The Question of the Atom

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THE question of the atom is really one of the most interesting and informing in contemporary knowledge. It is so interesting because the mere question "*Is* there an atom?" has been the *casus belli* of a fratricidal strife which for almost a generation has divided chemist against chemist, and it is so informing because it illuminates so clearly the workings of human nature in those cold regions of Science in which presumably, and ideally, human feelings have no place. The question "Is there an atom?" has associated with it all the *odium theologicum* of medieval days, all the proverbial hatred of contending divines, and, when chemist meets chemist, because the attitude of each man is fixed, because it is a personal matter, it is as impossible to discuss in intellectual honesty as either politics or religion. This is of course sufficiently curious and wrong, but the wrongness of it is emphasized through the consideration that it is a fundamental matter in the teaching of chemistry. When about half the chemical departments of the colleges and universities are teaching chemistry on the basis of the atomic theory and the other half refuse to mention the word atom, or mention it apologetically with a blush, and when, as is oftentimes the case, there is disaccord on the subject, and high debate, in any one instructional staff, it affords a poor prospect for a future crop of investigational chemists, and it may even be suspected that there is about the whole matter a certain unreason. All this may be a matter of surprise to the cultured layman, who probably takes his atoms, as he does his microbes, as a fact. But atoms are not a fact, but a theory, and therein lies the root of the trouble. We have had many theories in the past, some of them great fruitful theories, such as that of phlogiston, and of caloric, and of the corpuscular nature of light, and these theories are to-day nothing but discarded rungs in the ladder of man's advance. Is it not possible that the atomic theory is no more than these the expression of a truth of nature? Thus, one reason for all this regrettable disaccord is purely pedagogical, certain chemists believing that, owing to the tremendous utility and scope of the atomic theory in the explanation and elucidation of natural phenomena, some young gentlemen at the threshold of their science may find a quagmire of confusion between fact and theory, and therein a pitfall for their unwary feet. It is true that the physicist with his undulatory theory is not worried by such fanciful considerations, but cheerfully uses and teaches his light-waves, which, by the way, no man has seen any more than he has an atom. The biologist, too, is in no whit better case, yet he, too, teaches and uses his theory of evolution without overmuch regard for the undiscriminating student. There must be other reasons for this curious attitude of certain informed chemists, though these can scarcely be considered in an article of this general character. Meanwhile it may occur to the reader that the refusal of certain chemists to base their teaching on the conception of atoms may be due to evidence against the validity of the atomic theory. No. On the contrary—and this will be the subject-matter of my paper. The fact of this disaccord is introduced here merely to apprise the reader that in presenting and drawing conclusions from some certain new and very interesting knowledge, this knowledge is subject to partisan interpretation, to such an extent that the layman who happens to peruse these pages may, perhaps, form a judgment concerning it as good as that of any average party to the controversy.

With regard to absolute knowledge as to the ultimate constitution of matter, we all recognize it as impossible. Science is like Palomides, "that good knight" of the Arthurian romance, who pursued a beast called Galtisant. It was a "questing beast" and forever uncatchable; nevertheless with Palomides it was his "quest," which, with quite human divagations and excursions, he religiously pursued. The ultimate nature of matter is the "questing beast" of science.

But about this matter, accepting it as phenomena, it is either infinitely divisible or it is not; there is no *via media*. If it is not, then it is composed of ultimate particles. Now, the atomic theory states not that there are ultimate particles, but that there are ultimate particles of *chemical reaction*. It may be true, and, accepting the theory, doubtless is, that the ultimate particles of chemical reaction, or atoms, are themselves built up of particles smaller still. With these the atomic theory *per se* has nothing to do.

But about these ultimate particles of chemical reaction, or atoms, the evidence upon which the theory of their existence rests may be said to be all of chemistry, most of physics, and a large portion of every other field of natural knowledge; in other words, it is stupendous. This evidence, however, is wholly *inferential*, and so long as this is true there remains always the conceivability of some other explanation to account for the facts, innumerable though they be. But if we could take our atoms out of inferential into demonstrational evidence we should at once leap an infinity of difference in credibility—all the difference between the necessity of an indefinite piling of Ossa on Pelion of cumulative evidence, and a heaven of certainty where one fact is as good as a million. If we could but indubitably capture our atom. While I do not say that this can be done to-day, the approach to its accomplishment is so close and the attack is, if I may be permitted to use the word, so "sporting," that it has an absorbing human interest.

This appears when one considers what it means in the way of difficulty, this capturing of an atom.

The spectroscope is one of the most delicate instruments for the detection of matter ever devised by man. With this instrument Strutt has been able to show that it is possible to detect the gas neon in one-twentieth of a cubic centimetre of ordinary air; and on the basis of Ramsay's work it is a fact that this quantity of neon corresponds to about one-half of one-millionth of a cubic centimetre. Transferring the statement to terms readily understood, there is a particular particle lost in a thimbleful of air with four million others: problem, find that particle. It can be done.

One would think that a particle so unimaginably small would approach fairly close to the dimensions of the theoretical atom, but such is not the case. This particle, on the basis of the current conception of the atomic theory, must contain about ten million million atoms. As Sir J. J. Thompson says in another connection, if we had no better means of detecting an individual man than an individual atom we should conclude that the earth was uninhabited. It is apparent that the spectroscope, delicate though it is, does not make a beginning in the attempt to capture the individual atom. So much for the difficulty.

Let us, however, disregarding the fact that an immense, incalculable number of facts of organic chemistry, other chemistry, mechanics, diffusion, expansion, spectroscopy, light, heat, electricity, magnetism, sound, meteorology, radioactivity, and so on and so on indefinitely, all lie beautifully arranged, correlated, and explained within their proper limits, and ever increasing in volume because of the atomic theory—disregarding all this, and despite the immense difficulty of it, let us ask ourselves either for demonstrational evidence or for inferential evidence with which the *Chemical* Atomic Theory, if I may so call it, has nothing to do.

There is one instrument which is as much more delicate in detecting the existence of small particles of matter as, under certain conditions, the spectroscope is than the human eye. This instrument, marvellously little known, is the ultramicroscope. With the best modern microscope the smallest particle which it is possible to see is about 1-7000th of a millimetre in diameter. This diameter is just about the length of half a wave of visible light. It is unreasonable to expect the best microscope to possess a resolving power greater than this, for with particles smaller than half the length of a wave of light they obviously cannot reflect the light by which they may be seen; for example, one cannot expect a grain of sand to reflect a water wave; the wave simply embraces the grain. Outside of the fact that the limits of visibility may be somewhat extended by using light-waves of short lengths, as with ultra-violet light and photography, there is one way by which success may be achieved. Particles, no matter how small, may be seen if they are caused to emit a light of their own—to become sufficiently self-luminous. Whether this is a valid explanation of the observed phenomena, or whether the extension of visibility is due to illumination in a dark field, may be a matter of opinion, but the summarized facts are as follows. The light from a powerful arc-lamp or from the sun is passed through a strong condenser in such a fashion as to transform it into a superlatively intense but superlatively minute beam. This wisp of intense light passes through the windows of a cell and impinges there upon the substance under examination; the small area illuminated by it is then examined from above by a good microscope. As a result of this simple mechanism and under certain conditions there spring into visibility particles which are as small as the stars are distant. They are not unlike stars even in appearance as they lie twinkling there in the depths of the infinitely small. They are like stars, too, in that their actual shapes are not delineated, though they may be observed by the hour with fascinated interest. Even though it is actually true that their forms may not be observed, their average size may nevertheless be calculated, not in terms of theory, but of fact. Thus, in examining the particles of gold in ruby glass the area of the minute beam may be calculated, the number of particles of gold in this area may be counted, and since the weight of gold introduced into the glass and its specific gravity are both known, all the factors are provided for estimating their average size. So determined, the particles of gold in glass average six-millionths of a millimetre in diameter. *The smallest particles estimable in a colloidal solution of gold measured 1.7 millionth of a millimetre.* This means that in its capacity for determining minute quantities of matter the ultra-microscope is thirty-seven trillion thirty-one billion times as powerful as the best modern spectroscope, which, as we have seen, is capable of detecting one-half of one-millionth of a cubic centimetre of gas. A graphic idea of the transcendent powers of this instrument may be obtained by examining the diagrammatic representations in Fig. 1. The little dots *f*, *g*, and *h* represent visible particles of colloidal gold some six to fifteen millionths of a millimetre in diameter and magnified ten thousand times to render them representable; the corresponding circle A represents a human blood corpuscle, itself an excessively minute object, magnified in the same degree.

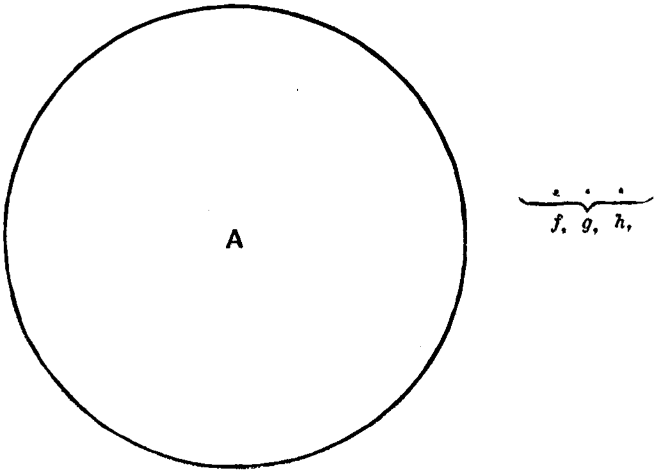


FIG. 1.—COMPARATIVE SIZE OF A BLOOD CORPUSCLE (A) AND PARTICLES OF COLLOIDAL GOLD (*f g. h.*)

Quite apart, therefore, from any inferential evidence, we have the positive demonstration of the fact that matter is capable of existing in the condition of discrete particles infinitesimally small. It therefore becomes an interesting matter to compare these particles of measured diameter with the calculated dimensions of our hypothetical atoms and molecules. This comparison is represented in Fig. 2. Here we have in figures *a, b,* and *c* the estimated diameters of the hypothetical molecules of hydrogen, alcohol, and chloroform magnified one million times, and in *e, f, g, h,* a conventional representation of our colloidal gold particle under the same magnification. It will be seen at once that the smallest particles of matter observed under the ultra-microscope, while they are not actually of molecular or atomic dimensions, are of the same order of magnitude; the ultra-microscope has jumped the difference between the wonderful power of detecting a particle of matter containing only ten million million hypothetical atoms, the ultimate achievement of the spectroscope, and one containing, let us say, a few thousand. It may therefore be taken as an indisputable fact not only that matter can exist in particles infinitesimally small, but that the dimensions of these particles are perilously close to those assigned in calculation to "the inferential atom."

But the ultra-microscope has proved capable of throwing a demonstrational light upon the theory of atoms in quite another phase.

Quite apart from the ultimate particles of matter in themselves are the motions of them. Molecular motions infer molecules, and molecules infer atoms, and atoms infer the atomic theory. The kinetic theory of gases, therefore, which deals with molecular motions, is an integral part of the atomic theory and stands or falls with it. This theory assumes that a gas consists of a vast number of particles in constant motion, in constant collision with one another and with the walls of the containing vessel. It assumes, too, that the particles travel in straight lines between collisions—in paths which are very long compared with the diameters of the particles concerned. It has been found possible by this conception to explain to a remarkable degree the physical properties of a gas and to predict successfully unknown relations of these properties. In fact, the kinetic theory of gases has been one of the most powerful engines of research ever devised for forwarding theoretical and experimental knowledge.

Turning, now, to the ultra-microscope and its revelations of infinitesimal particles, let us permit the original discoverer, Zsigmondy, to speak for himself of their properties.

"A swarm of dancing gnats in a sunbeam will give one an idea of the motion of the gold particles in the hydrosol of gold. They hop, dance, jump, dash together, and fly away from each other so that it is difficult to get one's bearings. This motion gives an indication of the mixing up of the fluid, and it lasts hours, weeks, months, and, if the fluid is stable, even years. The smallest particles which can be seen in the hydrosol of gold show a combined motion consisting of a motion of translation by which the particle travels from one hundred to one thousand times its own diameter in one-sixth to one-eighth of a second. . . ."

But the hydrosol of gold is a liquid, and the kinetic theory, while it certainly is applicable to liquids, has, after all, mainly to do with gases. It is interesting,

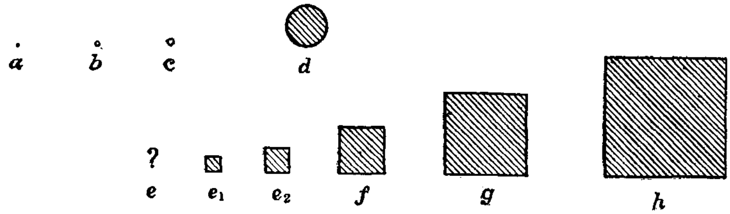
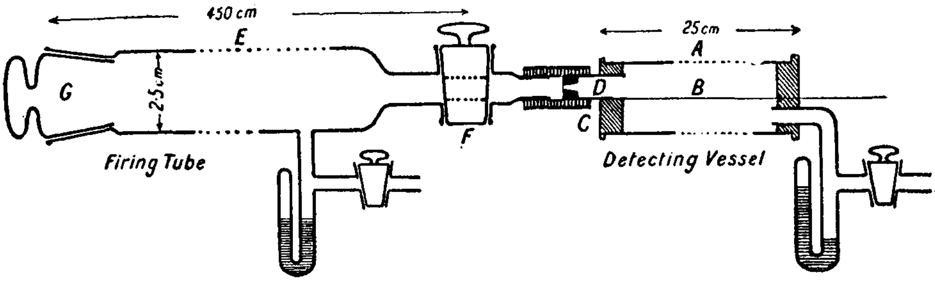


FIG 2.—HYPOTHETICAL MOLECULAR DIMENSIONS

a—Hydrogen molecule. *b*—alcohol molecule. *c*—chloroform molecule. *d*—molecule of soluble starch. *e f, g, h*—gold particles in colloidal gold solutions
Linear magnification, one to one million



RUTHERFORD'S MECHANISM FOR DETECTING THE INDIVIDUAL ELECTRON

then, to know that Ehrenhaft has recently succeeded in extending the observations of these movements to gases. Thus, by striking an electric arc between silver poles, he has been able to produce a fine silver dust in the air, and on examining the dusty air with the ultra-microscope the suspended particles showed not only the motions of those in liquids, but to an exaggerated degree. Let the reader notice, then, that these particles, which are more or less of the order of molecular magnitude, possess the type of motion ascribed to molecules by the kinetic theory of gases, which is a theory dependent upon a theory. The type, we say, but there is more than this to it. It has further been shown that using the kinetic theory it is possible to deduce by calculation, and with a fair degree of accuracy, the motions actually obtained.

One of the most striking confirmations of the kinetic theory of gases is due to the work of Perrin. As everybody knows, the density of the air decreases the higher one goes; thus, at about six thousand metres above the surface of the sea the air is but half as dense. All this is understandable, theoretically, always theoretically, on the basis of the kinetic theory of gases. Now, Perrin has obtained a suspension in water of practically equally-sized spherical particles of gamboge which, while exhibiting the characteristic motions referred to, gradually settle through gravity to the bottom of the vessel. On counting the relative numbers of these particles in layer after layer from the bottom up, he has discovered that the number diminishes in miniature just as the density of the air diminishes and in accordance with the same law. Moreover, it looks as though these particles in arranging themselves acted reciprocally with the molecules of the solution; in other words, that they behave as though they were molecules themselves. However this may be, we adequately explain the decrease in density of the air on the theory that the air consists of particles, but in the experiment above referred to we find demonstratively that particles experimentally behave in just that way. By means of this unique instrument, then, and quite apart from any theory, we see, literally see, first that matter can certainly exist in particles more or less of the order of atomic magnitude, and, next, that these particles have the movements of the type and character that on *a priori* considerations we have been compelled to ascribe to particles which, chemically speaking, are ultimate.

But the ultra-microscope does not actually capture the individual atom. This achievement has been reserved for an instrument still more powerful and the most sensitive in the world.

In the competent hands of Rutherford, and in a research which will stand as classical in its refined and accurate experimentation, the instrument which has proved capable of this incredible feat is the electrometer.

In a paper of this general character the method of its accomplishment must be summarized, but its essentials are as follows: Everybody knows that radium gives off rays of three types—the alpha, beta, and gamma rays. The alpha rays alone concern us. On the basis of an enormous amount of knowledge it may positively be taken for granted that these alpha rays consist of positively charged flying particles, and that these particles are of atomic dimensions.* It is true that the considerations upon which this statement is based are to a certain extent theoretical, but these theories have stood impregnable to the attack of immense experimentation, and they have nothing to do with the chemical philosophy of the atomic theory. The alpha rays are charged particles, they fly through the air at the rate of about twenty thousand miles a second, and they are of atomic dimensions. The feat to be accomplished consists in catching them one by one; it transcends any analogy with which one might attempt to compare it.

Its success depends upon the power these particles have of rendering electrically conductible the air through which they tear their way. This property, by what might be called a trigger arrangement, Rutherford succeeded in magnifying thousands of times, until finally it became adequate. A diagrammatic representation of this apparatus will be found in the accompanying illustration. Here in the text let us merely say that it is a most attractive study in ballistics. There is a firing chamber containing the radium, and there is a target chamber containing the detecting arrangement connected with an outside electrometer, and between the two there lies a window of thin mica only one and one-half millimetres in diameter. In the firing chamber, infinitesimal projectiles from the radium fly through the window into the detecting chamber, and there, upsetting the electrical equilibrium of the air within, they cause a ballistic jump of the electrometer needle connected with it. One, two, three, four, at the rate of about thirty a minute, as they enter through the window, they cause one, two, three, four corresponding jumps of the needle. Counting the atoms! It is, indeed, wonderful. If the reader is interested in watching a master at his work, let him read this research in its original presentation in Vol. 81 of the Proceedings of the Royal Society.

In this research he will find as well that Rutherford has laid his hands on an interesting confirmation of his work. Many people have seen, and will always remember, the scintillating stars of light that result on placing a bit of radium before a screen of zinc sulphide. It is like a swarm of fireflies on a dark night. Now, it has been suspected that the flashes of light were due, each of them, to the impact of an individual alpha particle, but no verifiable method existed for proving it. With the arrival of Rutherford's needle-jumps, however, the method arrives. If they really are due to the impact of individual alpha particles, then, under comparable conditions, they ought to correspond in number per minute with the needle-jumps of the electrometer. They do so correspond. Hence we have, now, not one, but two valid methods of identifying and counting the individual atoms.

But a critical reader at this point is likely to object: "These alpha particles of which we are speaking are 'queer' things. They may be of atomic dimensions, as you say, but how do we know that they are atoms? What are they atoms *of?*" This introduces Rutherford's crowning research.

In a research immediately following the one we have referred to, he and Mr. Geiger showed on the basis of theoretical assumptions that the alpha particle was almost certainly an atom of helium. This does not interest us so much except in so far as it exemplifies the amazing validity of these atomic hypotheses in radioactive investigations. It does not interest us, because, in a research almost immediately following this again, and published in the *Philosophical Magazine* for February, 1909, he with Mr. Royds proves, not thinks—*proves* that this is actually, veritably, the case.

How he accomplished it even the layman may understand in the research referred to.

The whole achievement rests upon the possibility of blowing a small glass tube having walls less than 1-100th of a millimetre in thickness; a tube of so thin a glass permits the alpha particles to fly through it, but resists a vacuum. Within this tube there is the radium, firing its alpha particles, and surrounding it is a vacuous space, into which the alpha particles fly. After the lapse of two days, but growing stronger and stronger up to

* The proof of this statement is too extended for consideration here, but it may be found simply stated, *in extenso*, in a book by the writer, *The New Knowledge*.

six days, there appeared in this vacuous space and between the electrical terminals within it a phosphorescent light which to the spectroscope lying in wait for it indisputably signified itself as helium. They proved that the helium was not in the glass used, was not due to any air leak, was not in the mercury within the apparatus, was not due to any leak of radium emanation; in fact, they proved indisputably, "up hill and down dale," that it was, and could not be anything else than, due to the alpha particles; that, in simple fact, a collection of discharged alpha particles is, *en gros*, helium.

The gas helium consists of particles, but are these particles atoms? Here follows the proof:

Dewar has shown, quite apart from theoretical considerations, and as a matter of fact, that one gram of radium produces a volume of 0.00000532 cubic millimetres of helium per second. Rutherford, by his counting method, has proved that this same gram of helium produces 136,000,000,000 alpha particles per second. But these 136,000,000,000 alpha particles constitute collectively the 0.00000532 cubic millimetres of helium. Therefore it follows by mathematical necessity that every cubic centimetre of helium under standard conditions contains 25,600,000,000,000,000,000 alpha particles. But this value is in remarkable accord with that which through a dozen different methods has always been held as the number representing the ultimate chemical particles in a cubic centimetre of gas. Therefore the discharged alpha particles in monatomic helium gas *are* the atoms.

But helium in its physical properties is more or less like any other gas; therefore every other gas presumably consists of particles. But every other gas, generally speaking, will, under suitable conditions, become liquid and solid; therefore every substance of any kind whatever presumably consists of ultimate particles of chemical reaction.

I do not say that this remarkable demonstration of the atomic theory of matter is absolute. Not at all. Let us say, rather, that, taking into consideration the immense amount of inferential evidence of the atomic theory, together with evidence of this demonstrational character, we are as sure of it as, for example, we are sure that the rings of Saturn consist of satellites, which every sensible person, on the basis of the evidence, is willing to believe. We are almost as sure of it as we are of parentage, which, after all, is a theory. In simple consistency we should expect the teacher who introduces young gentlemen to organic chemistry without the atomic theory to introduce us to his "putative father"; the atomic theory is the father of organic chemistry.

At any rate, it permits us to speak of atoms and molecules without a blush. It enables us, too, to deprecate this business of writing text-books of elementary chemistry without the atomic theory. This has always been illogical and essentially absurd, and while after a certain fashion it may be accomplished, it has always worked to the serious hamperment of chemical instruction.

Modern knowledge has thus enormously strengthened the validity of the atomic theory, but it has not informed us, and does not teach us, that these atoms are actually ultimate in their nature or simple in their constitution. The reverse is the case. We are no more sure of the validity of the atomic theory than we are that these atoms are actually highly complex. The modern idea of the atom is that it is, like the planet Saturn, made up of a nucleus related to satellites. We are sure that it consists in part of particles of negative electricity, we believe that it is made up in part of positive electricity, and we are inclined to think that there may be something in it quite apart from either. We shall never have a valid notion of the inner nature of the atom until we solve the nature of positive electricity, and about this, so far, literally nobody knows.

By the Second Intention

BY EDWARD S. MARTIN

"DEAR Mr. French," my letter began, "Cordelia and I have a mind again to get married. But having once been engaged and quit, we have no mind at all to be engaged again and divulge it. Would you mind, please, you and Mrs. French, if we eloped? It seems so much the more feasible and private way."

I would rather have broken it to him by word of mouth, but for some things it is written words or none. If you have determined to elope with a man's daughter, you can't very well go and ask leave of him. Suppose he objects! Of course he will object, especially after consulting his wife. The only way, if you propose to consult him at all, is to write, and mail the letter on the way to the church and come back to the house afterward for the answer.

Cordelia felt she just couldn't be publicly engaged to me again. Of course I didn't mind. I think meanly of the engaged state *per se*, but I had always rather be engaged to Cordelia than not. But that was only because I had always wanted to marry her, and had been glad to throw any convenient obstacle, even an engagement, in the way of her marrying any one else. The thing that had bothered me was to have the engagement end without our being married. I wanted to have it die a natural death in church, with flowers and a minister, and it had irked me very sore indeed to be "released" like a baseball-player before the end of the season. It left me on a miserably awkward footing with the rest of the world and with her, and it left her in the same case. Nobody quite knew whether to congratulate either of us on getting rid of the other. People naturally wanted to know why, and of course you can't tell in the newspaper. It was awkward for our families. There was a feeling that they ought to quarrel, because somebody must be to blame, and the other side ought to resent it. But they didn't want to quarrel, and wouldn't; not even a little, to keep up appearances. They held their tongues and went on about their business as before, but inevitably flocked more apart than they had been wont to do, because when they met it excited too much interest.

I don't mean that they were such conspicuous people that the London papers had cables about them. It was only that when Mrs. Fessenden or Mrs. Somebody Else got home from the Jenkinses' tea she told her family, and whomever she had to dinner, that Mrs. French and Harriet and Mrs. Jesup were at the Jenkinses' and spoke, as they passed, as politely as though nothing had happened. And then would follow a little chattering tribute of discourse about Cordelia French and Peregrine Jesup, and why did they break their engagement, anyway!

Not that my family, or Cordelia's, got direct reports of what was said at Mrs. Fessenden's dinner table. They didn't; at least, not often. But they knew what must have been said, and families don't like to be subjects of speculation, or of critical, or even compassionate, observation. They can bear the eye of approval, of admiration, and even of a moderate envy, but what family likes to have the Fessendens, the Jenkinses, the Underharrows, the Overtons, and the rest of the families getting their heads together to swap surmises as to what the Frenches and the Jesups have got in their closet!

Maybe you'd like to know why Cordelia and I loosed hands after our intentions had been six months on file. In this private way why should I not explain that it was not so much the fault of either of us as of the conditions of life as we found them. You see, I was twenty-three and Cordelia was two years younger. I was studying the profession in which I hope to be useful in my day and generation, and by the practice of which I hope