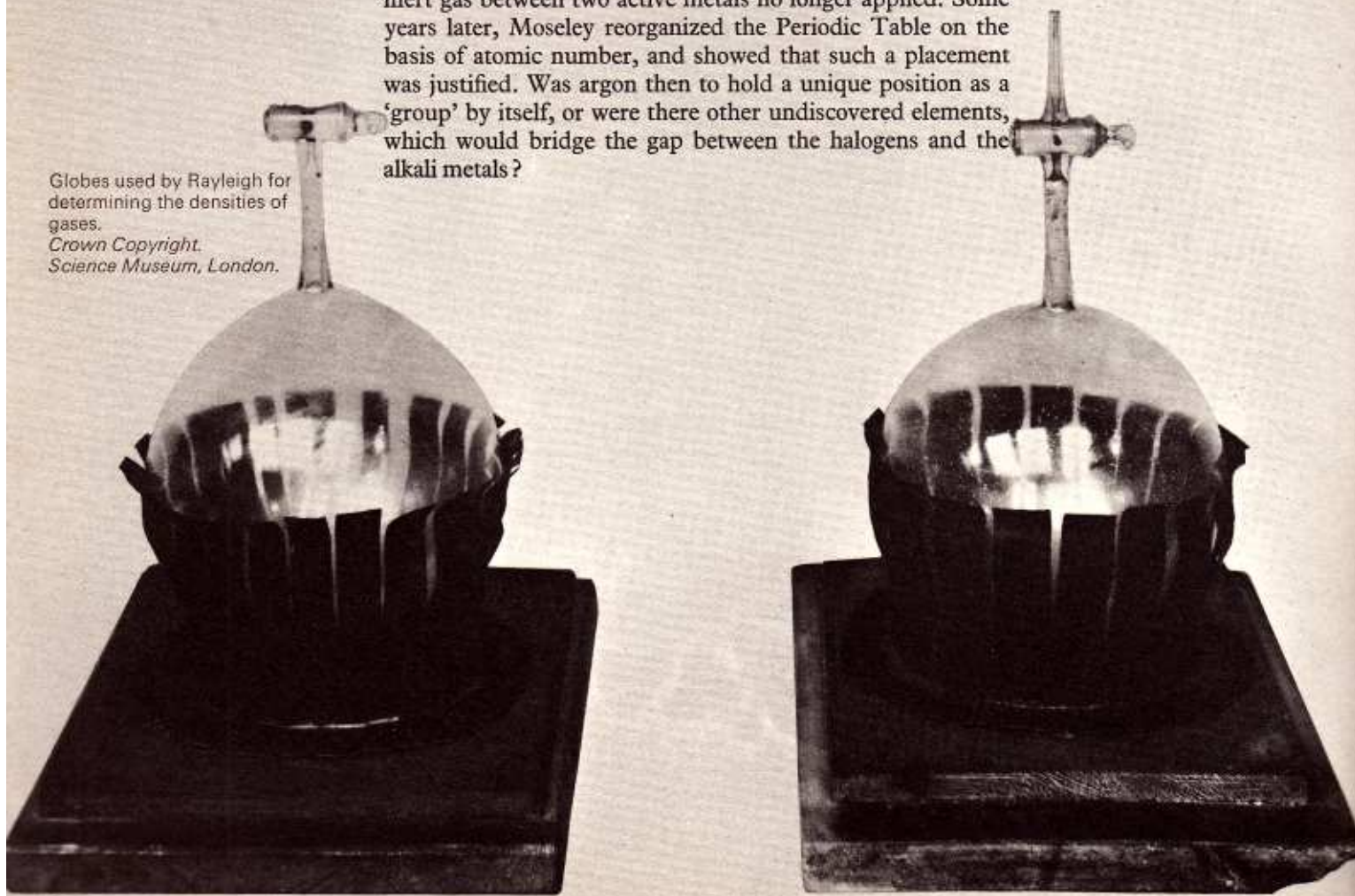
neck of a very large glass filled with air and excess of oxygen. A fountain of caustic soda solution, driven by a pump, continually sprayed the inside of the flask, keeping the glass cool and presenting a maximum liquid surface for absorption of the oxides of nitrogen. Excess oxygen was extracted with alkaline pyrogallol at the rate of nearly 20 litres per hour – about 10,000 times as fast as in Cavendish's apparatus. In this way Rayleigh and Ramsay were able to get a large quantity of the new gas in a short time.

However, it was still conceivable, although unlikely, that the 'new' gas was being produced by the very process designed for its separation – that, for example, sparking the oxygen/air mixture caused a reaction to take place whereby small amounts of the new gas formed. To refute this suggestion, and to show that the gas existed independently in air, Rayleigh and Ramsay devised an ingenious method of separating the constituents of air by letting a large volume stream slowly through a long train of church-warden pipe stems encased in an evacuated glass tube. They found, as they had expected, that the lighter gas, oxygen, diffused through the walls of the pipes more rapidly, so that the air issuing from the end of the pipe-train was considerably denser than the air originally admitted. They then repeated the experiment with air from which the oxygen had been removed and found that the issuing nitrogen was denser than ordinary atmospheric nitrogen. Obviously the 'new' denser gas was present in ordinary air. Rayleigh and Ramsay, with large amounts of the new gas to experiment with, examined its properties very carefully, and Rayleigh obtained the value 19.94 for its density, which is in close agreement with present-day figures. The gas did not appear to be present in animal or vegetable tissue of any kind, but it was found to be dissolved in water, in which its solubility is greater than that of nitrogen but less than that of oxygen. Independent determinations made in London and Paris of the percentage of argon in atmospheric nitrogen gave the identical figure of 1.186 per cent by volume. Rayleigh and Ramsay published their findings jointly and, unlike many scientists working on a cooperative project, their personal relations were always most friendly.

One problem they had a lot of bother solving was where argon fitted into the Periodic Table. They were unable to determine the atomic mass of argon by conventional methods of the time because they could not make any compounds of it.

From its density relative to hydrogen, they knew that its molecular mass was very nearly 40. If, then, the argon molecules were single atoms, the atomic mass must be 40 also. All the evidence pointed this way, but where was there room to be found in the Periodic Table for an inert element of atomic mass 40? If this were its mass, it should fall between the metals potassium and calcium and this was obviously absurd. Mendeleev's switchabout of iodine and tellurium in his Periodic Table (see the Background Book - *The Periodic Table*) created a precedent for introducing argon between chlorine and potassium, where the objection to placing an inert gas between two active metals no longer applied. Some years later, Moseley reorganized the Periodic Table on the basis of atomic number, and showed that such a placement was justified. Was argon then to hold a unique position as a 'group' by itself, or were there other undiscovered elements, which would bridge the gap between the halogens and the alkali metals?

Globes used by Rayleigh for determining the densities of gases.
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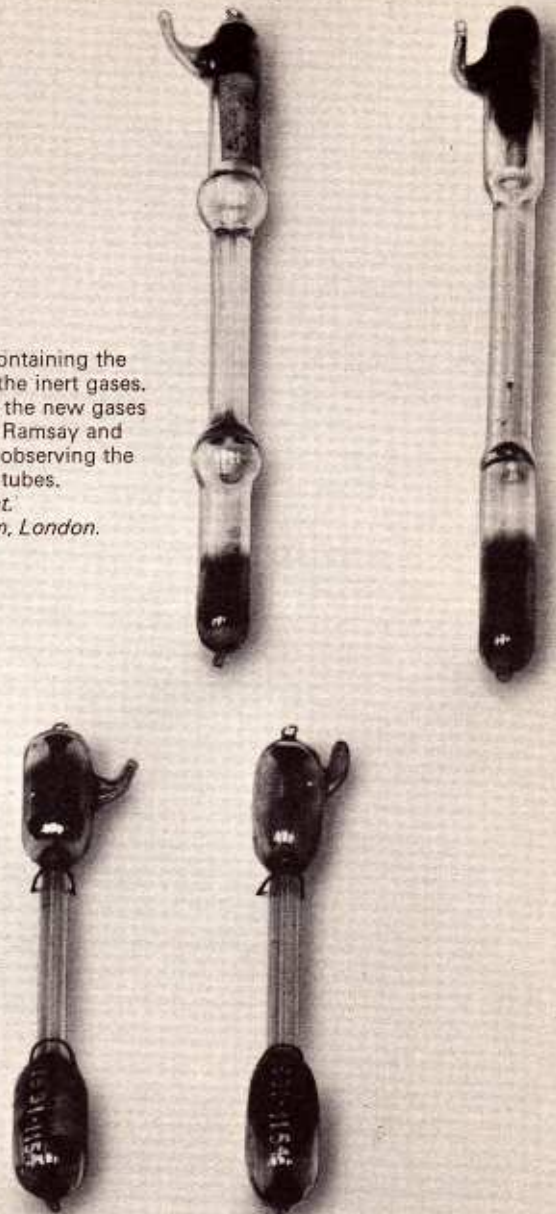


part three MORE NEW GASES

The sun element on earth – In 1888 Dr Hillebrande of the United States Geological Survey obtained a gas from the uranium ore cleveite by boiling the ore with dilute sulphuric acid. He thought the gas was nitrogen. After the discovery of argon, it was suggested to Ramsay that Hillebrande's gas might be worth investigating. With his assistant, W. M. Travers, Ramsay obtained a little of the gas from a small amount of cleveite, and repeatedly sparked it with oxygen until there was no contraction. He then filled a vacuum tube with the gas, which he had provisionally named krypton (meaning 'the hidden gas'), and compared its spectrum with that of argon. The two were quite dissimilar. At the same time, Sir William Crookes compared the spectrum of the new gas with that of argon from samples Ramsay had lent him. While Ramsay was writing up the notes of his observations, Crookes telegraphed: 'Krypton is helium. Come and see it.' Ramsay went. Crookes, an expert on the use of the spectroscope, was not mistaken; the element identified on the sun over twenty years before had at last been found on earth.

For some time the only known source of helium was minerals such as cleveite in which the gas was always associated with uranium or thorium. In fact the helium comes from the radioactive breakdown of these metals but, at the time, radioactivity was unknown, and it was assumed that the metals and helium were in some way combined. But all efforts to make helium combine with any other element failed, so Ramsay was convinced that he had a second inert gas. It was, however, much lighter than argon: assuming it to be monatomic, its atomic mass was four, which placed it in the Periodic Table between hydrogen and lithium.

Original tubes containing the first samples of the inert gases. The presence of the new gases was revealed to Ramsay and Travers through observing the spectra in these tubes.
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*Krypton made by comp.
analysis of the sample
to determine O₂ & N₂.
Same as original set.
in 1898. F. RAMSAY*

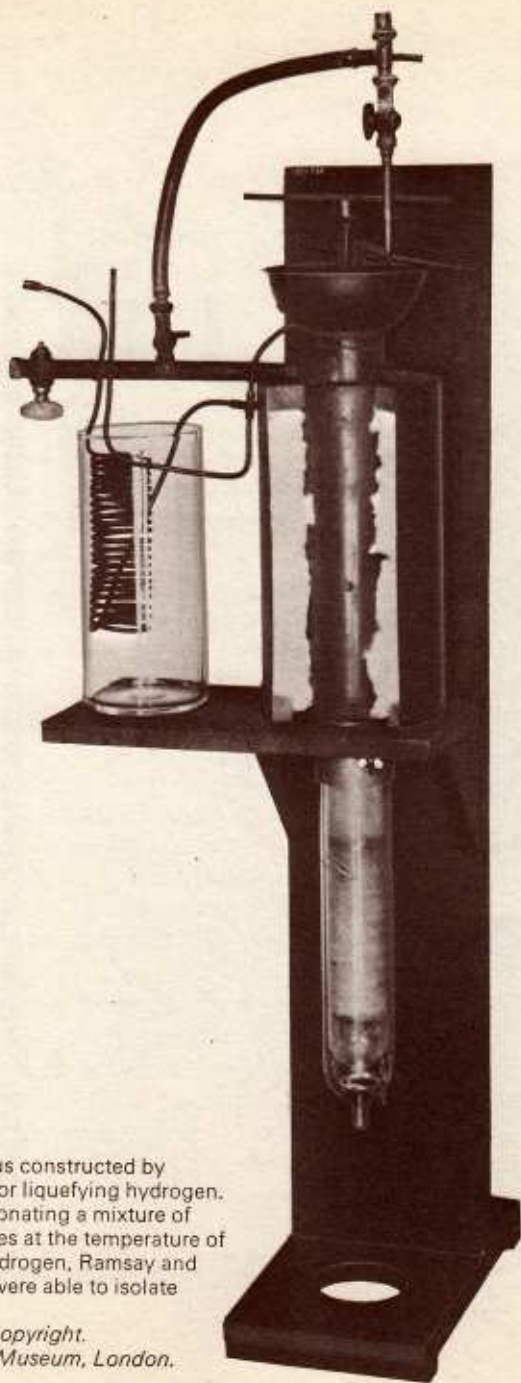
Two more gases to discover – Believing that the elements helium and argon formed part of a new group in the Periodic Table, Ramsay predicted that there were at least two more inert gas elements to be discovered. From the differences in atomic mass between elements in the other groups, he estimated that one should have an atomic mass of about 20 and the other an atomic mass of about 80. At the time, he and Travers were preoccupied with finding other mineral sources of helium and hoped that among these minerals they might come across the undiscovered gases. However, by the end of 1897 all possible sources of unknown gases appeared to have been exhausted, when a new method of investigation presented itself. The Polish professor Olszewski had just carried out some spectacular experiments on the behaviour of argon at the very low temperature of liquid oxygen (b.p. -187°C). At just about the same time, Dr Hampson in London invented a simple method of liquefying air so that, with the collaboration of the Brin's Oxygen Company (now the British Oxygen Company Ltd), liquid air now became available in large quantities. Thus Ramsay was able to pursue an idea he had had for some time: that these undiscovered inert gases might be in the air in trace quantities far smaller than even argon.

Early in 1898 Ramsay and Travers began distilling liquid air to obtain sufficient argon to carry out their search for other gases. They freed the argon as before from oxygen and nitrogen, except that they used a mixture of magnesium and lime which absorbs nitrogen more rapidly than pure magnesium. Transferring the gas to what is called a Plücher tube, they subjected it to an electrical discharge and examined the spectrum. As well as the argon lines, they saw a bright yellow line and a brilliant green line which were totally distinct from the lines of argon and helium. They had found another

element. That night they determined the density of their gas and found it to be about 22.5. Evidently it was a mixture of argon and a gas heavier than argon. This heavier gas, even before it had been discovered, Ramsay had given the name 'krypton' – the same name he had given to helium before he found it already had one.

Two days later, by means of a cleverly contrived piece of apparatus in which the liquid argon was allowed to evaporate from a glass bulb surrounded by liquid oxygen, Ramsay and Travers managed to separate argon into its most volatile and least volatile constituents. They drew off two 40cm^3 portions of the most volatile fractions and determined the density: it was 17.25, much less than the density of argon. Again they condensed and fractionally distilled this fraction. The density fell to 14.7, and when this lighter gas was put into a Plücher tube, as soon as an electric discharge was passed there was a great blaze of crimson light. Ramsay and Travers did not need a spectroscope to tell them that they had found the other 'undiscovered' gas. Its spectrum did contain a new bright yellow line. They called the gas 'neon' (from the Greek *new*).

In Travers's own words 'it became impossible to tell the story in the order of the sequence of events'. Gradually they built up supplies of the argon-neon mixture, with a view to separating elements by fractional distillation. Then they found that the mixture contained an appreciable amount of helium as well, and as neither helium nor neon could be liquefied at the lowest obtainable temperature, it seemed impossible to obtain a sample of pure neon. But the indefatigable Travers spent a hazardous month preparing a quantity of liquid hydrogen, the boiling point of which (b.p. -253°C) is so far below that of liquid air that argon was completely non-volatile in it. Helium, however, was not even liquefied at this tem-



Apparatus constructed by Travers for liquefying hydrogen. By fractionating a mixture of inert gases at the temperature of liquid hydrogen, Ramsay and Travers were able to isolate neon.

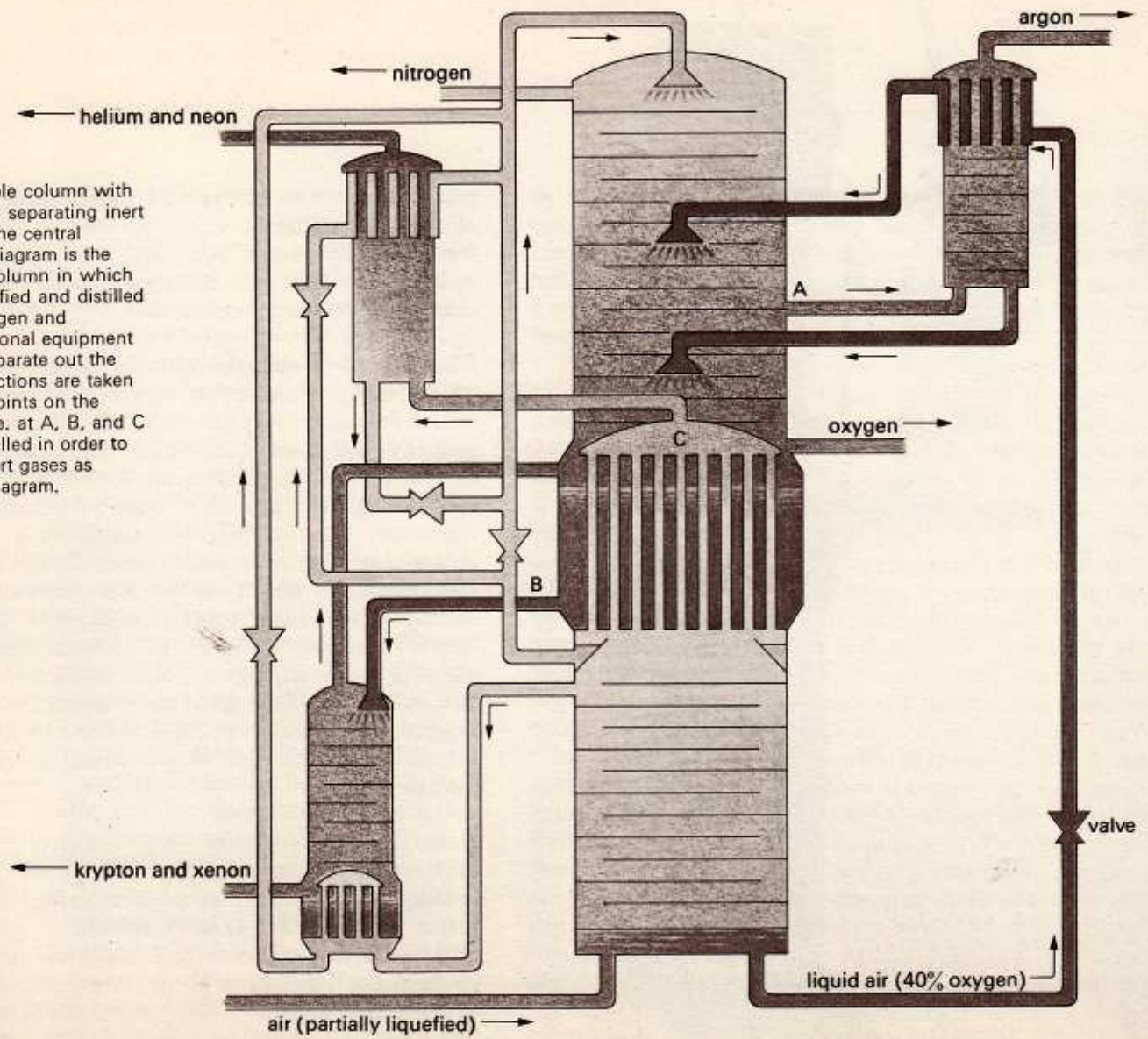
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perature. Here then were hopeful conditions for the separation of the three elements. The argon - helium - neon mixture was fractionated and refractionated at these low temperatures, and on 7 July 1900, pure neon was isolated and weighed. Its density was 10 and its atomic mass 20.

The stranger - Meanwhile with the large volume of argon which they had accumulated, Ramsay and Travers continued to look for denser inert gases which would complete the new group of the Periodic Table. Their old meticulous pattern of experiment - distillation, refractionation, and spectroscopic examination - had in 1898 revealed the presence of an even denser gas than krypton, which displayed, in its spectrum, brilliant blue lines never before observed. The amount which they were able to obtain was very small, yet they succeeded in finding its approximate atomic mass: 130. They called it 'xenon', meaning 'stranger'. In six years Ramsay, first in association with Rayleigh and then with Travers, had identified, isolated, and determined the properties of argon, helium, krypton, neon, and xenon, and shown that all of them are constituents of air. There was, however, one more gas to be discovered.

A radioactive gas - Shortly after Madame Curie isolated radium it was noticed that some kind of gas was being continually evolved from the metal. It was called radium emanation and it was found to be radioactive. Its properties were investigated by Rutherford and Soddy and they found it to be chemically inert. None of the investigators ever had more than a minute quantity of the gas with which to work, partly because of the scarcity of radium and partly because it breaks down very quickly into something else.

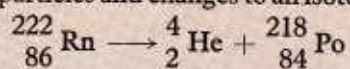
The Linde double column with attachments for separating inert gas fractions. The central section of the diagram is the Linde double column in which cold air is liquefied and distilled to separate oxygen and nitrogen. Additional equipment is needed to separate out the inert gases. Fractions are taken off at various points on the main column i.e. at A, B, and C and further distilled in order to produce the inert gases as shown in the diagram.



Nevertheless, Ramsay and Whytlaw-Gray found the density of radium emanation by means of the gas-density balance, to be 111.5. Ramsay proposed the name 'niton' (Latin: nitidus – shining) for the gas because of its brilliant glow when liquefied. However, it is now called 'radon'.

Radon is soluble in water and it may be collected by boiling a solution of a radium salt. Radon, helium, hydrogen, and oxygen are evolved. The hydrogen and oxygen are separated to give water and the radon is then separated from the helium by fractional liquefaction (radon liquefies below -150° ,

whereas the critical temperature of helium is 268°). The rate of radioactive decay of radium is slow; its half-life is nearly 1,600 years, whereas that of radon is only about four days. Radon emits α -particles and changes to an isotope of polonium



A less laborious method of separating the other inert gases than that of refractionation used by Ramsay and Travers was discovered by Dewar in 1908 – he absorbed the gases in activated charcoal.

Table of properties of the inert gases.

	helium (He)	neon (Ne)	argon (Ar)	krypton (Kr)	xenon (Xe)	radon (Rn)
atomic number	2	10	18	36	54	86
atomic mass	4.003	20.183	39.944	83.8	131.3	222
density 0°C , 760mm (Hg), gl^{-1}	0.1785	0.8999	1.7837	3.745	5.897	9.73
specific gravity compared with air = 1	0.1380	0.6964	1.3796	2.896	4.561	7.526
boiling point 760mm (Hg), $^{\circ}\text{C}$	-268.9	-245.9	-185.7	-153.4	-108.1	-61.8
vapour density at b.p. gcm^{-3}	0.0168	0.0095	0.0057	0.0083	0.0097	
<i>critical constants</i>						
$T^{\circ}\text{C}$	-267.9	-228.7	-122	-63.8	16.6	104
p , atm	2.26	26.9	48	54.2	57.6	62
density, gcm^{-3}	0.0693	0.4835	0.531	0.9085	1.105	



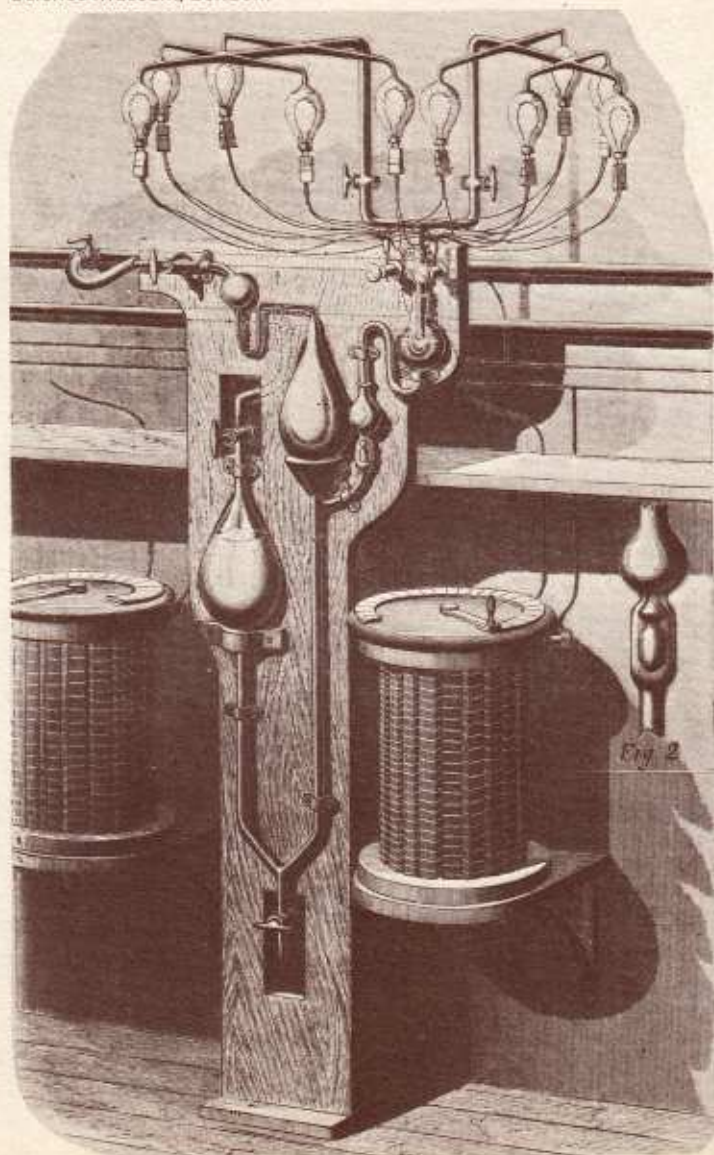
Compounds of the gases – Rayleigh, Ramsay, and Travers were convinced that all the gases of their new family were too inert to combine with other atoms, even their own. In 1950 claims were made that compounds of argon and krypton with quinol had been crystallized. However, these peculiar compounds are not held together by true chemical bonds. The rare gas atoms are simply imprisoned in ‘cages’ or holes in the crystal lattice of quinol, into which they happen to fit. Such compounds are called ‘clathrates’ (from the Greek: clathratus – imprisoned). No such ‘compounds’ of helium or neon exist because their atoms are so small that they slip through the ‘bars of the cage’. In 1962, however, a number of real compounds of xenon were prepared. Among them are a number of fluorides, such as XeF_6 and XeF_4 , and a fluoroplatinate $\text{Xe}^+ \text{PtF}_6^-$, which is a true salt.

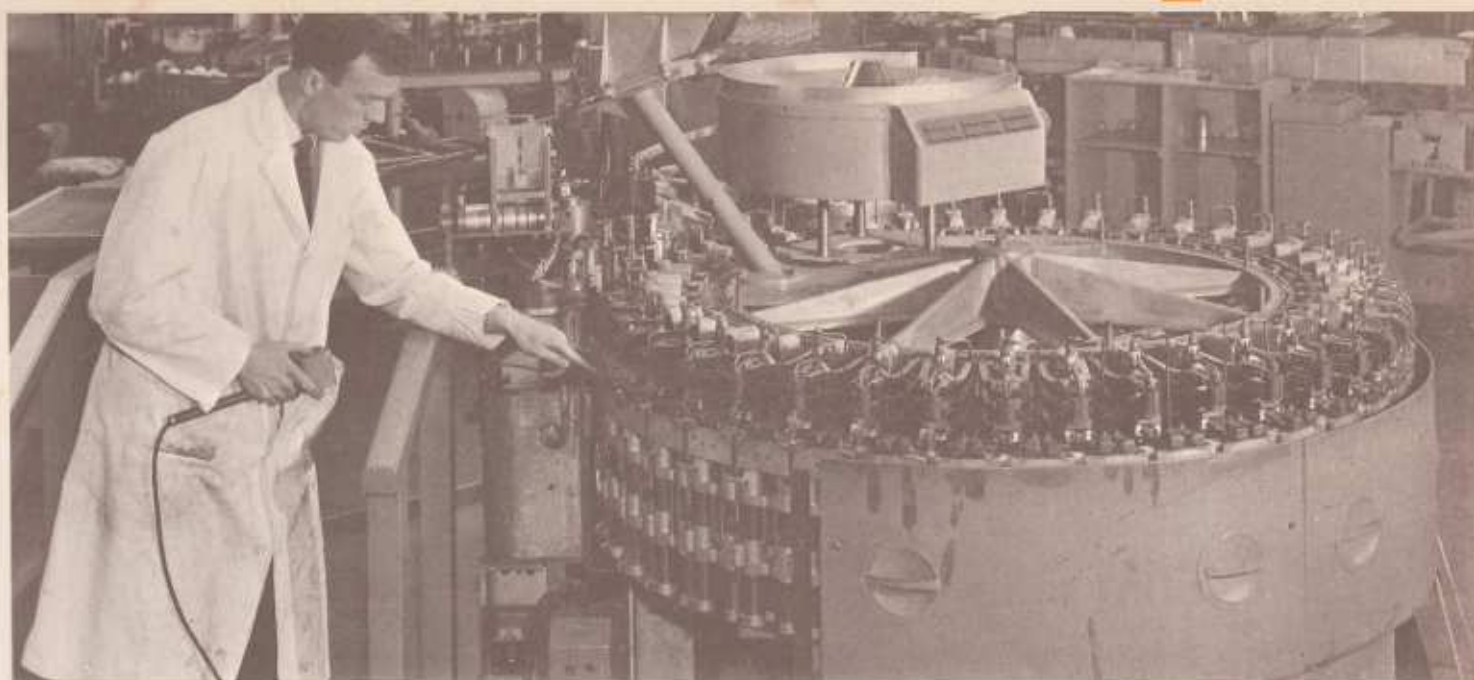
The formation of these compounds poses new problems, the unravelling of which will greatly increase knowledge in the extremely complex subject of the mechanism of chemical combination. The compounds also shatter a belief that has stood for sixty years – the inert gases, sometimes called ‘rare’ gases, sometimes ‘noble’ gases, are *not* completely inert.

Crystals of xenon tetrafluoride – one of the very few inert-gas compounds ever to be made. Professor N. Bartlett

Modern equipment (right) for making light bulbs filled with argon. General Electric Company.

Equipment for evacuating electric light bulbs – in the days before they were filled with argon. Science Museum, London.





Uses – The percentage of the inert gases in the earth's atmosphere is as follows:

	Per cent
Argon	0.94
Neon	0.0012
Helium	0.0004
Krypton	0.00005
Xenon	0.000006

It is clear from these percentages that argon is the cheapest and therefore the most suitable for everyday use; and indeed it does a useful job in most homes. In the days when electric light bulbs were evacuated ('vacuum filled') the hot tungsten filaments rapidly 'burned out' because there was nothing to stop them from vaporizing. Bulbs filled with nitrogen lasted longer because the gas molecules bombarding the filaments reduced their rate of vaporization. Today most lamps are filled with argon which is more efficient than nitrogen because of its higher density.

The familiar crimson glow of neon lighting is made by passing an electric current through a glass tube containing a small quantity of neon at low pressure. Neon, helium, and

argon are used in this type of lighting both separately and in various combinations. Krypton and xenon can be made to emit a very rapid flash of light and are put in flash bulbs for high speed photography. A krypton or xenon flash bulb can be used up to ten thousand times.

Welding and extraction of certain light metals must be done in an inert atmosphere. Titanium, for example, reacts with nitrogen at the very high temperature needed to extract the metal from its ore. Perhaps the most important industrial use for argon and helium is to provide an inert atmosphere.

Helium, being less soluble in the body tissues than nitrogen, is valuable for diluting oxygen, both in hospitals and in breathing apparatus for astronauts and deep-sea divers. It eliminates the danger of oxygen poisoning and of 'bends' – nitrogen, dissolved in the bloodstream while the diver is under high pressure, coming out as bubbles when he returns to the surface. Helium is also a safe gas for filling balloons, whereas hydrogen, though a little lighter and much cheaper, is inflammable and explosive.

Question Can you find out any other uses of the inert gases?

Chemistry Background Books

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