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FROM THE PONDERABLE TO THE IMPONDERABLE[1]

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CHEMISTRY has for its purpose the study of the composition of our material world. Its first task is to determine the simple basic substances—the chemical elements—out of which all other substances are made, and artificially to produce new kinds of substances from these same elements. After its problem had been thus recognized and defined, thanks chiefly to Robert Boyle, chemistry could be spoken of as a "science," striving, in contrast to the direction of earlier efforts, towards an ideal objective through unprejudiced researches. The prerequisite for these researches was the recognition of the fact that the weight of a chemical compound is equal to the sum of the weights of its constituents. We owe to the French chemist Lavoisier the recognition of the full significance and the ingenious application of this law. We have him to thank for introducing the well-known balance as a reliable guide in chemical work, whereby Lavoisier became the true founder of modern chemistry whose victorious march began in the nineteenth century and has continued at a steadily increasing tempo.

To be sure, Lavoisier's immortal services were poorly rewarded by his contemporaries; in 1794, during the confusion of the French Revolution, the Revolutionary Tribunal sent him to the guillotine.

My topic is "From the Ponderable to the Imponderable" in chemistry, in physics, and I might also add, in biology. How far can we extend the limits of our qualitative and quantitative tests of chemical compounds? Are there methods of investigation that are reliable at and beyond the present limits of our balances? What are the lower limits?

As a science develops, its methods are improved and its aids become more and more refined. The

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[1] Introductory public lecture.

quantitative analytical balance of the time of Lavoisier certainly differed very considerably from the balances used in chemical laboratories to-day by every young student of chemistry. But even along this line development has not yet ceased. As it becomes possible to work with smaller and still smaller quantities of material, to that same degree we refine our analytical methods and the delicacy of our tests. The methods of "microchemistry" have now been added to those of ordinary or "macro" chemistry.

The usual modern analytical balance permits a mass of a few hundred grams to be weighed accurately to within one ten-thousandth of a gram. About thirty years ago Nernst devised the micro-balance that bears his name, which weighs a few milligrams of material to within a few millionths of a gram. This device was followed by the Kuhlmann balance—now widely used in microchemistry—which weighs amounts of even twenty grams to within a millionth of a gram. This was a tremendous advance, but the end was not yet; special methods enable us to weigh smaller amounts of material with very much greater accuracy.

In such direct weighings the material is always still available in masses that are fractions of grams; by other methods it is possible to make qualitative and quantitative determinations of chemical compounds in masses whose lower limit is finally determined by their visibility under the microscope. It may be stated as a quite general truth that whenever, for any reason, it seems necessary positively to determine minute amounts of material, there will be found means and ways for doing so. This statement may be explained by a few examples.

When the world war was over and the victors imposed upon Germany the task of finding enormous sums for "reparations," Fritz Haber proposed to himself the most interesting scheme of extracting gold from the inexhaustible reservoir of the oceans. Previous determinations by other investigators had placed the gold content of sea water at five to ten milligrams of gold per metric ton (one thousand kilograms) of water. The gold ores of South Africa contain about one thousand times more gold per ton than does sea water, but the greater ease of working water, as compared with rigid rock, made the task seem very promising. If it succeeded it would open up an inexhaustible source of gold, for Arrhenius had estimated that, with a richness of six milligrams of gold per ton of water, the total content of all the seas amounted to eight billions of tons of gold.

The plan itself—to secure gold in this way—did not succeed and could not succeed. Instead of the assumed gold-content of five to ten milligrams per ton, Haber's numerous experiments showed only about one thousandth as much. But they accomplished a great advance in the analytical methods for separating out minute amounts of material. Microscopic measurement of the tiny gold spherules obtained from the precipitation enables one to determine with certainty one ten-millionth of a gram or less. This determination of microscopic traces of gold was successfully employed in explaining and combating experiments that in their day caused great excitement because they seemed to indicate the supposed transmutation of mercury into gold.

Mercury furnishes another illustration in this connection. While Alfred Stock was working in Berlin he became a victim of the injurious effects of small amounts of mercury. He combined his great educational campaign regarding the deleterious nature of the cheaper amalgam dental fillings, with the development of a demonstration of the presence of very small amounts of mercury in the saliva, in urine, and in exhaled air. As a result it is possible to demonstrate the presence of a hundred millionth of a gram of mercury in the form of tiny crystals of mercury iodide, so minute as to be barely visible under the microscope.

Many other chemical elements and compounds might be cited, that have been identified in such amounts by weight as would never have been possible without the aid of the increasingly important methods of microchemistry.

It will now be asked whether there is really any good reason for such extraordinary refinement in our experimental aids for recognizing and quantitatively determining such small amounts. It is by no means a matter of indifference whether we can prove the presence somewhere of a minute amount of a metal or of a chemical compound as an impurity of other metals or compounds. Modern research has demonstrated the great influence exerted upon the hardness, ductility and durability of metals by very small additions of other substances to them. Again, in all the life processes of plants as well as of animals, substances present in minutest amounts often play a much greater rôle than do those substances occurring in easily determinable quantities. Mere mention of enzymes, hormones, vitamins, is sufficient to point out such substances to you; we shall return later to their consideration.

In order to understand how it is that the smallest amount of a substance can so often produce such great effects, it must be remembered that even the smallest of the weights mentioned above, *viz.,* one one-hundred-millionth of a gram consists nevertheless of a very large number of those minute particles that we call atoms or molecules.

As to the number of molecules obtained in a given weight of a chemical compound, this can be accurately determined if we know its molecular weight, as it is called; and the latter can almost always be readily ascertained. The atomic or molecular weight in grams of a substance contains the inconceivably large number of 6×10^{23} atoms or molecules. Some interesting computations by the English physicist Aston[2] enable one to form some conception of their quantity. Suppose we have an absolutely evacuated incandescent lamp bulb of the usual size, and make an opening into it so fine that one million molecules of air enter in one second. Then one hundred million years must elapse before the bulb will fill with air to atmospheric pressure.

Again, suppose that in some way each of the molecules in the two hundred grams of water contained in an ordinary glass of water could be made visible, could be labeled or tagged. If this glassful of water were then poured into the ocean at any point—Australia, the Gulf of Mexico, some Russian river—then after a very long time the two hundred grams would be uniformly distributed throughout the oceans of the globe. Now if a glass of water were dipped up at random from the ocean at any point, whether from the surface or from a depth of six thousand meters, there would be found more than two thousand of those tagged molecules in this glass of sea water.

Finally, take an example from my own particular field of radioactivity. Through atomic disintegration the element uranium gradually changes into the element lead, in fact during every second ten thousand atoms are converted per gram of uranium. But seventy-one million years must elapse before this single gram of uranium has formed one hundredth of a gram of lead.

Returning to the tiny amounts of gold and of mercury mentioned above, it is easily computed that there must be millions of millions of atoms or of molecules in the microscopic particle of gold or of the mercury salt referred to. It is justifiable to inquire whether there are methods by which one can recognize amounts even smaller than those considered above—quantities lying beyond the limits of direct weighing or of direct vision. This question is answerable distinctly in the affirmative, and we shall now consider a series of such methods.

First in interest among these methods is that of spectrum analysis, devised by Bunsen and Kirchhoff, which reveals the chemical composition of a substance by the spectral lines that its vapor emits under appropriate excitation. You all know that this method has revealed to us the chemical composition of the heavenly bodies, and proved that they consist of precisely the same elements as does our earth. Bunsen and Kirchhoff sought to determine the smallest amount by weight that was recognizable by their method, and they found that in the case of sodium as little as 3×10^{-10} gram could be detected spectroscopically. To be sure, the practical execution of their experiments required considerably larger amounts (practical *vs* theoretical sensitivity). Many gaseous elements have a much higher spectroscopic sensitivity than do the solid metals like sodium. Paneth's researches in particular should be mentioned in this connection. He has been able to identify the noble gas helium in amounts as small as 2×10^{-14} gram, and to make quantitative determinations of as little as 2×10^{-11} gram, employing Otto Stern's later refinements of Pirani's method. Here again is illustrated the fact—so gratifying for the progress of science—that when a new task is set the means and methods for accomplishing it are also often discovered. Paneth and his coworkers employed his refined spectroscopic method in their quantitative determinations of the minute helium content of a large number of iron meteorites, and thereby determined the age of these heavenly bodies. Paneth came to the remarkable conclusion that meteorites probably originated within our solar system and not—as was previously assumed—from fixed stars outside that system.

Spectrum analysis has recently found an extraordinarily fruitful field in applied qualitative and quantitative chemical analysis. The demonstration by spectrum analysis of the "ultimate lines" of the elements now enters into an ideal contest with former micro-analytical methods, "spot" analysis and potentiometric titration in the determination of the least traces of impurities in metals, forensic preparations, and other substances (Gerlach and his coworkers).

Of late years x-ray spectroscopy also has developed as a powerful tool for chemical research, making possible the discovery of new elements at their lowest concentration, and the determination of impurities in metals that would certainly have escaped detection by ordinary chemical analysis.

To consider this broad and fruitful field of study in more detail would take us far beyond the limits of a one-hour address. A single method of optical identification may briefly be considered, however, since it served in its day to solve a problem that was of interest to the non-technical world. Organic chemistry knows of dyes whose aqueous solutions have very intense coloring powers; infinitely minute amounts of these dyes can be detected even at extraordinary degrees of dilution. Among these coloring substances is fluorescein, discovered by A. von Baeyer. At the suggestion of von Baeyer this property of fluorescein was employed in 1877 to determine a supposed subterranean connection between the Danube and the Rhine rivers. A solution of ten kilograms of fluorescein was sunk in the Danube near

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[2] F. W. Aston, *Nature*, 110: 702, 1922.

its head springs. After an interval of about sixty hours the characteristic fluorescence of the dye appeared in a little river which empties into Lake Constance and thence into the Rhine, but has no visible connection with the Danube. The coloration lasted for about thirty-six hours. The supposed connection between the two rivers has been proven experimentally.

Turning from these optical methods that impress the vision, to methods working through other senses, our attention is held above all by such substances as appeal to the sense of smell. Here it is found that through this sense one can recognize substances present in quantities that are far below the limits of the chemical balance.

As early as 1887 a classical investigation in this field was carried out jointly by Emil Fischer and E. Penzoldt. Up to that time the sense of smell was thought to be most sensitive toward the odor of attar of roses. The presence of an unbelievably small trace of this perfume can be detected in this manner. But these two investigators found that even smaller amounts of a derivative of hydrogen sulfide, mercaptan, could readily be recognized through its powerful and highly disgusting odor. When the air of the room contained by volume one part of mercaptan in three hundred million parts of air, the stench was so penetrating that "the odor passed off only gradually even after opening four windows, two doors, and setting up a strong draft." Fischer and Penzoldt found that as minute an amount as one part in fifty thousand million of air could thus be recognized. On the assumption that about fifty cubic centimeters of air must flow past the olfactory nerves of the nasal passages to make an odor noticeable, the amount of mercaptan that can be recognized by its stench is one four hundred and sixty thousand millionth of a gram, an absolutely unweighable quantity.

In the course of time the limits of detection by smell were determined for many other agreeable and evil smelling substances, and a great many of them were found to be as potent as is mercaptan. Among the fragrant substances are ionon (the essence of the violet) and vanillin (the fragrant substance in vanilla). Among the evil-smelling bodies may be mentioned butyric acid, whence comes the stench of rancid butter. The enjoyment of sweet butter is spoiled for us by absolutely unweighable amounts of that compound.

A computation of the number of molecules of these substances detectable by smell always shows that many million molecules of the substance are involved per cubic centimeter of air. There is no great wonder, then, that certain animals seem to be able to recognize a very much smaller amount of disagreeable and of fragrant substances. The dog's and the insect's sense of smell are good examples, and particularly that of butterflies—whose scenting powers actually border on the marvelous. The Swiss naturalists Fabre and Forel report the following experiment: The caterpillar of a butterfly was raised in the city of Zurich, spun its cocoon and emerged the following spring as a female butterfly. This female was imprisoned in a room with windows open, but within two days more than one hundred males of the same species had gathered in the room; they had traveled a number of kilometers from the forests in the environs of Zurich. Such statements might be relegated to the realm of fable had they not been adequately confirmed.

We turn now to another field. The preceding methods for identifying minute amounts of material have in common the feature that the substance is always recognized by some one of its specific characters. But there is an almost boundless number of phenomena in which the presence or absence of minute amounts of substances is detected, not directly, but through the effects they produce. Among these the most important are the effects upon life processes.

Thus, many metals and chemical compounds exert a poisoning influence on the lower organisms. Disinfection and antiseptic methods are based upon this fact. A couple of pictures showed how small the amount may be and yet produce an evident effect.

The first slide showed a group of houses in a small town of southern Germany. These houses are roofed with a flaggy limestone from the Jura, and in the course of time the growth of a great variety of mosses and lichens has given these slabs a beautiful dark patina. The picture showed that some of these house roofs are crossed by a pair of parallel white streaks. There the growth of moss and lichens is absent. The reason for this is that two naked copper wires pass above these houses, the rain dissolves traces of copper, the extremely dilute copper solution drips on the roofs, and in these areas the plant growth is interrupted.

This poisoning effect upon the lower organisms of minute amounts of metal was clearly shown in the next slide. A nutrient agar-agar preparation was inoculated with a culture of *Staphylococcus,* and a silver coin was laid upon it.[3] The dish was kept in the dark and at a low temperature for several days. Under these conditions the bacteria do not multiply, but traces of the silver can nevertheless diffuse through the nutrient. Later the dish was placed in a warm incubator, whereupon a luxuriant growth of bacteria developed. Around the coin, however, there was a space free from bacteria, where the dissolved metal had prevented their growth. In such a case it certainly would be very difficult to prove the presence

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[3] H. Beehold, *Kolloid-Z.,* 25: 158, 1919.

of silver by one of the usual chemical methods, for the silver content per cubic centimeter of nutrient solution could have been only a few hundred-millionths of a gram.

Recently the katadyne process had made extensive use of this so-called "oligodynamic" effect. The very large number of papers and patents relating to the sterilization of water, milk, and other substances, testify to the steadily increasing significance of this process. It is interesting to find that the ancient Egyptians employed this disinfecting action of minute amounts of dissolved metal. Open wounds healed better and more rapidly if they were covered with silver plates. The traces of dissolved silver prevented infection. Bone fractures repaired with silver wire show a greatly reduced tendency to infection.

In the cases here mentioned these infinitesimal amounts of material acted as poisons toward low forms of life. Much more important for all life-processes are those cases where the presence of a very small amount of substance is essential for life-processes, where lack of it produces deficiency phenomena and can mean illness and death.

This brings us to the supremely important field of the enzymes, vitamins and hormones. The catalytic enzyme or ferment reactions that are so determinative of organic phenomena find their inorganic, model-like counterpart in the catalytic decomposition of hydrogen peroxide into water and oxygen by minute traces of the noble metals present in the most finely divided state. Many years ago Bredig found that three millionths of a gram of colloidal platinum per liter of water produced a marked acceleration in the decomposition of hydrogen peroxide. Conversely, the slightest trace of "catalytic poisons" suffices to hinder this action by platinum; scarcely more than one millionth of a gram of hydrocyanic acid per liter of water was found to produce such a "poisoning."

The living cell shows corresponding catalytic reactions. The respiratory ferment, which is indispensable for cell growth, and which has been studied in detail by Otto Warburg, contains minute traces of iron—the so-called "enzyme iron." Only very delicate qualitative reactions can prove the presence of this iron. Nevertheless, the cell's life is extinguished if the iron is removed or its action is chemically prevented. As in the catalysis of hydrogen peroxide by platinum, very minute amounts of hydrocyanic acid put an end to the catalytic action, "poison" the respiratory ferment, and the respiratory activity ceases.

Less understood, as yet, than these enzyme reactions is the mechanism of the effects observed in connection with the "hormones." A few illustrations may be given. The human thyroid gland secretes thyroxine, an organic compound containing iodine, whose absence can induce severe metabolic diseases; in the lower animals a hereditary lack of this compound causes extraordinary effects. An American species of salamander, the Axolotl, often fails to complete its metamorphosis—particularly when in captivity—from the aquatic, gill-breathing larval stage to the fully developed terrestrial, lung-breathing animal. A single abdominal injection of a hundred thousandth of a gram of thyroxine suffices to produce promptly and positively the otherwise suspended metamorphosis.

A tadpole that develops very slowly if at all in water wholly freed of iodine, accomplishes its metamorphosis in a thyroxine solution of one part thyroxine to five thousand million parts water, and more rapidly than it would in an otherwise normal environment.

In these cases minute amounts of organically combined iodine have released vitally important functions, and in other cases minute amounts of other chemical elements have produced corresponding phenomena. During the past year Schmucker[4] in Göttingen has strikingly demonstrated the extraordinary and specific physiological activity of a minimum concentration of boric acid. He experimented with the pollen grains of tropical water lilies whose natural nutrient liquid contains small amounts of boric acid. If this boric acid is removed development ceases; if it is added in amounts of a hundred thousandth to a millionth, normal development is resumed. In this case the boric acid may actually be described as an "inorganic hormone."

Special interest attaches to the growth-producing substance "auxin" recently investigated by the Dutch botanist Went,[5] and prepared in the pure state by the German chemist Kögl.[6] The growth of plants requires extremely slight amounts of this hormone-like compound, in addition to the other materials belonging to plant structures. When an oat-sprout is "topped" to remove the tip, the growth of the sprout is stopped. If a trace of the "auxin" preparation—which can be extracted from the cut-off tip—is applied to the truncated end, growth is revived. An application of the "auxin" to one side of the sprout's end revives the growth on that side only; the sprout therefore curves toward the opposite side. The unit amount of "auxin," that which suffices to cause a curvature of about 10°, has been called the "avena unit." Kögl has now successfully prepared the pure crystallized growth-producing substance "auxin," and it has been found that the growth-unit just defined is produced by the fifty-millionth part of a milligram, that is, 2×10^{-11} gram of "auxin." In the first attempts to secure this very interesting substance maize

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[4] Schmucker, *Naturwissenschaften,* 20: 839, 1932.

[5] Went, *Naturwissenschaften,* 20: 596, 1932.

[6] Kögl, *Chem. Weekblad,* 29: 21, 1932.

and oat sprouts were used; but even one hundred thousand maize tips contain only very small amounts of "auxin." Its best source was finally found to be human urine, which is a source of many highly important physiological substances. It has been found that every human being, regardless of age or sex, secretes on the average two milligrams of auxin daily.

The foregoing expositions have shown that there are many ways, some direct and some indirect, for proving the presence of substances and determining their exact amounts when the latter are beyond the scope of the chemical balance. At the same time, however, it has been found that even the least of the amounts we have considered consists of a very large number of molecules. Is there, then, no bridge leading from these relatively gross quantities to the individual atoms?

In the closing years of the last century there were discovered the radioactive substances, and these actually do furnish the key that has, at one turn, opened the gate to this field formerly regarded as closed to exploration. The final section of this lecture will therefore be devoted to a consideration of these radioactive substances.

Radioactive elements are those which are subject to spontaneous intra-atomic disintegration. The discharge of small fragments of atoms—the so-called "radioactive rays"—gives rise to new elements possessing new chemical and physical properties. The radiant particles emitted during the disintegration are characterized by an enormous initial velocity and it is because of their high velocity that the particles, in spite of their merely atomic magnitude, reveal their presence in the most varying ways through the effects they produce. These effects of the radiation constitute the fundamental difference between the long-known chemical and the new radioactive methods of investigation. In the former case ordinary stable atoms are used for investigation, and all that has been said shows that many millions of atoms or of molecules are required for such work. In the case of the radioactive substances one measures at the instant of emission the rays coming from the disintegrating atoms. Thus it is not the absolute number of atoms present, but the number of atoms disintegrating during the period of measurement that is of importance. By studying this radiation-intensity it is possible to investigate a whole series of different radioactive atoms (chemical elements) in masses that are far below the limits of chemical identification. By means of their radiations invisible and unweighable masses can be recognized as present, and they can also be accurately analyzed and determined quantitatively. The broad field of applied radiochemistry employs these properties of radioactive substances to study the behavior of imponderable amounts in the presence or the absence of inactive accompanying substances; it puts into our hands the means for attacking and solving chemical and physico-chemical problems unanswerable by other methods.

There is not time to discuss this matter now in any detail and a few brief references must suffice. In connection with spectrum analysis it was mentioned that optical methods enabled us to demonstrate the presence of traces of impurities in metals and chemical compounds. Radioactive methods enable us to go yet further and to study the laws according to which unweighable amounts of foreign materials are taken up by their carriers.

The next photograph showed two crystals of different salts. One was a natural crystal, gypsum, which after irradiation had the striking property of phosphorescence along certain of its crystalline surfaces.[7] There is hardly any doubt but that this selective phosphorescence was due to minute amounts of impurities deposited regularly on the crystal as it was growing. The probable correctness of this explanation was shown by the second crystal, rubidium sulphate, which we made artificially and which contained less than one billionth of a gram of a radioactive substance (lead). This crystal was placed in the dark upon a photographic plate, and the latter was developed after a short exposure. The picture showed plainly that these absolutely imponderable amounts of radioactive material here also were deposited in a regular manner. The remarkable character of this distribution could not possibly be determined by other than radioactive methods, because the infinitesimal amounts involved in these inclusions can not be detected by analytical chemical methods.

When the radioactive substance is not embedded in a crystal, as in the case just considered, but is adsorbed by minute particles in a liquid or a gas, it is possible to determine directly the nature of the radioactive element emitting the rays, from their effects on a photographic plate. The next illustration showed how this is possible.[8]

One could notice that there were a number of dark circular figures of various diameters; the diameters of these circles are quite definitely characteristic of certain radioactive substances. Were other substances of this kind present, the circles or zones would have a different radius. This makes it possible to identify a chemical element in this way when perhaps a thousand or less atoms are present, and there is nothing to prevent the detection of a still smaller number of atoms.

These circles, called "radioactive zones," produced here artificially upon the photographic plate, occur naturally in many minerals and are of prime significance in problems on the history of our earth. In

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[7] *Handbuch der Experimentalphysik*, Band XXIII, 2 (Tomaschek).

[8] See Mlle. C. Chamié, *Comptes rendus*, 1929–1931.

the pleochroic halos, so-called, one has to do with very small, circular images; they are found in particularly beautiful development in a fluorite from southern Germany. The colored medium in this case is the decidedly less sensitive rock in place of the highly sensitive photographic plate. Our next slide showed photographs of such zones or halos.[9] They appear as a large number of concentric circles, each circle corresponding to a particular one of such radioactive decomposition-products as are found in uranium or thorium minerals. The interruption of the circular area by brighter annular bands results because the rays are most effective at the respective limits of their so-called "range." Minute traces of radioactive minerals are embedded in the inactive fluorite, and have sent their rays into the surrounding mineral which they have colored.

Experimental determinations of the number of rays necessary to produce these zones and the microscopical measurement of the volume of the radioactive dust particles that caused the halo, enabled Rutherford and Joly to figure out that in many cases several hundreds of millions of years were required to produce such halos. This demonstrates the tremendous age of the solid crust of the earth. The study of these pleochroic halos reveals the almost overwhelming fact that it is possible in this way to demonstrate atomic transformations in which, every few years, one single atom breaks down with the emission of a radiant particle. Compare with this the fact that in one milligram of radium, seventeen million atoms disintegrate every second, and yet thousands of years must elapse before this minute mass of radium has been completely transformed.

Radioactive phenomena, in fact, now offer us the possibility of determining and studying the behavior of substances consisting of only single atoms. The so-called "Wilson cloud-chamber" carries out such work in an especially intensive manner, and in conclusion some slides were presented demonstrating the principle of this method and pointing out what it can accomplish.

When the alpha rays of radioactive substances traverse the air it is well known that they produce positively or negatively charged air particles—the so-called "ions." If this air is saturated with water vapor and then rapidly cooled, the cooling causes the vapor to condense in cloud droplets where these ions are present. Under suitable illumination, the mist in the air chamber is plainly seen to be divided into sharp lines, and these lines correspond to the paths of the ions from the alpha rays. The length of the path represents the range of the alpha rays in air.

Each of the many straight lines corresponds to a radiant particle and therefore to a disintegrated atom. In a case illustrated, the disintegration of two different substances was involved, therefore there were noted two different groups of rays, one having a greater and the other a lesser field of action. Clearly a much smaller number of rays than that shown can be recognized in this way.

The next figure showed something else. In addition to the brush of numerous normal alpha rays, there appeared in one place a longer and much thinner ray.[10] This was a hydrogen ray that had been set in rapid motion by an alpha ray, a rather unusual phenomenon. These fog-tracks aid in the photographic recording of such rare atomic processes. The modern terms atomic disintegration, atomic structure, neutrons, indicate how extraordinarily fruitful for the modern physics of the atom is this method of photographing fog-tracks.

The Wilson photographs clearly demonstrate our ability to detect extremely minute amounts of material, but an even more striking illustration of the sensitivity of this method was furnished by an occurrence in the speaker's laboratory in the Kaiser Wilhelm Institute in Dahlem.

While Wilson photographs were being made in Professor Lise Meitner's room in the physics section of the institute, one of the speaker's collaborators opened, in the distant chemistry section, a vial containing a solution of a few milligrams of radium. A fraction of the radium emanation, not more than about one one-hundred-millionth of a gram, escaped into the laboratory. Thence a smaller fraction escaped into the corridor, and thus an infinitesimally small quantity entered the room where the Wilson photographs were being made. The result was recorded on the photograph shown in the last view. One could see a multitude of Wilson-paths running crisscross through the photographing chamber; these had been made by emanation atoms that had entered the Wilson-chamber, and, at the moment of exposure, had been disintegrated by ray emission. These minute traces of emanation "infected" the apparatus, and perfect records could not be made again until the last trace of emanation had been removed from the chamber, or had disintegrated.

We may esteem ourselves fortunate that the detection of non-radioactive substances is less sensitive than those that have been described. If we could see how many nuclei of dirt, dust, and disease are contained in the air we constantly inhale, we might be terrified and hardly dare to breath. Nature in her wisdom has arranged matters so that in the course from the ponderable to the imponderable the limits of visibility coincide approximately with the limits of weighability. Let us be thankful that it does not reach down to the individual atoms!

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[9] Gudden, *Z. Physik*, 26, 110, 1924.

[10] For these Wilson-photographs the speaker was indebted to Professor Lise Meitner.