The Functions of Research[1]

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THE functions of research as we analyze them industrially today are manifold, and perhaps the man who is interested only in the extremely technical phases overlooks a few of the very important contributions which science can make to the great questions of industry.

I would rather have a young man firmly grounded in elementary physics and chemistry, whether he ever did a chemical analysis or not, than any other one thing. I can teach him the specific application of the art, but I have never been able to teach him the fundamentals underlying science after he has once gotten his diploma. From an engineering standpoint, if I were to write the curriculum of an engineering course today, I would write it very simply: four years of physics, four years of chemistry and anything else you have to give the man. Why? Because chemists have been too specific.

Every great thing that the world has ever seen has been a re-arrangement of materials, and, to me, chemistry is only the construction, the constitution, of material. It is only the wonderful configurations that are built up from the elements, the wonderful handiwork of Nature that has provided us with the millions upon millions of materials. They tell me that in the hydrocarbon series alone there are so many compounds possible that if we used the very finest Japanese paper, printed with the finest type that the ordinary person can read, and gave only a quarter of an inch per page for each compound, we have not enough paper to print them all. The man who wants to be a chemist and tries to learn all those compounds is absolutely lost, but underlying all of these miraculous compounds there are a few fundamental principles in both physics and chemistry that are so basic that we can tell, without even having to determine many of their characteristics, what they would be, even though we had never heard of them. It seems to me, therefore, that the determination and application of such basic principles is of so much greater importance than analytical data as to make the latter seem a waste of time in comparison.

Chemical quantitative analysis is the art of chemistry. *Why* you analyze them is the science of chemistry. In procuring and directing research men, I would prefer to have them know *why* they want to find out something, *why* they want to know the constitution of a given material, than to be the most expert technicians in determining it.

Interpretation of Science to Public

I have been interested for a great many years in the application of scientific discoveries and scientific developments to the common, everyday workaday principles of life, because a great many years ago I recognized this very elementary principle: you may perform the most miraculous experiment in the laboratory and produce a most wonderful result, but so far as having contributed anything to the welfare of the human race is concerned, you have done nothing until you have delivered that result to a customer who may be entirely unconscious of its existence. Therefore, commercial research today is the translator of high and fine scientific ideals to a using public, who get the results and appreciate their value without knowing of their existence.

A recent news article discusses a synthetic method of producing phenol, and following that discussion it is stated that probably in due course of time, because of the low cost of the phenol, our furniture could be made out of synthetic resin. There are 115,000,000 people in the United States, and 114,750,000 think of resin as the stuff they put on the bow of a fiddle. They have not the slightest idea of what you are talking about when you speak of resin as furniture. They think of it only as being the most brittle stuff in the world.

Science in general has needed an interpreter to translate it into the terminology of the man on the street, and that is one of the great functions of industrial research. It translates what the men in the laboratory, the men who speak only in technical terms, have to say. We of industry perhaps represent a very much lower order of thought than the pure science researcher, but we are able at least to translate it into the terms of the man on the street. We represent the 114,750,000 people of the United States who pay the bills of translating the wonderful discoveries of physics and chemistry into the terms of the average man.

Determination of Facts

The next great function of research is the determination of facts in terms of commercialism. Like many others, I was taught, when in college, that a scientist is a man who works at his subject for the sake of the subject alone, and that a man who works on a scientific project with the idea of selling it has no right to be associated with science. I have since learned that a bank account in the black is the popular applause of a scientific accomplishment. Therefore, if I can translate a scientific fact into something that the people can use, and they are willing to pay more for it than it costs me, and I have a bank account in the black as a result, it is a very satisfactory situation, even though it may be a lower order of intelligence.

The procurement of facts is, of course, the basic principle of all research, but in the engineering world a fact is purely a question of opinion. You may have so eliminated opinions from the facts in the chemical industry that every one of them is a perfectly definite, relative thing, but that is not true of the engineering world. They say the most phenomenal thing that ever happens in engineering is to have two engineers agree upon any one point. However, there is this much to be said—that a chemical compound, say sodium chloride, does exist; that it is made up of two elements, at the present at least, of sodium and chlorine (some discussion as to which one of the isomers of chlorine might be used); that each one of these has a nucleus of a certain number of electrons (some doubt as to the number); and that if you put it on your egg it tastes salty. We know that much about sodium chloride, but there is a perfectly definite constitution of sodium chloride which remains as it is, regardless of what you and I think about it. That is why it is so important to get at the facts.

The more argument you have upon any subject, the less is known about that subject. So if you want to go into research, find out the things upon which there is the greatest disagreement and the most opinions, and you perhaps have a virgin field. Argument always presupposes a lack of knowledge.

Obtaining facts, entirely apart from individual opinion,

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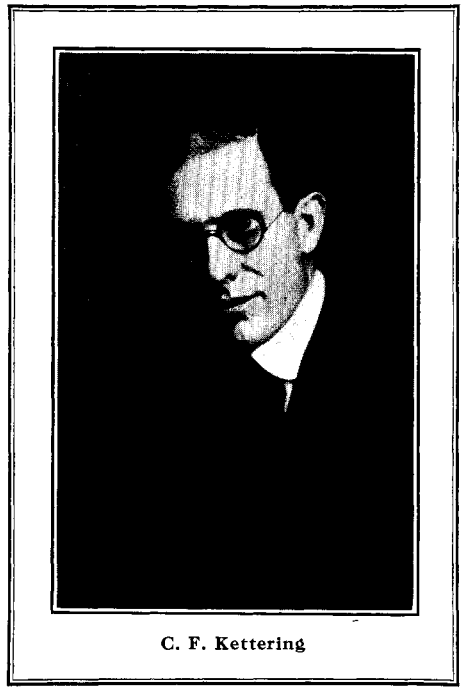
is a very important part of research. An example of wonderful advances through physical re-arrangement of materials is found in the development of transportation from the sailing vessel to the steamship, to the railway train, and to the airplane.

When people ask, "What next are we going to encounter?" I have only this to say. We shall have seen no marvelous phenomena in the world until we get the chemist to work, especially the organic chemist, who has it within his power to re-create and re-develop types of material of which you and I today know nothing.

We have been by-product experts up to the present time. We depended upon the sailing vessel, which was purely a by-product of the wind, until some one developed the steam engine, and when the development of the steamboat was first proclaimed you know what people thought of that. We are no different now than we were one hundred years ago. There is today being expressed in an embryotic way the most fundamental principles of our advanced civilization, and we pay no attention to them because they do not fit into our ways of thought. We have never recognized a fundamental principle of a great advance at the time it has been presented. The man who has the greatest foresight is the man who is most out of step at the present time. I believe that human nature has not changed, and therefore I think there is being expressed in many ways the most advanced things in scientific results which we may not appreciate because they do not fit into the category of today's operations.



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Selling Ideas

Another great function of research is that of selling. Every great industry today has a procurement department, which purchases the materials that industry needs. A recent national magazine has commented upon the procurement departments of our great industrial organizations, condemning them as great pirates. They accuse them of purchasing at the expense of the supplier and of employing sharp practices. I do not believe that to be a fact, but I simply relate it to show that every great industry has a procurement organization as well organized as possible for purchasing at the proper prices those materials which they need for their product. But there is not a single organization in the world that has had a department for the procurement of a new idea. There is not a single institution in the world that has listed a new idea among the materials which it uses. Therefore, industry has no possible way of procuring these new ideas. You have to sell an idea, sell it to them as an entirely different entity from what enters into their production. Therefore, research has a very important function, one which is about 90 per cent of its total function—namely, to sell its product, ideas.

You may look upon this with some question. I have been interested in research and development for a great many years. Pure scientific research is, in its last analysis, one which has to do 100 per cent with the science of materials and the laws governing their function, whereas this constitutes between 10 and 20 per cent of the total activities of an industrial research organization. The other percentage is the question of salesmanship, of selling the idea.

Selling the idea is a time function, and we have developed, over a long period of years, this very important thing, which is absolutely no criticism of anybody, that the ordinary period for selling a new idea is four years. It is at least four years from the time you talk about a thing until you can hope to offer it to a customer. That is just as much your fault as it is mine, and the reason is the influence of heredity, of instinct over intelligence.

The human race is the one distinctive creation in the world which I think has been the experiment of the Creator. I think the human race is the unfinished work of the Creator, because every other organism has operated in exactly the same way as far back as we have records. But the human race has not yet completed its evolution. It is going step by step; its method of life has changed from generation to generation. The one particular respect wherein we have been different from other creatures is that we have been given a thing called intelligence. We discovered that a few centuries ago, and for a long time intelligence was beginning to develop into a super ego, which, thanks to the chemist and the physicist, in the last generation or two or three, has been boiled down to the pure elements of intelligence.

Therefore, when we present a new idea today, the first instinctive reaction is against it, and that is why some philosopher said a few years ago that the second sober thought is always essential and seldom wrong.

Well, the only thought you had was the second one. The first one was your instinctive animal reaction against it, and when you took your second sober thought you said, "Come on in, intelligence, and see what you think about this thing," and it said, "Well, here is what we think about it." In other words, intelligence has had such a small amount of practice at this game of ours that we have to bring it in by ringing the bell; but instinct is always on the job and says, "I don't think that is any good."

So when you present a new problem, its history is as definite as the history of a silkworm. You lay a new idea on the table, and they push it off into the waste basket. Do not get discouraged at that. That is only the first time they pushed it off. Lay it on the table again and they will push it off again, and after you lay it on the table for about three successive years, they will say, "Where have we seen that before?"

That is no criticism of any industry. It is simply recognition of the applied principles of psychology, and you will react to something outside of your business in exactly the same way.

It is how people react toward it without thought that determines the success or failure of any proposition in the world today—it is not the thoughtful reaction. Therefore, you have to present it and present it until you get an unthoughtful, favorable reaction.

This question of psychological research is important, because they tell me a great many chemists are temperamental. Nobody should be temperamental and be in research work, because the only thing you get in research work is having your ideas shoved off into the waste basket. Well, you know where they are then and you can get them out again.

The only time that anybody can ever discourage me on a new idea is when they throw it in the waste basket after I have laid it on the table for four years. Then I do not blame them or the idea; I wonder what is wrong with me, that they have not seen the point. So the question of selling the idea is many, many times more important than the idea itself, because it does not do the human family any good at all until the thing is sold and put into production.

Fostering Dissatisfaction

A few years ago I was called on the carpet of a very important financial organization, one of our great New York banking establishments. A question which was extremely embarrassing was put to me. The banker said, "What right have you to exist?" I said, "I don't know. Ask me another."

"Well," he said, "the question I am talking about is this: You represent a great body of people known in this country as research people, and, so far as the banking fraternity are concerned, they are the most dangerous outfit in the world. We loan a concern half a million or a million dollars on a perfectly good bank statement today. In another year some guy comes along with a process that entirely upsets that situation, and, while their bank statement is good today, three years from now, when they are supposed to repay the money, some other fellow has put them out of business. Now, you are the people that make banking hazardous."

"I will give you a concrete illustration," he added. "Last night I drove out to my home in a perfectly good automobile, which happened to be made by one of the companies associated with your organization. The chauffeur said to me, 'Doesn't this motor run fine? It certainly is a marvelous car; just think, we have driven 10,000 miles and it runs this nice.' I agreed."

"When I got home there was a beautifully engraved invitation on my table: Wouldn't I please call in at the X-Y-Z Automobile Company and see a new model? This morning I stopped in at that company, which happened to be the same which sold me the car I was driving, and I saw the new model. I was tremendously impressed with it. It was beautiful. The advance made was quite marvelous. The only thing that made me sore was that they would not allow me within $200 on my old car of what I expected, and I left there very much disgruntled. All that you did with that new model was to depreciate $200 worth every one of the cars that you made last year."

"You are absolutely wrong," I replied, "Did we put a scratch on the paint of your car? Did we scratch a bearing? Did we score a cylinder? Did we break a spark plug? Did we punch a hole in your gasoline tank between last night and this morning?"

He said, "No."

"We did not touch your car, did we?" I said, "It is a hard thing to get a car touched even if you take it into a service department, let alone maliciously going out and doing it. But you say I depreciated your car $200 worth between last night and today. No, we did not do that. What we did was to appreciate your mind $200 worth by showing you a new model. We made you see in a new model what to you looked like a so much better automobile that, despite the fact that you are crabbing about the allowance for the old car, you are going to buy the new car—aren't you?"

He said, "Sure."

I said, "You are just simply learning to know that it is worth $200 to have a change of mind. That is what you are doing. We have elevated your mental idea of what an automobile should be—$200 worth," and I said, "If we had not done that, you would not have bought a new automobile, would you?"

He said, "No."

"Then," I said, "we would not have made one, the steel-maker would not have made the steel, the paint-maker would not have made the paint, and the tire-maker would not have made the tires, and then business would not have been so good."

One thing that the great financial organizations of this world have not yet discovered is this—that good business does not represent the great flow of money and exchanges through the banking houses. That is a secondary thing; that is the negative wire, so to speak, of the great electric current of prosperity. The positive current is the flow of useful materials through the channels of trade, and that can only be produced provided you are dissatisfied with what you have.

So the next great function of research, and by far the greatest of all of them, is to keep everybody reasonably dissatisfied with what they have. If we can keep you reasonably dissatisfied with what you have, you are going to buy something that satisfies you, at least for the time being. When you do, you are going to pass your money on to somebody else, they are going to pass it on to somebody else, and so on around the circle.

Hours are the only assets that you and I have; twenty-four a day have been given to every one, every human being no matter where he lives. Nature demands that you shall lie in an unconscious state eight or nine hours a day—and some of us exceed the limit. But the rest of the time we can consider the things that exist in the world and how we can reorganize them so we think we have a good time. That constitutes the progress of civilization; and any time you spend a dollar and are convinced you have your money's worth in exchange, it does not make a bit of difference whether it was gambling on a horse race or what not; you have spent your money well, because the question between having a good time and not having a good time is purely a mental and not a physical condition. I have seen men who have complained about conditions at home, that have gone out to fishing camps and put up with stuff that they simply would not tolerate around the house. Then they come back and tell what a wonderful time they have had.

The problem is how best to use the twenty-four hours that we have. To give a specific illustration, let us go back to a Robinson Crusoe story. Suppose two people land upon a desert island where there is no money, where there is practically nothing, that they have different ideals, and that one fellow goes down and sits on the beach, catching enough fish to keep him alive. Suppose the other fellow takes some stones and begins to lay up a wall for protection, finally building himself a hut. He finds some boughs, and tries to make himself more comfortable than the other. The other fellow laughs at him and says, "You are crazy for doing that, I would not do it." Finally, a storm comes and the one who has spent his time fishing gets angry because he is kept out of the hut, where the builder is protected against the storm. He does not get in, and begins to say, "Why, you are a cruel individual." We have lots of people exactly like that today.

The materials of the world were here long before the human race. The only modifications in material are brought about by the thoughts that had to exist in somebody's mind before the material ever changed. You cannot change a chemical compound in a test tube; you have got to change it in a man's head first. There have been a few accidents, but they have been very, very rare.

Translation of Technical Details into Results

We still must recognize, as the great problem in industrial and scientific research, that the people at large are not in-

terested in a chemical compound or a physical law. They are interested in a very much more ordinary thing than that which concerns us so-called scientists. We cannot touch their lives unless we can produce things which they can use in their ordinary workaday life entirely unconscious of underlying principles. They are not interested in the type of motor that they have in their automobile; they are not interested in the type of lubricating oil that they use or the type of gasoline that they burn; they do not know whether it is a carbohydrate or a hydrocarbon, and they don't care. They are interested in whether they pay 16 or 18 cents a gallon for it. They are not interested in technical details, but if they get better results from one than the other, they say the X-Y-Z gasoline is better than the W-X-Y, and that is all they know. Therefore, a great function of research is to convert technical relationships into the terms of the user.

I had laid on my desk something which read like this: I question it, but, nevertheless, here it is. "If a hydrogen atom is propelled in the plane of the orbit of the electron, the orbit assumes a varying elliptical path and as such it must radiate energy; a part of the propelling energy must be translated into this radiation. But if it moves at right angles to the plane of radiation, the path of the electron is that of a spiral, and, inasmuch as there is no change in acceleration, no radiant energy is supplied." It may or may not be a fact, but you could not be elected mayor of the City of Detroit on that kind of a platform. But if you can translate that over into something that affects a fellow's egg or coffee, he will say, "Well, this company has a better thing than the other." It has only been within the last ten years that industry has opened up its arms to the thing we call research.

Research Organization

I have translated another function of research which, to my notion, is as important as any we have in every industry today—a perfect set-up of organization. We have the financial organization which is composed of the treasurer's department, the auditor's department, etc. We have the manufacturing department, the sales department, and the engineering department. These departments have been recognized in the budgets of industry for years. They have been recognized in the great financial institutions. They say, "What is their financial set-up? How well are they equipped for manufacturing? Have they a good sales organization? Have they good engineers?" But people, without knowing it, have introduced the necessity of another department which is as important as any. I do not say it is more important any more than I say that one finger or the thumb of my hand is more important than another, but if you were hiring a fellow and he did not have any thumb and you wanted him to do a special piece of technical work, I do not think you would give him quite the same consideration as if he had a thumb, and I think you might question him if he had a thumb twice as long as normal.

So I do not hold that research is something which dominates any other part of the organization, but a great function of research, as I see it as an industrial research man, is the development of scientific change-making. It is the science of making changes in a systematic way, because every time some one establishes a new marriage relationship in the atomic world it affects in some way every industry in the world. If you re-combine a hydrocarbon molecule, it may affect the deposit on the porcelain of our spark plugs. Research is the organized function of knowing how to make changes, and that is essential in these transient days.

The most elementary form of research that can be applied to industry consists of one man at a desk, busy in getting from the world's technical journals and from all the technical societies those things which he believes have a bearing upon the particular industry with which he is associated. After he has washed them down and filtered them out he has a residue of which certain principles may apply. He should present to the management those things which, out of the whole gamut of changes which have been made in the scientific world, will affect his particular industry, saying "Here are things which have a possible effect upon the industry in which we are involved, and you should know about them." That is purely a question of gathering together elementary facts which have been obtained from the raw material by scientific minds and effort throughout the world.

Remedying Troubles

There is another function of research that belongs to this great change-making, and one upon which our particular laboratory at the General Motors operates—namely, trying to fix whatever is wrong with what you have. You would never guess from reading our advertisements that there is anything wrong with what we make, but every once in a while a fellow comes in with a slight difficulty. In trying to remedy what is wrong we get our problems. And so I felt that, in deference to the great scientific organizations I should not be the head of a research organization, and I have recommended to our board of directors that we be called "The General Motors Fixing Department" rather than the "Research Department." We start out to change what is wrong by using some of the things we make and know. We first find out the things that the chemists, physicists, and others have gathered together. Then, if we engineers cannot get from what they have found out the thing that we need to fix what is wrong with the particular thing that we are making, we have to go and dig out ourselves the particular kind of information which we must have to enable us to overcome the trouble. Then we become pure scientists, temporarily. I cannot see any difference in importance between digging out a fact when you need it and digging out one when you don't need it. The only difference between pure science and commercial research is that in commercial research you dig out a fact because you need it, and in pure science you dig out a fact because you want to dig it out.

When we start to remedy troubles we sometimes learn that these scientists have been woefully lax in not digging out the required information. The greatest way to prove that is to get the latest books, such as the International Critical Tables of Physical and Chemical Constants. When you go to look for a great many of those constants they are not there. Constants are there on both sides of the alphabet, but the particular one you want is not there—just like looking up anything in the encyclopedia. If it had been there you would never have a chance to find it out; somebody else would have been there long before you. So when you begin to solve some of these common, ordinary problems you will find many data missing. We have been working on gasoline and lubricating oils for years and we find many of those common, ordinary things to which nobody has paid any attention. I feel that that is largely because of religion. I dislike to mix religion and science here, but a lot of people believe that the earth has been created just for us and us alone, and therefore have relied upon natural products to be exactly suited to our particular needs. To them it has been rather sacrilegious to question it. Well, I don't question it but I would like to know why they are that way.

Consider rubber. I cannot believe that the rubber tree, when it developed that particular lymphatic circulation that is necessary to heal a tree scar, ever had a pneumatic tire in

mind. Nobody can tell me that that particular juice out of that particular kind of a plant is going to make the best rubber tire that the world has ever seen, because I think if that tree had been working on a juice particularly designed for rubber tires it would have made it different. The rubber chemists may not agree with me, but since I am not an authority on rubber, I can speak freely.

Neither have I believed that the petroleum products that happen to exist in the world were 100 per cent adapted to our motors whether for fuel or for lubricating oil. There are two or three fellows that agree with me now and they still hold their jobs. I cannot believe that any more than I could believe the fairy tale that a silkworm eating a mulberry leaf had in mind a woman's silk stocking. I don't believe he was thinking about it when he ate the leaf. I think that the rayon stockings are just as nice looking as the silk stockings and they don't cost so much. That is the economic phase of it, at least as far as I am personally concerned. In other words, I believe in trying to find out why we are, and what we are, because I think we ought to know.

The organic chemist today has the greatest opportunity because he can affect every phase of life. Our foodstuffs are just as accidental as many of the other things we have adopted. Nobody can convince me that a hen had in mind an omelet when she laid an egg or that an omelet is necessarily a good thing for a man to eat. It happens to be better than something else; that is the only reason we eat it. I believe that the organic chemist can build us a food better than a fried egg and a piece of bacon. We have simply been pirates of the rankest order in building up our present condition. I think that we ought to begin to think for ourselves.

That was recently illustrated in a little squib in, I think, either *Judge* or *Life*. A man came home in the evening and his wife said, "John, I want you to go out and shoot that cat." He said, "Why, dear?" She replied, "That cat got up in the tree in our back yard and caught one of those beautiful birds. I want you to shoot it." "All right, dear, I will do that in the morning. I don't know where the cat is tonight. Let's go out to dinner tonight." So they went out to dinner and he asked what she would like to have. Looking over the menu, she said, "Why don't we have some quail on toast?" Simply a different point of view, that is all.

Progress and Change-Making

The problem of getting into industry the importance of a systématic change-making that will keep step with the everyday progress of the scientific world is one of the greatest economic contributions that research can make. The world in general has fought change, and that is why we have no procurement departments for changes in our organizations. The manufacturing departments who hire some of us as research engineers would fire us if we went on their payrolls as change artists. More than anything else the world hates change, and yet it is the only thing that has ever brought progress. The fellow who wrote on the side of his factory, "We progress through change," had the right idea, but he would doubtless fire you if you made one. The human mind has not yet reached the point where it recognizes that the gradual systematic making of changes is the one thing that has made civilization what it is.

If you went back and picked up the products that were made ten years ago and tried to sell them today, you would fail, and the only reason you would fail is because of a very interesting change—and here is a point of which maybe even a chemist has not thought. The day you were born everybody in the world was older than you were. That, I think, we do not need to argue. One year from that day there were two and one-half million people younger than you and at the age of twenty-six there were just as many people younger as there were older, but you still were looking to the older people for guidance. At about twenty-five years you want to turn half-way around and begin to look down at this younger half of the population. That is why you always think the younger generation is so bad. Exactly the same thing was said about you. At fifty years of age, when you are supposed to be a sage and are still looking to those that are older than you for advice and guidance, the only fellow you can see is the undertaker and there is not much happiness in that. Turn around and look at the hundred million people that are younger than you, that have new ideas and new thoughts; and if you cannot learn from the younger generation after you are twenty-six, if you are looking to the older generation for your guidance, you are shifting the wrong way. You must recognize that every new generation comes into this picture without knowing some of the hardships you experienced, and therefore it looks upon the same facts with an entirely different attitude than you and I.

Entirely apart from the scientific relationships of research, if there is one function more important than another, it is this. Make people recognize that we are living in a state of change, that the great color of the world's attitude towards things is changing, and that we do not want them to be color-blind and fail to see the beauty of the changes.

State Support for Research

AS THE result of the addresses and writings of many prominent men, the public is beginning to have borne in upon its consciousness that material progress has no dependable foundation other than research for truth's sake. It is also beginning to be understood that the state may properly devote a portion of its revenue for the support of science, and that in many particulars our legislators have been too niggardly in their appropriations for such work and in their economy have at times practiced a penny-wise, pound-foolish policy. Some may look upon the state support of research as relatively new. It is therefore interesting to note the following quotation from "The Story of Philosophy," by Will Durant, from which it will be seen that as far back as the days of Alexander the Great the precedent of fostering research from public funds was established.

The Academy was devoted above all to mathematics and to speculative and political philosophy; the Lyceum had rather a tendency to biology and the natural sciences. If we may believe Pliny, Alexander instructed his hunters, gamekeepers, gardeners, and fishermen to furnish Aristotle with all the zoölogical and botanical material he might desire; other ancient writers tell us that at one time he had at his disposal a thousand men scattered throughout Greece and Asia, collecting for him specimens of the fauna and flora of every land. With this wealth of material he was enabled to establish the first great zoölogical garden that the world had seen. We can hardly exaggerate the influence of this collection upon his science and his philosophy.

Where did Aristotle derive the funds to finance these undertakings? He was himself, by this time, a man of spacious income; and he had married into the fortune of one of the most powerful public men in Greece. Athenaeus (no doubt with some exaggeration) relates that Alexander gave Aristotle, for physical and biological equipment and research, the sum of 800 talents (in modern purchasing power, some $4,000,000). It was at Aristotle's suggestion, some think, that Alexander sent a costly expedition to explore the sources of the Nile and discover the causes of its periodical overflow. Such works as the digest of 158 political constitutions, drawn up for Aristotle, indicate a considerable corps of aides and secretaries. In short we have here the first example in European history of the large-scale financing of science by the public wealth. What knowledge would we not win if modern states were to support research on a proportionately lavish scale!